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Sustainable use of Water for Some Selected Hybrid and Inbred Rice Cultivation in the Floodplain Areas (AEZ 26 and AEZ 28) of Bangladesh

Bulbul, Sheikh Helena

University of Rajshahi

SUSTAINABLE USE OF WATER FOR SOME SELECTED HYBRID AND INBRED RICE CULTIVATION IN THE FLOODPLAIN AREAS (AEZ 26 AND AEZ 28) OF BANGLADESH

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Submitted By

Sheikh Helena Bulbul
Registration No. 07110
Session: 2007-2008

Submitted To

Institute of Environmental Science (IES)
University of Rajshahi
Rajshahi – 6205, Bangladesh

June 2013

DEDICATED TO MY

BELOVED PARENTS

Declaration

I certify that the thesis entitled **"SUSTAINABLE USE OF WATER FOR SOME SELECTED HYBRID AND INBRED RICE CULTIVATION IN THE FLOODPLAIN AREAS (AEZ 26 AND AEZ 28) OF BANGLADESH"** submitted to the Institute of Environmental Science for the degree of DOCTOR OF PHILOSOPHY is the result of my own research, except where otherwise acknowledged under the supervision of Md. Safinur Rahman, Professor, Department of Zoology, University of Rajshahi and co- supervisors Dr. Md. Redwanur Rahman, Associate Professor, Institute of Environmental Science (IES), University of Rajshahi, Dr. M. A. Sattar, Chief Agricultural Engineer & Head, Irrigation and Water Management Division, Bangladesh Rice Research Institute (BRRI), Gazipur, Bangladesh; Dr. Md. Ansar Ali, Chief Scientific Officer and Head, Bangladesh Rice Research Institute (BRRI), Regional Office, Shampur, Rajshahi, Bangladesh, Dr. A. S. M. Masuduzzaman, PSO, Plant Breeding Division, Bangladesh Rice Research Institute (BRRI), Gazipur, Bangladesh and that this thesis (or any part of the same) has not been submitted for a higher degree (diploma/others academic purposes) at any other university or institution.

H. Bulbul
23.06.2013

Sheikh Helena Bulbul
PhD Research Fellow
Session: 2007-2008
ID No: 07110
Institute of Environmental Science
University of Rajshahi
Bangladesh

University of Rajshahi

Institute of Environmental Science (IES)

Certification

This is to certify that in order to achieve PhD degree the thesis entitled "**Sustainable use of Water for Some Selected Hybrid and Inbred Rice Cultivation in the Floodplain Areas (AEZ 26 and AEZ 28) of Bangladesh** " presented by **Sheikh Helena Bulbul** has conducted by our direct guidance and supervision. As far as we know, this is the researcher's own and it is not conjoint work.

We also certify that we have gone through the draft and final version of the thesis and found it satisfactory for submission to the Institute of Environmental Science, University of Rajshahi in partial fulfillment of the requirements for the degree of **Doctor of Philosophy**. We do believe that this thesis paper is eligible to submit for the evaluation by experts.

Principal Supervisor

23.06.2013

Professor Md. Safinur Rahman
Department of Zoology
University of Rajshahi
Rajshahi-6205, Bangladesh

1. Co-Supervisor

Md. Redwanur Rahman 23.06.2013

Dr. Md. Redwanur Rahman
Associate Professor
Institute of Environmental Science (IES)
University of Rajshahi.

2. Co-Supervisor

Dr. M.A. Sattar
Chief Agricultural Engineer & Head
Irrigation and Water Management Division
Bangladesh Rice Research Institute (BRRI)
Gazipur, Bangladesh

3. Co-Supervisor

Dr. Md. Ansar Ali
Chief Scientific Officer and Head
Bangladesh Rice Research Institute (BRRI)
Regional Office, Shampur
Rajshahi, Bangladesh

4. Co-Supervisor

Dr. A.S.M. Masuduzzaman
PSO, Plant Breeding Division
Bangladesh Rice Research Institute (BRRI)
Gazipur, Bangladesh

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PREFACE

This preface serves to provide a background to the origin of my motivation to conduct research to answer the question **'Does alternate Wetting and Drying technology save water for rice cultivation that encourages pro-sustainability practices'**. My academic knowledge and practical experience from both Rajshahi district of Bangladesh (my birth place) have facilitated my understanding and importance of work related the values of sustainable development.

I was born (5 November, 1979) Luxmipur city of Rajshahi district in Bangladesh in a family with a heritage of Sufi as well as patriotic tradition which believes in Allah as the Creator and Sustainers of the universe. My family has religiously demonstrated and encouraged me to acquire values such as respect, kindness, forgiveness, gratefulness, modesty, conservation, patience and perseverance. My family's simple lifestyle, happiness with less, tolerance and spontaneous teachings about the importance of moral values in people, testify its commitment to practices that encourage a gentle behavior towards other people, all creatures, natural resources and the environment.

I spent ten years in my grandmother's village named Dangpara which is close to the Barind tract. As we are the local inhabitant of Rajshahi since 250 years, many of my relatives are living in Rajshahi district. For this reason I have an opportunity to know the fact regarding water scarcity. In Rajshahi district water scarcity was so prominent that in summer season it became so dried that people could not take bath and drink water easily. Almost all tube well was failed to withdrawal water as the water table go down. The arable land became crackdown. Day after day there was no rainfall. The heat was terrible. The situation was as idle as a story. The people go out from the house and pray to Almighty **"Allah Meg Da, Pani Da, Chai a Da re tui Allah Meg Da" (Traditional song).** By this traditional song people cordially prayed to their sustainer Almighty Allah for offering rain.

But truth lies in the opposite- once Rajshahi was sufficiently rich in acquiring the resources of its water for cultivation all over the year.

Rajshahi was motherly blessed by Padma and her accessory Korotua and Mohananda. When, Padma began to flow total area used to take a festive look for having new water from Himalyan valies. But curse fell upon us when our mighty close neighbour India built a barrage at Farakka in 1974 in the upper part of the Ganges (Padma) located upstream of Bangladesh and started a unilateral withdrawal of water during the dry months (November to May). This has caused severe and long-term ecological shock on the rivers flowing across the northern region of Bangladesh – about 44 of them are on the point of dying and another 95 are on the way of losing existence (Khan, 2008). Despite over 100 bilateral talks to establish provision of guarantee for Bangladesh, the violation of the water-sharing agreement continues. This has resulted in serious adverse effects on natural resources, including salinity intrusion and desertification in the south-western and western districts of Bangladesh, affecting almost 20 percent of the country's area.

The introduction of the Green Revolution agricultural practices (or "seed-fertilizer-water" technologies) in Bangladesh in the 1960-70s sharply increased the demand for water, particularly for highly thirsty crops such as rice, wheat and potato. Farmers has to adopt new irrigation practices of using underground water (instead of the traditional reliance only on surface flows) which caused falling water tables in the irrigation regions as the natural seepage during the monsoon season could not recharge the amount of withdrawal (Shiva, 1993). This caused desertification as well as arsenic pollution problems.

In fact, India's unilateral withdrawals of water from the Ganges through the Farakka barrage and various canals and the Green Revolution crops have synergistically destabilized the water balance in the region resulting in a severe ecological imbalance.

These water crises have adversely affected the environment, agriculture, industries, fisheries, navigation of the river regime and salinity contamination in the surface and ground water.

This prolonged environmental hardship is causing socio-economic breakdowns and threatening the sustainability of the country, with the political regimes in

Bangladesh incapable of addressing the water issues. It is extremely important to acknowledge that the geographical and environmental changes due to natural and human causes also result in changing socioeconomic, development and governance sustainability scenarios and they all need a common reference point in order to be successfully addressed when planning for the future.

When I got admitted myself to pursue a PhD degree at the Institute of Environmental Science (IES), University of Rajshahi the focus of IES was to deals with the environmental degradation which included land, soil, air, water etc. The motivation of our teachers is to do something for your nation and for sustainability of natural resources. My values and my institutional focused inspired me to do this research.

SUMMARY

The water crisis is threatening the sustainability of the irrigated rice system and food security in Asia. Our challenge is to promote novel technology and production systems that allow rice cultivation to be maintained in the declining water availability. This paper introduces principles for sustainable water use and water saving technology for reducing water inputs and increasing water productivity, and assesses the opportunities of such technologies and systems at spatial scale levels from plant to field, to irrigation system, and to agro-ecological zones. The rapid growth of world population has resulted in significantly increased global water demand. According to a recent report on limited water supply, conservation techniques and water use policies are needed to preserve water resources. Worldwide agriculture is the largest consumer of water, particularly for growing rice. Water use for rice production was chosen because rice will continue to be a staple crop for the majority of the world's population and because of its pervasive use of water. Traditional lowland rice production in Asia requires much water: it consumes more than 50% of all irrigation water used in Asia. Water resources are, however, increasingly getting scarce and expensive. The supply of water for irrigation is endangered by declining water quality, declining resource availability, increased competition from other users, and increasing costs. During the past decades, rice production in Bangladesh experienced an impressive intensification. The change to dry season rice, constituting about 60% of national rice production, was largely due to groundwater irrigation by shallow tube wells (STW) and deep tube wells (DTW). This practice led to the massive extraction of groundwater, an overexploitation of groundwater, locally manifested by declining groundwater tables in Rajshahi. Correspondingly to the expansion of irrigation, demand for energy increased, as electricity or fuel are needed to lift groundwater to the surface. This also touches on the chronically deficient energy situation of

Bangladesh. To address problems of water scarcity, researchers have studied and developed a number of water-saving irrigation technologies such as saturated soil

culture and alternate wetting and drying (AWD) that can drastically diminish these losses. Under these technologies, yields may decline, but they have demonstrated that they save water and increase water productivity.

Hence, this thesis was designed to investigate water conservation possibilities for rice production in two water management regimes: alternate wetting and drying and continuous standing (the latter is the traditional water management technique in irrigated rice culture).

The study revealed that the alternate wetting and drying treatment reduced water use and increased rice grain yield than continuous standing water. Among the results of the study, it was found that BRRI hybrid2 gave better performance than other inbred varieties.

Logistic regression model used to estimate the contribution of key variables of adoption of AWD. Boro rice, it was suggested that farm size, education of household head, and contact with extension agents, water scarcity and dissemination through demonstration were the variables that had significant impact on the adoption of AWD.

It was also evident that water conservation benefits can potentially be realized if local government agencies (e.g., Phil- Rice and NIA), as well as international agencies (e.g., IRRI), continue to provide education and training about the latest research on AWD and other water-conserving technologies to local extension personnel, field technicians, and as well as farmers.

With calls for re-orientation of sustainable water use, the implications of the findings of this research suggest that alternate wetting and drying water saving technology is making a positive contribution towards sustainability.

It should be a valuable approach that should not be trivialized, stigmatized or ignored because of its potential to bring long-lasting impacts.

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List of Abbreviations

AWDI	=	Alternate Wetting and Drying Irrigation
BAU	=	Bangladesh Agricultural University
BBS	=	Bangladesh Bureau of Statistics
BRRI	=	Bangladesh Rice Research Institute
cm	=	Centimeter
CRME	=	Centre for Research in Medical Entomology
CFS	=	Chief Farm Superintendent
DAT	=	Days after Transplanting
FAO	=	Food and Agricultural Organization of the United Nations
UN	=	United Nations
Fig.	=	Figure
Gpm	=	Gallon per Minute
HYV	=	High Yielding Variety
Kg	=	Kilogram
Kg/ha	=	Kilogram per Hectare
LSD	=	Least Significant Difference
LS	=	Level of Significance
MV	=	Modern Variety
MP	=	Muriate of Potash
TSP	=	Triple Super Phosphate

Chapter 1

General Introduction

Chapter 1

General Introduction

1.1 Introduction

With respect to water resources, as with many other resources, sustainability has not been clearly defined, though several recent efforts have made progress in defining the issues (Golubev *et al.,* 1988, Koudstaal *et al*., 1992, Plate, 1993, Raskin *et al*., 1995). Water is not only essential to sustain life, but it also plays an integral role in ecosystem support, economic development, community well-being, and cultural values. As the International Year of Freshwater, 2003 is an opportunity to focus on the role of water as a precious and finite resource that we must use carefully.

In 30 years, the earth's population may be 8 billion people (UN, 2002; Rosegrant *et al*., 2002) and the number people dependent on rice for food may equal 5 billion (IRRI, 2002). Feeding them will require a massive increase in global rice production, and which thus will increase demand for water. More than 75% of the rice supply comes from 79 million ha of irrigated land. Recently, the scarcity of, and competition for, water has been increasing worldwide. By 2025, the per capita available water resources in Asia are expected to decline by 15–54 percent compared with 1990 availability (Guerra *et al*., 1998). Despite the constraints of water scarcity, rice production and productivity must rise in order to address the growing demand for rice driven largely by population growth and rapid economic development in Asia. Producing more rice with less water is therefore a formidable challenge for achieving food, economic, social, and water security for the region (Facon, 2000).

In agriculture sector rice is the only major grain crop that is grown almost exclusively as food need mush water to produce. Rice grown under traditional practices in the Asian tropics and subtropics requires between 700-1500 mm of water per cropping season depending on soil texture (Bhuiyan, 1992). However, this conventional water management method leads to a high amount of surface runoff, seepage, and percolation that can account for between 50–80 % of the total water input (Sharma, 1989).

The interactions between water use for rice cultivation, surface water and groundwater resources are often very close –such that active cross-sector dialogue and integrated vision are also needed to promote sustainable water use.

The sustainable use of water would require the maintenance of a desired flow of benefits to a particular group or place, undiminished over time. Benefits involve cultural values and issues, and are a function of the stock of, and the demand for, water, both of which vary with technology and population. Demands for water include not just what people need, but what they want. This latter demand is potentially much larger than minimum basic needs (Gleick, 1996). A better definition would incorporate the requirement that benefits to all current users be maintained, without reducing benefits to other users, including natural ecosystems.

As we approach the turn of the century, new approaches to long-term water planning and management for rice cultivation that incorporates principles of sustainability.

The term 'sustainability' emerged with the publication of the Brundtland Commission Report (1987) 'Our Common Future'. The report highlights the essence of sustainability or sustainable development and defines it as 'development that meets the needs of the present without compromising the ability of future generations to meet their own needs' (WCED, 1987). Mintzer (1992) supports this view and advocates that the essence of sustainable development is a stable relationship between human activities and the natural world, one that does not reduce the prospects of future generations to also enjoy a good quality of life.

Many, including the International Institute for Sustainable Development (IISD, 1999) agree that there are three basic dimensions to sustainability, namely environmental, social and economic:

- Environmental sustainability- whereby the natural capital remains intact. The extraction of renewable resources does not exceed the rate at which they are renewed, and the absorptive capacity of the environment to process wastes is not exceeded. In addition, the extraction of non-renewable resources is minimised and does not exceed agreed minimum strategic levels.
- Social sustainability – where by the cohesion of society and its ability to work towards common goals is maintained. Individual needs, such as those for health and well-being, nutrition, shelter, education and cultural expression is met.
- Economic sustainability – whereby development that leads to social and environmental sustainability is financially feasible (IISD, 1999).

Barnhill (2001) on the other hand, incorporates institutional wellbeing together with the above and understands sustainability as:

In addition to Barnhill, Spangenberg (2002) also advocates the need for institutional sustainability. Others have called for the inclusion of govern'A systemic concept, relating to the continuity of economic, social, institutional and environmental aspects of human society. It is intended to be a means of configuring civilization and human activity so that society, its members and its economies are able to meet their needs and express their greatest potential in the present, while preserving biodiversity and natural ecosystems, and planning and acting for the ability to maintain these ideals for a very long term. Sustainability affects every level of organization, from the local neighborhood to the entire planet. Sustainability is a vision for the world in which current and future humans are reasonably healthy; communities and nations are secure, peaceful and thriving; there is economic opportunity for all; and the integrity of the life-supporting biosphere is restored and sustained at a level necessary to make these goals possible. All four dimensions of sustainability must be addressed to achieve this vision.'

Rogers *et al.*, (2008) see sustainability as a matter of making adjustments to present human activities, to sustain twentieth century natural resources largely unchanged and unchallenged into the twenty-first century. Hence, the main feature of sustainability is the direct practical changes that it requires. Sustainability is often referred to as a process which leads to better relationships between humans and the natural environment and between themselves. Ruckelshaus (1989) emphasizes this relationship and reinforces that 'Sustainability is the doctrine that economic growth and development must take place, and be maintained over time, within the limits set by ecology in the broadest sense by the interrelations of human beings and their works, the biosphere and the physical and chemical laws that govern it. It follows that environmental protection and economic development are complementary rather than antagonistic processes, (*Scientific American*: September, 1989). The outcome of this interrelated process is balanced development. This is supported by the Florida Centre for Community Design and Research (2010) which states that 'Sustainability is the optimal balance of natural, economic and social systems overtimes.'

The sustainability concept argues for a holistic and balanced approach to life where economic prosperity, nature conservation and social justice are given equal weight in any long term strategies of development (Government of Western Australia, 2003). New definitions of sustainability are constantly emerging, however they all share common aspects. The Research Group on the Global Futures provides an array of definitions for sustainability but concludes that most definitions have three aspects in common. These are living within limits; understanding the interconnections between the economy, society and the environment; and equitable distribution of resources and opportunities (Research Group on Global Futures 2005).

It is unreasonable to expect that academics, politicians and other people will ever agree on any one particular definition because of the following inherent features of sustainability:

(1) It is a very complex concept which crosses borders between traditional academic disciplines;

(2) It is a value laden term on the political arena with different positions held by various organisations (such as UN, World Bank or NGOs) and country representatives (such as from developing and developed countries);

(3) In terms of governance, it is a challenge to make any one particular institution administratively responsible for this transformational agenda; instead sustainability should permeate across all sectors and government structures;

(4) Under the current pressures of climate change, global poverty and other manifestation of unsustainable development, there is a need for fast changes that humanity has never experienced before.

Sustainability is very important for this research as it deals with the way the sustainability concepts in terms of water use for rice cultivation are being transferred and reinforced in young people, researcher, farmers, and policy makers through the educational system.

Many researchers indicate that rice is the major consumer of irrigation water in Bangladesh. It is grown under two distinct water regions, continuous standing and alternate wetting. The conventional method of rice planting requires continuous ponded water on the field, which is possible where irrigation water is abundant and cheap. In this method irrigation water is used for evapotranspiration (ET) and seepage-percolation (S&P). But in reality, only ET is the true water requirement for crop growth and S&P are the unavoidable losses. However, rice can be grown under alternate wetting and drying conditions with necessarily sacrificing yields and adoption of such practices may allow savings of costly water.

"Alternate Wetting and Drying" (AWD) involves technology that tackles water scarcity in irrigated rice cultivation and has the potential to contribute to a more sustainable and effective water and energy use. This AWD tool is a single device designed to observe water level in rice field for deciding the time of irrigation. It involves installation of a perforated pipe (preferably PVC) in rice field to allow observation of water level. In one part, such pipe of 10 cm diameter and 30 cm long is installed having 10 cm above and 20 cm below the ground surface.

By applying AWD, farmers or pump-owners are able to save 15 to 30% of their irrigation water. Water productivity, *i.e.* the volume of irrigation water required to produce a certain amount of rice, increases compared to conventional cultivation (Lampayan *et al.*, 2009; Bouman *et al.*, 2007).

1.2 World Water Demand

Water for agriculture is becoming increasingly scarce. The causes might be decreased general water table, silting of reservoirs, water pollution and increased competition from other sectors such as urban and industrial uses. It is estimated that by 2025, 150-200 lakh hectares of irrigated rice globally will suffer from varied degree of water scarcity.

Only 2.7 % of the global water is available as fresh water, out of which only 30 per cent can be used for meeting the demand for humans and livestock. The demand for water (of appropriate quality) is expected to rise manifold owing to ever increasing population, rising demand for food, urbanization and industrialization and may even exceed its supply (ENVIS Centre, Punjab, 2005). Such a phenomenon will prevail in almost every part of the world, more pronounced in those economies where agriculture occupies a dominant position and accounts for a major chunk of water use (Third World Water Forum, 2003).

According to WWAP (2003), world water resources are in crisis in three key areas; water scarcity, water quality, and water-related disasters. Then again the United Nations figures show that "some 3000 basins are the scenes of current conflicts" (Swartz berg, 1997). There are many cases of upstream ~ downstream controversies worldwide. In the Middle East, for example, Israel and the Palestinians continue to negotiate their rights and obligations concerning their shared water (Demsey, 1999). In Asia, China has plans to build dams on the upper

Mekong River, which is regulated only in its lower reaches by a recent agreement concluded between Vietnam, Cambodia, Laos and Thailand (Jacobs, 1996). In the regions where groundwater is a major source of irrigation water, such as rice farming in the western part of the U.S., groundwater is depleted when pumping rates exceed the rate of natural recharge. This practice also results in lowered water tables and induced saline water to contaminate the aquifer (Rosegrant *et al.,* 2002). For example, lateral movement of saline water into fresh water by migration resulting from pumping was detected in areas of eastern and southern Arkansas (Newport, 1977; U.S. Geological Survey, 1984). Saline water can affect plant growth, decrease crop productivity, cause corrosion, and taste problems with drinking water. In addition, chloride concentration can increase above 100 mg/L, which can be harmful to plants and animals (Broom *et al.,* 1984; Morris, 1988). Increased ground water pumping will cause saline water intrusion problems to become more widespread and impact more irrigation and drinking water supplies.

The agriculture sector is the largest consumer of water while rainfed agriculture relies on soil moisture generated from rainfall, irrigated agriculture focuses on withdrawals of water from surface and ground water sources. In many arid and semi-arid regions such as India, Northern China as well as Pakistan groundwater is critical for development and food security. A similar situation is observed in developed arid regions of the world including the USA, Australia and Mexico. In the arid Southern and Eastern rims of the Mediterranean basin, agriculture accounts for 82 % of the water withdrawals in the region (Plan Bleu, 2009). In other regions of the world the situation is different. Countries in Sub-Saharan Africa, for example, could benefit from more intensive groundwater use for agricultural as well as other uses but are limited in their development due to among others a lack of infrastructure, poor energy access and low investment (Villholth and Giordano, 2007).

The recent UN projection for the world's population is 7.8 billion in 2025, of which 1.2 billion will be in more developed and 6.6 in less developed countries. In 2050, the world's population will reach 9 billion, an increase from 2025 by 1.2

billion, and the majority of this growth will occur in the less developed countries (UN, 2002). Nearly 7 billion people from sixty countries will confront water scarcity by 2050 (Gardner-Outlaw and Engelmann, 1997).

Population growth also increases food demand that requires more water for agricultural production and more irrigated land (WWAP, 2003). Dry-season agriculture has been expanded to increase agricultural production in many countries, particularly in Asia. During the dry season, rainfall is insufficient to support agricultural activities, which must depend on irrigated water. These activities resulted in depleting natural water resources both surface and underground. Globally, irrigated agriculture is the largest abstractor and predominant consumer of groundwater resources, with important groundwater-dependent agro economies having widely evolved. Allowing for substitutions of other foods for rice in diets as incomes increase, the world's annual rice production still must increase from 518 million tons in 1990 to 760 million tons in 2020 (IRRI, 1989).

1.3 Concept of Sustainable Water Use

Gaining an understanding of the sustainable water use can also be approached by understanding what constitutes the ''unsustainable'' use of water. Water use is unsustainable if the services provided by water resources and ecosystems, and desired by society, diminish over time. Equity also requires that a reduction of services over time to one user group be declared unsustainable even if other users are able to maintain their desired services. It should be noted, however, that inequities by themselves are not unsustainable; indeed, many inequities in resource allocation and use can be maintained for indefinite periods of time. Unsustainable water use can develop in two ways:

(1) through alterations in the stocks and flows of water that change its availability in space or time and

(2) through alterations in the demand for the benefits provided by a resource, because of changing standards of living, technology, population levels, or societal

mores. Water availability is affected by both natural and anthropogenic factors; including climatic variability and change, population growth that reduces per capita water availability, contamination that reduces usable water supplies, physical overuse of a stock, such as groundwater overdraft, and technological factors. Similarly, demands for water are not constant; they increase with growing populations, change as social values and preferences change, and increase or decrease with technological innovation and change. Similarly, changes in technology can increase or decrease the amount of water required to supply a particular societal benefit. If technological development proceeds independently of water constraints, a new technology to supply energy, for example, may require more water than previous alternatives. If water resources are constrained, technology can be manipulated to reduce overall water requirements in the same way that energy efficiency technologies reduce energy needs without sacrificing the desired benefit. Finally, truly sustainable water use must involve the management of the distribution of water in space and time. Social systems, i.e., institutions, to control water resources must be capable of coping with changes in supply and demand and in responding to varying priorities of water use under different conditions.

During the work of the World Commission on Environment and Development (WCED, 1987) and widely quoted:

Humanity has the ability to make development sustainable—
to ensure that it meets the needs of the
present without compromising the ability of future
generations to meet their own needs.

The desired set of benefits provided by a resource does not have to be, and is unlikely to be, the same across different users or periods of time. Indeed, desired benefits of water use vary widely given political, religious, cultural, and technological differences. But in any realistic discussion of sustainability, the benefits to be provided must be explicitly evaluated. Benefits of water use can be subdivided in several ways: by form or sector of use, such as domestic, agricultural, industrial, and ecosystem use; or by the well-being provided use, such as economic wealth, human and ecological health, level of satisfaction, and so on. Sophisticated measures of well-being are often difficult to quantify but provide a more complete view of the consequences of resource use than the traditional measures of simple quantities of per capita use.

The traditional water use (continuous standing) has been successful in producing rice cultivation but it has failed in many ways to equip them with the ethics and values for sustainable development as well as failed to convey the breadth and the magnitude of the sustainability concept.

Traditionally, rice is cultivated under a continuously flooded condition in most rice growing countries. A tremendous amount of water is used for rice growing under this traditional flooded rice cultivation which hampers not only agricultural sustainability but also environment. Nevertheless, it has been proven that physiologically rice cultivation does not necessarily require such amount of water.

Tabbal *et al.*, (2002) reported reduced water inputs and increased productivity of rice grown under saturated soil conditions, as compared with traditional flooded rice. Borell *et al.,* (1997) reported that saturated soil culture with rice grown on raised beds reduced the amount of water use by approximately 32 % as compared with conventional methods (continuous flooded). Water volume requirements for rice cultivation varies depending on soil texture, number and length of irrigation ditches, soil moisture before flooding, perimeter levees and irrigation ditch seepage, transpiration by plants, and evaporation. These factors play significant role in controlling amount of water requirement in rice culture.

There is also much evidence that water scarcity already prevails in rice-growing areas (Tuong and Bouman, 2002), where rice farmers need technologies to cope with water shortage. However, rice is very sensitive to water stress and attempts to reduce water inputs may result in yield reduction. Recent research has suggested that water demand in rice fields can be substantially reduced with new management techniques.

Intermittent drying or keeping soils only saturated during the growing season considerably lowers water requirement in rice culture. In subtropical China, Japan, and Korea, intermittent drying periods are associated with maximal rice yields (Borell *et al.*, 1991). Probably, drying the field can reduce toxicity of organic and inorganic toxins that accumulate from the decomposition of organic materials at the beginning of cropping season (Kongchum, 2005). Short aeration periods at the end of the tillering stage and just before flowering improve wetland rice yields only if followed by flooding (Neue, 1993).

1.4 Groundwater and Rice Cultivation in Bangladesh

Groundwater-fed irrigation is conducted to cultivate high-yielding rice during the dry season in South Asia where India and Bangladesh represent the world's second and fourth biggest rice-producing nations respectively (Scott and Sharma 2009; IRRI 2010). Over the last 50 years, groundwater abstraction on the Indian subcontinent increased from about 10 – 20 km3/year to approximately 260 km3/year (Shah *et al.*, 2003; Giordano 2009). Current abstraction exceeds potential groundwater recharge to the Ganges-Brahmaputra and Indus basins and is estimated to be ~ 246 km-3/years (CGWB 2006). In Bangladesh, total annual (2004– 2005) irrigation water use is estimated to be ~24 $km^{-3}$of which 18 km^{-3} comes from groundwater (Siebert *et al.*, 2010) via a range of pumping technologies. Recent studies in India and Bangladesh (Rodell *et al.*, 2009; Shamsudduha et al. 2009a; Tiwari *et al.*, 2009) report declining trends in groundwater levels (0.1 – 0.5 m/year) which indicate reductions in aquifer storage from unsustainable ground-water abstraction for both irrigation and urban water supplies

1.5 Water use and *Boro* Rice Cultivation in Bangladesh

Boro - a Bengali term originated from the Sanskrit word '*BORO*B'. It refers to a special cultivation of rice in low land pockets during November-May; taking advantage of the residual water in the field after harvest of *Kharif* crop, longer moisture retentively of the soil and surface water stored in the nearby ditches

(Singh *et al.*, 2003a). Thakur *et al.,* (2003) reported *Boro* in Shivapuran as one of the offerings to the God. In Bangladesh rice is grown in three distinct seasons; *Boro* (January to June), *Aus* (April to August), and *Amon* (August to December). Modern rice varieties were introduced for the *Boro* and *aus* seasons in 1967 and for the *amon* seasons in 1970 (Hossain *et al.*, 1994).

Boro rice is mainly cultivated by puddle transplanting with flood irrigation. More than 80% of irrigation water comes from underground water source. In Bangladesh irrigation is the most critical and valuable inputs for rice cultivation. It is the most important factor which can make a crop either economic or uneconomic. Although the monsoon climate with its high humidity and temperature, is favorable for rice planting in Bangladesh but the rainfall is not evenly distributed throughout the year. It is often said that the major problem of agriculture in Bangladesh are excess water or lack of water. About 96% of the total rainfall occurs during the month of April to October, leaving the remaining five month of the year essentially dry. Drought conditions prevail over most of the Bangladesh during the months from November to April, when potential evapotranspiration far exceeds rainfall (Manola, 1976). A rice crop cannot be sustained during this period from rainfall alone. Due to very limited available of rain water during dry season (November-April) the *Boro* rice is fully dependent on irrigation. Therefore, the expanding demand for food grains in the country will most likely be met expansion of irrigated area with the available water resources.

Water scarcity for agricultural use in Bangladesh is both seasonal and region-specific. Water is most scarce in the south-western and north-western regions of the country during the dry season due to low annual rainfall. The demand for both surface and groundwater for irrigation is on the rise in the dry winter season and amounts to 58.6 % of the total demand for Water (GOB, 2005). The principal crop during this season is *Boro* rice, which is 70 percent of the total crop production of Bangladesh (GOB, 2005). Moreover, it requires more water in the production process than either wheat or potato. According to an estimate by Biswas and Mandal (1993), water requirements are 11,500m^3 per hectare (ha) of *Boro* rice. So the judicial use of water resources in intensive irrigated area is a crucial need for maintaining both sustainable crop production and accessible water level.

1.6 Why AWD is Relevant in Rajshahi District?

The northwest region of Bangladesh broadly covers the whole Rajshahi Division, consisting of 16 districts of the country. The region is classified as medium- to high-land and is normally flood-free. Within the north-western region, the greater districts of Rajshahi, Dinajpur, Pabna, Rangpur and Bogra fall in the Barind Tract. A typical dry climate with comparatively high temperature prevails in this Barind area. Temperature ranges from minimum of 8°C in the winter to maximum of 44°C in the summer. Rainfall occurs from mid June to October and the magnitude of annual rainfall varies from 1500 to 2000 mm. Total cultivable area is 1.44 million acres of which 49% is clay, 34% loamy, 10% sandy and 7% is of other type. Out of the total cultivable land, 84% are single cropped, 13% are double cropped and the rest are triple cropped. Cropping intensity in the area is 117%, compared to the average of 178% for the whole country (BBS, 2008 National Food Policy Capacity Strengthening Programme Implemented by FAO in collaboration with FPMU/Ministry of Food and Disaster Management with financial support of EU and USAID).

Compared to the rest of Bangladesh, its Northwest has relatively unfavourable climatic conditions for agriculture. Ninety percent of its rainfall of 1200 to 1400 mm occurs within the three month period, June to August. Because of the nature of the soils (discussed below) and the monsoonal downpour, much of this rainfall is lost as surface runoff and causes considerable soil erosion. During the dry period of seven to eight months, evapotranspiration exceeds precipitation. In addition, the length of the monsoon varies considerably and extremes of temperature are experienced with many summer days above 400°C and several winter days below 50°C.

Zuberi (1992) reports the topsoil is very thin (often sandy) and beneath there is a hard clay pan. The clay pan impedes the penetration of water to underground areas and the water holding capacity of the soil is low. Furthermore Zuberi (1992) points out that the organic content of the soil is low (organic matter accounts for only 0.5 to 0.7 % of the soil content) and that the soil is deficient in plant nutrients such as nitrogen, in zinc and sulphur and trace elements. Considering all these aspects, northwest Bangladesh is a marginal area for agriculture, particularly crop growing. Nevertheless, cultivation in this area has expanded and more than three-quarters of the land in northwest Bangladesh is under cultivation, a higher percentage of land than in the more fertile Northeast (Dhaka Division) which has about 71 % of its area under cultivation.

On the other hand the impact of drought spreads disproportionately amongst regions of Bangladesh. There is a popular impression in Bangladesh that the north-western districts of Rajshahi, Dinajpur, Rangpur, Bogra, and Pabna are particularly drought-prone (Murshid, 1987). The impacts of drought are diverse and often ripple through the economy. Impacts can be classified as economic, environmental, and social. They are often referred to as direct or indirect, or they are assigned an order of propagation (*i.e.,* first-, or second- order) (Kates *et al.,* 1985). In a society where agriculture is the main economic activity, a direct or first-order impact of drought is observed in the form of decrease in food production via decrease in area and yield. The second-order impact is decreased employment and income. The delay in sowing and transplanting crops reduces agricultural employment. Employment opportunities are further reduced due to diminished need for weeding and harvesting.

Drought adversely affects all three rice varieties (*aman*, *aus*, and *Boro*) grown in three different cropping seasons in Bangladesh. It also causes damage to jute, the country's main cash crop, and other crops such as pulses, potatoes, oilseeds, minor grains, winter vegetables, and sugarcane. Rice alone accounts for more than 80% of the total cultivated land of the country. Droughts in March-April prevent land preparation and plowing activities from being conducted on time. As a result, broadcast *aman*, *aus*, and jute cannot be sown on schedule. Droughts in May and June destroy broadcast *aman*, *aus*, and jute plants. Inadequate rains in August delay transplantation of *aman* in high land areas, while droughts in September and October reduce yield of both broadcast and transplanted *aman* and delay the sowing of pulses and potatoes. *Boro*, wheat, and other crops grown in the dry season are also periodically affected by drought. Fruit trees, such as jackfruit, litchi, and banana, often die during drought. But the loss of rice production is the most costly damage incurred by droughts in Bangladesh.

About 100 years ago, less than 50 percent of the land in the Barind Tract was under cultivation. Zuberi (1992) states that " in the past, there was a long sustained, stable land use system as indicated from the historical accounts; the comparatively flat areas were cultivated with aman (rainfed) rice while the elevated high lands and slopes were grass lands and low jungles covered with fuel and fruit frees." Elsewhere Zuberi (1993) maintains that "North Western Bangladesh practically has no forest cover at all. But recent historical accounts show that more than 50 % of the area was covered with natural vegetation." But with the expansion of agriculture and increased population, most of these natural areas have been destroyed, along with the rich biodiversity associated with these. Loss of natural vegetation cover has reduced additions to soil organic matter, disrupted natural nutrient cycles and has exposed the soil to the elements resulting in rapid erosion of topsoil. In addition, rapid heating of the topsoil occurs thereby quickly oxidizing organic matter remain since the early 1940s cultivation of the Barind Tract has expanded at the expense of forested land, 'wasteland', grazing land, by the increased use of areas formerly used as ponds but either deliberately filled with soil or filled by silt from increased soil erosion.

The major portion of the cropland of the Barind Tract is used for rice production and most of this rice land is now shown with High Yielding Varieties (HYV) of rice. But paddy is a high user of water and encouragement of its production in a water-scarce region is risky, especially since it may quickly degrade the poor soil of this region.

Government policy has been to encourage intensification of cropping in this region including the increased cultivation of HYV rice. To this end, it established the Barind Integrated Area Development Project (BIADP) within the Ministry of Agriculture.

Against advice from foreign experts, deep tube wells are being installed in this region under this project (The Daily Star, July 13, 1996). One problem is that the use of water from underground sources is liable to exceed the rate of recharge of the aquifers. The actual and planned water supplies from these sources are in all probability unsustainable in the long-term. Already water tables have fallen in some areas. For example, mango trees are reported to have died in some areas around Rajshahi due to falling water tables.

Irrigation from underground sources has enabled the area doubled cropped and triple cropped to be substantially increased. This raises the rate of depletion of soil nutrients and accelerates soil erosion. Hence "reports of HYV (rice) yields of 2.6 t/ha decreasing to around 2.0 t/ha or lower (even only 1.2 t/ha) in many areas, are common in recent years" (Zuberi, 1993). Consequently several reports and papers highlight the lack of sustainability of current agricultural practices in this region and there is significant land degradation with evidence of desertification in some areas (Ministry of Environment and Forestry and IUCN, 1991).

In addition, it seems probable that current and planned supplies of underground water for irrigation particularly in rice cultivation are unsustainable. Thus the longer term prognosis for agricultural production in this region is bleak and the possibility of future environmental refugees from this region cannot be dismissed. This raises several questions in political economy. In particular why should the government support agricultural developments which, on the face of it, result in unsustainable increases in income?

There are several possible explanations. First, governments tend to be myopic in their decision-making. Existing government is able to claim credit for increases in income in the short to medium term. In the long term, if incomes have fallen, the government has usually changed and the issue of responsibility for projects which prove to be environmentally unsustainable becomes confused, particularly if there is initial uncertainty about whether the projects involved are sustainable. Furthermore, policies to restrict use of resources such as use of underground irrigation water are liable to be politically unpopular e.g. to introduce pricing which reflects user-costs. Consequently, political mechanisms are unlikely to favor conservation and sustainability.

Water is an essential input for modern agriculture, and more use of irrigation water, especially groundwater, has contributed to manifold increases in crop productivity in Bangladesh. Rice yield, for example, increased from 1.0 MT/ha in 1971/72 to 2.8 MT/ha in 2008/09. Much of this increase in yield was due to an increase in the share of rice area that is irrigated (especially during the *Boro* season), which increased from 10% in 1971/72 to 44% in 2006/071. The quantity and quality of water resource is not uniformly distributed throughout the country. Moreover, different crops need different quantities of water for their production. Cost effectiveness of using irrigation water for different crops in different regions needs to be examined so that the appropriate crops -in terms of profitability may be grown in different locations.

Ground water irrigation has probably been the most dramatic development in Bangladeshi agriculture in the past 25 years. Not many countries in the world, if any, are as dependent upon ground water as Bangladesh is Indeed, the contribution of ground water to total irrigated area was 77% in 2006-07. However, in some areas, especially the north-western part of the country, groundwater tables have been declining rapidly, and this decline threatens the economic viability of future rice production.

A gradual fall in the underground water level, delayed monsoon, less rainfall under the impact of climate change and drying up of rivers have been contributing to a water crisis and affecting agricultural production in the region. To develop agriculture and overall rural development in the region, the Government created a new authority named the Barind Multipurpose Development Authority (BMDA) in 1992. The Authority has been operating about 13,000 Deep Tube Wells to provide irrigation facilities in the region during the dry season. The Authority also reported that the ground water level declined substantially during the last decade, causing threat to the sustainability of water use for irrigation in the region. Farmers of this region used continuously standing water for rice cultivation. It is true that rice cultivation requires much water than any other crops. It may also be that high yield in this result in a strong time preference for present water use pattern and a belief that the long-term will somewhat take care itself.

Whether it does or not will depend on whether increases in man-made capital (Combined with technological progress) compensate for the decline in natural resources in Rajshahi. There is no indication that what is going to happen.

However, as documented in this paper, the continued increase in groundwater-intensity of agriculture has caused significant damage to the physical environment and threatened the sustainability of agricultural production.

Rice crop in general is considered to be the maximum user of the fresh water resources as the crop is grown under flooded or submerged condition. So under circumstances of increasing scarcity of water, sustainability of irrigated agriculture is an important issue of concern. Rice is extremely sensitive to water shortage where the soil water content drops below saturation – growth and yield formation are affected. Although rice is adapted to water logging, complete submergence can be lethal. Rice is unique among the major food crop in its ability to grow not only in wide ranges of soil types and climates but also in hydrological situation. Irrigated lowland rice is grown in bunded fields with irrigation. Usually farmers try to maintain 5-10 cm of water in the field. Rainfed lowland rice is grown in bunded field that are flooded with rainwater for at least part of the crop period to water depth exceeds 100 cm for not more than 100 days. In both irrigated and rainfed lowlands, fields are predominantly puddle. Irrigated rice is mostly grown with supplementary irrigation in the wet season, and entirely reliant on irrigation in the dry season.

Water for lowland rice is needed for land preparation and to maintain the unavoidable losses due to seepage, percolation, evaporation and transpiration during crop growth. The amount of water used for wetland preparation can be as low as 100-150 mm. After crop establishment, the soil is usually kept ponded until shortly before harvest. Total seasonal water input to rice field (rainfall and irrigation) is up to two to three times more than that for other cereals. As observed the total water loss ranges from 6-10 mm per day. Thus, on an average about 180-300 mm water per month is needed to produce a reasonably good crop of rice. Around 1300-1500 mm is a typical value for irrigated rice especially in our area.

To increase the productivity of rice under water scarcity situation options exist through varietal improvement and by better management of natural and man-made resources. With increasing water scarcity in irrigated systems, rice variety should be selected under condition of water saving technologies such as alternate wetting and drying or aerobic cultivation. The growth duration of the varieties so selected should be short so that reduced total outflows of evaporation, seepage and percolation at the field level is obtained. The combined effect of increased yield and reduced growth duration is that these varieties may result into three times higher water productivity with that of traditional varieties grown under similar water management.

1.7 Water Requirements of Different Growth Phases of Rice Plant

Numerous studies show that rice plant water requirements changes with each stage of crop growth. For water management purposes rice stages are usually divided as the seedling, vegetative growth (rooting and tilering), reproductive (Panicle initiation, panicle differentiation, and anthesis), and ripening (grain filling and maturity) stages. Each growth stage responds differently to water management practices.

Various studies have given conflicting reports on optimum water management during vegetative growth. De Datta (1987) recommends continuous shallow submergence (2.5- 7.5 cm depth) to facilitate tiller production and confirm root anchorage. O' Toole and Moya (1981) suggest that water deficit during vegetative development may have little effect on grain yield. Several studies found that delaying flooding until just prior to or at panicle initiation had little or no effect on grain yield and significantly increased water-use efficiency (McCauley and Turner, 1979; Beyrouty *et al.*, 1992; Norman *et al.,* 1992; Lilley and Fukai, 1994; Grigg *et al.*, 2000). Midseason soil drying during vegetative growth before panicle initiation, which is practiced in Japan and China, has been found to increase grain yields. This has been attributed to removal of anaerobic toxins, reduce ineffective late tillering, reduced lodging, increased N and P availability, and better root development (Wei and Song, 1989; Tuong, 1999; De Datta, 1987;). Intermittent flooding in which the field is flooded and dried at regular intervals with periods of no standing water during vegetative development has been found to be as effective as, and sometimes even better than, continuous static flooding (De Datta, 1987; Devi *et al,* 1996; Prasad *et al.* 1997; Lourduraj and Bayan, 1999; Channabasappa *et al.*, 1997; Raman and Desai, 1997; Sharma *et al.,* 1997). Borrel *et al.*, (1997) found that maintaining saturated (non-flooded) conditions in the paddy had no significant effect on yield quality or quantity as compared to the conventional practice of continuous shallow submergence.

Most studies suggest that continuous saturation or shallow flooding (~5 cm) is the optimum water management for the reproductive stage. Studies have shown that less than saturated soil conditions during reproductive growth starting with panicle initiation can significantly reduce yields (De Datta *et al.,* 1973; IRRI, 1999). Borrell *et al., (*1997) found no significant yield deference between continuous saturated soil culture (SSC) and traditional flooding. Studies have shown that flooding depths greater than 5 cm during reproductive growth can reduce yields and greatly decrease water-use efficiency (De Datta and Williams, 1996; Prasad *et al.,* 1997; Lourduraj and Banyan, 1999; Channabasappa *et al.*, 1996; Raman and

Desai, 1997; Sharma *et al.,* 1997; Bin and Loeve, 2000) while in others significant yield reductions were reported (De Datta, 1987).

Rice water requirements are low during the grain ripening stage. De Datta (1987) suggests that no standing water is required during most of the ripening stage. Flooded fields are usually drained at least a week before grain maturity (IRRI, 1999). Studies have found that terminating flooding as early as 2 weeks following heading does not affect grain yield or quality and can significantly reduce water consumption (Counce *et al.*, 1990; Dingkuhn and Le Gal, 1996; Grigg *et al.,* 2000).

1.8 Why Hybrid and Inbred Rice Varieties?

Rice, most loved cereal of Asia, feeds the majority of the world's population. More than 90% of the world's rice is grown and consumed in Asia where 60% of the earth's people and about two-thirds of the world are poor live (Khush and Virk, 2000). Green revolution helped to solve the world's demand for food, but is not enough to meet the 21st century's. Cultivable area under rice needs to be increased to improve the production demands. Due to over usage of land for cultivation by dumping in of inorganic fertilizers, poor crop rotation, use of underground water etc., the fertility of arable lands are undergoing a decline. Reclamation of land for acidity, salinity, alkalinity, hardpan, nutrients etc. needs to be undertaken periodically. Ahmed *et al.*, (2001) state that to cope up with the ever increasing demand for rice it should be met with quantum jump in production in fixed cultivable area. This is a daunting task, in view of plateauing trend observed in yield potential of high yielding varieties and decreasing and declining natural resource base.

Furthermore, the conversion potential from local to modern varieties seems to be limited as the ceiling adoption level of modern varieties in Bangladesh appears to be reached (Bera and Kelly, 1990). Currently, 61% of total rice area is allocated to modern varieties and the upper bound of conversion, set at 85% by Baffes and Gautam (2001), already seems to be optimistic as it assumes a minor increase in gross rice area while past experience revealed a stagnancy and/or minor decline in land under rice. Therefore, the principal solution to increasing food production lies in raising the productivity of land by closing the existing yield gaps and developing varieties with higher yield potential. On the other end of the spectrum, the United Nations projects that farmers will have to generate large marketable surplus to feed the growing urban population (estimated at 46% of total population of 173 million) by 2020 (Husain *et al.*, 2001). This implies that Bangladeshi farmers not only need to be more efficient in their production activities, but also to be responsive to market indicators, so that the scarce resources are utilized efficiently to increase productivity as well as profitability, and ensure supply to the urban market. Furthermore, efficiency gains will have a positive impact on raising farm income of these largely resource poor farmers. In fact, real income from modern rice farming over the past decade has fallen by 18% owing to stagnant output price and rising costs of production coupled with declining productivity.

1.9 Why the Study was Undertaken at Rajshahi and Gazipur?

The study was conducted in Rajshahi and Gazipur districts. These two areas were selected purposively for three reasons. First, they represented different rice environments. Rajshahi district was selected as drought prone area. The occurrence of physical water scarcity is more acute and pronounced in Rajshahi where *Boro* and sometimes even the Aman (monsoon) seasons are characterized by relatively severe water shortages. In the annual cycle, deep aquifers are refilled during the monsoon season, while the water table decreases during the dry season as water is extracted for irrigation. However, groundwater refill and water abstractions are no longer balanced. This means that, due to their hydrological connectivity with the deeper aquifers, shallower aquifers are becoming dry during the dry season. The minor irrigation systems implemented in Rajshahi Divisions, which play a major role in supplying rice with irrigation water during the dry season, are largely based on Shallow Tube Wells (STW) and Deep Tube Wells (DTW), which are common in Bangladesh. In Rajshahi, farmers used shallow tube well for irrigation in cultivating T. Aman rice, while farmers in Gazipur cultivated T. Aman rice in rainfed conditions.

In the third, socio-economic and biophysical data were gathered using a structured questionnaire designed for this study, Information was generated from four villages in Rajshahi and Gazipur district, through formal interview of 120 farmers and from these two villages 30 participants farmers from each village were employed for experiment in *Boro* season.

1.10 Concept of Productivity

Two sets of terminologies have to be used to describe water conservation and water productivity. The water use efficiency index measures water conservation and is defined as production unit (Y) per unit of water supplied. The water supply includes both diverted water plus rainfall. Water productivity is defined as productivity per unit of water consumed. Water consumed is essentially evapotranspiration, which includes evaporation from soil and transpiration through plants. The water use efficiency index is related to water productivity in following way:

$$\frac{\text{Production}}{\text{Water Supplied}} = \frac{\text{Production}}{\text{Water Consumed}} = \frac{\text{Production}}{\text{Water Holding Capacity}} = \frac{\text{Production}}{\text{Water Supplied}}$$

Or in other words, Water use efficiency = Water productivity ×Water uptake factor × Water management factor..........................(1)

The water use efficiency index can be increased by three factors as indicated in equation 1. The first factor is water productivity. It can be increased by increasing' Y' or reducing water consumed, or by both. Manipulation of this term is in the realm of plant scientists and bio-technologists. The second factor is the water uptake factor, which is in the realm of soil scientists. Given a particular type of plant, the issue is how to manipulate the soil and its structure to hold sufficient water and supply adequate water so that productivity can be increased. The third one is the water management factor where in the manager operates the system in such a way that he is able to supply water just sufficient to accommodate within the root zone and meet the crop water requirement in a timely manner. AWDI is one method of managing the water so that will not be wasted but it will aid the root growth, facilitate higher nutrient uptake and increase land and water productivity.

1.11 Water Use Efficiency (WUF)

Water-use efficiency (WUE) is often considered an important determinant of yield under stress and even as a component of crop drought resistance. It has been used to imply that rainfed plant production can be increased per unit water used, resulting in “more crop per drop”.

This opinionated review argues that selection for high WUE in breeding for water-limited conditions will most likely lead, under most conditions, to reduced yield and reduced drought resistance. As long as the biochemistry of photosynthesis cannot be improved genetically, greater genotypic transpiration efficiency (TE) and WUE are driven mainly by plant traits that reduce transpiration and crop water-use, processes which are crucially important for plant production. Since biomass production is tightly linked to transpiration, breeding for maximized soil moisture capture for transpiration is the most important target for yield improvement under drought stress. Effective use of water (EUW) implies maximal soil moisture capture for transpiration which also involves reduced non-stomatal transpiration and minimal water loss by soil evaporation. Even osmotic adjustment which is a major stress adaptive trait in crop plants is recognized as enhancing soil moisture capture and transpiration. High harvest index (HI) expresses successful plant reproduction and yield in terms of reproductive functions and assimilate partitioning towards reproduction. In most rainfed environments crop water deficit develops during the reproductive growth stage thus reducing HI. EUW by way of improving plant water status helps sustain assimilate partitions and reproductive success. It is concluded that EUW is a major target for yield improvement in water-limited environments. It is not a coincidence that EUW is an inverse acronym of WUE because very often high WUE is achieved

1.12 Evapotranspiration (ET)

In practical term ET is the combined losses of water due to evaporation from the surface of the cropped land and transpiration of water due to evaporation from the plant leaves (Wickham, 1971). Potential Evapotranspiration (PET) which is also called references crop ET, is the maximum rate of which water if fully available would be removed from the earth's surface and transpired by the plant expressed as the latent heat transfer per unit area or its equivalent depth of water per unit area (Burman *et al.*, 1983). ET is the combined effect of two terms: (1) evaporation, which refers to water evaporating from soil, water and the plant leaf surface; and (2) transpiration, which is the escape of water into the atmosphere through the process of water from the soil entering the plant roots for building plant tissues and its leaves to support photosynthesis and respiration.

Evapotranspiration (ET) is a major factor affecting dry matter, and hence the agricultural production potential of a given region depends on it (Tomar and O' Toole, 1979). The level of ET is controlled mainly by plant characteristics', extent of ground cover and stage of growth, water availability in the soil and meteorological parameters or the evaporative demand. For high yield, ET must be maintained at the potential rate. Rice yield, as that of most other crops, will decline with decreasing rate of ET (IRRI, 1981). For maintaining high, ET, the soil should remain at the saturation level or there should be standing water on the field. However, when water crisis occurs, it is more important to meet full ET needs during the reproductive stage of the crop than the vegetative period (Bhuiyan and Palanisami, 1987).

1.13 Seepage and Percolation (S&P)

Seepage is the lateral movement of water through and under paddy bunds, which may reaper at the surface in a lower elevation. Percolation is the downward movement of water through saturated or nearly saturated soil in responses to the force of gravity and eventually this percolation water reached the water table.

Seepage and Percolation (S&P) as part of the water requirement constitute water movement into the soil. It is difficult to measure the two components separately. However, the actual is an integrated effect of seepage and percolation and is, therefore, often measured together as one component of the water requirement of rice (Wickham, 1971). Methods that can be used to measure S&P in the field include, (1) the drum culture; (2) tanks or lysimeter, (3) the water balance method, and (4) the sloping gauge technique. The sloping gauge technique first used by Giron and Wickham (1976) has become popular because of the following reasons: (1) it is simple, (2) it estimates the problem associated with the method of using lysimeter tank or drum where the measured subsidence of water is attributed to only downward to only downward percolation, neglecting seepage; and it can used in farmers paddies without disturbing the crop.

The most important soil and environment factors affected the rate of S&P losses are soil topography, soil texture, soil structure, and porosity, and water table depth, density of drainage network and size of the rice growing area (Wickham, 1971; Ghani, 1987; Adhikary and Early, 1979). Heavy clay soils do not allow high rates of seepage or percolation and well puddle soils impede it in future.

The principal loss of irrigation water is caused by lateral percolation, the movement of water from the flooded fields laterally into the bunds and hence vertically down to the water table. Walker and Ruston (1986) indicated that from irrigated rice field, loss due to vertical flow through the low permeability plough layer and hard pan is about 2 mm/day and the losses through the buds may be 8 to 23 mm/day or sometimes higher.

1.14 Aims and Objectives of the Thesis

This thesis explored options for future water management and farmers adaptations of irrigated rice it two agro ecological zones (AEZ 26 and AEZ 28) in Bangladesh. The exploration of management options by detailed experiments and modelling lead to an improved understanding of the system, proposals for improved rice management and set the agenda for future research. The results of this thesis should assist researchers to set priorities, breeders to direct their breeding programmes, and policy makers to adopt agricultural policies to global change. Agricultural extensionists and development workers could draw practical lessons from the experiment.

The objectives of the research are:

1. To identify the sustainable water management for rice cultivation by practicing alternate wetting and drying (AWD).
2. To determine the water use efficiency and water productivity of AWD for *Boro rice* variety.
3. To analyze impact of wetting and drying on yield and yield contributing characters'.
4. To explore socio-economic characters' which leads farmers to adoption of alternate wetting and drying in the farmer's field?

1.15 Research Methodology

For this research a combination of two methods were used: three field experiments and farmer's field survey. This combination of methods has been used satisfactorily in explorative studies on rice water management before (Belder *et al.*, 2007; Haefele *et al.*, 2003b; Jing *et al.*, 2008). The field experiments provided realistic and sound data which were used to statistical analysis to know the effect of existing water management on yield and yield contributing characters. The field experiments were performed at Bangladesh Rice Research Institute, Gazipur and Rajshahi regional station. Both research stations were representative for large irrigated rice ecologies. A field survey was conducted Godagary and Gazipur two location of Bangladesh. Selective purposively as alternate wetting and drying water saving technology is not yet adoption by farmers throughout the country.

1.16 Significance of the Study

This study is significant as it reveals an effective, yet unexplored (in terms of variety) mode of irrigation system (alternate wetting and drying), that can save water and cost and contribute to sustainability. In order to irrigate paddy field, electricity or fuel is needed to bring water to the surface. Water pumping and delivery treatment facilities consume a significant amount of energy. Farmers are currently paying an equivalent of 25% to 30% of their rice harvest for irrigation and these costs are tending to increase (Sattar *et al.,* 2009). This presents another factor for the economic relevance of water-saving at the farm level. Experts state that on a national level, the implementation of AWD could save costs for irrigation of up to 56.4 million Euros in electricity or 78.8 million Euros in fuel (30 liter diesel/ ha) (Miah *et al.*, 2009). As irrigated rice systems serve as a large sink for atmospheric carbon dioxide and are a significant source of methane (Bouman *et al.*, 2007), it is assumed that reducing the standing water in rice fields will have positive ecological implications. Furthermore, the contamination of rice with arsenic, which is an acute problem in some regions of Bangladesh, is associated with an excessive withdrawal of underground water (Hussain & Kabir (2009) in Sattar *et al.*, 2009). Therefore, introducing AWD could have major impacts at the farm level and be important throughout the country by reducing irrigation costs and reducing the excessive use of ground water, leading to a more sustainable use of natural resources. In some regions of the world over 15% of total electricity consumption is devoted to water management. However, the demand for energy grossly exceeds the available supply by far (Economist Intelligence Unit, 2008). Diesel is not always available in some rural areas and is expensive for poor rice farmers, while farmers connected to a public power grid are subject to frequent power cuts (CPD, 2010). As a consequence, Bangladeshi rice farmers have to cope with unreliable irrigation water supply, either deriving from the physical unavailability of surface and groundwater resources, or caused by insufficient electricity and/or fuel supply for pumping. In order to address farmers' needs to save water, energy and fuel in irrigated rice alternate Wetting and Drying technology, which takes an average of 1,432 litters of evapotranspirated water to produce 1 kg of rough rice (IRRI, 2010).

A farmer receives from cultivating rice when his total revenue (or gross return) from selling rice and its related by-products, *i.e.* straw, exceed the total production costs. The total production costs for growing rice, however, are made up of fixed costs, *i.e.* the rent for the land, interest on loans, or interest of capital, and variable costs, *i.e.* expenses that change in proportion to the level of activity of a rice farmer. These variable costs include several input and labour costs, such as fertilizer, herbicide or fungicide inputs, expenses for water and energy, and labour. AWD-based irrigation has an impact on variable costs as the technology reduces irrigation costs. The total production costs for the *Boro* season for conventionally irrigated rice ranged in Bangladesh in 2009 from 475 Euros in Rajshahi (Hossain *et al.*, 2009) to 1010 Euros in Camilla (Kabir, 2009). Of these total costs between 12% (Chittagong) and 27% (Rajshahi) were irrigation costs, ranging in 2009 between 54 Euros/ha (Hossain *et al.*, 2009) and 226 Euros/ha (Kabir, 2009). Through implementing AWD-based irrigation between 15 Euros/ha (Hossain *et al.*, 2009) and 112 Euros/ha (Kabir, 2009) could be theoretically saved, *i.e.* if water and energy savings were transferred to the farmer. Therefore practice of irrigation technology like AWD can play a remarkable role in reducing water losses and cost of irrigation for crop production.

The significance of the research is that it access to contribute to environmental sustainability.Water is integrally linked to the health of the environment. Water is vital to the survival of ecosystems and the plants and animals that live in them, and in turn ecosystems help to regulate the quantity and quality of water. Groundwater level is also declining due to excessive withdrawal threatening the environment. Water resources are becoming scarce worldwide, Bangladesh is of no exception. As surface water supply is decreasing day by day, irrigation pressure is mounting on groundwater resource. But this resource is not unlimited and in intensive tube well areas water level is declining gradually in each dry season. Recently, arsenic contamination is being reported in groundwater as well as in the food chain, which is threatening consumption.

The final significant of the study as alternate wetting and drying water saving technology can helpful for habitat conservation. Minimizing irrigation water use helps to preserve fresh water habitats for local wildlife and migrating waterfowl, as well as reducing the need to build new dams and other water diversion infrastructures.

According to the recent estimates, out of 8.4 Mha of cultivable land, about 4.8 Mha has been brought under irrigation. It implies that about 57% of total cultivable lands are irrigated. Both surface and groundwater is used for the purpose. At present more than 70% of the irrigated area is served by groundwater and less than 30% by surface water. Groundwater is being extracted through 11, 28,991 shallow tube wells (STWs), 27,117 deep tube wells (DTWs), 826 force mode pumps (FMP), and 1, 15,876 un-mechanized (manually operated hand tube wells, treadle and rower) pumps for irrigation and domestic purposes. There are also 99,115 low-lift pumps (LLPs) and 5, 01,431 traditional irrigation units in operation for lifting surface water. So the judicial use of water resources in intensive irrigated area is a crucial need for maintaining both sustainable crop production and accessible water level.

1.17 Thesis Structure and Chapter Summary

Chapter one "**General Introduction**" this chapter introduces the background of the research and reveals the question which this thesis endeavours to answer. It gives an outline of the aims and objectives of the research followed by an overview of the research methodology and various aspects of the fieldwork. The significance of this research is also explained.

Chapter two "**Review of Literature**" This chapter explore the study related to alternate wetting and drying irrigation technology in different countries in the world.

Chapter Three **"Materials and Methods'**

Chapter Four ' **Results and Discussion** " This chapter explore the effect of AWD on yield and yield contributing characters', water use efficiencies compared to traditional irrigation system and the impact of AWD on different phonological stages e.g. vegetative, reproductive and ripening stages of rice plant. This chapter also examines the current level of adoption of AWD technologies and identifies the major socio-economic factors that influence the adoption, with a view to providing relevant information to guide farmers, researchers, extension workers and policy makers on this very important issue."

Chapter Five "**Conclusion**" draws conclusions that follow the introductory chapter through to the field study and survey studies, to reveal the potential contribution of alternate wetting and drying water saving technology. This thesis concludes that AWD can make a valuable contribution to save water for rice cultivation and provide a complementary pathway to irrigation system for sustainability.

Finally, Chapter Six "**Recommendation**"

1.18 Limitations of Implementing this Study

General limitations are related to the time of year within which the study was implemented. Data collection was conducted mainly during the months of August and September, during Aman season (July to November), while AWD is largely relevant and implemented in the *Boro* season (December to May). This may imply that responses that could be obtained from farmers on the previous *Boro* season are limited and lack precision. Also, data collection which posed a challenge in conducting interviews at local level, both in identifying farmers who were willing to be interviewed and who were sufficiently alert and focused to perform an intensive interview. When conducting the first interviews on the farm level, it became evident from the early stages of adoption that sampling technology users, by applying a common definition of "adopters of technologies" (Rogers, 2003) would not be possible. For this reason, farmers who received training or participated in an AWD demonstration and already tested the technology at least once were considered to be "adopters" for the purpose of sampling. Also, since "real" adopters were hard to find, it proved to be useful to assess the general situation of AWD in a more qualitative and descriptive way. Another constraint of data collection relates to the fact that marginal farmers and sharecroppers who received training were difficult to find. This might be due to the focus of extension organizations, initially targeting mostly small-, medium and large-scale farmers for dissemination. Also, marginal farmers tended to be working in the field and were therefore hard to find during the day. The random sampling based on the lists of trained farmers was also not always possible, as they were often unavailable, incomplete.

Chapter 2

Review of Literature on Sustainable Use of Water

Chapter 2

Review of Literature on Sustainable Use of Water

This section is an attempt to find relevant literatures related to study. This is important because the present study should be started from that point where the previous ended. Many researchers indicate that rice is the major consumer of irrigation water in Bangladesh. It is grown under two distinct water regions, continuous flooding and alternate flooding. The conventional method of rice planting requires continuous ponded water on the field, which is possible where irrigation water is abundant and cheap. In this method irrigation water is used for evapotranspiration (ET) and seepage-percolation (S&P). But in reality, only ET is the true water requirement for crop growth and S&P are the unavoidable losses. However, rice can be grown under alternate wet and dry conditions with necessarily sacrificing yields and adoption of such practices may allow savings of costly water. This AWD tool is a single device designed to observe water level in rice field for deciding the time of irrigation. It involves installation of a perforated pipe (preferably PVC) in rice field to allow observation of water level. In one part, such pipe of 10 cm diameter and 30 cm long is installed having 10 cm above and 20 cm below the ground surface.

By applying AWD, farmers or pump-owners are able to save 15 to 30% of their irrigation water. Water productivity, *i.e.* the volume of irrigation water required to produce a certain amount of rice, increases compared to conventional cultivation (Lampayan *et al.*, 2009; Bouman *et al.*, 2007).

Using AWD yields significant potential to reduce input costs for water, irrigation services, as well as energy and fuel. This method is referred to as alternate wetting and drying irrigation (AWDI). In certain areas and under the right conditions, AWDI is a promising method in irrigated rice cultivation with dual benefits of water saving and human disease control, while maintaining rice yields at least at the same level. AWDI is one method that can increase the productivity of water at the field level by reducing seepage and percolation during the crop growing period.

The International Rice Research Institute (IRRI) conducted a series of on-farm (field level) experiments between 1968 and 1972 to establish the relationship between the quantity of water applied and the rice yield. The hypothesis was that as the level of water applied diminishes; yields would drop very sharply, reflecting the extreme sensitivity of puddle rice to drought conditions. It was predicted that the general nature of the response would take the shape of a sigmoid or logistic curve. During the 1968 dry season, all experimental plots were kept flooded to a depth of 5 cm until panicle initiation (60 days after transplanting). Then water was applied at five-interval with five levels ranging from an average of 2 mm/day-6mm/day. The soil moisture content never fell below 50% of approximate field capacity. In 1969, seven treatments consisting of 2-8 mm average daily application applied at five-day intervals plus two flooded controls were used. The treatments were started shortly after transplanting (as compared with panicle initiation in 1968). The result indicated that yield was greatest at 8 mm per day. Maximum yield per millimeter of supplied water was achieved at 7 mm/day. Below a water application level of 6 mm/day, yields dropped sharply and were almost zero at 4 mm/day. At 8 mm/day, the pot was maintained from a flooded to saturation level. At 7 mm/day, intermittent flooded to saturation was maintained before flowering. From flowering to maturity, the pot fell below saturation. Total water application levels below 7 mm/day, all plots fell below saturation before flowering. The plants in the plot receiving 3 mm/day flowered bur produced no grain and plants in the plot receiving 2 mm/day did not flower (IRRI, 1972).

IRRI (1970) also analyzed the effect of environmental factors on the functional yield-stress relationship based on the data of dry season of 1969, 1970 and 1971. The results indicated that for a given season, low yields were closely associated with the duration of time during which the soil moisture had been seriously depleted. The 1969 dry season had more solar radiation during the last 45 days before harvest and less rainfall than the dry seasons in 1970 and 1971. The high solar radiation increased yields under ample water treatments to levels higher than in 1970 or 1971. But under low levels of water application the high solar radiation the decline of soil moisture. Thus, higher solar radiation appeared to be associated with higher yields only in the places where water is not a limiting resource.

Hoque *et al.*, (1994) conducted an experiment on the comparison of pan evaporation and Penman method by Doorenbos and Pruit (1977) for estimation of water requirement by crop and stated that consumption use was 461.02 mm and net irrigation requirement was 410.10 mm for *Boro* rice in Mymensingh area.

Rashid and Khan (2000) conducted an experiment on water saving during *Boro* season with 5 treatments in order to minimize losses of irrigation water from rice fields and thereby increase irrigation efficiency.The treatments were T_1= Continuous water (1-7cm), T_2=Shallow standing water, T_3= Irrigation (5-7cm) after 3 days of disappearing of standing water, T_4=Irrigation (5-7 cm) after 5 days of disappearances of standing water and T_5= (5-7cm) after 7 days of disappearances of standing water. The result revealed that treatment T_3 saved 28% of irrigation water over continuously standing water condition with only 2% yield reduction. Alam and Mondal (2003) reported that irrespective of water treatments, BRRI dhan29 produced the highest yield (5938 kg/ha) and IR68877H (5220 kg/ha) followed IR65650H (5625 kg/ha) and IR68877H (5220 kg/ha). For all varieties, continuous 3 to 7 cm standing water required the highest amount of water followed by 7cm irrigation water application after disappearances of standing water (T_2) and 7 cm standing irrigation water application 3 days after disappearances of standing water (T_3) treatments.

BRRI (1989) recommended that application of irrigation water 3 days after disappearances from rice fields is the most water saving and optimum yield producing irrigation technology for inbreed rice planting.

Khera *et al.*, (1991) emphasized that even on coarse textured soils continuous submergence is only required for 3 week period after transplanting to ensure seedling establishment. The field may be drained for 1 to 5 days, depending on the weather, before the next irrigation. There will be no adverse effect on yield and 25 to 50% of water can be saved.

Prasad *et al.*, (1997) studied the effect of applying improved water management technology during the wet season in canal-irrigated rice fields in Bihar, India and found that irrigation to a depth of 7 cm, 3 days after ponded water disappeared gave 34% more grain yield than the usual farmer's practice (more than 10 cm irrigation water continuously).

Bouman and Toung (2001) illustrated that major challenges are to save water, increase water productivity and produce more rice with less water. They analyzed that water input could be reduced by reducing ponded water depths to soil saturation or by alternate wetting and drying. They found water saving under saturated soil conditions were on an average 23% (+4%) with yield reductions of only 6 % (+6%). Yield was reduced by 10-14% when soil water potential in the root zone was allowed to reach-100 to 300 mbar. In clay soils, intermittent drying may lead shrinkage and cracking, thereby, risking increased soil water loss, increased water requirements and decreased water productivity.

Chow (1965) summarized findings of number of studies conducted to compare rice yields under continuous and intermittent flooding. Studies conducted in Taiwan indicated no yield reduction if water in paddy fields is delivered intermittently, but 20 to 50 % water saving can be achieved by intermittent flooding method compared with the continuously flooded fields.

Bhuiyan (1981) reported that the total water requirement of rice was about 1500 to 2000 mm of which about 500 to 550 mm was required to meet the demand of evapotranspiration and rest of it was lost in percolation. It means that 60 to 75% of the total water applied is not available by the rice crop.

De Datta (1981) reported that the amount of water required for the growing season depends on the water maintained, water management practices, soil type and evaporative demand. De data and Williams (1968) stated that continuous shallow to medium (2.5 to 7.5 cm) flooding required 600 to 800 mm of fresh water from transplanting to maturity for a short duration variety (8.5 to 91 days) in BRRI experimental field. They mentioned that when the depth is 15 cm, the water requirement goes upto 1400 mm due to higher seepage and percolation losses.

BRRI (1983) reported that there was no significant yield different between rice grown in 5 cm standing water and saturated field conditions.

Goel and Verma (1988) tested water management practices for rice in 1984-85 and found that submergence upto the tillering stage followed by irrigation at 4-days intervals upto 50% flowering and thereafter 5 cm irrigation to keep the soil at saturation upto harvest gave the highest average paddy yield of 7.09 t/ha, compared to 6.21 to 6.59 t/ha for other treatments, and also gave the highest water use efficiency of 55.80 to 59.48 kg paddy/cm water per ha compared to 45.80 to 55.30 kg/ha/cm for other treatments. Gnesh (2001) conducted three-year field trail during *Kharif* season to evaluate the effect of different moisture regimes on the grain and straw yield of three rice genotypes (KRH-1,KR H-2 and IR-64).He evaluated three moisture regimes: (M_1) maintaining 2.5 cm submergence from transplanting to 15 days after transplanting (DAT) and 5.0 cm submergence until 10 days before harvest; (M_2) maintaining 5cm submergence after the disappearance of the ponded water; and (M_3) maintaining soil moisture between field saturation and field capacity. He found that the grain and straw yields' were the highest in M_1 followed by M_2 and M_3 respectively.

Raman and Desail (1997) conducted a large scale experiment to determine the significance of improved water management practices for summer rice planting in Gujrat, India. In the study plot, (5+2) cm of irrigation water was applied 1 day after standing water disappeared; and in the control plot, farmers practices, (10+2) cm of irrigation water was followed. The result of the demonstration showed that 29% of irrigation water normally used by farmers was saved with about 55% higher yield per unit of water applied by adopting the improved water management practices. About 10.3% yield was increased in the study plot over the control plot.

2.1 Chinese Studies

In the southern part of China, over 70 % of the cultivated area comes under rice. Under the traditional method, termed as 'shallow flooding irrigation', the fields are covered with a shallow water layer during most of the rice-growing season here. Since the 1960s, in some provinces in South China, a new irrigation technique for rice, termed 'water saving irrigation. Hoi has been promoted (Mao, 1996). The basic feature of this new irrigation technique is that there is no water layer above the soil surface in rice fields during the growing season from the time the seedlings have recovered. This reduces the percolation, seepage and runoff from the field.

It is claimed that this technique not only saves water but also increases the rice yields, in the experimental fields of the Guangxi Autonomous Region, percolation under water saving irrigation was 67 % lower than under flood irrigation (Table 2.1).

Under flood irrigation, the groundwater table in rice fields rose up to the soil surface and kept this level during the period of submersion and it could be lowered to 0.3 to 0.8 m below 11e soil surface during the period of no submersion under 'water saving irrigation. The soil oxygen content in rice fields under water saving irrigation is 120 to 200 % of that under flooding irrigation (Mao, 1993). According to statistical figures from Yulin Prefecture in tic Guangxi Autonomous Region, where water saving irrigation for rice has been adopted in 30,000 hectares, about 100 million m3 of irrigation water for rice has been saved per year (Mao, 1996).

Table 2.1 Mean Value of Evapotranspiration, Percolation and Water Requirement over a Whole Growing season at the Guilin Experimental Station, Guangxi Autonomous Region, 1990-92.

Irrigation technique	Evapotranspiration (mm)	Percolation (mm)	Water requirement
Flood irrigation	765.4	514.9	1280.3
Water saving irrigation	688.8	169.3	858.1

However, at this larger scale it is difficult to estimate the contribution of AWD1 to the water savings because different changes took place at the same time. Most important was the introduction of volumetric charges for irrigation water in China, which was a major incentive to use less water. Measures were taken to reduce the conveyance losses of water in canal systems by lining sections of canals that had heavy seepage losses. The loss of water in the fields and in field channels was reduced through AWDI and construction of field irrigation ditches. The ratio of water irrigated to the field to the water diverted from the headwork for irrigation ranged from 0.43 to 0.53 before and 0.57 to 0.63 after the introduction of volumetric charging of water. Additionally, the irrigation application efficiency increased because of these measures so that the gross irrigation quota decreased remarkably. Combined with an increase of rice yield this resulted in high water productivity.

In the Zhanghe Irrigation System in Hubei Province, the AWDI method alternately consisted of a shallow water layer and damp and dry situation of soil on the rice fields at different growing stages of the rice. The water regimes on rice fields for this method are shown in Table 2.2.

Table 2.2 Water Regime Adopted in Zhanghe Irrigation System, Hubei Province, Chaina.

Growing stages	**Depth of water layer (mm)**
Transplanting rice shoots	10 to 20 mm
Revival of green	0.30 mm
Early and middle of tillering	80% of the available water
Late stage of tillering	Drained, dry field for 5 to 7 days
Booting and flowering	80% of the available water
Milk ripening	70% of the available water
Yellow ripe	Drained, dry field

Source: Mao and Yuanhua (1998)

Based on experimental fields and the practices on the larger area, the net irrigation water saved was 20 to 35 % (4500 m3/ha/year). Rice yield increased by 15 to 28 % after the reform of water charge. However, other agricultural practices including fertilizer application have also changed and will have contributed to yield increases. Based on the analysis of the data no in the experimental station and the investigations in the typical areas, the irrigation productivity in the "Zhanghe Irrigation System" was found to be 0.65 to 0.82 kg/m^3 and 1.18 to 1.50 kg/m^3 before and after the application of AWDI, respectively. Another example is from the Juankou Irrigation District in the Yulin Prefecture, Hunan Province with an irrigated area of 2,100 hectares. Before 1989, the land was cultivated (with rice) in only seven months (April-October) and remained fallow during the rest five months due to lack of irrigation water. Since 1990, water saving irrigation for rice has been adopted and the average gross irrigation quota for rice has been reduced by 180 mm. As a result, half of the agricultural land has been planted with vegetables in the winter and the farmers' average annual income has increased by about 27 %. AWDI was considered particularly suitable for areas where rates of evaporate and percolation are high with a low tendency of soil-crack (Lu, 1988).

Lu (1988) explored that introduction of AWDI in the 1970s, coincided with a dramatic reduction in malaria morbidity.The method is referred to as 'wet irrigation' and involves a period of continuous submersion for 10 to 15 days post transplanting, after which the fields are allowed to dry naturally before being re-irrigated immediately when all surface water has disappeared. This leads to 21 to 26 irrigation events during the 100 day growing period of the rice plants, with standing water disappearing within 1 to 2 days because of percolation and evaporation.

AWDI led to a reduction in the size of the immature population of *An. sinensis* by 84 to 86 % and *Cx. tritaeniorhynchus* by 81 to 91 %. There was a reduction in adult density of both species of more than 50 %. AWDI yielded an average of 7.2 tons of rice per hectare, compared with 6.4 t/ha under conventional irrigation. High water savings were reported and this success of the project led to its acceptance by most of the members of the local communes and by the mid 1980s about 35,000 hectares of land were under AWDI practice (Lu, 1988).

Mao (1996) reported that about 100,000 hectares are now under AWDI in the Guanxi Autonomous Region and Hunan Province. The most important vector of malaria in China is *a sinensis*, which mainly breeds in rice fields. Increase in population of this vector coincides with irrigation of the rice fields, reaching a peak once a year around August and September. In areas that cultivate two crops of rice per year without practicing AWD, a double peak in mosquito vector population densities was experienced (Bhuiyan and Sheppard, 1987).

Belder *el al.* (2004) conducted some experiments in irrigated lowlands and followed Alternately Submerged to Non Submerged (ASNS) practices as recommended to farmers in China. The sites had silty clay loam soils, shallow groundwater tables and percolation rates of 1 to 4.5 mm per day. Grain yields were 4.1 to 5.0 t/ha with 140 kg N/ha and 6.8to9.2 t/ha with 180 kg N/ha. Biomass and yield did not significantly differ between ASNS and CS, but water productivity was significantly higher under ASNS than under CS in two out of three experiments. There was no significant interaction (Water × N) on yield, biomass and water productivity. Combined rainfall plus irrigation water inputs were 600 to 960 mm under CS and 6 to 14% lower under ASNS condition. Irrigation water input was 15 to 1 °/o lower under ASNS than that under CS. Under ASNS, the soils had no ponded water for 40 to 60% of the total time of crop growth. During the non submerged periods, ponded water depths or shallow groundwater tables never went deeper than 35 cm and remained most of the time within the rooted depth of the soil. Soil water potentials did not drop below -10 k Pa. The results were typical for poorly drained irrigated lowlands in Asia and revealed that ASNS can reduce water use up to 15% without affecting yield when the shallow groundwater stays within 30 cm' below ground level. A hydrological characterization and mapping of Asia's rice area is needed to assess the extent and magnitude of potential water savings.

Balasubramanian *et al.,* (2001) conducted a study focusing on reducing the water requirement and improving its use efficiency in wet seeded and puddle lowland rice.Field experiments were conducted in collaboration with the Chinwag university, Zinhazwe, Chaina, at Tamil Nadu Agricultural University, Coimbatore, India, during the Kharif and Rabi seasons of 1 997 in a randomized block design with nine levels of irrigation replicated three times. Irrigation levels significantly influenced the weed population and biomass in both seasons. Grain yield was the highest with irrigation at 5 cm depth 1 day after the disappearance of ponded water direct seeded rice, transplanted rice and continuous submergence of 2.5 cm. Water use was the maximum with transplanted rice due to extended land preparation and nursery rising. Continuous submergence of 2.5 cm on wet seeded rice recorded the highest water productivity and saved 25% and 24% water than the transplanted rice in the Kharif and Rabi seasons respectively, without impairing productivity and net returns. Higher water productivity and considerable net returns and benefit-cost ratio clearly showed the scope for economizing irrigation water by continuous submergence of 2.5 cm in wet seeded rice. Hence continuous submergence of 2.5 cm may be recommended for wet seeded rice in lieu of 5 cm. which resulted in 25% savings in irrigation water than that of transplanted rice.

Hong *et al.,* (2001) showed changes in water allocation and crop production in Zhwiw Irrigation System (ZIS) and Zhanghe Irrigation District (ZID) in Hubei, China over the 33 to year period (1966 to 1998). The regulation and allocation of water among alternative uses, irrigation water supply in ZIS, the changes in crop area irrigated in ZID and by ZIS, rice production and land-water productivity in ZID were reviewed in the analysis. It showed several factors contributed to the increase in water productivity and sustained rice prod such as, economic and institutional reforms initiated in 1978, shift in cropping patter from two to one crop of rice, on-farm and system WSI (water saving initiatives) practices alternate wetting and drying (AWD) irrigation of rice fields), volumetric pricing of water development of alternate sources of water such as small reservoirs and groundwater and recapture and reuse of return flows through the network of reservoirs.

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Moya *et al.,* (2001) used the alternate wetting and drying (AWD) irrigation technique and continuous water application were to evaluate the on-farm water management strategies rice production in Tuanlin and Wenjiaxiang, Hubei, China during the wet seasons of 1999 and 2000. Detailed data regarding on-farm water management strategies, such as frequency and timing of irrigation, depth of water applied, sources of water, pond and pump USC were collected from 30 sample farmers from each site through field interviews. Input and output data of rice production including prices were also collected for economic comparison of the two sites in terms of rice production and profitability. Results showed that most farmers do 11 practices a pure form of AWD or of continuous flooding. However, more farmers in both site practiced AWD in 2000, when there was a higher shortage of irrigation water than in 1999.

Cabangon *et al.,* (2001) executed a study whose objective was to quantify the impact of alternate wetting and drying irrigation (AWD) and timing of N-fertilizer application on rice growth, water input, water productivity and fertilizer-use efficiency. The experiment was carried out in Jinhua, Zhejiang Province and in Tuanlin, Hubei Province, China following a split-plot design. The main plots received 2 water treatments (W1= AWD irrigation and Continuous flooding). The subplots consisted of four N-application treatments (F-control, n N fertilizer; Fir= 2 splits, as farmers practice; F_2 = 4 splits and F3 = 5 or 6 splits depending on the season). The total N input in all seasons was 150 and 180 kg N/ha in Jinhua and TL, respectively. Grain yields varied from 3.2 to 5.8 t/ha in Jinhua, while higher grain yields were about 27 %. AWDI was considered particularly suitable for areas where rates of evaporation and percolation are high with a low tendency of soil-crack (Lu, 1988).

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2.2 East-African Studies

Grainger (1947) carried out experiments in western Kenya with AWDI on 13 plots of approximately 20 square meters each, separated by irrigation channels. One plot was subjected to continuous flooding, whilst the other 12 were irrigated with a variety of wet and dry cycles ranging from 3 days irrigated and 7 days dry to 5 days irrigated and 4 days dry. In the first year, larval control was unsuccessful as the fields failed to dry out before adult mosquitoes had emerged, illustrating the importance of soil drainage characteristics for the success of this method. In the second year, heavy rainfall actually increased larval numbers compared to the previous year.

Ijumba (1997) did experiments in the 'Lower Moshe' irrigation scheme in Tanzania with different rice varieties and different water management methods. Active drainage was practiced and fields were left to dry out for three days before being flooded again for four days. AWDI resulted in increased mosquito production compared with permanent flooding, it was concluded that the small pools that were created by drying out the fields remained highly productive for the malaria vector. The results showed no evidence of significant association between different varieties of rice and mosquito productivity. The studies in East Africa clearly showed the importance of land preparation. If land leveling is not done properly, numerous small puddles will be left behind and this could even increase the egg laying potential if AWDI is practiced.

Mutero *et al.,* (2000) reported from experimental fields of Kwea, Kenya in 1998 that higher numbers of star larvae were found in AWDI fields than in continuously flooded fields, indicating that the AWDI water regime provided the most attractive environment for egg laying. For AWDI fields, however, survival rates of the larvae were very low. In contrast, the survival rate was much higher under flooded water management regimes. Rice yields and water use did not show statistically significant differences among fields with different water regimes in this study, where active drainage was used in the AWDI fields.

2.3 Indonesian Studies

Didiek (1998) conducted a field experiment at farm level in Indonesia, to study intermittent irrigation techniques and their influence on water saving. The aim of the study was to understand the response of several rice varieties under various intermittent irrigation patterns and to determine water use efficiency and effectiveness. The experimental design as split plot design with three replications of five levels of intermittent irrigation. The sub-plot factors were three rice varieties. There was no correspondence between variety and intermittent irrigation for crop growth and yield. Flooding of 5 to7 cm during the vegetative and ripening stages or flooding during the vegetative and reproductive stages showed higher water use efficiency than continuous flooding. The yield of IR to 64 rice variety was higher than Muncul and Ciliwung rice varieties under all intermittent irrigation treatments.

2.4 Japanese Studies

Mid season drying of rice fields has been recognized in Japan as a method to obtain l1ilc r yields for at least the last 300 years (Mogi, 1988). In the late 1950s, AWDI was promoted among farmers and has become a common practice. However, AWDI only starts about rule month after transplanting, till then the rice fields are flooded. The changes brought out by different ponding water depths under different water regimes such as continuous ponded intermittent ponding and variable ponding and also under different doses of application on rice crop production was investigated by Anbumozhi *et al.,* (1998) using controlled experimentation. In intermittent ponding, submergence was maintained panicle initiation stage followed by AWDI at an interval of every three days after the disappearance of ponding water. This investigation showed that

- At 9 cm ponding depth, a grain yield of 5.21 1/ha and 4.95 t/ha was obtained with continuous and intermittent ponding, respectively.
- At 9 cm ponding depth, AWDI accounted for increased water productivity (I .2u compared to continuous flooding (0.96 kg/rn3).
- Even though maximum yield per unit of water supplied always occurred with the ponding condition, the land productivity measured as grain production per unit of land was 62 % less than that of an optimum ponding water depth of 8 cm.

These observations demonstrated that considerable water savings are possible by maintaining an optimum ponding water depth under water-scarce conditions. Several studies in Japan have shown reductions in mosquito populations under

AWDT (Mogi, 1988). AWDI is a standard practice since 1960s but only from about one month after transplanting. Studies of AWDI for vector control have focused on Cx. *tritaeniorhynchus,* the main vector of Japan (Mogi. 1993).

A study was carried out at Kinryu, Saga City in western Japan. In this area, rice seedlings were normally transplanted in early July following a crop of winter barley. Two fields were selected for the experiment, one of 0.22 hectares and one of 0.11 hectares, with a comparison field o 0.06 hectares. The predator populations decreased with drying and remained low during AWDI with fish populations, in particular, suffering high mortality (Mogi, 1993). The general effect of this water management regime was to reduce the diversity of the aquatic communities and increase relative mosquito dominance as mosquito populations recover more quickly thin predator populations.

The author suggested that if AWDI is not practiced very carefully, it might favor mosquito reproduction in re-irrigated fields in the presence of a reduced predation pressure. The use of AWDI in rice cultivation has also increased since the 1960s but this has not affected vector abundance. The vector is either utilizing an alternative-breeding site or its population is limited by the availability of hosts, not for unavailability of breeding sites.

2.5 Korean Studies

- Won *et al.,* (2005) carried out a study to improve water productivity (the grain yield per unit volume of water irrigated) by water-saving irrigation techniques e.g. the effects of very shallow intermittent irrigation (VSII) with 2 cm irrigation, shallow intermittent irrigation (SII) with 4 cm irrigation and traditional deep water irrigation (DWI) with more than 10 cm on rice growth and yield in the field for two years. The amount of water irrigation during the rice growing period (average of two years) was 318, 391 and 469 mm in VSII, SII and DWI respectively.

- Rice growth and grain yield were not significantly influenced by the treatments. As the irrigation water input decreased, the water productivity increased. The water productivity was increased by 46% in VSII and 20% in SII, on an average, compared to DWI. The shallower the irrigation depth, the lower was the breaking weight, and consequently the higher the lodging resistance, the deeper was the roots in the soil. In DWI, the age of head rice was lower and the protein content was higher, suggesting deterioration in the palatability of cooked rice due to the increase of chalky rice. The water-saving rate was 32.9% in VSII and 17.2% in SII as compared with typical deep water irrigation in Korea.

2.6 North American Studies

North American Studies conducted in Texas, Missouri, Louisiana and Arkansas conducted that rice could be produced under non-flooded conditions using furrow and sprinkler irrigation, but that it is not economically viable under conditions in the southern United States (Lacey and Lacey, 1990). Reduced yields were an important factor in this outcome. Typically, as water supplies became restricted or more costly, it was more economically to switch to alternative supplies became restricted or more costly; it was more economically to switch to alternative crops than to grow rice under non-flooded conditions. This was especially true where capital-intensive irrigation systems such as sprinklers were used. Some of the salient findings of this research were:

- Rice yields under non-flooded conditions generally decreased proportionally with reduced water application (increased stress).
- There was a significant difference among cultivars with respect to drought tolerance.
- There were periods during the rice growth cycle when the yield was particularly sensitive to moisture stress.
- Under non-flooded conditions, the ability to apply light, frequent irrigation (every 2 to 4 days) was needed to avoid stress and efficiency utilizes rainfall.

- The average yield for sprinkler-irrigated rice was 20% less than yields of flooded rice on similar soils, but the specific causes of yields reduction were not fully apparent. The best performing (highest yielding) cultivars had yield reduction of 10 to 15 % compared to flooded rice.
- The most droughts –resistant rice cultivars produced the same yield under sprinkler irrigation, as under flooded conditions, however, those tend to be low-yielding varieties.
- Irrigation water requirement for non-flooded rice was 20 to 50 % less than for flooded rice, with the difference being strongly dependent on soil type, rainfall and water management practices.
- Tacker *et al.*, (2001) carried out field demonstrations of Multiple Inlet Rice Irrigation (MIRI) in 11 counties with 23 producers on 33 different fields.

  a comparative field study showed a minimal water savings with MIRI. However, labor was 50% less, cold-water rice was reduced, and fewer levee spills were required in the MIRI yield. The initial flood time was reduced by 4 days and re-flooded time was reduced by 3 days on a 155-acre MIRI field demonstration. MIRI on a 60 to 65 acre field saved 2 days/ week of pumping time. The initial flood time for a 550 gpm well supplying a 75 –acre field was reduced from 15 days to 9 days and re-flood time was 3 days instead of 7 days with MIRI. A Producer saved installing 60 spills in cross levees on 3 MIRI fields that included 270 acres.

2.7 Portuguese Studies

In the 1930s, South Portugal had a serious malaria problem related to submerged rice cultivation. Hill and Cambournac (1941) reported considerable success in controlling the vectors of malaria using a cycle of 10 days with water followed by 7 days without. Late stage larvae and pupae were reduced by up to 80 % in the experimental plots compared to the control plots subject to continuous submergence. Average water use in AWDI fields over a three-year period was 301 m^3/ha/day against 365 m^3/ha/day in the flooded fields. AWDI also reduced weed and algae growth and improved grain yields with no effect on rice quality. In fact, as a result of a law passed in 1938, AWDI was deemed compulsory in Portugal, if required, by the Malaria Service (Russell *et al.,* 1942).

2.8 Spanish Studies

Aguilar and Borjas (2005) conducted a study in Andalusia, the main rice producing region in Spain (40,000 ha). During the last decade it suffered several years of water shortage leading to a decrease in crop area. In this work, studies were performed to optimize water delivery and energy costs, comparing three flooding management systems:

1. Irrigating seven days a week (control system: traditional continuous flooding system)
2. Irrigating five days a week and
3. Irrigating four days a week (maintaining the traditional irrigation management until 55 days after seeding in both tested systems).

Total water used (water delivery) in the year 2000 corresponded to 44,917 m^3/ha (traditional), 34,445 m^3/ha (five days a week) and 29,209 rn^3/ha (four days a week). In 2001 these values were 45,607, 34,271 and 28,958 m^3/ha, respectively. No significant differences (LSI) 0.05) were found among the three flooding management systems in rice growth and yield. In 2000, irrigating five days a week, 23.3 1% of pumping energy was saved and 34.97% when irrigating four days a week. In 2001, these values were 24.86% and 36.5 1%, respectively.

2.9 Indian Studies

In the early 1940s, a three-year study was carried out by Russell *et al.,* (1942) in Tamil Nadu. There climatic condition was generally favorable for rapid drying out of fields except for the northeast monsoon. In this experiment, different wet and dry cycles in experimental fields were compared against fields that were continuously flooded to a depth of 10 cm (average depth used by local farmers). It was found that one day was not sufficient to drain surface water in any of the plots and four days was the maximum period of drying before cracks and clods formed in the soil. A system of five wet and two dry days per week practiced from the time irrigation water was made available in mid-June until the rice was in flower was effective against vector breeding and had no ill effect on the crop. AWDI successfully controlled mosquito populations except during the monsoon period, when even four days were not sufficient to dry out the fields. Russell *et at.,* (1942) emphasized the importance of careful control of water availability in order to ensure the success of the method.

Singh (1948) commented on the work of Russell and stated that despite its wide use in Bulgaria, Russia and Portugal, AWDI could probably not be introduced in India because of the need to adapt the irrigation infrastructure and because of reluctance of farmers to change in their methods of cultivation. However, he also advised that flooded rice cultivation should be prohibited within a radius of at least one mile of the outskirts of malaria and the epidemics from the towns and cities.

The Tamil Nadu Agricultural University (1996) had carried out studies on water management in the Periyar-Vaigai irrigation scheme. In the command area of a tank in this scheme, three types of water management were tested on farmers' fields. These were:

- The conventional method of continuous submergence
- AWDI with irrigation to a depth of five cm one day after disappearance of ponded water and
- Water supply in a four days 'on' and three days 'off' rotational schedule
- Results obtained from two seasons are given in Table 2.3. The methodology consisted of implementing a package of interventions which included AWDI and selected technology trials in the entire command of one or two outlets of a minor or distributary canal and comparing the results with an adjoining outlet treated as control. The results present some interesting observations:

- In all the centers there was an increase in grain yield and concomitant decrease in irrigation water supply in the experimental fields practicing AWDI method compared to control fields where continuous submergence was practiced. However, the percentage increase in grain yield and the percentage decrease in irrigation water supply varied over a wide range. Also, the range of absolute values from center or average value (CV) varied widely

- A number of reasons may be responsible for these wide variations. In the case of grain yield, non-water factors such as rice variety, climate, type of soil, amount of fertilizer applied and rice pests may affect the yield in addition to water factors

- A more general conclusion, which can be drawn from this research, is the superiority of AWDI against continuous submergence in that it increases the grain yield by 20 to 87 % and reduces the water supply by 10 to 77%

Table 2.3 Results of water management studies in Tamil Nadu

Description / Quantum	Conventional method		AWDI		Rotational water supply	
	Rabi[a] 95	Kharif[b] 95/96	Rabi 95	Kharif 95/96	Rabi 95	Kharif 95/96
Total water use (cm)	117.4	80.2	96.8	77.0	107.8	76.3
Water use efficiency (kg/rn3)	0.45	0.58	0.54	0.67	0.49	0.68
Yield (t/ha)	5.32	4.63	5.21	5.17	5.24	5.22
Percentage of water saved over conventional method			17.2	4.5	8.2	5.6

[a] Agricu1ral season from April to September
[b] Agricultural season from October to March
Source: Tamil Nadu Agricultural University (1996)

According to CRME (1991), surface water had been fully exploited in the scheme area and the limit of groundwater potential rapidly reached to its dead end. Any further expansion of the command area must therefore, rely on improved water management practices. AWDI was practiced on a pilot scale at some part of the Periyar-Vaigai system in Tamil Nadu, which had recently been modified and upgraded with the assistance of the World Bank. On a pilot scheme consisting of 100 hectares only 40 hectares were irrigated under local farmers' practices. i.e., continuous flooding when water was available, the remaining 60 hectares were subject to a water management regime, whereby the fields were flooded, allowed to dry out and then immediately re-irrigated.

Under AWDI, vector breeding was reduced to a period of three weeks post transplanting and water savings of 15 to 20 % were made. There was no clear cut reduction in *Anopheline* densities which breeds in rice fields during the early stages of rice cultivation, before the fields can be dried out (CRME, 1991). In years when water was scarce, conditions forced the farmers to adopt AWDI practices. Farmers were appreciative of the benefits of this system of irrigation and would even employ labors to operate the sluice gates; however, the farmers doubted their own ability to regulate the equitable distribution of water between farms. A further problem noted was the high vector population immediately after transplantation, when water levels must be maintained to allow for establishment of seedlings and avoidance of weed growth.

Rajendran *et al.,* (1995) conducted another study near Madurai on heavy clay soils. A total of' 16.2 hectares was kept under flooded irrigation and 22.3 hectares under AWDI. In the conventionally-irrigated fields, field-to-field drainage was practiced and a water depth of 5 to 15 cm was maintained throughout the growing cycle, except for a period 01' 10 to 14 days just prior to harvesting. In the AWDI fields, there was no field-to-field irrigation and transplantation was synchronous. A water depth of 2.5 cm was maintained for the first 10 to 14 days after transplantation, after which the fields were allowed to dry out naturally, before being re-irrigated to a depth of 5 cm as soon as all standing water had disappeared. In 1990, water was scarce due to drought and was only available for irrigation of either block for three days per week. As a result of the similarities of irrigation management on the two plots, there were no significant differences between them in terms of larval and pupae densities and grain yields. In 1991, ample water was available for irrigation and a significant difference in the numbers of mosquito pupae collected was observed in all weeks, except for the first, when all fields in both blocks were flooded. In addition, there was a significantly higher grain yield in AWDI fields (5.66 t/ha compared with 5.42 t/ha estimated from random samples of one square meter plots). It was also reported that using this method of irrigation, the fields never dried out completely and numerous small puddles remained.

To evaluate the performance of the summer rice cv. IET 4786 under stressed and non-stressed condition, an experiment conducted in the B.C.K. University, W. Bengal during 1997 to 1998 revealed that in case of intermittent ponding the yield of rice was a little less than the test cases for the intermittent ponding (Sarkar, 2001). It was also found that the grain yield decreased remarkably for the practice of intermittent ponding with the treatments (stress development) at the early, early+ middle and late stages. The lowest yield (5.37 t/ha) was found when intermittent ponding was maintained during the entire irrigation period.

Pot experiments on ten rice cultivars was carried out to determine the effect of 10 days drought stress during tillering and flowering stages (Yadav *et al*., 2001). It showed that water stress lowered the relative water content (RWC), leaf water potential (LWP) and osmotic potential (OP) but increased the leaf diffusive resistance (LDR) at both tillering and flowering stages. Revival of the moisture content again after dewatering of plants explored that the parameters i.e. RWC, LWP, OP and LDR recovered but could not reach its pre-stress values.

2.10 Bangladeshi Studies

Studies on utilization of irrigation water in rice field and water saving techniques like shallow application of water was conducted by the Bangladesh Rice Research Institute (BRRI) in different stations around the country during 2005 to 2006 which recommended that irrigation in *Boro* rice field should be provided 3 days after disappearing of standing water. Such a practice is economically more beneficial than the traditional practice of continuous standing water. In yield gap study conducted in the *Boro* season of 2005 to 06, BRRIdhan 29 with BRRI recommended practices produced grain yield of 8.73 t/ha, which was about 47% higher than farmers' practice (5.96 t/ha) at Kapasia, Gazipur. Such a practice is economically more beneficial than the traditional practice of continuous standing water. A net benefit of Tk 1207/ha can be achieved through this alternate wetting and drying method over the continuous standing water method (BRRI, 2006)

Islam *et al.,* (2005) conducted experiments on glass house at the Bangladesh Institute of Nuclear Agriculture (BINA) farm to find out the effect of water stress in two drought tolerant rice mutants developed by BINA. Five irrigation treatments were used in randomized complete block design (RCBD) and replicated thrice. The found the highest grain yield (7.07 t ha) in treatment T_3 (3 cm standing water + water stress up to 80% field capacity), but the highest water productivity was found in treatment T_5 (3 cm standing water + water stress up to 40% field capacity). The study revealed that the mutants could withstand up to 40% field capacity.

Bangladesh Institute of Nuclear Agriculture, BINA (2007) in their annual report of achievements commented on Non Commodity Technologies (NCT) like water saving in rice cultivation. Experiments were conducted on different rice varieties of BINA revealing that intermittent irrigation technique, what they call, alternate flooding and drying irrigation (AFDI) saves more than 40% irrigation water with insignificant reduction in yield. Hence, BINA recommended maintaining an interval of 5 to 7 days between consecutive irrigations. It was also found that AFDI technique reduces continuous decline of water table (BINA, 2007).

Research progress report of BRRI (2007) reported the interaction effect of' irrigation interval based on perched water table depth for water saving and N fertilization methods in rice cultivation. In this experiment conventional method of fertilizer application was found better. Poly Venal Carbon (PVC) tube was concluded to be one of the easiest tools for determining perched water table depth for water saving in rice field.

A field experiment at the Bangladesh Agricultural University farm was conducted by Jha *et al.*, (2007) to compare the traditional water management practices in the rice field with the modern water saving techniques. The experiment was figured using split plot design and consisted of 5 irrigation treatments viz., Treatment T_1, T_2, T_3, T_4 and T_5 meaning continuous submergence, application of irrigation water 3 days, 5 days, 7 days and 10 days after the disappearance of standing water from the plots, respectively. They also reported an increase in plant height with the increase in water requirement though its effect on the production unit remained insignificant. He recommended that 5 cm irrigation water should be applied 3 days after the disappearance of standing water from the soil surface to obtain the maximum water use efficiency.

Hossain (2008) conducted experiments on a small scale at the farm of Bangabandhu Sheikh Mujibur Raman Agricultural University (BSMRAU), Gazipur to find out possible effects of different level of irrigations on the production of MV *Boro* rice (BRRI dhan29). The experiment conducted in small pots using randomized complete block design (RCBD) was given ten irrigation treatments and replicated five times to obtain more representative results. To measure water level depletion, perforated pipes were installed. The treatments were: T_1 = Continuous submergence (2 inches), T_2 = Maintaining always saturation condition, T_3 = Application of 2 inches irrigation water when water level in the pipe depleted 2 inches below the ground level, T_4 = Maintaining saturation condition when water level in the pipe depleted 2 inches below the ground level, T_5 = Application of 2 inches irrigation water when water level in the pipe depleted 4 inches below the ground level, T_6 = Maintaining saturation condition when water level in the pipe depleted 4 inches below the ground level, T_7 = Application of 2 inches irrigation water when water level in the pipe depleted 6 inches below the ground level, T_8 = Maintaining saturation condition when water level in the pipe depleted 6 inches below the ground level, T_9 = Application of 2 inches irrigation water when water level in the pipe depleted 8 inches below the ground level and T_{10} = Maintaining saturation condition when water level in the pipe depleted 8 inches below the ground level. The result showed that the lowest (4.99 t/ha) yield was obtained for the treatment T_{10} and the highest being for the treatment T_1 (6.99 t/ha). The second highest yield (6.89 1/ha) was obtained for the treatment T_2 though the water requirement in this case was critically lower than the previous one. The study also revealed that higher plant heights were attributed by an increasing water requirement. Considering the water productivity, treatment T_2 was found to be the best without major reduction in yield.

2.11 Studies on Growth Stages

Numerous studies show that rice plant water requirements changes with each stage of crop growth. For water management purposes rice stages are usually divided as the seedling, vegetative growth (rooting and tilering), reproductive (Panicle initiation, panicle differentiation, and anthesis), and ripening (grain filling and maturity) stages. Each growth stage responds differently to water management practices and will be discussed separately below.

There appears to be agreement in the international community that prolonged water stress and excessive water should be avoided during vegetative development. Prolonged water stress can reduce tillering, panicle per unit area, and spikeletes per panicle (Boonjung and Fukai, 1996b). Excessive water hampers rooting and decreases tiller production (De Datta, 1987).

Various studies have given conflicting reports on optimum water management during vegetative growth. De Datta (1987) recommends continuous shallow submergence (2.5- 7.5 cm depth) to facilitate tiller production and confirm root anchorage. O' Toole and Moya (1981) suggest that water deficit during vegetative development may have little effect on grain yield. Several studies found that delaying flooding until just prior to or at panicle initiation had little or no effect on grain yield and significantly increased water-use efficiency (McCauley and Turner, 1979; Beyrouty *et al.*, 1992; Norman et al., 1992; Lilley and Fukai, 1994; Grigg *et al.*, 2000). Midseason soil drying during vegetative growth before panicle initiation, which is practiced in Japan and China, has been found to increase grain yields. This has been attributed to removal of anaerobic toxins, reduce ineffective late tillering, reduced lodging, increased N and P availability, and better root development (Wei and Song, 1989; Tuong, 1999; De Datta, 1987;). Intermittent flooding in which the field is flooded and dried at regular intervals with periods of no standing water during vegetative development has been found to be as effective as, and sometimes even better than, continuous static flooding (De Datta, 1987; Devi *et al,* 1996; Prasad et al. 1997; Lourduraj and Bayan, 1999; Channabasappa *et al.*, 1997; Raman and Desai, 1997; Sharma *et al.,* 1997). Borrel *et al.*, (1997) found that maintaining saturated (non-flooded) conditions in the paddy had no significant effect on yield quality or quantity as compared to the conventional practice of continuous shallow submergence.

Rice plant water requirements are highest during reproductive development. Water stress during this period causes a reduction in number of filled spikelets which results in severe yield reductions (De Datta, 1987; Lilley and Fukai, 1994; Boonjung and Fukai, 1999b). Excessive water during reproductive development causes reduced Culm strength and lodging which can result in significant yield reductions (De Datta, 1987; Setter *et al.,* 1997; Sharma, 1999).

Most studies suggest that continuous saturation or shallow flooding (~5 cm) is the optimum water management for the reproductive stage. Studies have shown that less than saturated soil conditions during reproductive growth starting with panicle initiation can significantly reduce yields (De Datta *et al.* 1973; IRRI, 1999). Borrell *et al.* (1997) found no significant yield deference between continuous saturated soil culture (SSC) and traditional flooding. Studies have shown that flooding depths greater than 5 cm during reproductive growth can reduce yields and greatly decrease water-use efficiency (De Datta and Williams, 1996; Prasad *et al.,* 1997; Lourduraj and Banyan, 1999; Channabasappa *et al.*, 1996; Raman and Desai, 1997; Sharma *et al.,* 1997; Bin and Loeve, 2000) while in others significant yield reductions were reported (De Datta and Williams, 1968; De Datta, 1987).

Rice water requirements are low during the grain ripening stage. De Datta (1987) suggests that no standing water is required during most of the ripening stage. Flooded fields are usually drained at least a week before grain maturity (IRRI, 1999). Studies have found that terminating flooding as early as 2 weeks following heading does not affect grain yield or quality and can significantly reduce water consumption (Counce *et al*., 1990; Dingkuhn and Le Gal, 1996; Grigg *et al.,* 2000)

2.12 Studies on adoption of AWD

Miah (undated) expressed that Aalternate Wetting and Drying (AWD) technology for saving water in irrigated rice fields was validated for three years in Bangladesh. This work was started by IRRI in 2005 in one location and subsequently expanded to 80,000 farmers through 11 different agencies and projects over the years. AWD has been accepted by researchers and farmers. The Government of Bangladesh has recently given a directive for its large scale adoption in all irrigated rice ecosystems. Farmers accepted it because it is easy to adopt with negligible resources saving 30 liter diesel/ha, reducing irrigation frequency by 4-20 depending on soil type, with the possibility of harvesting half a ton/ha of extra yield. One extra weeding was also required, but the cost of this was more than offset by the extra yield and saving of fuel. AWD also enhances the availability of zinc and sulfur in the sulfate form under aerobic conditions.

The owners of tube wells also liked AWD because they needed less labor to divert water to fields due to reduced irrigation frequency and the possibility of increasing the command area. The potential of saving Taka 500 core (US$ 73.5 million) for irrigating 4.8 million ha of *Boro* rice convinced policy makers. The necessity of one extra weeding attracted herbicide companies to promote the technology. Environmentalists considered it important because it saved 20-30% of irrigation water and reduced the mosquito menace.

CSISA (2011) found that water saving technology through the use of alternate wetting and drying (AWD) management was delivered to 5,362 farmers' fields covering 48 ha of *Boro* rice (Rangpur Hub). On average, the AWD technology reduced 4 irrigation applications, saved irrigation cost by US$ 15/ha, and increased yield by 0.36 kg/ha (5.8% higher yield than with flood irrigation). According to the farmers, AWD plots had less insect infestation and disease than the continuous flooded plots.

Kürschner *et al.*, (2010) found that one of the most decisive factors influencing adoption was found to be the irrigation serial, which determines the sequence and schedule by which a block in the command area receives water. Currently, this serial irrigation limits a farmer's ability to apply AWD irrigation. Farmers do not always receive water at the time of demand, since irrigation is executed by a pump operator or the pump owner. The greater the individual control over the timing of irrigation, as is the case with pump owners, the greater the practicality of implementing an AWD irrigation regime. Another factor that is critical for the adoption of AWD by farmers is the role of the pump owners and operators on the stipulation of irrigation charges and the payment system. Fixed-rate arrangements discourage farmers to adopt AWD since charges for irrigation are by fixed amounts, which are settled prior to the season. Pump owners up until now mostly do not pass on the economic benefits, which occur due to savings of irrigation water and energy by farmers practicing AWD. This system emerged as the most common payment arrangement in STW and DTW-based irrigation schemes. They also found that the role of field staff and their ability to provide effective training and support to farmers largely determine the effectiveness of the organizations' approaches in disseminating AWD. This mainly relates to three factors: Education and experience, the field staff's training in AWD and the general work environment.

Adeogun *et. al.*, (2008) conducted a study on Application of Logit Model in Adoption Decision: A Study of Hybrid Clarias in Lagos State, Nigeria. They found that like any new innovation, hybrid catfish technology must endure a phase of dissemination. In this study, a conceptual framework was developed for the decision to adopt or not to adopt and econometric analyses of the diffusion process are presented using Logistic regression model. While appropriate low-input, cost of production system and technology package should be emphasized, **the knowledge, accuracy and technical responsibilities** become more significant to the success of the technology as well as aquaculture industry.

Jamala *et. al.*, (2011) conducted a study on Evaluation of Factors Influencing Farmers Adoption of Irrigated Rice Production in Fadama Soil of North Eastern Nigeria. They found that five variables have significantly influenced adoption of rice production. The result indicates that holding other variables constant, if years of experience increase by a unit, on the average, the logit of the odds in favour of sole rice production increases by 5.33 units. Other variables such as level of education influence adoption as it eases understanding, interpretation and acceptance of the newly introduced techniques. These will enhance purchasing power of materials inputs, like fertilizer, pesticides, improve seeds. Gender also plays a significant role since male genders are more likely to adopt innovation than the female, probably due to the arduous nature of rice production in the project than the female counterparts.

Sarker *et. al.*, (2009) conducted a study on determinants of adoption decisions: The case of organic farming (OF) in Bangladesh. They found that among the respondent farmers, the majority (75%) were adopters of OF. The results of a logit regression model showed that **perceptions of OF, household access to extension services, number of family labourers and household income** were significantly associated with decisions to adopt OF. They also emphasized that to encourage the rapid expansion of OF in Bangladesh, it is essential to formulate an OF promotion policy, taking into account the above factors that influence farmers' adoption decisions.

Donkoh and Awuni (2011) conducted a study on Farmers' Perceptions and Adoption of Improved Farming Techniques in Low-Land Rice Production in Northern Ghana. They found that the proportion of farm techniques adopted was greater for: **experienced farmers; tenants**, as opposed to those **who owned the lands** on which they farmed; those **who received extension services and**

motivation; and those whose farms were closer to input stores. However, household labour negatively influenced adoption. They also found that farmers had in-depth **knowledge,** not only about the qualities of a good soil, but also the importance of local farm techniques. Their study revealed that there is the need for more extension work and motivation as well education on the misconception the farmers had about the fact that if they used organic manure in their rice fields they would turn upland.

Kaguongo *et. al.*, (2012) conducted a study on factors influencing adoption and intensity of adoption of orange flesh sweet potato varieties in Kenya. Their results suggest that **knowledge on value addition and nutritional benefits, and availability of vines** were the key factors for adoption. Their results also suggest that participation in a value chain extension programme enhanced the probability of adoption. Factors affecting intensity of adoption were site, value addition, vines availability, level of commercialization and having a child of up to five years.

Rubas (2004) conducted two studies on technology adoption: who is likely to adopt and how does the timing affect the benefits? The first study defines and tests for universality using met regression analysis on 170 analyses of agricultural production technologies. The second study, a case study on an emerging information technology – climate forecasts, examines how the timing of adoption affects the benefits. The results of the first study indicate that **technology-promoters may want to change their approach and focus on younger, more educated producers with larger farms**. The results of the second study are highly consistent for early adopters. They benefit the most, there is no incentive for more producers to adopt after 60% to 95% have adopted (meaning the adoption ceiling has been reached), and slower adoption corresponds to ceilings closer to 60% than 95%. They also revealed that technology adoption from two angles provides a deeper understanding of the adoption process and aids technology-promoters in achieving their goals. In addition to focusing on younger, more educated producers with larger farms, technology promoters wanting widespread adoption with high benefits need to push constituents to adopt early and fast.

Ebojei *et. al.*, (2012) conducted a study on Socio-economic Factors Influencing the Adoption of Hybride Maize in Giwa Local Government Area of Kaduna State, Nigeria. The results of their study indicate that the mean predicted probability of technology adoption was **Age**, **income**, **education** and **extension visits**. On the contrary, farming experience, family size, farm size had no significant influence on participation in hybrid maize. Their study suggests that there is a need for special training, seminars, field demonstrations and technical support for the maize farmers. As most of the households had no formal education, the extension program should be intended to the less educated farmers.

Awotide *et. al.*, (2012) conducted a study on impact of improved agricultural technology adoption on sustainable rice productivity and rural farmers' welfare in Nigeria: a local average treatment effect (late) technique. Their study revealed that **access to seed** was one of the significant determinants of adoption. **Poverty incidence** was also higher among the non-adopters than the adopters. The results showed a significant positive impact of on rice productivity and **total households' expenditure**. This suggests that adoption of improved rice varieties significantly generate an improvement in farming household living standard.

Wabbi (2002) conducted a study on Assessing Factors Affecting Adoption of Agricultural Technologies: The Case of Integrated Pest Management (IPM) in Kumi District, Eastern Uganda. He found that farmers' participation in on-farm trial demonstrations, accessing agricultural knowledge through researchers, and prior participation in pest training were associated with increased adoption of most IPM practices. Size of farmer's land holdings did not affect IPM adoption suggesting that IPM technologies are mostly scale neutral, implying that IPM dissemination may take place regardless of farmer's scale of operation. Farmers' perception of harmful effects of chemicals did not influence farmers' decisions in regard to IPM technology adoption despite their high knowledge of this issue, suggesting that these farmers did not consider environmental and health impacts important factors when choosing farming practices. Farmers' managerial capabilities were not important in explaining cowpea IPM technology adoption.

Chapter 3

Materials and Methods

Chapter 3

Materials and Methods

Experiment 1: Effect of Alternate Wetting and Drying (AWD) Irrigation for *Boro* Rice Cultivation in Bangladesh

3.1.1 Experimental Site

The Bangladesh Rice Research Institute (BRRI), Gazipur was selected as the experimental site during December 2009 to June 2010. The experimental site is located at $24.^0$ N latitude and $90.^0$ E longitude and 8.4 m about from sea level with sub-tropical climate, which is strongly influenced by south-western monsoons. Topography of the land being plain was suitable for check basin irrigation. Individual plots were located inside a close growing rice field so that actual growing condition (reception of the direct and diffused fluxes) prevails in the site.

3.1.2 Methods used for Soil Analysis

To determine the soil characteristics of experimental plot were air dried, ground, and sieved through a 2 mm sieve, and were kept in plastic bottles for soil analysis. The soils were analyzed for different nutrients along with texture, bulk density, and water holding capacity, pH and organic matter contents. The methods of soil analysis are prepared in the Table 3.1

Table 3.1 Methods used for Soil Analysis

Soil characteristics	Method of Analysis
pH	Glass-electrode pH meter with 1- 2.5 soil –water ratio (Jackson,1973)
Organic Carbon	Wet oxidation method (Nelson and Sommers, 1982). The organic matter was oxidized by 1 M potassium dichromate and added 85% H_3PO_4.Titration was performed with 0.5 M Ammonium ferrous sulfate solutions in presence of 0.16% Diphenylamide-4-sulfonic acid barium salt (Indicator) and organic C was calculated by Walkey and Black's method (1934).
Total N	Micro-kjeldahl method (Bremner and Mulvaney, 1982). Soil sample was digested with conc. H_2SO_4 in presence of 0.05 M HCL and 33% NaOH. Titration was performed in 0.05 NaOH in presence of indicator.
Extractable P	Extracted by 0.03M NH4F, 0.025 M HCL and determined calorimetrically using ammonium molybdate-ascorbic acid, measured the absorbance by spectrophotometer at 890 nm wavelength (Bray and Kurtz, 1945).
Extractable K	Extracted by 1 M NH4OAc repeated shaking and filtrated by filter paper. K concentration of extratent determined by flame photometer as outlined by Knudsen *et al.,* (1982).
Extractable S	Extracted by S extracting solution (primary calcium phosphate) Ca (H_2PO_4). H2O 37% HCL, and phenol). The extractable S was measured by spectrophotometer at 535 nm in the presence of acid seed solution and turbid metric reagent (Page *et al.,* 1982).
Extractable Zn,Cu, Mn and Fe	Extracted by DTPA solutions and determined directly by atomic absorption spectrophotometer with respected wave lengths and lamps (Lindsay and N).
Extractable B	The B was determined by 0.01 M $CaCl_2$ extraction method. The available B content of the soil was determined by spectrophotometer at 420 nm (Bingham, 1982).

3.1.3 Climatological Data Collection

Climatological parameters affect the production most than any other factor. Some important climatological parameters of the experimental site were collected from the Plant Physiology Division, BRRI, Gazipur, as given in Table 4.1.

3.1.4 Selection of Plot Area

The selection of the plot area was based on the facilities available for rice production. Moreover, a wide and open horizon along with unobstucture sunshine availability, irrigation facilities, ease in conveyance of water was among the other factors considered

3.1.5 Land Preparation and Irrigation

The experimental field was prepared using mould board plough powered by tractor, puddler and ladder. Pudding intensity was high enough to manipulate the upper root zone with a view to destroying the weeds. Wooden planks, after puddling, were used to level the soil surface so that there remains uniform depth of ponded water in the experimental plots. Total individual size of the plots was 4m×2.5 m with 8 plots in a row. Thus 3 replications resulted in a total of 24 plots in the fields. Levees were constructed surrounding each plots having size of 25 cm in width and 20 cm in height. Each experimental plot was separated by 1 m of transition zone while each of the replications was having a buffer zone of 1.5 m between them. To prevent seepage between adjoining plots the buffer zones were hand, to prevent seepage were created. On the other hand, to prevent seepage between the plots and the buffer zones, polythene sheets were pushed were into the edges of the levees along the inner perimeter of all of the plots.

3.1.6 Fertilizer Application

Fertilizers were applied at the rate of 220-120-85-and 10 kg/ha as urea, TSP, MP, gypsum and zinc sulphate in *Boro* season as per recommendation made by the Institute for research farm area. All TSP and MP were applied at final land preparation. No urea is used as basal dose. Total urea applied in 4 equal splits in the growing season. First dressing of urea was done on 20 days after transplanting and sowing 2nd, 3rd and 4th dressing were done on 35, 50 and 65 days after transplanting and sowing.

3.1.7 Experimental Design and Field Layout

The experimental plots (4 m x 2.5 m) were laid out with 2 factors RCBD combining two modern varieties of rice (BRRIdhan29 and BRRI hybrid2) and four irrigation treatments that were replicated thrice. This resulted in a total of 24 plots in the field with 8 plots in a row. Each of the plots was separated by 1 m of transition zone while each of the replications was demarcated by a buffer zone of 1.5 m in between. To prevent seepage, polythene sheets were pushed into the edges of the levees along the inner perimeter of all plots. PVC pipes of 4 cm in diameter and 40 cm in length were installed in the field keeping 7 cm above the soil and the remaining 33 cm which was perforated underneath to measure the depletion of soil water in the field. Irrigation water was applied when depleting water table inside the pipe reached a certain level.

3.1.8 Measurement through Perforated Pipe

The technique of alternate wetting and drying irrigation practice is quit new in the region. In this experiment some pieces of PVC pipes were used of measure the depletion of the soil water in the field. The diameter and the length of the PVC pipe were 4 cm and 40 cm, respectively, having perforations 2 cm away from each other. The pipe was installed in the field keeping 7 cm above the soil to check floating debris getting inside the pipe while 5 cm irrigation depth is applied and the remaining portion (33 cm) underneath. After irrigation had been level inside the pipe was the same as that outside. As time went by, the water in the soil and that level was indicated by the water level inside the pipe (below G.L). Thus, irrigation water was applied when depleting water table inside the pipe reached a certain demarcation.

3.1.9 Intercultural Operation

A very disappointing feature of AWDI is that, weed infestation in the field is awesome.To avoid this hazard during crop establishment stage, a continuous standing water level of 5 cm above G.L was maintained. Another vulnerable stage of weed infestation was during the transition period of vegetative stages to flowering stage. Since the weed competes with the rice plant and share the available nutrients in the soil, all the weeds were uprooted by hand whenever it got its head up in the experimental plots.

3.1.10 Irrigation Treatments

The irrigation treatments were the only variable whose effect is expected from the experiment. For this reason different levels of irrigation were applied. In each of the cases the field was allowed to be dried up to certain level. The depleted water table was observed from the pipes installed in the field. A wooden stick was used to measure the water level inside the pipe. The experiment had four irrigation treatments each of which was replicated thrice.

The treatments were

T_1 = 1 to 5 cm standing water; maintained throughout the growing season

T_2 = Application of 5 cm standing irrigation water when water level in the pipe fell 15 cm below the G. L.

T_3 = Application of 5 cm standing irrigation water when water level in the pipe fell 20 cm below the G. L.

T_4 = Application of 5 cm standing irrigation water when water level in the pipe fell 25 cm below the G. L.

3.1.11 Selection of Variety

Selection of rice variety was a critical choice to be made. A critical choice takes into account the popularity of some location specific varieties in hand and high yield potential on the other hand. BRRI dhan29 and BRRI hybrid2 are two varieties developed by Bangladesh Rice Research Institute (BRRI) which have both popularity and high yield potentials. All the characters of modern varieties are present in these cultivars.

3.1.12 BRRI dhan29

- Plant height ranging from 65 cm to 95 cm stems and leaves are straight and green
- 1000 to grain weight is 20.90 gm, medium fine grain and yield is about 5.5 to 8 t/ha
- Planting and harvesting time is the third week of December and last week of May
- With usual growth duration of 155 to 165 days (BRRI, 2004)

3.1.13 BRRI hybrid2

- Plant height ranging from 112 cm stems and leaves are straight and green
- 1000 to grain weight is 20.90 gm, medium fine grain and yield is about 8 t/ha
- Planting and harvesting time is the third week of December and last week of May
- With usual growth duration of 118 days (BRRI, 2004)

3.1.14 Collection of Seedlings

Seedling of both of the varieties was not grown separately for this study. The seedlings of BRRI dhan29 and BRRI hybrid2 were collected from the seedbed of the Division of Irrigation and Water management and Plant Breeding Division of BRRI, Gazipur. The seedlings were aged enough for transplanting.

3.1.15 Transplanting

The seedlings collected in 19th January 2009 were transplanted on the very same day at afternoon in the plots. Information related to transplantation of the plants are given in the Table 3.2

Table 3.2 Information related to the transplantation of the seedlings

Duration of transplantation in the farm	07-01-2009 to 23-01-2009
Date of Transplantation in the experimental plot	19-01-2009
Hill to hill distance	15 cm
Row to row distance	25 cm

First and last hill were kept at 7.5 cm away from their nearest levee along the width of plot. In this way each plot was planted with 25 hills along the length and 10 hills along the width. There was no standing water during transplantation but the soil was soft enough for the deed. No irrigation was applied immediately after transplantation and crops allowed to settle down for a while.

3.1.16 Irrigation Water Requirement

According to the design of the experiment, 5cm irrigation was supposed to be given to each of the plots after certain depletion of water level inside the PVC pipe as an indicator of the soil water depletion. It was noted that when irrigation was applied in the dry soil, initially all the water was consumed by the soil. Practical experience showed that it took another 30 strokes (45 liters) to start building a water layer. A bowl (2 liter) was used to irrigate the plots from the buffer zones. The calculation of the water volume for each plot (4 m × 2.5 m) is given below:

Amount of water needed for esblishement of a water layer of 5 cm is = 500 liters

Taking a 25% loss of water, the effective volume per stroke	=	1.5 liters
No of strokes required for an application of 5 cm water	=	500/1.5=312 nos.
So, total no. of strokes required established 5 cm standing water	=	(312+30)=342 nos.

3.1.17 Harvesting and Threshing

The grains of BRRI hybrid2 got ripened earlier than the BRRI dhan29. For this reason the two varieties had to be harvested at different dates. The BRRI hybrid2 was harvested at 25 April 2010 while BRRI dhan29 was harvested three weeks later (May 15, 2010) than the earlier one. From each plot 5 sample hills were selected randomly and harvested separately. The sample hills were investigated, threshed and packed separately. Crops inside 1 m squire (1m×1m) of land was harvested with a view to obtained the information related to yield and the yield contributing characters.

3.1.18 Determination and Moisture Content

Determination of moisture content of the samples was done an automatic moisture reader machine available at the division of soil Science, BRRI, Gazipur. Samples of 15 to 20 grams were taken in the recommended dishes of the apparatus and pure inside the machine which when rolled and tightened obtained, in consequence, a digital reading of the moisture content of the sample.

3.1.19 Grain Yield and Straw Yield

The grain moisture content was lowered or increased to 14% (wet basis), whichever was needed, for the subsequent measurements. Samples collected from each of the plot were dried under sun and weighted afterward. Similarly, straw yield was also calculated by taking the weight of the dried straw.

3.1.20 Collection of Data Regarding Yield and Yield Contributing Characters

Following yield and yield contributing data were taken before threshing the grains from the plant

- Plant height (cm)
- Number of effective tiller per hill
- Length of the panicle (cm)
- Number of filled and unfilled grain per panicle
- Grain yield (t/ha)
- Straw yield (t/ha)
- Biological yield (t/ha)

3.1.21 Grain Yield

Matured plants inside 1m square of land were harvested for subsequent analysis. Moisture content of the grains, however, was adjusted to 14% equivalent moisture content after measuring through digital grain moisture meter for subsequent analysis.

Quantitative information related to yield and all the yield contributing characters viz. plant height, effective tillers, length of the panicle, number of filled and unfilled grains per panicle, 1000 grain weight, grain yield, straw yield, harvest index and water use efficiency of the two varieties (BRRI dhan29 and BRRI hybrid2) were analyzed to obtain the effect for AWDI on rice production.

3.1.22 Tiller and Panicle Number

For tiller and panicle number, one sqm from each plot (average crop condition) was harvested. The number of tillers and panicles were counted and recorded.

3.1.23 1000-grain Weight

From one sqm harvested area 1000- grain weight was taken randomly and weighting them by an electrical balance.

3.1.24 Plant Height

Plant height was taken from 10 randomly selected plants of a plot. The length was measured in centimeter from the ground level to the extreme tip of the plant at harvesting stage.

3.1.25 Seepage and Percolation

In the paddy field, seepage and percolation (S&P) losses were measured by using the water subsidence techniques (Giron and Wickham 1976). In this method the water loss from a paddy field takes as evapotranspiration (ET), surface drainage (Dr), and seepage and percolation (S&P). If no water is added to or drained from the field, then the total water used is due to ET plus S&P and is given by the subsidence or loss of head of water on the paddy field surface.

For measuring the daily subsidence of water, an inclined meter stick with a slope of 5:1 and supported by a wooden frame was placed in the field. This inclination provides a magnification of fall in water depth. Water level on the inclined meter scale was recorded every day at 9:00 am. The difference in reading for two consecutive days shows the depth of fall due to ET and S&P, if no rainfall occurred. The S&P rate was then calculated using the formula:

$S \& P_t$	= WDt-1-WD (t)
Where, t	= Refers to the day of measurement
WD	= Water depth measured on the meter stick (mm), and
ET	= Daily rate of evapotranspiration (mm)

In case of rainfall occurrence, it was adjusted with the measured water depth in the field, provided the rain did not result in overflow across the paddy dike. Three seepage meters, one installed for each replication of paddy under water management T_1 (standing water plot) were used. The levees of the observation paddies were maintained regularly to void the effect of excessive biological activities such as those of rats and crabs.

3.1.26 Statistical Analysis

Finally, all the experimental data were statistically analysis following factorial experiment through MSTATE Package Programme. Duncan's Multiple Range Test (DMRT) was also estimated to test the means.

Experiment 2: Alternate Wetting and Drying: A Sustainable Water Management for Rice Cultivation in Rajshahi District

3.2.1 Experimental Site

The Bangladesh Rice Research Institute (BRRI), Shampur, Rajshahi was selected as the experimental site during November 2010 to May 2011. The experimental site is located at 24.69′ N latitude and 88.30′ E longitude and tropical wet and dry climate with monsoons, high temperature, considerable humidity and moderate rainfall.

3.2.2 Methods used for Soil Analysis

To determine the characteristics of experimental plot were air dried, ground, and sieved through a 2 mm sieve, and were kept in plastic bottles for soil analysis. The soils were analyzed for different nutrients along with texture, bulk density, and water holding capacity, pH and organic matter contents. The methods of soil analysis are prepared (same as Table 3.1).

3.2.3 Climatological Data Collection

Climatological parameters affect the production most than any other factor. Some important climatological parameters of the experimental site were collected from the weather office, Shampur, Rajshahi in appendix XVII.

3.2.4 Experimental Design and Field Layout

The experimental plots (4 m x 2.5 m) were laid out with two factor randomized block design) combining two modern varieties of rice (BRRIdhan 28 and BRRI hybrid2) and four irrigation treatments that were replicated thrice. This resulted in a total of 24 plots in the field with 8 plots in a row.

3.2.5 Irrigation Treatments

The experiment had four irrigation treatments each of which was replicated thrice.

The Treatments were

T_1 =1 to 5 cm standing water; maintained throughout the growing season

T_2= Application of 3 days of disappearance of standing water.

T_3= Application of 5 days of disappearance of standing water.

T_4= Application of 7 days of disappearance of standing water.

3.2.6 Selection of Variety

BRRI dhan28 and BRRI hybrid2 are two varieties developed by Bangladesh Rice Research Institute (BRRI) which have both popularity and high yield potentials. All the characters of modern varieties are present in these cultivars.

3.2.7 BRRI dhan28

- Plant height ranging from 90 cm stems and leaves are straight and green
- 1000 to grain weight is 20.90 gm, medium fine grain and yield is about 6.0 t/ha
- Planting and harvesting time is the third week of December and last week of April
- With usual growth duration of 140 days

3.2.8 BRRI hybrid2

- Plant height ranging from 112 cm stems and leaves are straight and green
- 1000 to grain weight is 20.90 gm, medium fine grain and yield is about 8 t/ha
- Planting and harvesting time is the third week of December and last week of May
- With usual growth duration of 118 days (BRRI, 2004)

3.2.9 Collection of Seedlings

Seedling of both of the varieties was not grown separately for this study. The seedlings of BRRI dhan28 and BRRI hybrid2 were collected from the seedbed of the Bangladesh Rice Research Institute, Shampur, Rajshahi. The seedlings were aged enough for transplanting.

3.2.10 Transplanting

The seedlings collected in 20th January 2010-2011 were transplanted on the very same day at afternoon in the plots. Information related to transplantation of the plants are given in the Table 3.3.

Table 3.3 Information Related to the Transplantation of the Seedlings

Duration of transplantation in the farm	07-01-2011 to 23-01-2011
Date of Transplantation in the experimental plot	20-01-2011
Hill to hill distance	15 cm
Row to row distance	25 cm

First and last hill were kept at 7.5 cm away from their nearest levee along the width of plot. In this way each plot was planted with 25 hills along the length and 10 hills along the width. There was no standing water during transplantation but the soil was soft enough for the deed. No irrigation was applied immediately after transplantation and crops allowed to settle down for a while.

3.2.11 Harvesting and Threshing

The grains of BRRI hybrid2 got ripened earlier than the BRRI dhan28. For this reason the two varieties had to be harvested at different dates. The BRRI hybrid2 was harvested at 23 April 2011 while BRRI dhan28 was harvested three weeks later (May 12, 2011) than the earlier one. From each plot 5 sample hills were selected randomly and harvested separately. The sample hills were investigated, threshed and packed separately. Crops inside 1 m squire (1m×1 m) of land was harvested with a view to obtained the information related to yield and the yield contributing characters.

Experiment 3: Assessment of Alternate Wetting and Drying Water management in Rice Cultivation.

3.3.1 Experimental Site

The Bangladesh Rice Research Institute (BRRI), Gazipur was selected as the experimental site during December 2010 to June 2011.

3.3.2 Climatological Data Collection

Some important climatological parameters of the experimental site were collected from the Plant Physiology Division, BRRI, Gazipur. During the study period (2010-2011), the climatological parameter such as rainfall, temperature and relative humidity were collected and presented in (Table 4.12)

3.3.3 Selection of Plot Area

The selection of the plot area was based on the facilities available for rice production. Moreover, a wide and open horizon along with unobstucture sunshine availability, irrigation facilities, ease in conveyance of water was among the other factors considered

3.3.4 Experimental Design and Field Layout

The experimental plots (4 m x 2.5 m) were laid out with 3 factor CRB design combining two modern varieties of rice (BRRI dhan36 and BRRI hybrid2) and four irrigation treatments that were replicated thrice.

3.3.5 Irrigation Treatments

The experiment had four irrigation treatments each of which was replicated thrice.

The Treatments were

i) T_1 =1 to 5 cm standing water; maintained throughout the growing season at vegetative, reproductive and ripening stages

ii) T_2 = 3 days dry at vegetative, reproductive and ripening stages

iii) T_3 = 5 days dry at vegetative, reproductive and ripening stages

iv) T_4 = 7 days dry at vegetative, reproductive and ripening stages

3.3.6 Selection of Variety

BRRI dhan36 and BRRI hybrid2 are two varieties developed by Bangladesh Rice Research Institute (BRRI) which have both popularity and high yield potentials. All the characters of modern varieties are present in these cultivars.

3.3.7 BRRI hybrid2 (V_1)

- Plant height ranging from 105 cm stems and leaves are straight and green
- 1000 to grain weight is 20.90 gm, small bold and yield is about 8.5 t/ha
- Planting and harvesting time is the third week of December and last week of May
- With usual growth duration of 145 days (BRRI, 2004)

3.3.8 BRRI dhan36 (V_2)

- Plant height ranging from 90 cm stems and leaves are straight and green
- Medium fine grain and yield is about 5.0 t/ha
- Planting and harvesting time is the third week of December and last week of May
- With usual growth duration of 140 days

3.3.9 Collection of Seedlings

Seedling of both of the varieties was not grown separately for this study. The seedlings of BRRI dhan36 and BRRI hybrid2 were collected from the seedbed of the Division of Irrigation and Water management and Plant Breeding Division of BRRI, Gazipur.

3.3.10 Transplanting

The seedlings collected in 22^{th} January 2010 were transplanted on the very same day at afternoon in the plots. Information related to transplantation of the plants are given in the Table 3.4.

Table 3.4 Information Related to the Transplantation of the Seedlings

Duration of transplantation in the farm	07-01-2009 to 26-01-2009
Date of Transplantation in the experimental plot	22-01-2009
Hill to hill distance	15 cm
Row to row distance	25 cm

First and last hill were kept at 7.5 cm away from their nearest levee along the width of plot. In this way each plot was planted with 25 hills along the length and 10 hills along the width. There was no standing water during transplantation but the soil was soft enough for the deed. No irrigation was applied immediately after transplantation and crops allowed to settle down for a while.

First and last hill were kept at 7.5 cm away from their nearest levee along the width of plot. In this way each plot was planted with 25 hills along the length and 10 hills along the width. There was no standing water during transplantation but the soil was soft enough for the deed. No irrigation was applied immediately after transplantation and crops allowed to settle down for a while.

3.3.11 Irrigation Water Requirement

According to the design of the experiment, 5 cm irrigation was supposed to be given to each of the plots after certain depletion of water level inside the PVC pipe as an indicator of the soil water depletion. It was noted that when irrigation was applied in the dry soil, initially all the water was consumed by the soil. Practical experience showed that it took another 30 strokes (45 liters) to start building a water layer. A bowl (2 liter) was used to irrigate the plots from the buffer zones. The calculation of the water volume for each plot (4 m × 2.5 m) is given below:

Amount of water needed for establishment of a water layer of 5 cm is	=	500 liters
Taking a 25% loss of water, the effective volume per stroke	=	1.5 liters
No of strokes required for an application of 5 cm water	=	500/1.5=312 nos.
So, total no. of strokes required established 5 cm standing water	=	(312+30)=342 nos.

3.3.12 Harvesting and Threshing

The grains of two varieties BRRI hybrid2 and BRRI dhan36 got ripened same time. For this reason the two varieties had to be harvested at same date. The BRRI hybrid2 and BRRI dhan36 was harvested at 25 April 2011. From each plot 5 sample hills were selected randomly and harvested separately. The sample hills were investigated, threshed and packed separately. Crops inside 1 m squire (1m×1 m) of land was harvested with a view to obtained the information related to yield and the yield contributing characters.

Experiment 4: Adoption of Water-Saving Irrigation Techniques for Sustainable Rice Production in Bangladesh

3.4.1 Selection of the Samples and Sampling Technique

Thirty sample farmers from the Rainonda village of Capasia union of Gazipur district were selected in the site where the AWD irrigation techniques are being practiced. Similarly, 30 other sample farmers were selected from the Chorboria of the same Union of Gazipur district where AWD is not practiced but where continuous irrigation is practiced. Similarly thirty sample farmers from Chapal Village of Godagary union of Rajshahi district were selected in the site where the AWD irrigation techniques are being practiced and 30 other sample farmers were selected from the Naraonpur village of Godagry Union Rajshahi district where AWD is not practiced but where continuous irrigation is practiced.

3.4.2 Data Collection Instruments

Keeping in view the expected outcomes of the assessment survey, appropriate data collection instruments were prepared. Interviewed schedule was prepared to collect primary data from the farmers. The schedule was pre-tested and modified accordingly before final use. The interviewed schedule was prepared in such a way that all aspects associated with the objectives could be included. In the pre-test survey, attention was paid to identify any new information, which was not included in the draft schedule. Then some parts of draft schedule were improved, rearranged and modified in the light of the experience gained from the field. Lastly, the final interview schedule was prepared to collect the information. The farming of the questions in interviewed schedule was done in such a way, that they could be easily understood by the informants and their responses could be quicker. Besides, leading questions were avoided; questions pertaining to the private and personal life of the respondents were also not included in the schedule. The questions were properly structured, so that even the most reluctant information's could have no hesitation in passing the necessary information. The questionnaire included the following items of information needed for the analysis.

a) Identification of the sample farmer.
b) Farm size and tenure status of sample farmer.
c) Use of material inputs for cultivation of rice.
d) Yield, outputs, cost and returns of producing of rice.
e) Problems faced by the rice growing farmers and suggested solution.

3.4.3 Collection of Data

The study is based on a set of field level primary data. The data were collected through direct interview with the help of pre-designed questionnaire in 2011. A brief introduction regarding the nature and objectives of the study was given to each respondent before interview. The respondents were given assurance that all information would be kept confidential, be used exclusively for research purpose and study will not affect their interest in any adverse way, rather it might produce some benefits to general mass in course of time. Before interviewing, the selected respondents were contacted so that they could be interviewed according to their convenient time. Then the questions were asked systematically in a very simple manner with necessary explanation. After completion of each interview, the interviewed schedule was checked to be sure that information to each of the items had been properly recorded. Any items overlooked or found contradictory were corrected in the second time visit.

3.4.4 Processing and Analysis of Data

After collecting requisite data, they were processed and analyzed with a view to achieve the objectives of the study. The primary data were collected from the rice growing farmers and then data were processed (edited and coded) and computerized using MS excel. All the collected qualitative and quantities data were analyzed in accordance with the objectives of the study so as to answer the issues involved in the study.

3.4.5 Analytical Techniques

Both tabular and statistical techniques were used to analyze the collected data. Tabular technique was followed to find out the crude association or differences between variables and outputs. Tabular technique is a well known and widely used technique to show the result of farm management study because it is simple, convenient and very easy to understand. The data and information so collected were recorded to tabular form which included classification of tables into meaningful results by some statistical measures like the sum, average, percentage etc. to show the relationship between /among the selected variables.Tabular analysis was done to address the objectives.

3.4.6 Logistic Regression Model

As the dependent variables are dichotomous (zero, one), a logit regression model can be applied. Logit model are widely applied statistical techniques in which the probability of a dichotomous outcome (for e.g adopter or non-adopter) is related to a set of explanatory variables that are hypothesized to influence the outcome (Neupane *et al.,* 2002).

Hosmer and Lemeshew (1989) pointed out that the logistic distribution (logit) has got advantage over the others in the analysis of dichotomous outcome variable in that it is extremely flexible and easily used model from mathematical point of view and results in a meaningful interpretation. The parameter estimates of the model were asymptotically consistent and efficient. The standardized coefficients correspond to the beta-coefficients in the ordinary least squares regression models. The binary logistic model does not make the assumption of linearity between dependent and independent variables and does not assume homoscedasticity (CIMMYT, 1993). Another advantage of using the logit model is relatively easy to compute and interpret. Hence, the logistic model is selected for this study. The probability that a farmer will adopt at least one improved rice variety was postulated as a function of some socioeconomic, demographic characteristic and institutional factors. Therefore, the cumulative logistic probability model is econometrically specified as follows:

$$P_i = F(Z_i) = F(\propto + \sum \beta X_i) = \frac{1}{1+e^{-Z_I}} \quad \text{.......................} (1)$$

Where,

Pi is the probability that a farmer will adopt rice AWD irrigation technology or not given Xi;

e denotes the base of natural logarithms, which is approximately equal to 2.718;

Xi represents the ith explanatory variables and

$\propto$ And β are parameters to be estimated.

Hosmer and Lemeshew (1989) pointed out that the logit model could be written in terms of the odds and log of odds, which enables one to understand the interpretation of the coefficients. The odds ratio implies the ratio of the probability (Pi) that a farmer adopt to the probability (1-Pi) that the farmer is non-adopter.

$$(1-P_i) = \frac{1}{1+e^{Z_I}}$$

Therefore

$$\frac{P_i}{1-p_i} = \frac{1+e^{Z_I}}{1+e^{-Z_I}} = e^{Z_I}$$

The natural log of equation (3), will give:

$$L_i = \left(\frac{P_i}{1-P_i}\right)$$

$$= \propto + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \text{...............} + \beta_n X_n \text{ ....} (2)$$

If the disturbance term (U_i) is taken into account, the logit model becomes:

$$L_i = \alpha + \sum_{i=1}^{7} \beta_i \ X_i + U_i \ \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3)$$

Equation (3) was estimated by maximum likelihood method. This procedure does not require assumptions of normality or homoscedasticity of errors in predictor variables. This analysis was carried using STATA Version 11. The variables used in logit model are described in the following (Table 3.5)

Table 3.5 Description of the Variables used in the Logit Model

Variable	Type	Measurement
Dependent variable		
Li	Dummy	1 if farmer has adopted AWD irrigation technology, Otherwise 0.
Explanatory variables		
Experience	Continuous	Experience of the household head (years)
Education	Dummy	Formal education of the household head. 1, if more than primary level 0, otherwise
Household size	Continuous	Total family member (No. of persons) per households
Farm size	Continuous	Amount of land under cultivation (ha)
Non-farm income	Dummy	Engagement in non-farm income generating activities 1, 0 otherwise
Contact extension agent	Dummy	Contact with extension agent by the respondent, 1 if farmer Contact with extension agents, 0 otherwise
Land ownership	Dummy	Ownership of the land, 1 if the land is owned, 0 otherwise
Farmers' training	Dummy	1, If farmers attend in AWD training.
Water scarcity	Dummy	1, if farmers face water scarcity
Rice crop area	Dummy	1, if rice crop area is more than non-rice crop area
Land quality or type	Dummy	If land is plain, then 1, otherwise 0
Regional Dummy	Dummy	1, if Gazipur, otherwise, 0
Dissemination through demonstration	Continuous	No. of times of demonstration, farmer observed.

Chapter 4

Results and Discussion

Chapter 4

Results and Discussion

This section includes description of the experimental outputs along with their detail discussion. Quantitative information's related to climatological data, Physio-chemical properties of the experimental plot, Seepage and percolation rate, evapotranspiration rate, yield and yield contributing characters viz. Plant height, effective tillers, length of the panicle, number of filled grain and unfilled grains per panicle, 1000 grain weight, grain yield, straw yield, harvest index and water productivity of the four varieties , with the best precision possible, were collected from the experiment plots at the BRRI farm, Gazipur and Rajshahi for subsequent analysis as given in the following topics.

Experiment 1: Effect of Alternate Wetting and Drying (AWD) Irrigation for *Boro* Rice Cultivation in Bangladesh

4.1.1 Climatological Data

Total rainfall of growing period was 303.00 mm (Table 4.1). It was found that in 2010 growing season January to May, the maximum rainfall occurred in the month of May 204.6 mm and the minimum rainfall occurred March 17.2 mm.

The minimum and maximum temperature ranged from 36.38 to 34.81°C in 2010 and 24.71 to 15.51 °C in 2010 respectively. The maximum temperature 36.38 °C was observed in February and the minimum 15.51 °C in February in 2010 respectively.

The highest percentage of relative humidity was recorded at 9.00 am and the lowest at 2.00 pm in the experimental year as shown in Table 4.1. The highest monthly average relative humidity of 88.18% was found in March 9 am in 2010 and the lowest 8.75 % in February in 2010, respectively.

Table 4.1 Monthly maximum and Minimum Temperatures, Rainfall and Humidity during Rice-Growing Seasons at the BRRI Farm, Gazipur in 2010.

Month	Year 2009					
	Monthly total RF(mm)	Monthly av. tem.(0C)			Monthly av. RH (%)	
		Max.	Min.	Mean	9 am	2 pm
January	Nil	35.0	21.25	28.125	9.00	2.00
February	Nil	36.38	15.51	25.945	8.75	55.62
March	17.2	34.87	22.32	28.595	88.18	60.90
April	81.2	34.81	24.71	29.76	76.0	63.2
May	204.6	35.1	21.3	28.2	83.1	65.2

Source: Plant Physiology Division, BRRI, Gazipur, Bangladesh.

4.1.2 Physio-chemical Properties of Soil of the Experimental Site:

Some essential physio-chemical properties of the experimental soil were determined and presented in the appendix XVII. The soil texture of the experimental field was found to be loam. The field capacity and bulk density ranged from 20 to 23% and 1.45 to 1.50 gm. /cm^3, respectively. The pH value ranged from 6.0 to 6.4, nitrogen (N) from 0.08 to 0.10%, phosphorous (P) from 10 to 15 ppm, potash (K) from 0.14 to 0.20 meq /100 gm., zinc (Zn) from 0.50 to 1.59 ppm, calcium (Ca) from 5.0 to 7.5 and that of organic matter ranged from 2.09 to 2.35 percent, respectively.

4.1.3 Seepage and Percolation (S&P) and Evapotranspiration (ET)

Seepage and percolation (S&P) and Evapotranspiration (ET) are given in Table 4.2. The experiment has been carried out in *Boro* season which started with in December and ended in May. In 2009 *Boro* season, S&P were 5.20, 5.26 and 5.24 mm/day; in 2010 these were 5.23, 5.24 and 5.20 mm/day, at vegetative, reproductive and ripening stages of the crop. The result revealed that the highest mean S&P of 5.26 mm/day was obtained in 2009 and the lowest mean S&P of 5.20 mm/day was found in the year 2009 and 2010, respectively. The highest mean S&P of 5.26mm/day was found in the of 2010 and the lowest mean S&P of 5.23 mm/day was observed in the year of 2009. Ritu and Mondal (2002) conducted studies on the effect of various standing water depths on S&P rate from the rice fields and observed that S&P increased with the increase in water depth in rice field. The depth of irrigation water varied from 2.5 cm to 12.0 cm with an increment of 0.5 cm and the S&P rate varied from 5 mm/day to 17.5 mm/day.

In 2009 *Boro* season, ET were 3.80, 3.92 and 3.99 mm/day; in 2010 it was 3.81, 3.92 and 4.00 mm/day, at vegetative, reproductive and ripening stages of the crop. The result revealed that the highest mean ETf of 3.91 mm/day was found in the year of 2010 and the lowest mean ET of 3.90 mm/day was found in the year of 2009. This is in agreement with that of Saleh and Fatema (1988) and Kasem (2003-2004) who found that ET varied from 3.59 to 4.61 mm/day in dry season and 3.03 to 4.54 mm/day in wet season.

Table 4.2 Seepage and Percolation (S&P) and Evapotranspiration (ET) of the Experimental Plots During *Boro* Seasons 2009 to 2010.

Season	S&P(mm/day)				ET(mm/day)			
	Veg.	Rep.	Rip.	Mean	Veg.	Rep.	Rip.	Mean
Boro 2009	5.20	5.26	5.24	5.23	3.80	3.92	3.99	3.90
Boro 2010	5.23	5.24	5.20	5.26	3.81	3.92	4.00	3.91
Mean	5.21	5.25	5.22	5.22	3.80	3.92	3.99	3.91

Veg. = Vegetative, Rep. = Reproductive, Rip. = Ripening

4.1.4 Irrigation Treatments (AWDI)

The two varieties stated above were subjected to different levels of irrigation developed by delaying the scheduled irrigation in the field. Starting from the very end of the first stage of crop development (tillering), four irrigation treatments were started with regular intervals. The time of water application, however, was indicated by the depletion of water level in different perforated pipes measured from the ground surface. Both of the experimental rice varieties, irrespective of their position in the field, receive different levels of irrigation treatments according to the demand of the respective fields in each replication.

Table 4.3 Total Number of Irrigation Required for Different Irrigation Treatments

Treat ment	*No. of Irrigation		Rainfall+ water for crop established (cm)	Total water required (cm)	
	BRRI dhan29	BRRI hybrid2		BRRI dhan29	BRRI hybrid2
T_1	14	12	55.3	122.2	112.20
T_2	9	9	55.3	97.20	91.20
T_3	8	8	55.3	92.20	87.20
T_4	7	7	55.3	87.20	81.20

*One irrigation means application of 5 cm irrigation water

Irrigation treatments were applied at different stages of the growing period depending on the depletion of the water level in the perforated pipe. The very first treatment stated at the end of the fourth week after transplantation. During this time 5 cm standing water was kept to avoid weed infestation in the plots. Table 4.3 shows that the highest number of irrigation (14 nos.) was given to the plots with treatment T_1 (continuous flooding) for BRRI dhan29. The other three treatments *viz*., T_2, T_3 and T_4 received a total of 9, 8 and 7 nos. of irrigation for BRRI dhan29 while 12, 9, 8 and 7 number of irrigation for BRRI hybrid2, respectively. Water required for crop establishment and water received from the rainfall was estimated to be 53.3 cm during the growing period for each of the treatments. For BRRI hybrid2, maximum amount of water (112.20 cm) was required for T_1, while, second maximum (91.20 cm) for T_2 was followed by other two treatments, T_3 (87.20 cm) and T_4 (81.20 cm). For BRRI dhan29 the treatments T_1, T_2, T_3 and T_4 required 122.2, 97.2, 92.2 and 87.2 cm of water, respectively. The graphical representation of water usage by different treatments after transplantation is shown in Fig.4.1

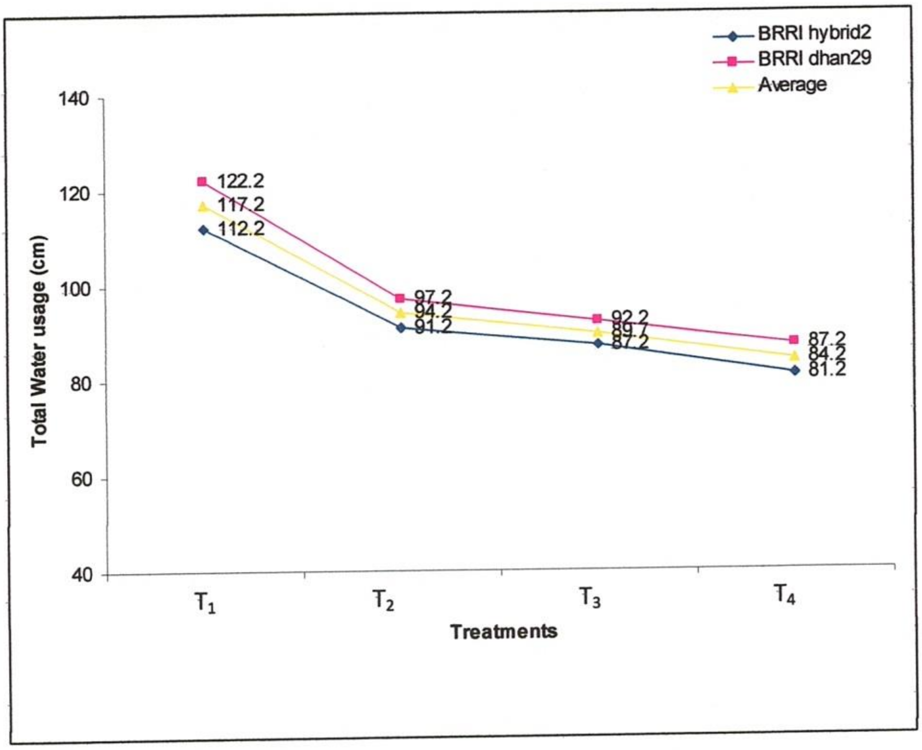

Fig.4.1 Water usage of different treatments for the production of BRRIdahn29 and BRRI hybrid2

4.1.5 Varietal Performances for Plant Characterizers and Yield of Transplant *Boro* Rice

The yield and yield contributing characters e.g. effective tiller, filled grain, unfilled grain, grain yield, straw yield and biological yield were significantly affected by the variety. The varietal performance for those characters and yield are presented in Table 4.1(Appendix I).

4.1.6 Plant Height

The analysis showed that varietal effect on plant height was statistically significant at 1% probability level. The tallest plant (107.00 cm) was found in BRRI hybrid2 (V_2). The shortest plant (101.95 cm) was found in BRRI dhan29 (V_1). Variation in plant height might be due to the differences in the genetic make –up of the varieties. The result is in consistent with findings of Shamsuddin *et. al.,* (1988) who also reported a variable plant height existed among the varieties.

4.1.7 Number of Total Tillers Hill^{-1}

The highest number of total tillers hill^{-1}(10.96) was found in BRRI hybrid2 and the lowest number of total tiller was found (10.63) in BRRI dhan29. Variable effects of variety on number of total tillers hill^{-1} were also reported by Hossain *et al.,(*1989a) who noted that number of total tillers hill^{-1} differed among the varieties. The variation in number of total tillers hill^{-1} might be due to varietal characteristics.

4.1.8 Number of Effective Tillers Hill^{-1}

Number of effective tillers hill^{-1} was statistically significant at 1 % level of probability (Appendix I). The highest number of effective tillers (9.11) was found in BRRI hybrid2 and the lowest number of effective tiller hill^{-1}(8.68) was found in BRRI dhan29.

4.1.9 Number of Non-Effective Tillers Hill^{-1}

The highest number of non-effective tillers (1.95) was found in BRRI dhan29 and the lowest number of non-effective tiller hill^{-1} (1.85) was found in BRRI hybrid2.

4.1.10 Panicle Length

The highest length of panicle (22.92 cm) was found in BRRI dhan29. The lowest length of panicle was (22.80 cm) in BRRI hybrid2. Varietal differences regarding the panicle length might be due to their differences in genetic make-up.

4.1.11 Number of Filled Grains Panicle^{-1}

Number of filled grains panicle^{-1} was statistically significant at 1% level of probability (Appendix I). The results showed that the highest grain yield (137.64) was achieved from BRRI hybrid2. The lowest grain yield (118.45) was achieved from BRRI dhan29.These differences occurred due to variations of genetic make-up among the varieties.

4.1.12 Number of Unfilled Grains Panicle^{-1}

Number of unfilled grains panicle^{-1} was statistically significant at 1% level of probability (Appendix I). 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 hybrid2 (Appendix I).

4.1.13 Weight of 1000 Grains

The result showed that the highest weight of 1000- grain (23.65 g) was obtained from BRRI hybrid2. The lowest weight of 1000-grain (23.35 g) was obtained from BRRI dhan29.

4.1.14 Grain Yield

Grain yield was statistically significant at 1% level of probability. The highest grain yield (5.64 t/ha) was achieved from BRRI hybrid2. The lowest grain yield (4.93 t/ha) was achieved from BRRI dhan29. These differences occurred due to variations of genetic make-up among the varieties.

4.1.15 Straw yield

The result shows that the highest straw yield (6.70 t ha^{-1}) was found from BRRI hybrid2. The lowest straw yield (5.83 t ha^{-1}) was found from BRRI dhan29.The highest yield occurred due to higher plant height, higher total tiller hill^{-1} and lower number non-effective tiller hill^{-1}. These results are consistent with those obtained by Chowdhury *et al.,*(1993) who reported differences in straw yield among varieties.

4.1.16 Biological Yield

The highest biological yield (12.34 t ha^{-1}) was obtained from BRRI hybrid2 and the lowest one (10.76 t ha^{-1}) was obtained from BRRI dhan29.

4.1.17 Harvest Index

Maximum harvest index (45.73%) was obtained from BRRI dhan29 and the minimum harvest index (45.65 %) was obtained from BRRI hybrid2.

4.1.2.1 Effects Irrigation Treatments (AWDI) on yield and yield Contributing Characters

The experiment aimed in exploring the possible effects of different irrigation treatments on the production and production related parameters. Different yield contributing characters viz., plant height (cm), number of effective tillers per hill, panicle length (cm), total number of filled grains per panicle, number of unfilled grains per panicle; 1000 seed weight (gm), grain yield (t/ha) and straw yield (t/ha) for each of the varieties were analyzed. Statistical relationships of the effect of four treatments on the individual yield contributing parameters along with their interaction with the variety are given with their detail statistical analysis and ANOVA (Appendix XIV)

4.1.2.2 Effect of Irrigation Treatments (AWDI) on Plant Height

Results obtained from the statistical analysis of the effect of variety and different degrees of delayed irrigation treatments on plant height are shown in Appendix II and III. The analysis showed that varietal effect on plant height was statistically significant (Appendix II) and, the irrigation treatments had significant effect on plant height at 5 % level of probability. The highest plant height (105.78 cm) was obtained in treatment T_4 (irrigation when water is 25 cm below from the soil surface) and the lowest (103.45 cm) in Treatment T_1 (continuous flooding) as shown in Fig. 4.2.

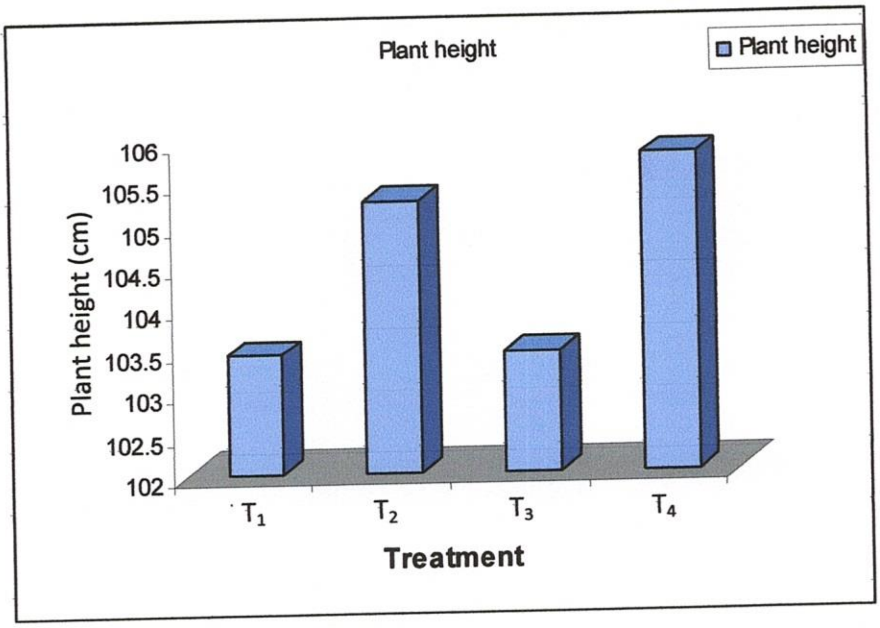

Fig. 4.2 Variation in Plant Height for different Degrees of Irrigation Treatments

This result is in agreement with the findings of Hassan *et al.*, (2008) who reported that treatment having continuous flooding could not improved plant height.

On the other hand, effect of the interaction between the varieties and the treatments was also found to be statistically significant at 1% level of probability. The tallest plant height (109.17 cm) was found for the interaction $V_2 \times T_2$ (V_2=BRRI hybrid2, T_2= Irrigation when water is 15 cm below from the soil surface).

4.1.2.3 Effect of Irrigation Treatments (AWDI) on Number of Effective Tillers per Hill^{-1}

Information obtained after analysis of the experimental findings, as shown in Table 3.7 showed that varietal effect on the number of effective tillers remained insignificant (at 1%) level of probability. The highest number of effective tillers per hill (11.06) was found in treatment T_2 followed by treatment T_3 (8.67) and treatment T_1 (8.06). The lowest number of effective tiller per hill (7.78) was found in treatment T_4.

4.1.2.4 Effect of Irrigation Treatments (AWDI) on Panicle Length

The results obtained from the experimental findings showed that was no effect of the variety on the panicle length. Neither the irrigation treatments nor interaction (variety × Irrigation) had any effect on the panicle length of the varieties. The cause of the non significant output of the panicle length might have occurred due to insufficient photosynthesis from the less vigorous crop canopy and reduced leaf area of BRRI dhan29 and BRRI hybrid2 (Appendix II and III)

4.1.2.5 Effect of Irrigation Treatments (AWDI) on the Number of Filled Grains per Panicle

A little delayed irrigation treatments using alternate wetting and drying irrigating method in rice field showed significant effects on the number of filled grains per panicle compared to one with continuous flooded (Appendix II and III). It was found that the highest number of filled grains (141.94) per panicle 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 20 cm below from the soil surface) and T_4 (Irrigation when water is 25 cm below from the soil surface). The lowest number of filled grains per panicle (119.32) was found for treatment T_1. Thus the result showed that applying irrigation water in rice field when water level goes 15 to 25 cm below G.L does not really reduce the total number of filled grains compared to that nursed with 5 cm standing water (Appendix II and III). However, treatment T_1 (continuous standing water) decreased the number of filled grains (Figs. 4.3).

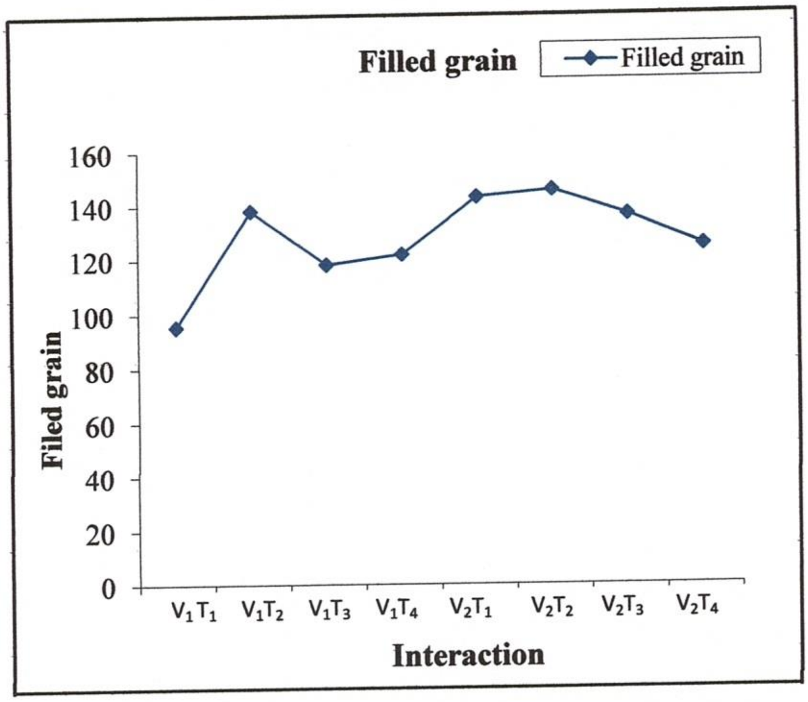

Fig. 4.3 Variation in Filled Grain for Different Degrees of Irrigation Treatments

Statistically significant variation was observed while analyzing the varietal effect on the number of filled grains. The highest value (141.94) was obtained T_2 and the lowest value 119.32 for T_1 (Appendix II). The interaction effect of the varieties and treatments also came significant at 5% level of probability. The highest number of filled grains (145.65) was, however, marked for the interaction ($V_2 \times T_2$) and the lowest number of filled grains (95.50) was obtained from V_1T_1 (Appendix III).

4.1.2.6 Effect of Irrigation Treatments (AWDI) on 1000 Grain Weight

Thousand grain weight (1000 grain weight), as it is called the test weight of the desired output, is referred to be considered as one of the most significant agronomic parameters ever trusted that contributes in having a reconnaissance over the possible production of a lot (gain yield). The values of 1000 grain weight were found to be significant in this analysis for the effects of treatments at the 5% level of probability. The highest 1000 grain weight (24.80) was obtained for the interactions ($V_2 \times T_2$) and the lowest 1000 grain weight (22.80) was obtained for the

$V_2 \times T_3$ (Appendix III). The study raveled that the varieties V_1 and V_2 and interaction effect between variety × treatment produced statistically insignificant variation in 1000 grain weight among themselves .Thus, it was clear from the interaction effect that AWDI method of irrigation treatments did not reduced the 1000 grain weight as irrigation delayed (Fig. 4.4).

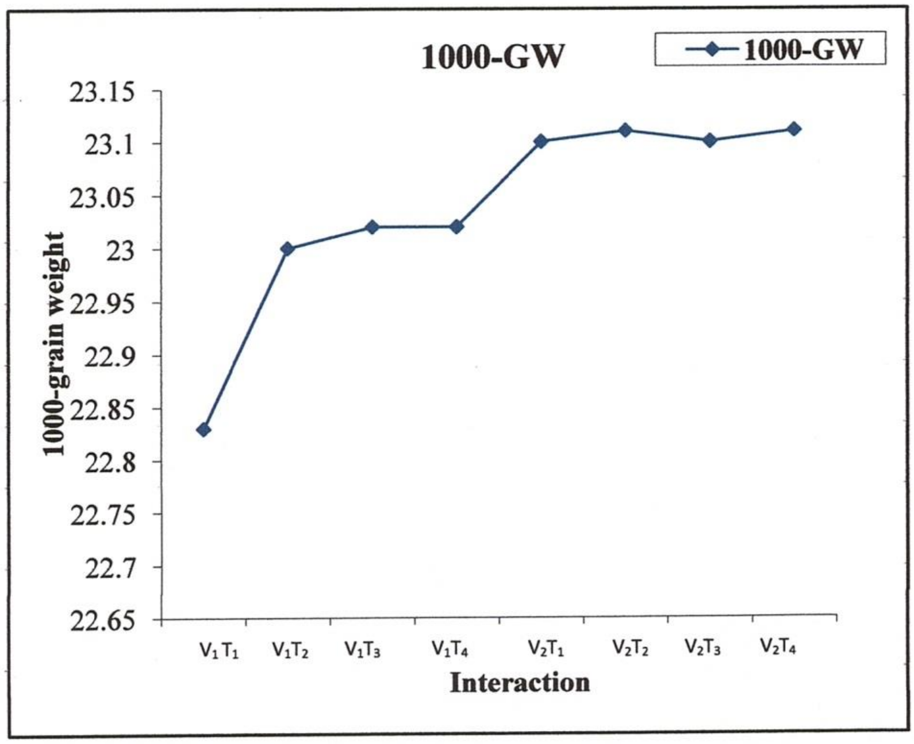

Fig. 4.4 Variation in 1000-Grain Weight for Different Degrees of Irrigation Treatments

4.1.2.7 Effect of Irrigation Treatments (AWDI) on Grain Yield

Grain yield, the most important character of an agronomic analysis, was found to be significantly influenced by varieties, different degrees of AWDI irrigation treatments and their interactions (Appendix II). Analysis of the data obtained from the experimental plots resulted in a clear depiction of the scenario. It showed that the varietal effect on the grain yield was significant at the 1% level of probability. The highest grain yield (5.69 t/ha) was obtained from treatment T_2 (irrigation when water is below 15 cm from the soil surface) and the lowest yield grain (4.71 t/ha) was obtained from treatment T_1 (continuous standing water). The results shows that the grain yield did not decreased when plants suffered little water stress. The second highest yield grain (5.45 t/ha) was found in the treatment T_3 (when irrigation is 20 cm below from the soil surface) (Fig. 4.5).

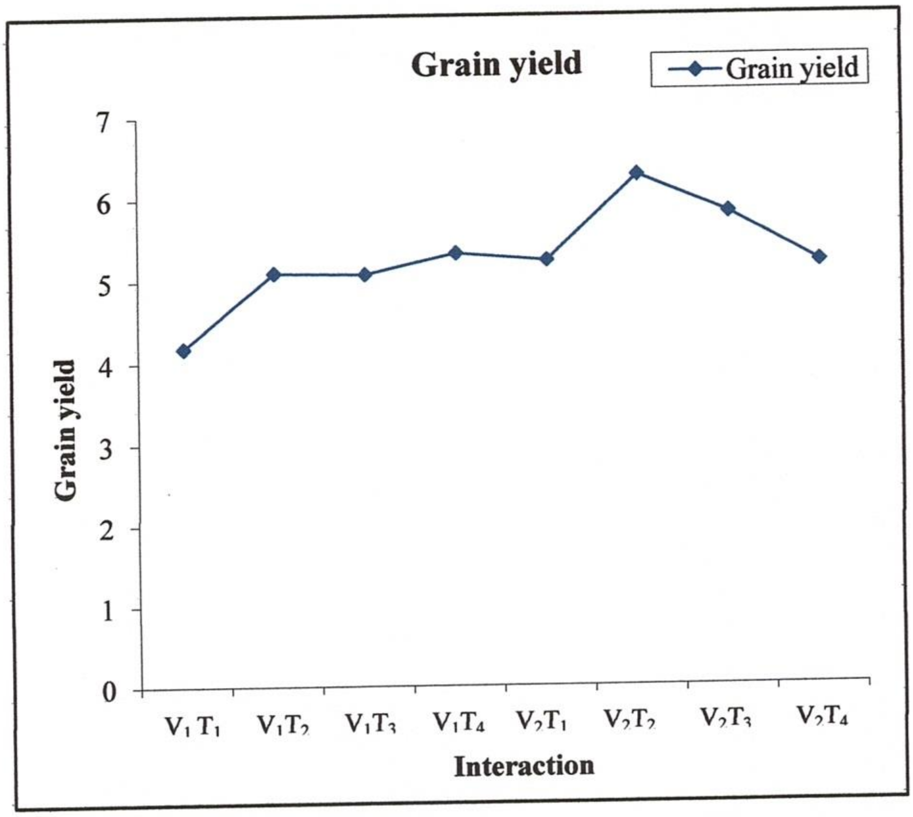

Fig. 4.5 Variation in Grain Yield for Different Degrees of Irrigation Treatments

The result agrees with Satter *et al.,* (2008) who reported that the highest grain yield was recorded from AWD method (irrigation 5 cm when water is 15 cm below the soil surface).

The interaction between the varieties and treatments, as shown in Appendix III also produced significant results for grain yield at the 5% level of probability. The highest grain yield of BRRI hybrid2 (6.28 t/ha) was obtained for the interaction ($V_2 \times T_2$) and the lowest grain yield (4.18 t/ha) was obtained from the interaction ($V_1 \times T_1$).

This result is in agreement with the findings of Satter *et al.,* (2008) who reported that treatment having continuous flooding could not improved grain yield. They found that highest grain yield was found from treatment when water is 15 cm below the soil surface.

4.1.2.8 Effect of Irrigation Treatments (AWDI) on Straw Yield

Straw yield from the experiment was found to be significantly affected by the variety, irrigation treatments and their combination at 5% level of probability (Appendix I, II and III). BRRI hybrid2 gave the highest straw yield (6.70 t/ha), while BRRI dhan29 (V_1) gave 5.83 t/ha. The maximum straw yield (6.57 t/ha) was found from the treatment T_1. The minimum straw yield (6.12 t/ha) was found from treatment T_1 Fig. 4.6.

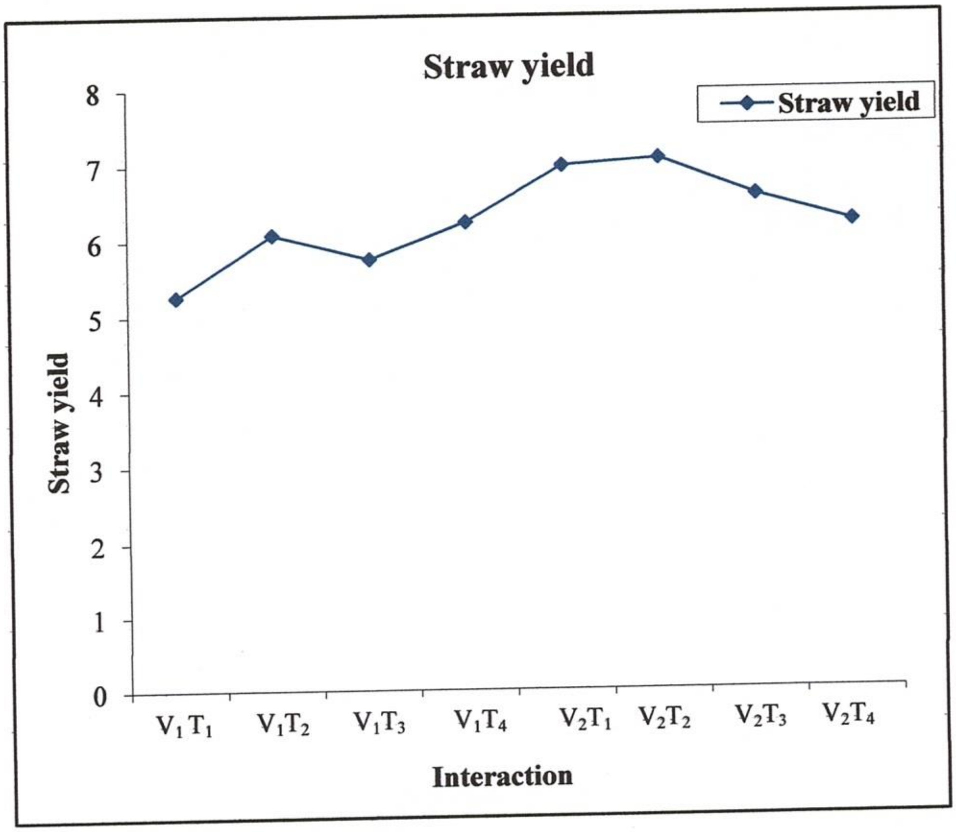

Fig. 4.6 Variation in Straw Yield for Different Degrees of Irrigation Treatments

The interaction between the varieties and treatments, as shown in Appendix III also produced significant straw yield at the 1% level of probability. The highest straw yield (7.06 t/ha) was obtained for the interaction ($V_2 \times T_2$) and lowest straw yield (5.26 t/ha) was obtained for the interaction ($V_1 \times T_1$).

4.1.2.9 Effect of Irrigation Treatments (AWDI) on Harvest Index (HI)

The varieties, irrigation treatments and of the experiment did not have any significant effect on the harvest index either at 1% or 5% level of probability. Appendix I and II shows the effect of different irrigation treatments on harvest index. The highest value of harvest index (46.96 %) was found for the treatment T_3 (Appendix I and III) and the minimum for the T_1 (43.61%). This result is in agreement with the findings of Stone *et al.,* (1985) who reported that treatment having continuous flooding could not improved harvest index. Interaction effect of the variety and the treatments were found insignificant either at the 1% or 5 % level of significant. The highest harvest index (47.08 %) for the treatment ($V_2 \times T_2$). The lowest harvest index (44.28 %) for the treatment ($V_1 \times T_1$) (Appendix III).

This result is in agreement with the findings of Satter *et al*., (2008) who reported that treatment having continuous flooding could not improve harvest index. Interaction effect of the variety and the treatments were found insignificant either at the 1% or 5 % level of significant.

4.1.2.10 Water Use Efficiency

There were significant differences between two varieties with respect to total water use. The highest amount of water supplied (118.69 cm) for the BRRI dhan29 was pretty less than the BRRIhybrid2 (113.82) as shown in Table 4.4. Water use efficiencies for the individual effect of different treatments were derived along with the values of WUE for the 8 interactions between treatments and varieties (Table 4.4). The highest water use efficiency, WUE was found to be 87.38 kg/ha/cm ($V_1 \times T_2$). All the highest water use efficiencies were found in the combinations having variety V_1 (BRRI dhan29). The lowest WUE was obtained in the treatment T_1 for V_2 (Fig. 4.4). In case of BRRI dhan29 (V_1) the highest WU was found to be 87.38 kg/ha/cm of water and the lowest was found to be 86.11 kg/ha/cm. The second highest WUE highest WUE (87.38 kg/ha/cm) was found in the treatment T_2 though it gave poor yield (5.10t/ha). Treatment T_2 gave high yield with high water use efficiency (85.55kg/ha/cm) among the others (Table 4.4).

This result is in conformity with the findings of Sharma (1987), Dubey (1995) and Sandhu *et al.,* (1980) who reported that under intermittent flooding condition less water was required as compared to continuous flooding for rice cultivation which resulted in higher water productivity of the crop. Water productivity was found to be the highest (0.046 t/ha/cm) in treatment T_2 (irrigation when water is 15 cm below the soil surface) followed by treatment T_3 (0.043t/ha/cm) (irrigation when water is 20 cm below the soil surface) and a minimum of 0.029 t/ha/cm treatment T_1 (continuous flooding). From these results, it can be seen that the water productivity decreased with the increase of irrigation water (Fig. 4.7).

Table 4.4 Water use Efficiency for Different Treatments And Interactions

Interactions	Total water required (cm)	Water applied (cm)	Grain Yield (ton/ha)	Water use efficiency (kg/ha/cm)	Treatments	Average total water required (cm)	Average grain yield (ton/ha)	Water use efficiency kg/ha/cm)	Water productivity (t/ha/cm)
V_1T_1	118.69	137.83	4.18	86.11	T_1	116.25	4.71	84.34	0.029
V_1T_2	116.08	132.83	5.10	87.38					0.037
V_1T_3	115.55	133.33	5.08	86.66	T_2	113.64	5.69	85.55	0.037
V_1T_4	115.55	130.33	5.33	86.66					0.039
V_2T_1	113.82	137.83	5.24	82.57	T_3	113.11	5.45	84.83	0.037
V_2T_2	111.21	131.83	6.28	84.31					0.046
V_2T_3	110.68	131.33	5.82	84.27	T_4	113.11	5.27	85.79	0.043
V_2T_4	110.68	131.33	5.21	84.27					0.038

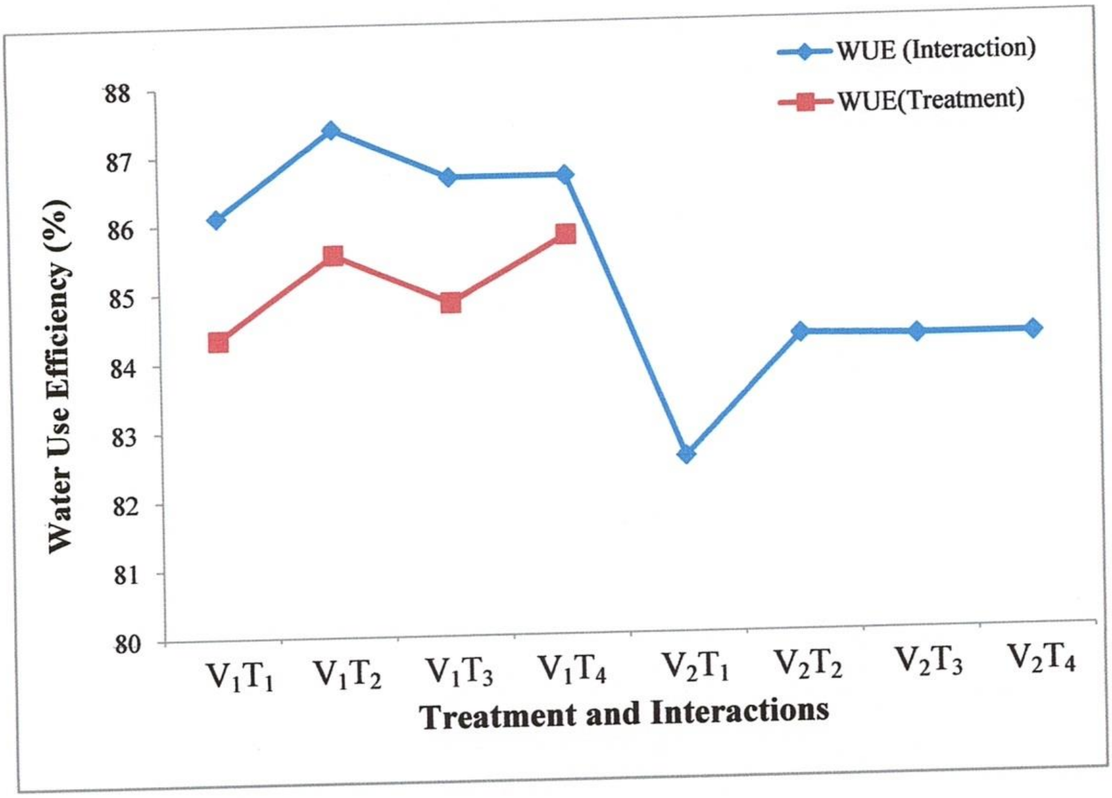

Fig. 4.7. Water use Efficiency (WUE) for Different Interactions among the Verities (V) and Irrigation Treatments (T).

4.1.2.11 Regression study

All the parameters discussed above, no doubt, altogether contribute to the yield of rice. Figures of all the parameters, in combination, are considered to be the most significant basis for the physical characterization of the possible output that may result in consequence of an agronomic experiment. For this reason, all these parameters are termed as the yield contributing characters. Simple regression analysis can relate each of these yields contributing character with the grain yield from which important parameters affecting the grain yield as well as their correlation with the output can be identified

Table 4.5 shows the correlation coefficients of relationships between yield contributing characters and grain yield. It shows that grain yield was positively correlated with number of effective tillers per hill ($R^2 = 0.2727$), number of filled grains per panicle ($R^2 = 0.7171$), 1000 grain weight ($R^2 = 0.3359$), straw yield ($R^2 = 0.6421$), and total water use ($R^2 = 0.8392$ for BRRI dhan29 and $R^2 = 0.4917$ for

BRRI hybrid2) as shown in Figs. 4.8, 4.9, 4.10, 4.11, 4.12 and 4.13 respectively. Regression analysis revealed that increases in plant height, numbers of effectives tillers per hill; length of panicle number of filled grains per panicle, 1000 to grain weight, straw yield was correlated with the corresponding increase in grain yield.

Table 4.5 Regression Analyses and the Coefficient of Determination Between Various Yield Contributing Characters vs. Grain Yield.

Characters		Coefficient of determination, R^2	Reference
Number of effective tillers/hill vs. grain yield		0.2727	Fig. 4.8
Length of panicle vs. grain yield		0.2341	Fig. 4.9
Number of filled grains/panicle vs. grain yield		0.7171	Fig. 4.10
1000 to grain weight vs. grain yield		0.3359	Fig. 4.11
Straw yield vs. grain yield		0.6421	Fig. 4.12
Total water use vs. grain yield	BRRI dhan 29	0.8392	Fig. 4.13
	BRRI hybrid2	0.4917	Fig. 4.13

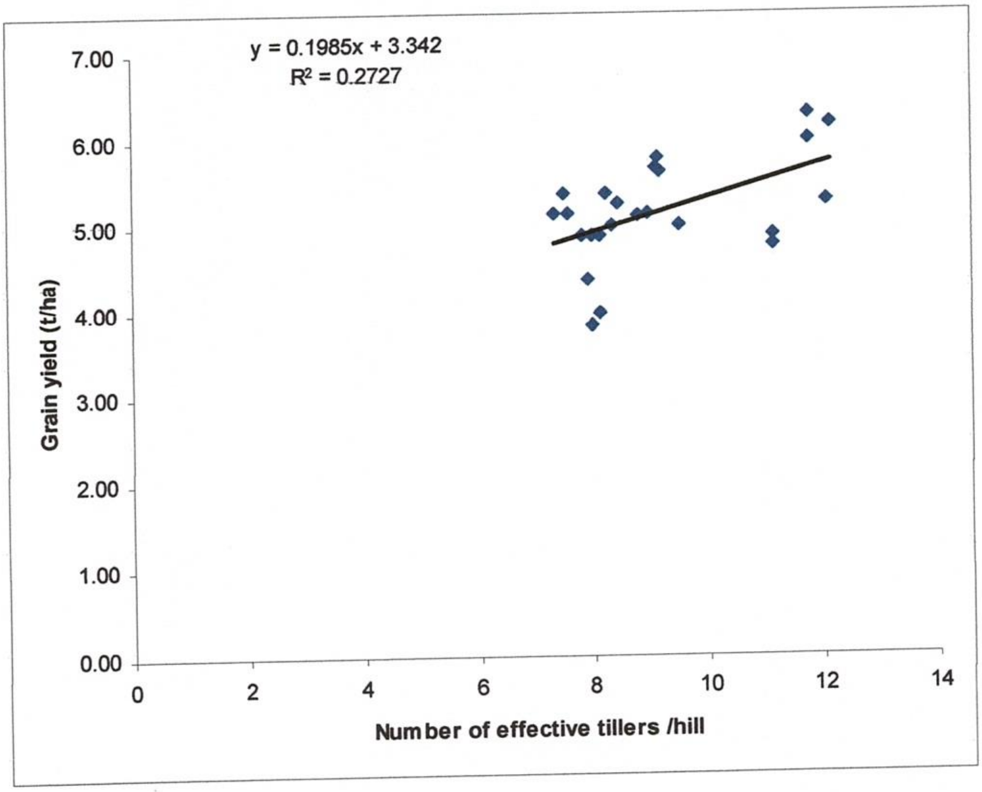

Fig. 4.8. Relationship between Number of Effective Tillers/Hill and Grain Yield of *Boro* Rice

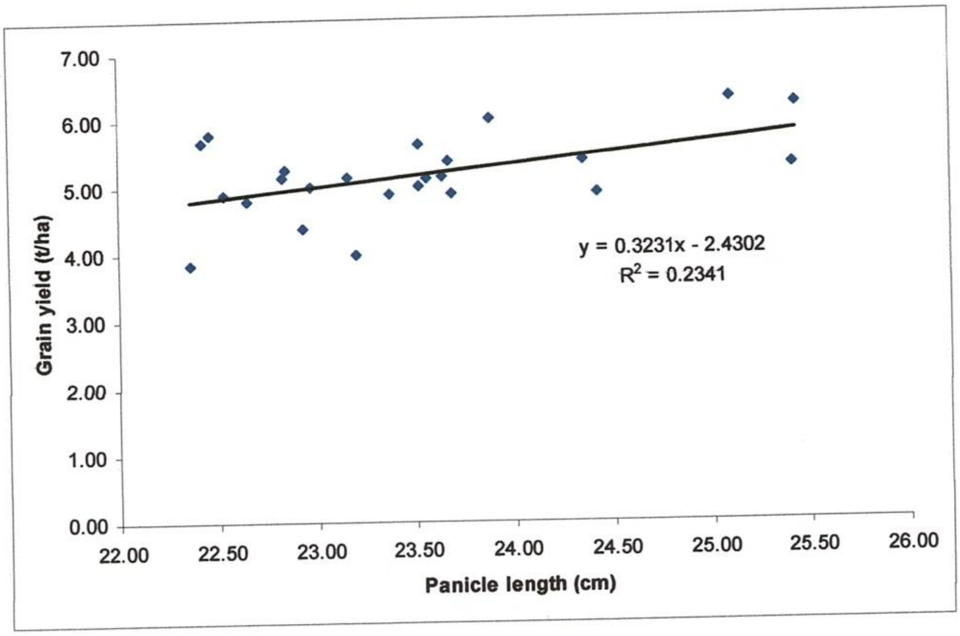

Fig. 4.9. Relationship between Panicle Length and Grain Yield of *Boro* Rice

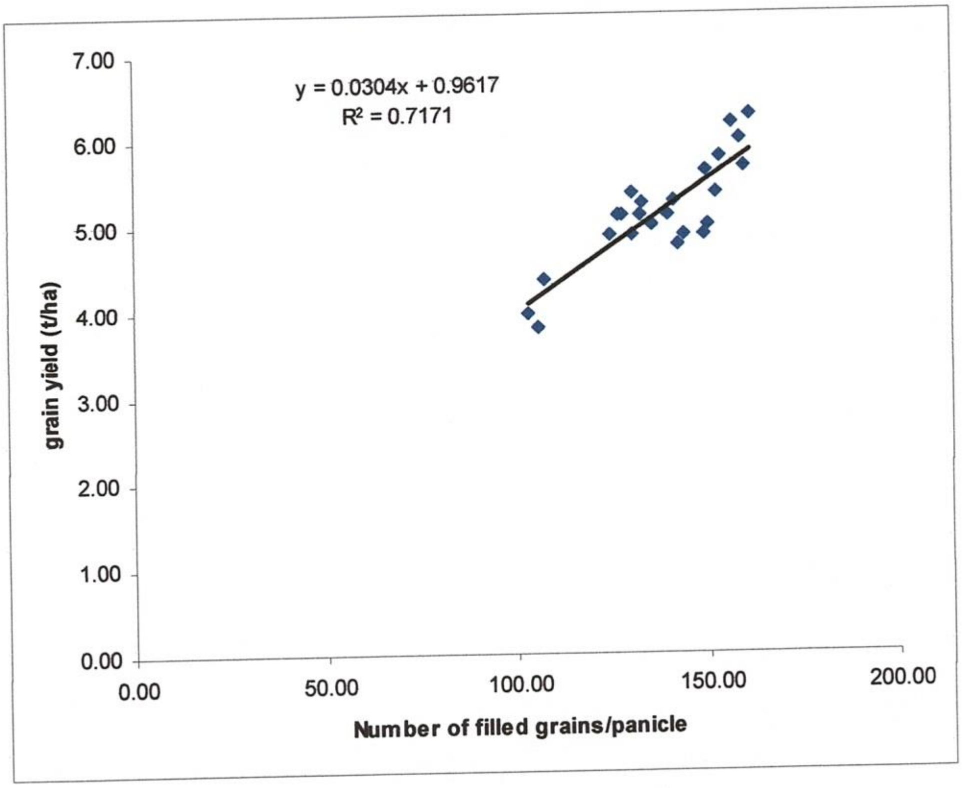

Fig. 4.10. Relationship between Number of Filled Grains/Panicle and Grain Yield of *Boro* Rice

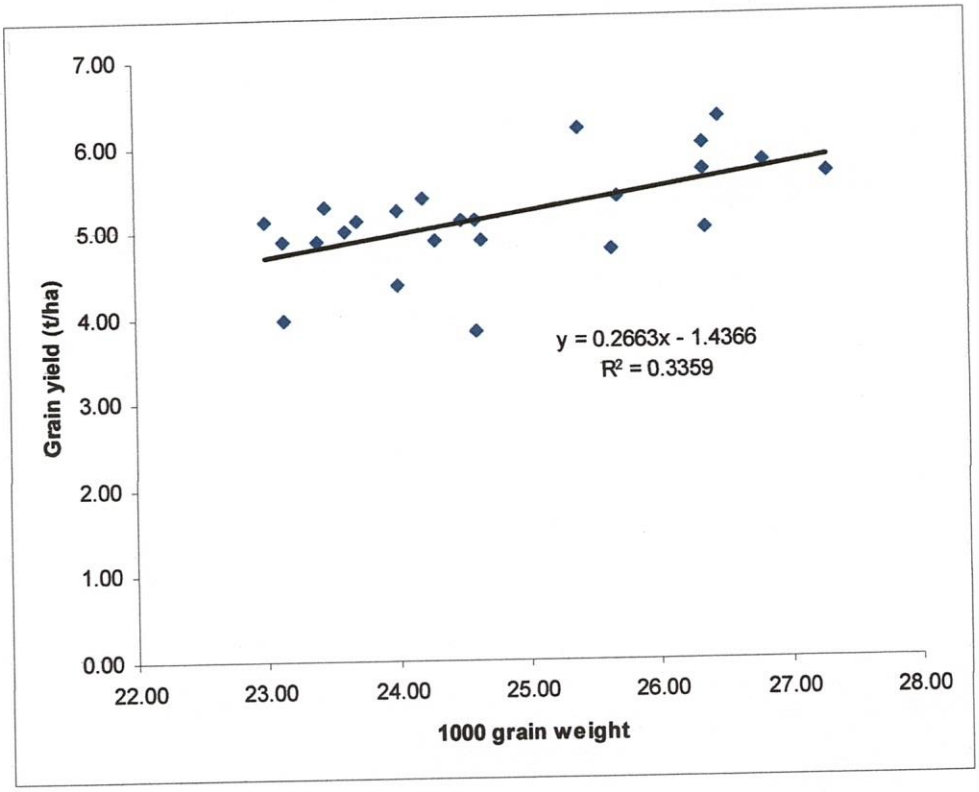

Fig. 4.11. Relationship Between 1000 Grain Weight and Grain Yield of *Boro* Rice

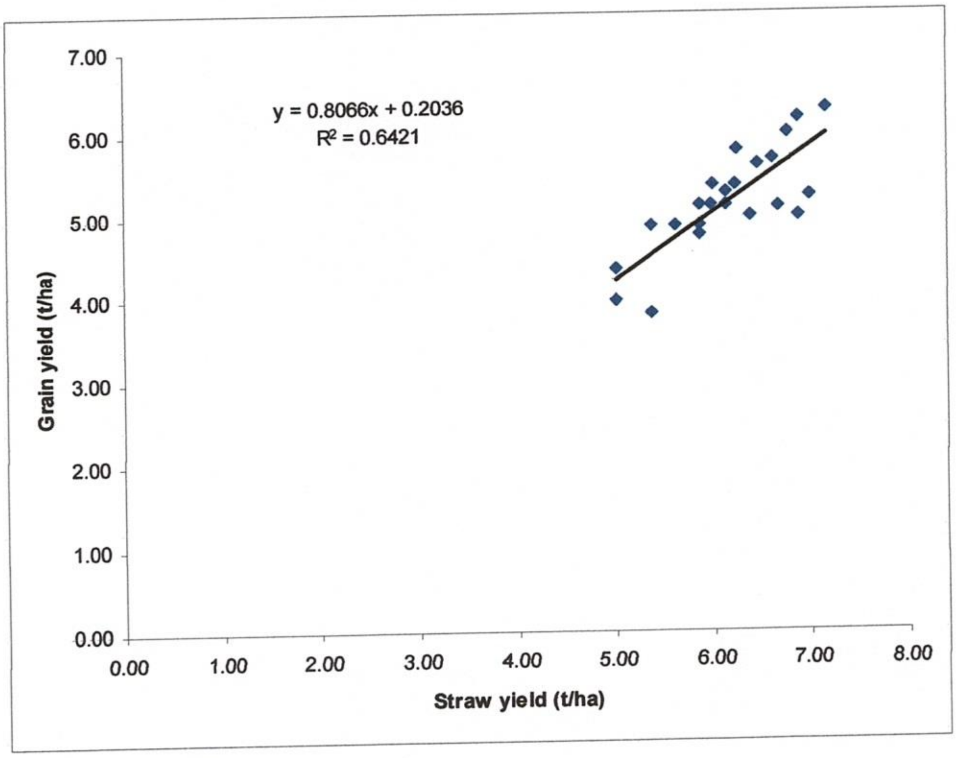

Fig. 4.12. Relationship Between Straw Yield and Grain Yield of *Boro* Rice

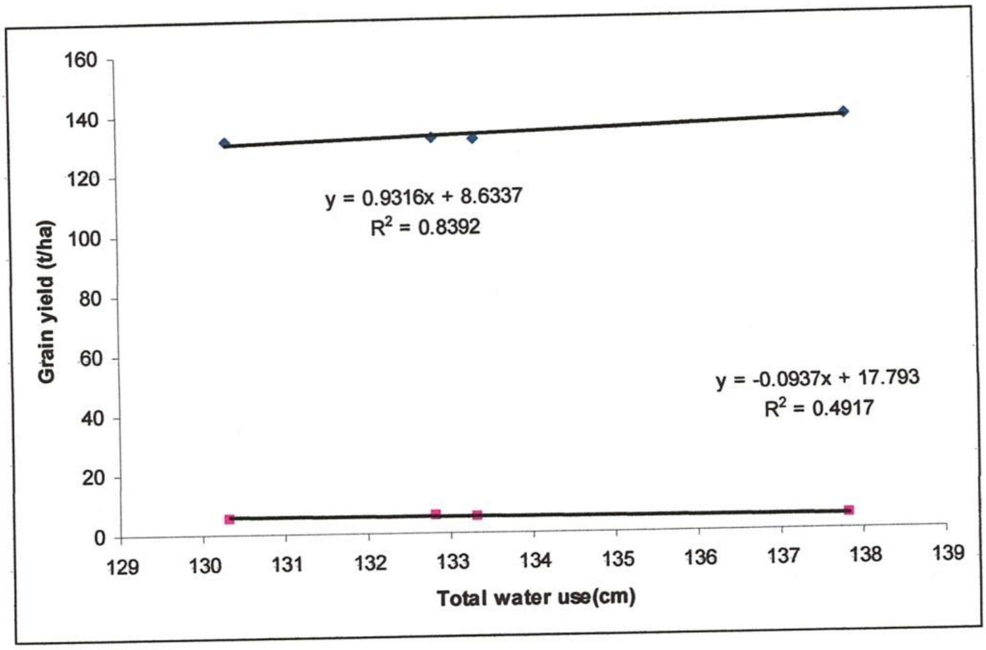

Fig. 4.13. Relationship between Total Water used and Grain yield of *Boro* Rice

Experiment 2: Alternate Wetting and Drying: A Sustainable Water Management for Rice Cultivation in Rajshahi District

4.2.1 Climatological Data

Total rainfall of growing period was 298.5 mm (Table 4.6). It was found that in 2011 growing season January to May, the maximum rainfall occurred in the month of May 187.9 mm and the minimum rainfall occurred January 6.2 mm. The minimum and maximum temperature ranged from 34.3 to 34.81 o C and 24.0 to 9.0 o C in 2010 respectively. The maximum temperature 34.3 o C was observed in April and the minimum 9.0 o C in January in 2011 respectively. The highest monthly average relative humidity of 82% was found in May and the lowest 65 % in March in 2011, respectively (Table 4.6).

Table 4.6 Monthly Maximum and Minimum Temperatures, Rainfall and Humidity During Rice-Growing Seasons at the BRRI Farm, Rajshahi in 2011.

Month	Year 2011				
	Monthly total RF(mm)	Monthly av. tem.(0C)			Monthly av. RH (%)
		Max.	Min.	Mean	Monthly Average
January	6.2	22.0	9.0	15.5	81%
February	nill	27.5	12.9	20.2	74%
March	11.0	33.1	19.1	26.1	65%
April	93.4	34.3	22.3	28.3	72%
May	187.9	33.9	24.0	28.9	82%

Source: Weather office, Shampur, Rajshahi.

4.2.2 Physio-chemical Properties of Soil of the Experimental Site:

Some essential physio-chemical properties of the experimental soil were determined and presented in Appendix XVIII. The soil texture of the experimental field was found to be loam. The pH value ranged from 8.1 to 8.2, nitrogen (N) from 0.03 to 0.04 %, phosphorous (P) from 10.2 to 11.1 pm, zinc (Zn) from 0.54 pm, and that of organic matter ranged from 0.55 percent, respectively.

4.2.3 Seepage & Percolation (S&P) and Evapotranspiration (ET)

Seepage and percolation (S&P) and Evapotranspiration (ET) are given in Table 4.7. The experiment has been carried out in *Boro* season which started with in December and ended in May 2011. Seepage and percolation evapotranspiration reading were taken from the standing water plots which maintained 2-5 cm standing water throughout the growing season. In 2011 *Boro* season, S&P were 2.30, 2.63 and 2.31 mm/day. In the year 2011 ET were 5.1, 5.3 and 5.2 mm/day.

Table 4.7. Seepage and Percolation (S&P) and Evapotranspiration (ET) of the Experimental Plots during *Boro* season in 2011.

Season	S&P(mm/day)				ET(mm/day)			
	Veg.	Rep.	Rip.	Mean	Veg.	Rep.	Rip.	Mean
Boro 2011	2.30	2.63	2.31	2.41	5.1	5.3	5.2	5.2

4.2.4 Irrigation Treatments (AWDI)

The two varieties stated above were subjected to different levels of irrigation developed by delaying the scheduled irrigation in the field. Starting from the very end of the first stage of crop development (tillering), four irrigation treatments were started with regular intervals. The time of water application, however, was indicated by the depletion of water level in different perforated pipes measured from the ground surface. Both of the experimental rice varieties, irrespective of their position in the field, receive different levels of irrigation treatments according to the demand of the respective fields in each replication.

Table 4.8. Total number of irrigation required for different irrigation treatments

Treatment	*No. of Irrigation		Rainfall+ water for crop established (cm)	Total water required(cm)	
	BRRIdhan28	BRRI hybrid2	42.1	BRRI dhan28	BRRI hybrid2
T_1	15	14	42.1	53.27	44.89
T_2	14	13	42.1	52.67	43.79
T_3	13	13	42.1	51.73	42.69
T_4	13	12	42.1	51.42	42.69

*One irrigation means application of 5 cm irrigation water

Table 4.9 Water Requirement (cm) and Water applied (cm) in Interaction Experiment, *Boro* Season, 2011 at BRRI Farm, Shampur, Rajshahi.

Treat.	Water requirement(mm)				Water applied (cm)				
	ET	S&P	Total	Average (cm)	No. of IR	LP	IR	RF	Total
V_1T_1	728	337.4	532.7	49.08	15	27.0	38.2	171.0/14.25/17.10	82.3
V_1T_2	728	325.35	526.67		14	27.0	20.5	171.0	64.6
V_1T_3	728	306.07	517.03	48.23	13	27.0	20.0	171.0	64.1
V_1T_4	728	301.25	514.62		13	27.0	19.0	171.0	63.3
V_2T_1	613.6	284.38	448.99	47.20	15	27.0	35.2	171.0	79.3
V_2T_2	613.6	262.38	437.99		14	27.0	30.5	171.0	74.6
V_2T_3	613.6	242.38	426.99	47.08	13	27.0	20.0	171.0	64.1
V_2T_4	613.6	240.38	426.99		12	27.0	19.0	171.0	63.1

Irrigation treatments were applied at different stages of the growing period depending on the depletion of the water level in the perforated pipe. The very first treatment stated at the end of the fourth week after transplantation. During this time 5 cm standing water was kept to avoid weed infestation in the plots. Table 4.8 and 4.9 shows that the highest number of irrigation (15 nos.) was given to the plots with treatment T_1 (continuous flooding) for BRRI dhan28. The other three treatments viz., T_2, T_3 and T_4 received a total of 14, 13 and 13 number of irrigation for BRRI dhan28 while 14, 13, 13 and 12 number of irrigation for BRRI hybrid2, respectively. Water required for crop establishment and water received from the rainfall was estimated to be 42.1 cm during the growing period for each of the treatments. For BRRI hybrid2, maximum amount of water (44.89 cm) was required for T_1, while, second maximum (43.79 cm) for T_2 was followed by other two treatments, T_3 (42.69cm) and T_4 (42.69cm). For BRRI dhan28 the treatments T_1, T_2, T_3 and T_4 required 53.27, 52.67, 51.73 and 51.42 cm of water, respectively. The graphical representation of water usage by different treatments after transplantation is shown in Fig 4.14

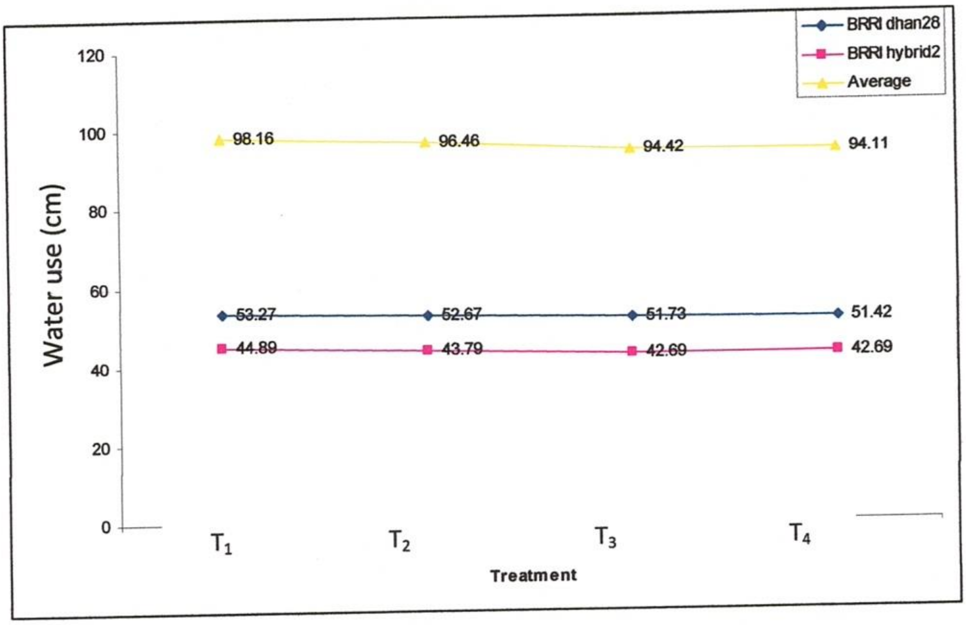

Fig. 4.14 Water Usage of Different Treatments for the Production of BRRI dhan28 and BRRI hybrid2.

4.2.5 Varietal Performances for Plant Characterizers and Yields of Transplant *Boro* Rice

The yield and yield contributing characters e.g. effective tiller, filled grain, unfilled grain, straw yield and biological yield were significantly affected by the variety. The varietal performance for those characters and yields are presented in appendix IV.

4.2.6 Plant Height

The analysis showed that varietal effect on plant height was statistically significant at 1% probability level. The tallest plant (104.50 cm) was found in BRRI hybrid2 (V_2). The shortest plant (101.64 cm) was found in BRRI dhan28 (V_1). Variation in plant height might be due to the differences in the genetic make –up of the varieties. The result is in consistent with findings of Shamsuddin *et. al.,* (1988) who also reported a variable plant height existed among the varieties.

4.2.7 Number of total Tillers Hill-[1]

The highest number of total tillers hill-1(11.75) was found in BRRI hybrid2 and the lowest number of total tiller was found (10.88) in BRRI dhan28. Variable effects of variety on number of total tillers hill^{-1} were also reported by Hossain *et al.*, (1989a) who noted that number of total tillers hill^{-1} differed among the varieties. The variation in number of total tillers hill^{-1} might be due to varietal characteristics.

4.2.8 Number of effective Tillers Hill^{-1}

Number of effective tillers hill^{-1} was statistically significant at 1 % level of probability (Appendix IV). The highest number of effective tillers (9.53) was found in BRRI hybrid2 and the lowest number of effective tiller hill^{-1}(8.79) was found in BRRI dhan28.

4.2.9 Number of Non-effective Tillers Hill^{-1}

The highest number of non-effective tillers (2.21) was found in BRRI dhan28 and the lowest number of non-effective tiller hill^{-1}(2.09) was found in BRRI hybrid2.

4.2.10 Panicle Length

The highest length of panicle (23.65 cm) was found in BRRI hybrid2. The lowest length of panicle was (23.35 cm) in BRRI dhan28. Varietal differences regarding the panicle length might be due to their differences in genetic make-up.

4.2.11 Number of Filled Grains Panicle^{-1}

Number of filled grains panicle^{-1} was statistically significant at 1% level of probability (Appendix IV). The results showed that the highest grain yield (149.92) was achieved from BRRI hybrid2. The lowest grain yield (118.45) was achieved from BRRI dhan28. These differences occurred due to variations of genetic make-up among the varieties.

4.2.12 Number of Unfilled Grains Panicle^{-1}

Number of unfilled grains panicle^{-1} was statistically significant at 1% level of probability (Appendix IV). The highest number of unfilled grains panicle^{-1} (30.80) was found in BRRI dhan28. The lowest number of unfilled grains (23.53) panicle^{-1} was found from BRRI hybrid2 (Appendix IV).

4.2.13 Weight of 1000 Grains

The result showed that the highest weight of 1000- grain (25.62 g) was obtained from BRRI hybrid2. The lowest weight of 1000-grain (23.93 g) was obtained from BRRI dhan28.

4.2.14 Grain Yield

Grain yield was statistically significant at 1% level of probability. The highest grain yield (5.52 t/ha) was achieved from BRRI hybrid2. The lowest grain yield (4.81 t/ha) was achieved from BRRI dhan28. These differences occurred due to variations of genetic make-up among the varieties. Dwivedi (1997) and BRRI (2000) also reported similar result.

4.2.15 Straw Yield

The result reveals that Shows that the highest straw yield (6.58 t ha^{-1}) was found from BRRI hybrid2. The lowest straw yield (5.71 t ha^{-1}) was found from BRRI dhan28.The highest yield occurred due to higher plant height, higher total tiller hill^{-1} and lower number non-effective tiller hill^{-1}. These results are consistent with those obtained by Chowdhury *et al.,* (1993) who reported differences in straw yield among varieties.

4.2.16 Biological Yield

The highest biological yield (12.10 t ha^{-1}) was obtained from BRRI hybrid2 and the lowest one (10.52 t ha^{-1}) was obtained from BRRI dhan28.

4.2.17 Harvest Index

Maximum harvest index (45.63%) was obtained from BRRI dhan28 and the minimum harvest index (45.57 %) was obtained from BRRI hybrid2.

4.2.18 Effects Irrigation Treatments (AWDI) on Yield and Yield Contributing Characters

The experiment aimed in exploring the possible effects of different irrigation treatments on the production and production related parameters. Different yield contributing characters viz., plant height (cm), number of effective tillers per hill, panicle length (cm), total number of filled grains per panicle, number of unfilled grains per panicle; 1000 seed weight (gm), grain yield (t/ha) and straw yield (t/ha)for each of the varieties were analyzed. Statistical relationships of the effect of four treatments on the individual yield contributing parameters along with their interaction with the variety are given with their detail statistical analysis and ANOVA (Appendix XVI).

4.2.19 Effect of Irrigation Treatments (AWDI) on Plant Height

Results obtained from the statistical analysis of the effect of variety and different degrees of delayed irrigation treatments on plant height are shown in appendix V. The analysis showed that varietal effect on plant height was statistically significant (Appendix V) and, the irrigation treatments had significant effect on plant height at 1 % level of probability. The highest plant height (104.38 cm) was obtained in treatment T_2 (Application of 3 days of disappearance of standing water) and the lowest (101.55 cm) in Treatment T_1 (continuous flooding) as shown in Fig. 4.15.

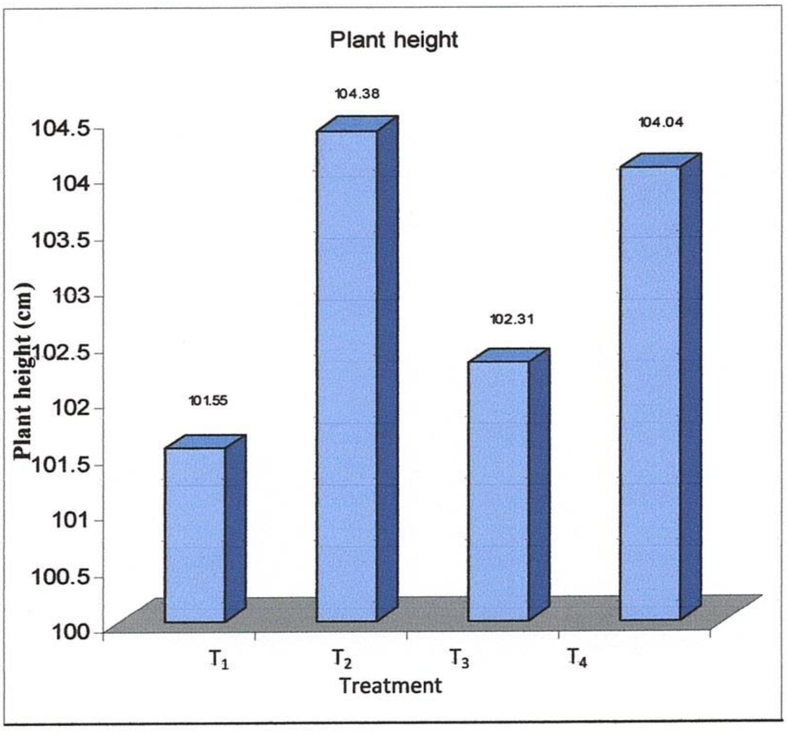

Fig 4.15 Variation in Plant Height for Different Degrees of Irrigation Treatments

This result is in agreement with the findings of Hassan *et al.,* (2008) who reported that treatment having continuous flooding could not improved plant height.

On the other hand, effect of the interaction between the varieties and the treatments was also found to be statistically significant at 1% level of probability. The tallest plant height (106.48 cm) was found for the interaction $V_2 \times T_2$.

4.2.20 Effect of Irrigation Treatments (AWDI) on Number of Effective Tillers per Hill^{-1}

Information obtained after analysis of the experimental findings showed that varietal effect on the number of effective tillers remained insignificant (either at 1% or 5%) while different degrees of delayed irrigations applied as treatments in the experimental plots revealed the consequences quite significant at 5% level of probability (appendix V). The highest number of effective tillers per hill (11.65) was found in treatment T_2 followed by treatment T_3 (8.69) and treatment T_1 (8.45). The lowest number of effective tiller per hill (7.85) was found in treatment T_4.

4.2.21 Effect of Irrigation Treatments (AWDI) on Panicle Length

The results obtained from the experimental findings showed significant effect on variety on the panicle length. Neither the irrigation treatments nor interaction (variety × Irrigation) had any effect on the panicle length of the varieties. The cause of the non significant output of the panicle length might have occurred due to insufficient photosynthesis from the less vigorous crop canopy and reduced leaf area of BRRI dhan28 and BRRI hybrid2 (appendix V and VI)

4.2.22 Effect of Irrigation Treatments (AWDI) on the Number of Filled grains per panicle

A little delayed irrigation treatments using alternate wetting and drying irrigating method in rice field showed significant effects on the number of filled grains per panicle compared to one with continuous standing (appendix V). It was found that the highest number of filled grains (150.55) per panicle was obtained in treatment T_2 (3 days of disappearance of standing water) followed by treatments T_3 (141.65) and T_4 (139.47). The lowest number of filled grains per panicle (120.84) was found for treatment T_1. Thus the result showed that applying irrigation water in rice field when 3 days of disappearance of standing water does not really reduce the total number of filled grains compared to that nursed with 5 cm standing water (Fig. 4.16). However, treatment T_1 (continuous standing water) decreased the number of filled grains.

The interaction effect of the varieties and treatments also came significant at 1% level of probability. The highest number of filled grains (158.67) was, however, marked for the interaction ($V_2 \times T_2$) and the lowest number of filled grains (105.48) was obtained from V_1T_1 (appendix VI) (Fig. 4.16).

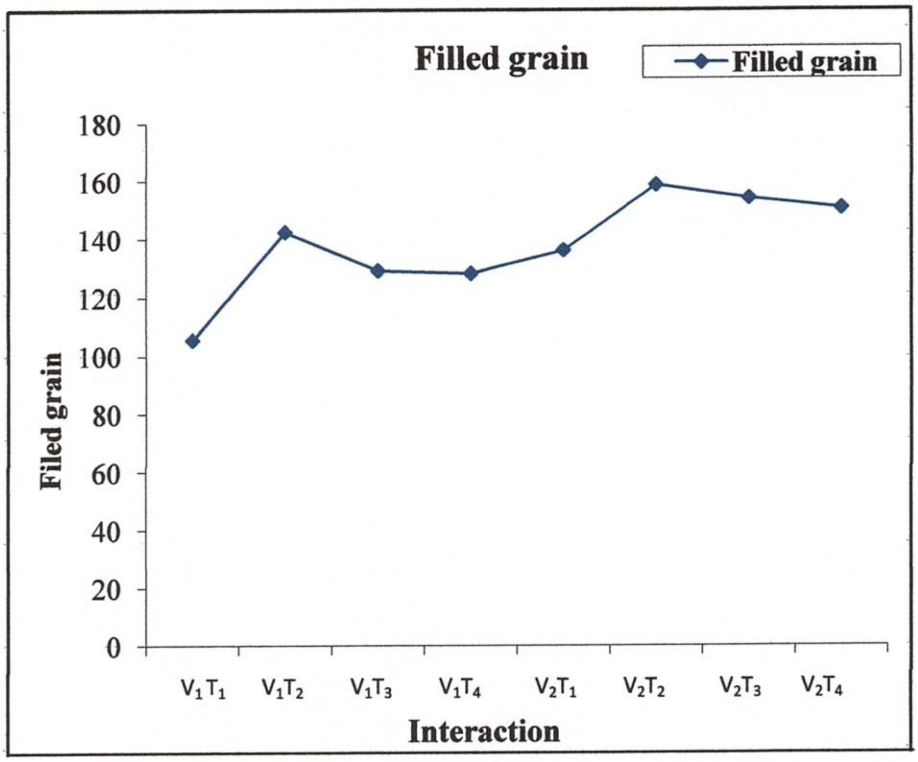

Fig. 4.16 Variation in Filled Grain for Different Degrees of Irrigation Treatments

4.2.23 Effect of Irrigation Treatments (AWDI) on 1000 grain weight

Thousand grain weight (1000 grain weight), as it is called the test weight of the desired output, is referred to be considered as one of the most significant agronomic parameters ever trusted that contributes in having a reconnaissance over the possible production of a lot (gain yield). The values of 1000 grain weight were found to be significant in this analysis for the effects of treatments at the 1% level of probability. The highest 1000 grain weight (26.82) was obtained for the interactions ($V_2 \times T_3$) and the lowest 1000 grain weight (23.63) was obtained for the V_2T_4 (appendix VI). The study raveled that the varieties V_1 and V_2 and interaction effect between variety × treatments produced statistically insignificant variation in 1000 grain weight among themselves. Thus, it was clear from the interaction effect that AWDI method of irrigation treatments did not reduced the 1000 grain weight as irrigation delayed (Fig. 4.17).

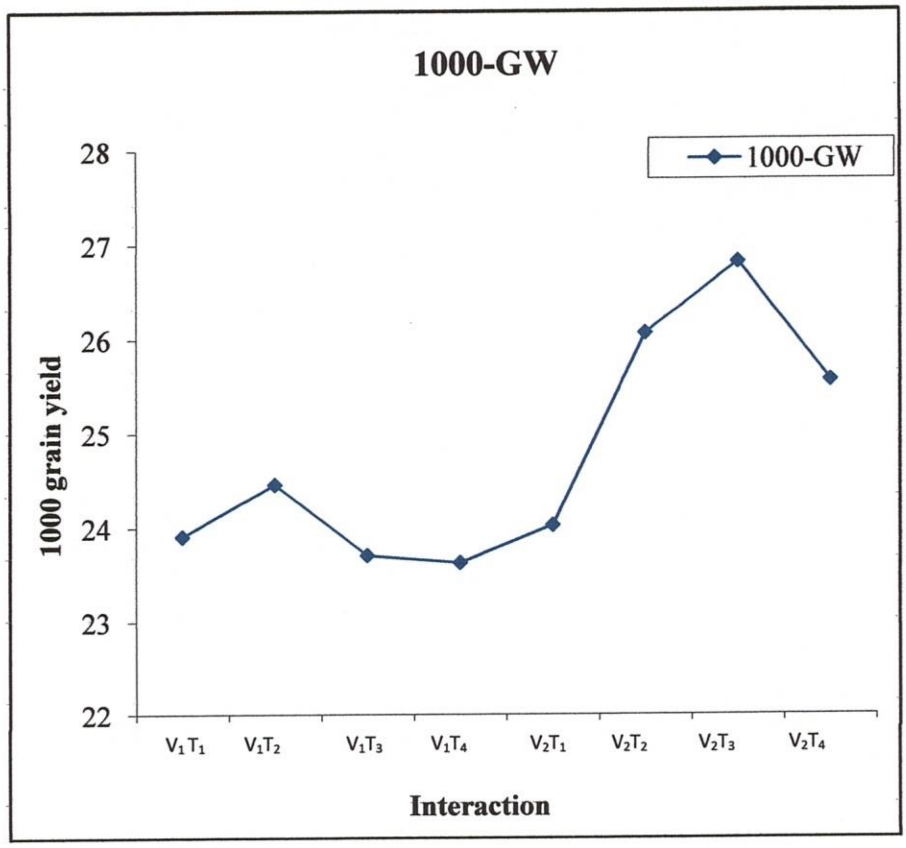

Fig.4.17. Variation in 1000-grain Weight for Different Degrees of Irrigation treatments

4.2.24 Effect of Irrigation Treatments (AWDI) on Grain Yield

Grain yield, the most important character of an agronomic analysis, was found to be significantly influenced by varieties, different degrees of AWDI irrigation treatments and their interactions (appendix IV, VI and VII). Analysis of the data obtained from the experimental plots resulted in a clear depiction of the scenario. It showed that the varietal effect on the grain yield was significant at the 1% level of probability. The highest grain yield (5.57 t/ha) was obtained from treatment T_2 (irrigation when water is 3 days of disappearance of standing water) and the lowest yield grain (4.59 t/ha) was obtained from treatment T_1 (continuous standing water). The results shows that the grain yield did not decreased when plants suffered little water stress. The second highest yield grain (5.33 t/ha) was found in the treatment T_3 (5 days of disappearance of standing water) (Fig. 4.18).

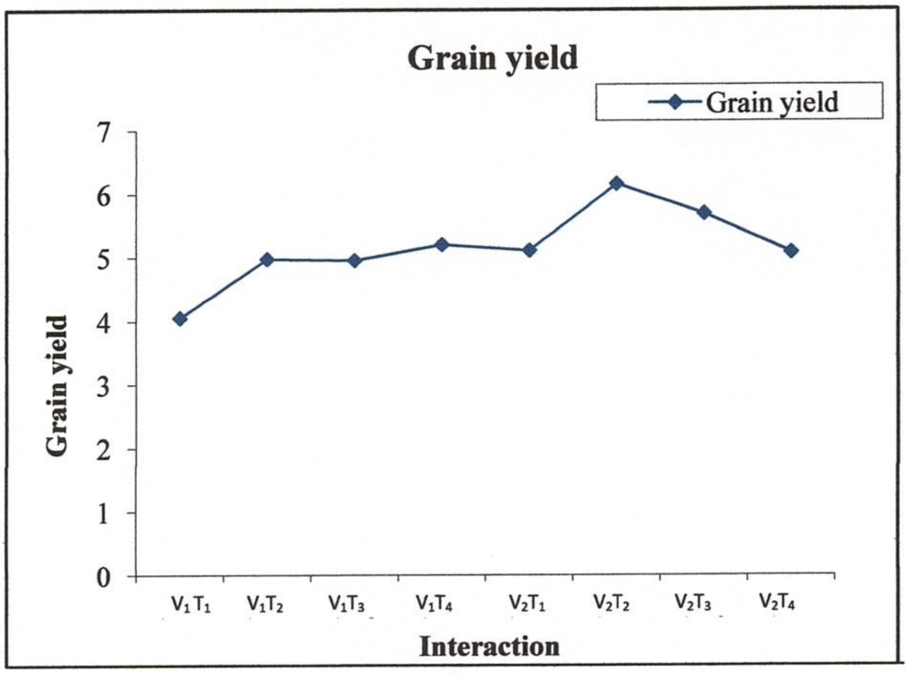

Fig. 4.18 Variation in grain Yield for Different Degrees of Irrigation Treatments

The result agrees with Satter *et al.*, (2008) who reported that the highest grain yield was recorded from AWD method (when water is 3 days of disappearance of standing water). Shi *et al.*, (2002); and Wardana *et al.*, (2002) have shown that rice grain yield increased with reduced water use. Rashid and Khan (2000) conducted an experiment on water saving during *Boro* season with 5 treatments in order to minimize losses of irrigation water from rice fields and thereby increase irrigation efficiency. The treatments were T_1= Continuous water (1-7 cm), T_2=Shallow standing water, T_3= Irrigation (5-7 cm) after 3 days of disappearing of standing water, T_4=Irrigation (5-7 cm) after 5 days of disappearances of standing water and T_5= (5-7 cm) after 7 days of disappearances of standing water. The result revealed that treatment T_3 saved 28% of irrigation water over continuously standing water condition with only 2% yield reduction.

The interaction between the varieties and treatments, as shown in appendix VI, also produced significant results for grain yield at the 5% level of probability. The highest grain yield of BRRI hybrid2 (6.16 t/ha) was obtained for the interaction

($V_2 \times T_2$) and the lowest grain yield (4.06 t/ha) was obtained from the interaction ($V_1 \times T_1$).

4.2.25 Effect of Irrigation Treatments (AWDI) on Straw Yield

Straw yield from the experiment was found to be significantly affected by the variety, irrigation treatments and their combination at 1% level of probability (Appendix IV, V and VI). BRRI hybrid2 gave the highest straw yield (6.58 t/ha), while BRRI dhan28 (V_1) gave 5.71 t/ha .The maximum straw yield (6.45 t/ha) was found from the treatment T_2. The minimum straw yield (6.00 t/ha) was found from treatment T_1.

The interaction between the varieties and treatments, as shown in appendix VI, also produced significant straw yield at the 1% level of probability. The highest straw yield (6.94 t/ha) was obtained for the interaction ($V_2 \times T_2$) and lowest straw yield (5.11 t/ha) was obtained for the interaction ($V_1 \times T_1$) (Fig. 4.19).

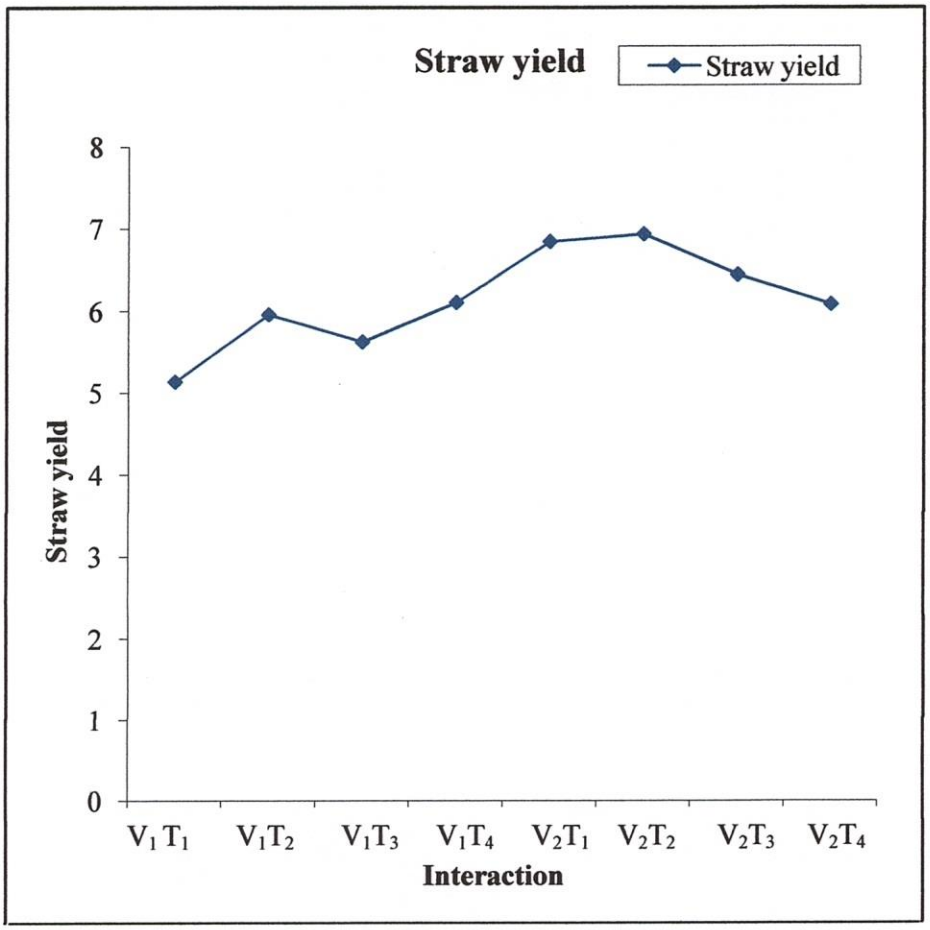

Fig. 4.19 Variation in Straw Yield for Different Degrees of Irrigation Treatments

This result is in agreement with the findings of Satter *et al*., (2008) who reported that treatment having continuous standing could not improved harvest index.

4.2.26 Effect of Irrigation Treatments (AWDI) on Harvest Index (HI)

The irrigation treatments of the experiment have significant effect on the harvest index either at 1% level of probability. Appendix V shows the effect of different irrigation treatments on harvest index. The highest value of harvest index (46.90%) was found for the treatment T_3 (Appendix V) and the minimum for the T_1 (43.46%). This result is in agreement with the findings of Stone *et al*., (1985) who reported that treatment having continuous standing could not improved harvest index. Interaction effect of the variety and the treatments were found insignificant either at the 1% or 5 % level of probability. The highest harvest index

(47.02 %) for the treatment ($V_2 \times T_2$). The lowest harvest index (42.79 %) for the treatment ($V_2 \times T_1$) (Appendix VI).

4.2.27 Water Use Efficiency

There were significant differences between two varieties with respect to total water use. The highest amount of water supplied (82.3cm) for the BRRI dhan28 was pretty less than the BRRIhybrid2 (79.3 cm) as shown in Table 4.10. Water use efficiencies for the individual effect of different treatments were derived along with the values of WUE for the 8 interactions between treatments and varieties (Table 4.10). The highest water use efficiency, WUE was found to be 81.67 kg/ha/cm ($V_1 \times T_4$). All the highest water use efficiencies were found in the combinations having variety V_1 (BRRI dhan28). The lowest WUE 56.60 kg/ha/cm was obtained in the treatment T_1 for V_2 (Fig. 4.10). In case of BRRI dhan28 (V_1) the highest WU was found to be 81.67 kg/ha/cm in treatment T_4 and the lowest WUE 64.64 kg/ha/cm in treatment T_1. The second highest WUE (87.38 kg/ha/cm) was found in the treatment T_2 though it gave poor yield (4.98 t/ha).Treatment T_4 gave high yield with high water use efficiency (81.67 kg/ha/cm) among the others (Fig. 4.20).

This result is in conformity with the findings of Sharma (1987), Dubey (1995) and Sandhu *et al.,* (1980) who reported that under intermittent flooding condition less water was required as compared to continuous flooding for rice cultivation which resulted in higher water productivity of the crop. Water productivity was found to be the highest (0.088 t/ha/cm) in treatmentT_4 (irrigation 5 days disappearance of standing) followed by treatment T_4 and T_2 (0.082 t/ha/cm) (irrigation 7 days and 3 days disappearance of standing water) and a minimum of 0.049 t/ha/cm treatment T_1 (continuous flooding).From these results, it can be seen that the water productivity decreased with the increase of irrigation water. This result reveals with Tabbal *et al.,* (2002) reported reduced water inputs and increased productivity of rice grown under saturated soil conditions, as compared with traditional flooded rice.

Table 4.10 Water use Efficiency for Different Treatments and Interactions

Interactions	Total water required (cm)	Water applied (cm)	Grain Yield (ton/ha)	Water use efficiency (kg/ha/cm)	Treatments	Average total water required (cm)	Average grain yield (ton/ha)	Water use efficiency kg/ha/cm)	Water productivity (t/ha/cm)
V_1T_1	53.2	82.3	4.06	64.64	T_1	49.04	4.59	60.62	0.049
V_1T_2	52.66	64.6	4.98	81.42					0.077
V_1T_3	51.70	64.1	4.96	80.65	T_2	48.22	5.57	70.05	
V_1T_4	51.46	63.3	5.21	81.67					0.082
V_2T_1	44.89	79.3	5.12	56.60	T_3	47.19	5.33	73.62	0.064
V_2T_2	43.79	74.6	6.16	58.69					0.082
V_2T_3	42.69	64.1	5.70	66.59	T_4	47.07	5.15	74.13	0.088
V_2T_4	42.69	63.1	5.09	66.59					0.080

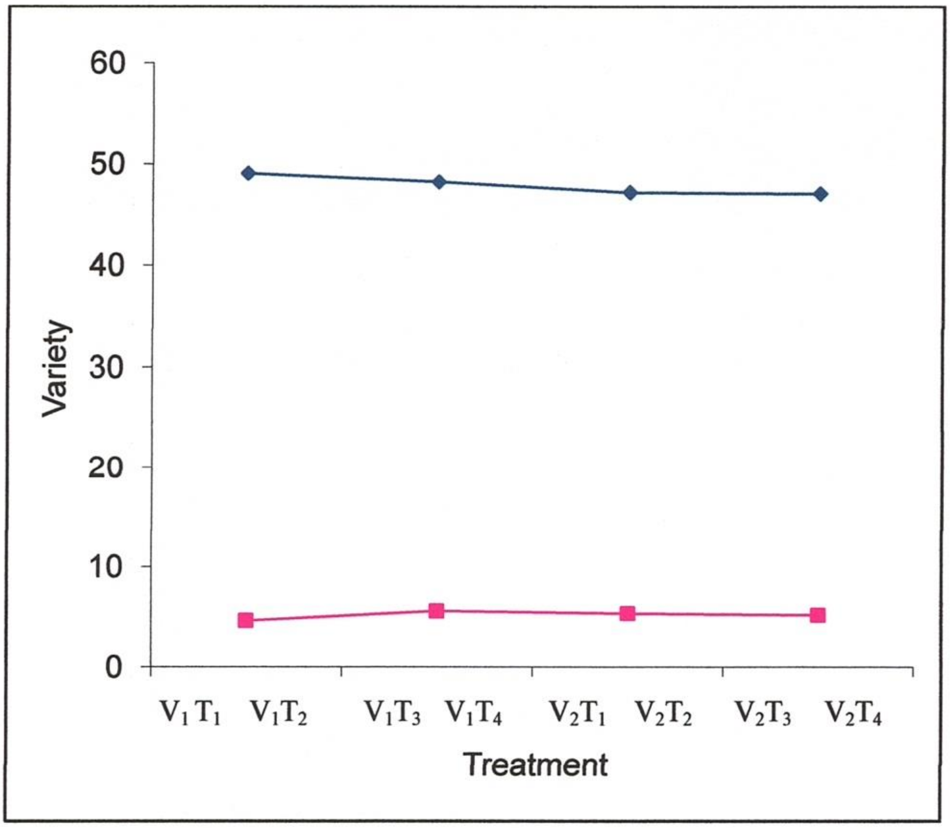

Fig. 4.20. Water use Efficiency (WUE) for Different Interactions among the Verities (V) and Irrigation Treatments (T).

4.2.28 Regression

All the parameters discussed above, no doubt, altogether contribute to the yield of rice. Figures 4.21, 4.22, 4.23, 4.24, 4.25 and 4.26 of all the parameters, in combination, are considered to be the most significant basis for the physical characterization of the possible output that may result in consequence of an agronomic experiment. For this reason, all these parameters are termed as the yield contributing characters. Simple regression analysis can relate each of these yields contributing character with the grain yield from which important parameters affecting the grain yield as well as their correlation with the output can be identified

Table 4.11 shows the correlation coefficients of relationships between yield contributing characters and grain yield. It shows that grain yield was positively correlated with number of effective tillers per hill (R^2 = 0.1208), number of filled grains per panicle (R^2 = 0.5985), 1000 grain weight (R^2 = 0.2341), straw yield (R^2 = 0.6421), and total water use (R^2 = 0.8392 for BRRI dhan28 and R^2 = 0.7848 for BRRI hybrid2) as shown in Figures 4.21, 4.22, 4.23, 4.24, 4.25 and 4.26 respectively. Regression analysis revealed that increases in plant height, numbers of effectives tillers per hill; length of panicle number of filled grains per panicle, 1000 to grain weight, straw yield was correlated with the corresponding increase in grain yield.

Table 4.11 Regression Analyses and the Coefficient of Determination Between Various yield Contributing Characters vs. Grain Yield.

Characters		Coefficient of determination, R^2	Reference
No. of effective tillers/hill vs. grain yield		0.1208	Fig. 4.21
Length or panicle vs. grain yield		0.07	Fig. 4.22
No. of filled grains/panicle vs. grain yield		0.5985	Fig. 4.23
1000 to grain weight vs. grain yield		0.2341	Fig. 4.24
Straw yield vs. grain yield		0.6421	Fig. 4.25
Total water use vs. grain yield	BRRI dhan 28	0.4917	Fig. 4.26
	BRRI hybrid2	0.7848	Fig. 4.26

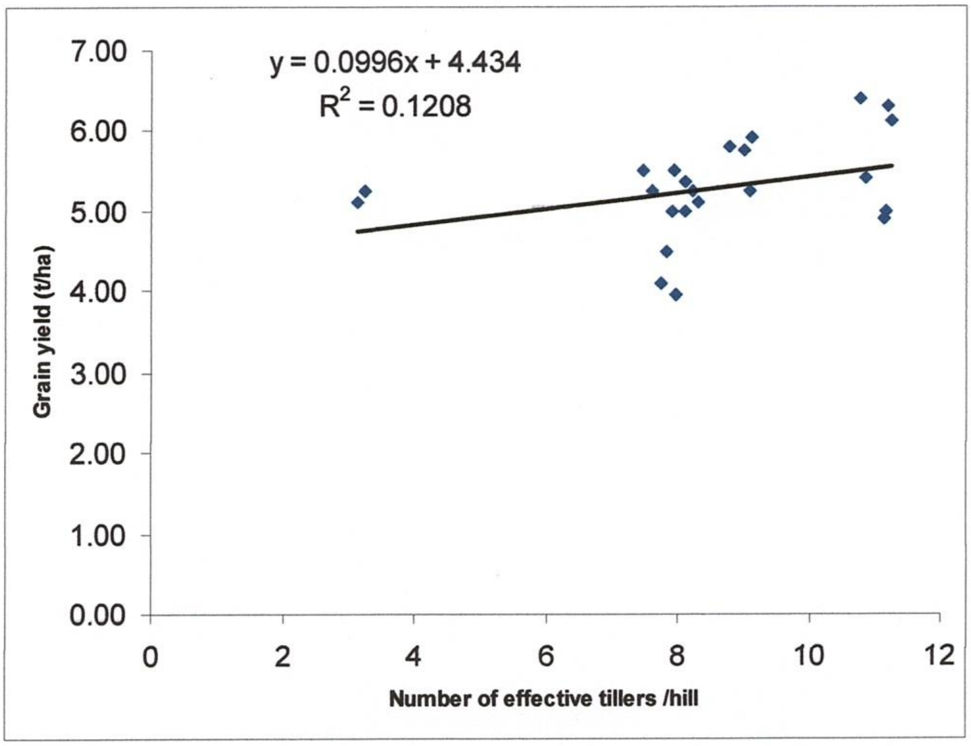

Fig 4.21 Relationship Between Number of Effective Tillers/hill and Grain yield of *Boro* Rice

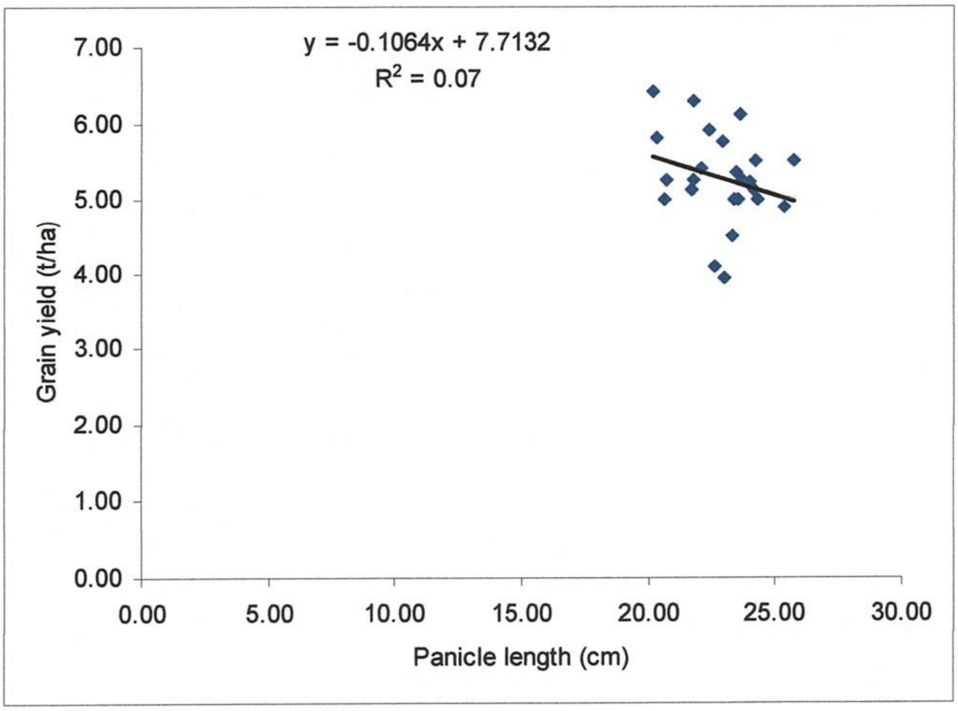

Fig 4.22 Relationship between Panicle Length and Grain Yield of *Boro* Rice

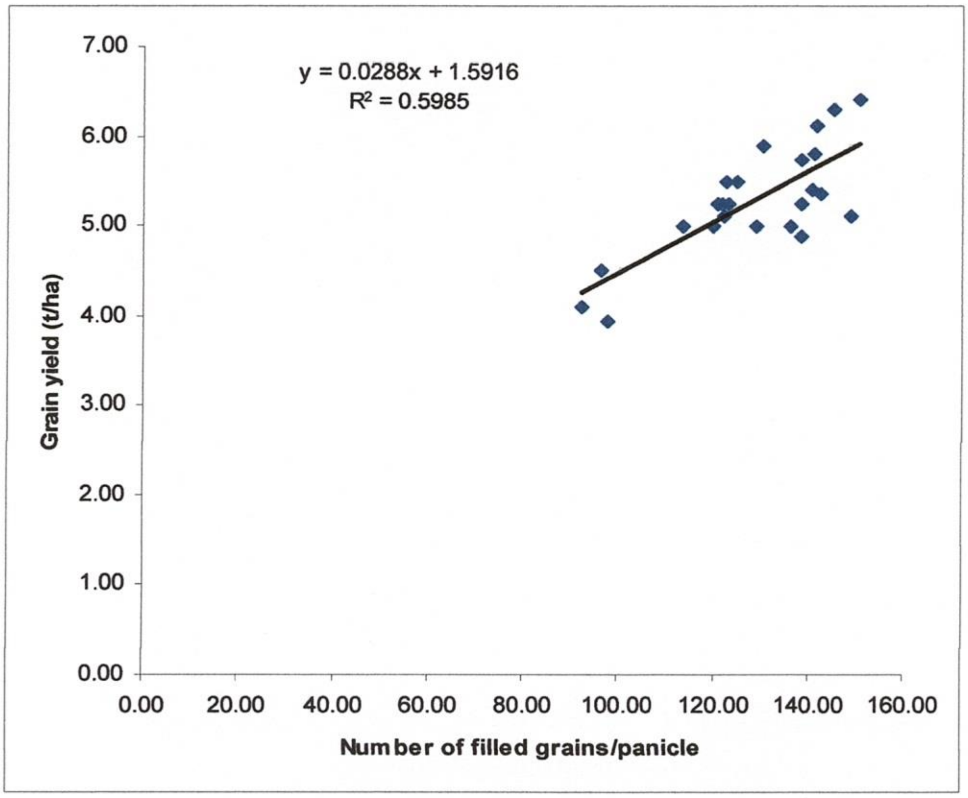

Fig 4.23 Relationship between no. of Filled Grains/Panicle and Grain Yield of *Boro* Rice

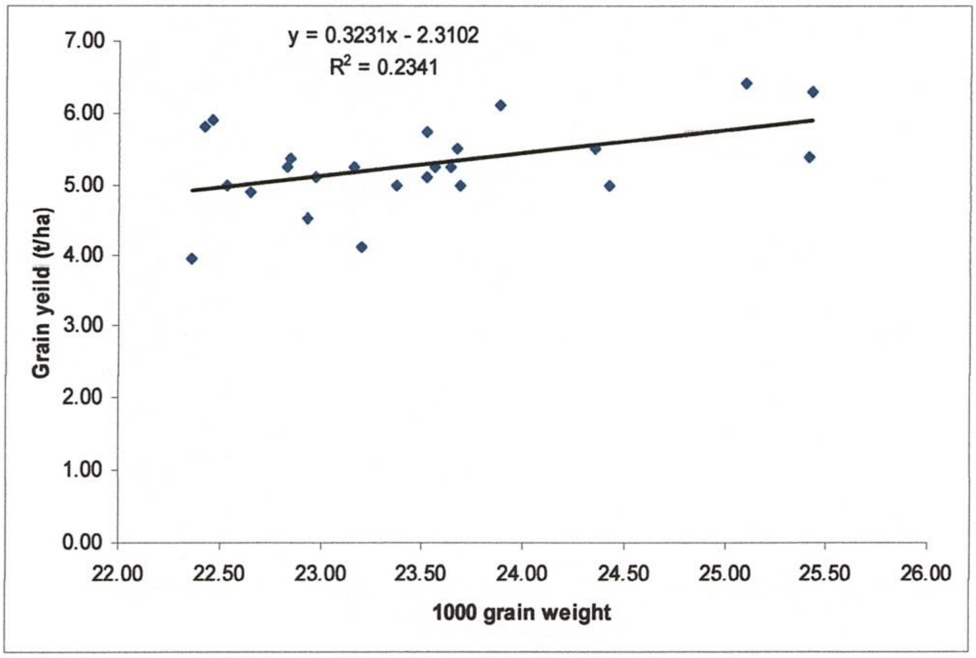

Fig 4.24 Relationship between 1000 grain weight and grain yield of *Boro* rice

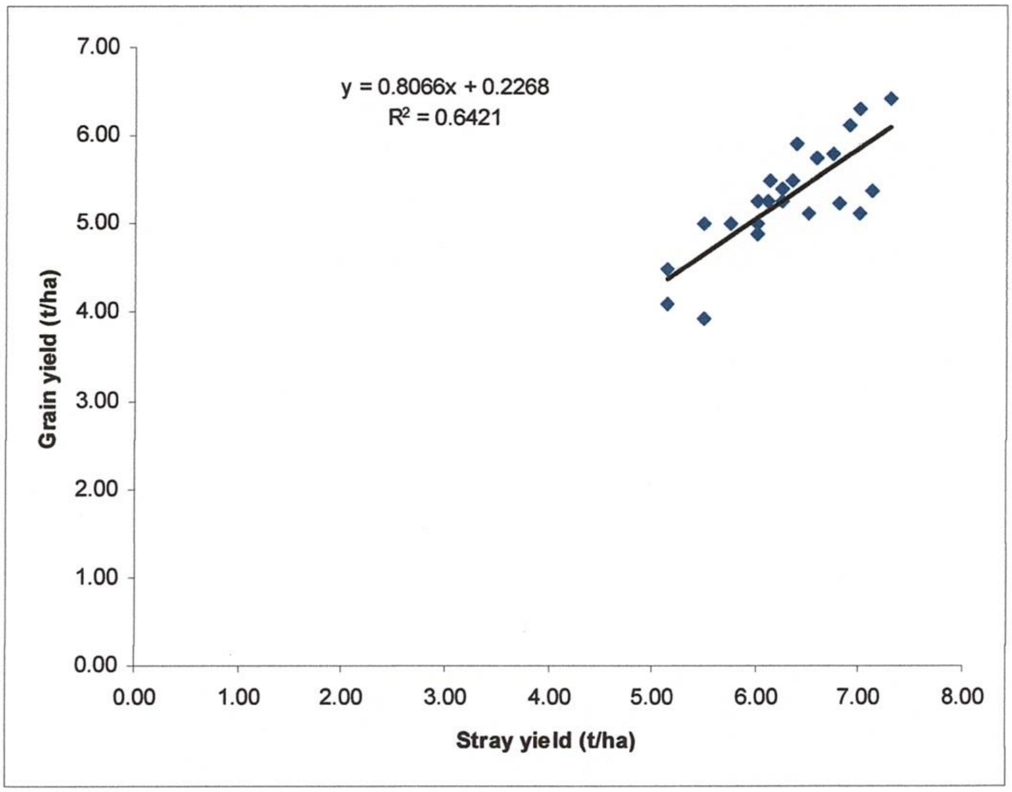

Fig 4.25 Relationship between Straw Yield and Grain Grain yield of *Boro* Rice

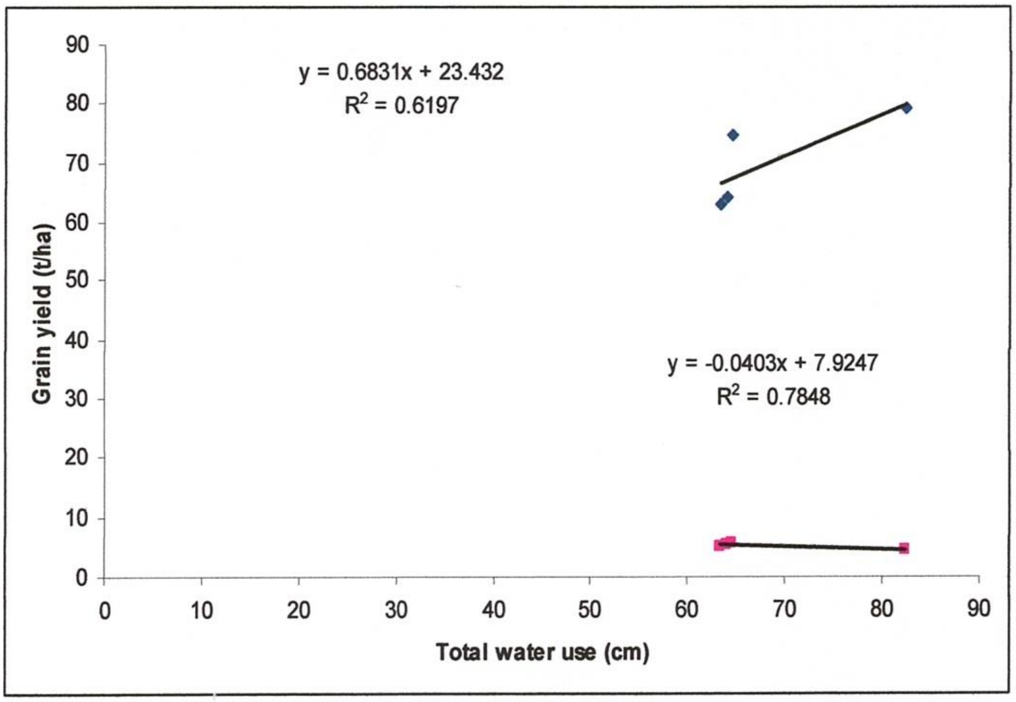

Fig 4.26 Relationship between Total Water Used and Grain Yield of *Boro* Rice

Experiment 3: Assessment of Alternate Wetting and Drying Water Management in Rice Cultivation.

4.3.1 Climatological Data

Total rainfall of growing period was 475.8 mm (Table 4.12). It was found that in 2011 growing season January to May, the maximum rainfall occurred in the month of May 227.4 mm and the minimum rainfall occurred March 72.8 mm.

The minimum and maximum temperature ranged from 33.48 to 23.65 °C and 23.0 to 10.31 °C in 2011, respectively. The maximum temperature 33.48 °C was observed in April and the minimum 10.31 °C in January in 2011 respectively.

The highest percentage of relative humidity was recorded at 9 am and the lowest at 2 pm in the experimental year as shown in Table 4.12. The highest monthly average relative humidity of 72.74% was found in May 9 am in 2011 and the lowest 45.7 % in February in 2011, respectively.

Table 4.12. Monthly Maximum and Minimum Temperatures, Rainfall and Humidity During Rice-Growing Seasons at the BRRI Farm, Gazipur, in 2011.

Month	Year 2011				
	Monthly total RF(mm)	Monthly av. cm.(0C)		Monthly av. RH (%)	
		Max.	Min.	9.00 am	2.00 pm
January	Nill	23.65	10.31	84.28	55.05
February	Nill	28.90	14.54	74.6	45.7
March	72.2	31.54	19.25	73.54	51.93
April	176.2	33.48	21.18	79.93	62.43
May	227.4	31.52	23.0	82.83	72.74

Source: Plant physiology Division, BRRI, Gazipur.

4.3.2 Seepage and Percolation (S&P) and Evapotranspiration (ET)

Seepage & percolation (S&P) and Evapotranspiration (ET) are given in Table 4.13 The experiment has been carried out in *Boro* season which started with in December and ended in May.

In 2011 *Boro* season, S&P were 5.22, 5.24 and 5.21 mm/day; at vegetative, reproductive and ripening stages of the crop. The result revealed that the highest mean S&P of 5.24 mm/day was obtained from reproductive stage and the lowest mean S&P of 5.21 mm/day was found in ripening stage. This is in agreement with that of found at Gazipur , in silty clay soil, seepage and percolation was varied from 5 to 7 mm/day between 3 to 5 cm standing water depth (BRRI, 1987).

In 2011 *Boro* season, ET were 3.90, 3.91 and 4.00 mm/day at vegetative, reproductive and ripening stages of the crop. The result revealed that the highest mean ET of 4.00 mm/day was found at ripening stage and the lowest mean ET of 3.90 mm/day was found at vegetative stage in the year of 2011. Saleh and Fatema (1988) and Kasem (2003-2004) who found that ET varied from 3.59 to 4.61 mm/day in dry season and 3.03 to 4.54 mm/day in wet season.

Table 4.13. Seepage and Percolation (S&P) and Evapotranspiration (ET) of the Experimental Plots During *Boro* Seasons 2011.

Season	S&P(mm/day)				ET(mm/day)			
	Veg.	Rep.	Rip.	Mean	Veg.	Rep.	Rip.	Mean
Boro 2011	5.22	5.24	5.21	5.22	3.90	3.91	4.00	3.93

Table 4.14 Total no. of irrigation required for different irrigation treatments

Treatment	*No. of Irrigation		Rainfall+ water for crop established (cm)	Total water required(cm)	
	BRRIdhan36	BRRI hybrid2		BRRI dhan36	BRRI hybrid2
T_1	14	14	72.58	107.96	107.96
T_2	9	9	72.58	66.72	66.72
T_3	8	8	72.58	58.68	58.68
T_4	7	7	72.58	55.16	55.16

*One irrigation means application of 5 cm irrigation water

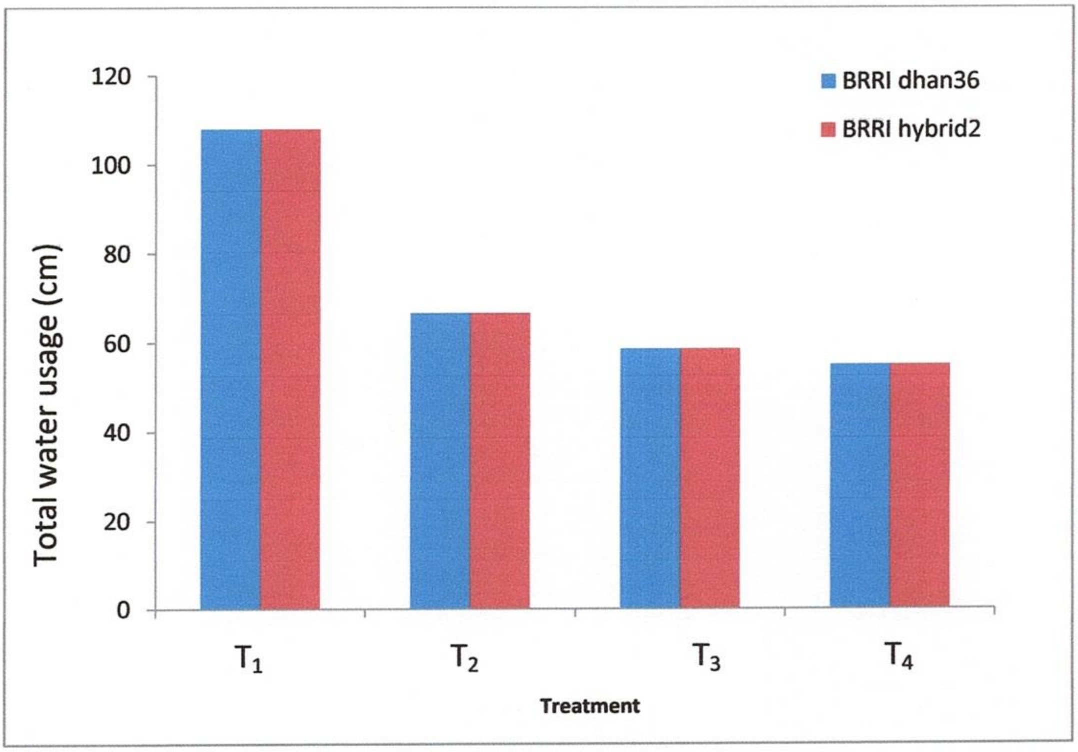

Fig.4.27 Water usage of Different Treatment for the Production BRRI dhan28 and BRRI hybrid2

4.3.3 Irrigation Treatments (AWDI)

Irrigation treatments were applied at different stages of the growing period depending on the depletion of the water level in the perforated pipe. The very first treatment stated at the end of the fourth week after transplantation. During this time 5 cm standing water was kept to avoid weed infestation in the plots table 4.14 shows that the highest number of irrigation (14 nos.) was given to the plots with Treatment T_1 (continuous flooding) for BRRI dhan36, the other three treatments viz., T_2, T_3 and T_4 received a total of 9, 8 and 7 number of irrigation for BRRI dhan36 while 9, 8 and 7 number of irrigation for BRRI hybrid2, respectively. Water required for crop establishment and water received from the rainfall was estimated to be 72.58 cm during the growing period for each of the treatments. for BRRI hybrid2, maximum amount of water (107.96 cm) was required for T_1, while, second maximum (66.12 cm) for T_2 was followed by other two treatments, T_3 (58.68 cm) and T_4 (55.16 cm). The graphical representation of water usage by different treatments after transplantation is shown in Table 4.14 (fig.4.27).

4.3.4 Varietal performance for plant characters' and yields of two transplant rice

The effect of variety was significant for the all the plant character under study including yield and yield attributes components (Appendix VII, VIII). The varietal performance for those characters' and yields are presented in appendix VII).

4.3.5 Plant Height

The analysis showed that varietal effect on plant height was statistically significant at 1% probability level. The tallest plant (99.78 cm) was found in BRRI hybrid2 (V_1). The shortest plant (94.88 cm) was found in BRRI dhan36 (V_2). Variation in plant height might be due to the differences in the genetic make –up of the varieties. The result is in consistent with findings of Shamsuddin *et. al.*, (1988) who also reported a variable plant height existed among the varieties.

4.3.6 Number of Total Tillers Hill^{-1}

The highest number of total tillers hill^{-1} (12.39) was found in BRRI hybrid2 and the lowest number of total tiller was found (8.11) in BRRI dhan36. Variable effects of variety on number of total tillers hill^{-1} were also reported by Hossain *et al.*, (1989a) who noted that number of total tillers hill^{-1} differed among the varieties. The variation in number of total tillers hill^{-1} might be due to varietal characteristics.

4.3.7 Number of Effective Tillers Hill^{-1}

Number of effective tillers hill^{-1} was statistically significant at 1 % level of probability (Appendix VII). The highest number of effective tillers (9.50) was found in BRRI hybrid2 and the lowest number of effective tiller hill^{-1} (7.24) was found in BRRI dhan36.

4.3.8 Number of Non-Effective Tillers Hill^{-1}

Number of non-effective tillers hill^{-1} was statistically significant at 1 % level of probability (Appendix VII).The highest number of non-effective tillers (2.90) was found in BRRI hybrid2 and the lowest number of non-effective tiller hill^{-1}(0.88) was found in BRRI dhn36.

4.3.9 Panicle Length

The highest length of panicle (22.79 cm) was found in BRRI hybrid2. The lowest length of panicle was (18.33 cm) in BRRI dhan36. Varietal differences regarding the panicle length might be due to their differences in genetic make-up.

4.3.10 Number of Filled Grains Panicle^{-1}

Number of filled grains panicle^{-1} was statistically significant at 1% level of probability (Appendix VII). The results showed that the highest filled grain (105.65) was achieved from BRRI hybrid2. The lowest grain yield (87.00) was achieved from BRRI dhan36.These differences occurred due to variations of genetic make-up among the varieties.

4.3.11 Number of Unfilled Grains Panicle^{-1}

Number of unfilled grains panicle^{-1} was statistically significant at 1% level of probability (Appendix VII).The highest number of unfilled grains panicle^{-1} (61.74) was found in BRRI hybrid2. The lowest number of unfilled grains (24.01) panicle^{-1} was found from BRRI dhan36.

4.3.12 Weight of 1000 Grains

The result showed that the highest weight of 1000-grain (20.95 g) was obtained from BRRIdhan36. The lowest weight of 1000-grain (20.63 g) was obtained from BRRI hybrid2.

4.3.13 Grain Yield

Grain yield was statistically significant at 1% level of probability. The highest grain yield (6.11 t/ha) was achieved from BRRI hybrid2. The lowest grain yield (4.09 t/ha) was achieved from BRRI dhan36. These differences occurred due to variations of genetic make-up among the varieties. Dwivedi (1997) and BRRI (2000) also reported similar result.

4.3.14 Straw Yield

The result revealed that the highest straw yield (6.60 t ha^{-1}) was found from BRRI hybrid2. The lowest straw yield (4.96 t ha^{-1}) was found from BRRI dhan36.The highest yield occurred due to higher plant height, higher total tiller $hill^{-1}$ and lower number non-effective tiller $hill^{-1}$. These results are consistent with those obtained by Chowdhury *et al.,* (1993) who reported differences in straw yield among varieties.

4.3.15 Biological Yield

The highest biological yield (12.71 t ha^{-1}) was obtained from BRRI hybrid2 and the lowest one (9.05 t ha^{-1}) was obtained from BRRI dhan36.

4.3.16 Harvest Index

Maximum harvest index (48.01%) was obtained from BRRI hybrid2 and the minimum harvest index (45.17 %) was obtained from BRRI dhan36.

4.3.17 Effects of Growth Stages on some Morphological Parameters under Different Water Management

4.3.18 Plant Height

The analysis showed that varietal effect on plant height was statistically non - significant at 1% or 5% probability level. The tallest plant (98.20cm) was found at vegetative stage. The shortest plant (96.50 cm) was found at reproductive stage.

4.3.19 Number of Total Tillers Hill^{-1}

The highest number of total tillers hill^{-1}(10.71) was found at vegetative stage and the lowest number of total tiller was found (9.68) at ripening stage.

4.3.20 Number of Effective Tillers Hill^{-1}

Number of effective tillers hill^{-1} was statistically significant at 1 % level of probability (Appendix VIII). The highest number of effective tillers (8.72) was found at vegetative stage and the lowest number of effective tiller hill^{-1}(7.88) was found at reproductive stage.

4.3.21 Number of Non-Effective Tillers Hill^{-1}

The highest number of non-effective tillers (1.99) was found at vegetative stage and the lowest number of non-effective tiller hill^{-1}(1.80) was found at ripening stage.

4.3.22 Panicle Length

The highest length of panicle (22.06 cm) was found Ripening stage. The lowest length of panicle was (19.77 cm) at reproductive stage.

4.3.23 Number of Filled Grains Panicle^{-1}

Number of filled grains panicle^{-1} was statistically significant at 1% level of probability (Appendix VIII). The results showed that the highest filled grain

(100.42) was achieved from vegetative stage. The lowest grain yield (92.51.) was achieved from reproductive stage. These differences occurred due to variations of genetic make-up among the varieties.

4.3.24 Number of Unfilled Grains Panicle^{-1}

Number of unfilled grains panicle^{-1} was statistically significant at 1% level of probability (Appendix VIII).The highest number of unfilled grains panicle $^{-1}$ (45.95) was found at ripening stage. The lowest number of unfilled grains (40.45) panicle^{-1} was found from vegetative stage.

4.3.25 Weight of 1000 Grains

The result showed that the highest weight of 1000- grain (22.35 g) was obtained from vegetative stage. The lowest weight of 1000-grain (18.31 g) was obtained from ripening stage.

4.3.26 Grain Yield

Grain yield was statistically significant at 1% level of probability. The highest grain yield (5.69 t/ha) was achieved from vegetative stage. The lowest grain yield (4.31 t/ha) was achieved from ripening stage. These differences occurred due to variations of genetic make-up among the varieties. Dwivedi (1997) and BRRI (2000) also reported similar result.

4.3.27 Straw Yield

The result that the highest straw yield (5.92 t ha^{-1}) was found from reproductive stage. The lowest straw yield (5.57 t ha^{-1}) was found from ripening stage.

4.3.28 Biological Yield

The highest biological yield (11.53 t ha^{-1}) was obtained from vegetative stage and the lowest one (9.88 t ha^{-1}) was obtained from ripening stage.

4.3.29 Harvest Index

Maximum harvest index (49.41%) was obtained from vegetative stage and the minimum harvest index (43.21 %) was obtained from ripening stage.

4.3.30 Effect of Varieties and Different Growth Stages on Some Morphological Parameters under Alternate wetting and drying Water Management

4.3.30.1 Plant Height

The analysis showed that varietal effect on plant height was statistically significant at 5% probability level. The tallest plant (100.33cm) was found at reproductive stage with variety BRRI hybrid2. The shortest plant (92.66 cm) was found at reproductive stage with variety BRRI dhan36. Variation in plant height might be due to the differences in the genetic make –up of the varieties. The result is in consistent with findings of Shamsuddin *et. al.*, (1988) who also reported a variable plant height existed among the varieties.

4.3.30.2 Number of total Tillers Hill^{-1}

The highest number of total tillers hill^{-1}(13.33) was found at vegetative stage with V_1 and the lowest number of total tiller was found (7.63) at reproductive stage with V_2. Variable effects of variety on number of total tillers hill^{-1} were also reported by Hossain *et al.,* (1989a) who noted that number of total tillers hill^{-1} differed among the varieties. The variation in number of total tillers hill^{-1} might be due to varietal characteristics.

4.3.30.3 Number of Effective Tillers Hill^{-1}

Number of effective tillers hill^{-1} was statistically significant at 1 % level of probability (Appendix IX). The highest number of effective tillers (9.92) was found at vegetative stage with V_1 and the lowest number of effective tiller hill^{-1} (6.56) was found at reproductive stage V_2.

4.3.30.4 Number of Non-Effective Tillers Hill^{-1}

Number of effective tillers hill^{-1} was statistically significant at 1 % level of probability (Appendix IX). The highest number of non-effective tillers (3.41) was found at vegetative stage with V_1 and the lowest number of non-effective tiller hill^{-1} (0.98) was found at ripening stage V_2.

4.3.30.5 Panicle Length

Number of effective tillers hill^{-1} was statistically significant at 1 % level of probability (Appendix I). The highest length of panicle (23.53 cm) was found Ripening stage V_1. The lowest length of panicle was (16.63 cm) at vegetative stage V_2.

4.3.30.6 Number of Filled Grains Panicle^{-1}

Number of filled grains panicle^{-1} was statistically significant at 1% level of probability (Appendix IX). The results showed that the highest filled grain (116.08) was achieved from vegetative stage with V_1. The lowest grain yield (94.42.) was achieved from ripening stage with V_2. These differences occurred due to variations of genetic make-up among the varieties.

4.3.30.7 Number of Unfilled Grains Panicle^{-1}

Number of unfilled grains panicle^{-1} was statistically significant at 1% level of probability (Appendix IX). The highest number of unfilled grains panicle^{-1} (69.95) was found at ripening stage with V_1.The lowest number of unfilled grains (21.95) panicle^{-1} was found from reproductive stage V_2.

4.3.30.8 Weight of 1000 Grains

The result showed that the highest weight of 1000- grain (22.84 g) was obtained from vegetative stage. The lowest weight of 1000-grain (18.31 g) was obtained from ripening stage and ripening stage.

4.3.30.9 Grain Yield

Grain yield was statistically significant at 1% level of probability. The highest grain yield (6.68 t/ha) was achieved from vegetative stage with BRRI hybrid2. The lowest grain yield (3.45 t/ha) was achieved from ripening stage with BRRI dhan36. These differences occurred due to variations of genetic make-up among the varieties. Dwivedi (1997) and BRRI (2000) also reported similar result.

4.3.30.10 Straw Yield

The result revealed that the highest straw yield (7.13 t ha^{-1}) was found from reproductive stage V_1. The lowest straw yield (4.72 t ha^{-1}) was found from reproductive stage V_2.

4.3.30.11 Biological Yield

The highest biological yield (13.63 t ha^{-1}) was obtained from reproductive stage V_1 and the lowest one (8.63 t ha^{-1}) was obtained from ripening stage V_2.

4.3.30.12 Harvest Index

Maximum harvest index (49.97%) was obtained from vegetative stage with V_1 and the minimum harvest index (40.02 %) was obtained from ripening stage V_2.

4.3.31 Effect of Different Growth Stages and Irrigations Treatments on Yield and Yield Contributing Characters.

4.3.31.1 Plant Height

The analysis showed that effect on plant height was statistically non-significant at 1% probability level. The tallest plant (103.40cm) was found in the combination effect of VeT_2. The shortest plant (86.00 cm) was found in the combination effect of ReT_4 (Fig.4.28).

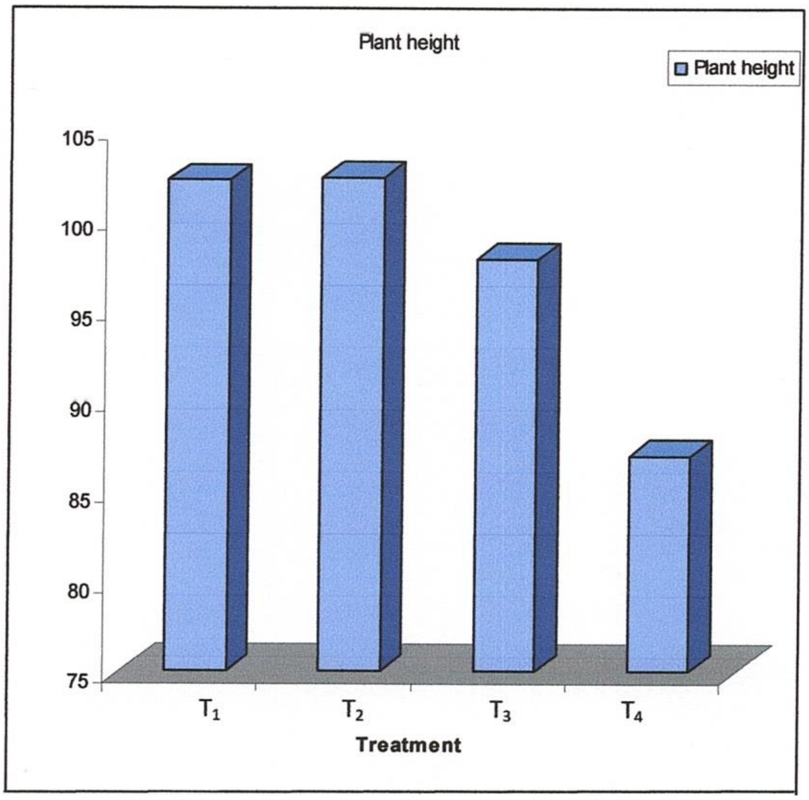

Fig 4.28. Variation in Plant Height for Different Degrees of Irrigation Treatments and Stages

4.3.31.2 Number of total Tillers Hill^{-1}

The analysis showed that effect of treatments on tillers hill^{-1}were statistically significant at 1% probability level. The highest number of total tillers hill^{-1} (12.88) was found in the combination effect of VeT_2 and the lowest number of total tiller (7.70) was found in the combination effect of ReT_4.

4.3.31.3 Number of Effective Tillers Hill^{-1}

Number of effective tillers hill^{-1} was statistically significant at 5 % level of probability (Appendix XII). The highest number of effective tillers (10.55) was found in the combination effect of VeT_2 and the lowest number of effective tiller hill^{-1} (6.38) was found in the combination effect of ReT_4.

4.3.31.4 Number of Non-Effective Tillers Hill^{-1}

The highest number of non-effective tillers (3.80) was found in the combination effect of VeT_1 and the lowest number of non-effective tiller hill^{-1} (0.73) was found in the combination effect of VeT_4.

4.3.31.5 Panicle Length

The highest length of panicle (22.85 cm) was found from in the combination effect of RiT_4. The lowest length of panicle was found (18.38 cm) in the combination effect of VeT_3.

4.3.31.6 Number of Filled Grains Panicle^{-1}

Number of filled grains panicle^{-1} was statistically significant at 1% level of probability (Appendix XII). The results showed that the highest filled grain (125.33) was achieved from the combination effect of RiT_2. The lowest grain yield (69.04) was achieved from the combination effect of ReT_4.

4.3.31.7 Number of Unfilled Grains Panicle^{-1}

Number of unfilled grains panicle^{-1} was statistically significant at 1% level of probability (Appendix I).The highest number of unfilled grains panicle $^{-1}$ (58.83) was found in the combination effect of ReT_4. The lowest number of unfilled grains (20.80) panicle^{-1} was found from in the combination effect of RiT_2.

4.3.31.8 Weight of 1000 Grains

The result showed that the highest weight of 1000- grain (24.15 g) was obtained from the combination effect of ReT_1. The lowest weight of 1000-grain (12.67 g) was obtained from the combination effect of RiT_3.

4.3.31.9 Grain Yield

Grain yield was statistically significant at 1% level of probability. The highest grain yield (6.55 t/ha) was achieved from the combination effect of VeT_2. The lowest grain yield (3.67 t/ha) was achieved from the combination effect of RiT_4.

4.3.31.10 Straw Yield

The result revealed Shows that the highest straw yield (6.73 t ha^{-1}) was found from the combination effect of VeT_2. The lowest straw yield (5.06 t ha^{-1}) was found from the combination effect of VeT_4.

4.3.31.11 Biological Yield

The highest biological yield (13.28 t ha^{-1}) was obtained from the combination effect of VeT_2 and the lowest one (8.87 t ha^{-1}) was obtained from the combination effect of RiT_4.

4.3.31.12 Harvest Index

Maximum harvest index (50.66%) was obtained from the combination effect of VeT_4 and the minimum harvest index (41.29 %) was obtained from the combination effect of RiT_4.

4.3.32 Effect of Alternate Wetting and Drying Water Management on Yield and Yield Contributing Characters of Two Rice Varieties.

4.3.32.1 Plant Height

The analysis showed that effect on plant height was statistically significant at 1% probability level. The tallest plant (102.35cm) was found in treatment T_2 (3 days dry at vegetative, reproductive and ripening stages). The shortest plant (86.96 cm) was found in treatment T_4 (7 days dry at vegetative, reproductive and ripening stages). Variation in plant height might be due to the differences in the genetic make –up of the varieties. The result is in consistent with findings of Shamsuddin *et. al.,* (1988) who also reported a variable plant height existed among the varieties. The interaction between varieties and treatments as shown in appendix X also produced significant results for plant height at the 5% level of probability. The highest plant height (108.79 cm) was observed from the combination effects V_1T_2. (Fig.4.29).

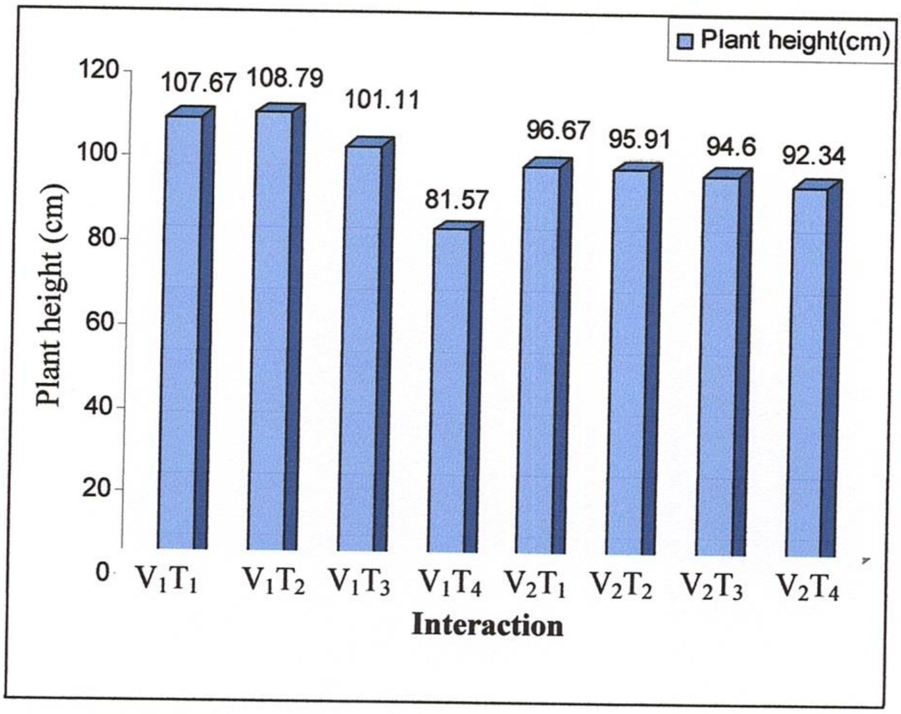

Fig. 4.29 Variation in Plant Height (cm) for Different Interactions Between Variety and Treatments

4.3.32.2 Number of Total Tillers Hill^{-1}

The analysis showed that effect treatments on tillers hill^{-1} were statistically significant at 1% probability level. The highest number of total tillers hill^{-1} (11.79) was found in treatment T_2 (3 days dry at vegetative, reproductive and ripening stages) and the lowest number of total tiller (7.71) was found in treatment T_4 (7 days dry at vegetative, reproductive and ripening stages).

4.3.32.3 Number of Effective Tillers Hill^{-1}

Number of effective tillers hill^{-1} was statistically significant at 5 % level of probability (Appendix X).The highest number of effective tillers (10.07) was found in treatment T_2 and the lowest number of effective tiller hill^{-1} (7.06) was found in treatment T_4 (Fig. 4.30).

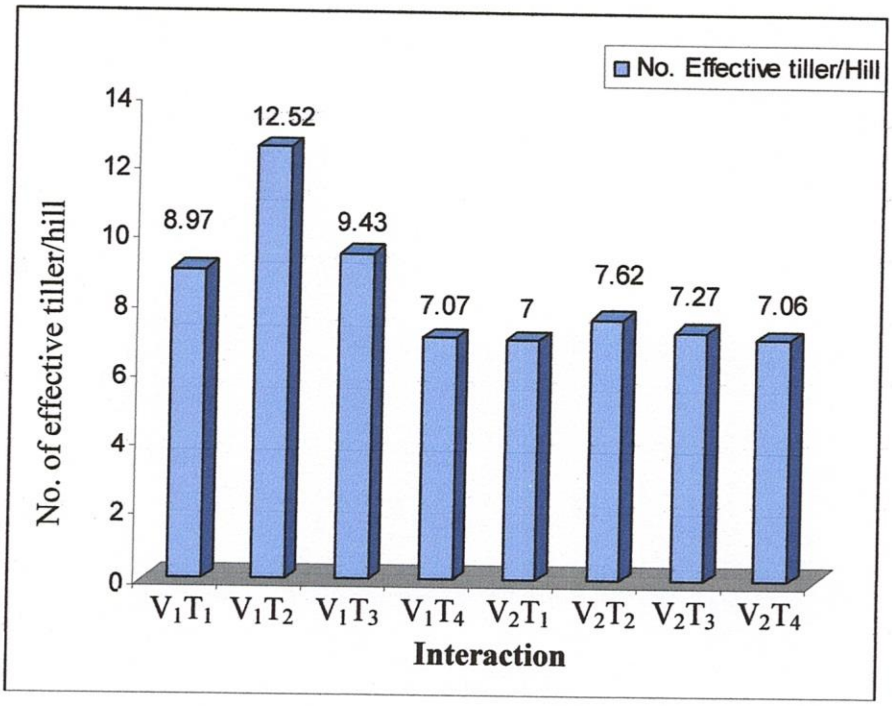

Fig. 4.30 Variation in Number of Effective Tiller/Hill for Different Interactions Between Variety and Treatments

4.3.32.4 Number of Non-effective Tillers Hill^{-1}

The highest number of non-effective tillers (3.57) was found treatment T_1 at and the lowest number of non-effective tiller hill^{-1}(1.08) was found in treatment T_4.

4.3.32.5 Panicle Length

The highest length of panicle (21.07 cm) was found from treatment T_1. The lowest length of panicle was found (20.02 cm) in treatment T_3.

4.3.32.6 Number of Filled Grains Panicle^{-1}

Number of filled grains panicle^{-1} was statistically significant at 1% level of probability (Appendix X). The results showed that the highest filled grain (119.86) was achieved from treatment T_2. The lowest grain yield (78.83) was achieved from T_4 (Fig. 4.31).

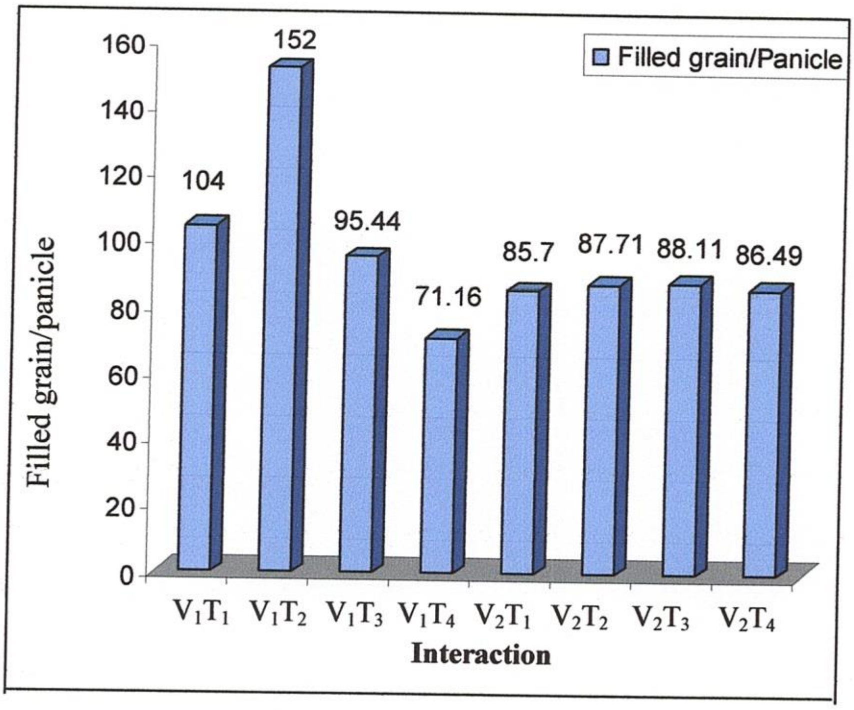

Fig. 4.31 Variation in Filled Grain/Panicle for Different Interactions Between Variety and Treatments

4.3.32.7 Number of Unfilled Grains Panicle^{-1}

Number of unfilled grains panicle^{-1} was statistically significant at 1% level of probability (Appendix X).The highest number of unfilled grains panicle^{-1} (57.56) was found in treatment T_4. The lowest number of unfilled grains (21.53) panicle-1 was found from T_2 (Appendix X).

4.3.32.8 Weight of 1000 Grains

The result showed that the highest weight of 1000- grain (23.55 g) was obtained from T_1. The lowest weight of 1000-grain (18.21 g) was obtained from T_3.

4.3.32.9 Grain Yield

Grain yield was statistically significant at 1% level of probability. The highest grain yield (5.86 t/ha) was achieved from treatment T_2 (3 days dry at vegetative, reproductive and ripening stages). The lowest grain yield (4.45 t/ha) was achieved fromT_4 (7 days dry at vegetative, reproductive and ripening stages) (Fig. 4.32).

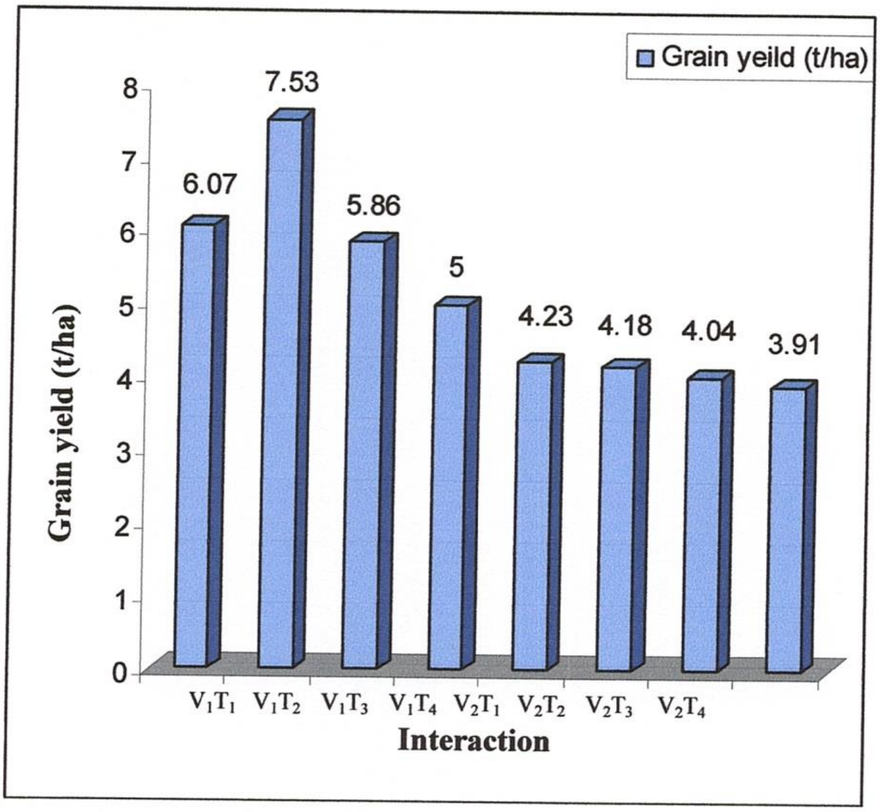

Fig. 4.32 Variation in Grain Yield (t/ha) for Different Interactions Between Variety and Treatments

4.3.32.10 Straw Yield

The result finds Shows that the highest straw yield (6.48 t ha^{-1}) was found from treatment T_2. The lowest straw yield (5.13 t ha^{-1}) was found from T_4. The interactions between variety and treatments as shown in appendix XI produced significant results for at the 1% level of probability. The highest straw yield was achieved from the combination effect of V_1T_2 (Fig. 4.33).

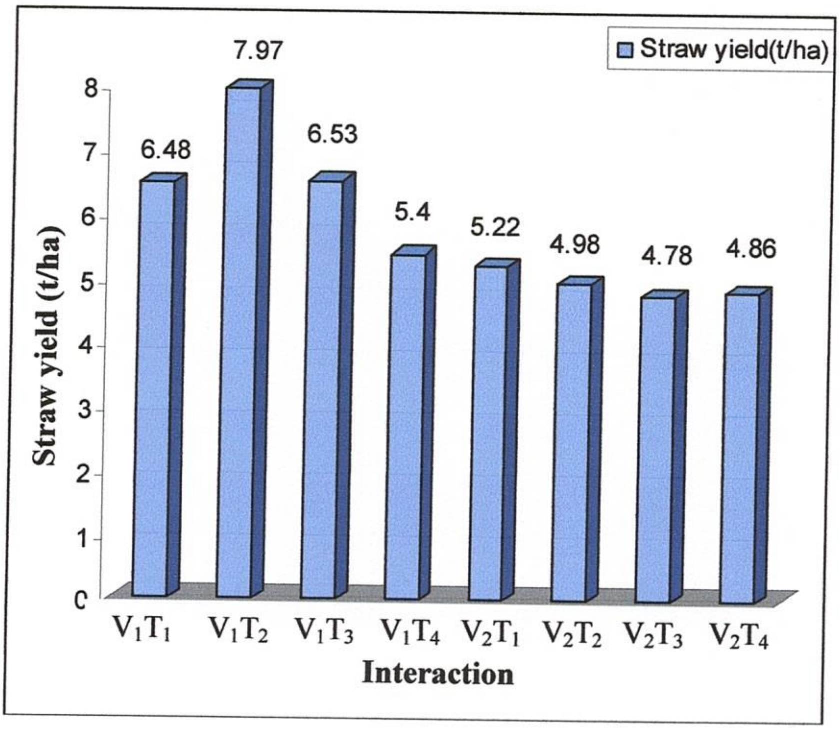

Fig. 4.33 Variation in Straw Yield (t/ha) for Different Interactions between Variety and Treatments

4.3.32.11 Biological Yield

The highest biological yield (12.33 t ha^{-1}) was obtained from Treatment T_2 and the lowest one (9.58 t ha^{-1}) was obtained from treatment T_4.

4.3.32.12 Harvest Index

Maximum harvest index (47.00%) was obtained from treatment T_2 and the minimum harvest index (46.14 %) was obtained from treatment T_4.

4.3.33 Effect of Varieties and Irrigation Treatments on Yield and Yield Contributing Characters at Two Rice Varieties.

4.3.33.1 Plant Height

The analysis showed that varietal effect on plant height was statistically significant at 5% probability level. The tallest plant (108.79cm) was found in treatment T_2

with BRRI hybrid2. The shortest plant (81.57 cm) was found in treatment T_4 with BRRI hybrid2.

4.3.33.2Number of Total Tillers Hill^{-1}

The highest number of total tillers hill^{-1} (15.12) was found in treatment T_2 with V_1 and the lowest number of total tiller was found (7.71) in T_4 with V_2.

4.3.33.3 Number of Effective Tillers Hill^{-1}

Number of effective tillers hill^{-1} was statistically significant at 1 % level of probability (Appendix XI). The highest number of effective tillers (12.52) was found in treatment T_2 with V_1 and the lowest number of effective tiller hill^{-1}(7.00) was found in treatment T_1 with V_2.

4.3.33.4 Number of Non-effective Tillers Hill^{-1}

Number of effective tillers hill^{-1} was statistically significant at 1 % level of probability (Appendix XI). The highest number of non-effective tillers (6.10) was found in treatment T_1 with V_1 and the lowest number of non-effective tiller hill^{-1} (1.03) was found in T_1 with V_2.

4.3.33.5 Panicle Length

Number of effective tillers hill^{-1} was statistically significant at 1 % level of probability (Appendix XI).

The highest length of panicle (24.13 cm) was found in T_1 with V_1. The lowest length of panicle was (17.92 cm) in T_4 with V_2.

4.3.33.6 Number of Filled Grains Panicle^{-1}

Number of filled grains panicle^{-1} was statistically significant at 1% level of probability (Appendix XI).The results showed that the highest filled grain (152.00) was achieved from T_2 with V_1. The lowest grain yield (71.16.) was achieved from

T_4 with V_1. These differences occurred due to variations of genetic make-up among the varieties.

4.3.33.7 Number of Unfilled Grains Panicle^{-1}

Number of unfilled grains panicle^{-1} was statistically significant at 1% level of probability (Appendix XI).The highest number of unfilled grains panicle^{-1} (89.00) was found in T_4 with V_1. The lowest number of unfilled grains (20.31) panicle^{-1} was found from T_2 with V_1.

4.3.33.8 Weight of 1000 Grains

The result showed that the highest weight of 1000- grain (24.20 g) was obtained from T_1 with V_2. The lowest weight of 1000-grain (18.21 g) was obtained from T_1 and T_3 with V_1 and V_2 also.

4.3.33.9 Grain Yield

Grain yield was statistically significant at 1% level of probability. The highest grain yield (7.53 t/ha) was achieved from T_2 with BRRI dhan36. The lowest grain yield (3.91 t/ha) was achieved from T_4 with V_2.

4.3.33.10 Straw Yield

The result shows that the highest straw yield (7.97 t ha^{-1}) was found from T_2 with V_1. The lowest straw yield (4.78 t ha^{-1}) was found from T_3 with V_2.

4.3.33.11 Biological Yield

The highest biological yield (15.51 t ha^{-1}) was obtained from T_2 with V_1 and the lowest one (8.77 t ha^{-1}) was obtained from T_4 with V_2.

4.3.33.12 Harvest Index

Maximum harvest index (48.54%) was obtained from T_2 with V_1 and the minimum harvest index (44.54 %) was obtained from T_3 with V_2.

4.3. 34. Interaction Effect of Treatment, Variety and Growth Stages on Yield and Yield Contributing Characters of Two Rice Varieties.

4.3. 34.1 Plant Height

The analysis showed that effect on plant height was statistically non-significant at 1% or 5 % probability level. The tallest plant (109.00cm) was found in the interaction $V_1 \times Re \times T_2$. The shortest plant (79.37 cm) was found in the interaction effect of $V_1 \times Ri \times T_4$.

4.3. 34.2 Number of Total Tillers Hill^{-1}

The analysis showed that effect treatments on tillers hill^{-1} were statistically non-significant at 1% probability level. The highest number of total tillers hill^{-1} (16.67) was found in the interaction effect of V_2VeT_2. The lowest number of total tiller (7.07) was found in the interaction effect of V_2ReT_4.

4.3. 34.3 Number of Effective Tillers Hill^{-1}

Number of effective tillers hill^{-1} was statistically non-significant at 5 % level of probability (Appendix XIII). The highest number of effective tillers (13.00) was found in the interaction effect of V_1VeT_2 and the lowest number of effective tiller hill^{-1}(6.10) was found in the interaction effect of V_2ReT_4.

4.3. 34.4 Number of Non-effective Tillers Hill^{-1}

The highest number of non-effective tillers (6.60) was found from the V_1VeT_1 and the lowest number of non-effective tiller hill^{-1}(0.23) was found in the interaction V_2VeT_3.

4.3. 34.5 Panicle Length

The highest length of panicle (25.50 cm) was found in the interaction effect of $V_1 \times Ri \times T_1$. The lowest length of panicle was found (15.33 cm) in the interaction effect of V_2ReT_4.

4.3. 34.6 Number of Filled Grains Panicle^{-1}

Number of filled grains panicle-1 was statistically significant at 1% level of probability (Appendix XIII).The results showed that the highest filled grain (153.67) was achieved from the interaction effect of V_1RiT_2. The lowest grain yield (60.09) was achieved from the interaction effect of V_1ReT_4. (Fig. 4.34)

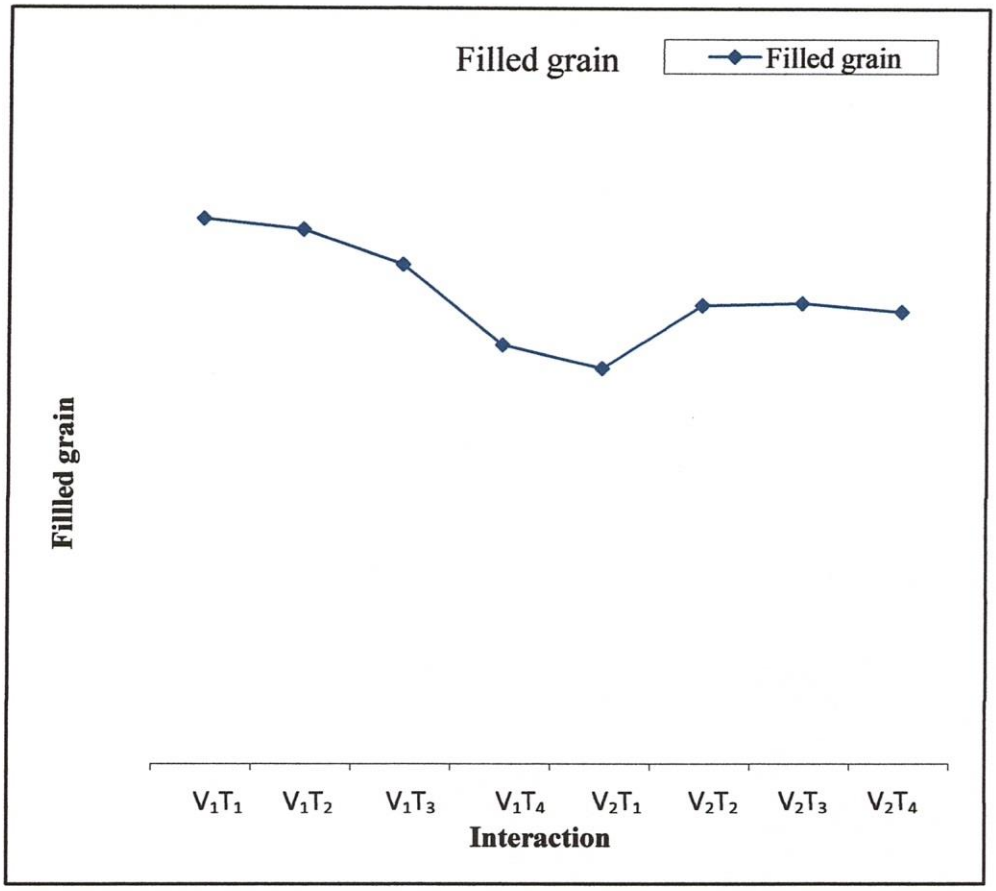

Fig. 4.34 Variation in filled grain for different degrees of variety and irrigation treatments

4.3. 34.7 Number of Unfilled Grains Panicle^{-1}

Number of unfilled grains panicle^{-1} was statistically significant at 1% level of probability (Appendix XIII).The highest number of unfilled grains panicle^{-1} (92.67) was found from the interaction effect of $V_1R_iT_4$. . The lowest number of unfilled grains (20.00) panicle^{-1} was found from the interaction effect of V_1ReT_2.

4.3. 34.8 Weight of 1000 Grains

The result showed that the highest weight of 1000- grain (25.10 g) was obtained from the interaction effect of V_2RiT_1.The lowest weight of 1000-grain (16.54 g) was obtained from the interaction effect of $V_1R_iT_2$.

4.3. 34.9 Grain Yield

Grain yield was statistically significant at 1% level of probability. The highest grain yield (8.13 t/ha) was achieved from the interaction effect of V_1VeT_2. The lowest grain yield (3.37 t/ha) was achieved from the interaction effect of $V_2R_iT_4$.

This result proved that alternate wetting and drying irrigation at vegetative stage do not reduce grain yield.

4.3. 34.10 Straw Yield

The figures show that the highest straw yield (8.51 t ha^{-1}) was found from the interaction effect of V_1ReT_2. The lowest straw yield (4.46 t ha^{-1}) was found from the interaction effect of V_2VeT_3.

4.3. 34.11Biological Yield

The highest biological yield (16.37 t ha^{-1}) was obtained from the interaction effect of V_1ReT_2 and the lowest one (8.37 t ha^{-1}) was obtained from the interaction effect of $V_2R_iT_1$.

4.3. 34.12 Harvest Index

Maximum harvest index (51.75%) was obtained from the interaction effect of V_1VeT_4 and the minimum harvest index (38.64 %) was obtained from the interaction effect of $V_2R_iT_4$.

4.3.35 Water Use Efficiency

There were significant differences between two varieties with respect to total water use. The highest amount of water supplied (107.96cm) for the both varieties BRRI dhan36 and BRRIhybrid2 as shown in Table 4.15. Water use efficiencies for the individual effect of different treatments were derived along with the values of WUE for the 8 interactions between treatments and varieties (Table 4.15). The highest water use efficiency, WUE was found to be 90.76 kg/ha/cm ($V_1 \times T_2$ and $V_2 \times T_2$). The lowest WUE 84.70 kg/ha/cm was obtained in the treatment T_3 for V_2 and V_1.

This result is in conformity with the findings of Sharma (1987), Dubey (1995) and Sandhu *et al.,* (1980) who reported that under intermittent flooding condition less water was required as compared to continuous flooding for rice cultivation which resulted in higher water productivity of the crop. Water productivity was found to be the highest (0.0523t/ha/cm) in treatment T_3 (irrigation 5 days disappearance of standing) followed by treatment T_4 (0.0461) (irrigation 7 days disappearance of standing water) and a minimum of 0.0333 t/ha/cm treatment T_1 (continuous flooding). From these results, it can be seen that the water productivity decreased with the increase of irrigation water (Fig. 4.35).

Table 4.15 Water Use Efficiency for Different Treatments and Interactions

Interactions	Total water required (cm)	Water applied (cm)	Grain Yield (ton/ha)	Water use efficiency (kg/ha/cm)	Treatments	Average total water required(cm)	Average grain yield (ton/ha)	Water use efficiency kg/ha/cm)	Water productivity (t/ha/cm)
V_1T_1	107.96	121.58	4.06	88.79	T_1	107.96	4.59	88.79	0.0333
V_1T_2	106.72	117.58	4.98	90.76					0.0423
V_1T_3	104.68	123.58	4.96	84.70	T_2	106.72	5.57	90.76	0.0401
V_1T_4	104.16	117.58	5.21	88.58					0.0443
V_2T_1	107.96	121.58	5.12	88.79	T_3	104.68	5.33	84.70	0.0421
V_2T_2	106.72	117.58	6.16	90.76					0.0523
V_2T_3	104.68	123.58	5.70	84.70	T_4	104.16	5.15	88.58	0.0461
V_2T_4	104.16	117.58	5.09	88.58					0.0432

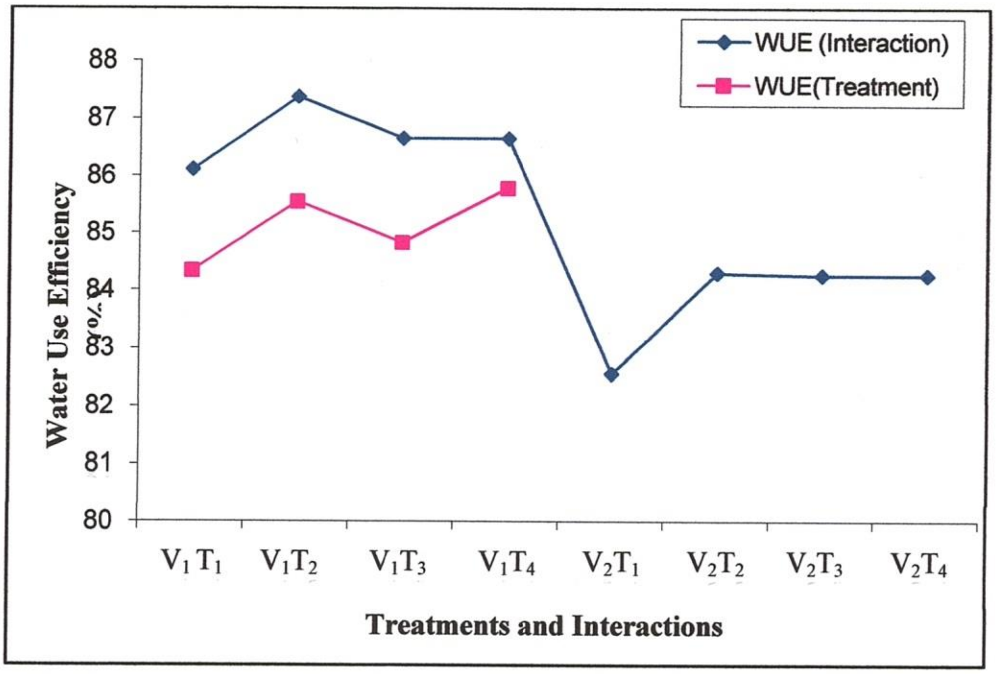

Fig.4.35 Water usage of Different Treatment for the Production BRRI hybrid2 and BRRI dhan36.

4.3.36 Regression

All the parameters discussed above, no doubt, altogether contribute to the yield of rice. Figures of all the parameters, in combination, are considered to be the most significant basis for the physical characterization of the possible output that may result in consequence of an agronomic experiment. For this reason, all these parameters are termed as the yield contributing characters. Simple regression analysis can relate each of these yields contributing character with the grain yield from which important parameters affecting the grain yield as well as their correlation with the output can be identified

Table 5.16 shows the correlation coefficients of relationships between yield contributing characters and grain yield. It shows that grain yield was positively correlated with number of effective tillers per hill (R^2 = 0.634), length of panicle (R^2 = 0.1779) number of filled grains per panicle (R^2 = 0.4968), 1000 grain weight (R^2 = 0.017), straw yield (R^2 = 0.714), and total water use (R^2 = 1.00 for BRRI dhan29 and R^2 = 0.1126 for BRRI hybrid2) as shown in Figures 4.36, 4.37, 4.38, 4.39, 4.40 and 4.41, respectively. Regression analysis revealed that increases in plant height, numbers of effectives tillers per hill; length of panicle number of filled grains per panicle, 1000 to grain weight, straw yield was correlated with the corresponding increase in grain yield.

Table 4.16 Regression Analyses and the Coefficient of Determination Between Various Yield Contributing Characters vs. Grain Yield.

Characters		**Coefficient of determination, R^2**	**Reference**
No. of effective tillers/hill vs. grain yield		0.634	Fig. 4.36
Length or panicle vs. grain yield		0.1779	Fig. 4.37
No. of filled grains/panicle vs. grain yield		0.4968	Fig. 4.38
1000 to grain weight vs. grain yield		0.017	Fig. 4.39
Straw yield vs. grain yield		0.714	Fig. 4.40
Total water use vs. grain yield	BRRI dhan 29	1.00	Fig. 4.41
	BRRI hybrid 2	0.1126	Fig. 4.41

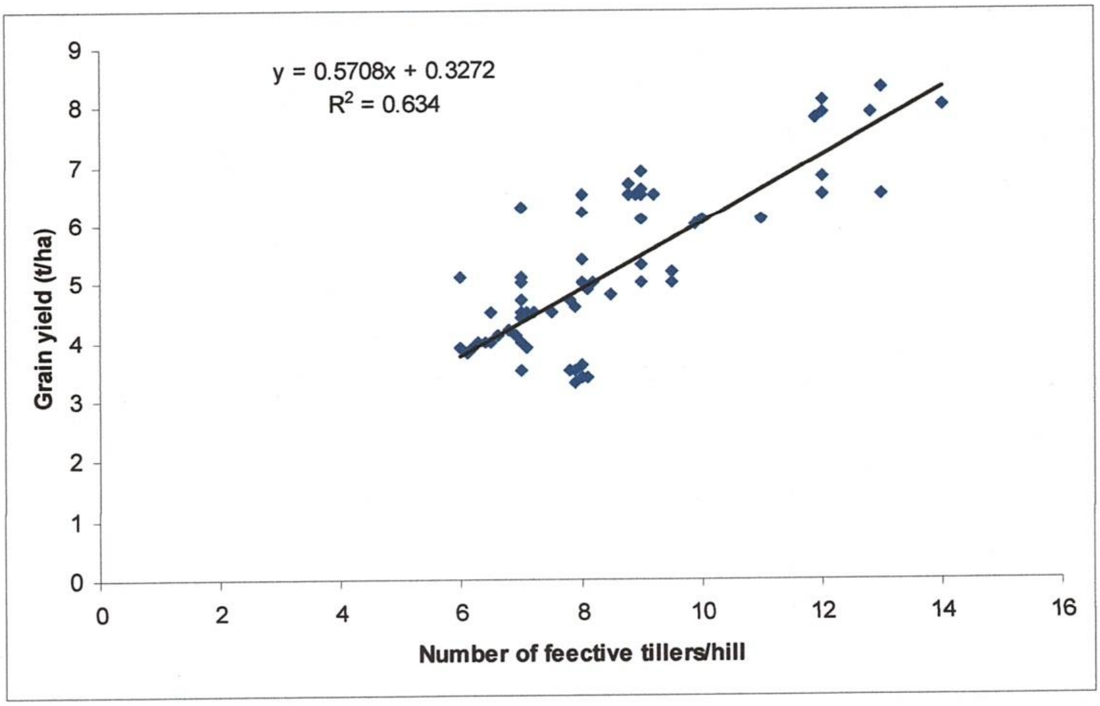

Fig 4.36 Relationship between Number of Effective Tillers/Hill and Grain Yield of *Boro* Rice

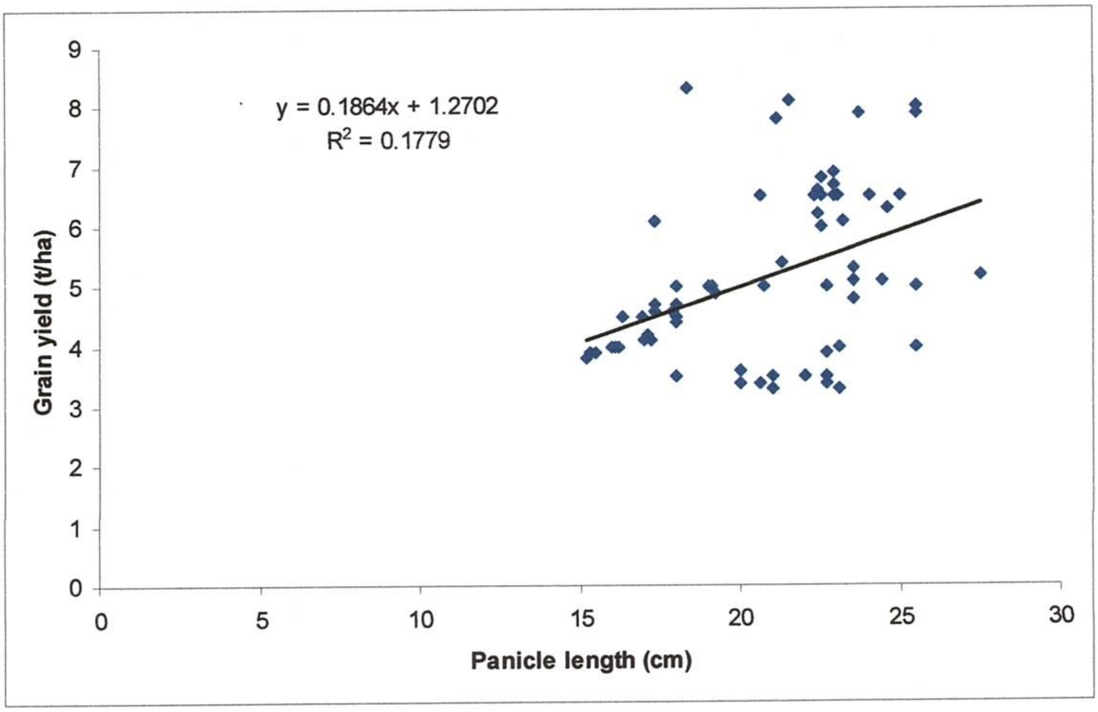

Fig 4.37. Relationship Between Panicle Length and Grain Yield of *Boro* Rice

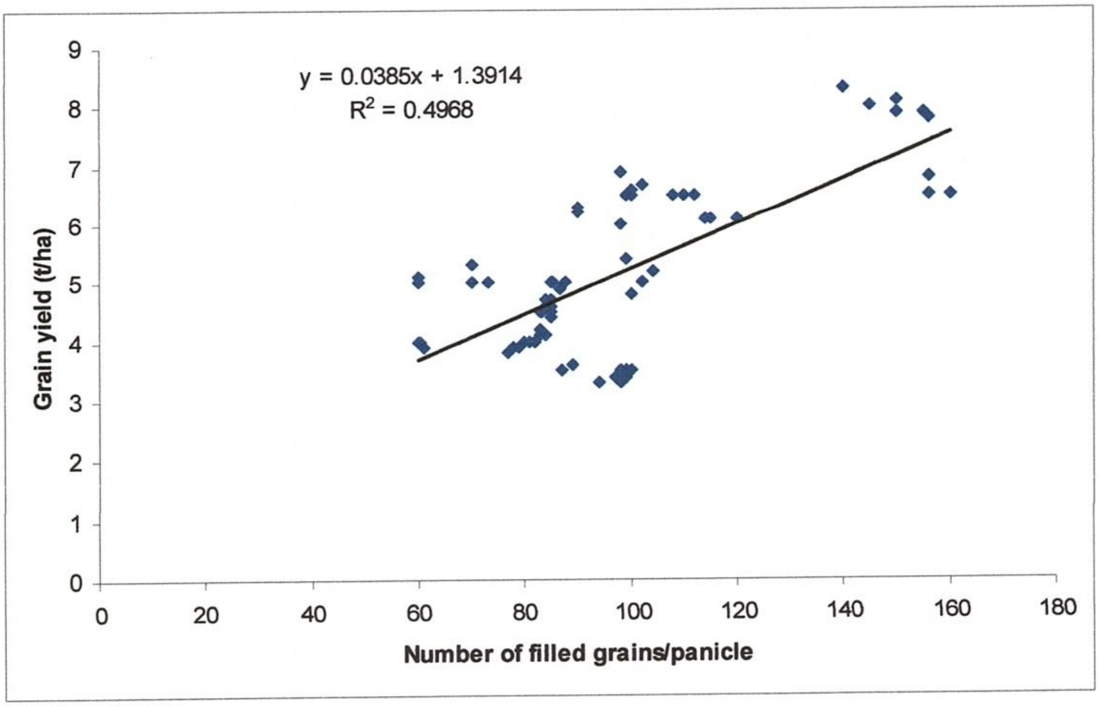

Fig 4. 38. Relationship between Number of Filled Grains/Panicle and Grain Yield of *Boro* Rice

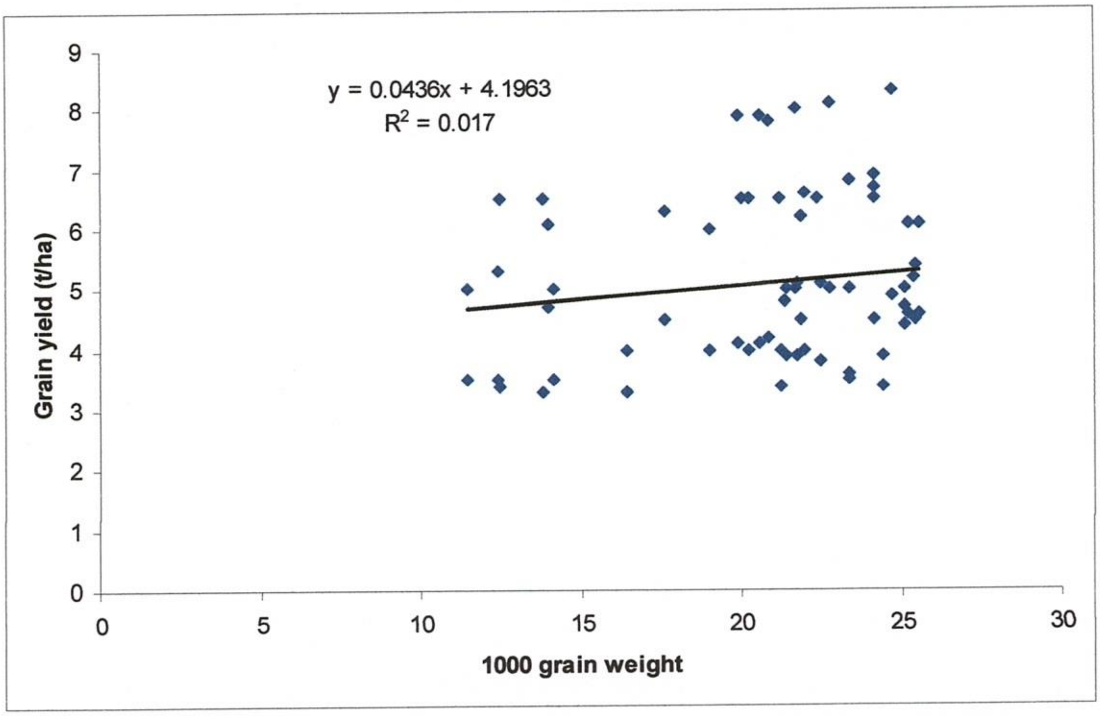

Fig 4.39. Relationship Between 1000 Grain Weight and Grain Yield of *Boro* Rice

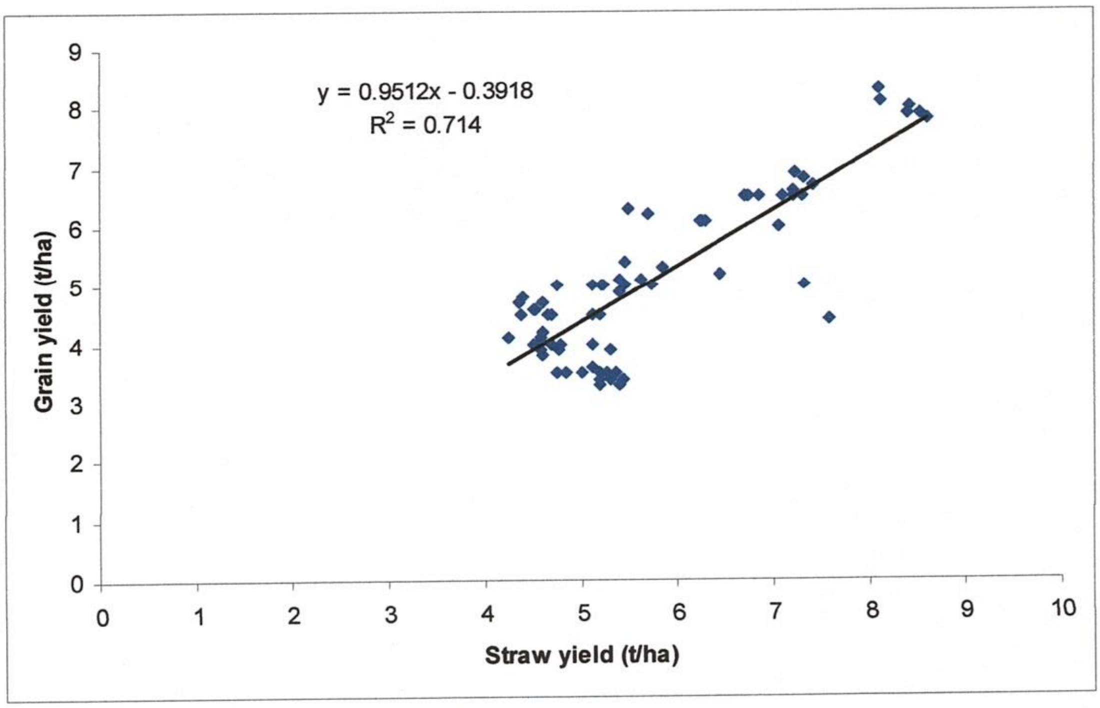

Fig 4.40. Relationship between Straw Yield and Grain Yield of *Boro* Rice

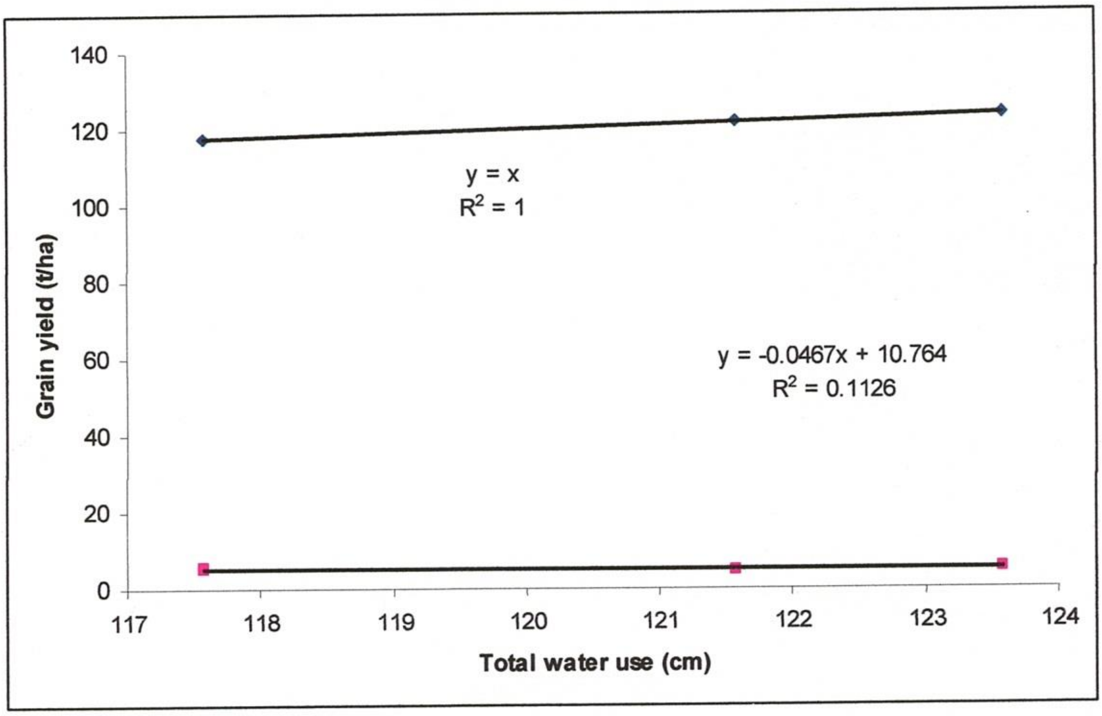

Fig 4.41. Relationship between Total Water Used and Grain Yield of *Boro* Rice

Experiment 4: Adoption of Water-Saving Irrigation Techniques for Sustainable Rice Production in Bangladesh

4.4.1 Results and Discussion

The mean farm size of the samples from both sites ranged from 0.66 to 0.68 hectare (Table 4.17). The samples have more or less similar socioeconomic characteristics as shown by the similar magnitudes of their age, farm size, family size and level of education. In total, 70% and 76% of the non-adopters of Gazipur and Rajshahi district did not receive any training on AWD. On average, farmers from AWD and Non- AWD have annual incomes of about 1,26,734 and 1,02216 taka respectively. In the field survey, farmers were able to discern water scarcity as a problem during the *Boro* season in both study regions. Also, among the control group of farmers, 82% confirmed that water scarcity occurs during the *Boro* season. The problem of water scarcity is particularly severe in Rajshahi Division, the high number of interviewees (39%) who identified groundwater shortages as their main problem of irrigation.

Table 4.17 Basic Farm and Household Characteristics of Sampled AWD Users and Non-AWD User Farmers for Both Sites

	Rajshahi		Gazipur	
	AWD	NON-AWD	AWD	NON-AWD
Number of sample	30	30	30	30
Mean farm size (hectare)	0.66	0.68	0.69	0.67
Mean household size	4.2	4.3	4.1	4.0
Mean age of farmers (Years)	35.42	39.51	37.38	40.26
Mean education of the farmer	9.1	8.5	8.98	7.70
Farmers' training (% of yes)	67	30	56	24
Extension facilities (% of yes)	88	52	82	32
Water scarcity	86	60	75	52
Proportion of Non-farm income share	0.72	0.41	0.88	0.52
% of rice crop area	82	65	94	51
% of active members in the family	56	52	65	59
Satisfaction about the quality of the extension service (% of satisfied households)	32	12	26	11
Dissemination through demonstration (No. of times)	1.5	0.6	1.1	0.5
Land quality type (good =1, otherwise 0)	50	32	46	36
Member of any social organization (%)	73	56	75	52
Total household income (TK)	128,810	99,078	124,658	105,354

The main purpose of this study is to explore the important factors that influence farmers' decisions to adopt Alternative Wetting and drying (AWD) technology. To this end, we performed Logit regression analysis. The results of the Logit regression model estimating factors influencing adoption of AWD technology are presented in (Table 4.18). The fit of the data was statistically significant at ($P < 0.001$), While the Nagelkerke $R^2 = 0.63$. These results shows that the overall model is significant and the explanatory variables used in the model are collectively able to explain the farmers' decisions regarding the adoption of AWD technology. The independent variables included in the model have been described here.

Table 4.18 Socio-Economic Factors Influencing Adoption of AWD Technology

Variable	Notation	Coefficient	Standard error	P>|z|
Constant		8.909	3.043	0.053
Experience	X_1	0.119	0.077	0.113
Education of household head	X_2	1.844**	0.777	0.018
Farm size	X_3	3.388*	0.407	0.065
Contact with extension agents	X_4	2.341***	0.856	0.004
Farmers' training	X_5	1.631	0.955	0.320
Water scarcity	X_6	0.243*	0.102	0.023
Rice crop area (1, if rice crop area is more than non-rice crop area)	X_7	0.573*	0.303	0.080
Dissemination through demonstration	X_8	0.639*	0.2910	0.028
Land quality or type (plain =1, otherwise 0)	X_9	0.363***	0.127	0.004
Regional Dummy (1, if Gazipur, otherwise, 0)	X_{10}	1.070	0.665	0.112

Source: Field survey 2012

Negelkerke $R^2 = 0.63$, * Significant at 10% level of significance, ** Significant at 5% level of significance, *** Significant at 1% level of significance

4.4.2 Experience

Normally aged farmers are experienced than young farmers. Though it is not significant but during field study, the observation was experienced farmers who were cultivating rice since 20 years or more, more interested and progressive to receive the AWD technology. The coefficient of farming experience 0.119 ($P< 0.10$) indicates that, holding other variables constant, if years of farming experience increase by a unit, on the average, the logit of the odds in favor of AWD irrigation technology sole increase by 0.119 units. The effect of farming experience on adoption of AWD irrigation technology could be due to the farmer's managerial ability, sincerity and understanding of the potentials of the AWD irrigation technology as a result of many years of farming.

4.4.3 Education

The result shows that the adoption of AWD significantly increased ($p<0.01$) as the years of education increase, which implies educated farmers are more motivated to adopt AWD technology. Exposure to education may increase farmers' ability to obtain, process, and use information relevant to the adoption of AWD technology. Education thus is thought to increase the probability that a farmer will adopt AWD technology. Lawal *et al.,* (2004) reported similar findings revealing that exposure to education increases farmer's ability to obtain process and use information relevant to adopt IRM for increased yield. The coefficient of education was expected positive to decrease risk aversion behavior and increase the rate of adoption.

4.4.4 Farm size

Farm size is an indicator of wealth and it can be thought of as a proxy for social status and influence within a community. A larger farm size is expected to be positively associated with the decision to adopt AWD technology. Farm size is another important factor that is statistically significant at 1% level of significance. It indicates that larger farm size is more likely to adopt AWD irrigation technology. Feeder *et al.*, (1985) stated that, the positive and significant coefficient of farm size indicates its positive influence in adoption new technology. They said it may be because the farm size is a surrogate for a large number of factors such as size of wealth, access to credit, capacity to bear risk, access to information and other factors.

Farm size can also encourage farmers to intensify agricultural production, in which case, a larger farm size is expected to be negatively related to the adoption of improved maize technology. Haque (2011) found that too small and too large farm size decreases farmers' efficiency. Hoque (1988) found that a farm size between 7 and 12 acres is the most efficient (overall efficiency) in the contest of Bangladesh agriculture.

4.4.5 Farmers' Training

Training sessions play a key role for successfully disseminating any new technology to farmers and assuring later adoption. It was hypothesized that attending in a training program about irrigation would have strong positive impact on the likelihood of AWD adoption. But it did not happen in our research.

Most farmers have received training very recently. From the non adopters who received training, mostly, explained that they did not receive adequate training or did not understand AWD. All types of farmers frequently criticized about the duration of training which is too short (maximum half an hour). On the other hand, most training sessions took place only once. Even most field officers agreed that to really understand AWD, more sessions would be necessary. Another major factor for not adopting the technology is connected to the timing of the training. Of the farmers, who did not adopt AWD, some of them criticized that the training starts too late in the season. When training was received in February or March, they were not able to effectively apply AWD anymore during that season. Kürschner *et. al.,* (2010) stated about training approach that was found in the field was a one-off training session that was given to unorganized groups on several irrigation matters i.e. on field days. Despite the advantages of raising awareness of AWD quickly and cost effectively and among many farmers, this kind of training does not support experience-based learning. In our case, it is also true that training does not necessarily increase adoption rates of AWD.

4.4.6 Water Scarcity

The result shows that farmers, who face water scarcity, adopt AWD technology. It was found that 86% farmers at Gazipur and 75% farmers at Rajshahi region faced water scarcity. Either they have financial problem, so that they are not or their plots are very far from the water source. On the other hand, in most cases, non adopters are owners of shallow tube wells or they can get water supply very easily. So, the scarcity of water is not only about the water source but also about the cost of irrigation. Kürschner *et. al.,* (2010) mentioned that farmers and pump-owners of the northern region of Bangladesh consider that high irrigation prices are a problem for irrigation. They also pointed that though there is a physical water scarcity; water is rather considered to be an economically scarce resource in the region. The problem of water scarcity in Bangladesh very often, is basically linked to the chronically deficient electricity supply. Practically all DTWs and many STWs are run with electricity. Bottlenecks in power supply therefore form a central obstacle for farmers in obtaining irrigation water in time.

Excursus: Farmers' view on water scarcity and Allah

"It is about Allah. Allah is angry with us. [...] 20 years ago, there were no water problems during monsoon season. You could find water everywhere! But in the last 2 years there has been an extreme water scarcity as it has rained very little. And this year it is even worse. There has not been any drinking water in my tube well for over 4 days. [...] If there is no rain then everything will be dry. When there is no water, the government cannot do anything. Not everything can be bought with money, in some cases we have to rely on nature. Allah is everything! If he wants to give us something, he will give it to us. We human beings cannot do anything against Allah. We must pray to him.

For some farmers the water situation is so drastic that they are considering discontinuing rice cultivation in the future. Many adopter farmers mentioned that farmers have to cope with an erratic electricity supply. In the northern region, continuous electricity supply sometimes lasts for just 10 minutes, while the overall electricity supply might last for only three hours each day. The lack of electricity is considered as the foremost problem of rice cultivation in both study regions by farmers

In contrast to electricity, fuel presents a much more secure but expensive source of energy for irrigation. Farmers also explained that fuel is sometimes hard to come by as distances to markets are far and fuel is not always available.

4.4.7 Area Allocated to Rice

Farmers, who allocate their land mostly for rice, are more conscious to adopt AWD technology. It may be due to the fact that if they fail to receive expected production, they have to suffer for the whole year. Therefore, to get sufficient amount of water at appropriate time, they want to adopt any new technology so that they can be ensured about water.

4.4.8 Contact With Extension Agents

Agricultural extension services provided by the Ministry of Agriculture are the major source of agricultural information in the study area. It is hypothesized that contact with extension workers will increase farmers' likelihood of adopting AWD technologies. The organizations involved in extension and development activities deploy staff at local level. This field staff must be able to take on the responsibility of conveying the knowledge about AWD and to convince water users to actually apply the new technology. The role of extension staff was also confirmed by the responses of farmers during the survey. It has been found that farmers who have frequent contacts with extension agents had higher probability to adopt AWD irrigation technology than those who are not connected with extension agents. When asked whose advice they trusted most, close to half of the farmers who did not receive training on AWD generally rely on extension staff when they have problems.

The result also suggested that in adoption of AWD irrigation technology could be motivated by frequent contacts with extension agents. Extension agents popularizes AWD irrigation technology adoption by making farms exchange idea, experiences, and makes it cheaper to source information, knowledge and skills in order to enable farmers to improve their livelihood.

4.4.9 Land Quality

Land is also an important factor to adopt AWD technology. During the study period, it was observed that farmers those who have plot in plain land, would like to learn the technology and interested to adopt compared to sloppy lands. It may be the reason that in plain land, water would stand that is not possible at the sloppy land.

4.4.10 Dissemination Through Demonstration Plots

The adoption process of AWD in Bangladesh is still in its early stages. Most of the farmers applied the technology for the first time in the 2010 or 2011. A large share of them started after conducting AWD demonstrations instructed by BRRI and DAE. In light of our results above, insights from studies about the flexible implementation of AWD (such as this one) need to be effectively disseminated to rice producers through extension and outreach programs.

For demonstration purposes, progressive leader farmers usually implemented an AWD-plot alongside a conventionally irrigated plot. This enabled farmers to test AWD on a small plot and to directly compare respective costs and benefits. The prerequisites for the plot itself were that it had to be close to the road, easily accessible and near a pumping system. The rice field is used as the learning tool as it combines both learning sessions in the field and follow-up support (FAO, 2007). Demonstration plots were often set up during Farmer Field Days and ended by organizing local crop-cutting ceremonies during harvesting, inviting the farmers of the area to join the AWD validation. Thus, the information on the results of the testing are passed on to a larger audience. The disseminating organizations usually supplied farmers with "demonstration packages" that included different field inputs and AWD pipes. Several goals are pursued with the set up of demonstration plots. Farmers can test the new technology through hands-on-experience and can learn how to use it. Using the "model-farmer" approach, normally small-scale farmers would follow the lead farmers, having the benefit of observing the application of AWD. Demonstration plots help to inform farmers, to start discussions about the technology and to help spread the news to other groups and villages. The result shows that the approach with demonstration plots was very successful as it allowed farmers to acquire an understanding of the technology. There is also group approach to disseminate AWD technologies. Farmers within the groups seem to be encouraged to share experiences with the new packages provided to farmers often consisted inputs such as seeds, fertilizers, pesticides and tools to measure the water level (AWD tube), depending on the resources of the organizations.

However, extension staff mostly expressed doubts that AWD - as a knowledge intensive technology - will spread based on farmers' observations only. The desired "snow-ball effect", of neighboring farmers taking over the technology from the model farmers might not work as desired.

Chapter 5

Conclusions

Chapter 5

Conclusions

The results of this research support the thesis that alternate wetting and drying treatment (known elsewhere as alternately flooded and drained, intermittent flooded and dry, or alternately submerged and no submerged) improves water use efficiency as compared to the continuous standing treatment (traditional water management in irrigated rice ecosystem worldwide). The practice of keeping rice fields dry for some period of time during the growing season resulted in a significant reduction in water use. Maintaining the rice field dry during mid season not only reduced water use and significantly increased grain yield as compared to continuous flooding treatment if alternate wetting and drying practice is adopted.

Countrywide, particularly in the water major rice growing areas where groundwater is major source of irrigation and the farmers grow 2-3 rice crops per year, water use would significantly decrease. Using water more efficiently over several agro-ecological zones of the country would help alleviate water shortages allowing water to be used for other needs.

This chapter includes summarization of some important facts that were evolved from the study undertaken at the Bangladesh Rice Research Institute, Gazipur and regional station Shampur, Rajshahi. It also aims in recommending the possible improvements that could be made in the study for further researches regarding the topic.

Experiment 1

The irrigation treatments significantly affected the rice yield and some other yield contributing characters. The results revealed that though the highest grain yield (5.69 t/ha) was found the treatment T_2, its water use efficiency was the (87.38 t/ha/cm)The highest water requirement (118.69 cm) was found in the treatment T_1 while treatment T_2 needed only 116.88 cm of water.The study also revealed that increasing water stress didn't reduced plant height, number of effective tillers per hill, grain yield, straw yield and biological yield as did for the harvest index. Considering all the outputs from the experiment, it can be inferred that practicing treatment T_2 would be the best choice for the rice cultivation in silty loam soil where farmers can be suggested to irrigate their lands 15/20 cm of water from the soil surface.

Varietal Effects

Varietal effect was found to be significant for plant height, number of effective tillers and filled grain. Highest grain yield (5.64 t/ha) was found for the BRRI hybrid2 and BRRI dhan29 gave a yield of 4.93 t/ha.

Interaction Effect

The interaction between varieties and treatments also produced significant results for grain yield. The highest yield of BRRI hybrid2 (6.28 t/ha) was obtained for the interaction ($V_2 \times T_2$) and the lowest (4.18 t/ha) for the interaction ($V_1 \times T_1$).

Experiment 2

The irrigation treatments significantly affected the rice yield and some other yield contributing characters. The results revealed that the highest grain yield (5.57 t/ha) was found the treatment T_2, its water use efficiency was the (70.05 t/ha/cm).The highest water requirement (49.04 cm) was found in the treatment T_1 while treatment T_2 needed only 48.22 cm. The study also revealed that increasing water stress didn't reduced plant height, number of effective tillers per, grain yield, straw yield and biological yield as did for the harvest index. Considering all the outputs from the experiment, it can be inferred that practicing treatment T_2 would be the best choice for the rice cultivation in agro ecological zones loam soil where farmers can be suggested to irrigate their lands after 3 days disappearance of standing water.

Varietal Effects

Varietal effect was found to be significant for plant height, number of effective tillers, filled grain. Highest grain yield (5.52 t/ha) was found for the BRRI hybrid2 and BRRI dhan28 gave a yield of 4.81 t/ha.

Interaction Effect

The interaction between varieties and treatments, as shown in Table 4.6, also produced significant results for grain yield. The highest yield of BRRI hybrid2 (6.16 t/ha) was obtained for the interaction ($V_2 \times T_2$) and the lowest (4.06 t/ha) for the interaction ($V_1 \times T_1$).

Experiment 3

The irrigation treatments significantly affected the rice yield and some other yield contributing characters at different growth stages. The results revealed that though the highest grain yield (5.86 t/ha) was found the treatment T_2 (3 days dry at vegetative, reproductive and ripening stages), its water use efficiency was the (90.76t/ha/cm). The highest water requirement (107.96 cm) was found in the treatment T_1 while treatment T_2 needed 106.72 cm. (of water saving about 25 cm of water.). The study also revealed that increasing water stress didn't reduced plant height, number of effective tillers per, grain yield, straw yield and biological yield as did for the harvest index. Considering all the outputs from the experiment, it can be inferred that practicing treatment T_2 would be the best choice for the rice cultivation in silty loam soil where farmers can be suggested to irrigate their lands after 3 days disappearance of standing water at vegetative, reproductive and ripening stages.

Varietal Effects

Varietal effect was found to be significant for plant height, no. of effective tillers, filled grain. Highest grain yield (6.11 t/ha) was found for the BRRI hybrid2 and BRRI dhan36 gave a yield of 4.09 t/ha.

Interaction Effect

The interaction among varieties, growth stages and treatments produced significant results for grain yield. The highest yield of BRRI hybrid2 (8.13 t/ha) was obtained for the interaction ($V_2 \times T_2 \times Ve$) and the lowest (3.37 t/ha) for the interaction ($V_2 \times Ri \times T_4$).

Experiment 4

The findings outlined in this experiment are a rough approximation of the factors that favor or hinder the adoption of AWD. Nevertheless, significant issues were identified that need to be considered generally to improve adoption at the farmers' level and that would eventually enable mass adoption. The study revealed that farm size, education of household head, and contact with extension agents, water scarcity and dissemination through demonstration were the variables that had significant impact on the adoption of AWD. So if contact with extension workers could be increased and/or the farmers could be shown the use of AWD techniques through field demonstration then the adoption rates can be increased.

Extension programs that provide general irrigation information and specific information regarding AWD can potentially encourage further adoption of this irrigation technique. As mentioned above the public benefit of adopting water-conserving technologies such as AWD should be emphasized in these extension programs. Water conservation benefits can potentially be realized if local government agencies (e.g., Phil- Rice and NIA), as well as international agencies (e.g., IRRI), continue to provide education and training about the latest research on AWD and other water-conserving technologies to local extension personnel, field technicians, and as well as farmers.

Chapter 6

Recommendation

Chapter 6

Recommendation

As a result of these research findings, water shortages could be alleviated by adopting proper water use protocol, which is the use of alternate wetting and drying water management practice in rice cultivation.

This research was conducted at the Bangladesh Rice Research Station, Gazipur and Rajshahi, Bangladesh. The dominant properties of silt loam soil is less water retention potential as compared to other heavy textural soils such as silty clay loam, clay loam, or clay. The silt loam soil quickly dried after the surface water was removed from the fields. As this point, farmers have to intensively manage and observe their rice fields to avoid water deficiency during the drying period.

Recent research showed that rice variety grown is also a major factor affecting the amount of water consumption. Thus, the shorter maturity varieties might have potential to reduce water used greater than this variety.

Consequently, the IIMI (International Irrigation Management Institute), IWMI (International Water Management Institute), UNEP (Unite Nations Environmental Program), FAO (Food and Agriculture Organization of the United Nations), IFPRI (International Food Policy Research Institute) etc. should conduct research and encourage use of the alternate wetting and drying water management technique in rice cultivation.

Further research is needed to determine impact of environment factors such as soil types, rice varieties, duration for drying, and climate on water consumption as related to rice yield. Site-specific water management in irrigated rice farming should be studied country wide in order to make a recommendation for water management practices. Optimistically, the results will be amplification for establishment of water use policy based on agro-ecological zones.

Groundwater was a major source of irrigated water used in this field experiment. Even though this research does not measure the depletion of groundwater in the study area, there are several articles reported that the depletion of ground water is extremely high, particularly in the country that use groundwater as a main source of irrigation water. Therefore the use of groundwater should be controlled and monitored by concerned agencies in order to prevent overuse.

In order to achieve a large-scale spread and adoption of AWD, at least in regions where water scarcity poses a threat to sustain and further improve rice cultivation, a number of constraints and issues at national, regional and local levels have to be overcome as suggested by the findings.

Since the further spread of AWD at this stage depends to a great extent on the actions taken and efforts made at the organizational level to improve and institutionalize the dissemination process in Bangladesh, recommendations, therefore, address in particular, both the stakeholders at large and the key factors involved in disseminating AWD to farmers and pump owners.

Lastly, the study offers some general recommendations and lessons for disseminating natural resource management technologies, based on experiences in Bangladesh, which are specific to the dissemination of AWD technology.

Following are some of the specific plots that have to be addressed in further studied:

- The study on the effects of AWDI on rice cultivation was done in small experimental fields. It needs further studies in farmer to managed fields for the verification of the results.
- Integrated approach of research on AWDI, including the soil, fertilizer, agronomic and IPM issues should be made and the findings can therefore be disseminated to the farmers through DAE, NGOs.
- Studies of AWDI need to be extended to consider the effects on disease prevalence and incidence, rather than just mosquito vector populations.

- Studies need to distinguish between active versus passive drainage and scheduled versus on demand flooding and effects of AWDI on other agricultural parameters, including fertilizer uptake and control of weeds and other pathogens require more detailed investigation.
- AWD dissemination should become a priority/vital issue on the agenda of the National Agricultural Technology Coordination Committee (NATCC)
- Formulate a national Plan of Action of AWD dissemination in Bangladesh
- Develop strategic partnerships for disseminating AWD
- Involve local government in the dissemination process. Including local government representatives in local processes of AWD dissemination will help to further promote the technology among farmers
- Adopt AWD dissemination approaches to local irrigation systems. The adoption of AWD is strongly affected by a variety of specifics that constitute an irrigation system, including the organization of its users, scheduling of irrigation and payment arrangements. It is essential that the approach of the disseminating organization takes the specific characteristics of an irrigation system into account as it promotes AWD to farmers in a certain location.
- Design training to fit AWD use in command areas of irrigation systems.
- Strengthen the quality of training for farmers.
- Address possible adoptions of AWD during training sessions.
- Improve monitoring and evaluation of AWD dissemination

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Appendix

Appendix

Appendix I: Varietal (BRRI dhan29 and BRRI hybrid2) Effect on the Yield and Yield Contributing Characters.

Variety	Plant height (cm)	Total tiller $hill^{-1}$	Effective tiller $hill^{-1}$	Non-effective tiller $hill^{-1}$	Panicle length (cm)	Filled grain $panicle^{-1}$	Unfilled grain $panicle^{-1}$	1000-GW	Grain yield ($t\ ha^{-1}$)	Straw yield ($t\ ha^{-1}$)	Biological yield	Harvest Index
V_1	101.95	10.63	8.68	1.95	22.92	118.45	22.64	23.35	4.93	5.83	10.76	45.73
V_2	107.00	10.96	9.11	1.85	22.80	137.64	20.49	23.65	5.64	6.70	12.34	45.65
LSD	0.369	0.106	0.072	0.094	0.348	0.926	0.354	0.176	0.047	0.047	0.066	0.319
Level of sig	**	NS	**	NS	NS	**	**	NS	**	**	**	NS

In a column figures with same letter or without letter do not differ significantly whereas figures with dissimilar letter differ significantly (as per DMRT)

V_1 = BRRI dhan29
V_2 = BRRI hybrid 2
NS = Not Significant
* = Significant at 5% level of probability
** = Significant at 1% level of probability

Appendix II: Effect of Different Irrigation Treatments on the Yield and Yield Contributing Characters.

Treatment	Plant height (cm)	Total tiller $hill^{-1}$	Effective tiller $hill^{-1}$	Non-effective tiller $hill^{-1}$	Panicle length (cm)	Filled grain $panicle^{-1}$	Unfilled grain $panicle^{-1}$	1000-GW	Grain yield ($t\ ha^{-1}$)	Straw yield ($t\ ha^{-1}$)	Biological yield	Harvest Index
T_1	103.43b	10.40b	8.06c	2.34a	23.41	119.32c	26.80a	23.07b	4.71c	6.12b	10.83c	43.61b
T_2	105.25ab	12.14a	11.06a	1.08b	22.89	141.94a	14.07c	24.48a	5.69a	6.57a	12.26a	46.33a
T_3	103.45b	10.86b	8.67b	2.19a	21.72	127.38b	23.04b	22.91b	5.45b	6.16b	11.61b	46.96a
T_4	105.78a	9.78c	7.78c	2.00a	23.43	123.57bc	22.36b	23.53b	5.27b	6.22b	11.49b	45.86a
LSD	0.738	0.212	0.145	0.187	0.696	1.852	0.707	0.352	0.095	0.093	0.132	0.637
Level of sig	*	**	**	**	NS	**	**	**	**	**	**	**

In a column figures with same letter or without letter do not differ significantly whereas figures with dissimilar letter differ significantly (as per DMRT)

T_1 = Continuous Standing water

T_2= Irrigation when water is 15 cm below from the soil surface

T_3 = Irrigation when water is 20 cm below from the soil surface

T_4 = Irrigation when water is 25 cm below from the soil surface

NS = Not Significant

* = Significant at 5% level of probability

** = Significant at 1% level of probability

Appendix III: Mean Effect of the interaction Between Varieties and Irrigation Treatments on the Yield and Yield Contributing Characters of BRRI dhan29 (V_1) and BRRI hybrid2 (V_2)

	Plant height (cm)	Total tiller hill^{-1}	Effective tiller hill^{-1}	Non-effective tiller hill^{-1}	Panicle length (cm)	Filled grain panicle^{-1}	Unfilled grain panicle^{-1}	1000-GW	Grain yield (t ha^{-1})	Straw yield (t ha^{-1})	Biological yield	Harvest Index
V_1T_1	99.85c	10.23	7.86	2.37	22.98	95.50e	27.31a	22.83	4.18d	5.26e	9.44e	44.28
V_1T_2	101.32c	11.95	11.04	0.91	23.92	138.22b	17.88d	24.16	5.10c	6.08c	11.18cd	45.59
V_1T_3	99.93c	10.47	8.37	2.10	21.57	118.17d	22.06c	23.02	5.08c	5.75d	10.83d	46.93
V_1T_4	106.72ab	9.86	7.44	2.42	23.23	121.93cd	23.32c	23.38	5.33c	6.23c	11.57c	46.11
V_2T_1	107.02ab	10.56	8.27	2.30	23.85	143.13ab	26.29ab	23.31	5.24c	6.97a	12.21b	42.93
V_2T_2	109.17a	12.32	11.07	1.25	21.87	145.65a	10.27e	24.80	6.28a	7.06a	13.33a	47.08
V_2T_3	106.98ab	11.24	8.97	2.27	21.87	136.58b	24.02bc	22.80	5.82b	6.57b	12.39b	46.99
V_2T_4	104.84b	9.70	8.12	1.58	23.63	125.20c	21.39c	23.67	5.21c	6.21c	11.41c	45.62
LSD	1.48	0.42	0.29	0.37	1.39	3.70	1.41	0.70	0.19	0.19	0.26	1.27
Level of sig	**	NS	NS	NS	NS	**	**	NS	**	**	**	NS

In a column figures with same letter or without letter do not differ significantly whereas figures with dissimilar letter differ significantly (as per DMRT)

* = Significant at 5% level of probability

** = Significant at 1% level of probability

NS = Not significant

Appendix IV: Varietal (BRRI dhan28 and BRRI hybrid2) Effect on the Yield and Yield Contributing Characters.

Variety	Plant height (cm)	Total tiller hill^{-1}	Effective tiller hill^{-1}	Non-effective tiller hill^{-1}	Panicle length (cm)	Filled grain panicle^{-1}	Unfilled grain panicle^{-1}	1000-GW	Grain yield (t ha^{-1})	Straw yield (t ha^{-1})	Biological yield	Harvest Index
V_1	101.64	10.88	8.79	2.09	23.35	126.33	30.80	23.93	4.81	5.71	10.52	45.63
V_2	104.50	11.75	9.53	2.21	23.65	149.92	23.53	25.62	5.52	6.58	12.10	45.57
LSD	0.28	0.08	0.09	0.10	0.18	0.77	0.59	0.18	0.05	0.05	0.07	0.33
Level of sig	**	**	**	NS	NS	**	**	**	**	**	**	NS

In a column figures with same letter or without letter do not differ significantly whereas figures with dissimilar letter differ significantly (as per DMRT)

V_1 = BRRI dhan28

V_2 = BRRI hybrid2

NS = Not Significant

* = Significant at 5% level of probability

** = Significant at 1% level of probability

Appendix V: Effect of Different Irrigation Treatments on the Yield and Yield Contributing Characters.

Treatment	Plant height (cm)	Total tiller $hill^{-1}$	Effective tiller $hill^{-1}$	Non-effective tiller $hill^{-1}$	Panicle length (cm)	Filled grain $panicle^{-1}$	Unfilled grain $panicle^{-1}$	1000-GW	Grain yield (t ha^{-1})	Straw yield (t ha^{-1})	Biological yield	Harvest Index
T_1	101.55b	10.92c	8.45b	2.47a	23.07b	120.84c	31.72a	23.97b	4.59b	6.00b	10.59c	43.46b
T_2	104.38a	12.94a	11.65a	1.29c	24.48a	150.55a	23.58b	25.27a	5.57a	6.45a	12.02a	46.26a
T_3	102.31b	11.64b	8.69b	2.95a	22.91b	141.65b	24.03b	25.27a	5.33ab	6.04b	11.37b	46.90a
T_4	104.04a	9.76d	7.85c	1.91b	23.53b	139.47b	29.34a	24.60ab	5.15ab	6.10b	11.25b	45.77a
LSD	0.57	0.16	0.19	0.20	0.35	1.53	1.17	0.36	0.09	0.09	0.13	0.65
Level of sig	**	**	**	**	**	**	**	**	**	**	**	**

In a column figures with same letter or without letter do not differ significantly whereas figures with dissimilar letter differ significantly (as per DMRT)

T_1 = Continuous Standing water
T_2 = 3 days disappearance of standing water
T_3 = 5 days disappearance of standing water
T_4 = 7 days disappearance of standing water
NS = Not Significant
* = Significant at 5% level of probability
** = Significant at 1% level of probability

Appendix VI: Mean effect of the Interaction Between Varieties and Irrigation Treatments on the Yield and Yield Contributing Characters of BRRI dhan28 (V_1) and BRRI hybrid2 (V_2)

	Plant height (cm)	Total tiller hill^{-1}	Effective tiller hill^{-1}	Non-effective tiller hill^{-1}	Panicle length (cm)	Filled grain panicle^{-1}	Unfilled grain panicle^{-1}	1000-GW	Grain yield (t ha^{-1})	Straw yield (t ha^{-1})	Biological yield	Harvest Index
V_1T_1	98.51e	10.45	8.01	2.44	22.83	105.48f	38.31a	23.91	4.06c	5.14e	9.20e	44.13
V_1T_2	102.28cd	12.41	11.43	0.98	24.16	142.42c	25.90c	24.46	4.98bc	5.96c	10.94cd	45.49
V_1T_3	101.29d	11.38	8.26	3.11	23.02	129.17e	24.95cd	23.71	4.96bc	5.63d	10.59d	46.86
V_1T_4	104.48ab	9.30	7.46	1.84	23.38	128.26e	34.04b	23.63	5.21abc	6.11c	11.33c	46.02
V_2T_1	104.59ab	11.39	8.90	2.49	23.31	136.20d	25.13cd	24.03	5.12abc	6.85a	11.97b	42.79
V_2T_2	106.48a	13.47	11.87	1.60	24.80	158.67a	21.27d	26.07	6.16a	6.94a	13.09a	47.02
V_2T_3	103.34bcd	11.90	9.12	2.78	22.80	154.13ab	23.10cd	26.82	5.70ab	6.45b	12.15b	46.93
V_2T_4	103.60bc	10.22	8.23	1.98	23.67	150.67b	24.63cd	25.57	5.09abc	6.09c	11.17c	45.52
LSD	1.13	0.32	0.37	0.41	0.70	3.07	2.35	0.72	0.19	0.19	0.26	1.30
Level of sig	**	NS	NS	NS	NS	**	**	NS	**	**	**	NS

In a column figures with same letter or without letter do not differ significantly whereas figures with dissimilar letter differ significantly (as per DMRT)

* = Significant at 5% level of probability

** = Significant at 1% level of probability

NS = Not significant

Appendix VII: Effect of Variety on Yield and Contributing Characters of BRRI hybrid2 and BRRI dhan36

Variety	Plant height (cm)	Total tiller $hill^{-1}$	Effective tiller $hill^{-1}$	Non-effective tiller $hill^{-1}$	Panicle length (cm)	Filled grain $panicle^{-1}$	Unfilled grain $panicle^{-1}$	1000-GW	Grain yield ($t\ ha^{-1}$)	Straw yield ($t\ ha^{-1}$)	Biological yield	Harvest Index
V_1	99.78a	12.39a	9.50a	2.90a	22.79a	105.65a	61.74a	20.63	6.11a	6.60a	12.71a	48.01a
V_2	94.88b	8.11b	7.24b	0.88b	18.33b	87.00b	24.01b	20.95	4.09b	4.96b	9.05b	45.17b
LSD	0.258	0.042	0.037	0.057	0.113	0.173	0.210	0.250	0.013	0.037	0.038	0.175
Level of sig.	**	**	**	**	**	**	**	NS	**	**	**	**

In a column figures with same letter or without letter do not differ significantly whereas figures with dissimilar letter differ significantly (as per DMRT)

V_1 = BRRI dhan 28
V_2 = BRRI hybrid 2
NS = Not Significant
* = Significant at 5% level of probability
** = Significant at 1% level of probability

Appendix VIII: Effect of Growth Stages and Irrigation on Yield and Contributing Characters of BRRI hybrid2 and BRRI dhan36

Stages of irrigation	Plant height (cm)	Total tiller hill^{-1}	Effective tiller hill^{-1}	Non-effective tiller hill^{-1}	Panicle length (cm)	Filled grain panicle^{-1}	Unfilled grain panicle^{-1}	1000-GW	Grain yield (t ha^{-1})	Straw yield (t ha^{-1})	Biological yield	Harvest Index
Vegetative	98.20	10.71a	8.72a	1.99	19.86b	100.42a	40.45c	22.35a	5.69a	5.84ab	11.53a	49.41a
Reproductive	96.50	9.68b	7.88b	1.80	19.77b	92.51c	42.24b	21.71b	5.31ab	5.92a	11.24a	47.15b
Ripening	97.30	10.37ab	8.51a	1.86	22.06a	96.05b	45.95a	18.31c	4.31b	5.57b	9.88b	43.21c
LSD	0.387	0.064	0.055	0.086	0.169	0.260	0.315	0.375	0.019	0.056	0.057	0.263
Level of sig.	NS	**	**	NS	**	**	**	**	**	*	**	**

In a column figures with same letter or without letter do not differ significantly whereas figures with dissimilar letter differ significantly (as per DMRT)

NS = Not Significant

* = Significant at 5% level of probability

** = Significant at 1% level of probability

Appendix IX: Effect of Variety and Growth Stages on Yield and Contributing Characters of BRRI hybrid2 and BRRI dhan36

Variety x Stages of irrigation	Plant height (cm)	Total tiller hill^{-1}	Effective tiller hill^{-1}	Non-effective tiller hill^{-1}	Panicle length (cm)	Filled grain panicle^{-1}	Unfilled grain panicle^{-1}	1000-GW	Grain yield (t ha^{-1})	Straw yield (t ha^{-1})	Biological yield	Harvest Index
V_1Ve	100.18a	13.33a	9.92a	3.41a	21.95c	116.08a	56.70c	21.86	6.68a	6.70b	13.38ab	49.97a
V_1Re	100.33a	11.72c	9.19a	2.53bc	22.90b	103.19b	58.58b	21.71	6.50ab	7.13a	13.63a	47.65b
V_1Ri	98.84b	12.14b	9.38a	2.75b	23.53a	97.68c	69.95a	18.31	5.17b	5.96c	11.12b	46.41c
V_2Ve	96.23c	8.10d	7.52b	0.58d	17.78e	84.76e	24.20e	22.84	4.70c	4.98d	9.68c	48.84ab
V_2Re	92.66e	7.63e	6.56c	1.08c	16.63f	81.83f	25.89d	21.71	4.13cd	4.72d	8.84cd	46.66c
V_2Ri	95.75d	8.61de	7.63b	0.98c	20.59d	94.42d	21.95f	18.31	3.45d	5.18e	8.63d	40.02d
LSD	0.775	0.127	0.110	0.172	0.338	0.520	0.631	0.750	0.039	0.112	0.115	0.525
Level of sig.	*	**	**	**	**	**	**	NS	**	**	**	**

In a column figures with same letter or without letter do not differ significantly whereas figures with dissimilar letter differ significantly (as per DMRT)

V_1 = BRRI dhan28

V_2 = BRRI hybrid2

Ve. = Vegetative

Re. = Reproductive

Ri = Ripening

NS = Not Significant

* = Significant at 5% level of probability

** = Significant at 1% level of probability

Appendix X: Effect of Irrigation Treatments on Yield and Contributing Characters of BRRI hybrid2 and BRRI dhan36

Methods of irrigation	Plant height (cm)	Total tiller hill^{-1}	Effective tiller hill^{-1}	Non-effective tiller hill^{-1}	Panicle length (cm)	Filled grain panicle^{-1}	Unfilled grain panicle^{-1}	1000-GW	Grain yield (t ha^{-1})	Straw yield (t ha^{-1})	Biological yield	Harvest Index
T_1	102.17a	11.55a	7.98bc	3.57a	21.07	94.85b	49.00b	23.55a	5.15ab	5.85b	11.00b	46.67
T_2	102.35a	11.79a	10.07a	1.72b	20.63	119.86a	21.53d	20.00c	5.86a	6.48a	12.33a	47.00
T_3	97.86b	9.53b	8.35b	1.18bc	20.02	91.78c	43.43c	18.21d	4.95bc	5.65b	10.60c	46.56
T_4	86.96c	8.14c	7.06c	1.08c	20.53	78.83d	57.56a	21.40b	4.45c	5.13b	9.58d	46.14
LSD	0.516	0.085	0.074	0.115	0.225	0.347	0.420	0.500	0.026	0.075	0.076	0.350
Level of sig.	**	**	**	**	NS	**	**	**	**	**	**	NS

In a column figures with same letter or without letter do not differ significantly whereas figures with dissimilar letter differ significantly (as per DMRT)

NS = Not Significant
* = Significant at 5% level of probability
** = Significant at 1% level of probability

Appendix XI: Effect of Variety and Irrigation Treatments on Yield and Contributing Characters of BRRI hybrid2 and BRRI dhan36

Variety and methods of irrigation	Plant height (cm)	Total tiller hill^{-1}	Effective tiller hill^{-1}	Non-effective tiller hill^{-1}	Panicle length (cm)	Filled grain panicle^{-1}	Unfilled grain panicle^{-1}	1000-GW	Grain yield (t ha^{-1})	Straw yield (t ha^{-1})	Biological yield	Harvest Index
V_1T_1	107.67a	15.07a	8.97c	6.10a	24.13a	104.00b	76.00b	22.89	6.07b	6.48b	12.55b	48.44
V_1T_2	108.79a	15.12a	12.52a	2.60b	22.36bc	152.00a	20.31f	20.00	7.53a	7.97a	15.51a	48.54
V_1T_3	101.11b	10.81b	9.43b	1.38cd	21.54c	95.44c	61.67c	18.21	5.86c	6.53b	12.38b	47.32
V_1T_4	81.57e	8.57c	7.07e	1.50c	23.13ab	71.16f	89.00a	21.40	5.00d	5.40c	10.40c	47.75
V_2T_1	96.67c	8.03cd	7.00e	1.03cd	18.00d	85.70e	22.00f	24.20	4.23e	5.22cd	9.45d	44.89
V_2T_2	95.91c	8.47c	7.62d	0.84cd	18.91d	87.71de	22.76ef	20.00	4.18ef	4.98cd	9.16de	45.46
V_2T_3	94.60cd	8.24c	7.27de	0.98cd	18.50d	88.11d	25.19de	18.21	4.04fg	4.78d	8.82e	45.80
V_2T_4	92.34d	7.71d	7.06e	0.65d	17.92d	86.49de	26.11e	21.40	3.91g	4.86d	8.77e	44.54
LSD	1.033	0.170	0.147	0.230	0.451	0.694	0.841	1.000	0.052	0.150	0.153	0.700
Level of sig.	**	**	**	**	**	**	**	NS	**	**	**	NS

In a column figures with same letter or without letter do not differ significantly whereas figures with dissimilar letter differ significantly (as per DMRT)

NS = Not Significant
* = Significant at 5% level of probability
** = Significant at 1% level of probability

Appendix XII: Effect of Growth Stages and Irrigation Treatments on Yield and Contributing Characters of BRRI hybrid2 and BRRI dhan36

Stages of irrigation and methods of irrigation	Plant height (cm)	Total tiller $hill^{-1}$	Effective tiller $hill^{-1}$	Non-effective tiller $hill^{-1}$	Panicle length (cm)	Filled grain $panicle^{-1}$	Unfilled grain $panicle^{-1}$	1000-GW	Grain yield (t ha^{-1})	Straw yield (t ha^{-1})	Biological yield	Harvest Index
VeT_1	102.00ab	11.80b	8.00de	3.80a	21.00	97.55e	46.00d	23.14	5.61c	6.20abc	11.81c	47.62
VeT_2	103.40a	12.88a	10.55a	2.33b	20.43	115.73c	21.30g	23.04	6.55a	6.73a	13.28a	49.20
VeT_3	98.57bc	10.05d	8.93c	1.12c	18.38	100.33d	38.17f	21.57	5.37d	5.36def	10.73de	50.15
VeT_4	88.85d	8.11ef	7.38f	0.73c	19.63	88.07h	56.33ab	21.64	5.23d	5.06f	10.29ef	50.66
ReT_1	101.50ab	11.65b	7.95def	3.70a	20.45	92.50fg	46.00d	24.15	5.60c	6.20abc	11.80c	47.33
ReT_2	101.48ab	10.80c	9.50b	1.30c	20.27	118.50b	22.50g	20.43	6.00b	6.49ab	12.49b	48.03
ReT_3	97.00c	8.55e	7.67ef	0.88c	19.25	90.00gh	41.62e	20.40	5.18de	5.89bcd	11.07d	46.77
ReT_4	86.00d	7.70f	6.38g	1.32c	19.10	69.04k	58.83a	21.88	4.47f	5.12ef	9.59gh	46.48
RiT_1	103.00a	11.20bc	8.00de	3.20a	21.75	94.50f	55.00b	23.35	4.25g	5.15ef	9.40hi	45.04
RiT_2	102.17ab	11.70b	10.17a	1.53bc	21.20	125.33a	20.80g	16.54	5.02e	6.21abc	11.22cd	43.76
RiT_3	98.00bc	9.99d	8.45cd	1.54bc	22.43	85.00i	50.50c	12.67	4.30fg	5.71cde	10.01fg	42.76
RiT_4	86.02d	8.60e	7.42ef	1.18c	22.85	79.37j	57.50ab	20.69	3.67h	5.21ef	8.87i	41.29
LSD	1.549	0.254	0.221	0.345	0.676	1.041	1.261	1.500	0.078	0.225	0.229	1.051
Level of sig.	NS	**	*	NS	NS	**	**	NS	**	**	**	NS

In a column figures with same letter or without letter do not differ significantly whereas figures with dissimilar letter differ significantly (as per DMRT)

NS = Not Significant

* = Significant at 5% level of probability

** = Significant at 1% level of probability

Appendix XIII: Interaction Effect of Variety, Growth Stages and Irrigation Treatments on Yield and Contributing Characters of BRRI hybrid2 and BRRI dhan36

Variety, stages of irrigation and methods of irrigation	Plant height (cm)	Total tiller hill^{-1}	Effective tiller hill^{-1}	Non-effective tiller hill^{-1}	Panicle length (cm)	Filled grain panicle^{-1}	Unfilled grain panicle^{-1}	1000-GW	Grain yield (t ha^{-1})	Straw yield (t ha^{-1})	Biological yield	Harvest Index
V_1VeT_1	108.00	15.60	9.00	6.60	24.00ab	110.00e	70.00d	21.18	6.51bc	6.77	13.28	49.03
V_1VeT_2	108.70	16.67	13.00	3.67	21.77bc	145.00c	20.13j	23.04	8.13a	8.21	16.35	49.76
V_1VeT_3	101.00	12.00	10.00	2.00	19.27de	116.33d	51.00f	21.57	6.10de	6.26	12.36	49.34
V_1VeT_4	83.00	9.03	7.67	1.37	22.77bc	93.00g	85.67b	21.64	5.97e	5.55	11.52	51.75
V_1ReT_1	108.00	15.20	8.90	6.30	22.90abc	100.00f	70.00d	24.15	6.70b	7.25	13.95	48.04
V_1ReT_2	109.00	13.73	12.23	1.50	23.43ab	153.67b	20.00j	20.43	7.87a	8.51	16.37	48.05
V_1ReT_3	102.00	9.60	8.97	0.63	22.40bc	99.00f	55.67e	20.40	6.37cd	7.19	13.55	46.96
V_1ReT_4	82.33	8.33	6.67	1.67	22.87abc	60.09l	88.67ab	21.88	5.07f	5.59	10.66	47.55
V_1RiT_1	107.00	14.40	9.00	5.40	25.50a	102.00f	88.00b	23.35	5.00f	5.43	10.43	48.25
V_1RiT_2	108.67	14.97	12.33	2.63	21.87bc	157.33a	20.80ij	16.54	6.60bc	7.20	13.80	47.81
V_1RiT_3	100.33	10.84	9.33	1.51	22.97abc	71.00k	78.33c	12.67	5.10f	6.13	11.23	45.66
V_1RiT_4	79.37	8.33	6.87	1.47	23.77ab	60.40l	92.67a	20.69	3.97i	5.07	9.03	43.94
V_2VeT_1	96.00	8.00	7.00	1.00	18.00d-g	85.10h	22.00hij	25.10	4.70gh	5.64	10.34	46.20
V_2VeT_2	98.10	9.10	8.10	1.00	19.10def	86.47h	22.47hij	23.04	4.97fg	5.25	10.21	48.63
V_2VeT_3	96.13	8.10	7.87	0.23	17.50efg	84.33hi	25.33ghi	21.57	4.63h	4.46	9.09	50.95
V_2VeT_4	94.70	7.19	7.10	0.09	16.50fg	83.13hi	27.00gh	21.64	4.49h	4.57	9.07	49.57
V_2ReT_1	95.00	8.10	7.00	1.10	18.00d-g	85.00hi	22.00hij	24.15	4.50h	5.15	9.65	46.63
V_2ReT_2	93.97	7.87	6.77	1.10	17.10efg	83.33hi	25.00g-j	20.43	4.13i	4.48	8.61	48.02
V_2ReT_3	92.00	7.50	6.37	1.13	16.10g	81.00ij	27.57g	20.40	4.00i	4.59	8.59	46.59
V_2ReT_4	89.67	7.07	6.10	0.97	15.33g	78.00j	29.00g	21.88	3.87i	4.65	8.52	45.40
V_2RiT_1	99.00	8.00	7.00	1.00	18.00d-g	87.00h	22.00hij	23.35	3.50j	4.87	8.37	41.84
V_2RiT_2	95.67	8.43	8.00	0.43	20.53cd	93.33g	20.80ij	16.54	3.43j	5.21	8.64	39.71
V_2RiT_3	95.67	9.13	7.57	1.57	21.90bc	99.00f	22.67hij	12.67	3.50j	5.28	8.78	39.87
V_2RiT_4	92.67	8.87	7.97	0.90	21.93bc	98.33f	22.33hij	20.69	3.37j	5.35	8.71	38.64
LSD	3.099	0.509	0.442	0.689	1.353	2.082	2.523	3.000	0.156	0.450	0.458	2.101
Level of sig.	NS	NS	NS	NS	**	**	**	NS	**	NS	NS	NS

NS = Not Significant

* = Significant at 5% level of probability ** = Significant at 1% level of probability

In a column figures with same letter or without letter do not differ significantly whereas figures with dissimilar letter differ significantly (as per DMRT)

Appendix XIV: Analysis of Variances of Yield and Yield Component of *Boro* rice 2009-2010 (Mean square)

Source	df	Plant height (cm)	Total tiller/Hill	Effective tiller/Hill	Non-effective tiller/ Hill	Panicle length (cm)	Filled grain/Panicle	Unfilled grain/Panicle	1000-GW (gm)	Grain yield (t/ha)	Straw yield (t/ha)	Biological yield (t/ha)	HI
Replication	2	10.196	0.923	0.064	0.599	2.681	28.287	3.425	0.862	0.059	0.073	0.263	0.015
Factor A	1	152.864**	0.64	1.097	0.061	0.086	2209.536	27.778	0.534	3.039	4.524	14.978	0.033
Factor B	3	8.865*	5.972	13.291	1.9	3.886	579.329	172.67	2.994	1.035	0.258	2.059	12.792
AB	3	32.21**	0.216	0.128	0.409	2.586	600.699	24.019	0.21	0.52	0.762	2.373	2.143
Error	14	2.134	0.176	0.082	0.137	1.897	13.416	1.956	0.484	0.035	0.034	0.068	1.589

In a column figures with same letter or without letter do not differ significantly whereas figures with dissimilar letter differ significantly (as per DMRT)

* = Significant at 5% level of probability
** = Significant at 1% level of probability
NS = Not significant

Appendix XV: Analysis of Variances of Yield and Yield Component of *Boro* rice 2010-2011 at BRRI Farm, Rajshahi (Mean square)

Source	Df	Plant height	Total tiller	Effective tiller	Non-effective tiller	Panicle length	Filled grain	Unfilled grain	1000-GW	Grain yield	Straw yield	Biological yield	HI
Replication	2	0.405	0.238	0.122	0.116	0.862	8.604	14.817	0.688	0.059	0.073	0.263	0.017
Factor A	1	49.221	4.463	3.293	0.089	0.534	3338.339	316.972	17.17	3.039	4.524	14.978	0.02
Factor B	3	11.052	10.66	17.309	3.065	2.994	934.709	96.335	2.314	1.035	0.258	2.059	13.406
AB	3	13.413	0.083	0.064	0.234	0.21	54.001	37.906	2.264	0.52	0.762	2.373	2.204
Error	14	1.26	0.1	0.134	0.163	0.484	9.206	5.395	0.508	0.035	0.034	0.068	1.665

* = Significant at 5% level of probability

** = Significant at 1% level of probability

NS = Not significant

In a column figures with same letter or without letter do not differ significantly whereas figures with dissimilar letter differ significantly (as per DMRT)

Appendix XVI: Analysis of Variances of Yield and Yield Component of *Boro* rice 2010-2011 at BRRI Farm Gazipur (Mean square)

Source	df	Plant height (cm)	Total tiller /Hill	Effective tiller/Hill	Non-effective tiller /Hill	Panicle length (cm)	Filled grain/ Panicle	Unfilled grain/ Panicle	1000 grain wt.(g)	Grain yield (t/ha)	Straw yield (t/ha)	Biologica l yield (/ha)	HI
Factor A	1	432.67	329.663	92.027	73.334	357.781	6260.246	25624.71	1.921	73.71	48.347	241.45	144.982
Factor B	2	17.534	6.691	4.612	0.235	40.33	376.789	188.911	112.916	12.21	0.837	18.671	235.688
AB	2	35.667	4.518	1.257	3.114	17.028	1213.782	474.632	1.921	0.659	4.038	7.895	57.098
Factor C	3	938.994	54.374	28.564	24.052	3.314	5296.506	4252.839	91.446	6.076	5.574	23.276	2.234
AC	3	523.865	41.768	18.183	20.01	9.599	5048.154	3769.855	1.921	4.086	4.792	17.501	3.68
BC	6	3.851	1.993	0.536	1.127	5.231	239.856	76.662	31.82	0.229	0.752	1.386	13.23
ABC	6	3.412	0.497	0.293	0.659	7.042	409.92	58.647	1.921	0.113	0.113	0.353	2.877
Error	4 8	10.688	0.288	0.217	0.529	2.037	4.823	7.083	10.019	0.027	0.225	0.234	4.914

* = Significant at 5% level of probability

** = Significant at 1% level of probability

NS = Not significant

In a column figures with same letter or without letter do not differ significantly whereas figures with dissimilar letter differ significantly (as per DMRT)

Appendix XVII: Physio-chemical Properties of the Soil of Experimental Field, BRRI, Gazipur, 2009-2010.

Sample	Properties								
	FC %	BD gm/cm3	PH	N%	P ppm	K Meq/100 gm	Zn ppm	Ca Meq/100 gm	Org. Matter %
1	21	1.50	6.2	.08	10	0.15	0.50	5.0	2.27
2	22	1.48	6.4	.09	11	0.17	.75	7.5	2.18
3	20	1.45	6.1	.09	12	0.16	.60	7.0	2.30
4	22	1.50	6.3	.10	15	0.20	1.00	6.0	2.27
5	13	1.45	6.3	.10	14	0.19	.80	7.5	2.09
6	22	1.50	6.4	.08	11	0.20	1.10	7.0	2.35
7	21	1.52	6.0	08	13	0.20	1.30	6.5	2.31
8	23	1.45	6.0	.09	12	0.16	1.50	6.0	2.33
9	20	1.47	6.2	.09	10	0.14	1.40	5.5	2.10
10	22	1.50	6.4	.08	13	0.17	0.90	7.5	2.20
Range	20. 23	1.45-1.50	6.0-6.4	.08-1.0	10-15	0.14-.20	0.50-1.50	5.0-7.5	2.09-2.5

Appendix XVIII: Physio-chemical Properties of the Soil of Experimental field, BRRI, Regional Station, Shampur, Rajshahi, 2011

Sample	Properties				
	pH	N%	P ppm	Zn ppm	Org. Matter%
1	8.2	0.03	10.2	0.54	0.55
2	8.2	0.04	11.0	0.54	0.55
3	8.2	0.03	10.3	0.54	0.55
4	8.2	0.03	11.0	0.54	0.55
5	8.1	0.04	11.1	0.54	0.55
6	8.2	0.02	10.2	0.54	0.55
7	8.2	0.03	10.3	0.54	0.55
8	8.1	0.04	10.2	0.54	0.55
9	8.2	0.03	10.3	0.54	0.55
10	8.2	0.03	10.4	0.54	0.55
Range	8.1-8.2	0.03-0.04	10.2-11.1	0.54	0.55

Appendix XIV

Questionnaires

Study of On-farm water-saving Irrigation Techniques

1. Identification of Respondent:

Name:………………Father's Name:…………………..Age:……...............

Education:……………..Village:……………………Upazilla/Thana:..……

District:………………..Major Occupation:……………....….......…..Minor Occupation:……………Farming experience…………………........……....

2. Information about family size:

Sl. no.	Name	Relation with respondent	Age	Level of education	Occupation	
					Main	Subsidiary
1						
2						
3						
4						
5						
6						
7						
8						
9						

2. **Information about farm size (acre):** Own…………..Homestead area………..

Rented in……………..Rented out…………..Pond……………….Others…………

Rice production area: Inbred………………..Hybrid………………………………

3. Plot specific information:

Plot size (acre)……………Plot tenancy…………..Variety……Land type…………

Soil type……………..Seedling age……………Seedling (No./hill)………………..

Contact with extension workers (No./month)……..Transplanting date……..........…

Harvesting date…….

4. B Cost and return for the specific plot:

Items	Amount
Seedbed:	
Area (dec.)	
Ploughing & laddering (TK)	
Seed treatment cost (TK)	
Fertilizer cost (TK)	
Pesticides cost (TK)	
Irrigation cost (TK)	
Quantity of seed (kg)	
Seed price (Tk/kg)	
Labor (man-days)	
Family	
Hired	
Labor wage without food (Tk/man-days)	
Land preparation other than ploughing (man-days)	
Family	
Hired	
Labor wage without food (Tk/man-days)	
Land preparation (animal pair days)	
Family	
Hired	
Cost of animal pair days (Tk)	
Cost of ploughing and laddering by power tiller (Tk)	
Cost of land preparation (contact) [Tk]	
Seedling Uprooting &Transplanting:	
Labor of Seedling Uprooting &Trans (Tk/man-days)	
Family	
Hired	
Cost of seedling uprooting & trans.(contact) [Tk]	

5. Fertilizer used in main plot:

Fertilizer	Basal QTY(kg)	Top dress (kg)				Unit price (Tk/kg)
Urea						
USG						
TSP						
DAP						
MP						
Gypsum						
ZnSo4						
Cow dung (md)						

6. Irrigation in plot:

Type of irrigation	Cost (Tk.)	Labor				Wage rate (Tk./man-days)
	Fuel (Tk.)	Cash	Kind/ paddy	Family	Hired	
DTW/STW/LLP						
Done/basket						

7. Weeding:

Weeding	Labor		
	Family	Hired	Wage rate (Tk./man-days)
1st weeding			
2nd weeding			
3rd weeding			

8. Insecticides and herbicides use in the plot:

Items	Cost (Tk.)
Herbicides (including labor)	
Insecticides (including labor)	

9. Harvesting & Carrying:

Labor for carrying and carrying	
Family	
Hired	
Labor wage without food (Tk./man-days)	
Cost of harvesting and carrying (contract in Tk.)	

10. Threshing:

Labor for threshing (man-days)	
Family	
Hired	
Labor wage without food (Tk./man-days)	
Cost of threshing (contact) [Tk.]	
Cost of harvesting, carrying and threshing(contact) [Tk.]	

11. Drying & Storing:

Labor for drying & storing (man-days).	
Family	
Hired	
Labor wage without food (Tk./man-days)	

Rental value (Tk./season/unit)..

14. Plot yield:

Yield (md)		Price	
Paddy	Straw	Paddy (Tk./md)	Straw (Tk./kg)

15. Information about income generation:

Sl. no.	Source	Monthly/season	(Total Tk./year)	Year 2011
1	Rice			
2	Non-rice crop			
3	Petty business			
4	Livestock			
5	Income from labor			
6	Service			
7	Rickshaw/van plying			
8	Labor sell			
9	Carpentry			
10	Others			
11	Total			

16. Water availability problems at different crop growth stages

Crop stages	Year 2011
Land preparation	
Transplanting	
Vegetative	
Reproductive	

17. Frequency of irrigation application according to soil condition

Soil condition	Year 2011
With standing water	
Saturated(wet)	
Dry	

18. Average number of irrigation applications during the crop-growth period according to soil-water condition

Soil-water status	Year 2011
With standing water	
Saturated(wet)	
Dry	

19. Problems and constraints faced by farmers in AWD implementation:

(i) How do you irrigate AWD field?	
(ii)Do you follow Alternate wetting and drying (AWD)?	
(iii) How do you practice AWD? Detail…………	
(iii) When do you reapply water(when cracks develop in soil) Yes/No	
If not then how do you decide?	
(iv) Do you follow AWD for whole crop period (Yes/No)	
(v) If not then how long you follow AWD (indicate crop growth stage)	
(vi) If you follow AWD during vegetative stage then what is the common water depth (shallow irrigation o flooding)	
(vii) Any problem in practicing AWD?	
(viii) How many times do you irrigate when the soil is dry?	
(ix) How many times do you irrigate when the soil is wet or saturated?	
(x) How many times do you irrigate when the soil is with standing water?	
(xi) Have you got any training regarding AWD?(Yes/No)	
(xii) If yes, then how many times?	
(xii) Do you contract with extension worker or agent?	
(xiii) Have your own pump?	
(xiv) How much expensive to irrigate for a season?	
(xv) Do you think AWDI saves irrigation water?	
(xvi) Do you think AWDI environment-friendly technology?	
(xvii) what's your future planning about AWDI?	

20. Solution of those problems:

i)……………………………………………………………………………………

ii)……………………………………………………………………………………

iii)……………………………………………………………………………………

iv) ……………………………………………………………………………………

v)……………………………………………………………………………………

vi) ……………………………………………………………………………………

vii)……………………………………………………………………………………

Viii)……………………………………………………………………………………

Name of Enumerator:

Date: