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Water and Fertilizer Use Efficiency of Rice under Raised Bed Cultivation

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WATER AND FERTILIZER USE EFFICIENCY OF RICE UNDER RAISED BED CULTIVATION

SUBMITTED BY

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Bhuyan, M.H.H., Ferdousi, M.R., and Iqbal, M.T. (2013) Fertigation with bed planting increases yield and agronomic efficiency compare to conventional planting for transplanted boro rice (Oryza sativa). International Journal of Agricultural and Biological Engineering (Under Review).

Bhuyan, M.H.H., Ferdousi, M.R., and Iqbal, M.T. (2013) Utilization of urea super granule in raised bed versus prilled urea in conventional flat method for transplanted aman rice (*Oryza sativa*). Thai Journal of Agricultural Science (Under Review).

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ABSTRACT

Rice production is well known to be extremely demanding for water and fertilizer. The supplemental application of water and fertilizer are pre-requisites for higher water and fertilizer use efficiency. Conventional cultivation method lead to losses and reduced water and fertilizer use efficiency. That's why, the present study was undertaken to introduce advance cultivation technique. The aims of this study to investigate water and fertilizer use efficiency of rice under various fertilizer application methods such as fertilizer broadcasting, fertigation, deep placement of Urea Super Granule (USG) and foliar spray in raised bed planting compared to fertilizer broadcast in conventional planting for aman and boro season. Different field experiments were conducted during aman (summer, non-irrigated) season and boro (winter, irrigated) season. The rice variety Swarna and BR 28 were selected as a testing plant for aman and boro season, respectively. The experiments were laid out in a randomized complete block design (RCBD) with three replications. Results showed that foliar spray of N in raised bed planting provided best growth parameters compared to fertilizer broadcasting, fertigation, deep placement of USG in raised bed and fertilizer broadcast in conventional planting for aman season. Likewise, foliar spray of split N fertilizer in raised bed planting provided best yield components such as grains panicle^{-1} and 1000-grains weight compared to fertilizer broadcasting, fertigation, deep placement of USG in raised bed and fertilizer broadcast in conventional planting for aman season. Foliar spray of N in raised bed planting provided highest value of agronomic efficiency of fertilizer N for aman season rice. Fertilizer broadcast in raised bed planting produced highest water use efficiency for aman season rice. In the subsequent experiment, foliar spray in raised bed planting provided best growth parameters with respect to panicle length and non-bearing tiller m^{-2} compared to fertilizer broadcasting, fertigation and Urea Super Granule (USG) in raised bed and fertilizer broadcast in conventional planting for boro season. In addition, Split foliar application of N in raised bed planting gave highest value of agronomic efficiency of fertilizer N for boro season rice among other fertilizer application method. This study concluded that foliar spray in raised bed planting was best in both aman and boro season rice production in respect with growth, yield, water use and agronomic efficiency compared to fertilizer broadcasting, fertigation, deep placement of USG in raised bed planting and fertilizer broadcast in conventional planting.

Statement of Authorship

“Except where reference is made in the text of the thesis, this thesis contains no material published elsewhere or extracted in whole or in part from a thesis by which I have qualified for or been awarded another degree or diploma.

No other person’s work has been used without due acknowledgements in the main text of the thesis.

This thesis has not been submitted for the award of any degree or diploma in any other tertiary institution”.

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CERTIFICATE

Certified that this thesis, entitled '**Water and fertilizer use efficiency of rice under raised bed cultivation'** is a record of research work done independently by **Mr. Md. Halim Mahmud Bhuyan** under my guidance and supervision and that it has not previously formed the basis for the award of any degree, diploma, fellowship or associate ship to him.

Dr. Md. Toufiq Iqbal
Supervisor

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Dedicated
To

The memory of my beloved father late Md. Mosharaf Hossain Bhuyan

Chapter 1

General introduction

Chapter 1

General Introduction

1.1. BACKGROUND OF THE STUDY

In raised bed planting systems, crops are grown on the raised beds and irrigated by furrows. Raised bed planting system promotes crop intensification and diversification besides saving irrigation water. A study showed that raised bed system saved 30-40% irrigation water as compared to conventional flood irrigation practice (Mann and Meisner, 2003). Application of chemical fertilizers has played a pivotal role in increasing crop production all over the world. The relative efficiencies of the various methods depend on many factors. Broadcast application may be less effective than fertigation, deep placed urea super granule (USG) and foliar spray application. The application of nutrients through irrigation systems is called "fertigation," a contraction of fertilization and irrigation. The most common nutrient applied by fertigation is nitrogen (N). This technique can reduce fertilizer application costs by eliminating high operational requirement. It may also improve nutrient efficiency by applying them closer to when the plant needs them. Also, it could conceivably reduce leaching or denitrification (gaseous) losses of nitrogen and lower the luxury uptake of nutrients by plants. The farmers of Bangladesh usually use prilled urea (PU) for cultivation of crops. To improve fertilizer use efficiency, different types of fertilizer materials are becoming available day by day. Urea Super Granule (USG) is one of the nitrogenous fertilizers that is now available in our country and the farmers are using it for boro (winter) and aman (summer) rice (Nazrul *et al.* 2006). It was found that USG as an alternative source of N than PU in terms of efficiency in wetland rice. Bangladesh Rice Research Institute (1988) reported that the USG application is more effective than PU application. The loss of N by leaching and volatilization is minimal in USG and it supplies more N to crops than PU. It is not really clear when foliar feeding started, but after the development of water-soluble and liquid fertilisers farmers have begun to use these fertilisers with sprayers, the same as it is used with applications of pesticides. At the beginning, this technique of spraying nutrients was used for correcting deficiencies of minor elements. However, fast curing has shown that plants can absorb some elements through their tissue. As a result, foliar feeding has gone through further development. These days foliar feeding is considered among the major techniques used for plant nutrition, supplementing the ground application.

Fertilizer broadcast is a method which causes high nutrient losses and low uniformity of fertilizer. Application of fertilizer by fertigation, deep placement of USG and foliar spray in raised bed planting may provide an effective approach to increase water and fertilizer use efficiency of rice. Examine the effect of fertigation, deep placement USG and foliar spray in raised bed planting helps to develop good farming practice for sustainable rice production in Bangladesh and other rice growing countries in the world.

1.2. RATIONALE OF THE STUDY

In order to get maximum efficiency from fertilizers, it should not only be applied in proper time and in right manner but other aspects like methods of application should also be given careful consideration. The N P K requirements of different crops are different and even for a single crop, the nutrient requirements are not the same at different stages of growth. Broadcast fertilizer leaves more fertilizer available to weeds. It also enhances N losses by volatilization, denitrification, leaching and surface run-off. Broadcast fertilizer requires rainfall or irrigation to move N into the plant root zone. Moreover fertilizer broadcast leaves non mobile nutrients (P, K, and some micronutrients) almost totally on the soil surface, making them unavailable to the plant root system. These losses can be reduced by management practices like fertigation, deep placement of Urea Super Granule (USG) and foliar spray. In the cases of urea and diammonium phosphate application, losses may occur through emission of ammonia to the air. Thus, a technique like fertigation was used in this study. Fertigation technique increased nutrient absorption by plants and reduce extra amount of fertilizer applied. However, to reduce nitrogen loss, it is strongly considered that application of the USG is an important alternative that may increase the efficiency of N. In addition, foliar application of specific nutrients is a method used to improve the efficiency of fertilizer use and increase yields. The increased use of foliar fertilizers in crop production in the last decade is due in part to changes in production philosophy. Therefore, these methods of fertilizer application of this study were selected to examine the water and fertilizer use efficiency of rice compared to existing broadcast method.

Transplanting of rice on raised bed omits puddling and hence avoids the detrimental effects of puddling. The general practice of irrigation is through flooding, a lot of water goes waste as deep percolation beyond the root zone of the growing crop. The water that percolates into the soil carries with it the nitrogen applied to the crop as fertilizer resulting in very poor nitrogen usage efficiency. It is imperative to grow crops using less water without any adverse effect on crop productivity especially rice. In conventional method, for transplanting rice, land is prepared by puddling the soil. The Furrow Irrigated Raised Bed-planting System (FIRBS) is a method where cultivation of crops is done on raised beds and it suits the rice crop. Experiments conducted during the past years have shown that growing rice on raised bed leads to economy in the usage of seed, fertilizer and water. That's why the water and fertilizer use efficiency of rice under raised bed planting was selected as a study title.

1.3. RESEARCH QUESTIONS

This study will answer the following questions:

(a) Why is raised bed technique more suitable than conventional cultivation method?
(b) How raised bed planting reduced weed infestation than conventional planting?
(c) How raised bed planting saved irrigation water than conventional planting?
(d) What are the benefits of fertigation in raised bed planting compared to fertilizer broadcast in conventional planting?
(e) How fertigation in bed planting enhanced water use efficiency than conventional planting?
(f) What are the advantages of using USG compared to prilled urea (PU)?
(g) How USG increase fertilizers use efficiency?
(h) How USG increase water use efficiency compared to PU?

(i) What mechanisms involved regarding foliar fertilization uptake?

(j) How foliar spray increase water use efficiency compared to fertilizer broadcast in conventional method?

1.4. OBJECTIVES OF THIS STUDY

Most of the studies on water and fertilizer use efficiency of different fertilizer application methods of transplanted aman and boro rice have been conducted in conventional planting. Existing research may not be appropriate to understand the effect of different fertilizer application method in raised bed planting. Therefore, in this thesis different experimental studies have been conducted to identify the water and fertilizer use efficiency of transplanted aman and boro rice in raised bed planting compared to conventional planting with the following objectives:

i. To determine and compare the fertilizer use efficiency of different fertilizer application methods in raised bed and conventional planting of aman and boro season rice.
ii. To evaluate and compare the water use efficiency of different fertilizer application methods in raised bed and conventional planting of transplanting aman and boro season rice.
iii. To investigate water requirement for transplanted aman and boro season rice between different methods of fertilizer application in raised bed and conventional planting.
iv. To compare the growth and yield components of aman and boro season rice among different methods of fertilizer application in raised bed and conventional planting.

Chapter 2

Review of literature

Chapter 2

Review of literature

2.1 INTRODUCTION

During the last decade, practice of raised bed planting has been emerging with a greater pace in Indo-Gangetic Plain. The major concern of this system is to enhance the productivity and save the irrigation water. There are evidences for the greater adoption of this practice in the last decade in other parts of the world like high-yielding irrigated areas. Potential agronomic advantages of raised beds include improved soil structure due to reduced compaction through controlled trafficking and reduced water logging and timely machinery operations due to better surface drainage. Raised beds planting also provide the opportunity for mechanical weed control and improved fertilizer placement.

Studies in the USA have also shown considerable water savings with furrow-irrigated rice on beds (Tracy *et al*., 1993; Vories *et al*., 2002). Beecher *et al*. (2006) reported no water saving from the raised bed rice cultivation compared with conventional ponded rice grown on a flat layout. When grown on raised beds, a variety needs to be able to compensate for the loss in cropped area (caused by the relatively large row spacing between the beds) by producing more productive tillers (Singh *et al.,* 2003).

Little research work on the response of rice to different methods of fertilizers application has been carried out in the rice growing countries of the world including Bangladesh. Some studies on different urea application in conventional planting show positive result in growth and yield of rice (Alam *et al*. 2010; Hassunazzaman *et al*.2009; Hassunazzaman *et al*.2013).

A better understanding of the effects of different methods of urea application on rice in raised bed planting of Bangladeshi soils would facilitate the development of suitable soil management practices for better rice production than conventional planting. In this chapter, an attempt has been made to review the research done in Bangladesh and elsewhere related to the water and fertilizer use efficiency of rice under raised bed cultivation.

2.2 RAISED BED PLANTING IN RICE CULTIVATION

Raised bed planting technique is a new approach for sustainable rice production. Farmers may often cultivate crops such as rice and wheat on the raised beds. However, the practice of growing rice, the major water-using crop on raised beds was introduced only very recently in the Indo-Gangetic Plains (IGP) to reduce water use, conserve rainwater and improve system productivity. In furrow irrigated raised bed (FIRB) system, water moves horizontally from the furrows into the beds and is pulled upwards in the bed towards the soil surface by capillarity, evaporation and transpiration and downwards largely by gravity. In raised bed planting, management of irrigation water is improved, is simpler, and more efficient. On an average it uses, 30% less water than flat bed methods and improves crop yields by more than 20 % (Sayre *et al*. 2001; RWC. 2002; Mann and Meisner. 2003). Thus, raised bed planting in rice cultivation may open up new opportunities for better rice production than conventional cultivation method.

2.2.1 Fertilizer use efficiency in raised bed cultivation

Raised beds are widely used in agriculture and have proven to be an excellent option for rice farming. Raised beds offer answers to the soil and management constraints in the rice-wheat system of South Asia. Previous experimental work with raised-bed planting in Nepal and Bangladesh has shown improvements in the efficient use of nitrogen fertilizer, and reduced weed infestation (Lauren *et al.*2013). However, under flat planting conditions with flood irrigation, post emergence nitrogen fertilizer is normally broadcast on the soil surface, which leads to a low nitrogen use efficiency (about 20%). But with raised bed planting, nitrogen use efficiency can reach 23% by band applying nitrogen fertilizer (urea) into the furrows with machinery to deepen the fertilizer placement. The Nitrogen fertilizer uptake efficiency can also be improved by 15 % (Fahong *et al.*2005). Bed planting has been shown to improve fertilizer use efficiency, reduced weed infestation and lodging and it also reduces seed rate without sacrificing yield (Hobbs *et al.* 2000). Likewise, Pandey *et al.* (2000) stated that fertilizer use efficiency can be increased in raised bed because of better placement including top dress applications. Therefore, compared with conventional farmer's practice, permanent raised bed system improved fertilizer use efficiency by 20-25 percent (Singh *et al.*2009).

2.2.2 Water use efficiencies in raised bed for rice cultivation

Rice requires very large amounts of water under the existing conventional cultivation method in Bangladesh. However, due to growing demand in the domestic and industrial sectors, water is becoming increasingly scarce, and there is a need to develop 'water saving irrigation techniques' that require less irrigation input than the conventional cultivation method. The need to produce more rice with less water is crucial for food security for many Asian countries where water scarcity for agricultural use is increasing (Guerra *et al.* 1998). One of the most studied water saving irrigation techniques is the cultivation of rice on raised beds under soil saturation culture (SSC). This method involves growing rice on raised beds where water is maintained in 0.3-m-wide furrows at about 0.1 m below the bed surface (Borrell *et al.* 1997, Ockerby & Fukai 2001). Under raised bed systems the furrows can promote good soil aeration for the rice crop by facilitating drainage. Beds reduced irrigation and total water input by as much as 200–500 mm, which amounts to a 20–45% reduction in total water input compared with well watered treatments (Cabangon *et al.*2005). Better irrigation efficiency can be achieved by adopting the bed and furrow irrigation technique for growing row crops, with many benefits over conventional basin irrigation methods(Gill *et al.*2005).Moreover, farmer and researcher trials in the Indo-Gangetic plains suggest irrigation water savings of 12–60% for direct-seeded and transplanted rice on beds, with similar or lower yields for transplanted compared with puddle flooded transplanted rice, and usually slightly lower yields with direct seeded rice (Balasubramanian *et al.*, 2003; Gupta *et al.*, 2003; Hossain *et al.*, 2003; Jehangir *et al.*, 2002). However, many studies in the northwest Indo-Gangetic plains indicate little effect of rice on beds on water productivity (typically around 0.30–0.35 g kg^{-1}) as the decline in water input was accompanied by a similar decline in yield (Jehangir *et al.*, 2002; Sharma *et al.*, 2003; Singh *et al.*, 2003). Therefore, crops grown in the flat basins using the flood irrigation method causes application losses of around 25–40% (World Bank, 1997), the water use efficiencies are quite low. Causes of low water application efficiencies in conventional flood method include over-irrigation, improper irrigation methods and timing, non-specific irrigation scheduling and non leveled fields (Gill, 1994). Lauren *et al.* (2008) observed that the furrow irrigated raised bed system consistently reduced water inputs by 14-38% for rice relative to conventional cultivation methods. Thus, potential gains from growing rice on raised beds are considered to be associated with the increased water use efficiency of the cropping system (Dunn *et al.*2004).

2.2.3 Agronomic efficiency of N fertilizer for raised bed rice cultivation

Nitrogen fertilizer is an important source of nutrient for vegetative growth of paddy rice plant. Agronomic efficiency (kg grain per kg above ground plant nitrogen) and nitrogen use efficiency (kg grain per kg fertilizer N applied) are the indicators to examine grain yield production potential as influenced by nitrogen fertilizer application (Kongchum, 2005). Agronomic efficiency is also related to proper timing of fertilizer application and adequate N rates are critical in meeting plant needs and in improving N use efficiency (Limon-Ortega *et al.,* 2000). Latest research activities in India and Pakistan indicates that bed planting of rice-wheat rotation cultivation system reduces N loses and improved agronomic efficiency of N (Gupta *et al*., 2000; Hobbs and Gupta, 2003; Connor *et al*., 2003a). The agronomic efficiency of N was also very important under precision land levelling with raised bed planting technique compared to other practices (Jat *et al.*2011). Because, Mollah *et al.* (2009) found that the highest agronomic efficiency was resulted in bed planting compared to conventional planting for transplanted aman rice. They revealed that transplant aman rice could be saved 20% N fertilizer without losing yield. These savings were attained due to the higher N use efficiency in bed planting method which contributed higher agronomic efficiency of N than conventional cultivation method. Similarly, Khalesque *et al.* (2008) revealed that raised bed and conventional flat planting method produced N use efficiency of 40.99 and 38.67 kg grain ha^{-1} kg N up take ha^{-1}, respectively. They also demonstrated that bed planting produced higher fertilizer N recovery compared to conventional planting. Finally, Dobermann (2005) speculated that key factors for contributing improved agronomic efficiency includes: (i) increased yields and more vigorous crop growth associated with greater stress tolerance of modern cultivars, (ii) improved management of production factors other than N, and (iii) improved N fertilizer management. Thus, proper N fertilizer management practices and growth as well as yield attributing characteristics are related to the agronomic efficiency of fertilizer N for raised bed cultivation.

2.3 Fertigation technique for rice cultivation

Fertigation technique has now been spreaded all over the world. Fertigation technique enables accurate supply of water and nutrients to the individual plants. Golberg *et al.* (1971) reported that fertigation technique is the distribution of minerals and nutrients from point sources of irrigation to roots. However, the daily application rate of fertigation changes during the growing season and is planned to follow plant daily demands according to its nutrients uptake strategy. Nutrients elements are taken up according to plants demands at a specific development stage (Andre *et al.,* 1978 a,b). Fertigation scheduling depends upon climatic factor, soil type and the fertilizer requirement of the growing plants. The uptake rate of nutrients (N, P, K) during growth of field crops were summarized by Bar Yosef (1999). Climatic conditions, soil type, system design and length of the growing season determine the frequency of fertigation. The smaller the root volume the higher the necessary frequency of fertigation. At high temperature around the roots, nitrate-N is a safer N form during fertigation. At low root temperature NO_3^- accumulates in the roots, resulting in N deficiency (Ali *et al.,* 1994). Thus the concentration and form of N applied in fertigation should be adopted of the winter and summer season, and according to specific crops demand and sensitivity (Kafkafi, 2006). Fertigation also offers the benefits of supply the correct amount of nutrients to the crop at the time when they are must needed by the plants, directly into the root zone. Moreover, fertigation has specific advantages over band placement or broadcast fertilization (Kafkafi, 2006). These includes (1) Frequent supply of nutrients reduced fluctuations of nutrients concentration in the soil solution (2) Efficient and precise application of nutrients that matches changing plant physiological demand (3) Fertilizers are supplied only to the irrigated soil volume (4) Nutrients can be applied to the soil compensate for nitrogen leaching caused by excessive rains, when soil or crop conditions would prohibit entry into the field with conventional equipment. Thus, fertigation technique may be suitable options for rice production where rainfall is limited.

2.3.1 Fertilizer use efficiency in fertigation technique

Fertigation as an attractive technology in modern irrigated agriculture that increases fertilizer use efficiency (Papadoulos.1994). It has been reported that with fertigation, N fertilizer use efficiency can be enhanced to 80–90% (Papadoulos.1994). Through fertigation, water and nutrients are applied to the root zone of the crop, where they are mostly needed, normally resulting in a better water and fertilizer use efficiency than with conventional irrigation and fertilization methods. On the other hand, fertigation is ideally suited for controlling the placement, time and rate of fertilizer application (Goldberg *et al.* 1976). By controlling these N fertilization practices it is possible to enhance the fertilizer nitrogen utilization efficiency and crop production and to minimize potential N losses (Papadopoulos. 2000). Fertigation also causes reduction in soil salinity due to the intermittent use of fertilizers, the soil solution conditions are improved particularly for salt sensitive crops (Papadopoulos. 1987). In this system fertilizer solution is distributed evenly in irrigation. The availability of nutrients is very high therefore the efficiency is more. In fertigation technique, liquid fertilizer as well as water soluble fertilizers is used. By this method, fertilizer use efficiency is increased from 80 to 90% (Venkatesh.2013). Likewise, TNAU (2013) describe advantages of fertigation that fertilizer use efficiency through fertigation ranges between 80 to 90%, which helps to save a minimum of 25% nutrients. This study also revealed that fertilizer use efficiency by nitrogen fertilizer was 30 to 50% in soil application and 95% in fertigation. The advantages of supplying mineral nutrients to crop roots using fertigation include greater control over where and when nutrients are delivered, leading to greater fertilizer use efficiency (Treeby *et al.*2011). Thus, fertigation technique can improved fertilizer use efficiency compared to other technique (Cassman, 2005).

2.3.2 Water use efficiency in fertigation technique

Introduction of fertigation techniques has been gained popularity in recent years, particularly in the widely-spread high-value crops. Precisely in controlled quantity and at appropriate time directly to the root zone as per crop needs at different growth stages. Fertigation techniques enhanced water use efficiency (Das *et al.* 2010). Water use efficiency is the ratio between yield and water consumption during the growing period (Moujabber *et al.* 2002). The fertigation technique has higher water use efficiency than the soil application of the similar rate (Mohammad *et al.* 2002). A study showed that the total water use efficiency for the conventional fertilization was the lowest (24 kg ha^{-1} cm^{-1}) and was the highest for the fertigation (51 kg ha^{-1} cm^{-1}) (Sagheb and Hobbi,2002). Water use efficiency can be improved through fertigation technique with micro irrigation systems (Papadopoulos, 1996). The efficient use of irrigation water is essential to keep food supply in balance with the increasing demand on environmentally sound practices (Papadopoulos, 1993). The scarcity of water underlined the need for improvement of water use efficiency (WUE) and it has been demonstrated that fertigation with modern irrigation technology could help substantially in this respect (Wabel *et al.* 2002). Fertigation seems to be the best available technique to balance water supply for economical crops (Janat and Somi, 2002).

Bringing more area under irrigation will largely depend upon efficient use of water. In this context, fertigation technique has most significant role to achieve higher water use efficiency (Jata and Nedunchezhiyan, 2013). Adoption of fertigation technique may help to increase the irrigated area and water use efficiency (Sivanappan, 1985). Fertigation technique had favourable and marked influence on water use efficiency for the hybrid rice. Fertigation recorded significantly higher water use efficiency than soil application of fertilizer (Kumar *et al.* 2011). By fertigation amount of water is also reduced substantially (TNAU, 2013). Therefore, water can be used efficiently in the fertigation technique.

2.3.3 Agronomic efficiency in the fertigation technique

Agronomic efficiency is an important criterion, which helps in measuring the response of certain inputs in quantitative terms (Aslam *et al.*2009). A study showed that applying both N and P by fertigation technique resulted in an increase of 240% agronomic efficiency (AE) over top-dressed N and P fertilizers application in conventional cultivation method (Alam *et al.* 2005). Similarly, Iqbal *et al.* (2003) indicated that the superiority of fertigation technique over conventional cultivation method. They revealed that agronomic efficiency were higher in fertigation than broadcast method. Likewise, other study showed that the premier agronomic efficiency was recorded in fertigation technique 147.7 % more than broadcasting method (Memon *et al.* 2011). Regardless of that higher agronomic efficiency over broadcasting method for the extra nitrogen were found for N fertigation by Rekha *et al.* 2005. However, agronomic efficiency decreased with increase in fertilizer N rate at conventional method and observed higher by fertigation over broadcasting method (Zhang *et al.* 2009). In addition, the application of fertilizer through fertigation could be a useful technique to increase 65% agronomic efficiency of N over broadcast method (Iqbal *et al.* 2013*)*. Moreover, significantly the highest agronomic efficiency was recorded with fertigation and the lowest with broadcast method (Shah *et al.*, 2006). Furthermore, Aslam *et al.* (2009) found that agronomic efficiency by fertigation was 18.2, whereas for fertigation was 12.3. Therefore, agronomic efficiency could be improved by fertigation technique compared to fertilizer broadcasting method.

2.4 Urea Super Granule (USG) technology for rice cultivation

Urea is the most dominant nitrogen fertilizer being used in the world. However, broadcasting application of urea fertilizer favours high losses of N, particularly through volatilization losses (60-70%). To avoid N losses as well as urea, point placement of USG has been developed and being popularized in Bangladesh, particularly in rice cultivation (Haque, 2002). Urea Deep Placement (UDP) is the practice of placing briquetted urea 5-7 cm deep in puddle transplanted rice fields, at spacing of 40 cm. The USGs are applied once growing season— a week after transplanting rice seedlings. One USG is applied geometrical between 4 rice stands. They are oval compacted pellets produced by briquetting granular urea using briquetting machines to 1.8 gm or 2.7 gm (Figure 2.1). The amount of N releases from the USG slowly and is placed out reach of weeds' roots (Tarfa and Kiger, 2013). It is reported that the efficiency of urea nitrogen in wetland rice is only about 30% of the applied urea and even less in many cases (Prasad and De Datta, 1979). However, the nature and magnitude of nitrogen loss largely depends upon the sources of nitrogenous fertilizer and its methods of application. Rymar *et al.* (1989) reported that slow release fertilizers i.e., nitrogen as encapsulated urea, granular oxamide and oxamide powder are more effective than the conventional fertilizers as ammonium sulphate or urea. Regardless of that the USG, a slow releasing nitrogenous fertilizer is being marketed in Bangladesh as a source of nitrogen. Deep placement of USG in rice field instead of broadcasting conventional prilled urea can increase the efficiency of applied nitrogen by improving absorption to a certain extent (Basak and Pandit, 2011). Application of half the dose of nitrogen fertilizer (as USG) would give higher grain yield and thus, reduced the cost of N-fertilizer. Moreover, pollution due to application of nitrogen fertilizer is reduced (BINA, 2012). De Datta (1984) reported that deep placement of fertilizer in reduced zone had been considered to be the most efficient method to increase N efficiency in low land rice. Similarly deep placement of USG was found to be superior to urea alone (Maskey *et al.,* 1992). Das and Singh (1994) also reported that the grain yield and N use efficiency of rice was more when USG was deep placed as compared with USG broadcasted and incorporated and prilled urea applied in three splits. Likewise, Craswell and De Dattta (1980) reported that the deep placement of fertilizer is generally more efficient than the traditional split application of urea. Deep placement of USG and slow release of nitrogen can reduce ammonia loss (Mikkelsen *et al.* 1978). Also, deep placement of USG reduces denitrification process and minimizes urea concentration in irrigation water, thus reduce nitrogen loss and improve nitrogen use efficiency by 20-25% for better grain production (Pillai, 1981). Slow release nitrogenous fertilizer increased the yield and N uptake by rice due to less loss of N from the soil (Ramaswamy, *et al.* 1987). Moreover, placement of USG in the root zone is the most effective method for increasing the N use efficiency and rice yield (Prasad *et al.* 1982). Thus, urea super granule technology is more efficient than prilled urea for rice cultivation.

Figure 2.1: Photographic views of urea super granule

2.4.1 Fertilizer use efficiency in Urea Super Granule (USG) technique

Research on deep placement of N fertilizer started in the 1940's (Mitsui, 1954) and many studies at the International Rice Research Institute (IRRI) and other institutions (De Datta, 1978) have demonstrated that fertilizer use efficiency in flooded rice production could be significantly increased by placing fertilizer N in the reduced soil layer at depths ranging from 5-15 cm (Obcemea *et al.,* 1984), except on soil with high percolation rates (Kaytal *et al.,* 1985). In Asia, prilled urea (PU) was conventionally surface broadcast by farmers to the transplanted rice, but its use was very inefficient because much of nitrogen was lost by ammonia volatilization. Bowen (2008) reported the results of over 500 on farm trials in Bangladesh to evaluate the performance of deep placed USG which showed that use of the USG has resulted in increased fertilizer use efficiency and decreased use of fertilizer (70 kg N ha^{-1}) in the boro season. The N fertilizer use efficiency significantly influenced by forms and doses of nitrogen. The USG showed higher N fertilizer use efficiency than the PU. The PU gave N fertilizer use efficiency up to 36% whereas the USG gave N fertilizer use efficiency up to 63% (Mamun *et al*. 2013). Similarly, Zia *et al.* (1992) demonstrated that deep placement of USG improving the efficiency of nitrogen fertilizer use for lowland rice than with the application of urea in puddle soil. TNAU (2013) suggested that in case of flooded field's use of slow release nitrogenous fertilisers like USG's minimised loss of nitrogen that can be increased fertilizer use efficiency. Khalil *et al.* (2006) suggested that the USG technique could increase fertilizer N use efficiency and decrease gaseous N losses over the PU. Mohanty *et al.* (1989) reported that the efficiency of applied N could be increased by point placement of USG in the subsoil particularly in soils of low permeability. The loss of N was 20% less from the USG's than the PU. Natarajan and Manickam (1991) also confirmed that more fertilizer N was utilized by rice with single deep placement of USG's than with split applied PU. The ammonia loss was less than 5% when fertilizer N was placed in soil at 10 cm depth by placement, or banding techniques compared to broadcast. Thus, deep placement of

USG technique can improve fertilizer use efficiency compared to PU broadcast in conventional cultivation method.

2.4.2 Water use efficiency in Urea Super Granule (USG) technique

The water use efficiency (WUE) can be described on various scales from leaf of a plant to farm level (Sinclair *et al.* 1984). Water use efficiency is an important physiological characteristic that is related to the ability of crop to cope with water stress. In simple terms, it is characterized by crop yield per unit of water used. The WUE can also be defined as biomass produced per unit area per unit water evapo-transpired. The biomass is usually determined as dry weight rather than as fresh weight, therefore the several methods are commonly used to determine water use efficiency (Frank *et al.* 1987). Fertilizer has an important role in enhancing water use efficiency of rainfed crops (Hegde *et al.* 1978). Application of fertilizer permits deeper penetration of soil by roots and thus the amount of water available for extraction increased (Sharma *et al.* 2007). It was reported that water was used more rapidly from fertilizer than unfertilized soil, while the water supply was ample, and more slowly after the water was exhausted (Linscott *et al.*1962). Fertilizer application has been found to increase water use efficiency through the physiological processes like water uptake, evapo-transpiration and transpiration (Prihar and Gajri.1988). Planting crop on raised beds is a practice for increasing water use efficiency. The crop is planted on beds and water is applied in furrows. The comparable or higher yields are obtained with saving of about 25 to 30 % water. This had been practiced in different cereal crops like rice, wheat and soybean (Singh *et al.*2012). Deep placement of USG has greater benefit over surface split application on soils with moderate to heavy texture, low permeability and percolation rate high cation exchange capacity and pH (Mohanty *et al.*1999). The efficiency of irrigation water use can be improved by making the right decisions regarding - crop type, irrigation scheduling, irrigation method, soil enhancement measures and source of water (FAO, 1986). Thus, water use efficiency for USG on raised bed may be a useful tool to determine better agronomic practice for sustainable rice production in comparison to conventional cultivation technique.

2.4.3 Agronomic efficiency in Urea Super Granule (USG) technique

Agronomic efficiency (AE) of applied N may be defined as an additional grain yield per kg of N applied over no N application i.e. control (Peng *et al.* 1996). The highest mean agronomic efficiency of granular urea was 29.2 kg kg^{-1} N and lowest mean value (20.4 kg kg^{-1} N) of agronomic efficiency was recorded by prilled urea (PU) broadcasting (Sirisena *et al.* 2002). Agronomic efficiency was considerably higher with USG compared to PU application (Choudhury *et al.* 1994). The AE of N was significantly improved under precision land leveling with raised bed planting technique compared to other practices (Jat *et al.* 2011). The proper deep placement of USG in transplanted rice makes it agronomical efficient compared to PU application (Savant and Stangel.1990). Similarly, Schnier *et al.* (1988) found that agronomic efficiency of USG deep point placed was 38 (kg grain kg^{-1} N applied) and 24 (kg grain kg^{-1} N applied) for fertilizer broadcast. Improved AE with USG relative to PU has been demonstrated by many others study (Sudjadi *et al.*1984). However, results of the analysis indicated that the AE of USG is greater than the efficiency of PU. The average agronomic efficiencies from the 162 experiments were equal to 15.9 and 21.0 kg of paddy kg^{-1} of N applied in the form of PU and USG, respectively (Martinez *et al.* 1981). Moreover, Savant and Stangel (1985) suggested that the agronomic efficiency of deep placed USG can be ensured by considered-(i) Use of USG in soil with low percolation rate (5-10 mm day^{-1}) and cation exchange capacity (CEC) more than 10 meq 100g^{-1} soil. (ii) Use of N responsive modern varieties with short to medium duration. (iii) Use 1 to 2 gm USG for each alternate four hills. The rate of basal deep placement of USG should be between 30 and 80 kg N ha^{-1}. Close the holes at the placement sites when puddling is improper or inadequate and when deep placement of USG is done a few days after transplanting. Thus, deep placed of USG can improve agronomic efficiency compared to PU broadcast in conventional cultivation method.

2.5 Introduction of foliar fertilizer application technology for crop production

Introduction of foliar fertilization is an important tool for the sustainable and productive management of crops (Fernandez *et al*. 2013). The ability of plant leaves to absorb water and nutrients was recognized approximately three centuries ago (Fernandez and Eichert, 2009). The application of nutrient solutions to the foliage of plants as an alternative means to fertilize crops in agriculture was noted in the early 19th century (Fernandez *et al*. 2013).

Judicious application of nitrogen is essential to obtain higher yield (Hasanuzzaman *et al.* 2009) .In terms of nutrient absorption, foliar fertilization can be from 8 to 20 times as efficient as ground application (Anonymous,2009). Spray of urea is not a common practice for field crop production. However, during nursery production foliar application can correct nitrogen deficiencies, decrease the amount of total nitrogen requirement (Giroux, 1984).

Foliar application of fertilizers has been increasing day by day due to the development of concentrated and highly soluble fertilizers and the increasing use of spraying machinery (Anowar *et al.*1998). Spraying of fertilizers solutions is most desirable when plant nutrients are absorbed with great difficulty from the soil through roots and when nutrients are required in the smallest possible quantities. Moreover, when ground application of fertilizers is no longer possible as a result of tall growth of some plants, spray application may serve the most practical and useful means to supply nutrients to the plant (Hasanuzzaman *et al*. 2009).

Furthermore foliar fertilization is theoretically more environmentally friendly, immediate and target-oriented than soil fertilization since nutrients can be directly delivered to plant tissues during critical stages of plants growth. However, while the need to correct a deficiency may be well defined, determining the efficacy of the foliar fertilization can be much more effective (Fernandez *et al*. 2013). Therefore, introduction of foliar fertilization technique can be an effective technique for sustainable crop production.

2.5.1 Mechanisms of penetration of liquid fertilizer into the plant due to foliar spray

The processes by which a nutrient solution applied to the foliage is ultimately utilized by the plant include foliar adsorption, cuticular penetration, uptake and absorption into the metabolically active cellular compartments in the leaf and then translocation as well as utilization of the absorbed nutrient by the plant. From a practical perspective, it is often difficult to distinguish between these processes though many trials using the term foliar uptake often refer to an increase in tissue nutrient content without directly measuring the relative biological benefit of the application to the plant as a whole. This confusion and imprecision greatly complicates the interpretation of both controlled environment laboratory and field experimentation and has undoubtedly resulted in inconsistent. Therefore, the challenges facing practitioners of foliar fertilization and for researchers attempting to understand the factors that determine the efficacy of foliar fertilizers are great (Fernandez *et al.* 2013).

The aerial surface of the plant is characterized by a complex and diverse array of specialized chemical and physical adaptation that serve to enhance plant tolerance to an extensive list of factors including unfavourable irradiation, temperatures, vapour pressure deficits, wind, herbivore, physical damage, dust, rain, pollutants, anthropogenic chemicals, insects and pathogens. Aerial plant surface and structures are also well adapted to control the passage of water vapour and gases and to restrict the loss of nutrients, metabolites and water from the plant to the environment under unfavourable conditions. These characteristics of aerial plant surfaces that allow them to protect the plant from environmental stress and to regulate water, gas and nutrient exchange also provide the mechanisms affecting the uptake of foliar applied nutrients. Aerial plant surfaces are generally covered by a hydrophobic cuticle and very often possess modified epidermal cell such as trichomes or stomata. The outer surface of the cuticles is covered by waxes that may confer a hydrophobic character to the plant's surface. The degree of hydrophobicity and polarity of the plant surface is determined by the species, chemistry and topography which are also influenced by the epidermal cell structure at a microscopic level. Like leaves, fruits are also protected by a cuticle and may contain epidermal structures such as stomata or trichomic that influences the transpiration pathway and contributes to its conductance of water (and nutrients) which are critical factor for fruit growth and quality (Gibert *et al.* 2005; Morandi *et al.* 2010).

A transverse section of a typical angiosperm leaf consists of a cuticle that covers the upper and lower epidermal cell layers enclosing the mesophile as illustrated in Figure 2.2 with a microscopic image shown in Figure 2.3E. Leaves differ in their structure between species but generally consist of palisade parenchyma near the upper epidermis layer and the lower epidermis. There are large intercellular spaces among the mesophile cells, especially in the spongy parenchyma (Epstein and Bloom, 2005). The epidermis is a compact layer with sometimes two or more layers of cells (Figure 2.3F) and the principal features, related to nutrient and water transport, which characterize the stomata.

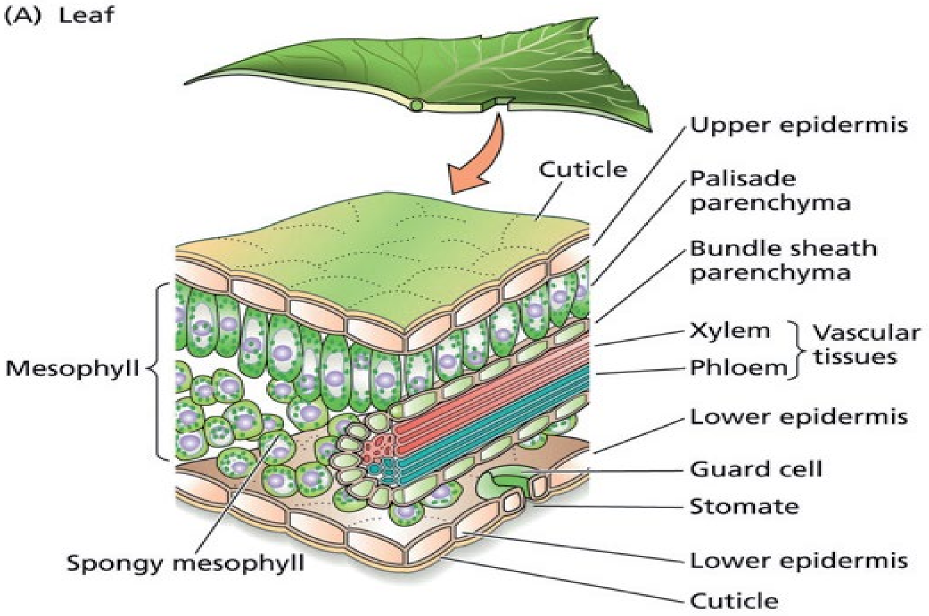

Figure 2.2. Typical structure of dicotyledonous leaf including vascular bundle in a leaf vein. (Adapted from Fernandez *et al.* 2013).

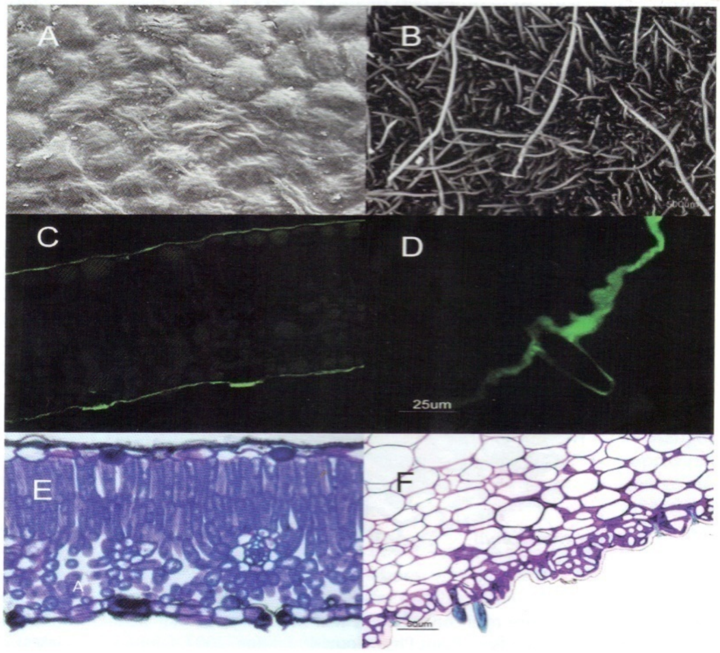

Figure 2.3.Micrographs of a peach leaf versus a peach fruit. Surface topography of a leaf (A) and fruit (B) observed by Scanning Electron Microscopy (SEM) (×400). Transversal section of a peach leaf and a peach fruit after tissue staining with auramine 0 (UV light observation; C and D) and toluidine blue (light transmission; E and F) (micrographs A and B by V. Fernandez; c and E by G.Lopez-Casado; D and F by E.Dominguez) (Adapted from Fernandez *et al.* 2013).

2.5.1.1 Role of plant morphology and structure on foliar fertilization

The fundamental requirement for an effective foliar nutrient spray is that the active ingredient penetrates the plant surface so it can become metabolically active in the target cells where the nutrient is required. A foliar applied liquid fertilizer may cross the plant leaf surface via the cuticle per along cuticular cracks or imperfections, or through modified epidermal structures such as stomata, trichomes or lenticels. The cuticle proves an effective barrier against the loss of water and yet, at the same time, it proves an equally effective one against the uptake of foliar applied chemicals. The waxes present in cuticle, either deposited onto, or embedded into, the cuticular matrix are mainly mixtures of ling chain aliphatic molecules and of aromatic (ring-chain) compounds (Samuels *et al.* 2008). Wax composition has been observed to vary between different plant species and organs, the stage of development and the prevailing environmental conditions (Koch *et al.* 2006; Kosma *et al.* 2009). Stomata are modified epidermal cells that control leaf gaseous exchange and transpiration water losses. They are generally present on the abaxial leaf side but in occur on the upper leaf side (Eichert and Fernandez, 2011). Stomata also occur in the epidermis of many crops at lower densities compared to the leaves. Stomatal density, morphology and functionality may vary between different plant species and organ and can be affected by stress factors such as nutrient deficiencies (Fernandez *et al.* 2008a; Will *et al.* 2011), or the prevailing environmental conditions such as light intensity and quality as illustrated by changes seen in plants growing in natural or artificial shade (Aranda *et al.* 2001; Hunsche *et al.* 2010).

2.5.2. Fertilizer use efficiency in foliar spray technique

Foliar fertilizer application is a technique using which the nutrients, especially the micronutrients can be provided to crop plants in the form of a spray where the nutrients readily reach the actual site of activity (Kołota and Osińska, 2000). Foliar fertilizer application results in better nutrients absorption by the plants than rest of the methods thus increasing fertilizer use efficiency (Kamel *et al.,* 1987). Foliar application of specific nutrients is a method that used to improve the efficiency of fertilizer use (Oosterhuis, 2009). The efficiency of foliar fertilization can be influenced by type of fertilizer, concentration and pH of the solution, use of adjuvant and compatibility with other agrochemicals. Wilson (2000) reported that the efficiency of foliar fertilizer applications can be as high as 95% and the efficiency will always be significantly higher when compared to soil applied fertilizer. Foliar applied products can be used to quickly correct a nutrient imbalance and stimulate the plant to increase nutrient uptake from the root system. It has been observed that utilization of fertilizers especially urea applied through soil is not as effective as when it is supplied to the plant through foliage along with soil application (Mosluh *et al.* 1978). Nitrogen use efficiency is very low and the recovery of N in wetland rice seldom exceeds 40% (De Datta and Buresh, 1989). Many factors determine the fertilizer efficiency for rice crop during cultivation of such as soil, cultivar, season, environment, planting time, water management, weed control, cropping pattern, source, form, rate, time of application and method of application (De Datta, 1978). In many cases aerial spray of nutrients is preferred and gives quicker and better results than the soil application (Jamal *et al.* 2006). Recently foliar application of nutrients has become an important practice in the production of crops while application of fertilizers to the soil remains the basic method of feeding the majority of the

crop plants (Alam *et al.* 2010). Foliar urea application provides significantly higher N efficiency than soil applied (Rosecrance *et al.* 1998a) but repeated applications are needed to deliver total annual N requirement (Johnson *et al.* 2001). Foliar applications may sometimes facilitate to the rapid absorption of mineral elements, avoiding the occurrence of soil interactions that may limit root uptake due to nutrient immobilization in the soil. Additionally, foliar fertilization may stimulate the capability of the root system to absorb nutrients from the soil solution (Kerin and Berova, 2003; Kannan 2010; Fernández and Eichert, 2009; McCall 1980; Lovatt ,1999; Kuepper, 2003; Taiz and Zeiger, 1998). Moreover, Wittwer *et al.* (1963) stated that where nutrients are fixed in the soil (phosphorus, iron, manganese) or leached (nitrogen, sulphur, potassium), foliar application can be more efficient than that of soil application. Thus, it can be said that foliar spray can improve fertilizer use efficiency compared to soil application of fertilizer.

2.5.3. Agronomic efficiency in foliar spray technique

This is an important criterion, which determines the vehemence of certain inputs on per unit basis in quantitative terms (Tandon, 1987) and is calculated by subtracting the yield of control from the yield recorded in fertilized treatment and dividing by rate of fertilizer application (Shah *et al.* 2001). Since, it is a yield dependant trait; hence those parameters influencing crop harvests would also be responsible for bringing likely changes in agronomic performance of the applied nutrients. Highest agronomic efficiency of 13.80 kg grain kg^{-1} N^{-1} was recorded in the treatments sprayed with 4% urea solution compared to soil application of N (Shah *et al.* 2003). Agronomic efficiency of foliar spray was higher compared to other treatment (Rutendo, 2012). Rutendo (2012) also stated that agronomic efficiency decreased with increase in the rate of foliar fertilizer applied. The foliar application treatments, although having high agronomic efficiency compared to soil application (NRCS, 2007*)*. Foliar application gave better agronomic efficiency (13.12 kg of paddy kg^{-1} of fertilizer applied) compared to control treatment (Ali *et al.* 2005). Sharpe's Soil Service (2013) stated agronomic benefits of foliar spray**.** Studies show that 40 to 70% of nitrogen applied is taken up by the crop in any given year. The challenge for farmers is to gain more from each pound of nutrient applied. Timing of application and accuracy of placement become important considerations. Applying nutrients as close as possible to the time when the crop can use them generally helps to maximize nutrient uptake. Positioning the nutrients in the root zone can also improve nutrient utilization by the crop. However, the agronomic efficiency of N fertilizer is dependent on several factors such as, for instance, the cultivar and N source used, soil type, management adopted and climatic conditions of the study area (Reis *et al.*2012). Thus, it can be concluded that foliar spray can improve agronomic efficiency compared to soil application of fertilizer.

2.6. CONCLUDING REMARKS AND RESEARCH GAP

Raised bed cultivation practice is using for some crops like wheat and other vegetables but not common in rice production. Fertilizer application in raised bed generally results in a better rate of nutrient utilization by the crop and, thus, higher nitrogen use efficiency will need to compare with a broadcast application. However, broadcasted urea or ammonium-N may remain on the surface during dry periods and lose of nitrogen as ammonia where exposed to sunshine on neutral to alkaline soils. Deep placement of Urea Super Granule (USG) in the reduced zone of flooded-rice soils is an N-conserving technology that contributes to more efficient use of N. In fertigation, fertilization is combined with irrigation, and the nutrients are supplied together with the water. In reality, it is a type of liquid fertilization. Beyond maximizing yields and quality of crops, the aim of fertigation is to improve utilization of nutrients and lower water consumption, while minimizing pollution by surplus nutrients. The saving may be possible up to 30–50 percent of water and nutrients through fertigation technique. Foliar fertilization is generally recommended for supplying additional N, Mg and micronutrients, but it can also be used to provide P, K and S. The main advantage of foliar fertilization is the immediate uptake of the nutrients applied. Thus, above discussion visualize raised bed cultivation, USG, fertigation and foliar technique for rice production.

Nitrogen is the major essential plant nutrient and key input for rice production Proper nitrogen fertilization is an important management practice which can increase yield, water and fertilizer use efficiency of rice .Many researches were done to find out the effect of different fertilizer application method in conventional planting for rice cultivation. However, no study was taken to identify the effect of different nitrogen fertilizer application method in raised bed cultivation system. Therefore, this present thesis was undertaken to compare the effect of different fertilizer application method on water and fertilizer use efficiency in raised bed planting for both transplanted aman and boro rice cultivation.

Chapter 3

Yield and growth response of transplanted aman rice under raised bed over conventional cultivation method

Chapter 3

Yield and growth response to transplanted aman rice under raised bed over conventional cultivation method

3.1. INTRODUCTION

Rice is the major staple food in Bangladesh and the majority of its food grain comes from paddy rice. About 80% of the cropped area of Bangladesh is used for rice cultivation, with annual production of 43.50 million metric tons in total acreage of 11.20 million ha. The average yield of rice in Bangladesh is 3.90 t ha^{-1} (BBS, 2011). This yield of paddy rice in Bangladesh is much lower than existing world average. Rice production is currently in stagnant condition because farmers do not fully follow the improved techniques in an integrated way, which creates a yield gap. In this situation, farmers, researchers, and scientists are looking for new methods or technologies to get higher rice yield. To meet the increasing food demand, rice production must be increased and continued.

Bed planting rice production systems may be a technique for improving the yield. In this system, the land is prepared conventionally and raised bed as well as furrows are prepared manually or using a raised bed planting machine. Crops are planted in rows on top of the raised beds, and irrigation water is applied in the furrows between the beds. Water moves horizontally from the furrows into the beds. This system is often considered for growing high-value crops that are more sensitive to temporary water logging stress. In conventional tillage system for transplanting rice, land is prepared by puddling the soil. For direct seeding of pre germinated rice seed, land is also prepared by puddling. Puddling and continuing inundation until maturity have significant effects on the physical, chemical, and biological status of soils that influence the growing conditions for all crops in the system (Sharma and Datta.,1986). Puddling softens soil, facilitates transplanting of rice, promotes root growth, aids weed control, and reduces water and nutrients losses through leaching. Though puddling offers significant advantages to rice it may not be necessary in fine textured soils (Utomo *et al.* 1994).

Preliminary research on bed planting at the Bangladesh Rice Research Institute showed positive responses (Elahi *et al.* 2001). Therefore, bed planting for rice production systems is an emerging researchable issue in Bangladesh. Determination of different agronomic aspects of bed planting for rice production systems like appropriate width of beds, optimum number of plant rows per bed seed and fertilizer rates are essential for development of sustainable resource conservation technologies. The aim of this study was to compare raised bed planting with conventional cultivation practice for water and fertilizer use efficiency of transplanted aman rice. It will be hypothesized that bed planting method will have more yield, water and fertilizer use efficiency than conventional cultivation method.

3.2. MATERIALS AND METHODS

3.2.1. Experimental site and soil

The experiment was conducted at the farmer's field at Chuadanga district of Bangladesh during August to November, 2011. The soil of the experiment plot was silt loam with pH 7.30.

3.2.2. Cultivator

The aman rice variety Swarna was used as an experimental plant. Because, this variety is widely used by the farmers in the Chuadanga district of Bangladesh.

3.2.3. Experimental design

The experiment was laid out in a randomized complete block design with three replications. The combination of treatments was randomly distributed in the plots within a block. The unit plot size was $8m^2$ (4m × 2m).

3.2.4. Land preparation

The land was prepared conventionally. The final land preparation was done by ploughing and cross ploughing by two wheel power tiller with two laddering before two days of transplanting. One day before
transplanting the plots was laid out as per experimental design.

3.2.5. Bed preparation

Raised bed and furrows were made manually by spade following the conventional land preparation. According to the treatments 60 cm (centre to centre of furrows) width bed were made. For the 60 cm bed, the top of the raised bed were 35 cm and furrow between the beds were 25 cm. The beds were made one day before transplanting the plots according to lay out of the experiment. The heights of beds were 15 cm.

3.2.6. Fertilizer application

The crop was fertilized with N, P, K, S, and Zn at the rates of 100, 20, 35, 10, and 4 kg ha^{-1}, respectively. The sources of N, P, K, S, and Zn were urea, TSP, MP, gypsum, and $ZnSO_4$, respectively. The all of TSP, MP, gypsum, and $ZnSO_4$ were applied at the time of final land preparation as basal dose in the plots with conventional treatment. In the plots with bed planting treatments, the basal doses were applied before transplanting on the top of the beds. The urea was top dressed in three equal splits at 15, 30, and 50 days after transplanting (DAT).

3.2.7. Transplanting of seedlings

Thirty day old seedlings were uprooted from the seedbed without making any injury to them and transplanted on the same day. Two to three seedlings hill^{-1} were transplanted maintaining row spacing at 25 cm and plant to plant spacing of 15 cm. Irrigation water was applied one day before transplanting between the furrows of bed to make the soil soft.

3.2.8. Irrigation

Though transplant aman rice was a rain fed crop, supplemental irrigation was needed for preparationof the plots with conventional treatment and for the bed planting of all plots. Another supplemental irrigation was done for all plots at flowering stage of rice.

3.2.9. Weeding

Manual weeding was done twice in the transplant aman rice field during growth period. The plots wereweeded at 15 and 30 DAT. Weed samples from each plot were collected at the time of weeding for comparing weed population and dry biomass yield of different treatments.

3.2.10. Pest control

The rice was infested by stem borer at tillering stage and by rice bug at grain filling stage. Furadan 5G at the rate of 10 kg ha^{-1} was applied at 40 DAS and Malathion 57 EC 5G at the rate of 1 L ha^{-1} was applied at grain filling stage to control stem borer and rice bug, respectively.

3.2.11. Crop harvesting

Rice was harvested and threshed by using pedal thresher.

3.2.12. Statistical analysis of data

The experiment was conducted with randomized complete block design replicated three times. All statistical analysis was conducted by *t* test.

3.2 RESULTS

3.2.1. Grain yield and yield components

The yield increase by bed planting over conventional method was 16%. A similar finding was also found in panicles, grains per panicle and 1000 gm grain wt. Raised bed planting had more 50 panicle number m^{-2}, 21 grain number per panicle and 0.19 gm in 1000 grain wt than conventional method. Likewise, grain yield and yield components significantly ($P \leq 0.01$) differed between bed planting and the conventional method (Table 3.1).

Table 3.1: Grain yield and yield components with respect to fertilizer application

Method of Fertilizer application	Yield and yield components			
	Grain yield (t ha^{-1})	panicles m^{-2} (no)	Grains $panicle^{-1}$ (no)	1000 grain wt (gm)
Fertilizer broadcasting in raised bed	5.83a	417a	161a	23.01a
Fertilizer broadcasting in conventional plot	4.90b	367b	140b	22.82b
Coefficient of Variation CV (%)	5.31	4.10	4.59	5.30
Level of significance	**	**	**	**

Where ** represent probability of ≤ 0.01. Values were means of three replicates. In a column figures with same letter do not differ significantly whereas figures with dissimilar letter differ significantly ($P \leq 0.01$).

3.3.2. Other plant attributes

Planting method affected plant height, panicle length, nonbearing tillers m^{-2}, sterility percentage, straw yield and harvest index of transplanted aman rice. Plant height, panicle length and harvest index were higher in bed planting than conventional method. On the contrary, nonbearing tillers m^{-2} and sterility percentage were higher in conventional method than bed planting. Likewise, lower number of nonbearing tillers m^{-2} was recorded in bed planting treatments than conventional method. Bed planting significantly ($P \leq 0.01$) reduced the sterility percentage as compared to conventional method. In bed planting, sterility was lower as compared to conventional method. The lower sterility might be accountable for higher grains in bed planting. Bed planting resulted in higher harvest index than conventional method (Table 3.2).

Table 3.2: Plant biomass with respect to raised bed and conventional method

Method of fertilizer application	Plant height (cm)	Panicle length (cm)	Non-bearing tiller (no-m^{-2})	Sterility (%)	Straw yield (tha^{-1})	Harvest index
Fertilizer broadcasting in raised bed	87.23a	24.88a	67b	10.16b	5.60a	0.51a
Fertilizer broadcasting in conventional plot	86.38b	24.30b	78a	12.41a	4.92b	0.49b
Coefficient of Variation CV (%)	3.25	3.47	4.25	6.14	4.52	5.30
Level of significance	**	**	**	**	**	**

Where ** represent probability of ≤ 0.01. Values were means of three replicates. In a column figures with same letter do not differ significantly whereas figures with dissimilar letter differ significantly ($P \leq 0.01$).

3.3.3. Tiller production

Transplanting of aman rice under different planting method affected the number of tillers m^{-2} of rice. The increasing trend of tillers m^{-2} was continued to 50 DAT. At 50 DAT, both planting methods attained the highest number of tiller m^{-2} and then started declining up to 100

DAT. Interestingly, tiller number did not differ significantly up to 40 days after transplanting in both raised bed and transplanting method. However, both methods differ significantly ($P \leq 0.01$) from 60 to 100 days after transplanting (Table 3.3).

Table 3.3: Effect of tiller production in both raised bed and conventional method

Method of fertilizer application	Tiller (number m^{-2}) at days after transplanting								
	20	30	40	50	60	70	80	90	100
Fertilizer broadcasting in raised bed	235a	543a	588a	626a	514a	502a	595a	489a	484a
Fertilizer broadcasting in conventional plot	196a	367a	441a	522b	490b	470b	462b	450b	445b
Coefficient of Variation CV (%)	6.58	6.95	7.10	4.55	5.37	6.45	7.25	6.48	5.17
Level of sig.	n.s.	n.s.	n.s.	**	*	**	**	**	**

Where n.s. *and **represent probability of >0.05, ≤0.05, and ≤0.01, respectively. Values were means of three replicates. In a column figures with same letter do not differ significantly, whereas figures with dissimilar letter differ significantly ($P \leq 0.01$).

3.3.4. Leaf area index

Planting method affected the leaf area index of transplant aman rice recorded at different DAT. Plant-to-plant distance in rows also influenced the leaf area index measured at different stages of crop growth. The highest leaf area index (LAI) was achieved at flowering stage (80 DAT) by planting method. It was also revealed that at early stage of crop growth the leaf area index of bed planting treatments was lower than conventional method and at maximum tillering stage to next stages. Result showed that LAI did not differ significantly between two methods at 20 days after transplanting. However, LAI differs significantly ($P \leq 0.01$) between two methods from 40 to 100 DAT (Table 3.4).

Table 3.4: Effect of leaf area index in both raised bed and conventional method

Method of fertilizer application	LAI at different DAT				
	20	40	60	80	100
Fertilizer broadcasting in raised bed	0.60a	4.96b	6.57b	8.35b	6.26b
Fertilizer broadcasting in conventional plot	1.32a	6.23a	12.47a	12.62a	9.47a
Coefficient of Variation CV (%)	4.52	6.28	7.45	8.25	5.17
Level of significance.	n.s.	**	**	n.s.	*

Where n.s. *and **represent probability of >0.05, ≤0.05, and ≤0.01, respectively. Values were means of three replicates. In a column figures with same letter do not differ significantly whereas figures with dissimilar letter differ significantly ($P \leq 0.01$).

3.3.5. Dry matter production

Planting method affected the dry matter production of transplanted aman rice recorded at different days after transplanting (DAT). In the first date of measurement (20DAT) it was observed that the conventional method produced higher dry matter yield than bed planting. Likewise, at the final date (100 DAT) highest dry matter production was also recorded in conventional method than bed planting method. However, dry matter production differs significantly ($P \leq 0.01$) at different days after transplanting except 60 and 70 DAT in both methods (Table 3.5).

Table 3.5: Effect of dry matter production in both raised bed and conventional method

Method of fertilizer application	Dry matter production (g m^{-2}) at different days after transplanting (DAT)								
	20	30	40	50	60	70	80	90	100
Fertilizer broadcasting in raised bed	75b	218b	617b	734b	1162a	1450a	1765b	2083b	2250b
Fertilizer broadcasting in conventional plot	107a	317a	835a	1160a	2282a	2825a	3970a	4724a	5101a
Coefficient of variation CV (%)	6.45	7.45	6.33	8.45	7.10	4.58	5.29	7.11	4.56
Level of significance	**	**	**	**	n.s.	n.s.	*	**	**

Where n.s. * and **represent probability of >0.05, ≤0.05, and ≤0.01, respectively. Values were means of three replicates. In a column figures with same letter do not differ significantly whereas figures with dissimilar letter differ significantly ($P \leq 0.01$).

3.3.6. Crop growth rate

At the initial stage (20 to 40DAT), the crop growth rate in bed planting was lower than conventional method. The greatest crop growth was observed at 50 to 60DAT in both planting method. However, crop growth rate significantly ($P \leq 0.01$) differed between both methods at all DAT (Table 3.6).

Table 3.6: Effect of crop growth rate in both raised bed and conventional method

Method of fertilizer application	Crop growth rate (g m^{-2} day^{-1}) at different days after transplanting (DAT)							
	20-30	30-40	40-50	50-60	60-70	70-80	80-90	90-100
Fertilizer broadcasting in raised bed	14.3b	39.9b	11.8a	42.8b	28.8b	31.5a	31.80b	16.70b
Fertilizer broadcasting in conventional plot	21a	51.8a	2.5b	111.2a	54.3a	04.5b	75.4a	37.7a
Coefficient of Variation CV (%)	5.26	5.78	6.10	4.88	6.49	6.70	8.20	4.91
Level of significance	**	**	**	**	**	**	**	**

Where **represents probability of ≤ 0.01. Values were means of three replicates. In a column figures with same letter do not differ significantly, whereas figures with dissimilar letter differ significantly ($P \leq 0.01$).

3.3.7. Weed population

Weed population and dry biomass were greatly influenced by different planting methods of transplanted aman rice. The bed planting method reduced weed population resulting in lower dry biomass than the

conventional method. The conventional method had significantly ($P \leq 0.01$) higher weed vegetation than the raised bed method (Table 3.7).

Table 3.7: Effect of weed growth in both raised bed and conventional method

Method of fertilizer application	Weed vegetation	
	Weed vegetation population (number m^{-2})	Dry biomass (kg ha^{-1})
Fertilizer broadcasting in raised bed	123b	113.3b
Fertilizer broadcasting in conventional plot	380a	337a
Coefficient of Variation CV (%)	8.14	6.47
Level of significance	**	**

Where ** represents probability of ≤0.01. In a column figures with same letter do not differ significantly, whereas figures with dissimilar letter differ significantly ($P \leq 0.01$).

3.3.8. Irrigation water

Amount of water required for different irrigations differed remarkably between the conventional and
bed planting methods. The conventional method received the higher amount of water at every irrigation and total amount was 142.66 cm. In bed planting method total amount received was 100.47 cm. Result showed that total water savings by bed over conventional method were 42%. At transplanting and reproductive stage, conventional method required significantly ($P \leq 0.01$) higher irrigation water than
raised bed method (Table 3.8).

Table 3.8: Irrigation water savings by bed planting of rice production over conventional method

Method of fertilizer application	Water required at different times of irrigation (cm)					Water saved over conventional method (%)
	Land preparation	Transplanting	Reproductive stage	Rainfall	Total	
Fertilizer broadcasting in raised bed	-	6.35a	41.62b	52.50a	100.47b	42%
Fertilizer broadcasting in conventional plot	13.06	6.20b	70.90a	52.50a	142.66a	
Coefficient of Variation CV (%)	-	3.54	7.25	6.33	4.37	
Level of significance	-	**	**	n.s.	**	

Where n.s. and **represent probability of >0.05 and ≤0.01, respectively. In a column figures with same letter do not differ significantly, whereas figures with dissimilar letter differ significantly ($P \leq 0.01$).

3.3.9. Water use efficiency

Water use efficiency for grain production and biomass production in bed planting was 51 kg ha $^{-1}$cm^{-1} and 114 kg ha $^{-1}$cm^{-1}, respectively. In contrast, water use efficiency for grain production and biomass production in conventional planting was 29 and 69 kg ha $^{-1}$cm^{-1}, respectively. However, water used efficiency for grain production and biomass production by bed planting over conventional was 57% and 61%, respectively (Table 3.9). In addition, water use efficiency for grain production is calculated by grain yield (kg ha^{-1}) to irrigation required (cm). Likewise, water use efficiency for biomass production is calculated by grain yield (kg ha^{-1}) plus straw yield (kg ha^{-1}) to irrigation required (cm).

Table 3.9: Water use efficiency in both raised bed and conventional method

Method of fertilizer application	Water use efficiency savings by bed planting of rice over conventional method	
	Water use efficiency for grain production (kg ha $^{-1}$cm^{-1})	Water use efficiency for biomass production (kg ha $^{-1}$cm^{-1})
Fertilizer broadcasting in raised bed	51a	114a
Fertilizer broadcasting in conventional plot	29b	69b
Coefficient of Variation CV (%)	5.12	3.99
Level of sig.	**	*

Where * and **represent probability of ≤0.05 and ≤0.01, respectively. Values were means of three replicates. In a column figures with same letter do not differ significantly, whereas figures with dissimilar letter differ significantly ($P \leq 0.01$).

3.3.10. Agronomic efficiency of nitrogen fertilizer

Agronomic efficiency (AE) of nitrogen fertilizer in raised bed was 32.15%. On the other hand AE for conventional plot was 27%. So, AE in raised bed was 20% higher than conventional plot (Table 3.10). In addition, AE of nitrogen fertilizer was calculated by the following equation:

$AE = (GYN_a – GYL_0)/NR$

Where, GYN_a is grain yield (kg ha^{-1}) with addition of nutrient.
GYL_0 is grain yield (kg ha^{-1}) without addition of nutrient.
NR is rate of added nutrient.

Table 3.10: Agronomic efficiency of fertilizer in both bed and conventional method

Method of Fertilizer application	Agronomic efficiency of fertilizer (%)
Fertilizer application broadcasting in raised bed	32.15
Fertilizer application broadcasting in conventional plot	27

3.4. DISCUSSION

3.4.1. Bed planting method produces higher biomass and yield than conventional method

The number of panicles m^{-2} was significantly ($P \leq 0.01$) higher in bed planting over conventional method. The difference of panicles number was 50 m^{-2} between these methods (Table 3.1). Bed planting method produced significantly ($P \leq 0.01$) higher grains panicle than conventional method. Likewise, Borrell *et al.* (1998) found that panicles number m^{-2} in rice plant for raised bed planting and flooded method was 228 and 210, respectively. They also found that panicle number per plant in raised bed and flooded methods was 2.3 and 2.0, respectively. They speculated that raised bed method has the potential to better utilize water and nutrients than conventional methods. This may result higher panicle number per plant in raised bed than conventional method. Tiller production in raised bed was significantly ($P \leq 0.01$) greater in bed planting over conventional method (Table 3.3). Singh *et al.* (2009) found that number of tillers of rice plant is almost double in bed planting over conventional method. They suggested that rice plant was generally sustained on the beds relative to conventional methods could be due to more rapid drying of the beds than flats, due to greater surface area and the greater concentration of roots in the bed tops. Weight of 1000 grain was also significantly higher in bed planting than conventional method (Table 3.1). Yadav *et al.* (2002), Zhongming and Fahong (2005), and Meisner *et al.* (2005) reported similar results. Likewise, Choudhury *et al.* (2007) found that 1000 grain weight (gm) in flat bed and raised bed was 20.0 and 20.5, respectively. They speculated that higher grain production in raised bed than flat method could be due to management and geometry of bed, less weed population, and better crop establishment. Raised bed planting method had 0.93 t ha^{-1} higher rice production than conventional method (Table 3.1). The yield increased by bed planting in transplant aman rice compared to conventional method was also reported by Hobbs and Gupta (2003), Balasubramanian *et al.*(2003), Meisner *et al.*(2005), and Jat and Sharma(2005). Likewise, Tang *et al.* (2005) also reported that bed planting method significantly increased rice yield by 6.7% compared with traditional cropping technique. Moreover, Ockerby and Fukai (2001) confirmed that yield of rice grown on raised beds was greater than rice grown in conventional method. They advised that effective N fertilizer utilized by rice paddy plants influenced better rice production in raised bed system. Other study speculated that potential agronomic advances of beds include improved soil structure due to reduced compaction through controlled trafficking and reduced water logging condition is responsible for improved rice production (Humphreys *et al.* 2005). Likewise, Govaerts *et al.* (2006) also suggested that bed planting provides a natural opportunity to reduce compaction by confining traffic to the furrow bottoms that increased rice production.

3.4.2. Bed planting method has less weed growth than conventional method

Weed production was significantly ($P \leq 0.01$) lower in bed planting than conventional method. Likewise, existing weed vegetation was significantly ($P \leq 0.01$) lower in raised bed planting than conventional method (Table 3.7). Singh *et al.* (2008) found that total weed dry weight and weed density were lower in raised bed planting method as compared to conventionally puddled transplanted rice. Similarly, Ram *et al.* (2005) also found lower weed biomass in raised beds than the conventional method. They speculated that the low number of weeds in beds might be due to dry top surface of beds that inhibited the weed growth. However, my speculation is that, at the time of bed preparation, the top soils of the furrows were mulched to the raised beds, which drastically reduced the weeds in furrow. Another probable cause was that the soil was not disturbed in the zero tillage systems under bed planting method. Moreover, other speculation is that this difference of weed growth between bed planting and conventional method may be due to agronomic management practices. In bed planting method, rice plants were grown in wet conditions while in conventional methods, rice plants were grown under standing water condition. This difference in weed growth between these two methods could also have been due to the contrasting weed flora and soil moisture conditions of fields. Likewise, Hobbs (2001) opined that bed planting method reduces weed growth compared with convention flat-bed planting method. He also suggested that bed planting provides additional options to farmers for controlling weeds. Similarly, Jat *et al.* (2005) suggested that planting of crops on raised bed systems reduces weed competition over conventional method. By adopting raised bed system, fertilizers are banded close to the rows enhancing crop accessibility to nutrient and competitiveness over weeds. The higher fertilizer used efficiency through better placement of fertilizer and faster drying of the top portion of raised bed is responsible for reduced infestation.

3.4.3. Input water use

The differences in total water use between these two methods were 42% higher in conventional over bed planting method for the entire cropping period (Table 3.8). Similarly, Thompson *et al*. (2003) grew rice on both raised beds and flat layout in small plots. They found that irrigation water savings of about 14% using beds compared with flat layout. Studies in the USA have also shown considerable water saving with furrow irrigated rice on raised bed over conventional flooding method (Vories *et al*. 2002). Likewise, Beecher *et al.* (2006) found that water use in flat and raised bed methods were 18.7 and 15.1ML ha^{-1}, respectively. They recommended that there is a good scope for saving water while maintaining yield on suitable rice soil through the use of raised beds. In another study, Boulal *et al.* (2012) speculated that compared to conventional method, the introduction of the raised bed planting system resulted in higher soil resistance to the penetration in the upper soil profile. This may protect deep percolation of irrigation water in the field. Regardless of that Fahong *et al.* (2004) suggested that the better performance of raised bed over conventional methods was considered to be due to reduced water logging, improved soil physical properties, reduced lodging, and decreased incidence of disease. However, my speculation is that the advantages come from the fact that irrigation water advances faster on bed planting soil than in a tilled soil and less water percolation loss in bed planting method over conventional method.

3.5. CONCLUSIONS

This study concludes that raised beds increased rice yield 16% than by the conventional tillage on the flat. Raised bed also reduced irrigation water requirement by 42% and so increased irrigation efficiency. This findings conclude that water and fertilizer use efficiency for grain production and crop productivity were higher in bed planting than conventional method. The potential gains from growing rice production on raised beds are considered to be associated with better agronomic management than conventional method. Also, the crust problem on the soil surface was eliminated and soil physical status was greatly improved in bed planting plot over conventional flat system. Based on the findings of this single season experiment, high yielding aman rice (depends on both irrigation and rainfall) crops have been successfully grown on raised bed, however, this research needs further validation. In this perspective, further study was conducted to investigate yield and growth response of transplanted boro rice (completely depends on irrigation) under conventional and bed planting method. Therefore, further research about raised bed over conventional method will be focused on water and fertilizer use efficiency for boro rice (irrigated) production (Chapter 7).

Chapter 4

Fertigation in bed- A practice for efficient fertilizer and water management over flooded irrigation in conventional planting

Chapter 4

Fertigation in bed- A practice for efficient fertilizer and water management over flooded irrigation in conventional planting

4.1. INTRODUCTION

Applying a portion of a crop's nitrogen (N) requirement with irrigation water is recognized best management practice to reduce nitrate leaching losses for some crops (De Datta and Buresh, 1989). This practice is called nitrogen chemigation but is more commonly referred to as fertigation (Young and Hargett, 1984).

The rate and time of fertilizer N application can be better controlled with fertigation i.e. application of fertilizer N through irrigation water (Papadopoulos, 2000). Fertilizer N utilization efficiency was improved with fertigation through simultaneous management of both irrigation water and N application (Hargert *et al.* 1978; Starck *et al.* 1993; Muchow and Sinclair 1994; Mohammad *et al.* 1999).

Extensive fertigation research on most vegetables crops is available (Hayens, 1985). However, no research has been conducted yet about fertigation technique in rasied bed with transplanted aman rice production. My previous studies showed that raised bed planting method had higher yield and water use efficiency than conventional method (Chapter 3) .Under this circumstance, the present study was undertaken to achieve the following objectives. (i) To explore the comparative advantages of using N-fertilizer mix with furrow water in raised bed over N-broadcast in conventional planting for transplanted aman rice production (ii) To examine the differences in yield and growth response of transplanted aman rice between two techniques (iii) To compare the water and fertilizer use efficiency for fertigation over conventional technique. It was hypothesized that fertigation technique in raised bed will be more efficient than conventional flat method for transplanted aman rice production.

4.2. MATERIALS AND METHODS

4.2.1. Experimental site

The experiment was conducted at the farmer's field in Daulatdiar, Chuadanga district of Bangladesh during aman season (July 2011 to November 2011). Geographically, the experimental area is located at $23^0$39' N latitude and $88^0$49' E longitudes at a mean elevation of 11.58 m above the sea level. The monthly average value of air temperature, relative humidity, rainfall and sunshine hours were 21.16^{0}C, 86.06%, 136.50 mm and 149.50 hrs respectively in the experimental site. The soil was silt loam in texture having pH 7.30.

4.2.2. Treatments and experimental design

Three treatments comparing fertilizer application method for rice were conducted concurrently in the same land. Treatment-1: urea (nitrogenous fertilizer) mix with furrow water in raised bed, Treatment-2: fertilizer broadcasting in conventional planting, Treatment-3: control (without addition of any nutrient). In raised bed planting method furrow were made manually by spade. The top of the beds were 35 cm. Each bed was 2m long. Each plot consisted of six beds. The height of the bed was 15 cm. The seedlings were transplanted on the top of the bed. For the beds, seedlings were transplanted in two rows at 25cm apart on the top of beds keeping 5 cm at each edge. In conventional planting method, nitrogen fertilizer was broadcasted. Flood irrigation system was practiced in conventional method. The width and depth of furrow was 25 and 15 cm, respectively. The furrow to furrow (center to center) distance was 60 cm. The buffers between the plots were 100 cm. The experiment was carried out in a randomized complete block design (RCBD) with three replications. The unit plot size was 8 m^2 (4m×2m). To prevent seepage flows between plots, polythene sheets were installed in the centre of the bunds down to a depth of 40 cm.

4.2.3. Cultural practices

The transplanted aman rice was fertilized with N, P, K, S and Zn at the rates of 66, 5, 18, 6 and 0.5 kg ha^{-1}, respectively (Fertilizer recommendation guide, 2005). The sources of N, P, K, S and Zn were urea, Triple Super Phosphate (TSP), Murate of Potash (MP), Gypsum and $ZnSO_4$, respectively. Whole TSP, MP, gypsum and $ZnSO_4$ were applied at the time of final land preparation as basal dose in conventional planting method. In raised bed planting treatment, the basal doses were applied before transplanting seedlings on the top of beds. Thirty days old seedlings were uprooted from the seedbed and transplanted on the same day. Two to three seedlings $hill^{-1}$ were transplanted and maintained 25 cm × 15 cm spacing. The aman rice variety Swarna was used as experimental crop. Irrigation water was applied using plastic water pot. In raised bed planting, irrigation was applied every alternate day to keep the root zone close to field capacity throughout the rice plant growing season. In conventional planting method, standing water of 3-7 cm depth was maintained from establishment to one week before harvest. In all treatments, last irrigation was applied about one week before harvest. The land was prepared conventionally. All plots were weeded manually twice during plant growing period. The collected weed samples were used for comparing weed density and dry biomass of different treatments. Necessary steps were taken to keep the plots insect and disease free.

4.2.4. Yield and yield components

To measure grain yields, 1 m^2 area was selected from each plot for harvesting. Border areas of all sides of the plot were excluded to avoid border competition effects. The grain weights were adjusted to 14% moisture for rice through natural drying. The dry weights of straw of all crops were recorded. Both grain and straw yields were expressed in t ha^{-1}. Other yield components were also measured.

4.2.5. Leaf area index (LAI)

To measure LAI, from each plot of rice, plant sample of 0.25 m^2 were collected from outside of the harvest area excluding brother plant rows at 20 days intervals. Whole sample plants were uprooted. For transplanted aman rice, six hills were collected following the same procedure and the second top most tillers were used as sample tillers. Green leaves of sample tillers were removed. Precautions were taken to keep the leaves from drying and curling before the leaf area was measured. The leaf area of sample tillers was measured by using an automatic leaf area meter. Other green leaves from the each sample were removed from the tillers. Then leaves from the sample tillers and leaves from the other tillers of the samples were dried and weighed separately. The LAI was computed by using the method given by Yoshida *et al.* (1976) as follow:

Leaf area of the sample =

$$\frac{\text{Total leaf area of the sample tillers (cm}^2\text{)} \times \text{Dry wt. of all leaves (g)}}{\text{Dry wt. of leaves from sample tillers (g)}}$$

Where, dry wt. of all leaves = dry wt. of sample leaves + dry wt. of remaining leaves

$$\text{LAI} = \frac{\text{Leaf area of the sample (cm}^2\text{)}}{\text{Area of land covered by the sample (cm}^2\text{)}}$$

4.2.6. Water use efficiency

Water use efficiency for grain and biomass production was calculated by the following equations:

Water use efficiency for grain production (kg ha $^{-1}$cm^{-1})

= grain yield (kg ha^{-1}) / total water required (cm)

Water use efficiency for biomass production (kg ha $^{-1}$cm^{-1})

= grain yield (kg/ha) + straw yield (kg ha^{-1})/ total water required (cm)

4.2.7. Agronomic efficiency of fertilizer

Agronomic efficiency (AE) of fertilizer was calculated by the following equation:

$AE = GY_{NA} - GY_{N0}/N_R$

Where $GY_{NA=}$ Grain yield (kg ha^{-1}) with addition of nutrient

GY_{N0}= Grain yield (kg ha^{-1}) without addition of nutrient

N_R= Rate of added nutrient (kg ha^{-1})

4.2.8. Harvest index (HI)

Harvest index were computed by dividing the grain yield by the total dry mater (total of grain yield and straw yield) as follows:

$$\text{HI}= \frac{Grain Yield}{Grainyield + Straw Yield}$$

4.2.9. Dry matter production

Dry matter yield and growth were measured from the same samples collected of LAI. The shoot and root of whole sample were separated. The plant samples were dried in an oven at 80^0 C until to reach a constant dry weight. Total dry matter was expressed in g m^{-2} and crop growth rate in g day $^{-1}m^{-2}$.

4.2.10. Tiller production

Three sample areas, on square meter each, were marked by bamboo stick in each plot to count total tiller production at different stages of growth and panicle per meter squire at maturity. Tiller number was counted at 10 days intervals staring from 20 DAT to maturity.

4.2.11. Measurement of field water status (FWS)

Field water status (FWS) was measured by using a ruler to maintain constant water head in furrows. Water depth was monitored at 2-day intervals from transplanting to maturity. Water consumption referred to water input and it was calculated from the sum of effective rainfall and irrigation application from transplanting to harvest (Bouman and Tuong, 2001). In all treatments, the amount of applied irrigation water was measured with a plastic water measuring pot.

4.2.12. Statistical analysis of data

Data were analysed following standard statistical procedure and means of treatments were compared based on the least significant difference test (LSD) at the 0.05 probability level.

4.3. RESULTS

4.3.1. Grain yield and yield components

The yield increased by nitrogen fertilizer mix with furrow water in bed planting over conventional method was 16.21%. A similar finding was also found in panicles, grains per panicle and 1000 gm grain wt. Nitrogen fertilizer mix with furrow water in bed planting had more than 44 panicle number m^{-2} , 27 grain number panicle^{-1} and 0.14 gm in 1000 grain wt than conventional method (Table 4.1).

Table 4.1: Grain yield and yield components with respect to nitrogen fertilizer mix with furrow water in bed and conventional method.

Method of Fertilizer application	Yield and yield components			
	Grain yield (t ha^{-1})	panicles/m^2 (no)	Grains/panicle (no)	1000 grain wt (gm)
Nitrogen fertilizer mix with furrow water in raised bed	5.09 a	320a	167a	23.02
Fertilizer broadcasting in conventional planting	4.38b	276b	140b	22.88
LSD at 5%	0.08	5.40	3.34	1.26
Level of significance	**	**	**	n.s.

Where ** represent probability of ≤ 0.01 and n.s. represents probability of >0.05. Values were means of three replicates. In a column figures with same letter do not differ significantly whereas figures with dissimilar letter differ significantly ($P \leq 0.01$).

4.3.2 Other plant attributes

Planting method affected plant height, panicle length, non-bearing tillers m^{-2}, sterility percentage, straw yield and harvest index of rice. Plant height, panicle length and harvest index were higher by nitrogen fertilizer mix with furrow water in bed planting than conventional method. Likewise, higher number of non-bearing tillers m^{-2} was recorded by nitrogen fertilizer mix with furrow water in bed planting treatments than conventional method. Nitrogen fertilizer mix with furrow water in bed planting significantly reduced the sterility percentage compared to conventional method. In bed planting sterility was lower. The lower sterility might be accountable for higher grains in bed planting. Bed planting resulted in higher harvest index than conventional method (Table 4.2).

Table 4.2: Plant biomass with respect to nitrogen fertilizer mix with furrow water in raised bed and conventional method

Method of fertilizer application	Plant height (cm)	Panicle length (cm)	Non-bearing tiller (nom^{-2})	Sterility (%)	Straw yield (t ha^{-1})	Harvest index
Nitrogen fertilizer mix with furrow water in raised bed	89.03a	25.75a	73a	9.14b	4.99	0.50
Fertilizer broadcasting in conventional planting	86.38b	24.30b	59b	12.41a	4.92	0.47
LSD at 5%	1.43	0.36	2.62	0.40	0.93	0.00
Level of significance	*	**	**	**	n.s.	n.s.

Where ** represent probability of ≤ 0.01 and n.s. represents probability of >0.05. Values were means of three replicates. In a column figures with same letter do not differ significantly whereas figures with dissimilar letter differ significantly ($P \leq 0.01$).

4.3.3 Tiller production

Transplanting of aman rice under different planting method affected the number of tillers m^{-2} of rice. The increasing trend of tiller m^{-2} was continued to 50 DAT by both planting method. At 50 DAT both planting method attained the highest number of tiller m^{-2} and then started declining up to 100 DAT. However, both method differ significantly (*P* ≤ 0.01) from 30 to 100 days after transplanting (Table 4.3).

Table 4.3: Effect of tiller production by nitrogen fertilizer mix with furrow water in raised bed and conventional method

Method of fertilizer application	Tiller (number m^{-2}) at days after transplanting								
	20	30	40	50	60	70	80	90	100
Nitrogen fertilizer mix with furrow water in raised bed	84	190b	425a	415a	410a	407a	402a	398a	393a
Fertilizer broadcasting in conventional planting	88	205a	371b	363b	354b	349b	342b	339b	335b
LSD at 5%	3.82	2.62	24.92	5.40	9.97	9.66	2.62	2.62	2.93
Level of significance	n.s.	**	*	**	**	**	**	**	**

Where ** represent probability of ≤ 0.01 and n.s. represents probability of > 0.05. Values were means of three replicates. In a column figures with same letter do not differ significantly whereas figures with dissimilar letter differ significantly (*P* ≤ 0.01).

4.3.4 Leaf area index

Planting method affected the leaf area index (LAI) of transplant aman rice recorded at different days after transplanting (DAT). Plant-to-Plant distance in rows also influenced the leaf area index measured at different stages of crop growth. The highest leaf area index was achieved at 80 DAT by conventional planting method. After 80 DAT the leaf area index was started declined and continued to 100 DAT by nitrogen fertilizer mix with furrow water. It was also revealed that at early stage of crop growth the leaf area index by nitrogen fertilizer mix with furrow water in bed planting treatments was lower than conventional method. The highest LAI was achieved in conventional method was 80 DAT. After 80 DAT the LAI was started declined and continued to 100 DAT by conventional method. However, LAI differ significantly (*P* ≤ 0.01) between two methods from 20 to 80 DAT (Table 4.4).

Table 4.4: Effect of leaf area index by nitrogen fertilizer mix with furrow water in raised bed and conventional method

Method of fertilizer application	LAI at different DAT				
	20	40	60	80	100
Nitrogen fertilizer mix with furrow water in raised bed	0.21b	2.13b	3.09b	4.36b	3.001
Fertilizer broadcasting in conventional planting	0.38a	2.47a	4.92a	4.97a	3.78
LSD at 5%	0.00	0.12	0.12	0.09	0.00
Level of significance	**	**	**	**	n.s.

Where *, ** and n.s. represents probability of ≤ 0.001, ≤ 0.01 and > 0.05, respectively. Values were means of three replicates. In a column figures with same letter do not differ significantly whereas figures with dissimilar letter differ significantly (*P* ≤ 0.01).

4.3.5 Dry matter production

Planting method affected the dry matter production of transplanted aman rice recoded at different days after transplanting (DAT). In the first date of measurement (20 DAT) it was observed that the conventional method produced higher dry matter yield than nitrogen fertilizer mix with furrow water in bed planting. Likewise, at the final date (100 DAT) highest dry matter production was also recorded in conventional method than nitrogen fertilizer mix with furrow water in bed planting method. However, dry matter production differs significantly ($P \leq 0.01$) between two methods from 20 to 100 DAT except 60 DAT (Table 4.5).

Table 4.5: Effect of dry matter production by nitrogen fertilizer mix with furrow water in raised bed and conventional method

Method of fertilizer application	Dry matter production (g m $^{-2}$) at different days after transplanting (DAT)								
	20	30	40	50	60	70	80	90	100
Nitrogen fertilizer mix with furrow water in raised bed	30b	84b	271a	418a	577	821b	961b	1080b	1162b
Fertilizer broadcasting in conventional planting	64a	127a	251b	350b	621	851a	1062a	1190a	1260a
LSD at 5%	2.62	3.82	9.30	4.98	328.51	9.30	13.09	6.54	10.35
Level of significance	**	**	*	**	n.s.	**	**	**	**

Where * and ** represents probability of ≤ 0.001 and ≤ 0.01, respectively. Values were means of three replicates. In a column figures with same letter do not differ significantly whereas figures with dissimilar letter differ significantly ($P \leq 0.01$).

4.3.6. Crop growth rate

At the initial stage (20 to 40 DAT), the crop growth rate (CGR) by nitrogen fertilizer mix with furrow water in bed planting is lower than conventional method. The greatest crop growth rate was observed in 60 to 70 DAT by nitrogen fertilizer mix with furrow water in bed planting method. On the other hand the highest crop growth rate was observed in 50 to 60 DAT by conventional flat plot. The lowest CGR was observed at 20 to 30 DAT by both planting method. However, crop growth rate significantly ($P \leq 0.01$) differed between both planting methods at all DAT except 60 to 70 DAT and 90 to 100 DAT. (Table 4.6).

Table 4.6: Effect of crop growth rate by nitrogen fertilizer mix with furrow water in raised bed and conventional method

Method of fertilizer application	Crop growth rate (g m $^{-2}$ day $^{-1}$) at different days after transplanting (DAT)							
	20-30	30-40	40-50	50-60	60-70	70-80	80-90	90-100
Nitrogen fertilizer mix with furrow water in raised bed	5.4b	18.70a	14.70a	15.90b	24.10	14b	11.90b	8.2
Fertilizer broadcasting in conventional planting	6.3a	12.40b	9.9b	27.1a	23	21.1a	12.80a	7
LSD at 5%	0.46	0.46	0.29	0.13	1.85	0.29	0.21	0.94
Level of significance	*	**	**	**	n.s.	**	**	n.s.

Where *, ** and n.s. represents probability of ≤ 0.001, ≤ 0.01 and > 0.05, respectively. Values were means of three replicates. In a column figures with same letter do not differ significantly whereas figures with dissimilar letter differ significantly ($P \leq 0.01$).

4.3.7. Weed population

Weed population and dry biomass were greatly influenced by different planting methods of transplanted aman rice. The nitrogen fertilizer mix with furrow water in bed planting method reduced weed population resulting in lower dry biomass than conventional planting. The conventional method had significantly ($P \leq 0.01$) higher weed vegetation than raised bed method (Table 4.7).

Table 4.7: Effect of weed growth by nitrogen fertilizer mix with furrow water in raised bed and conventional method

Method of fertilizer application	Weed vegetation	
	Weed vegetation population (number m $^{-2}$)	Dry biomass (kg ha^{-1})
Nitrogen fertilizer mix with furrow water in raised bed	115b	107.87b
Fertilizer broadcasting in conventional planting	380a	337a
LSD at 5%	4.98	2.62
Level of significance	**	**

Where ** represent probability of ≤ 0.01. Values were means of three replicates. In a column figures with same letter do not differ significantly whereas figures with dissimilar letter differ significantly ($P \leq 0.01$).

4.3.8. Climatic characteristics and natural rainfall condition

Rainfall is the primary source of water in agriculture at Bangladesh. The average annual rainfall is about 2150 mm. The rainfall distribution pattern greatly influences the growth and development of rice. The country receives about 95% of the total annual rainfall during the months from April to October. The total water requirement for rice cultivation ranges from 1000 mm to 1500 mm. The total rainfall received during the transplanted aman rice growing period (2nd week of August to 2nd week of November) was 525.00 mm (Table 4.8). Mean monthly temperature decreased from 24^0C in August to 15.22^0C in November (Table 4.8). In experiment, the vegetative period was very wet (over 600 mm of rain was recorded in August and September) and the grain filling period was dry (17mm of rain was recorded in October) (Table 4.8). In the vegetative growth stage the maximum water requirement was mitigated by rainfall. For this reason less irrigation was required in August (Table 4.9). The maximum irrigation required in October because of minimum rainfall (17 mm) occurred in this month (Table 4.8). The monthly average relative humidity was maximum in August which indicated the humid weather. The minimum relative humidity was in October which indicated dry weather (Table 4.8). The monthly average sunshine hours were maximum in October and it might be helped to ripen the paddy. The overall in weather in terms of temperature, rainfall, relative humidity and sunshine hours was favourable to normal growth and development of rice.

Table 4.8: Monthly average temperature, Relative humidity, Rainfall & sunshine hours recorded at local weather office, Chuadanga, during experimental period.

Months	Temperature ^{0}C	Relative humidity (%)	Rainfall (mm)	Sunshine (hrs)
August	24	89.5	393	93.38)
September	23.89	88.75	239	135.52)
October	21.55	83	17	196.98
November	15.22	83	1	172.13

Table 4.9: Irrigation required (mm) by the treatments during experimental period.

Treatments	August 2011	September 2011	October-2011
Nitrogen fertilizer mix with furrow water in raised bed	22.75 (mm)	136.37 (mm)	160.125 (mm)
Fertilizer broadcasting in conventional method	64.68 (mm)	138.00(mm)	179.20 (mm)

4.3.9. Irrigation water

Amount of water required for different irrigations differed remarkably between the conventional and bed planting methods. The conventional method received the higher amount of water at every irrigation and total amount of water was 142.66 cm. The total amount of water received by nitrogen fertilizer mix with furrow water in bed planting was 116.53 cm. Result showed that total water savings by nitrogen fertilizer mix with furrow water in bed over conventional method was 23% (Table 4.10).

Table 4.10: Irrigation water savings by nitrogen fertilizer mix with furrow water in bed planting of rice production over conventional method.

Method of fertilizer application	Water required at different times of irrigation (cm)					Water saved over conventional method (%)
	Land preparation (cm)	Transplanting (cm)	Reproductive stage (cm)	Rainfall (cm)	Total (cm)	
Nitrogen fertilizer mix with furrow water in raised bed	0b	6.35	57.68b	52.50	116.53b	23%
Fertilizer broadcasting in conventional planting	13.06a	6.20	70.90a	52.50	142.66a	
LSD at 5%	0.06	0.37	1.85	1.03	4.14	
Level of significance	**	n.s.	**	n.s.	**	

Where ** and n.s. represent probability of ≤ 0.01 and >0.05. Values were means of three replicates. In a column figures with same letter do not differ significantly whereas figures with dissimilar letter differ significantly ($P \leq 0.01$).

4.3.10. Water use efficiency

Water use efficiency for grain and biomass production by N fertilizer mix with furrow water in bed planting was 43.63 and 86.50 kg ha^{-1} cm^{-1}, respectively. In contrast, water use efficiency for grain production and biomass production in conventional planting was 30.63 and 65.11, kg ha^{-1} cm^{-1} respectively. However, water use efficiency for grain production and biomass production by N fertilizer mix with furrow water bed planting was significantly higher than conventional method by 42% and 33%, respectively (Table 4.11).

Table 4.11: Water use efficiency by nitrogen fertilizer mix with furrow water in raised bed and conventional method.

Method of fertilizer application	Water use efficiency savings for fertilizer mix with furrow in raised bed over conventional method	
	Water use efficiency for grain production (kg/ha-cm)	Water use efficiency for biomass production (kg/ha-cm)
Nitrogen fertilizer mix with furrow water in raised bed	43.63a	86.50a
Fertilizer broadcasting in conventional planting	30.63.b	65.11b
LSD at 5%	2.07	0.47
Level of significance	**	**

Where ** represent probability of ≤ 0.01. Values were means of three replicates. In a column figures with same letter do not differ significantly whereas figures with dissimilar letter differ significantly ($P \leq 0.01$).

4.3.11. Agronomic efficiency of N fertilizer

Agronomic efficiency of fertilizer (AE) by nitrogen fertilizer mix with furrow water in raised bed was 67.52%. On the other hand AE for conventional planting was 43.67%. Agronomic efficiency of fertilizer by nitrogen fertilizer mix with furrow water in raised bed was significantly ($P \leq 0.01$) higher than the conventional planting method (Table 4.12).

Table 4.12: Agronomic efficiency of fertilizer by nitrogen fertilizer mix with furrow water in bed and conventional method

Method of Fertilizer application	Agronomic efficiency of fertilizer (%)
Nitrogen fertilizer mix with furrow water in raised bed	67.52a
Fertilizer broadcasting in conventional planting method	43.67b
LSD at 5%	2.62
Level of significance	**

Where ** represent probability of ≤ 0.01. Values were means of three replicates. In a column figures with same letter do not differ significantly whereas figures with dissimilar letter differ significantly ($P \leq 0.01$).

4.4. DISCUSSION

4.4.1. Climatic characteristics regulates water consumption and liquid fertilizer application effect

High rainfall, temperature and relative humidity demand less irrigation water in raised bed than conventional method in the month of August (Tables 4.8 and 4.9). This could be due to the fact that less surface area covered in furrow as compared to conventional flat method. Secondary data collected from local weather station of Chudanga district of Bangladesh suggested that less day light hours and high rainfall occurs in August (Table 4.8). Likewise, Murphy (1983) speculated that temperature is an important factor in the use of N fertilizers by plant. Nitrogen absorption and diffusion to roots are slower at lower temperature. This causes less growth rate of rice plant and resulted less water consumption in fertilizer mixed with furrow water. Similarly, in September, high day light hours resulted in less rainfall which contributed to high irrigated water consumption by both fertilizer application methods (Tables 4.8 and 4.9). The maximum irrigation required in October because of minimum rainfall occurred in this month. The maximum number of day light hours was in October which indicated less cloudy condition. The lowest temperature recorded in November which may resulted in less rainfall. Long day light hour and less relative humidity occurred in October and November that may help to ripe the paddy.

The total water consumption was significantly ($P > 0.05$) higher in conventional cultivation method as compared to furrow mixed with fertilizer treatment (Table 4.11). Likewise, nitrogen fertilizer mixed with furrow received 62.62 cm less irrigation water than conventional method although 52.5 cm rainfall was received at that time (Table 4.8). The total water consumption was less by fertilizer mix with furrow over conventional method due to the less surface area of furrow water than conventional method. Speculation for this is that because of less surface area in furrow water allowed less evaporation loss which may result less irrigation water consumption than conventional method. The percolation loss was high in conventional method compared to furrow mixed fertilizer method. This may resulted high water consumption by conventional method than furrow mixed fertilizer method. Borrell *et al.* (1997) also reported that flooded irrigation provided a greater hydraulic head for increased percolation. Therefore raised bed with furrow irrigation reduced water loss due to percolation. Other possible reason is that high day temperature and solar radiation and low night temperatures are apparently conducive to producing more panicles without much reduction in spikelet number. This causes less water consumption by rice paddy plant in nitrogen fertilizer mixed with furrow irrigation in the raised bed than conventional flat method.

4.4.2. Split nitrogen fertilizer mix with furrow irrigation has positive impact on raised bed than conventional flat method

Agronomic efficiency was significantly ($P \leq 0.01$) higher in nitrogen fertilizer mixed with furrow in raised bed than conventional flat method (Table 4.12). Likewise, water use efficiency for both grain and biomass production was significantly ($P \leq 0.01$) greater in nitrogen fertilizer mix with furrow water in raised bed than conventional flat method (Table 4.11). Findings in this study also showed that split nitrogen fertilizer mixed with furrow reduced irrigation water use by 23% relative to conventional flat method (Table 4.10). These advantages come from the fact that split nitrogen fertilizer mixed with irrigation water advances faster in raised bed soil than in a conventionally cultivated soil. Also less water percolation loss occurs in raised bed than conventional flat method. This findings also suggested that both agronomic and water use efficiency has greater impact in raised bed than conventional method. This could be due to the fact that when nitrogen fertilizer, whether organic or inorganic, is bio-logically transformed to nitrate that is highly soluble in water. In this soluble form, nitrate can readily be absorbed and used by plants. Likewise, Muirhead *et al.* (1985) speculated that in furrow irrigation system carrier containing urea are likely to be carried further into the root zone.

4.4.3. Benefits of furrow irrigation with split nitrogen fertilizer application over conventional flat method

Furrow irrigation saved irrigation water and nitrogen fertilizer as well as increases yield. In this study furrow irrigation saved 23% irrigation water and increased yield by 16.21% compared with flooded irrigation (Tables 4.8 and 4.1). Likewise, Yang *et al.* (2007) found that compared with conventional irrigation, the water saving irrigation increased grain yield by 7.4 to 11.30%, reduced irrigation water by 24.5 to 29.2% and increased water productivity by 43.1 to 50.3%. They speculated that the limiting values of soil water potential related to specific growth stages of grain and water consumption to furrow irrigation over conventional flat method.

Split nitrogen fertilizer mixed with furrow irrigation receives about 1.0 g more for the weight of thousand grains than the conventional flat method (Table 4.1). Other study also conducted by Chunlin (2010) found that furrow irrigation produced the weight per thousand grains by 1.0 g was more than conventional flat method. He suggested that improved soil condition and reduced rice disease is the major reason to increase thousand grain in furrow irrigation as compared to conventional planting method. Chunlin (2010) also suggested that furrow irrigation system may also reduce humidity of the rice field and enhance gas transport in the soil and light penetration, which led to reduced rice diseases and increased leaf vitality and increases in tiller and effective spikes by 11.53%. Speculation for this is that the furrow irrigation technique enhanced gas exchange in the soil, which provides a better growth environment for thousand grain production of rice.

Split nitrogen fertilizer application mixed with furrow irrigation on raised bed had higher tillers, panicle numbers and leaf area index than conventional flat method (Tables 4.2, 4.3 and 4.4). Likewise, Ockerby and Fukai (2001) found that the grain yields of rice were slightly greater in paddy rice than on raised beds with continuous furrow irrigation, but pointed out that all cultivars grown with the furrow irrigation system had more tillers, leaf area, and dry weight at anthesis, suggesting a greater yield potential. They speculated that the furrow irrigation technique met the water demand for growth, and also reduced water loss due to evaporation and seepage. This could be due to the fact for greater benefit of furrow irrigation compared to conventional flat method. Meanwhile, He (2010) reported that the furrow irrigation technique also enhanced gas exchange in the soil, which provides a better growth environment for rice production.

Split nitrogen fertilizer application mixed with furrow irrigation produced higher paddy rice yield parameters than conventional flat method (Tables 4.1 and 4.2). Similarly, Wells *et al.* (1990) found that urea-ammonium nitrate solution gave yields of 1.17 and 1.27 t ha^{-1} when broadcast and 0.95 and 1.126 t ha^{-1} when titrated into the irrigated water at 0.024 and 0.036 t ha^{-1} respectively. They speculated that mixed urea with surface soil in the bed should lead to decreased losses of applied N via leaching but increased losses via denitrification and ammonia volatilization should result in increased uptake by crop plants. This may be the reason for greater rice yield in split N fertilizer mix with furrow than conventional flat method. Likewise, Dhindwal *et al.* (2006) speculated that furrow irrigation reduced evaporation due to the absence of surface water layer in the field that may cause greater beneficial effect in furrow irrigation with split N fertilizer application over flat method.

4.4.4. Yield response

The yield increased by N fertilizer mix with furrow water in bed planting over conventional method was 16.21% (Table 4.1). Similarly, Bouman *et al.* (2005) found that rice yield under aerobic conditions was 32 to 38% higher than under flooded conditions. Ockerby and Fukai (2001) found higher dry weight of all rice cultivars with furrow irrigation than with flooding irrigation. My speculation is that fertigation in raised bed allowed greater nutrient availability in the fertilized zone which ensured greater nutrient uptake from the applied fertilizer. This contributed increased yield by fertigation over fertilizer broadcast in conventional planting. Bakker *et al*. (2005) and Holland *et al*. (2007) have demonstrated that raised beds could significantly increase grain yield due to improved air filled porosity and plant-available water capacity and reduced water logging. Mohammad *et al.* (2003) also reported that higher yield response was obtained by fertigation than soil application of nitrogen. This higher yield was enhanced due to more efficient timing and placement of nitrogen. Likewise, Mohseni *et al.* (2012) found that yield was lower in conventional broadcasting fertilization than fertigation. They speculated that under conventional method of fertilization plant nitrogen at each sensitive stage may decrease the yield. However, my speculation in this thesis is that in fertigation technique, dissolving urea in the irrigation water has been demonstrated to be an effective method for applying N fertilizer during the growth of rice. It is possible that application of N fertilizer by varying the proportion of applied as a basal dressing and the quantity incorporated each irrigation. Generally at least half of the fertilizer is applied as a top dressing application and the remainder dissolved in the irrigation water during the grand period of growth produced better rice yield in fertigation technique than conventional method.

4.5. CONCLUSIONS

This study demonstrated that fertigation in raised beds increased rice yield by 16.21% when compared with fertilizer broadcast in conventional planting. Fertigation in bed also reduced irrigation water requirement by 23% as well as increased irrigation efficiency. This finding concluded that water use efficiency for grain and biomass production were higher in fertigation on raised beds planting than by the fertilizer broadcast in conventional method. The agronomic efficiency of fertilizer was also significantly higher in fertigation on bed planting than the conventional method. The potential gains from growing rice production with fertigation on raised beds are considered to be associated with better agronomic management than fertilizer broadcast in conventional planting. Therefore, further research of fertigation in raised bed over conventional method on water and fertilizer use efficiency will be focused for boro rice (winter rice that completely depends on irrigation) production (Chapter 8).

Chapter 5

Utilization of urea super granule in raised bed versus prilled urea in conventional flat method for transplanted aman rice (*Oryza sativa*)

Chapter 5

Utilization of urea super granule in raised bed versus prilled urea in conventional flat method for transplanted aman rice (*Oryza sativa*)

5.1. INTRODUCTION

Paddy rice crop requires massive amounts of mineral nutrients especially nitrogen (N) for its growth, development and yield (Goswami and Banerjee, 1978; Sahrawat, 2000). However, the efficiency of added N is very low, generally around 30-40% and in many cases even lowers (De Datta, 1978; Choudhury and Khanif, 2001). The low utilization efficiency is attributed to losses like volatilization, denitrification, leaching and surface run-off (Ponnamperuma, 1972; De Datta, 1981). These losses can be reduced by management practices like use of modified forms of urea. This modified form of urea is called urea super granule (USG). The USG can be produced locally in the factory by using roll press machine. It is provided in deep point placement and has some advantages. These include (i) reduced N loss by runoff, volatilization and denitrification, (ii) delayed N uptake and (iii) reduced ammonium fixation (Westsellar, 1985).

Research showed that the superiority of USG over conventional prilled urea (PU) in rice production regarding N use efficiency (Cao *et al*. 1984; De Datta, 1987). Generally farmers are accustomed to using N fertilizer in the form of PU which is very easy to apply though rice plant can receive only 25 to 30% of applied fertilizer (BRRI, 2007). To reduce nitrogen loss, it is strongly considered that application of the USG is an important alternative that can increase the efficiency of N to about 20 to 25 % and yield by 15 to 20% (BRRI, 2008).

My previous study showed that fertigation technique in raised bed planting had higher water and fertilizer use efficiency of transplanted aman rice compared to conventional flood planting (Chapter 4). However, no study was undertaken for the USG application on bed planting as compared to the PU on conventional flat method. Therefore, this study was conducted to determine the role of USG on raised bed planting as compared to the PU in conventional cultivation method. The hypothesis of this study is that the deep placement of USG technique on raised bed will produce higher water and fertilizer use efficiency than PU broadcast in the conventional planting.

5.2. MATERIALS AND METHODS

5.2.1. Experimental site

The experiment was conducted at the farmer's field located in the village of Daulatdiar of sadar Upa Zilla in Chuadanga district high Ganges river flood plain in Bangladesh. The experimental field is located at $23^0 39'$N latitude and $88^0 49'$E longitudes at a mean elevation of 11.58 m above the sea level. The soil of the experiment plot was silt loam with a pH of 7.30. The average air temperature, relative humidity, rainfall and sunshine hours were 21.16^0C, 86.06%, 136.50 mm and 149.50 hours, respectively on the experimental field site.

5.2.2. Raised bed preparation and its advantages

Raised bed was prepared manually for the experiment. It can also be prepared through raised bed planting machine. Paddy rice crops were transplanted in two rows on top of the raised bed and irrigation water was applied within the furrows between the beds.

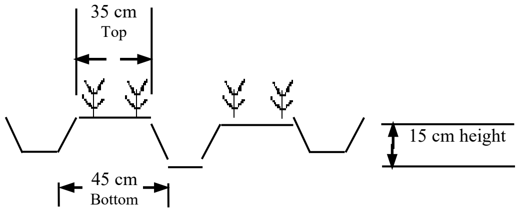

Fig. 5.1: Two rows paddy rice on raised bed.

Water moves horizontally from the furrows into the beds. The height of the beds was maintained 15 cm, top was 35 cm and bottom was 45 cm with 6 beds per plot (Fig. 5.1). The furrow width was 25 cm. The major concern of raised bed technique is to enhance the productivity and save the irrigation water. Potential agronomic advantages of raised beds also include improved soil structure due to reduced compaction through controlled trafficking, reduced water logging and timelier of machinery operations due to better surface drainage.

5.2.3. Conventional flat land preparation and its drawbacks

Land was prepared by puddling the soil in conventional method for transplanting paddy rice. The final land was prepared through ploughing and cross ploughing by two wheel power tiller with two laddering before two days of transplanting. The main difference between conventional flat and raised bed was furrow and transplanted aman rice on top of the bed in two rows. Conventional flat method also maintains continuing inundation until maturity. This affects soil physical, chemical and biological properties that influence the growing condition of paddy rice. In contrast, conventional flat method has some problems such as destruction of soil structure that leading to higher bulk density, higher soil penetration resistance and enhanced surface cracking.

5.2.4. Experimental design and procedure

Two planting methods for comparison of utilization of N fertilizer under conventional flooded and raised bed as well as furrows conditions were established across a soil. The combinations of treatments were deep placement of USG in raised bed and PU broadcasting in conventional flat method. Plots were 4 m wide × 2 m long. Two 30 day old seedlings hill^{-1} of swarna, a popular aman (July to November growing period) rice variety, were transplanted on 9th August 2011 at a row to row and hill to hill spacing of 20 cm on both beds and the flat. Only two rows of rice were planted on each bed and plant density was much higher in the conventional treatment. Fertilizer was applied at the following rates: N=66, P=5, K=18, S=6 and Zn=0.5 kg ha^{-1} applied as urea, Triple Super-Phosphate (TSP), Muriate of potash (MP), Gypsum and Zinc Sulphate ($ZnSO_4$), respectively. Whole of TSP, MP, gypsum and $ZnSO_4$ were applied at the time of final land preparation as basal dose in the plots with conventional treatment. In the plots with bed planting treatments, the basal doses were applied before transplanting on the top of the beds. The conventional PU was top dressed in three equal splits at 15, 30 and 50 days after transplanting (DAT) in conventional plot. In bed planting within a week after transplanting of aman rice, the USG briquettes are (1.8 gm weight) inserted into the puddled soil by hand, being placed to a depth of 7-10 cm (deep placement) in the middle of alternating squares of four hills of rice (BRRI, 2009).

5.2.5. Crop harvesting and measurements

Rice was harvested at 11th November, 2011. Twenty randomly selected hills from each plot were used for agronomic measurements. An area of 1 m^2 from centre portion of each plot was harvested for determination of grain yield. Rice was threshed by using pedal thresher. Immediately after harvest grain moisture content and weight were recorded. Grain yield was adjusted to 14% moisture content after drying.

5.2.6. Water management

Conventional plots were continuously flooded to a depth of approximately 8 cm until drainage at 80% grain maturity about 2 weeks before harvest. In the raised bed-furrow system, enough irrigation water was kept in the furrows to just submerge the beds for seedling establishment and weed control during the first two weeks after transplanting. Thereafter, irrigation was scheduled to maintain a water head of about half the height of the beds never allowing the beds to be submerged throughout the growing season.

5.2.7. Irrigated water measurement

Irrigation water was measured by using a delivery pipe and water pan. A plastic delivery pipe was connected from the water pump to the experimental field. A water pan with 300 litre volume was filed by irrigation through the delivery pipe and time required was recorded. Then plots with different methods of planting were irrigation through the delivery pipe and times required were recorded. The amount of irrigation water applied in different plots was calculated as follows:

Amount of water applied per plot=

$$\frac{\text{Volume of water pan (L)} \times \text{Time required to irrigation the plot (sec)}}{\text{Time required filling the water pan (sec)}}$$

5.2.8. Weeding

Manual weeding was done twice in the transplant aman rice field during growth period. The plots were weeded at 15 and 30 DAT. Weed samples from each plot were collected at the time of weeding for comparing weed population and dry biomass yield of different treatments.

5.2.9. Pest control

The rice was infested by stem borer at tillering stage and by rice bug at grain filling stage. Furadan 5G at the rate of 10 kg ha^{-1} was applied at 40 DAT and Malathion 57 EC 5G at the rate of 1 litre ha^{-1} was applied at grain filling stage to control stem borer and rice bug, respectively.

5.2.10. Water use efficiency calculation

Water use efficiency for grain and biomass production was calculated by the following equations:

Water use efficiency for grain production (kg ha^{-1}cm^{-1})

= grain yield (kg ha^{-1})/ total water required (cm)

Water use efficiency for biomass production (kg ha^{-1}cm^{-1})

= [grain yield (kg ha^{-1}) + straw yield (kg ha^{-1})]/ total water required (cm)

5.2.11. Agronomic efficiency of fertilizer

Agronomic efficiency (AE) of fertilizer was calculated by the following equation:

$AE= GY_{NA}-GY_{N0}/N_R$

Where $GY_{NA=}$ Grain yield (kg ha^{-1}) with addition of nutrient

GY_{N0}= Grain yield (kg ha^{-1}) without addition of nutrient

N_R= Rate of added nutrient (kg ha^{-1})

5.2.12. Statistical analysis of data

Data were analysed following standard statistical procedure and means of treatments were compared based on the least significant difference test (LSD) at the 0.05 probability level.

5.3 RESULTS

5.3.1. Grain yield and yield components

The yield increased by 12.32% when urea super granule (USG) was used in bed planting over prilled urea (PU) broadcasting in conventional method. A similar finding was also found for the panicles, grains per panicle and 1000 gm grain wt. The results were significantly different when compared to conventional method. Where by the USG in bed planting had 9 panicles m^{-2}, 20 grains panicle^{-1} and 0.24 gm in 1000 grains weight more than PU in conventional method (Table 5.1).

Table 5.1: Grain yield and yield components with respect to urea super granule (USG) in raised bed and conventional prilled urea (PU) technique

Method of Fertilizer application	Yield and yield components			
	Grain yield (t ha^{-1})	panicles m^{-2} (no)	Grains panicle^{-1} (no)	1000 grain wt (gm)
USG in bed planting	4.92a	285a	160a	23.12
PU broadcasting in conventional planting	4.38b	276b	140b	22.88
LSD at 5%	0.013	3.215	2.618	0.840
Level of significance	**	**	**	n.s.

Where n.s. and ** represents probability of > 0.05 and ≤ 0.01, respectively. Values were means of three replicates.

5.3.2. Other Plant attributes

Planting method affected plant height, panicle length, non-bearing tillers m^{-2}, sterility percentage, straw yield and harvest index of rice. Plant height, panicle length and harvest index were higher by USG in bed planting than PU in conventional method. On the contrary, non-bearing tillers m^{-2} and sterility percentage were higher PU broadcasting in conventional method than the USG in bed planting. Likewise, lower number of non-bearing tillers m^{-2} was recorded by the USG in bed planting treatments than the PU in conventional method. The USG in bed planting significantly reduced the sterility percentage compared to the PU in conventional planting. In bed planting sterility was lower. The lower sterility might be accountable for higher grains in bed planting. The bed planting resulted in higher harvest index than conventional method (Table 5.2).

Table 5.2: Plant biomass with respect to USG in raised bed and PU application in conventional planting.

Method of fertilizer application	Plant height (cm)	Panicle length (cm)	Non-bearing tiller (no-m^{-2})	Sterility (%)	Straw yield (tha^{-1})	Harvest index
USG in bed planting	90.24a	24.46	55b	9.78b	5.32a	0.48a
PU broadcasting in conventional planting	86.38b	24.30	59a	12.41a	4.92b	0.47b
LSD at 5%	1.114	0.281	2.225	0.379	0.125	0.109
Level of significance	**	n.s.	**	**	**	**

Where n.s. and ** represent probability of > 0.05 and ≤ 0.01, respectively. Values were means of three replicates.

5.3.3. Tiller production

Transplanting of aman rice under different planting method affected the number of tillers m^{-2} of rice. The increasing trend of tiller m^{-2} was continued to 40 days after transplanting. At 40 days after transplanting both planting method attained the highest number of tiller m^{-2} and then started declining up to 100 days after transplanting (Table 5.3).

Table 5.3: Effect of tiller production by USG in raised bed and PU in conventional planting

Method of fertilizer application	Tiller (no. m^{-2}) at days after transplanting								
	20	30	40	50	60	70	80	90	100
USG in bed planting	91	210	383	370	359	355	346	341	340a
PU in conventional plot	88	205	371	363	354	349	342	339	335b
LSD at 5%	2.069	4.984	9.662	5.396	4.139	14.19	2.18	9.438	2.34.
Level of significance	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	*	n.s.	**

Where n.s.,* and ** represent probability of > 0.05, ≤ 0.01 and ≤ 0.001, respectively. Values were means of three replicates.

5.3.4. Leaf Area index

Planting method affected the leaf area index (LAI) of transplant aman rice recorded at different days after transplanting (DAT) (Table 5.4). Plant-to-plant distance in rows also influenced the leaf area index measured at different stages of crop growth. The highest leaf area index was achieved at 60 DAT by USG in bed planting method. After 60 DAT the leaf area index started declining and continued to 100 DAT by USG in bed planting. It was also revealed that at early stage of crop growth the leaf area index by USG in bed planting treatments was lower than conventional planting. The highest LAI was achieved by PU in conventional planting at 80 DAT. After 80 DAT the LAI started to decline and continued to 100 DAT by PU in conventional method. However, LAI differ significantly ($P \leq 0.01$) between two methods from 20 to 80 DAT (Table 5.4).

Table 5.4: Effect of leaf area index by USG in raised bed and PU in conventional planting

Method of fertilizer application	LAI at different DAT				
	20	40	60	80	100
Urea super granule (USG) in bed planting	0.13b	2.38b	5.22a	5.01a	3.80
Prilled urea broadcasting in conventional planting	0.38a	2.47a	4.92b	4.97b	3.78
LSD at 5%	0.013	0.013	0.093	0.013	0.185
Level of significance	**	**	**	*	n.s.

Where n.s.,* and ** represents probability of > 0.05, ≤ 0.01 and ≤ 0.001, respectively. Values were means of three replicates.

5.3.5. Dry matter production

Planting method affected the dry matter production of transplanted aman rice recoded at different days after transplanting (DAT) (Table 5.5). In the first date of measurement (20 DAT) it was observed that the PU in conventional method produced higher dry matter yield than USG in bed planting. Likewise, at the final date (100 DAT) highest dry matter production was also recorded by USG in bed planting method than PU in conventional planting. However, dry matter production differs significantly ($P \leq 0.01$) at 20 to 100 DAT in both planting method except 80 and 90 DAT.

Table 5.5: Effect of dry matter production by USG in raised bed and PU in conventional planting

Method of fertilizer application	Dry matter production (g m^{-2}) at different days after transplanting (DAT)								
	20	30	40	50	60	70	80	90	100
USG in bed planting	31b	73b	268a	433a	662a	860a	1066	1196	1293a
Prilled urea (PU) broadcasting in conventional planting	64a	127a	251b	350b	621b	851b	1062	1190	1260b
LSD at 5%	2.07	2.93	2.07	19.08	21.53	2.07	13.09	5.93	10.35
Level of significance	**	**	**	**	*	**	n.s.	n.s.	**

Where n.s.,* and ** represents probability of > 0.05, ≤ 0.01 and ≤ 0.001, respectively. Values were means of three replicates.

5.3.6. Crop growth rate

Results from the crop growth rate are shown in Table 5.6. At the initial stage (20 to 30 DAT), the crop growth rate (CGR) by USG in bed planting is lower than PU in conventional planting. The greatest CGR was observed at 50 to 60 DAT for both USG in bed planting and PU conventional planting method. In contrast, the lowest CGR was observed at 20 to 30 DAT for both by USG in bed planting and PU conventional planting method. However, crop growth rate significantly ($P \leq 0.01$) differed between both planting methods at all DAT except 70 to 80 and 80 to 90 DAT.

Table 5.6: Effect of crop growth rate by USG in raised bed and PU in conventional planting

Method of fertilizer application	Crop growth rate (g m^{-2} day^{-1}) at different days after transplanting (DAT)							
	20-30	30-40	40-50	50-60	60-70	70-80	80-90	90-100
Urea super granule in bed planting	4.20b	19.5a	16.5a	22.9b	19.8b	20.6	13.0	9.30a
Prilled urea broadcasting in conventional planting	6.3a	12.40b	9.9b	27.1a	23a	21.1	12.80	7.0b
LSD at 5%	0.33	0.59	0.47	0.13	1.86	0.56	0.49	0.96
Level of significance	**	**	**	**	*.	n.s.	n.s.	*

Where *, ** and n.s. represents probability of ≤ 0.001, ≤ 0.01 and > 0.05, respectively. Values were means of three replicates. In a column figures with same letter do not differ significantly whereas figures with dissimilar letter differ significantly ($P \leq 0.01$).

5.3.7. Weed population

Weed population and dry biomass were greatly influenced by different planting methods of transplanted aman rice (Table 5.7). The USG in bed planting method reduced weed population resulting in lower dry biomass than PU in conventional planting. The PU in conventional method had significantly ($P \leq 0.01$) higher weed vegetation than raised bed planting.

Table 5.7: Effect of weed growth by USG in raised bed and PU in conventional planting

Method of fertilizer application	Weed vegetation	
	Weed vegetation population (no.m^{-2})	Dry biomass (kg- ha^{-1})
Urea super granule in bed planting	110b	103.31b
Prilled urea broadcasting in conventional planting	380a	337a
LSD at 5%	4.984	1.873
Level of significance	**	**

Where ** represent probability of ≤ 0.001. Values were means of three replicates.

5.3.8. Irrigation water

Amount of water required for different irrigations differed remarkably between the conventional and bed planting methods (Table 5.8). The PU in conventional planting received a higher amount of water at every irrigation and the total amount was 142.66 cm. The total amount of irrigation water received by USG in bed planting was 103.44 cm. Result showed that total water savings by USG in bed over PU in conventional method was 40%.

Table 5.8: Irrigation water savings by USG in raised bed and PU in conventional planting method

Method of fertilizer application	Water required at different times of irrigation (cm)					Water saved over conventional method (%)
	Land preparation	Transplanting	Reproductive stage	Rainfall	Total	
USG in bed planting	-	5.62b	45.32b	52.50	103.44b	40
PU broadcasting in conventional planting	13.06	6.20a	70.90a	52.50	142.66a	
LSD at 5%	0.059	0.262	0.296	0.654	2.094	
Level of significance	-	*	**	n.s.	**	

Where n.s.,* and ** represents probability of > 0.05, ≤ 0.01 and ≤ 0.001, respectively. Values were means of three replicates. "-"indicates data not available.

5.3.9. Water use efficiency

Water use efficiency for grain and biomass production by USG in bed planting was 35.40 kg ha^{-1}cm^{-1} and 98.99 kg ha^{-1}cm^{-1}, respectively (Table 5.9). In contrast, water use efficiency for grain production and biomass production in conventional planting was 30.63 kg ha^{-1}cm^{-1} and 65.11 kg ha^{-1}cm^{-1}, respectively. However, water use efficiency for grain production and biomass production by USG bed planting over PU in conventional was 49% and 40.88%, respectively.

Table 5.9: Water use efficiency by USG in raised bed and PU in conventional planting method.

Method of fertilizer application	Water use efficiency savings by USG in raised bed planting over PU in conventional method	
	Water use efficiency for grain production (kg $ha^{-1}cm^{-1}$)	Water use efficiency for biomass production (kg $ha^{-1}cm^{-1}$)
USG in bed planting	35.40a	98.99a
PU in conventional planting	30.63b	65.11b
LSD at 5%	1.083	2.121
Level of significance	**	**

Where ** represent probability of ≤ 0.001. Values were means of three replicates.

5.3.10. Agronomic efficiency of N fertilizer

Agronomic efficiency of N fertilizer by the USG in raised bed was 55.04% (Table 5.10). On the other hand, agronomic efficiency for PU in conventional planting was 43.67%. Agronomic efficiency of N fertilizer by USG in raised bed was significantly ($P \leq 0.01$) higher than the PU in conventional planting method.

Table 5.10: Agronomic efficiency of fertilizer by USG in raised bed and PU in conventional planting method

Method of Fertilizer application	Agronomic efficiency of fertilizer (%)
USG in bed planting	55.04a
PU in conventional method	43.67b
LSD at 5%	4.225
Level of significance	**

Where ** represent probability of ≤ 0.001. Values were means of three replicates.

5.4. DISCUSSION

5.4.1. The USG techniques in bed planting increases plant growth parameters than the PU in conventional flat methods.

The increase in plant height by the USG in raised bed over the PU in conventional method was 4.46% (Table 5.2). Other studies also found that the USG techniques in bed planting produced taller plants than the PU in conventional cultivation techniques (Singh and Singh, 1986; Reddy and Mitra, 1985; Roy, 1988). This could be due to effective utilization of nitrogen fertilizer by rice plant during their vegetative growing period. Likewise, Puckridge *et al*. (1991) found that the paddy rice plant N uptake increased immediate after super granule placement into the soil during their vegetative growth period. They suggested that this increase in N uptake by rice plant during their vegetative growth period could be due to variation of stress on rice plants.

The USG treated plot in bed planting significantly recorded higher number of tiller and panicles m^{-2} compared to the PU in conventional planting method (Table 5.2). Similarly, Joseph *et al*. (1991) found that tiller number m^{-2} was 265 and 309 for PU and USG, respectively. Similarly, Thakur (1991) found that panicles m^{-2} was 170 and 289 for PU and USG, respectively. However, they conducted their experiment in conventional flat method.

This indicates that the USG is always superior to the PU in any condition for rice production. This could be due to the fact that the increase in N levels was responsible for increased number of leaves, resulting in higher photosynthesis, metabolic activity and cell division, which consequently increased growth and hence yield attributes (Jaiswal and Singh, 2001). Likewise, Jaisal and Singh (2001) also suggested that deep placement of the USG played a vital role for adequate nutrient supply with minimizing losses of nitrogen, NH_3 volatilization, nitrification and denitrification which ultimately increased the plant growth characteristics in raised bed plot.

5.4.2. Grain and straw yields attributed to higher in raised bed for USG than conventional PU technique

Higher grain and straw yields for the USG treated plots in bed planting were attributed to higher number of tiller and panicle (Tables 5.2 and 5.3). The superiority of the USG in bed planting over the PU in conventional planting regarding grain and straw yields of rice was found in many other investigations (De Datta, 1987; Bhuiyan *et al*. 1985; Choudhury and Bhuiyan, 1994). Similarly, Jena *et al*. (2003) found that deep placement of the USG significantly improved grain yield, straw yield and nitrogen use efficiency of rice and reduced the volatilization loss of ammonia relative to the application of the PU. Regardless of that, Lal *et al*. (1988) found that transplanted rice grain yield was 3.5 and 4.8 t ha^{-1} for PU and USG, respectively. This finding indicated that the USG is also suitable in conventional plot other than raised bed. They speculated that a high yield with the USG application seems to be associated with high N uptake due to higher N availability. Other study suggested that high yield of rice for placement of the USG in reduced soil layer could be due to decrease in N loss by volatilization, denitrification and aquatic weed competition including algal immobilization (Thomas and Prasad, 1982).

My speculation is that existing conventional practice by farmers in Bangladesh often use urea inefficiently either because of this optimum is unknown, or the recommended doses is misleading or because of limited access to fertilizer. Likewise, Tran *et al*. (1989) reported that fertilizer and water use inefficiencies have substantially contributed to low yield in rice. Similarly, Pillai and Vamadevan (1978) speculated that the apparent reason for increased grain yield may be due to slower rate of urea hydrolysis of large sized urea super granule. Further, as the material was placed in the reduce zone of soil, losses of nitrogen due to nitrification-denitrification and leaching were minimized. Thus, the efficiency of applied nitrogen was increased which in turn contributed to increased grain yield (Pillai and Vamadevan, 1978).

5.4.3. Nitrogen use efficiency was greater in the USG in raised bed than the PU in conventional method

The USG in raised bed had significantly ($P \leq 0.01$) lower nitrogen fertilizer utilization efficiency than the conventional plot (Table 5.10). Wes Emmott *et al*. (2013) reported that at basal dose N required 50 kg ha^{-1}. At active tillering stage N required by the rice plant was 89 kg ha^{-1}. The N required at the panicle initiation stage by the rice plant was 104 kg ha^{-1} at heading stage N required by rice plant was 30 kg ha^{-1}. The highest N required by the rice plant was observed at panicle initiation stage. However, the USG was applied 7 days after transplanting at the rate of 81 kg ha^{-1} in this experiment. So, N required by the rice plant was 37 kg ha^{-1}. In the method of deep placement (7-10 cm) of USG in bed planting the fertilizer was applied at active tillering stage. Because of large size of USG allow slower hydrolysis rate of urea fulfilled the highest demand of N at the panicle initiation stage. This may save the amount of N fertilizer required by the rice plant. Joseph *et al*. (1991) also found that nitrogen use efficiency was higher in USG than the conventional PU technique. Likewise, BRRI (2008) reported that nitrogen fertilizer use efficiency can be increased up to 20-25% and 30% of urea fertilizer can be saved by the USG application than the PU conventional cultivation method. Similarly, Thakur (1991) found that nitrogen use efficiency for PU and USG were 26.1 and 32.8 kg grain kg^{-1} N^{-1}, respectively. This might be due to the placement of USG in the reduced zone and its bigger size may have increased its efficiency by minimizing loss of N through ammonia volatilization and denitrification (Nommick, 1976). There also may be possibility that the USG were placed below soil surface that minimize N loss through runoff and volatilization. Similarly, Cao *et al*. (1984) speculated that with deep placement of urea, the losses due to N_2 denitrification and NH_3 volatilization can be reduced, which accounts for the superiority of deep placement of USG to PU application. Likewise, Thakur (1991) opined that the size of USG and less losses or better utilization through deep placement of the USG is responsible for higher nitrogen use efficiency than the PU in conventional flat method. Regardless of that the apparent reason for increased nitrogen use efficiency for the USG may be due to slower rate of urea hydrolysis from the large size USG and this release is in synchrony with the rice plant requirements. Further, as the USG was placed in the reduced zone of soil, losses of nitrogen due to nitrification-denitrification and leaching were minimized. Thus, the efficiency of applied nitrogen was increased which in turn contributed to increased grain yield (Pillai and Vamadevan, 1978).

5.4.4. The USG in raised bed attributed better agronomic efficiency of N fertilizer and suppress the activities of weed growth than the PU in conventional method

Agronomic efficiency of N fertilizer was 12% higher using USG in bed planting over PU in conventional planting (Table 5.10). Higher agronomic efficiency of N fertilizer with USG over PU was also found in some other investigations (Choudhury and Bhuiyan, 1994; Choudhury *et al*. 1994). My speculation is that the higher agronomic efficiency of N fertilizer using USG over PU could be due to the high recovery of applied N in the field. This might possibly be due to different losses like denitrification, ammonia volatilization, runoff and immobilization were too low in the USG than the PU. Further, hence the placement of USG on raised bed can provide agronomic benefits and minimize N application rate and loss.

Weed population were significantly ($P \geq 0.01$) higher in the conventional PU application than the USG in raised bed planting method (Table 5.7). This may be better agronomic management practices and deep placement of USG in raised bed than conventional PU application. However, Mohanty *et al*. (1999) speculated that the USG application in rice field retarded weed growth due to limited nitrification-denitrification process and biological nitrogen fixation is promoted under reduced floodwater N concentration.

5.4.5. The USG in raised bed use less water and has higher water use efficiency than the conventional flat method

The USG in bed planting saved 40% irrigation water than the conventional flat method. This water saving mainly occurred in transplanting and reproductive stage (Table 5.8). Likewise, water use efficiency was significant by higher ($P \leq 0.001$) in raised bed for USG than the conventional flat method (Table 5.9). Other study like Kahlown (2006) found that raised bed system generally use 10 to 30% less water than the amount applied to farmers to their flooded basins. Thompson *et al.* (2003) also showed that irrigation water savings of about 14% using bed compared with flat method. Likewise, Beecher *et al.* (2006) found that raised bed (17.2 ML ha^{-1}) use significantly less water than the conventional flat (18.7 ML ha^{-1}) method. They speculated that saving in irrigation water use is related to the amount of time a crop is intermittently irrigated, thus the longer ponding occurs, the lesser it will be the water will be saving. These findings concluded that continuous submergence is not a must for rice production. Saturated soil condition is optimum for rice production.

5.5. CONCLUSIONS

The findings of this study demonstrated that the USG in bed planting is superior to PU broadcasting in conventional planting method for transplanted rice production. Placement of USG in raised bed produced higher number of panicles m^2, panicle weight, number of grains panicle^{-1} and 1000-grain weight, which ultimately gave the highest grain yield than the PU in conventional plot. This study also concluded that the USG application within raised bed proved beneficial over conventional PU technique, especially with respect to grain yield, yield attributes, agronomic efficiency and water use efficiency. Deep placement of the USG in raised bed effectively increased N-use efficiency as compared to conventionally applied PU. The placement of the USG below plough layer (5cm) is considered the best method to decrease N losses and thereby to increase fertilizer use efficiency. This study also suggests that the deep placement of the USG in raised bed is feasible for water and nitrogen use efficiency and reduction in soil compaction. Deep placement of USG in raised bed planting, new rice based farming systems, offers many potential advantages. Therefore, deep placement of the USG at 7-10 cm depth (reduced soil layer) on raised bed is one of the most efficient N management techniques developed for rice production. There is a good prospect of utilization of this technology to benefit the rice farmers. Further experiment will be conducted to distinguish role USG application on raised bed as compared to PU broadcast in conventional method for transplanted boro rice (completely depends on irrigation) production (Chapter 9).

Chapter 6

Foliar spray of nitrogen fertilizer on raised bed increase yield of transplanted aman rice over conventional method

Chapter 6

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6.1 INTRODUCTION

Foliar spray of fertilizer did not only increase the crop yields but also reduce the quantities of fertilizer applied through soil. Foliar application can also reduce the lag time between application and uptake by the plant (Ahmad and Jabeen, 2005). The use of foliar fertilizing in agriculture has been a popular practice within farmers since the 1950s, when it was learned that foliar fertilization was effective. Radioisotopes were used to show that foliar applied fertilizers passed through the leaf cuticle and into the cells (Brasher *et al.* 1953). Various studies have shown that a small amount of nutrients (nitrogen, potash or phosphate) applied by foliar spraying significantly increases the yield of crops (Rauthan and schnitzer, 1981; Malik and Azam, 1985; Chen and Aviad, 1990; Tattini *et al.* 1990; David *et al.* 1994; Gamiz *et al.* 1998; Asenjo *et al.* 2000; Haq and Mallarino, 2000).

In fact, foliar fertilization does not totally replace soil applied fertilizer but it does increase the uptake and hence the efficiency of the nutrients applied to the soil. This application technique is especially useful for micronutrients, but can also be used for major nutrients like N, P, and K basically because the amount applied at any time is small and thus it requires several applications to meet the needs of a crop. The increased efficiency reduces the need for soil applied fertilizer, reduces leaching and run off of nutrients, reducing the impact on the environment of fertilizer salts (Ludders and Simon, 1980; Suwaranit and Sestapukdee, 1989 and Venugoplan *et al.* 1995).

Little information is available about the effects of foliar nitrogen fertilizer application on yield and growth response of transplanted aman rice under raised bed over conventional method. Foliar application of nitrogen fertilizer may be the most effective means for maximizing yield of transplanted aman rice. My previous study showed that fertigation in raised bed produced higher water use efficiency and grain production compared to conventional cultivation method (Chapter 5). However, it was not considered for foliar spray of nitrogen fertilizer in raised bed compared to conventional method. Therefore, this study was undertaken to determine the effect of foliar nitrogen fertilizer spray on raised bed over conventional cultivation method. It was hypothesized that foliar fertilizer spray on raised bed receives higher fertilizer use efficiency and yield of transplanted aman rice than the conventional cultivation method.

6.2 MATERIALS AND METHODS

6.2.1. Experimental site and soil

The experiment was conducted at the farmer's field in Chuadanga, Bangladesh, during transplanted aman rice growing period. The soil of the experiment plot was silt loam with a pH of 7.30.

6.2.2. Cultivator

The aman rice variety swarna was used as an experimental crop, because this variety is widely using by the farmers in the experimental area.

6.2.3. Experimental design

The experiment was laid out in a randomized complete block design with three replications. The combination of treatments was randomly distributed in the plots within a block. The unit plot size was 8m^2 (4m × 2m).

6.2.4. Land preparation

The land was prepared conventionally. The final land preparation was done by ploughing and cross-ploughing by two wheel power tiller with two laddering before two days of transplanting. One day before transplanting, the plots were laid out as per experimental design.

6.2.5. Bed preparation

Raised bed and furrows were made manually by spade following the conventional land preparation. According to the treatments 60 cm (centre to centre of furrows) width bed was made. For the 60 cm bed, the top of the raised bed was 35 cm, and furrow between beds was 25 cm. The beds were made one day before transplanting the plots according to layout of the experiment. The heights of beds were 15 cm (Figure 6.1).

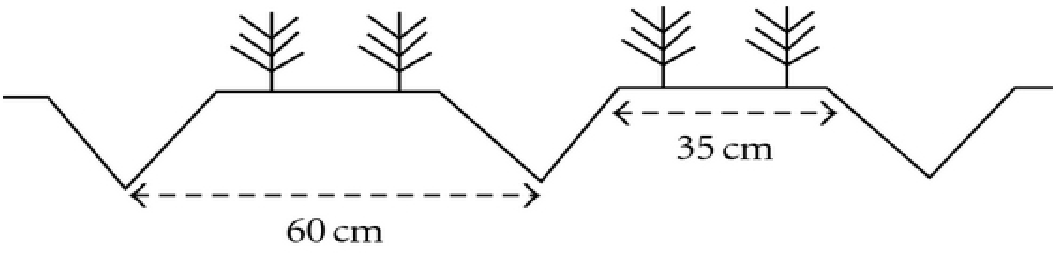

Figure 6.1: Two rows of rice on the top of the beds (TPR)

6.2.6. Fertilizer application

The crop was fertilized with N, P, K, S and Zn at the rates of 66, 5, 18, 6 and 0.5 kg ha^{-1} respectively (BARC, 2005). The sources of N, P, K, S and Zn were urea, Triple Supper

Phosphate (TSP), Muriate of potash (MP), Gypsum and $ZnSO_4$ respectively. Whole of TSP, MP, gypsum and $ZnSO_4$ were applied at the time of final land preparation as basal dose in the plots with conventional treatment. In the plots with bed planting treatments, the basal doses were applied before transplanting on the top of the beds. The urea was top dressed in three equal splits at 15, 30 and 50 days after transplanting (DAT) in conventional planting. The urea spray volumes were prepared by mixing 2 kg of urea in 100 L of water as per treatment. The foliar spray was 2% @ 38 kg ha^{-1}. The plots were sprayed during late afternoon hours when wind speed was less than 10 km hr^{-1}.

6.2.7. Transplanting of seedlings

Thirty day old seedlings were uprooted from the seedbed without making any injury to them and transplanted on the same day. Two to three seedlings hill^{-1} were transplanted maintaining row spacing of 25 cm and plant to plant spacing of 15cm. Irrigation water was applied one day before transplanting between the furrows of bed to make the soil soft.

6.2.8. Irrigation

Though transplant aman rice was a rain fed crop, supplemental irrigation was needed for preparation of the plots with conventional treatment and for the bed planting of all plots. Another supplemental irrigation was done for all plots at flowering stage of rice.

6.2.9. Weeding

Manual weeding was done twice in the transplant aman rice field during growth period. The plots were weeded at 15 and 30 DAT. Weed samples from each plot were collected at the time of weeding for comparing weed population and dry biomass yield of different treatments.

6.2.10. Pest control

The rice was infested by stem borer at tillering stage and by rice bug at grain filling stage. Furadan 5G at the rate of 10 kg ha^{-1} was applied at 40 DAT and Malathion 57 EC 5G at the rate of 1 L ha^{-1} was applied at grain filling stage to control stem borer and rice bug, respectively.

6.2.11. Water use efficiency calculation

Water use efficiency for grain and biomass production was calculated by the following equations:

Water use efficiency for grain production (kg ha^{-1}cm^{-1})

= grain yield (kg ha^{-1})/Irrigation required (cm)

Water use efficiency for biomass production (kg ha^{-1}cm^{-1})

= grain yield (kg ha^{-1}) + straw yield (kg ha^{-1})/Irrigation required (cm)

6.2.12. Crop harvesting

Rice was harvested and threshed by using pedal thresher.

6.2.13. Agronomic efficiency of fertilizer

Agronomic efficiency (AE) of fertilizer was calculated by the following equation:

$AE= GY_{NA}-GY_{N0}/N_R$

Where $GY_{NA=}$ Grain yield (kg ha^{-1}) with addition of nutrient

GY_{N0}= Grain yield (kg ha^{-1}) without addition of nutrient

N_R= Rate of added nutrient (kg ha^{-1})

6.2.14. Statistical analysis of data

The experiment was conducted by randomized complete block design replicated with three replications. All statistical analysis was conducted based on the least significant difference test (LSD) at the 0.05 probability level.

6.3 RESULTS

6.3.1. Grain yield and yield components

The yield increased by foliar spray in bed planting over conventional method was 9.33%. A similar finding was also found in panicles, grains per panicle and 1000 gm grain wt. Foliar spray in bed planting had more than 22 panicle number m^{-2}, 25 grain number per panicle and 0.22 gm in 1000 grain wt than conventional method (Table 6.1).

Table 6.1: Grain yield and yield components with respect to foliar spray in bed and conventional method

Method of Fertilizer application	Yield and yield components			
	Grain yield (t ha^{-1})	panicles m^{-2} (no)	Grains $panicle^{-1}$ (no)	1000 grain wt. (gm)
Foliar spray of fertilizer in raised bed	4.68	298a	165a	23.10
Fertilizer broadcasting in conventional planting	4.37	276b	140b	22.88
LSD at 5%	0.26	3.34	4.98	1.32
Level of significance	n.s.	**	**	n.s.

Where ** represent probability of ≤ 0.01 and n.s. represents probability of >0.05. Values were means of three replicates. In a column figures with same letter do not differ significantly whereas figures with dissimilar letter differ significantly ($P \leq 0.01$).

6.3.2. Other plant attributes

Planting method affected plant height, panicle length, non-bearing tillers m^{-2}, sterility percentage, straw yield and harvest index of rice. Plant height, panicle length and harvest index were higher by foliar nitrogen fertilizer spray in bed planting than conventional method. On the contrary, non-bearing tillers m^{-2}, straw yield and sterility percentage were higher in conventional method than foliar spray in bed planting. Likewise, lower number of non bearing tillers m^{-2} was recorded by foliar spray in bed planting treatments than conventional method. Foliar spray in bed planting significantly reduced the sterility percentage compared to conventional method. In bed planting sterility was lower. The lower sterility might be accountable for higher grains in bed planting. Bed planting resulted in higher harvest index than conventional method (Table 6.2).

Table 6.2: Plant biomass with respect to foliar spray in raised bed and conventional method

Method of fertilizer application	Plant height (cm)	Panicle length (cm)	Non-bearing tiller (no-m^{-2})	Sterility (%)	Straw yield (tha^{-1})	Harvest index
Foliar spray of fertilizer in raised bed	91.34a	24.67	46b	9.28b	4.72	0.49
Fertilizer broadcasting in conventional planting	86.38b	24.30	59a	12.41a	4.92	0.47
LSD at 5%	1.57	0.33	2.07	0.46	0.21	0.00
Level of significance	**	n.s.	**	**	n.s.	n.s.

Where ** represent probability of ≤ 0.01 and n.s. represents probability of >0.05. Values were means of three replicates. In a column figures with same letter do not differ significantly whereas figures with dissimilar letter differ significantly (*P* ≤ 0.01).

6.3.3. Tiller production

Transplanting of aman rice under different planting method affected the number of tillers m^{-2} of rice. The increasing trend of tiller m^{-2} was continued to 50 DAT. At 50 DAT both foliar spray in bed planting method attained the highest number of tiller m^{-2} and then started declining up to 100 DAT. However, both method differ significantly (*P* ≤ 0.01) from 20 to 100 days after transplanting (Table 6.3).

Table 6.3: Effect of tiller production by foliar spray in raised bed and conventional method

Method of fertilizer application	Tiller (no. m^{-2}) at days after transplanting								
	20	30	40	50	60	70	80	90	100
Foliar spray of fertilizer in raised bed	73b	171b	309b	302b	296b	291b	287b	282b	279b
Fertilizer broadcasting in conventional planting	88b	205a	371a	363a	354a	349a	344a	339a	336a
LSD at 5%	2.07	2.07	9.44	3.34	4.63	13.09	2.07	2.62	2.07
Level of significance	**	**	**	**	**	**	**	**	**

Where ** represent probability of ≤ 0.01 and n.s. represents probability of > 0.05. Values were means of three replicates. In a column figures with same letter do not differ significantly whereas figures with dissimilar letter differ significantly (*P* ≤ 0.01).

6.3.4. Leaf area index

Planting method affected the leaf area index (LAI) of transplant aman rice recorded at different days after transplanting (DAT). Plant-to-Plant distance in rows also influenced the leaf area index measured at different stages of crop growth. The highest leaf area index was achieved at 60 DAT by foliar spray in bed planting method. After 60 DAT the leaf area index was started declined and continued to 100 DAT by foliar spray. It was also revealed that at early stage of crop growth the leaf area index by foliar spray in bed planting treatments was lower than conventional method. The highest LAI was achieved in conventional method was 80 DAT. After 80 DAT the LAI was started declined and continued to 100 DAT by conventional method. However, LAI differ significantly ($P \leq 0.01$) between two methods from 20 to 40 DAT (Table 6.4).

Table 6.4: Effect of leaf area index by foliar spray in raised bed and conventional method

Method of fertilizer application	LAI at different DAT				
	20	40	60	80	100
Foliar spray of fertilizer in raised bed	0.175b	2.38b	5.32	5.05	3.83a
Fertilizer broadcasting in conventional planting	0.38a	2.47a	4.92	4.97	3.78b
LSD at 5%	0.001	0.001	0.31	0.04	0.00
Level of significance	**	**	n.s.	n.s.	*

Where *, ** and n.s. represents probability of ≤ 0.001, ≤ 0.01 and > 0.05, respectively. Values were means of three replicates. In a column figures with same letter do not differ significantly whereas figures with dissimilar letter differ significantly ($P \leq 0.01$).

6.3.5. Dry matter production

Planting method affected the dry matter production of transplanted aman rice recoded at different days after transplanting (DAT). In the first date of measurement (20 DAT), it was observed that the conventional method produced higher dry matter yield than foliar nitrogen spray in bed planting. Likewise, at the final date (100 DAT) highest dry matter production was also recorded in conventional method than foliar spray in bed planting method. However, dry matter production differs significantly ($P \leq 0.01$) at different days after transplanting (DAT) in both planting method (Table 6.5).

Table 6.5: Effect of dry matter production by foliar spray in raised bed and conventional method

Method of fertilizer application	Dry matter production (g m^{-2}) at different days after transplanting (DAT)								
	20	30	40	50	60	70	80	90	100
Foliar spray of fertilizer in raised bed	36b	90b	242b	383a	576b	802b	913b	1094b	1198b
Fertilizer broadcasting in conventional planting	64a	127a	251a	350b	621a	851a	1062a	1190a	1260a
LSD at 5%	2.07	2.07	2.07	4.98	19.63	2.07	15.18	5.93	4.98
Level of significance	**	**	**	**	*	**	**	**	**

Where * and ** represents probability of ≤ 0.001 and ≤ 0.01, respectively. Values were means of three replicates. In a column figures with same letter do not differ significantly whereas figures with dissimilar letter differ significantly ($P \leq 0.01$).

6.3.6. Crop growth rate

At the initial stage (20 to 40 DAT), the crop growth rate (CGR) by foliar spray in bed planting is lower than conventional method. The greatest crop growth rate was observed in 60 to 70 DAT by foliar spray in bed planting method. On the other hand the highest crop growth rate was observed in 50 to 60 DAT by conventional flat plot. The lowest CGR was observed at 20 to 30 DAT by both planting method. However, crop growth rate significantly ($P \leq 0.01$) differed between both planting methods at all DAT except 60 to 70 DAT (Table 6.6).

Table 6.6: Effect of crop growth rate by foliar spray in raised bed and conventional method

Method of fertilizer application	Crop growth rate (g m^{-2} day^{-1}) at different days after transplanting (DAT)							
	20-30	30-40	40-50	50-60	60-70	70-80	80-90	90-100
Foliar spray of fertilizer in raised bed	5.4b	15.2a	14.1a	19.3b	22.6	11.1b	18.1a	10.4a
Fertilizer broadcasting in conventional planting	6.3a	12.4b	9.9b	27.1a	23	21.1a	12.8b	7b
LSD at 5%	0.46	0.41	0.13	0.29	1.87	0.13	1.03	1.00
Level of significance	*	**	**	**	n.s.	**	**	**

Where *, ** and n.s. represents probability of ≤ 0.001, ≤ 0.01 and > 0.05, respectively. Values were means of three replicates. In a column figures with same letter do not differ significantly whereas figures with dissimilar letter differ significantly ($P \leq 0.01$).

6.3.7. Weed population

Weed population and dry biomass were greatly influenced by different planting methods of transplanted aman rice. The Foliar spray in bed planting method reduced weed population resulting in lower dry biomass than conventional planting. The conventional method had significantly ($P \leq 0.01$) higher weed vegetation than raised bed method (Table 6.7).

Table 6.7: Effect of weed growth by foliar spray in raised bed and conventional method

Method of fertilizer application	Weed vegetation	
	Weed vegetation population (no. m^{-2})	Dry biomass (kg ha^{-1})
Foliar spray of fertilizer in raised bed	115b	107.8b
Fertilizer broadcasting in conventional planting	380a	337a
LSD at 5%	4.72	2.75
Level of significance	**	**

Where ** represent probability of ≤ 0.01. Values were means of three replicates. In a column figures with same letter do not differ significantly whereas figures with dissimilar letter differ significantly ($P \leq 0.01$).

6.3.8. Irrigation water

Amount of water required for different irrigations differed remarkably between the conventional and bed planting methods. The conventional method received the higher amount of water at every irrigation and total amount was 142.66 cm. The total amount of irrigation water received by foliar spray in bed planting was 102.47 cm. Result showed that total water savings by foliar spray in bed over conventional method was 39% (Table 6.8).

Table 6.8: Irrigation water savings by foliar spray in bed planting of rice production over conventional method.

Method of fertilizer application	Water required at different times of irrigation (cm)					Water saved over conventional method (%)
	Land preparation	Transplanting	Reproductive stage	Rainfall	Total	
Foliar spray of fertilizer in raised bed	-	6.35	43.62	52.50	102.47b	39%
Fertilizer broadcasting in conventional planting	13.06	6.20	70.90	52.50	142.66a	
LSD at 5%	-	0.37	0.00	1.03	2.62	
Level of significance	n.s.	n.s.	n.s.	n.s.	**	

Where ** and n.s. represent probability of ≤ 0.01 and >0.05. Values were means of three replicates. In a column figures with same letter do not differ significantly whereas figures with dissimilar letter differ significantly ($P \leq 0.01$).

6.3.9. Water use efficiency

Water use efficiency for grain and biomass production by foliar spray in bed planting was 45.67 kg $ha^{-1}cm^{-1}$ and 91.75 kg $ha^{-1}cm^{-1}$ respectively. In contrast, water use efficiency for grain production and biomass production in conventional planting was 30.63 kg $ha^{-1}cm^{-1}$ and 65.11 kg $ha^{-1}cm^{-1}$ respectively. However, water use efficiency for grain production and biomass production by foliar spray bed planting over conventional was 49% and 40.88% respectively (Table 6.9).

Table 6.9: Water use efficiency by foliar spray in raised bed and conventional method

Method of fertilizer application	Water use efficiency savings by foliar spray in bed planting of rice over conventional method	
	Water use efficiency for grain production (kg $ha^{-1}cm^{-1}$)	Water use efficiency for biomass production (kg $ha^{-1}cm^{-1}$)
Foliar spray of fertilizer in raised bed	45.67a	91.73a
Fertilizer broadcasting in conventional planting	30.63.b	65.11b
LSD at 5%	1.85	5.04
Level of significance	**	**

Where ** represent probability of ≤ 0.01. Values were means of three replicates. In a column figures with same letter do not differ significantly whereas figures with dissimilar letter differ significantly ($P \leq 0.01$).

6.3.10. Agronomic efficiency of fertilizer

Agronomic efficiency of fertilizer (AE) by foliar spray in raised bed was 93.82%. On the other hand, AE for conventional planting was 43.67%. Agronomic efficiency of fertilizer by foliar spray in raised bed was significantly ($P \leq 0.01$) higher than the conventional planting method (Table 6.10).

Table 6.10: Agronomic efficiency of fertilizer by foliar spray in bed and conventional planting

Method of Fertilizer application	Agronomic efficiency of fertilizer (%)
Foliar spray of fertilizer in raised bed	93.82a
Fertilizer broadcasting in conventional planting	43.67b
LSD at 5%	5.26
Level of significance	**

Where ** represent probability of ≤ 0.01. Values were means of three replicates. In a column figures with same letter do not differ significantly whereas figures with dissimilar letter differ significantly ($P \leq 0.01$).

6.4. DISCUSSIONS

6.4.1. Foliar spray in bed planting method produces higher biomass and yield than conventional method

The number of panicles m^{-2} was significantly ($P \leq 0.01$) higher in bed planting over conventional method. The difference of panicles number was 22 m^{-2} between these methods (Table 6.1). Bed planting method produced significantly ($P \leq 0.01$) higher grains panicle than conventional method. Likewise, Borrell *et al*. (1998) found that panicles number m^{-2} in rice plant for raised bed planting and flooded method was 228 and 210 respectively. They also found that panicle number per plant in raised bed and flooded methods were 2.3 and 2.0 respectively. They speculated that the raised bed method has the potential to better utilize water and nutrients than conventional methods. This may result in higher panicle number per plant by foliar spray in raised bed than conventional method.

Planting method showed significant ($P \leq 0.01$) effect on plant height of transplanted aman rice. Foliar spray in bed planting attends significantly higher plant height than conventional method. The lower plant height in conventional method indicated that the poor growth of plant that might influence the grain yield and yield components. Likewise, planting method significantly influenced the number of nonbearing tillers of transplanted aman rice. Foliar spray in Bed planting treatments irrespective of bed widths and plant rows per bed significantly ($P \leq 0.01$) reduced nonbearing tillers as compared to the conventional method. Similarly, planting method also affected sterility percentage of transplant aman rice. From the data presented in Table 6.2, it was revealed that foliar spray in bed planting system greatly reduced the sterility of transplanted aman rice compare to the conventional method. The low sterility in bed planting system might be the basis of higher grains panicle^{-1}, which directly added the grain yield. The results presented in Table 6.2 showed that the higher harvest index

(HI) was obtained by foliar spray in bed and lower HI was obtained by conventional method. The higher and lower HI was resulted due to higher and lower grains yield.

Foliar spray in bed planting method had 0.31t ha^{-1} higher rice production over conventional method (Table 6.1). The yield increased by bed planting in transplant aman rice compared to conventional method was also reported by Hobbs and Gupta (2003a), Balasubramanian (2003), Meisner *et al.* (2005) and Jat and Sharma (2005). Likewise, Tang *et al.* (2005) also reported that bed planting method significantly increased rice yield by 6.7% compared with traditional cropping technique. Moreover, Ockerby and Fukai (2001) confirmed that yield of rice grown on raised beds were greater than rice grown in conventional method. They advised that effective N fertilizer utilized by rice paddy plants influenced better rice production in raised bed system. Other study speculated that potential agronomic advances of beds include improved soil structure due to reduced compaction through controlled trafficking and reduced water logging condition is responsible for improved rice production (Humphreys *et al.* 2005).

Weight of 1000 grain was also higher in foliar spray in bed planting than conventional method (Table 6.1). Yadav *et al.* (2002), Zhongming and Fahong (2005) and Meisner *et al.* (2005) reported similar results. Likewise, Choudhury *et al.* (2007) found that 1000 grains weight (gm) in flat bed and raised bed was 20.0 and 20.5 respectively. They speculated that higher grain production in raised bed than flat method could be due to management and geometry of bed, less weed population and better crop establishment.

6.4.2. Foliar spray in bed planting method has less weed growth than conventional method

Weed production was significantly ($P \leq 0.01$) lower foliar spray in bed planting than conventional method. Likewise, existing weed vegetation was significantly ($P \leq 0.01$) lower in raised bed planting than conventional method (Table 6.7). Sing *et al.* (2008) found that total dry weight and density of weed were lower in raised bed planting method as compared to conventionally puddle transplanted rice. Similarly, Singh *et al.* (2005) also found lower weed biomass in raised beds than the conventional method. They speculated that the low number of weeds in beds might be due to dry top surface of beds that inhibited the weed growth. However, my speculation is that, at the time of bed preparation, the top soils of the furrows were mulched to the raised beds, which drastically reduced the weeds in furrow. Another probable cause was that the soil was not disturbed in the zero tillage systems under bed planting method. Another speculation is that this difference of weed growth between bed planting and conventional method may be due to agronomic management practices. In bed planting method, rice plants were grown in wet conditions while in conventional methods, rice plants were grown under standing water condition. This difference in weed growth between these two methods could also have been due to the contrasting weed flora and soil moisture conditions of fields. Likewise, Hobbs (2001) opined that bed planting method reduces weed growth compared with conventional flat-bed planting method. He also suggested that bed planting provides additional options to farmers for controlling weeds. Similarly, Jat *et al.* (2005) suggested that planting of crops on raised bed systems reduces weed competition over conventional method. By adopting raised bed system, fertilizers are banded close to the rows enhancing crop accessibility to nutrient and competitiveness over weeds. The higher fertilizer use efficiency through better placement of fertilizer and faster drying of the top portion of raised bed is responsible for reduced infestation.

6.4.3. Input water use

The differences in total water use between these two methods were 39% higher in conventional over foliar spray in bed planting method for the entire cropping period (Table 6.8). Similarly, Thompson *et al.* (2003) grew rice on both raised beds and flat layout in small plots. They found that irrigation water savings of about 14% using beds compared with flat layout. Studies in the USA have also shown considerable water saving with furrow irrigated rice on raised bed over conventional flooding method (Vories *et al*. 2002). Likewise, Beecher *et al.* (2006) found that water use in flat and raised bed methods were 18.7 and 15.1 ML ha^{-1} respectively. They recommended that there is a good scope for saving water while maintaining yield on suitable rice soil through the use of raised beds. In another study, Boulala *et al.* (2012) speculated that compared to conventional method, the introduction of the raised bed planting system resulted in higher soil resistance to the penetration in the upper soil profile. This may protect deep percolation of irrigation water in the field. Regardless of that Fahong *et al.* (2004) suggested that the better performance of raised bed over conventional methods was considered to be due to reduced water logging, improved soil physical properties, reduced lodging and decreased incidence of disease. However, my speculation is that the advantages come from the fact that irrigation water advances faster on bed planting soil than in a tilled soil and less water percolation loss in bed planting method over conventional method.

6.5. CONCLUSIONS

This study concludes that foliar spray in raised beds increased rice yield by 9.33% when compared with conventional tillage on the flat. Raised bed also reduced irrigation water requirement by 39% as well as increased irrigation efficiency. This finding concludes that water use efficiency for grain and biomass production were higher in foliar spray in bed planting than by the conventional method. The agronomic efficiency of fertilizer was also significantly higher in foliar spray of bed planting than the conventional method. The potential gains from growing rice production on raised beds are considered to be associated with better agronomic management than conventional method. Also, the crust problem on the soil surface was eliminated and soil physical status was greatly improved in bed planting plot over conventional flat system. Based on the findings of this single season experiment, high yielding aman rice (depends on both irrigation and rainfall) crops have been successfully grown on raised bed under foliar spray; however, this research needs further validation. In this perspective, further study of foliar spray in raised bed planting over conventional method on water and fertilizer use efficiency will be focused for transplanted boro rice (completely depends on irrigation) (Chapter 10).

Chapter 7

Raised bed planting provides higher yield and less water inputs for transplanted boro rice (*Oryza sativa*) than conventional cultivation method

Chapter 7

Raised bed planting provides higher yield and less water inputs for transplanted boro rice (*Oryza sativa*) than conventional cultivation method

7.1. INTRODUCTION

Boro (winter, irrigated) rice is the most important crop in Bangladesh in respect of volume of production. The growing period of boro rice in Bangladesh is December to May. It reveals that due to higher yields, farmer become more interested to bring more area under this crop. Total area under boro crop has been estimated at 48.10 lac hectares in Bangladesh (BBS, 2011).

Raised beds are formed by moving soil from the furrows to the area of the bed, thus raising its surface level (Bhuyan *et al.* 2012a). Transplanting of boro rice on raised beds was better than conventional in terms of greater plant height, number of panicle m^{-2}, length of panicle and 1000 grain weight and ultimately higher yield than conventional method (Samar *et al.* 2002). In raised bed system, rice is grown on beds that are kept at saturated by water in furrows in between the beds. While most researchers agreed that bed planting reduced water inputs compared to conventional flooding, reports on its effects on rice yield and water productivity have been diverse (Borrell *et al.* 1997; Thompson 1999. Gupta *et al.* 2002). Tuong (2003) also reported that bed planting reduced water input compared to conventional planting method. Bed planting may also facilitate the establishment of upland crops after rice because beds and furrow improve drainage when rainfall is heavy (Humphreys *et al.* 2004).

My previous study showed that yield and growth response to transplanted aman rice (partially depends on irrigation and rainfall) was greater in raised bed over conventional cultivation method (Chapter 3). However, it was not considered for transplanted boro (winter, completely irrigated) rice to find out seasonal and climatic (temperature, humidity, rainfall) variation with fertilizer broadcasting in raised bed and conventional method. Therefore, this study was undertaken to compare between the effect of fertilizer broadcasting in raised bed and fertilizer broadcasting in conventional planting method for transplanted boro season rice production. It will be hypothesized that fertilizer broadcasting on raised bed receives higher yield and growth response as well as less water inputs than conventional cultivation method.

7.2. MATERIALS AND METHODS

7.2.1. Geographical location of the experimental site

The field experiment was carried out the farmer field, Chuadanga, Bangladesh, during boro (December-May) season of 2012. Research field was located at 11.5 m above mean sea level. Geographically, it is located at $23^0 39^{/}$N latitude and $88^0 49^{/}$ E longitudes.

7.2.2. Meteorological information during the crop season

The Meteorological data for the cropping season were recorded at local weather station, Chuadanga district of Bangladesh. The rainfall received during the growth period of crop (February-May) total of 128 mm. The mean maximum and minimum temperature were recorded 34.28ºC and 22.03ºC respectively for the cropping season. The relative humidity ranged between 63.8% in the month of March and 71.5% in the month of February.

7.2.3. Basic soil properties of the experimental site

Soil physical and chemical properties of the experimental site are as below:

Textural class	Silt loam
Soil pH	7.30
OC (%)	0.88
Total N (%)	0.11
Available P (ppm)	5.68
Exchangeable K (meq 100 g^{-1})	0.15
Available S (ppm)	12.10
Available Zn (ppm)	0.22

These properties were measured at regional soil testing laboratory of Soil Resources Development Institute, Jhenidah, Bangladesh.

7.2.4. Experimental design and layout

The experiment was laid out in a randomized complete block design (RCBD) with three replications. The entire experimental area was divided into three block representing three replications to reduce soil heterogenic effects and each block was divided into three unit plots with raised bunds as per treatments. Thus the total number of unit plots was 9. The size of each unit plot was 4 m × 3.5 m. Plots were separated from one another by ails of 0.25 m. Unit blocks were separated from one another by 1 m drains. Treatments were randomly distributed within the blocks.

7.2.5. Characteristics of rice variety

BRRI dhan28, a high yielding variety of rice was used as the test crop in this experiment. The variety was released for boro season by Bangladesh Rice Research Institute (BRRI), Joydebpur, Gazipur in 1994 after regional and zonal trial and evaluation. The variety was developed after selection of bread line BR601-3-3-4-2-5, which was obtained from crossing line IR 28 with purbachi. Then the line BR 601-3-3-4-2-5 was released for boro season as BRRI dhan 28. It is a transplant boro rice cultivar with average yield 5.0 t ha^{-1}. Life cycle of this variety ranges from 135 to 140 days, which however may vary due to change in climatic condition.

7.2.6. Cultural practices of rice

Two fertilizer application methods for comparison of raised bed and conventional planting were established across a soil. The combinations of treatments were fertilizer broadcasting in raised bed, fertilizer broadcasting in conventional planting and control. Two 45 day old seedlings hill^{-1} of BRRI 28, a popular boro (winter, irrigated) rice variety were transplanted on 29th February 2012. The row to row and hill to hill spacing were 25 cm and 20 cm for both beds and flat. Only two rows of rice were planted on each bed and plant density was much higher in the conventional treatment. Fertilizer was applied at the following rates: N=120, P=14, K=36, S=1.0 kg ha^{-1} applied as urea, Triple Super-Phosphate (TSP), Murate of Potash (MP), Gypsum and Zinc sulphate ($ZnSo_4$), respectively. Whole of TSP, MP, gypsum and $ZnSO_4$ were applied at the final land preparation as basal dose in the plots with conventional treatment. In the plots with bed planting treatment, the basal doses were broadcasted before transplanting on top of the beds. Urea was broadcasted in three equal splits at 15, 30, and 50 days after transplanting of rice. Manual weeding was done twice in the transplant boro rice field during growth period. The plots were weeded at 15 and 30 DAT. Weed samples from each plot were collected at the time of weeding for comparing weed population and dry biomass yield of different treatments. The rice was infested by stem borer at tillering stage and rice bug at grain filling stage. Furadon 5G at the rate of 10 kg ha^{-1} was applied at 40 DAT and Malathion 57 EC 5G at the rate of 1 litre ha^{-1} was applied at grain filling stage to control stem borer and rice bug, respectively.

7.2.7. Plant height and tiller number observation

Randomly selected and tagged 10 plants were used for the measurement of plant height at an interval of 15 days from 15th day after transplanting and ending with just flowering. It was measured from base to tip of the upper leaves of the main stem. Numbers of tiller per plant were counted from one meter row length.

7.2.8. Leaf area index

Leaf area (cm^2) of the functional leaves obtained from samples drawn for dry matter accumulation study was measured by automatic leaf area meter. Then leaf area of the plants/units is will be worked out by following formula:
Leaf area index (LAI) = Leaf area/Ground area

7.2.9. Yield attributed characters of rice

Observation regarding the effective tiller per row length was recorded just before harvesting the crop and the average values was used to obtain the effective panicles per meter row length. The length of panicle was taken from the 10 panicles from each plot which were randomly selected just before harvesting and mean were calculated. Number of filled and unfilled grains was counted to determine the number grains per panicle. Thousand grains were counted from the grain yield of each plot and weighted with the help of automatic electronic balance.

7.2.10. Biomass yield and grain yield

Biomass yield and grain yield was taken at harvesting from each plot. All the plants from 1 m length were uprooted and weighed to determine the total biomass yield. Digital grain moisture meter was used to record the moisture of the grain. Finally grain yield was adjusted at 14% moisture using the formula as suggested by Paudel (1995).

Grain yield (t ha^{-1}) at 14% moisture = (100-MC) x plot yield (ton) x 10000(m^2)/ (100-14) x plot area (m^2)

Where, MC is the moisture content in percentage of the grains.

7.2.11. Harvest index

Harvest index (HI) was computed by dividing grain yield with the total dry matter yield as per following formula.

$$HI = (\text{grain yield})/\ (\text{grain yield} + \text{straw yield})$$

7.2.12. Irrigated water measurement

Irrigation water was measured by using a delivery pipe and water pan. A plastic delivery pipe was connected from the water pump to the experimental field. A water pan with 300-liter volume was filed by irrigation through the delivery pipe and time required was recorded. Then plots with different methods of planting were irrigated through the delivery pipe and times required were recorded. The amount of irrigation water applied in different plots was calculated as follows:

Amount of water applied per plot=

$$\frac{\text{Volume of water pan (L)} \times \text{Time required to irrigation the plot (sec)}}{\text{Time required filling the water pan (sec)}}$$

7.2.13 Water use efficiency calculation

Water use efficiency for grain and biomass production was calculated by the following equations:

Water use efficiency for grain production (kg $ha^{-1}cm^{-1}$)

= grain yield (kg ha^{-1})/total water required (cm)

Water use efficiency for biomass production (kg $ha^{-1}cm^{-1}$)

= [grain yield (kg ha^{-1}) + straw yield (kg ha^{-1})]/ total water required (cm)

7.2.14 Agronomic efficiency of fertilizer calculation

Agronomic efficiency (AE) of fertilizer was calculated by the following equation:

$AE= GY_{NA}-GY_{N0}/N_R$

Where $GY_{NA=}$ Grain yield (kg ha^{-1}) with addition of nutrient

GY_{N0}= Grain yield (kg ha^{-1}) without addition of nutrient

N_R= Rate of added nutrient (kg ha^{-1})

7.2.15. Statistical analysis of data

The experiment was conducted using randomized complete block design with three replications for each treatment. Data were analysed following standard statistical procedure and means of treatments were compared based on the least significant difference test (LSD) at the 0.05 probability level. Microsoft Excel was used for tabulation and simple calculation, presentation of table for different comparisons.

7.3. RESULTS

7.3.1. Grain yield and yield components

The average yield data in the Table 7.1 indicated that the grain yield of rice differed significantly with two method of planting. The yield increased by 15.90% in bed planting over conventional planting. Likewise, the higher thousand grain weight was observed in bed over conventional planting method. Similarly, the raised bed planting had 10 grains panicle^{-1} more than the conventional planting method. In addition, the panicle number m^{-2} was significantly higher in raised bed over conventional planting method (Table 7.1).

Table 7.1: Grain yield and yield components with respect to fertilizer broadcasting in raised bed and fertilizer broadcasting in conventional planting.

Method of Fertilizer application	Yield and yield components			
	panicles m^{-2} (no)	Grains panicle^{-1} (number)	1000 grain wt (gm)	Grain yield (t ha^{-1})
Fertilizer broadcasting in bed planting	470a	116a	24.88	5.10a
Fertilizer broadcasting in conventional planting	430b	106b	21.00	4.40b
LSD at 5%	4.98	3.82	2.60	0.38
Level of significance	**	*	n.s.	*

Where, n.s.,* and ** represents probability of > 0.05, ≤ 0.001 and ≤ 0.01, respectively. Values were means of three replicates.

7.3.2. Plant growth components

Plant biomass was higher in fertilizer broadcasting on raised bed than conventional flat method (Table 7.2). The length of panicle was 0.48 cm higher in raised bed planting than the conventional planting method. Interestingly, the plant height at maturity was 0.48 cm higher in conventional planting over bed planting method. However, the sterility percentage was 22.52% higher in conventional planting compared to bed planting. The higher number of grains per panicle was accountable for lower sterility percentage in raised bed. On the other hand the higher sterility in conventional planting might be due to the lower number of grains per panicle. The straw yield in raised had 0.47 t ha^{-1} more than the conventional planting. The higher straw yield produced by bed planting over conventional planting might be due to the higher dry matter accumulation. Moreover, the appraisal of data in Table 7.2 revealed that the harvest index of different planting method was insignificant. The harvest index was high in bed planting over conventional planting with higher yield.

Table 7.2: Plant biomass with respect to fertilizer broadcasting in raised bed and fertilizer broadcasting in conventional planting

Method of Fertilizer application	Plant height (cm)	Panicle length (cm)	Non-bearing tiller (number m^{-2})	Sterility (%)	Straw yield (t ha^{-1})	Harvest index
Fertilizer broadcasting in bed planting	85.78	24.58	75b	13.23b	5.39	0.48
Fertilizer broadcasting in conventional planting	87.34	24.10	102a	16.21a	4.92	0.47
LSD at 5%	2.35	1.36	2.62	1.60	0.37	0.00
Level of significance	n.s.	n.s.	**	*	n.s.	n.s.

Where, n.s.,* and ** represents probability of > 0.05, ≤ 0.001 and ≤ 0.01, respectively. Values were means of three replicates.

7.3.3. Tiller number and crop growth rate

Different planting method of transplanted boro rice affected the number of tiller m^{-2} (Table 7.3). In raised bed, the highest tiller production was observed in 40 days after transplanting (DAT). After 50 DAT, the number of tiller was started to declined and continued to 100 DAT. In conventional planting method the highest tiller number was recorded at 40 DAT. The tiller production differed significantly ($P \geq 0.05$) by raised bed over conventional method except 80 and 90 DAT.

Table 7.3: Effect of tiller production by fertilizer broadcasting in raised bed and fertilizer broadcasting in conventional planting.

Method of Fertilizer application	Tiller (number m^{-2}) at days after transplanting								
	20	30	40	50	60	70	80	90	100
Fertilizer broadcasting in bed planting	80a	218a	247a	209a	170a	154a	144	142	140a
Fertilizer broadcasting in conventional planting	76b	209b	240b	200b	162b	149b	141	139	135b
LSD at 5%	2.07	2.62	2.62	2.07	2.42	1.31	2.07	2.07	2.62
Level of significance	*	**	**	**	**	**	n.s.	n.s.	*

Where, n.s.,* and ** represents probability of > 0.05, ≤ 0.001 and ≤ 0.01, respectively. Values were means of three replicates.

7.3.4. Leaf area index

Leaves are the main photosynthesis organ and area of the leaf surface per unit area is the leaf area index (LAI) (Gomez, 1972), which is an important yield determining growth parameter of plants (Watson, 1947). In bed planting method, the highest LAI was recorded at 60 DAT (Table 7.4). From Table 7.4 it was showed that the early stage of crop growth (20 DAT), the LAI was higher in conventional planting than the bed planting. The highest LAI was observed by conventional planting at 80 DAT. However, LAI differed significantly ($P < 0.01$) between two methods except 40 DAT.

Table 7.4: Effect of leaf area index by fertilizer broadcasting in raised bed and fertilizer broadcasting in conventional planting.

Method of Fertilizer application	LAI at different DAT				
	20	40	60	80	100
Fertilizer broadcasting in bed planting	0.28b	2.45	5.76a	5.30	3.94
Fertilizer broadcasting in conventional planting	0.42a	2.50	5.03b	5.08	3.85
LSD at 5%	0.00	0.46	0.19	0.29	0.10
Level of significance	**	n.s.	**	n.s.	n.s.

Where, n.s. and ** represents probability of > 0.05 and ≤ 0.01, respectively. Values were means of three replicates.

7.3.5. Dry matter production

Crops yield depends upon the dry matter production per unit area therefore high production of total dry matter was first pre requisite for high yield. The effects of different treatments in dry matter production are shown on Table 7.5. At 20 DAT, the conventional planting method produced higher dry matter yield than the bed planting. Likewise, at the last date of measurement (90 DAT) the raised bed planting produced higher dry matter yield than the conventional planting method. From Table 7.5, it showed that the progressive increase in total dry matter production as crop attained maturity by both planting method.

Table 7.5: Effect of dry matter production by fertilizer broadcasting in raised bed and fertilizer broadcasting in conventional planting.

Method of Fertilizer application	Dry matter production (gm m^{-2}) at different days after transplanting (DAT)							
	20	30	40	50	60	70	80	90
Fertilizer broadcasting in bed planting	37b	234b	505	641a	1020a	1121a	1293a	1308a
Fertilizer broadcasting in conventional planting	61a	257a	492	619b	903b	1049b	1282b	1294b
LSD at 5%	2.07	2.62	10.83	2.07	9.44	19.93	2.62	9.44
Level of significance	**	**	n.s.	**	**	**	**	**

Where, n.s. and ** represents probability of > 0.05 and ≤ 0.01, respectively. Values were means of three replicates.

7.3.6. Crop growth rate

Further, the crop growth rate was highest at 50 to 60 DAT by bed planting (Table 7.6). The lowest crop growth rate was observed at 80 to 90 DAT by bed planting method. In conventional planting the highest crop growth rate was observed at 50 to 60 DAT. The lowest crop growth rate was recorded at 80 to 90 DAT by conventional planting method. The crop growth rate differed significantly ($P \geq 0.05$) by two planting method except 20-30 and 30-40 DAT.

Table 7.6: Effect of crop growth rate by fertilizer broadcasting in raised bed and fertilizer broadcasting in conventional planting.

Method of Fertilizer application	Crop growth rate (gm m^{-2} day^{-1}) at different days after transplanting (DAT)						
	20-30	30-40	40-50	50-60	60-70	70-80	80-90
Fertilizer broadcasting in bed planting	19.70	27.10	13.6a	37.9a	10.10b	17.20b	1.50a
Fertilizer broadcasting in conventional planting	19.60	23.50	12.70b	28.40b	14.60a	23.30a	1.20b
LSD at 5%	0.39	1.51	0.39	0.38	1.58	1.22	0.26
Level of significance	n.s.	n.s.	*	*	**	**	**

Where, n.s.,* and ** represents probability of > 0.05, ≤ 0.001 and ≤ 0.01, respectively. Values were means of three replicates.

7.3.7. Weed vegetation

The conventional planting method produced 243 numbers more weeds m^{-2} than the bed planting method (Table 7.7). As a result the conventional planting method also produced 207.86 kg ha^{-1} more dry mass of weed than the raised bed planting method. Interestingly, dry weed biomass significantly ($P \geq 0.05$) differed between these two methods.

Table 7.7: Effect of weed growth by fertilizer broadcasting in raised bed and fertilizer broadcasting in conventional planting.

Method of Fertilizer application	Weed vegetation	
	Weed vegetation population (number m^{-2})	Dry biomass (kg ha^{-1})
Fertilizer broadcasting in bed planting	146	137.12b
Fertilizer broadcasting in conventional planting	389	344.98a
LSD at 5%	1.31	1.38
Level of significance	n.s.	**

Where, n.s. and ** represents probability of > 0.05 and ≤ 0.01, respectively. Values were means of three replicates.

7.3.8. Irrigation requirement

Different planting method affected the irrigation water requirement .The total irrigation water required by bed planting was 109.82 cm (Table 7.8). On the other hand the conventional method received 149.00 cm irrigation water. Result showed that the total water savings by bed planting over conventional planting was 35%.

Table 7.8: Irrigation water savings by fertilizer broadcasting in raised bed and fertilizer broadcasting in conventional planting.

Method of Fertilizer application	Irrigation required (cm)	Rainfall (cm)	Total Irrigation required (cm)	Water saved over conventional method (%)
Fertilizer broadcasting in bed planting	97.02b	12.8	109.82	
Fertilizer broadcasting in conventional planting	136.20a	12.8	149.00	35%
LSD at 5%	2.17	0.21	2.15	
Level of significance	**	n.s.	n.s.	

Where, n.s. and ** represents probability of > 0.05 and ≤ 0.01, respectively. Values were means of three replicates.

7.3.9. Water use efficiency

In raised bed planting method the water use efficiency for grain and biomass production was 46043 and 95.51 kg ha^{-1} cm^{-1}, respectively (Table 7.9). On the other hand water use efficiency for grain and biomass production in conventional planting method was 29.53 and 62.55 kg ha^{-1}cm^{-1}, respectively. In addition, the water use efficiency for grain and biomass production by bed planting was 57.22% and 52.69% higher over conventional planting.

Table 7.9: Water use efficiency by fertilizer broadcasting in raised bed and fertilizer broadcasting in conventional planting.

Method of Fertilizer application	u Efficiency savings by fertilizer broadcasting in raised bed and fertilizer broadcasting in conventional planting.	
	Water use efficiency for grain production (kg ha^{-1}cm^{-1})	Water use efficiency for biomass production (kg ha^{-1}cm^{-1})
Fertilizer broadcasting in bed planting	46.43a	95.51a
Fertilizer broadcasting in conventional planting	29.53b	62.55b
LSD at 5%	1.29	2.75
Level of significance	**	**

Where, ** represents probability of ≤ 0.01. Values were means of three replicates.

7.3.10. Agronomic efficiency of N fertilizer

The agronomic efficiency of N fertilizer for bed planting was 28.33% (Table 7.10). Likewise, the agronomic efficiency of N fertilizer for conventional planting was 22.56%. The agronomic efficiency of N fertilizer in bed planting was 25.57 % higher over conventional planting method.

Table 7.10: Agronomic efficiency of fertilizer by fertilizer broadcasting in raised bed and fertilizer broadcasting in conventional planting.

Method of Fertilizer application	Agronomic efficiency of fertilizer (%)
Fertilizer broadcasting in bed planting	28.33a
Fertilizer broadcasting in conventional planting	22.56b
LSD at 5%	1.85
Level of significance	**

Where, ** represents probability of ≤ 0.01. Values were means of three replicates.

7.4. DISCUSSIONS

7.4.1. Transplanted boro rice produced higher yield components in raised bed than conventional cultivation method

Transplanted boro rice has 0.71 t ha^{-1} more yield for fertilizer broadcasting in raised bed than fertilizer broadcasting in conventional flat method. Likewise, fertilizer broadcasting in raised bed produced about 3 gm thousand grain weights than fertilizer broadcasting in conventional flat method. Similarly panicle number, grains per panicle was significantly ($P \leq 0.01$ and $P \leq 0.05$) higher in fertilizer broadcasting in raised bed than fertilizer broadcasting in conventional flat method (Table 7.1). Likewise, Husain *et al*. (2003) found higher number of panicle m^{-2} under raised bed planting than the conventional planting method. This study found that higher number of grains panicle^{-1} was recorded in bed planting. This findings also supported by Husain *et al*. (2004). They observed the higher number of grains panicle^{-1} under raised bed compared to farmers practice. Planting method also effect the 1000 grains weight. In my study the weight of 1000 grains was higher in raised bed planting than conventional planting method. My speculation is that the bed planting encouraged proper crop growth and development and assimilate synthesis in the grains. Bari (2004) also observed that planting method had no significant influence on 1000-grains weight. But Husain *et al.* (2004) and Hossain *et al.* (2003) observed higher 1000-grains weight under bed planting compared to the farmers practice. Fertilizer broadcasting in bed produced 15.90% higher grain yield than fertilizer broadcasting in conventional flat method. Nissanka and Bandara (2004) reported that grain yield in raised bed was 9% higher than conventional planting method. Connor *et al.* (2003) demonstrated that bed planting of rice improved grain yield 6.2 % compared to conventional flat method. Likewise, Talukder *et al.* (2010) reported that boro rice in raised planting increased grain yield 14% over the conventional planting method. Similarly, Lauren *et al.* (2013) demonstrated that raised bed increased rice yield by 13 to 16 percent compared to conventional planting. They speculated that raised bed build soil aggregation and provide deeper rooting and better air-water relationship in soils that results improve rice yield. My speculation is that bed planting cultivation method allowed to the vigorous and healthy growth, development of more productive tillers and leaves ensuring greater resource utilization than conventional planting which contributed to higher grain yield for the transplanted boro rice.

7.4.2. Plant growth attributes in transplanted boro rice

Plant growth parameters in transplanted boro rice were significantly ($P \leq 0.05$) higher for fertilizer broadcasting in raised bed than conventional flat method. Panicle numbers were significantly ($P \leq 0.05$) greater in raised bed than conventional flat method (Table 7.1). Other study conducted by Aslam *et al.* (2008) found that bed planting of rice produced higher number of panicle m^{-2} than conventional planting method. They suggested that lower number of panicle m^{-2} were produced by conventional planting method due to lower availability of nutrients in the submerged field. Likewise, panicle length was 0.48 cm more in fertilizer broadcasting on raised bed than conventional cultivation practice (Table 7.2). Similar findings were found from other study. El-Bably *et al.* (2008) found that panicle length of rice in bed planting was 1.5 cm more than conventional planting. They stated that higher panicle length in bed planting could be attributed to the varietal differences. Similarly, tiller numbers were significantly ($P \leq 0.05$) greater in fertilizer broadcasting on raised bed than conventional flat method up to 70 days after transplanting (Table 7.3). Regardless of that crop growth rate were significantly ($P \leq 0.05$) higher in fertilizer broadcasting on raised bed that conventional flat method from 40 to 60 days after transplanting (Table 7.6). This finding was supported from other study. Mollah (2005) showed that transplanted rice in beds (70 cm wide) produced higher number of tiller and crop growth rate at maturity over conventional planting. He suggested that wider beds (80 and 90 cm wide) could not produce higher number of tiller compared to conventional planting method. However, sterility percentage was significantly ($P \leq 0.05$) higher in fertilizer broadcasting on conventional flat than raised bed planting (Table 7.2). This result was supported by Javaid *et al.* (2012). They stated that higher sterility percentage in conventional planting was probably due to severe competition of plants for resources on account of higher number of tiller and panicle per unit area.

Speculation in this study is that under bed planting practices the root system is several times longer and deeper enabling them to access for nutrients even in much greater volume of nutrient poor soil. Deeper root growth encouraged higher nutrient absorption subsequently higher assimilation which was favored higher tiller and panicle production than conventional planting. Transplanted of rice in bed planting provided sufficient nutrient for vegetative growth and also for reproductive phase which ultimately leads to increased plant height than conventional planting. The higher percentage of sterility in conventional planting was because of more tertiary tiller production, which bear late flowering. Among them some were fertilized and majority remained un-fertilized due to weak tiller. Rice transplanted under bed planting might have recovered fast enough due to lower transplanting shock and started absorbing nutrients and water to support faster growth and hence higher dry matter production was observed. The better plant growth performance in bed planting could be due to improved soil physical properties, reduced lodging and incidence of disease. On raised beds, border effects allows the canopy to intercepts more solar radiation, it strengthens the straws, and the soil around the base of the plant is drier to prevent crop from lodging which directly contributed to higher plant growth parameter. Raised bed rice planting provided more favorable root-zone conditions exist for plant growth since there is a greater depth of surface soil, and the furrows act as drains, so rapid re-aeration of the root-zone occurs following irrigation or rainfall.

7.4.3. Raised bed suppressed weed vegetation

Density of weeds in fertilizer broadcasting on bed planting was higher than fertilizer broadcasting in conventional planting method (Table 7.7). Dry biomass of weeds in fertilizer broadcasting on bed planting were significantly ($P \leq 0.05$) higher over fertilizer broadcasting in conventional planting method (Table 7.7). This result supported by Karim (2011). He found that the population and dry weight of weeds were less in bed planting than in conventional planting method. Mishra (2004) also reported the same result. He found that furrow irrigated raised bed system reduced the population of weeds. He stated that raised bed caused least soil disturbance and hence less emergence of weeds. Further, Hobbs *et al.* (2000) demonstrated that fewer weeds germinated in raised bed planting compared with farmers practice. They suggested that permanent bed planting offered farmers an alternative to herbicide use for weed control since most weeds can be controlled by mechanical cultivation through driving down the furrows. In addition, Hossain *et al.* (2012) found that conventional planting of rice resulted acute weed stress compared to permanent raised bed planting. He suggested that poor crop growth in conventional planting could not compete as well with weeds. Furthermore, Mollah (2005) reported that reduced number of weeds m^{-2} and dry biomass yield were in bed planting compared to conventional planting. He suggested that the low number of weeds in beds might be due to dry top surface of beds that inhibited the weed growth. In contrast, Tuong *et al.* (2004) differed with our findings. They reported that bed planting produced higher weed infestation. They suggested that bed planting increased diversity of weeds flora as a result of differing water regimes for weed germination and establishment. My speculation is that the most of the crop-growing period, the furrow between beds in bed planting remained inundated that drastically reduced weeds in furrows. The profuse tillering of rice in beds also filled up the top of beds very rapidly keeping a little space for weed growth. Therefore, weed population and biomass yield was lower in beds than conventional planting method. Moreover, at the time of bed preparation, the top soil of the furrow was mulched to the beds, which reduced weeds in furrow. Weed density was reduced in bed compared to conventional planting because of without disturbance and with drier soil; few weeds were germinated or established.

7.4.4. Broadcasting fertilizer application in raised bed uses irrigation water efficiently over conventional flat method

The irrigation water saved 35% by the fertilizer broadcasting in bed planting over conventional flat method (Table 7.8). EL- Bably *et al*. (2008) reported that irrigation water applied were 1480 mm and 919 mm for traditional and bed planting respectively. So bed planting method saved 37.9% of irrigation water compared with traditional planting method. These results are in accordance with those reported by Atta (2005), Devivder *et al*. (2005), Atta *et al*. (2006) and Jagroop *et al*. (2007). Water use efficiency for grain and biomass production in bed planting were 57.22% and 52.69% higher over conventional planting method (Table 7.9). EL-Bably *et al.* (2008) also demonstrated that field water use efficiency (FWUE) of beds increased 65.8% more than traditional planting method .Similar results were reported by Velhaiya *et al*. (2003). Borell *et al.* (1997) found that water savings were 34% of bed planted rice compared to flooded rice. Bouman *et al.* (2007) reported that irrigation water savings of rice transplanted on beds about 37-40% compared to puddle flat transplanted rice. Connor *et al.* (2003) found that water savings of rice in bed planting was 42% over conventional planting. Talukder *et al.* (2010) demonstrated that the raised beds system saved water use by about 30% compared with conventional planting. Findings in this study are also confirmed by Cabangon *et al*. (2005). They reported that rice grown on raised beds reduced irrigation and total water input by as much as 200-500 mm, which amounts to a 20-45% reduction in total water input compared with well watered rice planting method. Thompson *et al*. (2003) found that irrigation water savings of about 14% using raised bed for growing rice compared to flat irrigation design. Beecher *et al*. (2005) demonstrated that total input water use for rice crop cultivation in raised bed was 18.1 MLha^{-1} and 18.7 MLha^{-1} in flat cultivation method. There are many reports of substantial irrigation water savings with rice on beds compared with continuously flooded flat transplanted rice. However, some studies suggest that where similar irrigation scheduling is used, irrigation water use of transplanted rice in beds and puddle flats is similar.

Further, Choudhury *et al.* (2007) reported that total water input (irrigation plus rainfall) varied from 930 mm (raised beds) to 1600 mm (flooded transplanted). Total water input in rice on raised beds was 38–4l % less than in flooded transplanted rice and 32–37% less than in flooded wet seeded rice. For comparison, Humphreys *et al.* (2005) reported that reductions in irrigation water use of 12–60% in transplanted or dry-seeded rice on raised beds compared with flooded transplanted rice. Hossain *et al.* (2004) demonstrated permanent bed (PB) reduced irrigation water use by 32% relative to conventionally tilled on the flat (CTF). My speculation is that bed planting system involves growing rice on raised bed with a shallow water table (about 10 cm below the surface of the beds) by maintaining a shallow water depth in the furrows. The low percolation rates are attributed to shallow water table. This may resulted low water input by bed planting over conventional cultivation of rice. Another probable cause of allowing the soil in raised beds to dry out a little bit more reduced irrigation water inputs than conventional planting. Irrigation water advances faster in untilled soil (bed) than in a tilled soil (conventional) may be another cause of less water input in bed planting method. In addition, the application of fertilizer in bed planting facilitated root growth, which can extract soil moisture from deeper layers. Furthermore, application of fertilizers in raised bed facilitated early development of canopy that covers the soil and intercepts more solar radiation and there by reduces the evaporation component of the evapo-transpiration which contributed less water input in raised bed planting. Water surface have a higher evaporation rate than soil surface. Bed planting reduced the duration that the field flooded may also decreased the amount of evaporation. Bed planting maintained shallow water depth in rice field reduced the hydrostatic pressure which resulted less water loss through percolation.

7.5. CONCLUSIONS

This research demonstrated that fertilizer broadcasting in bed planting increased yield by 15.90% compared to fertilizer broadcasting in conventional planting for transplanted boro (winter, irrigated) rice. Raised bed produced higher panicle number, grains per panicle and thousand grain weights over conventional planting method. Better plant growth parameter of boro rice in bed planting was observed compared to conventional planting. Raised bed planting saved irrigation water by 35% as well as increased irrigation efficiency. Bed planting provided less weed density and dry biomass than conventional planting. These findings concludes that water use efficiency for grain and biomass production was higher in fertilizer broadcasting of bed planting than fertilizer broadcasting in conventional method. The agronomic efficiency of fertilizer was also significantly higher in fertilizer broadcasting of bed planting than the fertilizer broadcasting in conventional method.

The potential gains from growing boro rice on raised beds are considered to be associated with better agronomic management than conventional method. It is likely that the raised bed technique will have long term soil physical benefits without sacrificing yield. The incorporation of fertilizer broadcasting in raised bed introduced a new boro rice based farming system offers many advantages. Based on the findings of this experiment, high yielding boro rice (winter, irrigated) crops have been successfully grown on raised bed under fertilizer broadcasting. There is a good prospect of utilization of this technology to benefit the rice farmers. More studies is needed to establish bed planting, a better planting method of boro rice cultivation in Bangladesh as well as other countries in the world. Further study will be conducted to determine the effect of fertigation on raised bed as compared to conventional planting for boro rice (winter, irrigated) production (Chapter 8).

Chapter 8

Fertigation with bed planting increases water use efficiency and yield of transplanted boro rice (*Oryza sativa*) over conventional cultivation method

Chapter 8

Fertigation with bed planting increases water use efficiency and yield of transplanted boro rice (*Oryza sativa*) over conventional cultivation method

8.1. INTRODUCTION

Fertigation is the application of water soluble solid fertilizer or liquid fertilizer through irrigation system (Biswas, 2010) spread all over the world. The advantages of fertigation technique showed a slow-release of fertilizer and lower loss of N and therefore a lower degree of ground water contamination which not only increased the N uptake by the plant as well as the leaf and root weight, but it also produced higher yields (Cadahia, 1993). Fertigation technique can also reduce fertilizer application costs by eliminating an operation and improve nutrient efficiency.

Fertigation enables users to put the fertilizers in plant root zone or on canopy in desired frequency, amount and concentration at appropriate time (Kumar *et al*., 2000). Efficient use in fertilizer requires contact between fertilizer and crop requirements, which could be achieved by applying N fertilizer with furrow irrigation (Rice & Symth, 1994). Thus, 50% of recommended dose of fertilizer application through fertigation was as effective to produce yield as that of conventional method of fertilizer application (Tumbare, 1999) and 25-50% fertilizer could be saved. Extensive fertigation research on most vegetables crops is available (Hayens, 1985). There may be no research work available how N fertilizer application through fertigation technique reduce fertilizer use efficiency.

My previous study showed that fertigation in raised bed planting had higher yield and water use efficiency compared to fertilizer broadcast in conventional method for transplanted aman rice (non-irrigated, rain fed) (Chapter 4). However, no study has been conducted in fertigation technique on raised bed compared with conventional technique for transplanted boro rice production (winter, irrigated). Under this circumstance, the present study was undertaken to achieve the following objectives. (i) To explore the comparative advantages of using N fertilizer through fertigation in raised bed over N-broadcast in conventional planting for transplanted boro rice production (ii) To examine the differences in yield and growth response of transplanted boro rice between these two techniques (iii) To compare the water use efficiency and agronomic efficiency of N for fertigation in raised bed planting over conventional technique. It was hypothesized that fertigation technique in raised bed will be more efficient compared to conventional flat method for transplanted boro rice production.

8.2. MATERIALS AND METHODS

The field experiment was carried out the in the farmer field, Chuadanga, Bangladesh, during boro (December-May) season of 2012.

8.2.1. Site description

8.2.1.1. Geographical location

The experimental area was located at 11.5 m above mean sea level. Geographically, it is located at 23^0 39$^/$ N latitude and 88^0 49$^/$ E longitudes.

8.2.1.2. Agro-ecological region

The experimental field was belongs to the Agro-ecological zone (AEZ) of 11 that is High Ganges river floodplain.

8.2.1.3. Climate

The meteorological data for the cropping season were recorded at local weather station, Chuadanga district of Bangladesh. The rainfall received during the growth period of crop (February-May) total of 128 mm. The mean maximum and minimum temperature were recorded 34.28ºC and 22.03ºC respectively for the cropping season. The relative humidity ranged between 63.8% in the month of March and 71.5% in the month of February.

8.2.1.4. Soil

One week before transplanting, soil samples (0-15 cm depth) were collected from the field for physio-chemical analysis (Table 8.1). Soil samples were analysed for particle size distribution by hydrometer method (Bouyoucos, 1962). Soil pH was measured in water (Soil water ratio 1:1) and electrical conductivity of the soil suspension was measured using conductivity meter. The P, K and Zn were determined by using AB-DTPA method (Soltanpour and Workman, 1979). For K determination from plant samples, wet digestion method (nitric acid + perchloric acid in 2: 1 ratio) was followed and measured the concentration by flame photometer (Rhoades, 1982). The data on the initial analysis soil samples for organic carbon, pH , available N, P and K are furnished in Table 8.1.

Table. 8.1. Soil physical and chemical properties (Initial Analysis)

Location	Season	Soil type	pH	Organic Carbon (%)	Total N (%)	Available P (ppm)	Exchangeable K (meq 100 g$^{-1)}$	Available S (ppm)	Available Zn (ppm)
Chuadanga	boro	Silt loam	7.30	0.88	0.11	5.68	0.15	12.10	0.22

8.2.2. Experiment details

8.2.2.1. Experimental design

The experiment was laid out in a randomized complete block design (RCBD) with three replications. The entire experimental area was divided into three block representing three replications to reduce soil heterogenic effects and each block was divided into three unit plots with raised bunds as per treatments. Thus, the total number of unit plots was 9. The size of each unit plot was 4 m × 3.5 m. Plots were separated from one another by ails of 0.25 m. Unit blocks were separated from one to another by 1 m drains. Treatments were randomly distributed within the blocks.

8.2.3. Crop/Planting material

Rice variety (BRRI dhan 28) was used as a testing plant material. Alternatively, it is called BR28.

8.2.3.1. Description of variety: BRRI Dhan 28 or BR28

BRRI dhan28, a high yielding variety of rice was used as the test crop in this experiment. The variety was released for boro season by Bangladesh Rice Research Institute (BRRI), Joydebpur, Gazipur in 1994 after regional and zonal trial evaluation all over Bangladesh. The variety was developed after selection of bread line BR601-3-3-4-2-5, which was obtained from crossing line IR 28 with purbachi. Then the line BR 601-3-3-4-2-5 was released for boro season as BRRI dhan 28 or BR28. It is a transplant boro rice cultivar with average yield of 5.0 t ha^{-1}. Life cycle of this variety ranges from 135 to 140 days, which however may vary due to change in climatic condition.

8.2.4. Land preparation

The land was prepared conventionally. The final land preparation was done by ploughing and cross ploughing by two wheel power tiller with two laddering before two days of transplanting. One day before transplanting the plots was laid out as per experimental design.

8.2.5. Bed preparation

Raised bed and furrows were made manually by spade following the conventional land preparation. According to the treatments, a 60 cm (centre to centre of furrows) width bed was made. For the 60 cm bed, the top of the raised bed were 35 cm and furrow between beds were 25 cm. The beds were made one day before transplanting the plots according to lay out of the experiment. The heights of beds were 15 cm.

8.2.6. Transplanting of seedlings

Two 45 day old seedlings per hill of BR 28, a popular boro (winter, irrigated) rice variety were transplanted. The row to row and hill to hill spacing were 25 cm and 20 cm for both beds and flat. Only two rows of rice were planted on each bed and plant density was much higher in the conventional treatment.

8.2.7. Fertilizer application in conventional planting

Fertilizer was applied at the following rates: N=120, P=14, K=36, S=1.0 kg ha^{-1} applied as Urea, Triple super-phosphate (TSP), Murate of potash (MP), Gypsum and Zinc sulphate ($ZnSO_4$), respectively. Whole of TSP, MP, gypsum and $ZnSO_4$ were applied at the final land preparation as basal dose in the plots with conventional treatment. Urea was broadcasted in three equal splits at 15, 30, and 50 days after transplanting of rice in conventional planting method.

8.2.8. Fertilizer application in fertigation with raised bed planting

In the plots with fertigation in raised bed planting the basal doses were broadcasted before transplanting on top of the beds. Urea was applied through the irrigation water in three equal splits at 15, 30, and 50 days after transplanting of rice in fertigation with raised bed planting method.

8.2.9. Weeding

The plots were weeded at 15 and 30 DAT. Weed samples from each plot were collected at time of weeding for comparing weed population and dry biomass yield of different treatments.

8.2.10. Detailed procedures of collecting data

8.2.10.1. Plant height and tiller number observation

Randomly selected and tagged 10 plants were used for the measurement of plant height at an interval of 15 days from 15th day after transplanting and ending with just flowering. It was measured from base to tip of the upper leaves of the main stem. Numbers of tiller per plant were counted from one meter row length.

8.2.10.2. Leaf area index

Leaf area (cm^2) of the functional leaves obtained from samples drawn for dry matter accumulation study was measured by automatic leaf area meter. Then leaf area of the plants $units^{-1}$ worked out by following formula:
Leaf area index (LAI) = Leaf area/Ground area

8.2.10.3. Yield attributed characters of rice

Observation regarding the effective tiller per row length was recorded just before harvesting the crop and the average values was used to obtain the effective panicles per meter row length. The length of panicle was taken from the 10 panicles from each plot which were randomly selected just before harvesting and mean were calculated. Number of filled and unfilled grains was counted to determine the number grains per panicle. Thousand grains were counted from the grain yield of each plot and weighted with the help of automatic electronic balance.

8.2.10.4. Biomass yield and grain yield

Biomass yield and grain yield was taken at harvesting from each plot. All the plants from 1 m length were uprooted and weighed to determine the total biomass yield. Digital grain moisture meter was used to record the moisture of the grain. Finally grain yield was adjusted at 14% moisture using the formula as suggested by Paudel (1995).
Grain yield (t ha^{-1}) at 14% moisture = (100-MC) x plot yield (ton) x 10000(m^2)/ (100-14) x plot area (m^2)

Where, MC is the moisture content in percentage of the grains.

8.2.10.5. Harvest index

Harvest index (HI) was computed by dividing grain yield with the total dry matter yield as per following formula.
HI = (grain yield)/ (grain yield + straw yield)

8.2.10.6. Irrigated water measurement

Irrigation water was measured by using a delivery pipe and water pan. A plastic delivery pipe was connected from the water pump to the experimental field. A water pan with 300- liter volume was filed by irrigation through the delivery pipe and time required was recorded. Then plots with different methods of planting were irrigation through the delivery pipe and times required were recorded. The amount of irrigation water applied in different plots was calculated as follows:
Amount of water applied per plot=

$$\frac{\text{Volume of water pan (L)} \times \text{Time required to irrigation the plot (sec)}}{\text{Time required filling the water pan (sec)}}$$

8.2.10.7. Water use efficiency calculation

Water use efficiency for grain and biomass production was calculated by the following equations:
Water use efficiency for grain production (kg $ha^{-1}cm^{-1}$)
= grain yield (kg ha^{-1})/total water required (cm)
Water use efficiency for biomass production (kg $ha^{-1}cm^{-1}$)
= [grain yield (kg ha^{-1}) + straw yield (kg ha^{-1})]/ total water required (cm)

8.2.10.8. Agronomic efficiency of fertilizer calculation

Agronomic efficiency (AE) of fertilizer was calculated by the following equation:
AE= GYNA-GYN0/NR
Where GYNA= Grain yield (kg ha^{-1}) with addition of nutrient
GYN0= Grain yield (kg ha^{-1}) without addition of nutrient
NR= Rate of added nutrient (kg ha^{-1})

8.2.10.9. Statistical analysis of data

The experiment was conducted using randomized complete block design with three replications for each treatment. Data were analysed following standard statistical procedure and means of treatments were compared based on the least significant difference test (LSD) at the 0.05 probability level. Microsoft Excel was used for tabulation and sample calculation, presentation of table for different comparisons.

8.3. RESULTS

8.3.1. Yield attributing parameters

8.3.1.1. Number of panicle m^{-2}

Substantial differences were found in the number of panicle m^{-2} between the fertigation in bed planting and conventional planting from the analyzed data (Table 8.2). Fertigation in bed planting produced significantly (≤0.001) higher number of panicle m^{-2} compared to fertilizer broadcast in conventional planting for transplanted boro rice. The higher number of panicle m^{-2} in fertigation of bed planting contributed to the higher grain yield of fertigation treatment.

Table 8.2 Grain yield and yield components with respect to fertigation in raised bed and fertilizer broadcasting in conventional planting.

Method of Fertilizer application	Yield and yield components			
	panicles m^{-2} (number)	Grains panicle^{-1} (number)	1000 grain wt. (gm)	Grain yield (t ha^{-1})
Fertigation in bed planting	452a	124a	25.00a	5.15 a
Fertilizer broadcasting in conventional planting	430b	106b	21.00b	4.40b
LSD at 5%	9.438	4.139	2.069	0.395
Level of significance	*	**	*	*

Where * and ** represents probability of ≤ 0.001 and ≤0.01, respectively. Values were means of three replicates.

8.3.1.2. Number of grains panicle^{-1}

Bed planting with fertigation produced significantly (*P* ≤0.01) higher number of grains panicle^{-1} compared to fertilizer broadcast in conventional planting for transplanted boro rice (Table 8.2). Fertigation in raised bed planting had 18 grains panicle^{-1} more compared to the conventional planting method.

8.3.1.3. 1000- grains weight

Weight of 1000 grain was significantly (*P* ≤0.001) higher in fertigation with bed planting compared to conventional planting. Fertigation in bed planting had more 4 gm in 1000 grain wt compared to conventional method (Table 8.2). The higher grain weight directly contributed to the higher grain yield in fertigation with bed planting.

8.3.1.4. Grain yield

Planting methods clearly affected the grain yield of transplanted boro rice. Fertigation in bed planting produced significantly (P ≤ 0.01) higher grain yield compared to conventional planting (Table 8.2). The yield increase by fertigation in bed planting over conventional planting was 17.04%. The higher grain yield in fertigation with bed planting was related to higher number of panicle m^{-2}, higher number of grains panicle^{-1} and higher individual grain weight. The grain yield of conventional planting was lower due to less number of panicle m^{-2}, less number of grains panicle^{-1} and lower individual grain weight.

8.3.2. Plant growth parameters

8.3.2.1. Plant height

Plant height was not significantly differed between the fertigation in bed planting and fertilizer broadcast in conventional planting for transplanted boro rice. However, the plant height was tended to be higher in fertigation technique over conventional planting at maturity stage (Table 8.3).

8.3.2.2. Panicle length

Panicle length was not significantly affected by planting method. It was observed that the fertigation in bed planting produced longer panicle compared to conventional planting (Table 8.3).The shorter length of panicle was found in conventional planting compared to fertigation in bed planting. The longer panicle length might be matched up to the higher number of grains panicle^{-1} in the fertigation of bed planting treatment.

Table 8.3 Plant biomass with respect to fertigation in raised bed and fertilizer broadcasting in conventional planting.

Method of Fertilizer application	Plant height (cm)	Panicle length (cm)	Non-bearing tiller (no-m^{-2})	Sterility (%)	Straw yield (tha^{-1})	Harvest index
Fertigation in bed planting	84.82 a	25.65 b	57 b	12.25 b	5.20 a	0.497 b
Fertilizer broadcasting in conventional planting	87.34 a	24.10 b	102 a	16.21 a	4.92 a	0.47 b
LSD at 5%	2.910	1.507	2.618	2.364	0.190	0.013
Level of significance	n.s.	n.s.	**	*	n.s.	n.s.

Where n.s,* and ** represents probability of > 0.05, ≤ 0.001 and ≤ 0.01, respectively. Values were means of three replicates.

8.3.2.3. Non-bearing tiller

Planting method was influenced by the number of non-bearing tiller of transplanted boro rice. Non-bearing tiller m^{-2} was significantly lower in fertigation of raised bed planting compared to conventional planting method (Table 8.3).

8.3.2.4. Sterility

Influence of planting method on sterility of transplanted boro rice is presented in table 8.3. It was revealed that fertigation in bed planting significantly ($P \leq 0.01$) reduced the sterility percentage than fertilizer broadcast in conventional planting method. The lower sterility in fertigation of bed planting might be a cause of high number of grains panicle^{-1}.

8.3.2.5. Straw yield

The straw yield of transplanted boro rice was not significantly differed by fertigation in bed planting and conventional planting (Table 8.3). The higher straw yield was found in fertigation of raised bed planting compared to fertilizer broadcast in conventional planting.

The higher number of panicles m^{-2} might be responsible for higher straw yield in fertigation of raised bed planting.

8.3.2.6. Harvest index

Planting method was not significantly influenced the harvest index of transplanted boro rice. Harvest index was increased by 5.433% at fertigation in bed planting over conventional planting (Table 8.3). The lower harvest index in the conventional planting compared to fertigation in bed planting may be the result of lower grain yield and straw yield.

8.3. 3. Tiller production

Different planting method of transplanted boro rice affected the number of tiller m^{-2}. At starting (20 days after transplanting) the number of tiller m^{-2} was higher in conventional planting compared to fertigation in bed planting (Table 8.4). However, at final counting (100 DAT) fertigation in bed planting produced higher number of tiller m^{-2} than conventional planting. Likewise, in fertigation with raised bed planting, the highest tiller production was observed in 40 days after transplanting (DAT). After 40 DAT, the number of tiller was started to decline and continued to 100 DAT. Similarly, in conventional planting method the highest tiller number m^{-2} was recorded at 40 DAT. The results pointed out that the number of tillers m^{-2} for both treatments were highest at 40 DAT and after that started to decrease due to death of some tertiary tillers, which continued up to maturity.

Table 8.4. Effect of tiller production by fertigation in raised bed and fertilizer broadcasting in conventional planting.

Method of Fertilizer application	Tiller (no. m^{-2}) at days after transplanting								
	20	30	40	50	60	70	80	90	100
Fertigation in bed planting	61b	205a	224b	203a	162b	157a	148b	145c	141a
Fertilizer broadcasting in conventional planting	76a	209a	240b	200a	162b	149b	141b	139c	135a
LSD at 5%	2.069	4.984	13.08	9.662	8.738	2.618	9.438	10.347	10.35
Level of significance	**	n.s.	n.s.	n.s.	n.s.	**	n.s.	n.s.	n.s.

Where ns, and ** represents probability of > 0.05, and ≤ 0.01, respectively. Values were means of three replicates.

8.3.4. Leaf area index

The leaf area index of transplanted boro rice, measured at different days after transplanting varied by the fertigation and conventional planting. At early stage (20 days after transplanting) the conventional planting resulted higher leaf area index compared to fertigation in bed planting (Table 8.5). However, at maturity stage (100 DAT) fertigation in bed planting gave higher leaf area index compared to conventional planting. The highest leaf area index was found by fertigation in bed planting at 60 DAT. On the other hand, the highest leaf area index was found in conventional planting at 80 DAT.

Table 8.5 Effect of leaf area index by fertigation in raised bed and fertilizer broadcasting in conventional planting.

Method of Fertilizer application	LAI at different DAT				
	20	40	60	80	100
Fertigation in bed planting	0.39a	2.58b	5.81a	5.21b	4.01a
Fertilizer broadcasting in conventional planting	0.42a	2.50b	5.03b	5.08b	3.85a
LSD at 5%	0.013	0.463	0.093	0.207	0.137
Level of significance	n.s.	n.s.	**	n.s.	n.s.

Where ns, and ** represents probability of > 0.05, and ≤ 0.01, respectively. Values were means of three replicates.

8.3.5 Dry matter production

Planting method significantly affected dry matter production of transplanted boro rice at different days after transplanting. At 20 DAT conventional planting produced significantly higher dry matter production compared to fertigation in bed planting (Table 8.6). After 20 DAT fertigation in bed planting gave significantly higher dry matter production (except 50 DAT) up to 90 DAT than conventional planting. The highest dry matter production was found in fertigation at 90 DAT. Similarly, in conventional planting method the highest dry matter production was found at 90 DAT.

Table 8.6. Effect of dry matter production by fertigation in raised bed and fertilizer broadcasting in conventional planting.

Method of Fertilizer application	Dry matter production (gm m^{-2}) at different days after transplanting							
	20	30	40	50	60	70	80	90
Fertigation in bed planting	56b	225b	502a	621b	913a	1057a	1294a	1312a
Fertilizer broadcasting in conventional planting	61a	257a	492b	619b	903b	1049b	1282b	1294b
LSD at 5%	2.618	4.984	2.618	9.301	3.926	2.424	4.139	11.70
Level of significance	*	**	**	n.s.	*	**	**	*

Where ns,* and ** represents probability of > 0.05, ≤ 0.001 and ≤ 0.01, respectively. Values were means of three replicates.

8.3.6. Crop growth rate

The crop growth rate of transplanted boro rice measured at different days after transplanting (DAT) were differed by fertigation and conventional planting. At early stage (20 -30 days after transplanting) crop growth rate was significantly higher in conventional planting compared to fertigation in bed planting (Table 8.7). At maturity stage (80-90 DAT) the fertigaion in bed planting produced significantly higher crop growth rate compared to conventional planting. The highest crop growth rate was found at 50-60 DAT by fertigaion in bed planting. Similarly, in conventional planting method the highest crop growth rate was recorded at 50-60 DAT.

Table 8.7. Effect of crop growth rate by fertigation in raised bed and fertilizer broadcasting in conventional planting

Method of Fertilizer application	Crop growth rate (g m^{-2} day^{-1}) at different days after transplanting (DAT)						
	20-30	30-40	40-50	50-60	60-70	70-80	80-90
Fertigation in bed planting	16.90b	27.70a	11.90b	29.20b	14.40a	23.40a	1.80a
Fertilizer broadcasting in conventional planting	19.60a	23.50b	12.70a	28.40b	14.60a	23.30a	1.20b
LSD at 5%	0.382	2.490	0.207	1.656	1.449	2.492	0.262
Level of significance	**	*	**	n.s.	n.s.	n.s.	*

Where ns,* and ** represents probability of > 0.05, ≤ 0.001 and ≤ 0.01, respectively. Values were means of three replicates.

8.3.7. Weed vegetation

Weed population and dry biomass were greatly influenced by different planting methods of transplanted boro rice. Fertigation in bed planting method reduced weed population resulting in lower dry biomass compared to conventional planting. The conventional method had significantly ($P \leq 0.01$) higher weed vegetation compared to fertigation in raised bed method (Table 8.8).

Table 8.8. Effect of weed growth by fertigation in raised bed and fertilizer broadcasting in conventional planting.

Method of Fertilizer application	Weed vegetation	
	Weed population (number m^{-2})	Dry biomass (kg ha^{-1})
Fertigation in bed planting	192b	180.14b
Fertilizer broadcasting in conventional planting	389a	344.98a
LSD at 5%	2.618	4.198
Level of significance	*	**

Where * and ** represents probability of ≤ 0.001 and ≤ 0.01, respectively. Values were means of three replicates.

8.3.8. Irrigation requirement

Different planting method affected the irrigation water requirement. The total irrigation water required by fertigation in bed planting was 94.86 cm (Table 8.9). On the other hand the conventional method received 149.00 cm irrigation water. Result showed that the total water savings by fertigation in bed planting over conventional planting was 36.33%.

Table 8.9. Irrigation water savings by fertigation in raised bed and fertilizer broadcasting in conventional planting.

Method of Fertilizer application	Irrigation required (cm)	Rainfall (cm)	Total Irrigation required (cm)	Water saved over conventional method (%)
Fertigation in bed planting.	82.06b	12.80a	94.86b	36.33%
Fertilizer broadcasting in conventional planting	136.20a	12.80a	149.00a	
LSD at 5%	4.000	0.262	2.618	
Level of significance	**	ns	**	

Where ns, and ** represents probability of > 0.05, and ≤ 0.01, respectively. Values were means of three replicates.

8.3.9. Water use efficiency

Water use efficiency for grain and biomass production by fertigation in bed planting was 54.29 and 109.10 kg ha^{-1}cm^{-1}, respectively (Table 8.10). In contrast, water use efficiency for grain production and biomass production in conventional planting was 29.53and 62.55 kg ha^{-1}cm^{-1}, respectively. However, water use efficiency for grain production and biomass production by fertigation in bed planting was 83.81% and 74.44 %, respectively higher compared to conventional planting.

Table 8.10. Water use efficiency by fertigation in raised bed and fertilizer broadcasting in conventional planting.

Method of Fertilizer application	er Efficiency savings by fertigation in raised bed and fertilizer broadcasting in conventional planting.	
	Water use efficiency for grain production (kg ha^{-1}cm^{-1})	Water use efficiency for biomass production (kg ha^{-1}cm^{-1})
Fertigation in bed planting	54.29a	109.10a
Fertilizer broadcasting in conventional planting	29.53b	62.55b
LSD at 5%	1.864	2.114
Level of significance	**	**

Where, ** represents probability of ≤ 0.01.Values were means of three replicates.

8.3.10. Agronomic efficiency of N fertilizer

The agronomic efficiency of N fertilizer for fertigation in bed planting was 27.08 % (Table 8.11). Likewise, the agronomic efficiency of N fertilizer for conventional planting was 22.56%. The agronomic efficiency of N fertilizer in fertigation on bed planting was 20.03 % higher over conventional planting.

Table 8.11. Agronomic efficiency of N fertilizer by fertigation in raised bed and fertilizer broadcasting in conventional planting.

Method of Fertilizer application	Agronomic efficiency of fertilizer (%)
Fertigation in bed planting	27.08a
Fertilizer broadcasting in conventional planting	22.56b
LSD at 5%	2.696
Level of significance	*

Where, * represents probability of ≤ 0.01. Values were means of three replicates.

8.4. DISCUSSION

8.4.1. Fertigation techniques is more beneficial to increase yield of transplanted boro rice compared to conventional cultivation method

Fertigation techniques increase grain yields of transplanted boro rice than conventional cultivation method. Boro rice yield for fertigation technique in raised bed planting was 5.15 t ha^{-1} whereas boro rice yield for fertilizer broadcasting in conventional cultivation method was 4.40 t ha^{-1}. (Table.8.2). We also found that yield component like panicle m^{-2}, grains panicle^{-1} and 1000-grains weight were significantly ($P > 0.05$) higher by fertigation in bed planting compared to fertilizer broadcasting in conventional planting method. Therefore, fertigation in raised bed planting significantly increased rice yield compared to the fertilizer broadcasting in conventional planting. Soman (2012) also found that rice yield under fertigation was 3.8 t ha^{-1}, whereas 3.1 t ha^{-1} for flooded irrigation. He speculated that keeping the soil wet alone and not providing standing water results in yields comparable or more than in flooded (with standing water) condition. Likewise, Kumar *et al.* (2011) found that soil application of fertilizer produced 4.163 t ha^{-1} grain yield of Rabi (winter) rice. On the other hand, fertigation in raised bed planting gave 4.338 t ha^{-1} rice yield of Rabi (winter) rice. This study revealed that higher grain yield by fertigation in bed planting over soil application of fertilizer due to higher number of productive tiller hill^{-1}. Similarly, Govindan *et al.* (2012) indicated that fertigation in raised bed system accelerates the pace of rice production. They speculated that fertigation is an integrated approach to soil-water-plant nutrient management at the plant root zone. Fertigation is the direct application of water and nutrient to plants through irrigation system which increased rice production. Biswas (2010) indicated that fertigation technique provide better yield and quality of products. He observed that fertigation allow optimization of nutrient balance in soils by supplying the nutrients directly to the effective root zones as per the requirement which may contribute to yield. IRRI conducted a study to determine the most suitable time and proper method of fertilizer application for rice cultivation. IRRI (2010) proposed that fertigation is a tool that can increase rice yield. In addition, Sivanappan (2006) reported that fertigation increased crop yield. He pointed out that fertigation is a useful technology by which inorganic fertilizer could be applied to crops through the drip irrigation system. Moreover, Anbumozhi *et al.* (1998) estimated that fertigation condition (9 cm) improved paddy yield compared to too shallow or too deep ponding water depth. Similarly, Ramasamy (2008) stated that fertigation technology for rice cultivation in raised bed with furrow irrigation would be futuristic and have great impact on rice yield. Another study conducted by Stevens *et al*. (2008) found same results. They observed that fertigation treatments yielded higher than the flooded dry urea for rice cultivation.

My speculation is that higher number of panicle m^{-2} was in fertigation treatment because of fertilization with N results in more luxury consumption than with other nutrients causing healthy growth of rice plants. The higher 1000-grains weight in fertigation was possible that at initial stage, more numbers of panicles may be developed due to urea application but due to excessive number of panicles, only healthier and stronger panicles could be survived. Rest of other panicles would have lost due to their week structure or any other factor. My speculation is that the increase in grain yield by fertigation might be attributed to more N utilization in the plant system, hence more chlorophyll synthesis and efficient translocation of assimilates to reproductive parts. Observation of this study is that in fertigation nutrients are placed at very low concentrations through water move down into the lower soil layers where the absorptive roots exist which may contribute to grain yield. This study also speculated that in fertigation plant enjoys continuous nutrition because nutrients are directed to the active root zone which enables optimal match between plant requirements and nutrients supply .This may be another cause of higher boro rice yield in fertigation than conventional cultivation method. Fertigation was shown to enhance overall root activity, improve the mobility of nutritive elements and their uptake, as well as increased yield of boro rice. This study also observed that higher yield in fertigation treatment over conventional planting may be obtained by supply nitrogen at each growing stage of boro rice. Under conventional method of fertilization plant nitrogen at every sensitive stage may decrease the yield of rice.

8.4.2. Fertigation in bed planting for transplanted boro rice produced better growth attribute compared to conventional planting

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Fertigation in bed planting affected growth parameters of transplanted boro rice. Overall, better growth attributes of boro rice were observed by fertigation in raised bed compared to conventional planting method (Table 8.3). My findings revealed that higher number of plant height, panicle length and harvest index in fertigation under bed planting compared to conventional planting for transplanted boro rice. Similar results were also found by Kumar *et al.* (2011). They found that fertigation in bed produced taller plant than soil application of fertilizer. They also estimated that plant height of rice under fertigation was 96.4 cm and 84.3 cm in soil application of fertilizer. They speculated that plant height was high in the fertigated plots, due to higher uptake of nutrient from the fertilizers. Likewise, Satsangi and Yadav (2013) reported that urea fertigation produced plant height of 78.33 cm and 43.33 cm by control. Similarly, Taha *et al.* (1996) found that fertigation improves plant growth parameters. They speculated that fertigation enhanced nutrient uptake and limits nutrient losses which may contributed to better growth attribute. Higher number of tillers m^{-2} was observed with fertigation and broadcasting fertilizer in conventional planting produced less tillers m^{-2} (Table.8.4). Fertilizer application practice showed varied response in vegetative and reproductive characteristics. The significant effect of fertigation in bed planting was observed in non-bearing tiller and sterility percentage over conventional planting (Table.8.3). Other growth parameters measured between fertigation and conventional irrigation was not different, these included plant height, panicle length, straw yield and harvest Index in conventional planting. The dry matter production at early growth stage in the conventional planting was higher, but significantly lower than that from the fertigation in bed planting at maturity (Table.8.6).This indicates that infiltration irrigation had better gas exchange and higher temperature, which facilitated root growth and longevity.

My speculation is that fertigation in furrow on raised bed planting reduced moisture content in the rice field, promoted light penetration and gas exchange and lowered reduced materials, which in turn led to higher growth rate compared to fertilizer broadcasting in conventional planting. This is reflected by the reduction in the tiller number at the early stage of growth, the increases in the quality of tillers and the rate of spike formation. The improvement of rice growth under the fertigation in bed planting system is also evident by higher dry biomass weight of different plant components. This study revealed that lower plant growth of boro rice in conventional planting was due to insufficient supply of nitrogen at each growth stage. At the same time fertigation in bed planting supply nitrogen uniformly to rice plants which contributed better growth parameter. This study also speculated that nitrogen fertigation results in more luxury consumption than fertilizer broadcasting in conventional planting causing healthy growth of boro rice plants. In addition fertigation in bed planting was suited for controlling the placement, time and rate of nitrogen fertilizer application. By controlling this nitrogen fertigation was possible to enhanced better growth of boro rice.

8.4.3. Fertigation in bed planting for boro rice saved water and enhanced water use efficiency compared to conventional flood planting

Fertigation in bed planting had favorable and marked influence on water use efficiency (WUE) of transplanted boro rice. My findings revealed that fertigation in bed planting provided significantly higher WUE efficiency (54. 29 kg ha^{-1}cm^{-1}) compared to conventional cultivation method. The low WUE of 29.53 kg ha^{-1}cm^{-1}was observed on fertilizer broadcasting in conventional planting (Table 8.10). Similarly, Kumar *et al.* (2011) estimated that water use efficiency in fertigation was 6.04 kg ha^{-1} mm^{-1} and 6.04 kg ha^{-1} mm^{-1} under soil application of fertilizer. They stated that higher quantity of irrigation water saving coupled with higher water and nutrient use efficiencies indicate the practical feasibility of adopting fertigation for sustainable rice production. Higher consumptive use of water to the extent of 149.00 cm was registered in fertilizer broadcasting of conventional planting than fertigation in bed planting. The low consumptive use of water like 94.86 cm was observed under fertigation in bed planting (Table 8.9). This study revealed that fertigation in bed planting saved 36.33% irrigation water compared to conventional planting method (Table 8.9). Likewise, Soman (2012) found that fertigation technique consume irrigation water of 3.2 million litre ac^{-1} for rice production. Flood irrigation consumes 9.5 million litre ac^{-1} irrigation water. So, fertigation saved 50.79% water compared to flood irrigation in conventional planting. Regardless of that Alam (2009) stated that fertigation technique for rice cultivation saved water use by 50 percent compared to conventional planting. In addition, Govindan *et al.* (2012) stated that fertigation in raised bed is a water saving irrigation technique that require less irrigation water than the traditional method for rice cultivation. They suggested that fertigation technique in raised bed planting produce more rice with less water.

My speculation is that fertigation is an efficient method to deliver water and nutrients to the plants because water is directly applied to the effective root zone of crop plants. The loss of water is minimum and that results in the lower water requirement in the fertigation irrigation system. Less water consumption in fertigation was made possible due to moisture availability in soil is kept close to the crop water requirement on a continuous basis. This study revealed that the higher water productivity was obtained in fertigation for water saving irrigation system. It might be due to the reason of higher grain yield and less water consumption under fertigation treatment. Fertigation in bed planting also offered more effective control over irrigation and drainage as well as their impacts on transport and transformations of nutrients, and rainwater management. In furrow irrigated raised bed system, water moves horizontally from the furrows into the beds and is pulled upwards in the bed towards the soil surface by capillarity, evaporation and transpiration, and downwards largely by gravity. This study also speculated that lower overall irrigation water applied to fertigation on raised beds is probably the result of reduced evaporation, less area wetted and soil configuration in the raised beds, and over-irrigation in the basins. Thus, management of irrigation water in fertigation was improved, simpler, and more efficient compared to conventional flood method.

8.4.4. Weed vegetation of transplanted boro rice in fertigation of raised bed planting was lower compared to conventional planting

Substantial differences were observed in the weed vegetation per square meter between the fertigation in raised bed and conventional planting of boro rice (Table 8.8). Statistically it was observed that significantly the higher weed vegetation per square meter was obtained from fertilizer broadcast in conventional planting. The low weed vegetation per square meter was observed in fertigation on raised bed planting (Table 8.8). Similarly, Kafkafi (2006) found that fertigation decreased weed infestation. He stated that fertigation able to supply of nutrient reduced fluctuation of nutrient concentration in the soil. This might cause less weed infestation in fertigation over broadcast fertilizer. Likewise, Sonam (2012) demonstrated that weeds in fertigation can be managed easily than conventional flood planting which reduced weed population in fertigation. He also speculated that weeds in fertigation system of rice cultivation may be controlled by mulching the seedbed with rice husk at planting and one manual weeding or by minimum herbicide application. Moreover, Haifa Group (2011) reported that fertigation reduced weed population. They speculated that fertigation enables optimal match between plant requirements and nutrients supply which facilitated better plant growth compared to weeds. For this reason less weed population observed in fertigation treatment. This study also revealed that fertilizer broadcast in conventional planting produced significantly the higher dry biomass of weeds compared to fertigation treatment (Table 8.8). Similarly, Mollah (2005) found lower weed dry biomass in raised bed than conventional planting. He stated that lower dry biomass and number of weeds in raised bed planting compared to conventional planting might be due to dry top surface of beds that inhibited the weed growth. In addition, Ram *et al.* (2005) also found that lower weed biomass in raised beds compared to the conventional planting.

My speculation is that since the rice crops was grown in fertigation on raised bed planting, most time of the growing period the furrows remained inundated resulting very little weeds in furrows. The abundant tillering of rice in bed filled up the top of the beds very quickly keeping a little space for weed growth on top soil. On the other hand, in conventional planting at the time of transplanting the land was kept free from standing water. As a result weeds grew more. Therefore, weed population and biomass yield were lower in fertigation on raised bed compared to conventional planting. Regardless of that nitrogen fertilizer timing and application method are important components of weed management for rice cultivation. In fertigation nitrogen fertilizer demonstrated greater nitrogen uptake by rice plant, and lower nitrogen uptake by weeds. Which might contribute less surface germinate of weeds in fertigation of raised bed planting compared to the surface broadcast of nitrogen in conventional planting. This study also speculated that less weeding was needed in fertigation compared to conventional flat land possibly because the soil was drier and the banded urea in the drier raised bed was less available for weeds. Thus, successful long-term weed management for rice cultivation requires a shift away from simply controlling problem weeds to systems that reduce weed establishment and minimize weed competition with crops.

8.4.5. Fertigation in raised bed planting enhanced agronomic efficiency of N compared to conventional planting for transplanted boro rice

Agronomic efficiency was significantly affected by N placement methods of transplanted boro rice (Table 8.11). The higher agronomic efficiency of N was found on fertigation in raised bed planting. This study revealed that agronomic efficiency of N in raised bed planting was 27.08 % and 22.56 % for conventional planting (Table 8.11). Similarly, Mollah *et al.* (2009) found that agronomic efficiency of N in raised bed planting was 27.00 kg grain kg^{-1} N and 17.50 kg grain kg^{-1} N for conventional flat planting. They revealed that the bed planting system could use N more efficiently than conventional method which contribute higher agronomic efficiency of N in bed planting. Statistically lower agronomic efficiency of N was found by fertilizer broadcast in conventional planting (Table 8.11). Similarly, Qin *et al.* (2012) found lower agronomic N use efficiency (AE_N) in farm practice fertilizer (FFP) and it was 12.5. They demonstrated that earlier application of high N rate of farm practice fertilizer (FFP) led to low agronomic N use efficiency. This study also observed that fertigation in bed planting enhanced agronomic efficiency of N compared to fertilizer broadcast in conventional planting (Table8.11). Likewise, Biswas (2010) reported that fertigation system provided better fertilizer use efficiency. He speculated that increased fertilizer use efficiency in fertigation due to improved available of nutrient and their uptake by crops. Moreover, Rajput (2010) showed that nitrogen use efficiency in fertigation was 95% where as broadcast fertilizer produced 40%. He speculated that higher nitrogen use efficiency in fertigation over broadcast fertilizer due to proper dose and time of fertilizer application. In addition, Kafkafi (2006) indicated that fertigation technique improve fertilizer use efficiency. He demonstrated that in fertigation system nutrients are applied only to the active root zone, which reduced losses of nutrients through leaching or soil fixation and enhance fertilizer use efficiency.

My speculation is that fertigation provides an opportunity to use nutrients more efficiently through better timing and placement. In fertigation, synchronizing fertilizer N application to rice with crop N demand can result in reduce losses of N, and increase agronomic efficiency of N. In conventional planting nitrogen is applying too early holds the risk of losing it through leaching before the crop takes it up, especially if rains are to come. The best approach, in such cases is to split the nitrogen application with fertigation, where most of the nitrogen fertilizer just before the crop's maximum demand for nitrogen. This study revealed that the lower agronomic efficiency of N in conventional planting due to the applied nutrients cannot be fully utilized by plant roots as they move laterally over long distances. Fertigation can improve N utilization and there are reduced losses through nitrate leaching. At the same time plants take up more N by fertigation compared with broadcast, and the uptake of nutrients is also enhanced agronomic efficiency of N. In addition, fertigation was shown to enhance overall root activity, improve the mobility of nutritive elements and their uptake. The fertigation technique is used mainly with N fertilizer. This study suggested that in fertigation systems, the best practice would be to apply frequent small applications of N fertilizer, at rates that meet the crop requirements.

8.5. CONCLUSIONS

This research demonstrated that fertigation in bed planting increased grain yield by 17.04% for boro (winter, irrigated) rice compared to fertilizer broadcasting in conventional planting method. Fertigation in raised bed produced higher number of panicles per unit area, number of grains per panicle and 1000-grain weight for transplanted boro rice which ultimately gave the higher grain yield than the fertilizer broadcasting in conventional planting. This study also concluded that the fertigation in raised bed planting proved beneficial over conventional planting, especially with respect to grain yield, yield attributes, agronomic efficiency of N and water use efficiency. Fertigation in raised bed planting is considered the most effective method to decrease N losses and thereby to increase fertilizer use efficiency. The fertigation in raised bed planting saved irrigation water by 36.33% as well as increased irrigation efficiency over fertilizer broadcasting in conventional planting. Bed planting with fertigation provided less weed density and dry biomass than conventional cultivation method. These findings conclude that water use efficiency for grain and biomass production was higher in fertigation with bed planting than fertilizer broadcasting in conventional method. The agronomic efficiency of N fertilizer was also significantly higher in fertigation of bed planting than the fertilizer broadcasting in conventional planting method.

It was found from my previous study that fertigation in bed planting system for transplanted aman (summer, partially irrigated) rice achieved higher water and fertilizer use efficiency than fertilizer broadcasting in conventional flat method (Chapter 3). The potential gains from growing boro rice on raised bed planting with fertigation are considered to be associated with better agronomic management than fertilizer broadcasting in conventional method. It is likely that the raised bed planting will have long term soil physical benefits without sacrificing yield. The incorporation of fertigation in raised bed planting introduced new boro rice based farming system offers many advantages. Based on the findings of this experiment, high yielding boro rice (winter, irrigated) crops have been successfully grown on raised bed planting under fertigation. There is a good prospect of utilization of this technology to benefit the rice growers in the world. More studies is needed to establish bed planting with fertigation, a better planting method of boro rice cultivation in Bangladesh as well as other countries in the world.

Chapter 9

A comparative appraisal of urea super granule application in raised bed and prilled urea application in conventional planting for transplanted boro rice *(Oryza sativa)*

Chapter 9

A comparative appraisal of urea super granule application in raised bed and prilled urea application in conventional planting for transplanted boro rice *(Oryza sativa)*

9.1. INTRODUCTION

Boro rice is one of the major cereal food grains in Bangladesh, which is transplanted in winter season (December to February). Total area under boro crop has been estimated at 48.10 lac hectares in the year 2011-12 (BBS 2011-12). Total boro production of 2011-12 has been estimated at 187.59 lac metric tons as compared to 186.17 lac metric tons in 2010-11 which is 0.77 percent higher than that of previous year (BBS.2011-12). This type of rice has been cultivated traditionally in river basin deltas of Bangladesh. This practice is spreading even to those non-traditional areas where irrigation is available. More important advantage is the lower winter temperature during the earlier crop growth. This facilitates the accumulation of photo-syntheses, thereby increasing carbon: nitrogen ratio (Singh, 2002).

Farmers apply urea in rice field mainly on the soil surface. As urea is a highly water-soluble and quick release fertilizer, its application to the soil surface may result in a significant loss in various ways (as ammonia volatilization, denitrification, surface run-off and leaching) thus, reducing its efficiency. It is reported that the efficiency of urea nitrogen in wetland rice is only about 30% of the applied urea and even less in many cases (Prasad and De Datta, 1979). However, the nature and magnitude of nitrogen loss largely depends upon the sources of nitrogenous fertilizer and its methods of application. According to Craswell and De Datta (1980), broadcast application of urea on surface soil causes losses up to 50% but point placement of urea super granules (USG) in 10 cm depth results negligible loss. In recent years, a deep understanding on mechanisms causing poor N utilization help to develop cultural practices to improve nitrogen use efficiency (NUE) in lowland rice. Urea super granule (USG), a physical modification of ordinary urea, is considered a slowly available N fertilizer and found efficient when properly deep placed (Savant and Stangel, 1990). Urea super granule (USG), a slow releasing nitrogenous fertilizer is being marketed in Bangladesh as a source of nitrogen. Agronomic, economic and environment advantages of deep point placement of USG have been well established (Cao *et al.* 1984; Welselaar 1985 ; Inssffer 1985, 1986 ; Kumar *et al.* 1989 ; Chalam *et al.* 1989; Sarvanan *et al.* 1988 ; Stangel 1989; Savant *et al.* 1991 , 1992; Shukla *et al.* 1993; Misra *et al.* 1995). Experimental results showed that with USG, it is possible to save 20% - 40% of the urea N for the same grain yield, compared with conventional urea application (Yamada *et al.* 1979, Kumar *et al.* 1989). Deep placement of urea super granule had increased grain yields and improved N use efficiency in research plots and farmers fields (Deftardar and Savant 1995, Singh *et al.* 1995). Improved N recovery and efficiency of USG has been well documented in lowland rice, but its market availability and placement methods pose problem (Mohanty *et al.*1999).

My previous study showed that deep placement of USG in raised bed planting for transplanted aman rice had higher yield and water use efficiency than PU in conventional method (Chapter 5). However, no study was undertaken to determine the effect of USG in bed planting for boro (winter, irrigated) rice as compared to the PU broadcasted in conventional planting method. Therefore, this study was undertaken to determine the role of USG on bed planting for transplanted boro rice as compared to the PU in conventional planting method. The hypothesis of this study is that the USG technique on raised bed planting will be achieved higher transplanted boro rice yields and water use efficiency than the PU in conventional planting.

9.2. MATERIALS AND METHODS

9.2.1. Location and climate of the experimental site

The field experiment was carried out in a farmer's field, Chuadanga district of Bangladesh, during boro season (November-March). Experimental site was located at 11.5 m above mean sea level. Geographically, it was located at $23^0 39'$N latitude and $88^0 49'$E longitudes. The Meteorological data for the cropping season were recorded at the local weather office, Chuadanga district of Bangladesh. The rainfall received during the crop growth period of crop totaled 128 mm. The mean maximum and minimum temperatures were recorded at 34.28^0C and 22.03^0C respectively for the cropping season. The relative humidity ranged between 63.8% in the month of March and 71.5% in the month of February. Climate is most dominating factor influencing the sustainability of crop in a particular region. The yield potential of the crop depends on the climate. The most important factor influencing growth, development and yield of crop are solar radiation, temperature and rainfall (Upadhaya, 2005).

9.2.2. Basic soil properties of the experimental field

The soil was silt-loam with 0.88% and 0.11% organic carbon and total nitrogen, respectively and also 5.68 ppm, 0.15 meq, 12.10 ppm, 0.22 ppm of available phosphorus, exchangeable potash, available sulphur and zinc, respectively with a pH of 7.30.

9.2.3. Experimental design and treatments

The experiment was laid out in a randomized complete block design (RCBD). The entire experimental area was divided into three blocks representing three replications to reduce soil heterogenic effects and each block was divided into three unit plots with raised bunds as per treatments. The size of each unit plot was 4 m × 3.5 m. Plots were separated from one another by aisles of 0.25 m.Unit blocks were separated from one another by 1 m drains. Treatments were randomly distributed within the blocks. The combinations of treatments were deep placement of urea super granule (USG) in raised bed and prilled urea (PU) broadcasted in conventional planting.

9.2.4. Characteristics of rice variety

BRRI dhan28, a high yielding variety of rice was used as the test crop in the experiment. The variety was released for the boro season by Bangladesh Rice Research Institute (BRRI), Joydebpur, and Gazipur in 1994 after regional and zonal trials and evaluation. The variety was developed after selection of bread line BR601-3-3-4-2-5, which was obtained from crossing line IR 28 with purbachi .Then the line BR 601-3-3-4-2-5 was released for the boro season as BRRI dhan 28. It was a transplant boro rice cultivar with an average yield of 5.0 t ha^{-1}. The life cycle of this variety ranges from 135 to 140 days, which may however vary due to changes in climatic conditions.

9.2.5. Deep placement of Urea super granule (USG) in raised bed planting

In bed planting within a week after transplanting rice, the USG briquettes are (2.7 gm weight) inserted into the top soil of bed by hand, being placed to a depth of 7-10 cm deep placement in the middle of alternating squares of four hills of rice (BRRI, 2009).

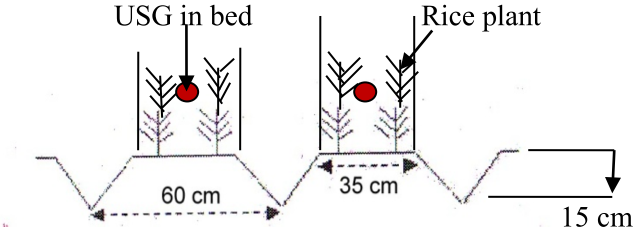

Fig .9. 1. Deep placement of USG in raised bed planting

9.2.6. Prilled urea (PU) broadcasted in conventional planting

Prilled urea (PU) broadcasted at the following rates: N=120, P=14, K=36, S=1.0 kg ha^{-1} applied as urea, Triple super-phosphate (TSP), Murate of potash (MP), Mypsum and Zinc sulphate ($ZnSO_4$), respectively. Whole of TSP, MP, gypsum and $ZnSO_4$ were applied at the final land preparation as basal dose in the plots with conventional treatment. The prilled urea (PU) was broadcasted in three equal splits at 15, 30 and 50 days after transplanting (DAT) in conventional planting.

Fig. 9.2. Prilled urea (PU) broadcasted in conventional planting

9.2.7. Experimental procedure

Raised bed was prepared manually for the experiment. It can also be prepared through raised bed planting machine. Paddy rice crops were transplanted in two rows on top of the raised bed and irrigation water was applied within the furrows between the beds. Water moves horizontally from the furrows into the beds. The height of the beds was maintained 15 cm; top was 35 cm with 6 beds per plot (Fig. 9.1). The furrow width was 25 cm. Two 45 days old seedlings hill^{-1} of BRRI 28, a popular boro (winter, irrigated) rice variety, were transplanted. The row to row and hill to hill spacing were 25 cm and 20 cm for both beds and flat. Only two rows of rice were planted on each raised bed and plant density was much higher in the conventional treatment. Manual weeding was done twice in the transplant boro rice field during growth period. The plots were weeded at 15 and 30 DAT. Weed samples from each plot were collected at time of weeding for comparing weed population and dry biomass yield of different treatments. The rice was infested by stem borer at tillering stage and rice bug at grain filling stage. Furadon 5G at the rate of 10 kg ha^{-1} was applied at 40 DAT and Malathion 57 EC 5G at the rate of 1 liter ha^{-1} was applied at grain filling stage to control stem borer and rice bug, respectively.

9.2.8. Plant growth parameter observation

Ten randomly selected and tagged plants were used for the measurement of plant height at an interval of 15 days from 15th day after transplanting and ending with just flowering. It will be measured from base to tip of the upper leaves of the main stem. Number of tiller per plant was counted from one meter row lengths. Leaf area (cm^2) of the functional leaves obtained from samples drawn for a dry matter accumulation study, were measured by an automatic leaf area meter .The leaf area of the plants units^{-1} was then worked out by the following formula:
Leaf area index (LAI) = Leaf area/Ground area

9.2.9. Yield parameter observation

Observations regarding the effective tiller per row length were recorded just before harvesting the crop and the average values were used to obtain the effective tiller per meter row length. The length of panicle was taken from the 10 panicles from each plot which were randomly selected just before harvesting and the mean was calculated. The number of filled and unfilled grains was counted to determine the number of grains per panicle. One thousand grains were counted from the grain yield of each plot and weighted with the help of an automatic electronic balance. Grain yield and straw yield were taken at harvesting from each plot. A digital grain moisture meter was used record the moisture of the grain. Finally the grain yield was adjusted at 14% moisture using the formula as suggested by Paudel (1995).
Grain yield (t ha^{-1}) at 14% moisture = (100-MC) × plot yield (ton) × 10000(m^2)/ (100-14) × plot area (m^2)
Where, MC is the moisture content in the percentage of the grains.
The harvest index was computed by dividing grain yield with the total dry matter yield as per the following formula:-

H.I. = (grain yield)/ (grain yield+ straw yield)

9.2.10. Irrigation water measurement

Irrigation water was measured by using a delivery pipe and water pan. A plastic delivery pipe was connected from the water pump to the experimental field. A water pan, with a 300-liter volume, was filled by irrigation through the delivery pipe and the time required to fill was recorded. Then the plots with different methods of planting were irrigated through the delivery pipe and the times required were recorded. The amount of irrigation water applied to the different plots was calculated as follows:

Amount of water applied per plot=

$$\frac{\text{Volume of water pan (L)} \times \text{Time required irrigating the plot (sec)}}{\text{Time required to fill the water pan (sec)}}$$

9.2.11. Water use efficiency calculation

Water use efficiency for grain and biomass production was calculated by the following equations:

Water use efficiency for grain production (kg $ha^{-1}cm^{-1}$)

= grain yield (kg ha^{-1})/total water required (cm)

Water use efficiency for biomass production (kg $ha^{-1}cm^{-1}$)

= [grain yield (kg ha^{-1}) + straw yield (kg ha^{-1})]/ total water required (cm)

9.2.12. Agronomic efficiency of N fertilizer calculation

Agronomic efficiency (AE) of N fertilizer was calculated by the following equation:

$AE= GY_{NA}-GY_{N0}/N_R$

Where $GY_{NA=}$ Grain yield (kg ha^{-1}) with addition of nutrient

GY_{N0}= Grain yield (kg ha^{-1}) without addition of nutrient

N_R= Rate of added nutrient (kg ha^{-1})

9.2.13. Statistical analysis

The experiment was conducted using randomized complete block design with three replications for each treatment. Data was analyzed following standard statistical procedures and means of treatments were compared based on the least significant difference test (LSD) at the 0.05 probability level .Microsoft Excel was used for tabulation and simple calculation and presentation of tables for different comparisons.

9.3. RESULTS

9.3.1. Grain yield and yield components

The yield increased by 18.18% when urea super granule (USG) was used in bed planting over prilled urea (PU) broadcasting in conventional method (Table 9.1). A similar finding was also found for the panicles, grains per panicle and 1000 gm grain wt. These results were significantly ($P \leq 0.05$ for grain yield and 1000 g grain, $P \leq 0.01$ for panicle) different when compared to conventional method. The USG in bed planting had 32 panicle number m^{-2}, 18 grain number per panicle and 4.33 g in 1000 grain wt more than PU in conventional method.

Table 9.1. Grain yield and yield components with respect to USG in raised bed and fertilizer broadcasting in conventional planting.

Method of Fertilizer application	Yield and yield components			
	panicles m^{-2} (number)	Grains $panicle^{-1}$ (number)	1000 grain wt (gm)	Grain yield ($t\ ha^{-1}$)
USG in bed planting	472a	124a	25.33a	5.20a
Prilled urea broadcasting in conventional planting	430b	106b	21.00b	4.40b
LSD at 5%	9.44	4.63	2.35	0.41
Level of significance	**	**	*	*

Where * and ** represents probability of ≤ 0.001 and ≤ 0.01 respectively. Values were means of three replicates. In a column figures with same letter do not differ significantly whereas figures with dissimilar letter differ significantly ($P \leq 0.01$).

9.3.2. Other Plant attributes

Planting method affected plant height, panicle length, non-bearing tillers m^{-2}, sterility percentage, straw yield and harvest index of rice. Plant height, panicle length and harvest index were higher by USG in bed planting than PU in conventional method (Table 9.2). On the contrary, non-bearing tillers m^{-2}, and sterility percentage were higher PU broadcasting in conventional method than the USG in bed planting. Likewise, lower number of non bearing tillers m^{-2} was recorded by the USG in bed planting treatments than the PU in conventional method. The USG in bed planting significantly ($P \leq 0.05$) reduced the sterility percentage compared to the PU in conventional planting. In bed planting sterility was lower. The lower sterility may be accountable for higher grains in bed planting.

Table 9.2: Plant biomass with respect to USG in raised bed and fertilizer broadcasting in conventional planting.

Method of Fertilizer application	Plant height (cm)	Panicle length (cm)	Non-bearing tiller ($number.m^{-2}$)	Sterility (%)	Straw yield (tha^{-1})	Harvest index
USG in bed planting	89.93a	25.08a	62b	13.24b	5.25a	0.49a
Prilled urea broadcasting in conventional planting	87.34a	24.10a	102a	16.21a	4.92b	0.47a
LSD at 5%	2.34	2.74	2.62	1.14	0.23	0.01
Level of significance	n.s.	n.s.	**	*	*	n.s.

Where *, ** and n.s. represents probability of ≤ 0.001, ≤ 0.01 and < 0.05 respectively. Values were means of three replicates. In a column figures with same letter do not differ significantly whereas figures with dissimilar letter differ significantly ($P \leq 0.01$).

9.3.3. Tiller production

Transplanting of boro (winter, irrigated) rice under different planting methods affected the number of tillers m^{-2} of rice. The increasing trend of tiller m^{-2} was continued to 40 days after transplanting for both planting method. At 40 days after transplanting both planting method attained the highest number of tiller m^{-2} and then started declining up to 100 days after transplanting (Table 9.3).

Table 9.3: Effect of tiller production by USG in raised bed and fertilizer broadcasting in conventional planting.

Method of Fertilizer application	Tiller (number. m^{-2}) at days after transplanting								
	20	30	40	50	60	70	80	90	100
USG in bed planting	64b	223a	247a	213a	168a	164a	159a	152a	149a
Prilled urea broadcasting in conventional planting	76a	209b	240a	200a	162b	149b	141b	139b	135a
LSD at 5%	2.07	2.62	9.44	9.66	2.42	4.14	9.44	2.62	9.44
Level of significance	**	**	n.s.	n.s.	*	**	*	**	n.s.

Where *, ** and n.s. represents probability of ≤ 0.001, ≤ 0.01 and < 0.05 respectively. Values were means of three replicates. In a column figures with same letter do not differ significantly whereas figures with dissimilar letter differ significantly ($P \leq 0.01$).

9.3.4. Leaf Area index

Planting method affected the leaf area index (LAI) of transplanted boro rice recorded at different days after transplanting (Table 9.4). The highest leaf area index was achieved at 60 DAT by USG in bed planting method. After 60 DAT the leaf area index started declining and continued to do so until100 DAT by USG in bed planting. Table 9.4 shows that at early stages of crop growth, the leaf area index by USG in bed planting treatments was lower than conventional planting. The highest LAI was achieved by PU in conventional planting at 80 DAT. After 80 DAT the LAI started to decline and continued to 100 DAT by PU in conventional method.

Table 9.4: Effect of leaf area index by USG in raised bed and fertilizer broadcasting in conventional planting

Method of Fertilizer application	LAI at different DAT				
	20	40	60	80	100
USG in bed planting	0.41a	2.64a	5.89a	5.42a	4.06a
Prilled urea broadcasting in conventional planting	0.42a	2.50a	5.03b	5.08a	3.85b
LSD at 5%	0.09	0.46	0.09	1.07	0.07
Level of significance	n.s.	n.s.	**	n.s.	**

Where ** and n.s. represents probability of ≤ 0.01 and < 0.05 respectively. Values were means of three replicates. In a column figures with same letter do not differ significantly whereas figures with dissimilar letter differ significantly ($P \leq 0.01$).

9.3.5. Dry matter production

Planting method affected the dry matter production of transplanted boro rice recoded at different days after transplanting (Table 9.5). In the first date of measurement (20 DAT) it was observed that the USG in bed planting produced higher dry matter yield than PU in conventional method. Likewise, at the final date (100 DAT) highest dry matter production was also recorded by USG in bed planting method than PU in conventional planting. However, dry matter production differs significantly ($P \leq 0.01$) at 20 to 100 DAT in both planting method except 30 and 50DAT.

Table 9.5: Effect of dry matter production by USG in raised bed and fertilizer broadcasting in conventional planting.

Method of Fertilizer application	Dry matter production (g m^{-2}) at different days after transplanting (DAT)							
	20	30	40	50	60	70	80	90
USG in bed planting	79.67a	258.57a	570a	625a	1090.68a	1256.12a	1421.5a	1556.37a
Prilled urea broadcasting in conventional planting	61b	257a	492b	619a	903b	1049b	1282b	1294b
LSD at 5%	2.06	2.60	4.98	29.06	9.66	8.84	9.44	9.96
Level of significance	**	n.s.	**	n.s.	**	**	**	**

Where ** and n.s. represents probability of ≤ 0.01 and < 0.05 respectively. Values were means of three replicates. In a column figures with same letter do not differ significantly whereas figures with dissimilar letter differ significantly ($P \leq 0.01$).

9.3.6. Crop growth rate

Results from the crop growth rate was shown in Table 9.6.At the initial stage (20 to 30 DAT), the crop growth rate (CGR) by USG in bed planting was lower than PU in conventional planting. The greatest crop growth rate was observed at 50 to 60 DAT for both planting method. On the other hand the highest crop growth rate was observed in 50 to 60 DAT by PU in conventional planting. The lowest crop growth rate was observed at 40 to 50 DAT by USG in bed planting and 40 to 90 DAT by PU in conventional planting. The crop growth rate differed significantly ($P \leq 0.01$) in the two planting methods except at 20 to 30 and 60 to 70 DAT.

Table 9.6: Effect of crop growth rate by USG in raised bed and fertilizer broadcasting in conventional planting

Method of Fertilizer application	Crop growth rate (g m^{-2} day^{-1}) at different days after transplanting						
	20-30	30-40	40-50	50-60	60-70	70-80	80-90
USG in bed planting	17.89a	31.14a	5.5b	46.56a	16.54a	16.53b	13.48a
Prilled urea broadcasting in conventional planting	19.60a	23.50b	12.70a	28.40b	14.60a	23.30a	1.20b
LSD at 5%	2.15	2.13	0.50	1.65	1.51	2.36	0.93
Level of significance	n.s.	**	**	**	n.s.	**	**

Where ** and n.s. represents probability of ≤ 0.01 and < 0.05 respectively. Values were means of three replicates. In a column figures with same letter do not differ significantly whereas figures with dissimilar letter differ significantly ($P \leq 0.01$).

9.3.7. Weed population

Weed population and dry biomass were greatly influenced by different planting methods of transplanted boro rice (Table 9.7). The USG in bed planting method reduced weeds population resulting in lower dry biomass than PU in conventional planting. The PU in conventional method had significantly ($P \leq 0.01$) higher weeds vegetation than raised bed planting.

Table 9.7: Effect of weed growth by USG in raised bed and fertilizer broadcasting in conventional planting.

Method of Fertilizer application	Weed vegetation	
	Weed vegetation population (number m^{-2})	Dry biomass (kg ha^{-1})
USG in bed planting	162b	152.14b
Prilled urea broadcasting in conventional planting	389a	344.98a
LSD at 5%	2.07	9.46
Level of significance	**	**

Where, ** represent probability of ≤ 0.01. Values were means of three replicates. In a column figures with same letter do not differ significantly whereas figures with dissimilar letter differ significantly ($P \leq 0.01$).

9.3.8. Irrigation water

Different planting methods affected the irrigation water requirement (Table 9.8). The PU in conventional planting received a higher amount of water at every irrigation and the total amount was 149 cm. The total amount of irrigation water received by USG in bed planting was 100.96 cm. Results showed that total water savings by USG in raised bed planting compared to PU in conventional method was 47.58%.

Table 9.8: Irrigation water savings by USG in raised bed and fertilizer broadcasting in conventional planting

Method of Fertilizer application	Irrigation required (cm)	Rainfall (cm)	Total Irrigation required (cm)	Water saved over conventional method (%)
USG in bed planting	88.16b	12.8a	100.96b	47.58%
Prilled urea broadcasting in conventional planting	136.20a	12.8a	149.00a	
LSD at 5%	2.85	0.85	2.62	
Level of significance	**	n.s.	**	

Where ** and n.s. represents probability of ≤ 0.01 and < 0.05 respectively. Values were means of three replicates. In a column figures with same letter do not differ significantly whereas figures with dissimilar letter differ significantly ($P \leq 0.01$).

9.3.9. Water use efficiency

Water use efficiency for grain and biomass production by USG in bed planting was 51.50 kg $ha^{-1}cm^{-1}$ and 103.50 kg $ha^{-1}cm^{-1}$, respectively (Table 9.9). The water use efficiency for grain production and biomass production in the conventional planting was 29.53 kg $ha^{-1}cm^{-1}$ and 62.55kg $ha^{-1}cm^{-1}$, respectively. Therefore water use efficiency for grain production and biomass production in raised bed planting was 74.39% and 65.46% higher than PU in conventional planting.

Table 9.9: Water use efficiency by USG in raised bed and PU in conventional planting method.

Method of fertilizer application	Water use efficiency savings by USG in raised bed planting over PU in conventional method	
	Water use efficiency for grain production (kg $ha^{-1}cm^{-1}$)	Water use efficiency for biomass production (kg $ha^{-1}cm^{-1}$)
USG in bed planting	51.50a	103.50a
PU in conventional planting	29.53b	62.55b
LSD at 5%	2.44	2.68
Level of significance	**	**

Where ** represent probability of ≤ 0.01. Values were means of three replicates. In a column figures with same letter do not differ significantly whereas figures with dissimilar letter differ significantly ($P \leq 0.01$).

9.3.10. Agronomic efficiency of N fertilizer

Agronomic efficiency of N fertilizer in raised bed planting was 42.6 % (Table 9.10) while agronomic efficiency for PU in conventional planting was 22.56%. Agronomic efficiency of N fertilizer by USG in raised bed was significantly ($P \leq 0.01$) higher than the PU in conventional planting method.

Table9.10. Agronomic efficiency of fertilizer by USG in raised bed and fertilizer broadcasting in conventional planting.

Method of Fertilizer application	Agronomic efficiency of fertilizer (%)
USG in bed planting	42.69a
Prilled urea broadcasting in conventional planting	22.56b
LSD at 5%	2.67
Level of significance	**

Where ** represent probability of ≤ 0.01. Values were means of three replicates. In a column figures with same letter do not differ significantly whereas figures with dissimilar letter differ significantly ($P \leq 0.01$.

9.3.11. Advantages of USG application over PU

Urea super granule (USG) was applied in bed 59 kg N ha^{-1} and prilled urea (PU) broadcasted in conventional planting 95 kg N ha^{-1}. So, USG in bed saved 61% N fertilizer compared to PU in conventional planting (Table 9.11). Economic benefit in USG application instead of PU was also assessed and the result was presented in (Table 9.12). It appears that 78.26 kg of urea could be saved by using USG. Using USG, 11.87 US dollar could be saved since price of USG was higher and additional labor cost for USG application was 25 USD ha^{-1}. The main benefit as gained was additional yield of 0.80 t ha^{-1} (18.18% higher) and the additional benefit was USD 175 ha^{-1}.

Table 9.11: Nitrogen (N) fertilizer applied in raised bed and conventional planting

Method of Fertilizer application	Added N fertilizer (kg ha^{-1})	N fertilizer saved by USG in bed planting over Prilled urea broadcasting in conventional planting (%)
USG in bed planting	59	61
Prilled urea broadcasting in conventional planting	95	

Table 9.12: Comparative advantages of USG use over PU application

Items	Total amount (kg)	US dollar
Urea applied in bed in USG form (kg ha^{-1})	128.26 (@0.31 USD Kg^{-1})	39.76
PU applied in conventional planting (kg ha^{-1})	206.52 (@0.25 USD kg^{-1})	51.63
US dollar saved from urea (US dollar ha^{-1})	11.87	11.87
Additional labor cost for USG application (US dollar ha^{-1})	10 labour (@2.5 USD labour^{-1})	25
Yield of USG plot (t ha^{-1})	5.20 (18.18%)	
Yield of PU plot (t ha^{-1})	4.40	
Additional yield from USG plot (t ha^{-1})	0.80 (@ 218.75 USD ton^{-1})	175
Additional benefit from USG plot (US dollar ha^{-1})		161.87

Note: Figures in the parentheses indicate percent increase.

9.4. DISCUSSION

9.4.1. Benefits of deep placement of USG over PU in conventional planting

Economic benefit in USG application instead of PU was also assessed and the result was presented in Table. 9.12. It appears that on average, 78.26 kg of urea could be saved by using USG. In my experiment 128.26 kg urea ha^{-1} was applied in bed planting as a form of USG and PU broadcasted 206.52 kg urea ha^{-1} in conventional planting. The market value of 128.26 kg USG was 40.08 USD (@ USD 0.31USG kg^{-1}). On the other hand the market value of 206.52 kg PU was Tk.4130.40 (@ Tk.20 PU kg^{-1}). So USG in bed planting saved expenditure for urea by 11.87 USD ha^{-1} over PU. Regardless of that, nearly 10 more labor was needed in the USG using plots compared to that of PU user plots. This contributed additional labor cost for USG application was 25USD ha^{-1} (Table.9.12). This study suggested that USG in bed planting reduced expenditure for urea by 22.36% over PU in conventional planting. Similarly, IFDC innovation about deep placement of urea super granule observed that USG reduces expenditure for urea by 20%-25%. Similarly, Roy (2010) reported that yearly requirement of urea in Bangladesh is 2.9 million tons (mt) of which 80 per cent (2.3 mt) is used for rice alone. The country produces 1.7 mt and the rest is (1.2 mt) imported at a cost of 465 million USD. If all the urea could be applied in super granule form, then 1.15 mt urea could be saved. In that case only 0.05 mt urea needs to be imported and its market value is 19.375 million USD .So, it can reduced expenditure for urea nearly 445.625 million USD yearly by using USG instead of prilled urea (PU).

Deep placement of USG in bed produced grain yield 5.20 t ha^{-1} and PU in conventional planting produced 4.40 t ha^{-1} (Table.9.1). Deep placement of USG produced 18.18% more yield than PU in conventional planting. The main benefit as gained by USG in bed was additional yield of 0.80 tha^{-1} (18.18% higher) and the additional benefit was Tk. 12923.90 ha^{-1} over PU in conventional planting (Table.9.12). Other study conducted by Savant and Stangel (1998) have shown that N loss is significantly reduced in USG, which results in a significant increase in rice grain yield under flooded conditions compared with split applied PU. Likewise, Singh and Allgood (2013) demonstrated that fertilizer deep placement (FDP) is an innovative, proven fertilizer application technology that achieves average yield increases of 18 percent while reducing fertilizer use by about one-third. This technology has resulted from IFDC-applied research to improve nitrogen-uptake efficiency. It is a simple, low-cost technology that is extremely well suited to small-scale rice production. Moreover, experiments with N-labeled peat ball fertilizer showed that deep placement of nitrogen at the panicle formation stage resulted in 86% of the nitrogen being taken up by the rice plant; surface broadcasting gave only 50% nitrogen uptake (Mitsui, 1977).

My speculation is that deep placement of USG reduces possible losses of nutrients, particularly losses of nitrate nitrogen, between applications and uptake by the plants through gradual nutrient release. They also reduce evaporation losses of ammonia. This substantially decreases the risk of environmental pollution. However, the benefits of USG such as mitigation of nitrogen loss mechanisms, improving crop uptake to support yield improvement and lower application of high cost fertilizers. Deep placement of USG encourages algal biological nitrogen fixation because of low floodwater nitrogen concentrations weeding and pest control is made easier, minimizes ammonium and phosphate fixation and immobilization, reduces the number of ineffective tillers in rice plants and results in bigger panicles and ensures nitrogen availability beyond the flowering stage when applied at an appropriate rate.

9.4.2. Deep placement of USG in bed saved N fertilizer consumption over conventional planting

In this experiment urea super granule (USG) was applied in bed 59 kg N ha^{-1} and prilled urea (PU) broadcasted in conventional planting 95 kg N ha^{-1}. So, USG in bed saved 61% N fertilizer compared to PU in conventional planting. These results are in accordance with Hasanuzzamman *et al*. (2013). They found that deep placement of urea super granule in boro rice reduced 60% N fertilizer compared to prilled urea. Likewise, Dr. Ray B. Diamond, an IFDC agronomist, demonstrated that deep-placed USG resulted in an average saving of urea fertilizer of about 35%. He also stated that in most cases, the agronomic performance of deep placed USG was superior to that of two or three split broadcast applications of prilled urea (B. Diamond). Similarly, Alam *et al.* (2011) assessed the economic benefit in USG application instead of PU. They found that urea saved (kg ha^{-1}) by USG over PU were 55, 32, 25, 129 in four research station. These findings suggested that average 60 kg of urea could be saved by using USG over PU. Islam *et al.* (2012*)* demonstrated that deep placement of USG could be a profitable N management technique. They also found that grain yield with only 55 kg N ha^{-1} in USG form as against 80 kg N ha^{-1} in the form of prilled urea was same. Deep placement of USG saved 45.45% N compared to PU. Eusuf *et al.* (1993) reported that 58 kg USG and 87 kg PU produced almost similar grain yield. As a result using USG at the same level of crop yield can save one third of nitrogen required for conventional split application of urea. The use of N as USG has more efficiency than that of PU (Rashid *et al.*1996). From this study, it reveals that deep placement of USG is an effective means of increasing nitrogen use efficiency of rice as compared to the traditional split application of PU. The USG with deep placement provided a zone of concentrated urea solution where the denitrifying bacteria cannot enter and therefore nitrogen is left at the root zone for uptake by the plants (Mukherjee, 1986). Deep placement of urea super granule (USG) was best suited to conditions where the predominant N loss mechanism is ammonia volatilization rather than leaching or de nitrification. Deep placement of USG thus has greater benefit over surface split application on moderate to heavy textured soils (Mohanty *et al.*1999).

In contrast Sarder *et al.* (1988) evaluated about slow release nitrogenous sources and urea fertilizer on wetland rice. Conventional method of urea application as broadcast was compared with USG in deep placement. Results showed that point placement of urea super granules were superior to the conventional method of urea application only at the higher nitrogen rates. Urea super granules did not show any advantage over conventional method of urea application.

My speculation is that urea super granules (USG) application in the root zone at 8-10 cm depth of soil (reduced zone of rice soil) can save nitrogen than prilled urea (PU) because of deep placement are restricted to leaching or by diffusion of ammonium to the surface. Volatilization loss of ammonia can be minimized by mixing of nitrogen fertilizers in soil rather than broadcasting on soil surface, deep placement of urea super granules (USG) in puddle rice field. Dentrification loss can be minimized by avoiding the use of NO_3 form of nitrogenous fertilizer in rice and use of deep placement of urea sugar granules (USG) in flooded rice field. To minimize N losses deep placement of nitrogen fertilizers are promising for Bangladesh. Deep placement of USG is to make the amount of N released coincide with the nitrogen requirement of growing plants, especially the tillering and heading stages, and thereby reducing N losses. This study speculated that this modified form of urea, because of its larger granule size, may go deeply into the mud simply by force throwing and thus may be expected to be more efficiently used than PU which may contribute to reduce N loss.

9.4.3. Effect of USG as a source of nitrogen on the growth parameters of boro rice

The fertilizer treatment had effect on the plant height at different growth stage. The higher plant height (89.93 cm) was obtained for USG in bed planting and shorter plant (87.34 cm**)** with prilled urea (PU) in conventional planting (Table 9.2). The increase in plant height in response to application of USG in bed enhanced more leaf probably resulting in higher photo assimilates and thereby resulted in more dry matter accumulation. These results are supported by the findings of Hasanuzzaman *et al.* (2013). They reported that the highest plant height at harvest was obtained by USG and shortest plant with control. Likewise, Xiang *et al*. (2013) also found that deep placement of urea super granule (USG) produced higher plant height than surface application of urea. The higher panicle length (25.08 cm) was observed in USG in bed planting. Application of USG in bed produced 4.06% higher panicle length over PU broadcasting in conventional planting (Table.9.2). The USG in bed planting released nitrogen slowly ensuring sufficient availability at panicle initiation stage. The result was good accordance with the findings of Hasanuzzaman *et al.* (2009). Deep placement of USG in bed showed the higher number of tiller than PU in conventional planting (Table.9.3). This higher tiller may be due to little loss of N from soil and slowly releasing process. The continuous availability of N from in bed played a vital role in cell division that helped in increasing the number of tillers. Similarly, Pandey *et al.* (2001) reported that the placement of USG favored for higher tiller production than PU splits for rice cultivation. Urea super granule (USG) treated plot produced higher number of tiller compared to PU treated plots within the same N level (Choudhury *et al.*2009). In addition, Azam *et al*. (2012) found that 2.7 gm size USG placement at 8 days after transplanting produced highest number of tiller hill^{-1}. Similar result observed by Hasanuzzaman *et al.* (2009) reported that deep placement of USG @ 75 kg N ha^{-1} showed highest number of tillers. This result also in agreement with the findings of Rahman (2003) and Alam (2002).The USG treated plot in bed planting produced significantly higher leaf area index (LAI) at 60 days after transplanting (DAT) compared to PU in conventional planting (Table.9.4). After 60 DAT the LAI declined probably due to senescence of leaves with the progress of maturity. The effect of USG fertilizer is to increase the rate of leaf expansion, leading to enhanced interception of solar radiation by the canopy. These findings are same with the findings of Masum *et al.* (2008) and Miah *et al.* (2004). It was evident from Table 9.5 that at harvesting time, total dry matter production (TDM) was found significantly higher in USG treated bed planting than PU in conventional planting. The higher dry matter of USG in bed could be due to the positive effects of some important physiological processes. These results are in agreement to the findings of Rao *et al.* (1986). They concluded that USG was the most effective in increased TDM than split application of urea. In my experiment USG in bed planting produced higher biological yield (Grain yield + Straw yield) (10.45 t ha^{-1}) than PU in conventional planting (9.32 t ha^{-1}). So, USG in bed produced 12.12% higher biological yield than PU in conventional planting. The result agreed with the findings of Ahmed *et al.* (2005) who observed the positive effect of nitrogen application on biological yield (12 t ha^{-1}) of rice. The higher straw yield of 5.25 t ha^{-1} was obtained from USG in bed planting and lower straw yield of 4.9 t ha^{-1} was observed by PU in conventional planting. Application of USG in bed produced 6.70% higher straw yield than PU in conventional planting. More straw yield could be explained as higher capability of hybrid rice to utilize more nitrogen through the expression of better growth by accumulating more dry matter. These results are confirmed by the findings of BRRI (2009) and Awan *et al.* (2011*).* Similarly, Jena *et al. (*2003) also reported that deep placement of urea super granule (USG) significantly improved straw yield of rice relative to the application of prilled urea.

This finding speculated that almost growth parameters were best with USG application among all treatments.USG as slow-release nitrogen reduces total N concentration in surface soil and is likely to minimize loss through volatilization and surface runoff. This study also speculated that urea-induced toxicities may be the main cause of poor growth when urea was applied on soil surface during the early growth stage. Deep placement of USG reduced the adverse effects of urea, this is because deep placement of USG can reduce nitrogen loss by ammonia volatilization and ammonia is known the main cause of urea-induced toxicities. Deep placement of USG also improved soil physical properties and provided higher availability of nutrient in rice field may be attributed higher growth parameter than PU.

9.4.4. Deep placement of USG in bed planting provided higher agronomic efficiency over PU in conventional planting

Urea super granule (USG) in raised bed significantly increased agronomic efficiency compared to prilled urea (PU) in conventional planting. In my experiment agronomic efficiency of N fertilizer by USG in bed planting was 42.69% and 22.56% by PU in conventional planting (Table 9.10). IRRI-CREMNET (1998) reported that in Bangladesh agronomic efficiency of N (AE_N) for boro rice was 22 by farmers practice and 41 for deep placement of USG. So, deep placement of USG provided higher agronomic efficiency of N over farmers practice (conventional planting). Muniruzzaman (2009) stated that use of urea super granule increased nitrogen fertilizer use efficiency to 20-25% over conventional planting. Regardless of that Patel *et al.* (1989) showed that N use efficiency of urea super granule was 27.6 and 21.8 for prilled urea. However, Zaman *et al.* (1993) also found same result. They showed that urea super granule consistently produced significantly higher agronomic efficiency of N with USG than PU. Moreover, Naher *et al.* (2011) demonstrated that USG deep placement for boro rice provided N use efficiency 27 whereas prilled urea produced N use efficiency of 14.2.They speculated that if USG applied instead of prilled urea at 12 –15 days after transplanting USG application save N fertilizer and increase use efficiency compared to prilled urea. Devasenapathy and Palaniappan (1993) found that agronomic efficiency of ADT36 variety rice for point placement of USG at 7 DAT was

27.5.On the other hand prilled urea (PU) broadcasted for same rice variety produced agronomic efficiency of 15.8. An IFDC innovation showed that deep placement of USG increased efficiency of fertilizer use in flooded rice due to reductions of loss through gaseous emissions and floodwater runoff. IFDC speculated that, with broadcast application of urea, volatilization losses alone could account for 30%-50% of applied fertilizer. Choudhury *et al.* (2009) showed that agronomic efficiency of added N ranged from 11.84 to 17.93 for PU while the range was 16.83 to 20.00 for USG. Higher agronomic efficiency of added N with USG over PU was also found in some other investigations (Choudhury and Bhuyan, 1994; Choudhury *et al.* 1994).

In contrast Sarder *et al.* (1988) evaluated about slow release nitrogenous sources and urea fertilizer on wetland rice. Conventional method of urea application as broadcast was compared with USG in deep placement. Results showed that point placement of urea super granules were superior to the conventional method of urea application only at the higher nitrogen rates. Urea super granules did not show any advantage over conventional method of urea application.

My speculation is that deep point placement of USG improved N fertilizer use efficiency due to (ì) limits the concentration of N in flood water and in the surface oxidized layer (ìì) decreased N losses through runoff, NH_3 volatilization and denitrification (ììì) minimizes weed use of the applied fertilizer (ìv) minimizes NH_4 fixation (v) ensures prolonged N availability up to flowering (vì) reduced tillering, but gives all productive tillers and big panicles. These findings speculated that USG deep placement technology is best suited to conditions where the predominant N loss mechanism is ammonia volatilization rather than leaching or denitrification. Deep placement of USG has greater benefits over surface split application on soil with moderate to heavy texture, low permeability and percolation rate, and high cation exchange capacity and pH.

9.5. CONCLUSIONS

This study demonstrated that USG in bed planting increased grain yield by 18.18 % for boro (winter, irrigated) rice compared to prilled urea (PU) broadcasting in conventional planting. Deep placement of USG in raised bed planting produced higher number of panicles per unit area, number of grains per panicle and 1000-grain weight for transplanted boro rice which ultimately gave the higher grain yield than the PU in conventional planting. This study also concluded that the deep placement of USG in raised bed planting proved beneficial over conventional PU technique, especially with respect to grain yield, yield attributes, agronomic efficiency and water use efficiency. Deep placement of USG in raised bed planting effectively increased N-use efficiency as compared to PU in conventional planting. Deep placement of USG in raised bed planting is considered the most effective method to decrease N losses and thereby to increase fertilizer use efficiency. This study also suggests that the deep placement of USG in raised bed planting for boro rice is feasible for water and nitrogen use efficiency and reduction in soil compaction. The USG in raised bed planting saved irrigation water by 47.58% as well as increased irrigation efficiency over PU in conventional planting. Bed planting provided less weed density and dry biomass than conventional planting. These findings concludes that water use efficiency for grain and biomass production was higher by deep placement of USG in bed planting than PU broadcasting in conventional method. The agronomic efficiency of N fertilizer was also significantly higher in USG of bed planting than the PU broadcasting in conventional planting method.

It was found from my previous study that the deep placement of USG in bed planting system for transplanted aman rice achieved higher yield than PU in conventional flat method. Likewise, the potential gains from growing transplanted boro rice on raised beds with USG are considered to be associated with better agronomic management than PU in conventional method. It is likely that the raised bed technique will have long term soil physical benefits without sacrificing yield. The incorporation of USG in raised bed introduced a new transplanted boro rice based farming system offers many advantages. Based on the findings of this experiment, high yielding transplanted boro rice (winter, irrigated) crops have been successfully grown on raised bed under deep placement of USG. There is a good prospect of utilization of this technology to benefit the rice farmers. More studies is needed to establish bed planting with USG, a better planting method of transplanted boro rice cultivation in Bangladesh as well as other countries in the world.

Chapter 10

Impact of split foliar nitrogen application on water use efficiency and productivity of boro rice in raised bed over conventional method

Chapter 10

Impact of split foliar nitrogen application on water use efficiency and productivity of boro rice in raised bed over conventional method

10.1. INTRODUCTION

Foliar fertilization that is nutrition through plant leaves is very efficient technique of fertilization for certain crops which can tolerate aerial spray without being damaged. The absorption of the nutrients occurs through leaf stomata as well as leaf cuticle. Amount of nutrients uptake by foliar fertilization are relatively small but the effects of foliar nutrition are manifested very quickly and refers to the change in leaf colour, character of turnover of nutrients in the plants , growth and yield production. In many cases aerial spray of nutrients is preferred and gives quicker and better results than the soil application (Jamal *et al.* 2006). However, now it is also proved that ions also absorbed by leaves stomata's (Eichert *et al.* 1998; Eichert and Burkhardt, 2001). When the stomata are open, foliar absorption is often easier (Burkhardt *et al.* 1999). Recently foliar application of nutrients has become an important practice in the production of crops while application of fertilizers to the soil remains the basic method of feeding the majority of the crop plants. Foliar fertilization provides more rapid utilization of nutrients and permits the correction of observed deficiencies in less time than would be required by soil application. Gooding and Davis (1992) reported that there are several potential benefits of providing N to cereals via the foliage as urea solution. These include reduced N losses through denitrification and leaching compared with N fertilizer applications to the soil.

The furrow irrigated raised bed planting system in which crops are sown on ridge or beds .The height of the bed is maintained at about 15 to 20 cm and having a width of about 40 to 70 cm depending on the crops. The furrow width is generally 25 cm. Potential agronomic advantages of beds include improved soil structure due to reduced compaction through controlled trafficking, and reduced water logging and timely machinery operations due to better surface drainage. Beds also provide the opportunity for mechanical weed control and improved fertilizer placement. Balasubramanian *et al.* (2003) and Hobbs and Gupta (2003) reported yield of rice transplanted or direct seeded on beds was plus/minus 5-6% of that of puddle transplanted rice, while irrigation water savings averaged about 37-40%. Kukul *et al.* (2005), however, reported yield reductions of up to 50% and more of rice grown on raised beds compared with puddle transplanted rice. Farmer and researcher trials in the Indo-Gangetic plains suggest irrigation water savings of 12–60% for direct-seeded and transplanted rice on beds, with similar or lower yields for transplanted compared with puddle flooded transplanted rice, and usually slightly lower yields with direct seeded rice (Balasubramanian *et al.* 2003; Gupta and Gill, 2003; Hossain *et al.* 2003; Jehangir *et al.* 2002). However, many studies in the northwest Indo- Gangetic plains indicate little effect of rice on beds on water productivity (typically around 0.30–0.35 g kg^{-1}) as the decline in water input was accompanied by a similar decline in yield (Jehangir *et al.* 2002; Sharma *et al.* 2003; Singh *et al.* 2003). Studies in the USA have also shown considerable water savings with furrow-irrigated rice on beds (Tracy *et al.*, 1993; Vories *et al.* 2002).The raised bed treatment used up to 32% less water than paddy with permanently flooded. Ockerby (1995) grew a commercial rice crop on raised bed using continuous furrow irrigation to form a constant water table 0.13 m below the soil surface. The crop yielded 6.7 t ha^{-1}. Beecher *et al*. (2006) reported no water saving from the raised bed rice cultivation compared with conventional ponded rice grown on a flat layout.

It is also unclear whether the yield of rice crops grown on raised bed has been limited by insufficient crop nitrogen (N). Whereas N supply and uptake of N by paddy rice is well understood, the N transformations in the raised bed system will be complex due to water and N fluxes between the flooded and oxidized soil layers and these have yet to be studied. Similarly, cultivar traits that may promote yield on raised beds in response to the water and N have not been identified.

My previous study showed that foliar spray of nitrogen fertilizer on raised bed increases yield of transplanted aman rice (partially irrigated) over conventional method (Chapter 6). However, it was not considered for transplanted boro (winter, irrigated) rice with foliar spray of N in raised bed than fertilizer broadcasting in conventional method. Therefore, this study was undertaken to determine the effect of foliar spray of N on raised bed than fertilizer broadcasting in conventional planting for transplanted boro rice production. It will be hypothesized that foliar spray of N on raised bed receives higher yield and less water inputs than conventional flat planting.

10.2. MATERIALS AND METHODS

10.2.1. Location and climatic condition of the experimental site

To evaluate the effect of split foliar application of nitrogen fertilizer on yield and yield components of rice, an experiment was conducted at farmer's field, daulatdear, chuadanga (high ganges river flood plain) of Bangladesh, during boro season (December-May' 2012). Research field was located at 11.5 m above mean sea level. Geographically, it is located at $23^0 39^/$ N latitude and $88^0 49^/$ E longitudes. The meteorological data of experimental site were recorded at regional weather station, Chuadanga district of Bangladesh. The rainfall received in rice growing period (February-May'2012) was 128 mm. The mean maximum and minimum temperature were recorded 34.28ºC and 22.03ºC, respectively for the cropping season. The relative humidity ranged between 63.8% in the month of March and 71.5% in the month of February'2012.

10.2.2. Soil conditions of the experimental site

One week before transplanting, soil samples (0-15 cm depth) were collected from the field for physico-chemical analysis (Table 10.1). Soil samples were analysed for particle size distribution by hydrometer method (Bouyoucos, 1962). Soil pH was measured in water (Soil water ratio 1:1) and electrical conductivity of the soil suspension was measured using conductivity meter. The P, K and Zn were determined by using AB-DTPA method (Soltanpour and Workman, 1979). For K determination from plant samples, wet digestion method (nitric acid : perchloric acid in 2: 1 ratio) was followed and measured the concentration by flame photometer (Rhoades, 1982). The data on the initial analysis soil samples for organic carbon, pH, available N, P and K are furnished in Table 10.1. These properties were measured at regional soil testing laboratory of Soil Resources Development Institute (SRDI), Jinaydah, Bangladesh.

Table 10.1. Soil physical and chemical properties

Location	Season	Soil type	pH	Organic carbon (%)	Total N (%)	Available P (ppm)	Exchangeable K (meq 100 g^{-1})	Available S (ppm)	Available Zn (ppm)
Chuadanga	Boro	Silt loam	7.30	0.88	0.11	5.68	0.15	12.10	0.22

10.2.3. Foliar nitrogen (urea) application pattern

Fertilizer was applied at the following rates: N=30, P=14, K=36, S=8 and Zn=1 kg ha^{-1} as Urea, Triple super phosphate (TSP), Murate of potash (MP), Gypsum and Zinc sulphate ($ZnSO_4$), respectively (Fertilizer Recommendation Guide, 2005). Whole of TSP, MP, gypsum and $ZnSO_4$ were broadcasted before transplanting on top of the beds. The nitrogen (urea) spray volumes were prepared by mixing 2 kg of urea in 100 litre of water as per treatment. The foliar spray was 2% at 30 kg ha $^{-1}$ of N. The plots were sprayed during late afternoon hours when wind speed was less than 10 km hr^{-1}. Foliar spray of nitrogen (urea) fertilizer is shown in Table 10.2.

Table 10.2. Treatment details for foliar spray in raised bed.

Treatments details	Basal fertilizer application	Spray 1	Spray 2	Spray 3	Total N,P,K,S (kg ha^{-1})
Foliar spray in bed planting	Whole rate of P,K, gypsum and $ZnSO_4$ applied before transplanting on top of the beds.	2 % urea at 15 DAT	2 % urea at 30 DAT	2 % urea at 50 DAT	N=30 P=14, K=36 S=8, Zn=1.0

10.2.4. Fertilizer broadcasting in conventional planting

The crop was fertilized with N, P, K, S, and Zn at the rates of 120, 14, 36, 8, and 1 kg ha^{-1}, respectively. The sources of N, P, K, S, and Zn were urea, TSP, MP, gypsum, and $ZnSO_4$, respectively. All of the TSP, MP, gypsum, and $ZnSO_4$ were applied at the time of final land preparation as basal dose in the plots with conventional planting. The urea was top dressed in three equal splits at 15, 30, and 50 days after transplanting (DAT) in conventional planting. Fertilizer application pattern is described below in Table 10.3.

Table 10.3. Treatment details for conventional planting.

Treatments details	Basal fertilizer application	Split 1	Split 2	Split 3	Total N, P, K, S (kg ha^{-1})
Fertilizer broadcasting in conventional planting	Whole rate of P,K, gypsum and ZnSo$_4$ were applied at the final land preparation.	1/3 of urea at 15 DAT	2/3 of urea at 30 DAT	Rest amount of urea at 50 DAT	N=120, P=14 K=36, S=8 Zn=1

10.2.5. Experiment details

The experiment was laid out in a randomized complete block design (RCBD) with three replications. The entire experimental area was divided into three blocks. The total number of unit plots was 9. The size of each unit plot was 4 m × 3.5 m. Plots were separated from one another by aisle of 0.25 m. Unit blocks were separated from one another by 1 m drains. Treatments were randomly distributed within the blocks. BRRI dhan28, a high yielding variety of rice was used as the test crop in this experiment. The variety was released for boro season by Bangladesh Rice Research Institute (BRRI), Joydebpur ,Gazipur in 1994 after regional and zonal trial as well as evaluation. Life cycle of this variety ranges from 135 to 140 days, which however may vary due to change in climatic condition.

10.2.6. Observations undertaken

Ten randomly selected and tagged plants were used for the measurement of plant height at an interval of 15 days from 15th day after transplanting and ending with just flowering. It was measured from base to tip of the upper most leaves of the main stem. Number of tillers per plant was counted from one meter row length. Leaf area (cm^2) of the functional leaves obtained from samples drawn for dry matter accumulation study was measured by automatic leaf area meter. The effective tiller per row length was recorded just before harvesting the crop and the average values was used to obtain the effective panicles per meter row length. The length of panicle was taken from the 10 panicles from each plot which were randomly selected just before harvesting and mean were calculated. Number of filled and unfilled grains was counted to determine the number of grains per panicle. Thousand grains were counted from the grain yield of each plot and weighed using automatic electronic balance. Biomass yield and grain yield were taken at harvesting from each plot. All the plants from 1 m length were uprooted and weighed to determine the total biomass yield. Digital grain moisture meter was used to record the moisture of the grain. Harvest index (HI) was computed by dividing grain yield with the total dry matter yield.

10.2.7. Irrigation water measurements

Irrigation water was measured by using a delivery pipe and water pan. A plastic delivery pipe was connected from the water pump to the experimental field. A water pan with 300-liter volume was filed by irrigation through the delivery pipe and time required was recorded. Then plots with different methods of planting were irrigated through the delivery pipe and times required were recorded. The amount of irrigation water applied in different plots was calculated as follows:

Amount of water applied per plot=

$$\frac{\text{Volume of water pan (L)} \times \text{Time required to irrigation the plot (sec)}}{\text{Time required filling the water pan (sec)}}$$

10.2.8. Water use and agronomic efficiency calculation

Water use efficiency for grain production (kg $ha^{-1}cm^{-1}$)

= grain yield (kg ha^{-1})/total water required (cm)

Water use efficiency for biomass production (kg $ha^{-1}cm^{-1}$)

= [grain yield (kg ha^{-1}) + straw yield (kg ha^{-1})]/ total water required (cm)

10.2.9. Agronomic efficiency (AE) of N fertilizer

AE= GYNA-GYN0/NR

Where GYNA= Grain yield (kg ha^{-1}) with addition of nutrient

GYN0= Grain yield (kg ha^{-1}) without addition of nutrient

NR= Rate of added nutrient (kg ha^{-1})

10.2.10. Data analysis

Data were analysed following standard statistical procedure and means of treatments were compared based on the least significant difference test (LSD) at the 0.05 probability level. Microsoft Excel was used for tabulation and simple calculation, presentation of table for different comparisons.

10.3. RESULTS

10.3.1. Yield contributing parameters

10.3.1.1. Number of panicle m^{-2}

The number of panicles m^{-2} increased with foliar N fertilization. However, the number of panicles m^{-2} significantly lower in fertilizer broadcasting in conventional planting method (Table 10.4). The increased in the panicle per m^2 may be attributed due to higher availability of nutrients by foliar spray of urea in raised bed as compared to fertilizer broadcasting in conventional planting. This might have facilitated better utilization of resources by the plants converting majority of the tillers into productive tillers or panicles.

Table 10.4. Grain yield and yield components with respect to foliar spray in raised bed and fertilizer broadcasting in conventional planting.

Method of Fertilizer application	Yield and yield components			
	panicles m^{-2} (number)	Grains $panicle^{-1}$ (number)	1000 grain wt (gm)	Grain yield (t ha^{-1})
Foliar spray in bed planting	470a	128a	25a	5.26a
Fertilizer broadcasting in conventional planting	430b	106b	21.00a	4.40b
LSD at 5%	5.40	3.34	2.93	0.44
Level of significance	**	**	n.s.	*

Where ** represent probability of ≤ 0.01 and n.s. represents probability of >0.05. Values were means of three replicates. In a column figures with same letter do not differ significantly whereas figures with dissimilar letter differ significantly ($P \leq 0.01$).

10.3.1.2. Number of grains $panicle^{-1}$

Perusal of the data revealed significant effect of foliar application of nitrogen on number of grains per panicle (Table 10.4). Maximum number of grains per panicle was produced by foliar application of N in bed compared to conventional flat planting. This could be attributed to the fact that application of macronutrients may have improved the photosynthetic ability of crop thereby more food material synthesized contributed to the improvement in number of grains per panicle.

10.3.1.3. Thousand grains weight

Analysis of the data revealed that foliar application of nitrogen solution resulted higher in thousand grains weight (Table 10.4). This may be due to the foliar application of macro nutrients might have enhanced accumulation of assimilate in the grains and thus resulting in heavier grains of rice. The increase in 1000 grain weight by foliar spray in bed could be attributed to the fact that application of macronutrients may have improved the photosynthesis thus, more food material synthesized contributed to the improvement in 1000 grain weight compared to conventional flat planting.

10.3.1.4. Grain yield

Planting method had significant effects on grain yield. Grain yield showed a significant response to nitrogen fertilization method (Table 10.4). Maximum yield was obtained with the foliar nitrogen application on raised bed compared to fertilizer broadcasting in conventional flat method. The lower grain yield obtained by fertilizer broadcasting in conventional flat method. Therefore, the lower yields in conventional planting would be explained by its lower panicle density. Comparatively lower grain yield obtained with conventional flat method could be attributed to poor nutrition to the crop because of insufficient nitrogen uptake.

10.3.2. Growth characters

10.3.2.1. Plant height

The results in Table 10.5 clearly showed that taller plant was produced from fertilizer broadcasting in conventional planting .However, foliar spraying of nitrogen in bed after transplanting rice recorded lower increase in plant height. The lower plant height with foliar spray of urea might be due to the reduced uptake of nitrogen through foliage.

10.3.2.2. Panicle length

Foliar spraying of nitrogen in raised bed increased panicle length by 6.72% compared with fertilizer broadcasting in conventional planting (Table 10.5). Foliar spraying after transplanting in raised bed enhanced rice plant to higher photosynthesis rate which contributed to higher panicle length. This longer panicle in bed planting might helped in producing higher number of grain per panicle.

Table 10.5. Plant biomass with respect to foliar spray in raised bed and fertilizer broadcasting in conventional planting.

Method of Fertilizer application	Plant height (cm)	Panicle length (cm)	Non-bearing tiller (no-m^{-2})	Sterility (%)	Straw yield (t ha^{-1})	Harvest index
Foliar spray in bed planting	87.27a	25.72a	45b	13.12b	5.28a	0.49a
Fertilizer broadcasting in conventional planting	87.34a	24.10a	102a	16.21a	4.92b	0.47a
LSD at 5%	2.19	1.51	2.62	1.13	0.13	0.00
Level of significance	n.s.	n.s.	**	**	**	n.s.

Where ** represent probability of ≤ 0.01 and n.s. represents probability of >0.05. Values were means of three replicates. In a column figures with same letter do not differ significantly whereas figures with dissimilar letter differ significantly ($P \leq 0.01$).

10.3.2.3. Spikelet sterility

Spikelet sterility significantly increased with fertilizer broadcasting in conventional planting compared to foliar spray of nitrogen in bed planting (Table 10.5). The percentage of filled spikelet was higher by foliar spray of nitrogen in bed planting. The lower sterility in bed might be higher grains per panicle, which directly added to the grain yield.

10.3.2.4. Straw yield

Foliar spray of nitrogen in raised bed registered significantly higher straw yield compared with fertilizer broadcasting in conventional planting (Table 10.5). Foliar spray in bed planting provided sufficient nutrient for vegetative growth and also for the reproductive phase which ultimately leads to increased straw yield. My interpretation is that foliar spray of urea in bed increased the straw yield over conventional planting which might have been due to the effect of roots thereby increasing uptake nutrients from soil ultimately enhancing the vegetative growth.

10.3.2.5. Harvest index

The results presented in Table 10.5 showed that the higher harvest index was obtained in foliar spray of nitrogen in bed planting. The lower harvest index was recorded in conventional method. These higher and lower harvest indexes were resulted due to higher and lower grain yield, respectively.

10.3.3. Tiller production

Transplanting of boro rice under different planting method affected the number of tillers per m^2 of rice. The increasing trend of tiller per m^2 was continued to 40 DAT. At 40 DAT both planting method attained the highest number of tiller per m and then started declining up to 100 DAT. However, both planting method differed significantly ($P \leq 0.01$) from 20 to 100 days after transplanting except 40 and 50 DAT (Table 10.6). The higher number of tillers per m^2 (147) of rice at maturity was observed from foliar spray of N in bed and the lower (135) in case of fertilizer broadcasting in conventional planting.

Table 10.6. Effect of tiller production by foliar spray in raised bed and fertilizer broadcasting in conventional planting.

Method of Fertilizer application	Tiller (number m^{-2}) at days after transplanting								
	20	30	40	50	60	70	80	90	100
Foliar spray in bed planting	82a	216a	251a	214a	173a	162a	153a	149a	147a
Fertilizer broadcasting in conventional planting	76b	209b	240a	200a	162b	149b	141b	139b	135b
LSD at 5%	2.07	3.82	10.35	51.87	3.34	2.07	2.93	2.07	4.72
Level of significance	**	*	n.s.	n.s.	**	**	**	**	*

Where *, ** represent probability of ≤ 0.01, ≤ 0.01 and n.s. represents probability of >0.05. Values were means of three replicates. In a column figures with same letter do not differ significantly whereas figures with dissimilar letter differ significantly ($P \leq 0.01$).

10.3.4. Leaf area index

The observed result for foliar spray in bed showed that the leaf area index increased from 20 DAT to 60 DAT and declined towards maturity mainly due to leaf senescence (Table 10.7). It was observed that the response of LAI on fertilizer broadcasting in conventional planting increased from 20 DAT to 80 DAT and declined towards maturity. The highest leaf area index was achieved at 60 DAT by foliar spray in bed planting method. After 60 DAT the leaf area index started to decline and continued to 100 DAT by foliar spray. The higher LAI achieved in conventional method at 80 DAT. After 80 DAT the LAI started to decline and continued to 100 DAT by conventional method. However, LAI differs significantly ($P \leq 0.01$) between two methods from 60 to 100 DAT.

Table 10.7. Effect of leaf area index by foliar spray in raised bed and fertilizer broadcasting in conventional planting.

Method of Fertilizer application	LAI at different DAT				
	20	40	60	80	100
Foliar spray in bed planting	0.43a	2.61a	5.86a	5.39a	4.01a
Fertilizer broadcasting in conventional planting	0.42a	2.50a	5.03b	5.08b	3.85b
LSD at 5%	0.00	0.47	0.09	0.07	0.04
Level of significance	n.s.	n.s.	**	**	**

Where ** represent probability of ≤ 0.01 and n.s. represents probability of >0.05. Values were means of three replicates. In a column figures with same letter do not differ significantly whereas figures with dissimilar letter differ significantly ($P \leq 0.01$).

10.3.5. Dry matter production

Dry matter production (DMP) had a significant response to nitrogen fertilization. In the first date of measurement (20 DAT), it was observed that the foliar spray of urea produced higher dry matter yield than conventional method (Table 10.8). Likewise, at the final date (100 DAT), higher dry matter production was also recorded in foliar spray in bed compared to conventional method. However, dry matter production differs significantly ($P \leq 0.01$) at different days after transplanting (DAT) in both planting method (Table 10.8). Fertilizer broadcasting in conventional planting had lower dry matter production than foliar spray of nitrogen in bed, which could be due to its lower density of tillers and panicles. Variation in DMP at particular stage due to varying water availability resulted in poor yield components and yield.

Table 10.8. Effect of dry matter production by foliar spray in raised bed and fertilizer broadcasting in conventional planting.

Method of Fertilizer application	Dry matter production (g m^{-2}) at different days after transplanting (DAT)							
	20	30	40	50	60	70	80	90
Foliar spray in bed planting	70a	238.97b	510a	645a	1026a	1129a	1296a	1315a
Fertilizer broadcasting in conventional planting	61b	257a	492b	619b	903b	1049b	1282b	1294b
LSD at 5%	2.07	3.34	4.98	4.72	4.63	1.31	2.62	5.93
Level of significance	**	**	**	**	**	**	**	**

Where ** represent probability of ≤ 0.01. Values were means of three replicates. In a column figures with same letter do not differ significantly whereas figures with dissimilar letter differ significantly ($P \leq 0.01$).

10.3.6. Crop growth rate

At the initial stage (20 to 40 DAT), the crop growth rate (CGR) by foliar spray in bed planting is lower than conventional method (Table 10.9). The higher crop growth rate was observed in 50-60 DAT by foliar spray in bed planting method. Similarly, higher crop growth rate was observed in 50 - 60 DAT by conventional flat planting. However, crop growth rate significantly ($P \leq 0.01$) differed between both planting methods at all DAT except 40 to 50 DAT.

Table 10.9. Effect of crop growth rate by foliar spray in raised bed and fertilizer broadcasting in conventional planting.

Method of Fertilizer application	Crop growth rate (g m^{-2} day^{-1}) at different days after transplanting (DAT)						
	20-30	30-40	40-50	50-60	60-70	70-80	80-90
Foliar spray in bed planting	16.89b	27.10a	13.50a	38.10a	10.30b	16.70b	1.90a
Fertilizer broadcasting in conventional planting	19.60a	23.50 b	12.70a	28.40b	14.60a	23.30a	1.20b
LSD at 5%	1.24	1.51	0.50	2.28	1.64	2.32	0.21
Level of significance	*	*	n.s.	**	*	**	**

Where *, ** represent probability of ≤ 0.01, ≤ 0.01 and n.s. represents probability of > 0.05. Values were means of three replicates. In a column figures with same letter do not differ significantly whereas figures with dissimilar letter differ significantly ($P \leq 0.01$).

10.3.7. Weed population

Bed planting treatments significantly ($P \leq 0.01$) reduced the weed population per m^2 (Table 10.10) over the conventional planting method. Reduction (128% and 116.07% respectively) in weed density (number m^{-2}) and weed dry biomass (kg ha^{-1}) was recorded in foliar spray in bed compared with fertilizer broadcasting in conventional planting. Less weed population on raised beds because, without disturbance and with drier soil, few weeds would germinate or establish.

Table 10.10. Effect of weed growth by foliar spray in raised bed and fertilizer broadcasting in conventional planting.

Method of Fertilizer application	Weed vegetation	
	Weed vegetation population (number m^{-2})	Dry biomass (kg ha^{-1})
Foliar spray in bed planting	170b	159.66b
Fertilizer broadcasting in conventional planting	389a	344.98a
LSD at 5%	3.34	2.49
Level of significance	**	**

Where ** represent probability of ≤ 0.01. Values were means of three replicates. In a column figures with same letter do not differ significantly whereas figures with dissimilar letter differ significantly ($P \leq 0.01$).

10.3.8. Irrigation water use

Amount of water required for different irrigations differed remarkably between the conventional and bed planting methods. The conventional method received the higher amount of water at every irrigation, and total amount was 149.00 cm (Table 10.11). The total amount of irrigation water received by foliar spray in bed planting was 106.37 cm. Result showed that total water saving by foliar spray in bed over conventional method was 40.14 %.

Table 10.11. Irrigation water savings by foliar spray in raised bed and fertilizer broadcasting in conventional planting.

Method of Fertilizer application	Irrigation required (cm)	Rainfall (cm)	Total Irrigation required (cm)	Water saved over conventional method (%)
Foliar spray in bed planting	93.52b	12.8a	106.32b	
Fertilizer broadcasting in conventional planting	136.20a	12.8a	149.00a	40.14%
LSD at 5%	2.24	0.26	2.22	
Level of significance	**	n.s	**	

Where ** represent probability of ≤ 0.01 and n.s. represents probability of >0.05. Values were means of three replicates. In a column figures with same letter do not differ significantly whereas figures with dissimilar letter differ significantly (*P* ≤ 0.01).

10.3.9. Water use efficiency

Water use efficiency for grain and biomass production by foliar spray in bed planting was 50.90 kg ha^{-1} cm^{-1} and 99.13 kg ha^{-1} cm^{-1}, respectively (Table.10.12). In contrast, water use efficiency for grain production and biomass production in conventional planting was 29.53 kg ha^{-1} cm^{-1} and 62.55 kg ha^{-1} cm^{-1}, respectively. The water use efficiency for grain production in raised bed planting was 72.36% higher over conventional planting. Similarly, foliar spray in bed planting produced 58.48% more water use efficiency for biomass production compared to fertilizer broadcasting in conventional planting. The higher water use efficiency in bed planting due to higher grain yield and less water input.

Table 10.12: Water use efficiency by foliar spray in raised bed and fertilizer broadcasting in conventional planting.

Method of Fertilizer application	Efficiency savings by foliar spray in raised bed and fertilizer broadcasting in conventional planting.	
	Water use efficiency for grain production (kg ha^{-1}cm^{-1})	Water use efficiency for biomass production (kg ha^{-1}cm^{-1})
Foliar spray in bed planting	50.90a	99.13a
Fertilizer broadcasting in conventional planting	29.53b	62.55b
LSD at 5%	1.38	2.02
Level of significance	**	**

Where ** represent probability of ≤ 0.01. Values were means of three replicates. In a column figures with same letter do not differ significantly whereas figures with dissimilar letter differ significantly (*P* ≤ 0.01).

10.3.10. Agronomic efficiency of nitrogen fertilizer

Agronomic efficiency (AE) of fertilizer nitrogen by foliar spray in raised bed was 94.40% (Table 10.13). On the other hand AE for conventional planting was 22.56 %. Agronomic efficiency of N fertilizer by foliar spray in raised bed was significantly ($P \leq 0.01$) higher than the conventional Planting method.

Table 10.13: Agronomic efficiency of fertilizer by foliar spray in raised bed and fertilizer broadcasting in conventional planting.

Method of Fertilizer application	Agronomic efficiency of fertilizer (%)
Foliar spray in bed planting	94.40a
Fertilizer broadcasting in conventional planting	22.56b
LSD at 5%	3.01
Level of significance	**

Where ** represent probability of ≤ 0.01. Values were means of three replicates. In a column figures with same letter do not differ significantly whereas figures with dissimilar letter differ significantly ($P \leq 0.01$).

10.4. DISCUSSIONS

10.4.1. Comparison of growth response of transplanted boro rice between foliar spray in raised bed and conventional cultivation method

The plant height at maturity was higher in conventional planting compared to foliar spray in raised bed planting (Table 10.5). Similar result was reported by Hasanuzzaman *et al. (*2009). They demonstrated that the lowest plant height with foliar spray of urea might be due to the reduced uptake of N through foliage. Alam *et al.* (2010) also reported same result. They showed that soil and foliar application of urea fertilizer produced plant height of 78.4 cm and 76.5 cm, respectively. They speculated that foliar spray of urea produced lower plant height due to poor performance of N compared to soil application of N fertilizer. Shafiee *et al.* (2013) differed with these results. They showed that foliar spray produced higher plant height. They stated that foliar fertilization may be increased the level of macro- and micro-nutrients in the leaf, thus it enhanced the net photosynthetic rate of treated rice plant which contributed to higher plant height. The higher tiller production was observed by foliar spray in raised bed compared to conventional planting. My results were supported by the findings of Shaygany *et al*. (2011). They reported that foliar application of different nutrient increased tiller number of rice plant. The panicle length, leaf area index and dry matter production was recorded 25.72 cm, 4.01 and 1315 g m^{-2} by foliar spray in bed planting and 24.10 cm, 3.85 and 1294 g m^{-2} for conventional planting . So, foliar spray in bed planting produced higher panicle length, leaf area index and dry matter than conventional planting. This findings supported by Zayed *et al.* (2011). They showed that panicle length, leaf area index and dry matter was 21.30 cm, 5.60 and 32.80 g $hill^{-1}$ in foliar spray and 19.35 cm, 4.72 and 26.57 g $hill^{-1}$ in control for rice production. They suggested that foliar spray of micronutrient improved rice growth parameters, as they encouraged rice plants to produce more dry matter as a result of increasing chlorophyll content and optimizing rice canopy with appropriate leaf area index. In this study the biological yield was 10.51 t ha^{-1} by foliar spray in bed planting and 9.3 t ha^{-1} in conventional planting. So, foliar spray in bed planting produced 1.21 t ha^{-1} more biological yield than conventional planting. This result supported by Shaygany *et al.* (2012). They found that foliar spray produced higher biological yield. This findings also supported by Annadurai and Palaniappan (1994). They observed that 2% Di Ammonium Phosphate spray given more biological yield. My speculation is that foliar fertilization provides more rapid utilization of nutrients and permits the correction of observed deficiencies in less time than would be required by soil application. Foliar spray also reduced N losses through denitrification and leaching compared with N fertilizer applications to the soil, the ability to provide N when root activity is impaired .This study also speculated that in foliar application, the nutrients penetrate the cuticle of the leaf or the stomata and then enter the cells. Hence, crop response occurs in short time in foliar application compared to soil application which may contributed to better crop growth response by foliar application of fertilizer.

10.4.2. Yield and yield components

Foliar spray of urea in raised bed significantly ($P < 0.01$) increased grain yield compared to conventional planting (Table.10.4). Yield contributing parameter such as panicle m^{-2} ,grain panicle^{-1} and 1000-grain weight was also observed higher by foliar spray in raised bed planting over conventional planting (Table.10.4). Likewise, Shaygany *et al.* (2012) showed that a significant increased in number of panicle m^{-2}, 1000 grain weight, biological yield and grain yield with foliar application of nutrient. They concluded that five foliar applications of balanced amounts of fertilizers at the seedling stage (two sprays), tillering (single spray) and at panicle initiation and panicle differentiation (two sprays) helped in enhancing yield and yield components of rice. Similar results had also been obtained by Badole and Narkhede (1999) reported that the yield of rice increased significantly with the application of 50, 50 and 50 kg ha^{-1}(N:P:K) as a basal rate and foliar spray of urea at the three growth stages. This treatment also recorded the highest values of the yield attributing characters. They suggested that 2% urea 3 times at the tillering, panicle initiation and grain filling stages gave highest yield and yield components on transplanted rice. Similar findings regarding significant effect of foliar urea application have also been obtained by Duraisami and Mani *(*2002). They demonstrated that urea foliar spray gave the highest chaff per panicle (12.4) , harvest index (43.64%) and number of grains per panicle .They suggested that 100% P and K rates and 2.5% urea foliar spray at active tillering, panicle initiation, mid-heading, first flowering and 50% flowering stages provided better yield attributing parameters. Subramanian *et al*. (1980) reported that split foliar spray of N fertilizer significantly increased grain yield of transplanted rice. They speculated that 50% N in the soil at transplanting, 25% N as foliar spray at tillering and 25% N as foliar spray at panicle initiation gave higher yield over 90 kg N ha^{-1} in a single dose at transplanting .

My speculation is that foliar spraying of urea after transplanting enhance rice plant to be more availability of N, increased photosynthesis rate and yield components of rice leading to high grain yield. Foliar application of macronutrients might raise dry matter transformation from store parts to sink part. It was observed that foliar application was effective in improving rice growth and subsequently main yield components such as filled grains per panicle, panicle weight and 1000-grain weight. This study also speculated that at early growth stage when plant roots are not well developed, foliar fertilization is more advantageous in absorption compared to soil application. Soil application method is more common and most effective for nutrients, which required in higher amounts. However, under certain circumstances, foliar fertilization is more economic and effective. Foliar nutrients are mobilized directly into plant leaves, which are the goal of fertilization to begin with, increasing the rate of photosynthesis in the leaves, and by doing so stimulate nutrient absorption by plant roots. Foliar feeding is an effective method for correcting soil deficiencies and overcoming the soil's inability to transfer nutrients to the plant under low moisture conditions. Foliar spray of nutrients should be avoided at high temperature during the day to avoid leaf burning. Similarly, windy days may drift the applied nutrient solution and rain immediately after application may washout the sprayed material and reduces its efficiency.

In contrast Alam *et al.* (2010) found that soil application of urea (282 kg urea ha^{-1}) and 2% foliar spray of urea produced grain yield 5.34 t ha^{-1} and 5.04 t ha^{-1}, respectively. They also recorded that effective tiller hill^{-1} (number), grains panicle^{-1} (number) and 1000-grain weight (gm) was 12.1, 134.4, 22.20 in soil application of urea and 10.0, 137.10 and 22.00 for foliar spray of urea, respectively. They suggested that 2% urea solution (92 kg N ha^{-1}) gave a statistically comparable yield with soil application of 130 kg N ha^{-1}. When foliar spray is applied 38 kg N (82 kg urea) could be saved and it could be alternative of soil application. Hasanuzzaman *et al.* (2009) also differed with my findings. They demonstrated that conventional urea application with 3 equal splits produced grain yield of transplanted boro rice 7.0 t ha^{-1} and 5.1 t ha^{-1} by foliar spray of urea. They also showed that panicle hill^{-1} (number), grains panicle^{-1} (number) and 1000-grain weight (gm) was 8.1, 94.5 and 22.30 for conventional urea (200 kg ha^{-1}) at 3 equal splits and 6.9, 81.2 and 20.9 in 1% foliar spray of urea.

10.4.3. Variation between conventional and foliar method in relation to water use efficiency

Total irrigation required by conventional planting was significantly ($P < 0.05$) higher over foliar spray in bed planting (Table 10.11). Bed planting consumed 40.14% less water than conventional planting. Similarly, water use efficiency for grain production by foliar spray in bed planting was significantly ($P < 0.05$) higher over conventional planting (Table 10.12). Water use efficiency for biomass production by foliar spray in bed planting was also significantly higher ($P < 0.05$) over conventional planting. In this study water use efficiency was 29.53 kg ha^{-1}cm^{-1} for conventional transplanted rice. Jha *et al.* (1988) reported that water use efficiency was 2.53 kg ha^{-1}mm^{-1} for continuous flooding (7 cm water) rice cultivation. They suggested that scheduling 7 cm irrigation water 6 days after disappearance of water gave a net savings of 38-47 % irrigation water and 60 to 80 % increase in water use efficiency. Pathak (2010) showed that water productivity was 0.40 kg grain m^{-3} for conventional puddle rice. He stated that transplanted rice with continuous standing water has relatively high water inputs which contributed low water productivity. Singh *et al.* (2006) found that water productivity for conventional puddle rice was 29 kg ha^{-1}cm^{-1}. They stated that if irrigation is applied one day after drainage or two days after drainage, precious water can be saved without any adverse impact in water productivity. In my experiment water use efficiency was

50.90 kg ha^{-1} cm^{-1} in raised bed and 29.53 kg ha^{-1} cm^{-1} in conventional planting. So, raised bed increased water use efficiency by 72.36 % over conventional planting (Table 10.12). This result supported by Tabbal *et al.* (2002). They showed that water productivity for transplanted rice in flooded condition was 1.06 g grain kg^{-1} water and 1.81 g grain kg^{-1} water for saturated soil condition (raised bed). Saturated soil condition increased water productivity by 70.75 % compared to conventional planting. Kahlown *et al.* (2004) showed that water use efficiency in raised bed and traditional transplanting on puddle soil was 0.33 kg m^{-3} and 0.20 kg m^{-3}, respectively. Raised bed contributed 65% higher water use efficiency compared to conventional planting .They stated that if the furrows in bed planting refill with water, on the day after free water left the furrows .This change in irrigation practice almost doubled the water productivity. Bably *et al.* (2008) demonstrated that field water use efficiency in bed and traditional planting were 11.69 and 7.22 kg grain mm^{-1}, respectively. Bed planting method increased field water use efficiency by 65.8 % more than traditional planting. They suggested that higher field water use efficiency in bed planting due to higher productivity of rice. But Kukul *et al.* (2010) differed with my findings .They demonstrated that puddle transplanted rice on sandy loam soil increased 11% irrigation water productivity than transplanted raised bed planting. Irrigation water productivity of transplanted rice on permanent beds decreased mainly due to declining grain yield as the beds aged. Cabangon and Tuong (2005) found that water productivity in bed (centre to centre spacing of 65 cm) was 0.65 kg m^{-3} and 0.45 kg m^{-3} for conventional flat planting. So, raised bed provided 44.45% more water productivity than conventional flat planting. They speculated that low water stress contributed higher water productivity in raised bed planting. My speculation is that the soil water of raised bed planting changes gradually, that is the ratio of gain and loss is balanced. The soil water of flat planting, however, changes more markedly and does not increase as much with increase in soil depth. Raised bed planting has the benefit of better distributing the limited water in the soil and thus creating a more stable soil water environment for the growing root system. This study can conclude that an increase in water consumption led to a decrease in soil moisture in the flat planting, and that the range in soil water content of traditional flat planting is greater than that of raised bed planting which contributed to water use efficiency.

10.4.4. Foliar split urea fertilizer application on raised bed is agronomical more efficient than conventional flat method

In this study the agronomic efficiency of N fertilizer by foliar spray in bed and conventional planting was 94.40 % and 22.56 %, respectively (Table 10.13). The agronomic efficiency of N fertilizer of foliar spray in bed planting significantly ($P < 0.05$) increased over conventional planting. Agronomic efficiency for N fertilizer (120 kg ha^{-1}N) in conventional flat planting was 22.56 %. Similarly, Qin *et al.* (2012) found that agronomic N use efficiency (AE_N) in farm practice fertilizer (FFP) was 12.5. They demonstrated that earlier application of high N rate of farm practice fertilizer (FFP) led to low agronomic N use efficiency. Artacho *et al.* (2009) reported that agronomic N use efficiency for 150 kg ha^{-1} N was 24 kg kg^{-1} and 19 kg kg^{-1} in site 1 and site 2, respectively for flooded rice. They suggested that variation in agronomic N use efficiency between cropping sites, would reflect site specific difference in temperature and solar radiation. Raun *et al. (*1999) supported our results. They stated that world nitrogen use efficiency (NUE) for cereal production is approximately 33%. They suggested that increased cereal NUE is unlikely, unless a systems approach is implemented that uses varieties with high harvest index, incorporated NH_4–N fertilizer, application of prescribed rates consistent with in-field variability using sensor-based systems within production fields, low N rates applied at flowering and forage production system. They showed that total N applied 120 kg ha^{-1} in conventional planting rice gave agronomic efficiency of N was 21.0 kg grain kg^{-1} N^{-1}. FAO (2003) reported that agronomic N use efficiency for rice in Bangladesh is low (35 % and lower). These findings also similar to my results. FAO suggested that the enhancement of N use to medium levels, coupled with efficiency improvement measures, is important for the Bangladesh .In my study the agronomic efficiency of N was recorded 94.40% for foliar spray in bed and 22.56% for conventional planting. Alam *et al.* (2010) supported my findings. They demonstrated that agronomic efficiency of N was 80% in foliar application and 16.49% for soil application of urea fertilizer. They pointed out that the higher agronomic efficiency of N fertilizer in foliar application might be a lower level of nitrogen for a successful plant growth. My speculation is that the higher agronomic efficiency of N fertilizer by foliar spray in bed planting may be the immediate uptake of the nutrient applied which facilitated minimum loss due to leaching, deep percolation, denitrification and amonia volatilization. Agronomic efficiency of N fertilizer may be improved by minimizing the fertilizer losses from the soil that are caused by poor water management, for example leaching or denitrification. The agronomic efficiency of N fertilizer can also be improved by ensuring that lack of water does not at any stage retard crop growth or nutrient uptake appreciably. Excess water can be a cause of nutrient losses, and insufficient water at a critical stage can limit growth and yield.

10.5. CONCLUSIONS

This research demonstrated that foliar spray of N in bed planting increased yield by 19.54 % compared to fertilizer broadcasting in conventional planting for transplanted boro (winter, irrigated) rice. Foliar spray in raised bed produced higher panicle number, grains per panicle and thousand grain weights over conventional planting method. Better plant growth parameter of boro rice by foliar spray in bed planting was observed compared to conventional planting. Foliar spray of N in raised bed planting saved irrigation water by 40.14% as well as increased irrigation efficiency. Foliar spray in bed planting provided less weed density and dry biomass than conventional planting. These findings concludes that water use efficiency for grain and biomass production was higher in foliar spray of bed planting than fertilizer broadcasting in conventional method. The agronomic efficiency of N fertilizer was also significantly higher in foliar spray of bed planting than the fertilizer broadcasting in conventional method.

The potential gains from growing transplanted boro rice on raised beds are considered to be associated with better agronomic management than conventional method. It is likely that the raised bed technique will have long term soil physical benefits without sacrificing yield. The incorporation of foliar spray in raised bed introduced a new boro rice based farming system offers many advantages. Based on the findings of this experiment, high yielding boro rice (winter, irrigated) crops have been successfully grown by foliar spray on raised bed. There is a good prospect of utilization of this technology to benefit the rice farmers. More studies is needed to establish foliar spray in bed planting, a better planting method of transplanted boro rice cultivation in Bangladesh as well as other countries in the world.

Chapter 11

General Discussion

Chapter 11

General Discussion

The focus of this thesis has been to quantify water and fertilizer use efficiencies under various fertilizer application techniques in raised bed over conventional cultivation method. The growth and yield performance of aman rice swarna (summer, non-irrigated) and boro rice BR 28 (winter, irrigated) was compared between different fertilizer application method in raised bed and conventional planting in various experimental chapters (Chapter 3 to Chapter 10). Aman and boro season was selected for water and fertilizer use efficiencies as both seasons differ irrespective to water application as well as considered summer and winter. The key findings are: raised bed in broadcasting, urea super granule (USG), fertigation and foliar techniques was better for both aman and boro rice than conventional cultivation method. A number of additional issues relating to these experiments will be discussed in this chapter.

11.1. Rationale of varieties selection

Swarna (MTU 7029), which was released in 1979 in India, is still grown over 5 million ha and is currently the most popular rice variety of India. Approximately, 1 million ha area in Bangladesh and Nepal is covered by this variety, although it was never officially released in these countries (Singh *et al.* 2013). Breeding line IR 49830-7-1-2-3, which derives its tolerance from FR 13A, has good agronomic characters and its resistance to bacterial leaf blight and green leafhopper (Mackill *et al.*1993). This line has been used extensively in breeding programs for the improvement of submergence tolerance variety swarna. To further enhance the adaption of rain fed lowland rice varieties, the submergence tolerance gene SUB1 has been successfully introduced into several popular high yielding varieties including swarna using marker assisted block crossing at IRRI (Mackill *et al.* 2012, Collard *et al.* 2013). The tiller number, plant height and panicle length of swarna rice were 25-30, 75-85 and 19.5 cm, respectively. It is a transplant aman rice cultivar with average yield 4.5-6.0 t ha^{-1}. Life cycle of this variety ranges from 120 to 125 days, which however may vary due to change in climatic condition (Laxuman, 2010). The national seed board (NSB) approved Swarna-Sub1 (IR81213-246-237) as BRRI dhan51 for flash flood prone areas in transplanted aman. This submergence tolerant rice variety can produce 4.0 tha^{-1} grain yields despite 10-16 days of flash flooding (BRRI Research Achievement 2009). The second most popular variety "SWARNA" (11.6 % of the area) which has Indian origin and moved to Bangladesh through informal exchange of varieties across the border, also had lower yield (3.84 t ha^{-1}) compared to the newly developed aman season varieties by BRRI. Swarna was found a dominant aman variety in districts bordering West Bengal, India. In chuadanga district of Bangladesh, swarna is the most popular rice variety that covered 50.59% of land during aman season (Hossain *et al.*2005).

The BR 28 rice (Popularly known as BR 28) which was released in the 1994 alone covered 32% of rice area in boro season of 2009 (BRRI Research Achievement, 2009). The variety was developed after selection of breed line BR601-3-3-4-2-5, which was obtained from crossing line IR 28 with purbachi. Then the line BR 601-3-3-4-2-5 was released for boro season as BRRI dhan 28 (Hossain, 2004). It is a transplant boro rice cultivar with average yield of 5.5-6.0 t ha^{-1}(Fact sheet BRRI dhan 28, BRRI). Life cycle of this variety is 140 days. The popularity of BR 28 is due to its shorter life cycle (Hossain *et al.*2005). It matures two to three weeks earlier than BR 29 if planted on the same date with seedlings of same age. The BR 28 is grown in medium and higher lands. The shorter life cycle of this variety allows farmers to go for double or even triple cropping in many areas of Bangladesh. The average yield of improved varieties is 1.0 to 1.5 tha^{-1} higher in the boro season compared to the aman season due to the favorable growing environment such as high sun shine (increased photosynthesis efficiency) and low pest pressure. The Chuadanga district of Bangladesh is also suitable for BR 28 rice cultivation for boro season (BRRI, 2007 and AIS, 2008).

In my research, the grain yield of aman rice ranges 4.37-5.09 t ha^{-1}and boro rice ranges from 4.40-5.26 t ha^{-1}.So, grain yield between aman and boro rice are seem to be similar. The BR 28 rice was least sensitive to environmental conditions and might be specially advocated for unfavorable environments where it would give average yield performance (Biswas *et al.* 2011). Considering growth duration and grain yield, BR 28 rice was identified as most suitable variety for boro season (winter, irrigated). In Bangladesh, out of the 2.65 million ha flash-flood prone areas, about 1.6 million ha rice are frequently inundated. Even during normal years, approximately 20% of the geographical area of Bangladesh is affected by flooding (Singh *et al.* 2013). Therefore, during flash flooding, Swarna cultivars must be able to tolerate submergence, and these cultivars should exhibit limited elongation in response to complete inundation. For these reason Swarna was selected as most suitable variety for aman season (summer, non-irrigated). Further, climate change did not affect on growth and yield of both Swarna and BR28 varietis due to its sustainability. This is also reason to select of these two varieties for two seasons. In addition life cycle of these two varieties is very much similar. That's why both swarna and BR 28 was selected as a testing plant.

11.2. Suitability of fertilizer application methods in raised bed planting for aman season

11.2.1. Plant Growth Parameter

The growth, yield, water use efficiency and agronomic performance of transplanted aman rice was compared with different fertilizer application method in between raised bed and conventional planting method, previously (Chapter 3 to Chapter 6). Different fertilizer application method in raised bed planting such as fertilizer broadcasting, fertigation, deep placement of Urea Super Granule (USG), foliar spray and fertilizer broadcast in conventional planting was compared in aman season. Among these method, foliar spray of N in raised bed planting showed superiority with respect to growth, yield and agronomic efficiency.

Foliar spray of N in raised bed planting provided best growth parameters compared to fertilizer broadcasting, fertigation, deep placement of USG in raised bed and fertilizer broadcast in conventional planting for aman season. Increase in growth parameters by foliar nitrogen fertilizer spray in raised bed planting resulted on account of cumulative effect of need based, gradual and continuous supply of N at the time of its critical requirement by the rice crop, efficient utilization of supplied N and lesser N loss. Foliar fertilization in raised bed planting provides more rapid utilization of nitrogen fertilizer than soil application method such as fertilizer broadcast, fertigation and urea super granule in bed planting and fertilizer broadcast in conventional planting. When nitrogen are applied to soils by fertilizer broadcasting, fertigation, and deep placement of USG absorbed by plant roots and translocated to the shoots. In case of foliar application, the nitrogen penetrates the cuticle of the leaf or the stomata and then enters the cells. Hence, crop response occurs in short time in foliar application compared to different soil application methods which may contribute better growth performance of transplanted aman rice plant.

Foliar spray may also provide better growth parameters due to low air temperature. Foliar spray was done in the afternoon when air temperature was low. This low temperature facilitated to the efficient absorption of foliar nitrogen fertilization compared to other soil application of fertilizer. Windy day was avoided for foliar spray that may be a cause of best performance of foliar spray compared other fertilizer application method. If foliar fertilization is done in a windy day which can drift the spray solution. Rainy day was also avoided for the best application efficiency of nutrient by foliar spray. No rain was occurred 3-4 hours later foliar spray. As a result sprayed nutrients were not washout after foliar spray. This may contributed to best growth performance by foliar spray compared to fertilizer broadcast, fertigation and deep placement of USG in raised bed and conventional planting for aman season.

Foliar spray in raised bed planting increased plant height and reduced number of non-bearing tiller m^{-2} compared to fertilizer broadcasting, fertigation, urea super granule in raised bed and fertilizer broadcast in conventional planting method. The tallest plants were produced by the foliar spray compared to other fertilizer application method in aman season. The increases in plant height by foliar spray in bed planting probably due to the more availability of nitrogen than fertilizer broadcasting, fertigation and USG in raised bed and fertilizer broadcast in conventional planting for aman season. Foliar spray of N fertilizer in raised bed significantly reduced non-bearing tiller m^{-2} compared to other treatments for aman season. Probably adequacy of nitrogen and uniform supply through foliar spray favored the cellular activities during panicle formation and development which leaded to increase number of effective tiller m^{-2}.This may caused lowest number of non-bearing tiller m^{-2} from foliar spray of N in raised bed planting compared to fertilizer broadcast, fertigation, deep placement of USG in bed and fertilizer broadcast in conventional planting for aman season.

Table 11.1 Growth parameters, yield components and agronomic efficiency of different fertilizer application methods in raised bed and conventional planting of swarna rice in aman season

Method of fertilizer application	Plant height (cm)	Non-bearing tiller (no-m^{-2})	Grains $panicle^{-1}$ (number)	1000 grain wt (gm)	Agronomic efficiency of N fertilizer
Fertilizer broadcasting in conventional planting	86.38b	59c	140b	22.88	27e
Fertilizer broadcasting in raised bed planting	87.23b	67b	161a	23.01	32.15d
USG in raised bed planting	90.24a	55d	160a	23.09	55.04c
Fertigation in raised bed planting	89.03ab	73a	164a	23.02	67.52b
Foliar spray of fertilizer in raised bed planting	91.34a	46e	165a	23.10	93.82a
LSD at 5%	2.34	4.18	10.90	1.23	4.01
Level of significance.	*	**	**	n.s.	**

Where n.s.,* and ** represents probability of > 0.05, ≤ 0.001 and ≤ 0.01, respectively. Values were means of three replicates.

11.2. 2. Yield Components

Further, the yield and yield component of transplanted aman rice were also compared previously with different fertilizer application methods in between raised bed and conventional planting technique (Chapter 3 to Chapter 6). Different fertilizer application method in raised bed planting such as fertilizer broadcasting, fertigation, deep placement of Urea Super Granule (USG), foliar spray and fertilizer broadcast in conventional planting was compared in aman season. Among these method, foliar spray of split N fertilizer application in raised bed planting also showed highest performance with respect to yield components among all methods.

Foliar spray of split N fertilizer in raised bed planting provided best yield components such as grains $panicle^{-1}$ and 1000-grains weight compared to fertilizer broadcasting, fertigation, deep placement of USG in raised bed and fertilizer broadcast in conventional planting for aman season (Table 11.1). Increase in the number of grains $panicle^{-1}$ by split foliar nitrogen spray in raised bed planting might be due to availability of nitrogen during flowering and fruiting including seed formation and higher partitioning of dry matter to the grains. This could be attributed to the fact that nitrogen helped to produce better vegetative growth as a result which photosynthetic area increased thereby more food material synthesized contributed to the improvement in number of grains panicle^{-1}. The increase in number of grains panicle^{-1} due to foliar fertilization in bed planting might be due to its effect in enhancing the physiological functions of the rice crop, like photosynthesis and translocation of plant nutrients which ultimately increased the number of grains panicle^{-1} compared to fertilizer broadcasting, fertigation, deep placement of USG in raised bed and fertilizer broadcast in conventional planting for aman season.

Foliar spray in raised bed planting increased the 1000-grains weight compared to fertilizer broadcasting, fertigation, urea super granule in raised bed and fertilizer broadcast in conventional planting method for aman season. The highest 1000-grains weight by foliar spray in raised bed planting may be the application of N increased the protein percentage which in turn increased the grains weight. The possible reason might be due to more accumulation of dry matter in grains which increase 1000-grains weight by the application of split foliar spray of N in raised bed planting. In foliar spray photosynthesis assimilates is translocated from vegetative organs to the other parts and this considerably enhanced 1000-grains weight compared to fertilizer broadcasting, fertigation, urea super granule in raised bed and fertilizer broadcast in conventional planting method for aman season. Foliar fertilization of N resulted in an increase in the amount of metabolites synthesized by rice plant and this, in turn, might account much for the superiority of 1000-grains weight. Comparative increase in 1000-grains weight with the application of N by foliar spray in raised bed planting might be due to more efficient participation of N in various metabolic processes involved in the production of healthy seeds. Regardless of that maximum number of grains per panicle and the highest 1000-grains weight by split foliar application of N might be due to involvement of N in reproductive growth. Nitrogen was responsible for better pollination, seed setting and more grain formation for the transplanted aman rice growing in aman season.

11.2. 3. Agronomic Efficiency of N Fertilizer

Agronomic efficiency of N fertilizer for transplanted aman rice were calculated under different methods like fertilizer broadcasting, fertigation , Urea Super Granule (USG) and foliar spray in raised bed and fertilizer broadcast in conventional planting (Chapter 3 to Chapter 6). Foliar spray of N in raised bed planting provided highest value of agronomic efficiency of fertilizer N for aman season rice (Table 11.1).

Agronomic efficiency of N fertilizer was defined as the ratio of grain yield with N application minusgrain yield without N application to N application and was used to describe the capability of yield increase per kilogram pure N. Results showed that with increasing of N application, agronomic efficiency of N decreased (Table 11.1). It indicated that the capability of yield increase per kilogram pure N declined remarkably with increasing N application. Further, foliar spray require very low quantities of N fertilizer compared to fertilizer broadcasting, fertigation and USG in raised bed and fertilizer broadcast in conventional planting. This may cause the highest agronomic efficiency of N by foliar spray of N in raised bed planting. Highest agronomic efficiency of 93.82 kg grain per kg N was found in the treatments sprayed with 2% urea solution (Table 11.1). Highest agronomic efficiency might be the outcome of higher N uptake due to enhanced efficiency of foliar sprayed urea in raised bed compared to fertilizer broadcasting, fertigation and USG in raised bed and fertilizer broadcast in conventional planting.

Foliar spray of N in raised bed planting minimizes N losses by preventing N from being dissolved in floodwater or oxidized in soil near the surface. Foliar split spray of N fertilizer in raised bed planting reduced the loss of N due to volatilization which may contribute highest agronomic efficiency of N compared to other methods of fertilizer application in bed and conventional planting. Foliar spray of 2% urea solution is relatively efficient. It results in relatively rapid crop response. Agronomic efficiency of N is also affected by fertilizer placement methods. Foliar spray incorporates urea fertilizer direct to the rice plant leaf. It avoids undue losses of urea which enhance growth and yield parameters. It may be another probable cause of highest agronomic efficiency achieved by foliar spray of N in raised bed planting compared to fertilizer broadcasting, fertigation and USG in raised bed and fertilizer broadcast in conventional planting.

11.3. Suitability of fertilizer application methods in raised bed planting for boro season

11.3.1. Plant growth parameter

The growth parameters of transplanted boro rice under fertilizer broadcasting, fertigation, Urea Super Granule (USG) and foliar spray in raised bed and fertilizer broadcast in conventional planting were discussed in previous chapters (Chapter 7 to Chapter 10). Foliar spray in raised bed planting provided best growth parameters with respect to panicle length and non-bearing tiller m^{-2} compared to fertilizer broadcasting, fertigation and Urea Super Granule (USG) in raised bed and fertilizer broadcast in conventional planting (Table 11.2).

Panicle length is an important growth parameter as longer the panicle more will be number of grains which ultimately lead toward better yield. Comparison of different methods of fertilizer application in bed and conventional planting, foliar spray in raised bed planting showed highest panicle length. Urea applied as foliar spray which ensures sufficient N at panicle formation stage that confers best results. The longest panicles were produced by foliar spray in raised bed planting because of 2 tiller seedlings hill^{-1} were transplanted. Karmakar *et al.* (2002) reported that length of panicle was reduced gradually with increasing number tiller seedling hill^{-1}. Inter-tiller seedling competition for various growth factors in a hill resulted in the reduced panicle length. Optimum dose of nitrogen fertilization plays a vital role in growth and development of rice plant. Nitrogen nutrient took part in panicle formation as well as elongation and for this panicle length increased with foliar spray of N fertilizer.

Foliar spray in raised bed planting produced significantly lower number of non-bearing tiller compared to fertilizer broadcasting, fertigation, Urea Super Granule (USG) in raised bed and fertilizer broadcast in conventional planting (Table 11.2). This result might be due to the increase in tiller fertility with efficient application of N by foliar spray. Foliar spray provides sufficient nutrient for vegetative growth and also for reproductive phase which ultimately leads to increased productive tillering and reduced non-bearing tiller. Lowest number of non-bearing tiller in case of foliar spray in raised bed planting compared to fertilizer broadcasting, fertigation and Urea Super Granule (USG) in raised bed and fertilizer broadcast in conventional planting was attributed to competition free environment and extensive root development. Foliar spray in raised bed planting ensure adequate supply of N that might had increased the uptake and availability of other essential nutrients, which resulted in improvement of plant metabolic process and finally increased the crop growth. Moreover, lowest number of non bearing tillers m^{-2} in foliar spray may be explained in terms of availability of moisture and nutrients to the rice plants at the panicle initiation stage.

In addition, it was observed that foliar application was effective in improving rice growth. Foliar application of N might raise dry matter transformation from store parts to sink part. Foliar application might be better than fertilizer broadcasting, fertigation, and Urea Super Granule (USG) in raised bed and fertilizer broadcast in conventional planting which response to the applied nutrient is almost immediate, so deficiencies can be corrected during the growing season.

Table 11.2 Growth parameters, yield components and agronomic efficiency of different fertilizer application methods in raised bed and conventional planting of BR 28 rice in Boro Season

Method of fertilizer application	Panicle length (cm)	Non-bearing tiller(no-m^{-2})	Grains panicle^{-1} (number)	Grain yield (t ha^{-1})	Agronomic efficiency of N fertilizer
Fertilizer broadcasting in conventional planting	24.10	102a	106c	4.40b	22.56d
Fertilizer broadcasting in raised bed planting	24.58	75b	116b	5.10a	28.33c
USG in raised bed planting	25.08	62c	124ab	5.20a	42.69b
Fertigation in raised bed planting	25.65	57d	124ab	5.15a	27.08c
Foliar spray of fertilizer in raised bed planting	25.72	45e	128a	5.26a	94.40a
LSD at 5%	1.86	2.45	4.27	0.35	2.10
Level of significance.	n.s.	**	**	**	**

Where, n.s., and ** represents probability of > 0.05, and ≤ 0.01, respectively. Values were means of three replicates.

11.3.2. Yield and yield components

The yield and yield components of transplanted boro rice were compared previously with different fertilizer application methods in between raised bed and conventional planting technique (Chapter 7 to Chapter 10). Different fertilizer application method in raised bed planting such as fertilizer broadcasting, fertigation, deep placement of Urea Super Granule (USG), foliar spray and fertilizer broadcast in conventional planting were compared in boro season. Foliar spray of split N fertilizer application in raised bed planting provided highest performance with respect to grains panicle^{-1} and yield among all fertilizer techniques.

Foliar spray of split N fertilizer in raised bed planting provided highest grains panicle^{-1} compared to fertilizer broadcasting, fertigation, deep placement of USG in raised bed and fertilizer broadcast in conventional planting for boro season (Table 11.2). It is well known that yield is directly related with number of grains per panicle. Number of grains panicle^{-1} depends upon the activity of rice plant during the reproductive phase. Foliar spray of N fertilizer facilitated more nitrogen during reproductive stage. This may increased the photosynthetic activity during the reproductive phase which increased the number of grains panicle^{-1} due to foliar spray in raised bed planting compared to fertilizer broadcasting, fertigation, deep placement of USG in raised bed and fertilizer broadcast in conventional planting for this transplanted boro rice. Highest number of grains per panicle in foliar spray of N in bed planting might be the higher availability of nutrients and moisture at grain formation stage on this transplanted boro rice. The availability of nutrients and moisture continued translocation of carbohydrates for a longer period of time which may produce highest number of grains panicle^{-1} by foliar spray in raised bed planting.

Foliar spray of N in raised bed planting produced highest grain yield compared to fertilizer broadcasting, fertigation, deep placement of USG in raised bed and fertilizer broadcast in conventional planting in transplanted boro rice (Table 11.2). Grain yield is the product of various parameters such as number of productive tillers, number of grains per panicle and 1000-grains weight. Foliar spray of nitrogen in three splits may helped in continuous and gradual highest supply of nitrogen into the plants to maintain greenness of leaves for longer period which in turn helped in greater dry matter accumulation that might have contributed highest grain yield compared to fertilizer broadcasting, fertigation, deep placement of USG in raised bed and fertilizer broadcast in conventional planting for transplanted boro rice. Moreover, foliar spray of N may ensure adequate N uptake in each growth phase of rice plants. As a result the plants produce a large amount of carbohydrates during reproductive and ripening stages which gave highest yield. In addition, the differences in the grain yield among the different fertilizer application methods were mainly due to their variations in the availability of N and other nutrients. Adequacy of nitrogen probably favored the cellular activities during panicle initiation and development that led to increased grain yield by foliar spray of N in raised bed planting compared to fertilizer broadcasting, fertigation, deep placement of USG in raised bed and fertilizer broadcast in conventional planting for transplanted boro rice.

Furthermore, solar energy is the most important climatic factor in rice cultivation in temperate climates. The plant's most critical period of solar energy requirement is from panicle initiation to until about 10 days before maturity which is important for the accumulation of dry matter. The yield of rice during boro season is higher may be due to the higher levels of solar radiation received during the crop's grain filling and ripening stages.

11.3. 2. Agronomic efficiency of N fertilizer application

Agronomic efficiency of N fertilizer application for transplanted boro rice were evaluated under different methods like fertilizer broadcasting, fertigation , Urea Super Granule (USG) and foliar spray in raised bed and fertilizer broadcast in conventional planting (Chapter 7 to Chapter 10). Split foliar application of N in raised bed planting gave highest value of agronomic efficiency of fertilizer N for boro season rice among other application method (Table 11.2).

The increased grain yields and reduced N-fertilizer rates resulted significant gain in agronomic efficiency of split fertilizer N application by foliar spray in raised bed planting among other fertilizer application methods. Several factors contributed to the increased agronomic efficiency of N with foliar spray. Farmers' practices typically relied on a large N-fertilizer application early in the season, when the capacity for crop uptake was small and additional N was top dressed .In this situation N fertilizer was lost due to leaching and runoff. As a result higher amount of N fertilizer required under different methods like fertilizer broadcasting, fertigation, USG in raised bed and fertilizer broadcast in conventional planting compared to split foliar spray of N in raised bed planting .This may contributed highest agronomic efficiency of N by foliar spray in raised bed planting than other methods. The highest agronomic efficiency in foliar N spray was probably due to the reduced the losses of N through volatilization, leaching, denitrification and gaseous emission compared to fertilizer broadcasting, fertigation, USG in raised bed and fertilizer broadcast in conventional planting. It was found that the benefits of split foliar N sprays compared to soil applications include lower application rates and the ease of obtaining timely, uniform applications. The agronomic efficiency of foliar applied N was nearly 95 percent (Table 11.2). Based on the findings of this research, it can be concluded that foliar-applied N has an agronomic efficiency of three times compared to fertilizer broadcasting, fertigation, USG in raised bed and fertilizer broadcast in conventional planting. Similar result observed by Dixon (2003). He found that that foliar-applied N has an efficiency of 1.3 to 1.6 times soil-applied N at the low end and 7 at the upper end.

Moreover, N fertilizer could be saved without losing yield by split foliar spray. These savings were contributed to highest agronomic efficiency of N in split foliar spray compared to fertilizer broadcasting, fertigation, USG in raised bed and fertilizer broadcast in conventional planting. In addition, the recovery of foliar spray N was best compared to other soil fertilizer application method. In split foliar spray N enters the rice plant fasters from leaves than from roots. Foliar N uptake also stimulate root uptake of other nutrients compared to fertilizer broadcasting, fertigation, USG in raised bed and fertilizer broadcast in conventional planting. This may be another reason of highest agronomic efficiency of N by foliar spray in raised bed planting.

Chapter 12

Conclusions, limitations, recommendations and implications of the study

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Conclusions, limitations, recommendations and implications of the study

Rice is the staple food grain in Bangladesh as well as part of the Asian countries and covers about 80% of the total cropped area and contributes over 90% of the total food grain production. To meet up increasing food demand, the productivity of rice must need to be improved. In order to grow more rice the effective use of fertilizer and water requirement also need to be improved. Therefore, the present study was undertaken to evaluate a potential fertilizer application method in raised bed planting for rice production. The rice variety BR 28 and Swarna were selected for boro and aman season due to the yield of these variety were almost similar even in two separate rice growing season in Bangladesh.

12.1. Conclusions

This study demonstrated that foliar spray of split N fertilizer in raised bed planting provided highest number of grains panicle^{-1} and 1000-grains weight compared to fertilizer broadcasting, fertigation, deep placement of USG in raised bed and fertilizer broadcast in conventional planting in aman season. The tallest plants were produced by the foliar spray in raised bed planting compared to other fertilizer application method in aman season. Foliar spray of N fertilizer in raised bed significantly ($P \leq 0.01$) reduced the number of non-bearing tiller m^{-2} compared to fertilizer broadcasting, fertigation, deep placement of USG in raised bed and fertilizer broadcast in conventional planting. Foliar spray in raised bed planting provided significantly ($P \leq 0.01$) highest value of agronomic efficiency of N fertilizer for aman season rice.

Similarly, split foliar N spray in raised bed planting showed highest panicle length compared to fertilizer broadcasting, fertigation, deep placement of USG in raised bed and fertilizer broadcast in conventional planting for boro season. Foliar spray in raised bed planting produced significantly ($P \leq 0.01$) lower number of non-bearing tiller compared to fertilizer broadcasting, fertigation, Urea Super Granule (USG) in raised bed and fertilizer broadcast in conventional planting for boro season. Highest number of grains panicle^{-1} was observed by foliar spray in raised bed planting. Foliar spray of N in raised bed planting produced highest grain yield compared to fertilizer broadcasting, fertigation, deep placement of USG in raised bed and fertilizer broadcast in conventional planting in transplanted boro rice.

The findings of this study indicated that foliar spray in raised bed was best in both aman and boro season in respect with growth, yield, water use and agronomic efficiency. Less number of non-bearing tiller produced in boro season compared to aman season by foliar spray in raised bed planting. Grains panicle^{-1} was higher in aman seaon compared to boro season. Boro season produced higher agronomic efficiency of N compared to aman season by foliar spray in raised bed planting. More irrigation water saved by boro season compared to aman season.

Foliar spray with bed planting in boro season gave higher water use efficiency than aman season.

Results also revealed that, comparatively low amount of urea was needed in rice fields using foliar spray instead of fertilizer broadcasting, fertigation, deep placement of USG in raised bed and fertilizer broadcast in conventional planting for boro and aman season. Comparatively high labors were needed for the treatment with USG application than the other fertilizer application method. This study concluded that the use of foliar spray in raised bed planting would be more economic since this practice required less urea in producing modern aman and boro rice. From the results presented in this investigation, it can be concluded that irrigation water applied in rice fields could be reduced without sacrificing rice yield by using the raised bed planting compared to conventional planting for both aman and boro season rice. Weeds infestation was lower by different fertilizer application method in raised bed than fertilizer broadcast in conventional planting for boro and aman season.

Finally, it can be said that the fertilizer and water use efficiency of rice may be increased by adopting split foliar spray in raised bed planting. Therefore, the foliar spray in raised bed planting may be recommended as a good option of sustainable technology for rice production. Thus the foliar spray in raised bed technique can be extended to a larger rice growing area consisting of small landholding farmers and thereby maximizing total production of rice, ultimately contributing to national food security. The farmers of Bangladesh as well as other part of the world may be benefited by adopting foliar spray in raised bed planting instead of existing fertilizer broadcasting in conventional flat planting for rice production. So, it could be concluded that foliar spray with bed planting culture might be the alternate option to maximize water and fertilizer use efficiency of rice for both aman and boro rice production.

12.2. Limitations of the study

- The experiment was conducted in one season (both aman and boro season separately) to avoid variation of climate change effect**.** If this study perform multi seasonal that will be more effective to draw conclusions about the climate effect.

- To reach a specific conclusion and recommendation the same experiment need to be repeated and more research work should be done other different Agro ecological zones in Bangladesh.

- Nitrogen content and nitrogen uptake of rice was not undertaken in this study.

- No relation between the requirement of nitrogen by rice plants and then link this to the rate of nitrogen release by different fertilizer application method was conducted.

- Water use efficiency was calculated based on different irrigation rates. No other factor like evaporation, evapotranspiration and climatic condition was considered.

- The weeds were controlled manually. This lack of weed control through Japanese rice weeder probably influenced the yield results.

12.3. Recommendations for further study

- Further study may be conducted to evaluate the effect of different urea application method in raised bed over conventional cultivation method for the rice –wheat cropping pattern in Bangladesh.

- Further research may be conducted to explore the performance of organic fertilizer in raised bed over conventional planting for rice production.

- This study may be tested in saline region of Bangladesh to find out the effect of salinity over different urea application method in raised bed over conventional planting method for rice production.

12.4. Implications of the study

- Deep placement of urea super granule in raised bed may be effective options for better rice production due to decrease in nitrogen loss compared to conventional planting.

- Utilization of nitrogen fertilizer can be reduced half by implementing foliar spray of nitrogen fertilizer in Bangladesh.

- This study demonstrated that weed population in rice cultivation may be reduced drastically by adopting raised bed planting technique compared to conventional planting method.

- Fertigation technique in raised can be used by farmers due to its dual management practice like irrigation and fertilization.

Chapter 13

References

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References

Ahamed, M., Islam, M., and Paul, S.K., (2005).Effect of nitrogen on yield and other plant character of local T.aman rice, Var. *Jatai. Research Journal of Agriculture, Biology Science* **1(2):** 158-161.

Ahmad, R., and Jabeen, R. (2005) "Foliar spray of mineral elements antagonistic to sodium—a technique to induce salt tolerance in plants growing under saline conditions," *Pakistan Journal of Botany* **37** **(**4): 913–920.

AIS. (2008). *Krishi Diary 2008*. Dhaka: Agricultural Information Service (AIS).

Alam, B.M.R. (2002). Effect of different level of urea super granule on the growth and yield of three varieties of *boro* rice. MS (Ag.) Thesis, Dept. Agron. Bangladesh Agril. Univ. Mymensingh.

Alam, E.,(2009) Fertigation to cut water, fertilizer cost by half **.**The Daily Star**,** Saturday, February14**,** 2009.

Alam, S. S., Moslehuddin, A. Z. M., Islam, M. R., and Kamal, A. M. (2010). Soil and foliar application of nitrogen for Boro rice (BRRIdhan 29). Department of Soil Science, Bangladesh Agricultural University, Mymensingh-2202, Bangladesh. *Journal of Bangladesh Agricultural University* **8(2)**: 199–202.

Alam, S.M., Shah, S.A. and Iqbal, M.M (2005). Evaluation of method and time of fertilizer application for yield and optimum P-efficiency in wheat. *Songklanakarin Journal of Science Technology* **27(3):** 23-28 .

Alam, S., Saiful, M, M. I., and Islam, M. A. (2011). Farmers' Efficiency Enhancement through Input Management: The Issue of USG Application in Modern Rice. *Bangladesh Journal of Agricultural Research* **36(1):** 129-141.

Ali, A., Salim, M., Zia, M.S., Mahmoodand, I.A., Shahzad, A. (2005) Performance of rice as affected by foliar application of different K fertilizer sources. *Pakistan Journal of Agricultural Science* **42(1-2)**: 14-20.

Ali, I., Kafkafi, U., Sugimoto, Y., and Inanaga, S. (1994). Response of sand-grown tomato supplied with varying ratios of NO3/NH4at constant and variable root temperatures. *Journal of Plant Nutrition* **17**:2001-2024.

Aminun, N. U., Saleque, M .A., Panhwar, Q. A., Radziah, O., and Jusop, S. (2011). Techniques of efficient fertilizer management for wetland rice- a review *Australian journal of crop science* **5(12)**:1661-1669.

Anbumozhi, V., Yamaji, E., and Tabuchi, T. (1998) Rice crop growth and yield as influenced by changes inponding water depth, water regime and fertigation level. *Agricultural Water Management* **37**:241- 253.

André, M.D., D. Massimino, and A. Daguenet. (1978a). Daily patterns under the life cycle of a maize crop. I. Photosynthesis, transpiration, respiration. *Physiologia Plantarum* **43**:397-403.

André, M.D., D. Massimino, and A. Daguenet. (1978b). Daily patterns under the life cycle of a maize crop. II. Mineral nutrition, root respiration, and root excretion. *Physiologia Plantarum* **44**:197-204.

Annadurai, K.A., and Palanniappan, S. P. (1994) Effect of phosphorus levels and DAP spray on low land rice yield. *Madras Agricultural Journal* **81(11)**: 633-634.

Anonymous, (2009). Urear baboher kome asbe 80 bhag Jugantor (a daily bangla newspaper).

Anowar, S.M.S., A.A. Mamun, M. Nasim and H.M. Babar, (1998). Grain yield and yield attributes of Boro rice as affected by cultivars and weeding in haor area. *Pakistan Journal of Science and Industry Research* **4(4)**: 208-211.

Aranda, I., Bergasa, L.F., Gil, L. and Pardos, J.A. (2001). Effects of relative irradiance on the leaf structure of Fagus sylvatica L. seedlings planted in the understory of a Pinus sylvestris L. stand after thinning. *Annals of Forest Science* **58:**673-680.

Artacho, P., Bonomelli, C., and Meza, F. (2009). Nitrogen Application in Irrigated Rice Grown in Mediterranean Conditions: Effects on Grain Yield, Dry Matter Production, Nitrogen Uptake, and Nitrogen Use Efficiency**.** *Journal of Plant Nutrition* **32**: 1574–1593.

Asenjo,M.C.,Gonz´alez,J.L., and Maldonado,J.M. (2000)"Influence of humic extracts on germination and growth of ryegrass," *Communications in Soil Science and Plant Analysis* **31(1-2):** 101–114.

Aslam, M., Hussain, S., Rahzan, M., and Akhter, M. (2008). Effect of different stand establishment techniques on rice yields and its attribures. *Journal of Animal and Plant Science* **18**: 21-26.

Aslam, M., Memon, M.Y., Khan, P., Imtiaz, M., and Nizamuddin. (2009). Performance of fertigation technique for phosphorus application in cotton. *Soil & Environment* **28(1):** 45-48.

Atta Y.I.M. (2005). Strip planting of rice: A new method for increasing water use efficiency under splitting of nitrogen fertilizer. *Egyptian Journal of Applied Science* **20 (10B):** 501-511.

Atta YIM, Meleha ME, Tallet A, and Gawish UM (2006). Improving water productivity in rice cultivation with high potential for water saving. The 3rd Arab world region conference, Cairo, 4-11 December, 2006.

Awan, T.H., Ali, R.I., Manzoor, Z., Ahmed, M.and Akhtar, M. (2011). Effect of different nitrogen levels and row spacing on the performance of newly evolted medium grain rice variety, KSK-133.*Journal of Animal Plant Science* **21**: 231-234.

Azam M.T., Ali, M.H., Karim, M.F., Rahman, A., Jalal, M.J., and Mamun, A.F.M. (2012). Growth and Yield of Boro Rice as Affected by Different Urea Fertilizer Application Methods. *International Journal of Sustainable Agriculture* **4 (3)**: 45-51, 2012.

Badole, W.P. and Narkhede, A. H. (1999). Effect of concentration and time of foliar spray of urea on growth and economic yield of rice (Oryza sativa) .*Indian Journal of Agronomy* **44(4)**: 705- 709.

Bakker D.M., Hamilton G.J., Houlbrooke D.J., Spann C. (2005) The effect of raised beds on soil structure, water logging, and productivity on duplex soils in Western Australia. *Australian Journal of Soil Research* **43**:575–585.

Balasubramanian, V., Ladha, J. K., Gupta, R. K., Naresh, R. K., Mehla, R. S., and singh, Y. B. (2003) “Technology option for rice in the rice- wheat systems in Asia,” in Improving Productivity and Sustainability of Rice-Wheat Systems: Issues and Impact, *American society of Agronomy Special Publication* **65:** 115–148.

Balasubramanian, V., Ladha, J. K., Gupta, R. K., Naresh, R. K., Mehla, R. S., Bijay-Singh, R. S., and Yadvinder-Singh, R. S. (2003). Technology options for rice in therice–wheat system in South Asia. In ‘‘Improving the Productivity and Sustainability of Rice–Wheat Systems: Issues and Impacts’’ (J. K. Ladha, J. E. Hill, J. M. Duxbury,R. K. Gupta, and R. J. Buresh, Eds.). pp. 1–25. *ASA Special Publication* **65**. ASAInc.,CSSAInc., SSSAInc., Madison, WI.

Bar- Yosef B. (1999). Advances in fertigation. *Advance Agronomy* **65**: 1-70.

BARC (2005). Bangladesh Agricultural Research Council, Fertilizer Recommendation Guide, Ministry of Agriculture, Governments of the People’s Republic of Bangladesh, Dhaka, Bangladesh: 174-175.

Basak, N. C., and Pandit, J. C. (2011). Farmers’ attitude towards the use of USG in rice cultivation in three selected villages of Netrakona district. Bangladesh Agricultural University journal **9(2)**: 179–185.

BBS (2011). Bangladesh Bureau of Statistics , Government of the People’s Republic of Bangladesh, Agriculture Wing ,Parishankhyan Bhaban , E-27/A, Agargaon, Dhaka- 1207.

BBS (2011-12) Bangladesh Bureau of Statistics, Government of the People's Republic of Bangladesh. Agriculture Wing, Parishankhyan Bhaban, E-27/A, Agargaon, Dhaka-1207.

Beecher, G., Thompson J.A., Dunn B.W. and Mathews S.K. (2005). Permanent raised beds in irrigated farming systems in the Murrumbidgee / Murray Valleys of NSW.

Beecher, H. G., Dunn, B.W., Thompson, J. A., Humphreys, E., Mathews, S. K., and Timsina, J. (2006). "Effect of raised beds, irrigation and nitrogen management on growth, water use and yield of rice in south-eastern Australia. *Australian Journal of Experimental Agriculture* **46(10):** 1363–1372.

Bhuiyan, N.I., Mazid, M.A. & Saleque, M.A. (1985). Fertilizer nitrogen deep placement status of research by BRRI. IN Proceedings Fertilizer Nitrogen Deep Placement for Rice. Dhaka, Bangladesh: Bangladesh Agricultural Research Council: 27-36.

BINA (2012). Bangladesh Institute of Nuclear Agriculture .Non-commodity Technologies.

Biswas, B. C. (2010) Fertigation in High Tech Agriculture .A Success Story of A Lady Farmer *Fertilizer Marketing News* **41(10)**:4-8.

Biwas, P. L., Barman, H. N., Ghosal, S., Tohiduzzaan, S., and M. H. Ali, (2011). Stability study for growth duration and grain yield of exotic hybrid rice genotypes in Bangladesh. *Bangladesh Journal of Agriculture Research* **36(1):** 97-102.

Borell AK, Carsid AL, and Fukai S (1997). Improving efficiency of water use for irrigated rice in a semi- arid tropical environment. *Field Crops Research* **52:** 231-248.

Borell,A.K.,Kelly,R.M.,and Van Cooten, D.E. (1997). Improving management of rice in semi-arid eastern Indonesia: responses to irrigation, plant type and nitrogen. *Australian Journal of Experimental Agriculture* **38**: 261-71.

Borrell, A. K., Kelly, R. M., and Van Cooten, D. E. (1998). Improving management of rice in semi-arid eastern Indonesia: responses to irrigation, plant type and nitrogen. *Australian Journal of Experimental Agriculture* 38 (3): 261–271.

Boulala, H., G´omez, H., Macphersona. and Villalobosa, F. J. (2012). "Permanent bed planting in irrigated Mediterranean conditions: short-term effects on soil quality, crop yield and water use efficiency. *Field Crops Research* **130:** 120–127.

Bouman, B.A.M., and Tuong, T.P. (2001). Field water management to save water and increase its productivity in irrigated lowland rice. *Agricultural Water Management* **49**: 11-30.

Bouman, B.A.M., Feng L., Tuong TP, Lu G., Wang H., and Feng Y. (2007). Exploring options to grow rice under water short conditions in northern China using a modelling approach. II. Quantifying yield, water balance components and water productivity. *Agricultural Water Management* **88**:23-33.

Bouman, B.A.M., Peng, S., Casteneda, A.R.., and Visperas, R.M. (2005) Yield and water use of irrigated tropical aerobic rice systems. *Agricultural Water Management* **74**: 87-105.

Bouyouscos, G.J. (1962). Hydrometer method improved for making particle size analysis of soils. *Agronomy Journal* **54**: 464-465.

Brasher, E. P., Wheatley, J. R., and Ogle, W. L. (1953). Foliar Nutrition Sprays on Vegetable Crops, University of Delaware Agricultural Experiment Station, Newark, NJ, USA, 1953.

BRRI (2007) Bangladesh Rice Research Institute .Impact of LCC and USG on rice production in same selected areas. Annual Research Review Report, Agricultural Economics Division, Bangladesh Rice Research Institute, Gazipur, 14-17 January.

BRRI (2008). Bangladesh Rice Research Institute. ``*Adhunik Dhaner Chash*”- Bengali Version, Bangladesh Rice Research Institute, Gazipur-1701.

BRRI (2009) Bangladesh Rice Research Institute, Fact sheet; soil & fertilizer management: 3-5.

BRRI (2009). BRRI Annual Internal Review 2007-2008. Soil Science Division. Bangladesh Rice Research Institute, Gazipur-1701.

BRRI (Bangladesh Rice Research Institute) (2007). Bangladesh Rice Knowledge Bank. Http: //riceknowledgebank.brri.org. Accessed on January, 2007.

BRRI (Bangladesh Rice Research Institute), *Fact sheet; Boro rice varieties*. BRRI dhan 28: 2.12.

BRRI 2008. Adhunik Dhaner Chash, 14th Edition, Bangladesh Rice Research Institute, Gazipur-1701, Bangladesh: 13-15.

BRRI. (1988). Annual Report for 1986. Bangladesh Rice research Institute. Gazipur, Bangladesh.

Burkhardt, J., S. Dreitz, S., Goldbach, H. E., and Eichert T. (1999). Stomatal uptake as an important factor for foliar fertilization. In: Technology and Application of Foliar Fertilizers: Proceedings of the Second International Workshop on Foliar Fertilization, ed. Soil and Fertilizer Society of Thailand: 63–72. Bangkok: Soil and Fertilizer Society of Thailand.

Cabangon, R, J and Tuong, T.P. (2005). Effect of water regime on grain yield, water input and water productivity of rice grown on raised beds. Presented in ACLAR Workshop on Permanent Bed Planting Systems. 1-3 Mar.2005. Griffith, NSW, Australia.

Cabangon, R.J., Tuong T.P., and Janiya. J.D (2005). Rice grown on raised beds: effect of water regime and bed configuration on rice yield, water input and water productivity. Evaluation and performance of permanent raised bed cropping systems in Asia, Australia and Mexico edited by C.H. Roth, R.A. Fischer and C.A. Meisner ACIAR Proceedings No. 121 (printed version published in 2005).

Cadahia, C. (1993) Pre-plant slow-release fertilization of strawberry plants before fertigation. *Fertilizer Research* **34(3)**: 191-195.

Cao Z. H.,De Datta, S. K.,and Fillery I.R..P (1984) Nitrogen.15 balance and residual effects of urea- N in wetland rice fields as affected by deep placement techniques. *Soil Science Society of America Journal* **48**:203-208.

Cao, Z.H., De Datta, S.K.,and Fillery,I.R.P. (1984). Effect of placement methods on floodwater properties and recovery of applied N (^{15}N- labeled urea) in wetland rice. *Soil Science Society of America Journal* **48(1)**: 196-203.

Cassman, K. G. (2005). Ecological Intensification of Agriculture and Implications for Improved Water and Nutrient Management .Department of Agronomy and Horticulture, University of Nebraska-Lincoln, Lincoln, NE 68583-0724, USA.

Chalam, A. B., Chakaravorti, S. P.,and Mohanty, S. K,.(1989) Comparative efficiency of urea super granules and prilled urea for lowland rice (*Oryza sativa*) using ^{15} N. *Indian Journal Agriculture science* **59**:400-401.

Chen, Y., and Aviad, T. (1990) "Effects of humic substances on plant growth," in *Humic Substances in Soil and Crop Sciences: 161*–182, ASA and SSSA, Madison, Wis, USA, 1990.

Choudhury, A.T.M.A., and Bhuyan, N.I. (1994). Effect of rates methods of nitrogen application of grain yield and nitrogen uptake of wetland rice. *Pakistan Journal of Scientific and industrial Research* **37 (3)**: 104-107.

Choudhury, A.T.M.A., Bhuiyan, N.I., Hashem, M.A., and Matin, M.A. (1994).Nitrogen fertilizer management in wetland rice culture. *Thai Journal of Agricultural Science* **27**:259–267.

Choudhury, A.T.M.A., Bhuyan, N.I., Hashem, M.A., Matin, M.A. (2009) Nitrogen fertilizer deep placement in wetland rice culture. *Bangladesh Research Publication Journal* **2(2)**: 499-505.

Choudhury, A.T.M.A., and Khanif, Y.M. (2001). Evaluation of effects of nitrogen and magnesium fertilization on rice yield and fertilizer nitrogen efficiency using ^{15}N tracer technique. *Journal of Plant Nutrition* **24(6)**: 855-871.

Choudhury, B. U., B. A. M. Bouman., and Singh, A. K. (2007). “Yield and water productivity of rice-wheat on raised beds at New Delhi, India,” *Field Crops Research* **100(2-3)**: 229– 239.

Chunlin, H. (2010) Effects of furrow irrigation on the growth, production, and water use efficiency of direct sowing of rice. *The Scientific World Journal* **10**: 1483-1497.

Collard B.C.Y., Septiningsih, E.M., Das, S.R., Carandang, J.J., Pamplona, A.M., Sanchez, D.L., Kato, Y., Ye, G., Reddy, J.N., Singh, U.S., Iftekharuddaula, K.M., Venuprasad, R., Vera-Cruz, C.N., Mackill, D.J., and Ismail, A.M. (2013). Developing new flood-tolerant varieties at the International Rice Research Institute (IRRI). *SABRAO J. Breed. Genet.* **45**: 42-56.

Connor, D. J., Timsina, J. and Humphreys, E. (2003a). Prospects for permanent beds for the rice-wheat system. *In:* Improving Productivity and Sustainability of Rice-Wheat Systems: Issues and Impact. *American Society of Agronomy Spec. Publ.* **65:** 197-210.

Connor, D.J., Timsina, J., and Humphreys, E. (2003). Prospects for permanent beds in the rice wheat system. In Ladha JK, Hill JE, Duxbury JM, Gupta RK, and Buresh RJ (eds) ‘Improving the Productivity and Sustainability of Rice-Wheat Systems: Issues and Impacts’. *ASA Special Publication* **65,** 197–210. ASA Inc, CSSA Inc, SSSA Inc, Madison, USA.

Craswell, E. T. and De Dutta, S. K. (1980). Recent developments in research in nitrogen fertilizers for rice. *IRRI Research Paper Series* **19**:11.

Craswell, E.T. and De Datta, S.K. (1980). Recent developments in research on nitrogen fertilizers for rice. *Indian Journal of Agronomy:* **31(4)**: 387-389.

Daftardar, S.Y., and Savant, S.K. (1995) Evaluation of environmentally friendly fertilizer management for rainfed lowland rice on tribal farmers’ fields in India. Pages 173-186 in Fragile lives in fragile ecosystems. Proceedings of the international Rice Research conference; 13-17 Feb 1995. International Rice Research Institute. P.O Box 933. Manila, Philippines.

Das, A., Munda, G. C., Patel, D. P. (2010). Technological Options for Improving Nutrient and Water Use Efficiency. Page: 1-15.

Das, S. and T. A. Singh (1994). Nitrogen use efficiency by rice and floodwater parameter as affected by fertilizer placement techniques. *Journal of Indian Society Soil Science* **42(1)**: 46-50.

David, P. P., Nelson, P. V., and Sanders, D. C. (1994) "A humic acid improves growth of tomato seedling in solution culture," *Journal of Plant Nutrition* **17(1):** 173–184.

De Datta, S. K. (1978). Fertilizer management for efficient use in wetland rice soils. In soil and rice. IRRI, Los Banos, Philippines'*:* 671-701.

De Datta, S. K. (1984). Availability and management of N in low land rice in relation to soil characteristics. Workshop on "Characterization, classification and utilization of wetland soils" manual. IRRI, Manila. Philippine.

De Datta, S. K., and Buresh R. J. (1989) Integrated nitrogen management in irrigated rice. *Advances in Soil Science* **10**: 143-169.

De Datta, S.K. (1978). Fertilizer management for efficient use in wetland rice soils. In Soils and Rice. Los Banos, Phlippines: International Rice Research Institute: 671-679.

De Datta, S.K. (1981). Principles and Practices of Rice Production. New York, USA: John Wiley Sons, Inc.

De Datta, S.K. (1987). Advances in Soil Fertility Research and Nitrogen Fertilizer Management for Lowland Rice. In Efficiency of Nitrogen Fertilizers for Rice. Los Banos, Philippines: International Rice Research Institute: 27-41.

Devasenapathy, P., and Palaniappan, S.P. (1993). Fertilizer Management - Inorganic Source. Band placement of urea solution increase N use efficiency in transplanted low land rice. *International Rice Research Notes* **20(3)**: 19.

Devinder, S., Mahey, R.K., Vashist, K.K., and Mahal, S.S. (2005). Economizing irrigation water use and enhancing water productivity in rice (*Oryza sativa* L.) through bed/furrow planting. *Environment and Ecology* **23(3)**: 606-610.

Dhindwal, A.S., Hooda, I.S., Malik, R.K., and Kumar, S. (2006) Water productivity of furrow-irrigated rainy-season pulses planted on raised beds. *Indian Journal of Agronomy* **51**: 49-53.

Dixon, C. (2003). Foliar Fertilization Improves Nutrient Use Efficiency. *Fluid Journal*, winter 2003.

Dobermann A. (2005).Nitrogen Use Efficiency – State of the Art. IFA International Workshop on Enhanced-Efficiency Fertilizers. Frankfurt, Germany, 28-30.

Dunn, B.W., Mathews, S.K., Beecher, H.G., Thompson, J.A., and Humphreys, E. (2004) Growing rice on raised beds in south-eastern Australia. New directions for a diverse planet: *Proceedings of the 4th International Crop Science Congress Brisbane, Australia,* 26 Sep - 1 Oct 2004.

Duraisami, V.P. and Mani, A.K. (2002). Yield maximization and economics in rice grown during winter season under irrigated condition. *Mysore Journal of agricultural science* **36(3)**: 212-217.

Eichert, T., and Burkhardt, J. (2001). Quantification of stomatal uptake of ionic solutes using a new model system. *Journal of Experimental Botany* **52**: 771–781.

Eichert, T., and Fernández, V. (2011). Uptake and release of elements by leaves and other aerial plant parts. In Marschners' mineral nutrition of higher plants. P. Marschner, editor. Academic Press, Oxford: 71-84.

Eichert, T., Goldbach, E. H.,and Burkhardt, J. (1998). Evidence for the uptake of large anions through stomatal pores. *Botanica Acta* **111**: 461–466.

Elahi, M. N. F., Mollah, M. I.U., Karim, S. M. R., Khatun, A. and Chaudhury, N. H. (2001). "New establishment methods of rice and non-rice crops in rice-wheat and rice-rice cropping systems, "in Proceedings of the International Workshop on Conservation Agriculture for Fiid Security and Environment Protection in Rice-Wheat Cropping Systems, Lahore, Pakistan, February 2001.

El-Bably, A.Z. Meleha, M.E., Abd Allah, A.A., and El-Khoby, W.M. (2008). Increasing Rice Productivity, Water Use Efficiency ,Water Saving and Rice Productivity in North Delta, Egypt. The 3rd International Conference on Water Resources and Arid Environments (2008) and the 1st Arab Water Forum. p.8.

Emmott, W., Kernighan, T., Tobin, C., Gonzalez, H., Freeman, B. (2013). Growth stages of rice-plant Agriculture. Source: www.plant.uoguelph.ca/courses/pbio-3110/documents/Rice 08. pdf.

Epstein, E., and Bloom, A.J. (2005). Mineral nutrition of plants: *Principles and perspectives.* **380**.

Fahong, W., Xuqing, W., and Sayre, K. (2004). "Comparison of conventional, flood irrigated, flat planting with furrow irrigated, raised bed planting for winter wheat in China," *Field Crops Research* **87(1)**: 35–42.

Fahong, W., Xuqing, W., Feng Bo., Jisheng, S., Shengdong, L., and Zhongming, M. (2005). Raised bed planting for wheat in China 2005.

FAO (1986). Irrigation Water Management: Irrigation Water needs.

FAO (2003). The State of Food Insecurity in the World 2003. Food and Agriculture Organization of the United Nations, Viale delle Terme di Caracalla, Rome, Italy, 36p.

Fernandez, V., and Eichert, T. (2009). Uptake of hydrophilic solutes through plant leaves: Current state of knowledge and perspectives of foliar fertilization. *Critical Reviews in Plant Sciences* **28**:36-68.

Fernandez, V., Del Rio, V., Pumarino, L., Igartua, E., Abadia, J., and Abadia, A. (2008a). Foliar fertilization of peach (Prunus persica L. batsch) with different iron formulations: 120 Foliar fertilization: scientific principles and field practices Effects on re-greening, iron concentration and mineral composition in treated and untreated leaf surfaces. *Scientia Horticulturae* **117**:241-248.

Fernández, V., Sotiropoulos, T., and Brown, P. (2013). Foliar Fertilization Scientific Principles and Field Practices. *International Fertilizer Industry Association* (IFA) Paris, France, 2013.

Frank, A.B., Barker, R.E., and Berdahl, J.D. (1987). Water use efficiency of grasses grown under controlled and field conditions. *Agronomy Journal* **79**: 541-544.

Gamiz, R., Espejo, J. A., Tejada, M., Dobao, M. M., and Gonzalez, J. L. (1998) "Evoluci ´on de los contenidos de clorofilas en plantas de esp´arrago verde (Asparagus officinalis, L.) tras la adici on de amino´acidos y ´acidos h´ umicos," in *Proceedings of the VII Simposio Nacional-III Ib´erico Sobre Nutrici´on Mineral de las Plantas* **1:**173–178.

Gibert, C., Lescourret, F., Genard, M., Vercambre, G., and Pastor, A.P. (2005). Modelling the effect of fruit growth on surface conductance to water vapour diffusion. *Annals of Botany* **95**:673-683.

Gill, M.A. (1994). On-farm water management historical overview. National conference on On-farm Water Management, 29–30 May, Islamabad, Pakistan.

Gill, M.A., Ahmad, M., and Awan, N.A. (2005) Evaluation and performance of growing crops on permanent raised beds in Pakistan's Punjab. Edited by C.H. Roth, R.A. Fischer and C.A. Meisner ACIAR Proceedings No. 121 (printed version published in 2005).

Giroux, M., (1984). Effects d'application d'uree au soluet au feuillage sur le redement, le poids specifique et la nutrition azote´e de la pomme de terre. *Nat. Can.* **111**: 157-166.

Goldberg, D., Gornat, B., and Bar Yosef, B. (1971). The distribution of roots, water and minerals as a result of trickle irrigation. *Journal of the American Society for Horticultural Science* **96**:645-648.

Goldberg, D., Gornat, B., and Rimon. D., (1976). Drip Irrigation Principles, Design and Agricultural Practices. Drip Irrigation Scientific, far Shmariahu, Israel.

Gooding, M. J., and Davies, W. P. (1992). Foliar urea fertilization of cereals: A review. *Fertilizer Research* **32**: 209–222.

Goswami, N.N., and Banerjee, N.K. (1978). Phosphorus, potassium and other microelements. in Soils and Rice. Los Banos, Philippines: International Rice Research Institute: 561-580.

Govaerts, B., Sayre, K. D., Ceballos-Ramirez, J. M. (2006). Conventionally tilled and permanent raised beds with different crop residue management: effects on soil C and N dynamics. *Plant and Soil* **280 (1-2)**:143–155.

Govindan, R., Grace, T. M.(2012) Influence of drip fertigation on growth and yield of rice varieties (*Oryza sativa* L.). *Madras Agricultural Journal* **99 (4/6)**: 244-247.

Guerra, L. C., Bhuiyan, S. I., Tuong T. P., and Barker, R. (1998). Producing more rice with less water from irrigated system. SWIM paper No.5. International water Management Institute, P.O.Box 2075. Colombo, Srilanka.

Gupta, R. K., Hobbs, P. R., Salim, M., Malik, R. K., Varma, M. R., Pokharel, T. P., Thakur, T. C. and Tripathri, J. (2000). Research and extension issues for farm-level impact on the productivity on rice-wheat systems in the Indo-Gangetic Plains of India and Pakistan. Rice-Wheat Consortium Sem. Rep. Ser. 1. Rice-Wheat Consortium for the Indo-Gangetic Plains. New Delhi, India. 26 p.

Gupta, R. K., Naresh, R. K., Hobbs, P. R., and Ladha, J. K. (2003). Adopting conservation agriculture in the rice–wheat system of the Indo-Gangetic Plains: New opportunities for saving water. In ‘‘Water-Wise Rice Production’’ (B. A. M. Bouman, H. Hengsdijk, B. Hardy, P. S. Bindraban, T. P. Tuong, and J. K. Ladha, Eds.). pp. 207–222. Proceedings of a Thematic Workshop on Water-Wise Rice Production, 8–11 April 2002 at IRRI Headquarters in Los Ban˜ os, Philippines. International Rice Research Institute, Los Ban˜ os, Philippines**.**

Gupta, R.K ., Naresh, R.K., Hobbs, P.R., and Ladha, J.K .(2002) . Adopting conservation agriculture in the rice wheat system of the Indo- Gangetic Plains: new opportunities for saving water. In “water wise rice production” . (Eds .BAM Bouman , H Hengsdijk , B hardy , PS Bindraban , TP Tuong , JK Ladha) Los Banos (Philippines): IRRI : 207-222.

Gupta, R.K. and Gill, M.A. (2003) Reclamatin and management of alkaline soil. In Addressing Resource Conservation Issues in Rice-Wheat Systems of South Asia: A Resource Book. Rice-Wheat Consortium for the Indo-Gangetic Plains Intl. Maize and Wheat Impr. Cent., New Delhi, India. 199-204.

Haifa Group (2011) Pioneering the Nutrigation Way .The Benefits of Nutrigation. www.haifa group.com/community.

Haq, M. U., and Mallarino, A. P. (2000). “Soybean yield and nutrient composition as affected by early season foliar fertilization,” *Agronomy Journal* **92(1):**16–24.

Haque, S.A. (2002) Urea super granule point placement on potato: A new concept. Department of Soil Science, Bangladesh Agricultural University, Mymensingh- 2202, Bangladesh.

Hargert, G.W., Frank, K.D., and Rehm, G.W. (1978). Anhydrous ammonia and N-serve for irrigated corn. University of Nebraska Lincoln Agronomy Department Soil Science Research Report: 3.1-3.4.

Harun, Eusuf., Quayum, M, M. A., Razzaq, A., Alam, M. S., Jabber, M. A., and Quyum, A. (1993) Economic Analysis of Urea Super Granules Application In Irrigated Rice. *Bangladesh rice journal* **4(1&2)**: 23-27.

Hasanuzzaman, M., Nahar, K., Alam., Hossain, M.Z., and Islam, M. R. (2009). Response of Transplanted Rice to Different Application Methods of Urea Fertilizer. *International Journal of Sustainable Agriculture* **1 (1)**: 01-05.

Hasanuzzaman, M., Nahar,K., Alam, M.M., Hossain, M.Z., and Islam, M. R. (2009). Response of Transplanted Rice to Different Application Methods of Urea Fertilizer. *International Journal of Sustainable Agriculture* **1 (1)**: 1-5.

Hasanuzzaman,M., Ali, M. R., Karim, M.F., Masum, S.M., and Mahamud, J.A. (2013) Influence of prilled urea and urea super granules on growth and yield of hybrid rice. *Journal of .Experimental Biological Science* **4(1)**: 1-8.

Hayens, R.J. (1985) Principles of fertilizer use for trickle irrigated crops. *Fertilizer Research* **5(2):**235-255.

He, C. (2010) Effects of furrow irrigation on the growth, production, and water use efficiency of direct sowing rice. *The Scientific World Journal*: TSW Environment **10:** 1483-1497.

Hedge, B.R., Havangi, G.V., and Ready, N.M. (1978).Fertilizer need and water use efficiency of dry land ragi in a cow pea-ragi sequence. *Mysore Journal of Agricultural Science* **12:**433-436.

Hobbs, P. R. (2001) “Tillage and crop establishment in South Asian rice-wheat systems: present practices and future options,” *Journal of Crop Production* **4 (1):** 1–22.

Hobbs, P. R., and Gupta, R. K. (2003) “Resource-conserving technologies for wheat in the rice-wheat sys tem,” in Improving Productivity and Sustainability of Rice-Wheat Systems: Issues and Impact, *American Society of Agronomy Special Publication* **65:**149–171, American Society of Agronomy, Madison, Wis, USA, 2003.

Hobbs, P. R., and Gupta, R. K. (2003). “Resource-conserving technologies for wheat in the rice-wheat system,” in Improving Productivity and Sustainability of Rice-Wheat Systems: Issues and Impact, *American society of Agronomy Special Publication* **65:**149–217.

Hobbs, P. R., and Gupta, R. K. (2003a) “Resource-conserving technologies for wheat in the rice-wheat system,” in Improving Productivity and Sustainability of Rice-Wheat Systems: Issues and Impact, *American Society of Agronomy Special Publication* **65:**149–171.

Hobbs, P. R., and Gupta, R. K. (2003). Resource-conserving technologies for wheat in the rice-wheat system. *In:* Improving Productivity and Sustainability of Rice-Wheat Systems: Issues and Impact. *American Society of Agronomy* Spec. Publication **65:** 149-171.

Hobbs, P. R., Sing, G. S., Giri., Lauren, J. G., and Duxbury, J. M. (2000). Direct Seeding and Reduced Tillage Options in the Rice-Wheat Systems of the Indo-Gangetic plains of South Asia. Paper presented at IRRI workshop, Bangkok, Thailand, 25-28 January, 2000.

Hobbs, P.R., Gupta, R.K., Ladha, J.K., and Balasubramanian, V. (2000). Crop Establishment and Management: New Opportunities. Paper Presented at the International Workshop on Developing an Action Program for Farm-Level Impact on Rice-Wheat Systems of the Indo-Gangetic Plains. 25-27 September 2000. New Delhi, India.

Holland JE, White RE, Edis R (2007) The relation between soil structure and solute transport under raised bed cropping in south-western Victoria. *Australian Journal of Soil Research* **45**: 577-585. doi: 10.1071/SR07068.

Hossain, M. I., Sufian, M. A., Hossain, A. B. S., Meisner, C. A., Lauren, J. G., and Duxbury, J. M. (2003). ‘‘Performance of Bed Planting and Nitrogen Fertilizer Under Rice–Wheat–Mungbean Cropping Systems in Bangladesh.’’ *Wheat Research Centre Internal Review Reports*. Bangladesh Agricultural Research Institute, Dinajpur, Bangladesh.

Hossain, M.A. (2004).Characteristics of BRRI varieties. Updated materials for rice production training. Compiled by Training Division, BRRI, 2004.

Hossain, M.I., Karim, S.M.R., Hossain, M.I., Islam, M.S., Mandal, R.I., and Tiwary, T.P. (2012). Weed growth and grain yield in wheat and rice as affected by tillage system and weed management practices in rice-wheat cropping system in Bangladesh. *Pakistan Journal of Weed Science Research* **18:** 775-783 Special Issue.

Hossain, M.I.C., Meisner, J.M., Duxbury, J.G., Lauren, M.M., Rahman, M.M., and Rashid, M.H. (2004). Use of raised beds for increasing wheat production in rice-wheat cropping systems. 4th International Crop Science Congress.

Hossain, M.Z., Hossain, S.M.A., Anwar, M.P., Sarker, M.R.A., and Mamun, A.A. (2003). Performance of BRRI Dhan 32 in SRI and Conventional Methods and Their Technology Mixes. *Pakistan Journal of Agronomy* **2(4):** 195-200.

Hossain, M., Jaim, W.M.H., and Alam, M. S., and Rahman, A.N.M. (2005). Rice biodiversity in Bangladesh: Adoption, Diffusion and Disappearance of Varieties. A Statistical Report from Farm Survey in 2005, Published by: BRAC Research and Evaluation Division, Dhaka, Bangladesh, February, 2013.

Humphreys, E., Gupta, R., Meisner, C., Timsina, J., Beecher, H.G., Young, L.U.T., Yadvinde-Sing., Gill, M.A., Zheng, Jia. Cuo., and Tompson, J.A. (2004). Water saving in rice wheat system. *Plant Production Science* **8(3):** 231-241.

Humphreys, E., Meisner, C., Gupta, R. (2005) "Water saving in rice-wheat systems," *Plant Production Science* **8(3)**: 242–258.

Humphreys, E., Meisner, C., Gupta, R., Timsina, J., Beecher, H.G., Lu, T.Y., Yadvinder-Singh., Gill, M.A., Masih, I., Guo, Z.J., Thomposon, J.A.(2005). Water savings in rice-wheat systems. *Plant Production Science* **8**:242-258.

Hunsche, M., Blanke, M.M., and Noga, G. (2010). Does the microclimate under hail nets influence micromorphological characteristics of apple leaves and cuticles*? Journal of Plant Physiology* **167**:974-980.

Husain, A.M.M., Chowhan, G., Rahman, A.B.M.Z., Uddin, R., and Barua, P. (2004). Report on the system of rice intensification. PETRRA Technology Workshop, BRRI Auditorium, Gazipur. May 23-24.

IFDC Innovation- More Rice with Improved Nitrogen Efficiency. Deep Placement of Urea Super granules. P-4. Web Site: www.ifdc.org.

Insffer—International Network on Soil Fertility and Fertilizer Evaluation for Rice (1985). Summary reports on the fifth international trial on nitrogen fertilizer efficiency in irrigated wetland rice (1981-84). International Rice Research Institute. P.O. Box 933. Manila, Philippines.

Insffer—International Network on Soil Fertility and Fertilizer Evaluation for Rice (1986). Progress report on the first international trial comparison of hand and machine applied prilled urea and urea super granules in lowland rice (1984-85). International Rice Research Institute. P.O. Box 933. Manila, Philippines.

Iqbal, Z, A., Latif., Ali, S., and Iqbal, M.M. (2003). Effect of fertigated phosphorus on P use efficiency and yield of wheat and maize. *Songklanakarin Journal of Science and Technology* **25(6)**: 697- 702.

Iqbal, Z., Yaqub, M., Akram, M., and Ahmad, R. (2013) Phosphorus fertigation: A technique for enhancing P fertilizer efficiency and yield of wheat and maize. *Soil Environment* **32(2):** 146- 151.

IRRI (2010) Jain Irrigation sign MoU on water efficient irrigation .ET Bureau Feb 20,20 file:///I:/28418348_1_drip-irrigation-fertigation.htm.

IRRI-CREMNET (International Rice Research Institute - Crop and Resource Management Network). 1998. Progress Report for 1997. IRRI, Los Baños, Philippines.

Islam, M., Sarkar, A, R., Uddin, S.,and Parvin, S. (2012). Yield of Fine Rice Varieties as Influenced by Integrated Management of Poultry Manure Urea Super Granules and Prilled Urea. *Journal of Environment Science & Natural Resources* **5(1)**: 129 -132.

Jagroop, K., Mahey, R.K., Vashist, K.K., and Mahal, S.S. (2007). Growth and productivity of rice (Oryza sativa L.) and water expense efficiency as influenced by different planting Techniques. *Environment and Ecology* **25(1):** 235-238.

Jaisal, V.P., and Singh, G.R. (2001). Performance of urea super granule and prilled urea under different planting methods in irrigated rice (*Oryza sativa*). *Indian Journal of Agricultural Sciences* **71(3):** 187-189.

Jamal, Z., Hamayun, M., Ahmad, N., and Chaudhary, M.F (2006). Effect of soil and foliar application of different concentrations of NPK and foliar application of (NH4)2SO4 on different parameters in wheat. *Journal Agronomy* **5(2)**: 251-256.

Janat, M., and Somi, G. (2002). Comparative study of nitrogen fertilizer use efficiency of cotton growth under conventional and fertigation practices using 15 N methodology. Water balance and fertigation for crop improvement in west Asia, IAEA, Vienna.

Jat M. L., and Sharma, S. K. (2005). "On-farm studies on FIRB system for improving crop and water productivity and profitability in rice-wheat cropping system," Agenda Notes, 3rd Regional Technical Conrdination Committee Meeting of RWC For the IGP, Technical Coordination Committee, Dhaka, Bangladesh.

Jat, M. L., Singh, S., Rai, H. K., Chhokar, R. S., Sharma, S. K., and Gupta, R. K. (2005). "Furrow Irrigated Raised Bed (FIRB) planting technique for diversification of rice-wheat system in indo- gangetic plains," *Japan Association for International Collaboration of Agriculture and Forestry* **28 (1)**: 25–42.

Jat, M., Gupta, R., Saharawat, Y., and Khosla, R. (2011) Layering Precision Land Leveling and Furrow Irrigated Raised Bed Planting: Productivity and Input Use Efficiency of Irrigated Bread Wheat in Indo-Gangetic Plains. *American Journal of Plant Sciences* **2(4)**: 578-588.

Jata, S. K., Nedunchezhiyan, M. (2013). Fertigation in High ValueTuber Crops - A Review. *Odisha Review,* **May** – 2013.

Javaid, T., Awan, I.U., Baloch, M.S., Shah, I.H., Nadim, M.A., Khan, E.A., Khakwani, A.A., and Abuzar, M.R. (2012). Effect of planting methods on the growth and yield of coarse rice. *The Journal of Animal & Plant Sciences,* **22(2):**358-362.

Jehangir,WA.,Murrayy-Rust H, Masih.I.,and Shimizu,K. (2002). Sustaining Crop and Water Productivity in the Irrigated Rice-Wheat System. Paper presented at, national workshop on rice –wheat cropping system management, Pakistan Agricultural Research Council Rice-Wheat consortium for Indo-Gangetic Plains. December 11-12, 2002, Islamabad, Pakistan.

Jena, D., Misra, C., Bandyopadhyay, K. K. (2003) Effect of prilled urea and urea super granules on dynamics of ammonia volatilisation and nitrogen use efficiency of rice. *Journal of the Indian Society of Soil Science* **51(3):** 257- 261.

Jha, K.P., and Sahoo, N. (1988). Influence of various water regimes on yield attributed of rice under Mahanadi delta condition. *Oryza* **25**:32-37.

Jing, X., Haden, V. R., Peng, S., Bas, S., Bouman, A.M., Huang, J., Cui, K .,Romeo, M., Zhu, V.D., Zhang, Y., H. Chen, H. (2013) Effect of deep placement of nitrogen fertilizer on growth, yield, and nitrogen uptake of aerobic rice. *Australian Journal of Crop Science* **7(6):**870-877.

Johnson, R.S., Rosecrance, R.C., Weinbaum, S.A., Andris, H., and Wang, J. (2001). Can we approach complete dependence on foliar-applied urea nitrogen in an early-maturing peach? *Journal of America Society Horticulture Science* **126**:364-370.

Joseph, K., Tomy, P.J., and Nair, N.R. (1991). Effect of sources and levels of nitrogen on the growth, yield and nitrogen use efficiency of wetland rice. *Indian Journal of Agronomy* **36(1):**40-43.

Julie, L., John D., Meisner, C., and Hossain, M.I. (2013) Permanent raised beds for the rice-wheat cropping system of South Asia. Cornell University.

Kafkafi, Uzi. (2006). Global Aspects of Fertigation Usage .Department of Field Crops, Faculty of Agricultural, Food & Environmental Quality Sciences, The Hebrew University of Jerusalem, Rehovot 76100, Israel.

Kahlown, M. A., and Raoof, A. (2004). Efficient Water Application Methods for Growing Paddy in the Indus Basin. Innovative Technologies and Management for Water Saving in Agriculture. Page-7.

Kahlown, M.A. (2006). Low cost, innovative water conservation practices in irrigated agriculture. The 2nd International Conference on Water Resources and Arid Environment: 9-10.

Kamel, M.S., Metwally, A.A., and Abdalla, S.T. (1987). Effect of soil and foliar fertilization on inoculated and uninoculated soybeans. *Journal of Agronomy Crop Science* **158:** 217-226.

Kannan, S. (2010) Foliar fertilization for sustainable Crop production, Genetic Engineering, Bio-fertilization, Soil quality and Organic Farming. *Sustainable Agriculture reviews* **4**:371-402.

Karim, S.M.R. (2011). Weed growth and grain yield in wheat and rice as affected by tillage system and weed management practices in rice-wheat cropping system in Bangladesh. Universiti of Malaysia Kelantan-Respository Files.

Karmakar, B., Sarkar, M. A. R., Uddin, M. R., and Biswas, M. (2002). Effect of row arrangements, number of seedlings per hill and nitrogen rates on yield and yield components of late transplant aman rice. *Bangladesh Journal of Agricultural Science* **29 (2):** 275-281.

Katyal, J.C., Singh, B., Sharma, V.K., and Craswell, E.T. (1985).Efficiency of some modified fertilizer for wet land rice grown on permeable soil. *Fertilizer Research* **8**:137-146.

Kerin, V., and Berova, M. (2003) Foliar fertilization in plants. *Videnov & Son, Sofia*. 2003; Bulgarian.

Khalesque, M.A., Paul, N.K., Meisner, C.A., (2008). Yield and N use efficiency of wheat as influenced by bed planting and N application. *Bangladesh Journal of Agriculture Research* **33(3)**:439-448.

Khalil, M. I., Schmidhalter, U., and Inubushi, K. (2006). Fertilizer N Movement and Recovery by Spring Wheat with Urea Super Granules Point-Placed at Different Soil Depths.

Koch, K., Hartmann, K.D., Schreiber, L,. Barthlott, W., and Neinhuis, C. (2006). Influences of air humidity during the cultivation of plants on wax chemical composition, morphology and leaf surface wet ability. *Environmental and Experimental Botany* **56**:1-9.

Kołota, E., and Osińska, M. (2000). The effect of foliar nutrition on yield of greenhouse tomatoes and quality of the crop. *Acta Physiol. Plant* 22: 373-376.

Kongchum, M. (2005).Assessment of water conservation technique in rice culture to develop water use policies .Master Degree Thesis. The Department of Environmental Studies, Louisiana State University and Agricultural and Mechanical College.

Kosma, D.K., Bourdenx, B., Bernard, A., Parsons, E.P., Lue, S., Joubes, J., and Jenks, M.A. (2009). The impact of water deficiency on leaf cuticle lipids of arabidopsis. *Plant Physiology* **151**:1918- 1929.

Kukal, S.S., Singh. Y., Humphreys, E., Dhillon, S. S., and Singh, B. (2005). Soil water dynamics and crop performance in rice-wheat on permanent beds in Indo-Gangetic Plains of India. Presented in ACIAR Workshop on Permanent Bed Planting Systems. 1-3 Mar. 2005. Griffith, NSW, Australia.

Kukal, A., S. S., Humphreys, E., S Yadav, S. C., and Singh, A. Y. (2010). Irrigation water productivity of rice grown with resource conservation technologies. 19th World Congress of Soil Science, Soil Solutions for a Changing World 28, 1 – 6 August 2010, Brisbane, Australia. Published on DVD.

Kumar, S., R., Asrey and Yojana, R.S. (2000) Fertigation, the need of modern agriculture. *Fertilizer News* **44(7):**31, 32, 37.

Kumar, V., Gurusamy, A., P.P. Mahendran, P.P., and Mahendran, S. (2011) Optimization of water and nutrient requirement for yield maximization in hybrid rice under drip fertigation system AICRP-WM Scheme, Madurai Centre, TNAU, Madurai-625104, INDIA.

Kumar, V., Shrotriya, G.C., Kaore, S.V. (Eds.) (1989). Urea super granules for increasing nitrogen use efficiency. Indian Farmers Fertilizer Co-operative, New Delhi, India. *Soil fertility use* **3:** 143.

Lal, P., Gautam, R.C., Bishat, P.S., Pandey, P.C. (1988). Agronomic and economic evaluation of urea super granule and sulphur coated urea in transplanted rice. *Indian Journal of Agronomy* **33(2):**186-190.

Lauren, J., Duxbury, J., Meisner, C., Hossain, M.I. (2013). Permanent raised beds for the rice wheat cropping system of South Asia. VIVO, Research & Expertise across Cornell, Cornell University.

Lauren, J.G., Shah, G., Hossain, M.I., Talukder, A.S.M.H.M., Duxbury, J.M., Meisner, C.A., Adhikari, C. (2008).Research station and on-farm experiences with permanent raised beds through the Soil Management Collaborative Research Support Program. In 'Proceedings of permanent beds and rice residue management for rice–wheat systems in the Indo-Gangetic Plain. Ludhiana, India 7-9 September 2006'. *ACIAR Proceedings* **127**:124-132.

Laxuman, (2010) Molecular mapping and tagging of quantitative trait loci (Qlts) for morphological, physiological and yield trait in rice (*Oryza sativa* L.). Department of genetics and plant breeding, College of agriculture, Dharwad University of Agricultural Sciences, Dharwad-580005.

Limon,O. A., Sayre, K. D., and Francis, C. A. (2000). Wheat nitrogen use efficiency in a bed planting system in Northwest Mexico. *Agronomy Journal* **92:** 303-308.

Linscott ,D.L., Foxrl and Lipps, R.C (1962).Corn root dinitrification and moisture extraction in relation to nitrogen fertilizer and soil properties. *Agronomy Journal* **54**:185-189.

Lovatt, C.J. (1999) Management of foliar fertilization. *Terra.* **17(3)**:257-264.

Ludders, P., and Simon, P. (1980). Foliar Nutrition in Orchard (1965–1979*),* *Universitatsbibliotek der Technischen Universitat,* Berlin, Germany.

Mackill, D.J., Amante, M.M., Vergara, B.S., Sarkarung, S. (1993). Improved semi-dwarf rice lines with tolerance to submergence of seedlings. *Crop Science* **33**:749-753.

Mackill, D.J., Ismail, A.M., Singh, U.S., Labios, RV., Paris, T.R. (2012). Development and rapid adoption of submergence-tolerant (Sub1) rice varieties. *Advance Agronomy* **115**: 303-356.

Malik, K. A., and Azam, F. (1985). Effect of humic acid on wheat (*triticum aestivum* L.) Seedling growth. *Environmental and Experimental Botany* **25(3)**:242–245.

Mamun, M.A.A., Islam, M.R., and Shahidullah, S.M. (2013). Effect of nitrogen source and water management on rice yield and nitrogen use efficiency. *Agricultural Advances* **2(11)**: 292-298.

Mann, R.A., and Meisner, C.A. (2003). Proceedings of the national workshop on rice-wheat systems in Pakistan, 11-12th December, 2002. Islamabad, Pakistan. *A Rice Wheat Consortium Paper Series* **15:** 2-3.

Martinez, A., Ray B., Diamond and Sakti P. Dhua. (1981). Agronomic and Economic Evaluation of Urea Placement and Sulfur-Coated Urea for Irrigated Paddy in Farmers' Fields in Eastern India. *International Fertilizer Development Center,* Muscle Shoals, AL 35660 U.S.A.

Maskey, S. L., Bhattarai, S., and Ghimire, N.P. (1992). International trial on integrated use of organic and inorganic fertilizer on rainfed lowland rice. In: Rice research Report proceedings. The 17thNatioanal Summer Crops Workshop held on 26-31 Jan, 1992, *NRRP Parwanipur*: 156-160.

Masum, S.M., Ali, M.H., and Ullah, M.I. (2008). Growth and yield of two T. aman rice varieties affected by seedling number hill^{-1} and urea super granules. *Journal of Agriculture Education Technology* **11(1 & 2)**: 51-58.

McCall W (1980). Foliar application of foliar fertilizers, Hawaii cooperative extension service, University of Hawaii, *General hove garden series.1980*; **24.**

Meisner, C. A., Talukdar, H. M., and Hossain, I. (2005). "Introduction and implementing a permanent bed system in the rice-wheat cropping pattern in Bangladesh and Pakistan," in Proceedings of the ACIAR Workshop on Permanent Bed Planting Systems, Griffith, NSW, Australia, March 2005.

Memon, M. Y., Shah, J.A., Khan, P., Aslam, M., and Depar, N.(2011). Effect of phosphorus fertigation in wheat on different soil varying in CaCO3 levels. *Pakistan Journal of Botany* **43(6):** 2911-2914.

Miah, M.N.H., Talukder, S., Sarkar, M.A.R. ,and Ansari, T.H. (2004). Effect of number of seedlings hill^{-1} and urea super granules on growth and yield of rice CV.BINA Dhan 4. *Journal of Biology Science* **4 (2):** 122-129.

Mikkelsen, D.S., De Datta S.K., Obcemea, W.N., (1978). Ammonia volatilization losses from flooded rice soils. *Soil Science Society America Journal* **42:**725-730.

Mishra, J.S. (2004). Tillage and weed management - Technical Bulletin-I, National Research Centre for Weed Science, Jabalpur.

Misra, C., Mohanty, B.C., Das, B S., Savant, N. K. (1995) Relationship between some selected soil properties and yield of transplanted rice fertilized with urea briquettes. *Oryza* **32**:178-183.

Mitsui, S. (1977) Recognition of the importance of denitrification and its impact on various improved and mechanized applications of nitrogen to rice plant. In: Proc. Int. Seminar of Soil Environment and Fertility Management in Intensive Agriculture (SEFMIA). *Society of science soil manure:* 259-268.

Mitsui,S. (1954) Inorganic Nutrition, Fertilizer and Soil Amelioration for lowland rice.,2nd ed. Yokendo Press, Tokyo.

Mohammad, M.J., Zuraiki, D, S., and Qawasmi, W. (2002). Nitrogen and water utilization by trickle fertigated garlic using the neutron gauge and 15N technologies. Water balance and fertigation for crop improvement in west Asia, IAEA, Vienna, 2002.

Mohanty, S.K., Chakravorti, S.P., Bhadrachalam, A. (1989). Nitrogen balance studies in rice using 15N labelled urea and urea super granules. *Journal of Agriculture Science* 113**(1):** 119-121.

Mohanty, S.K., Singh, U., Balasubraamanian, V., and Jha, K.P. (1999) Nitrogen placement technologies for productivity profitability and environmental quality of rainfed lowland rice system. South Jersey Farming. Page-57.

Mohanty, S.K., Singh, U., Balasubraamanian, V., and Jha, K.P. (1988). Nitrogen deep-placement technologies for productivity, profitability, and environmental quality of rainfed lowland rice systems. *Nutrient Cycling in Agroecosystems* **53 (1)**: 43-57.

Mohanty, S.K., Singh, U., Balasubramanian, V., Jha, K.P. (1999). Nitrogen deep-placement technologies for productivity, profitability, and environmental quality of rainfed lowland rice systems. *Nutr. Cycl. Agroecosys* **53**:43-57.

Mohmmad, M.J., Zuraiqi, S., Quasmeh, W., and Papadoppulos, I. (1999). Yield response and nitrogen utilization efficiency by drip-irrigated potato. *Nutr Cycling in Agro-eeosystem* **54**: 243-249.

Mohmmad, M.J., Zuraiqi, S., Quasmeh, W., and Papadoppulos, I. (2003). Yield response and nitrogen utilization efficiency by drip-irrigated potato. *Nutrient Cycling in Agro-ecosystem* **54**: 243-249.

Mohseni, A., Hosseni, H. M. S., and Abbasi, F. (2012) Comparison of fertigation with conventional (broadcast) fertilizer application method in uptake and losses of nitrogen in corn cultivation. *International Journal of Agricultural Research and Review* **2(3)**:211-217.

Mollah, M. I. U., Bhuiya, M. S. U., and Khatun, A. (2009) Nitrogen Use Efficiency of Wheat and Transplant *Aman* Rice under Bed Planting Method in Rice-Wheat Cropping System. *Journal of Agriculture and Rural Development* **7(1&2):** 41-49.

Mollah, M.I.U. (2005) Effect of bed planting technique on the productivity and resource conservation in rice- wheat cropping system .PhD Thesis. Department of Agronomy, Bangladesh Agricultural University, Mymensingh, November-2005.

Morandi, B., Manfrini, L., Losciale, P., Zibordi, M., and Corelli-Grappadelli, L. (2010). The positive effect of skin transpiration in peach fruit growth. *Journal of Plant Physiology* **167**:1033-1037.

Moujabber, M. El., Atallah, Th., and Darwish, T. (2002). Crop modeling and water use efficiency of protected cucumber. Water balance and fertigation for crop improvement in west Asia,IAEA, Vienna,2002.

Muchow, R.C., and Sinclair, T.R. (1994). Nitrogen response of leaf photosynthesis and canopy radiation use efficiency in field-grown maize and sorghum. *Crop Science* **34**: 721-727.

Muirhead, W.A., Melhuish, F.M., and White, R.J.W. (1985) Comparison of several nitrogen fertilizers applied in surface irrigation systems. I. Crop response. *Fertilizer Research* **6**: 97-109.

Mukherjee, S.K. (1986). Chemical technology for producing fertilizer nitrogen in the year 2000.Global aspects of food production. International Rice Research Institute. Tycooly international: 227-237.

Muniruzzaman, M. M. (2009). Increase or Decrease of Rice Yield as Affected by Weather, Cultivation and Management Practices. Page-2.

Murphy, L. (1983) Fertilizer placement: A primer. *Journal of Soil and Water Consumption* **38(3)**: 246-249.

Natarajan, K., and Manickam, T.S. (1991). Fate and Efficiency of urea nitrogen in flooded soil. *Fertilizer News* **36(3):** 27-49.

Nazrul, M.I., Hossain, M.J., Ali, M.Y., and Shahmim, R.U.(2006). Use of Urea Super Granule (USG) in vegetables cultivation: A profitable technology (Booklet). Published by Bangladesh Agricultural Research Institute, Gazipur. 8p.

Nissanka, S.P., and Bandara, T. (2004). Comparison of productivity of system of rice intensification and conventional rice farming systems in the dry-zone region of Sri Lanka. New directions for a diverse planet: Proceedings of the 4th International Crop Science Congress. Brisbane, Australia, 26 Sep.- 1 Oct.

Nommik, H. (1976). Further observations on ammonia loss from urea applied to forest soil with special reference to the effect of pellet size. *Plant and Soil* **45**: 279-282.

NRCS. (2007) National Research Centre for Soybean NRCS. Potassium nutrition in balanced fertilization of a Soybean-Wheat cropping system in Madhya Pradesh. *Research findings- No*. **11**, March 2007.

Obcema, W. N.,De Datta, S.K., and Broadbent, F.E. (1984) Movement and distribution of fertilizer nitrogen as affected by depth of placement in wetland rice. *Fertilizer Research* **5:** 125-148.

Ockerby, S. E., and Fukai, S. (2001) “The management of rice grown on raised beds with continuous furrow irrigation,” *Field Crops Research* **69(3)**: 215–226.

Ockerby, S.E. (1995). On farm development of a tropical irrigated rice-soybean cropping system. Final report for the rural industries research and development corporation and the grains research and development corporation. Queesland department of primary industries, *Mareeba, Qld* (ISSN 0727-6281).

Ockerby, S.E., and Fukai, S. (2001) The management of rice grown on raised beds with continuous furrow irrigation. *Field Crop Research* **69**:215-226.

Oosterhuis, D. (2009). Foliar fertilization: Mechanisms and magnitude of nutrient uptake. *Paper for the Fluid Fertilizer Foundation meeting in Scottsdale,* Arizona. February 15-17, 2009.

Pathak, H. (2010). Mitigating greenhouse gas and nitrogen loss with improved fertilizer management in rice: quantification and economic assessment. Received: 26 October 2009 / Accepted: 18 January 2010 / Published online: 4 February 2010. *Nutr Cycl Agroecosyst* **87**:443–454.

Pandey, N., Upadhyay, S.K., Joshi, B.S., and Tripathi, R.S. (2001) Integrated Use Of Organic Manures And Inorganic Fertilizer For The Cultivation Of Lowland Rice In Vertisol. *Indian Journal of Agriculture Research* **35 (2)**: 112 - 114.

Pandey, V. P., Singh, B., and Tripathi, H.P. (2000). Planting Of Crops With Furrow Irrigated Raised Bed (FIRB) System And Advantages Of Raised Bed Planting (RBP) in Crop Production. Department of Agronomy Narendra Deva University of Agriculture and Technology, Kumarganj Faizabad-224229 (U.P.)

Papadopoulos, I. (1987). Nitrogen fertigation of greenhouse-grown tomato. *Communication in Soil Science and Plant Analysis* **18**: 897-907.

Papadopoulos, I. (1993). Regional Middle East and Europe projection Nitrogen Fixation and water balance studies. Amman, Jordan, 18–27 October, 1993. RER /5/004 - 0, 5. 62 p.

Papadopoulos, I. (1994). Irrigation/fertigation research and application at farmers level in Cyprus. Expert consultation on research and extension in effective water use at farm level in the near east region. Cairo, Egypt.

Papadopoulos, I. (1996). Use of saline and brackish waters for irrigation in Cyprus. Mediterranean colloquim on protected cultivation, October 6–9, 1996. Morocco: A 6.1 – A 6.22.

Papadopoulos, I. (2000). Fertigation: present and future prospects. In: Ryan J. (ed.), Plant Nutrient Management under Pressurized Irrigation Systems in the Mediterranean Region. Proceedings of the IMPHOS International Fertigation Workshop organized by the World Phosphate Institute (IMPHOS), Amman, Jordan. ICARDA, Aleppo, Syria, pp. 232-245.

Patel, S .K., Panda, D., and Mohanty, S.K. (1989). Relative ammonia loss from urea-based fertilizers applied to rice under different hydrological situation *.Fertilizer Research* **19**: 113-119.

Paudel, M.N. (1995). Nutrient management for Sulphan buri- 90 rice variety in acid sulfate soil with green leaf manure. M.Sc. Thesis, Asian Institute of Technology, Bankok, Thailand.

Peng, S., Garcia, F.V., Laza, R.C., Sanico, A.L.,Visperas , R.M., and Cassman, K.G. (1996). Increased N use efficiency using a chlorophyll meter on high yielding rice. *Field Crops Research* **47**:243-252. permanent raised beds in Pakistan's Punjab. Edited by C.H. Roth, R.A. Fischer and C.A. Meisner

Pillai, K.G. (1981). Agronomic practices to improve the N use efficiency of rice. *Fertilizer News* **26 (2):** 3-9.

Pillai, K.G., and Vamadevan, V.K. (1978). Studies on the integrated nutrient supply system for rice. *Fertilizer News* **23(3):**11-14.

Ponnamperuma, F.N. (1972). The Chemistry of submerged Soils. *Advances in Agronomy* **24:** 29-96.

Prasad, R., and De Datta, S.K. (1979). Increasing fertilizer nitrogen efficiency in wetland rice. In: Nitrogen and Rice. *Intl. Rice Res. Inst., Los Banos, Philippines, pp. 465-479.*

Prashad, R., Singh, S., Prasad, M., Thomas, J. (1982). Increased efficiency of fertilizer nitrogen applied to rice through urea super granules. Paper presented at the seminar of Indians Farmers Fertilizers Co-operative Ltd. held at Bangalore during 27-28 May 1982. *Indian Journal of Agriculture Science* **59 (3):** 154-156.

Prihar, S.S., and Gagri, P.R. (1988). Fertilizer of dryland crops, paper presented at national symposium on recent advances in dry land agricultural. CRIDA, Hyderabad, 13-16, September, 1988. Primefact 1089: NSW Primary Industries.

Puckridge, D.W., Wiengweera, A., Thongbai, P., Sangtong, P., Sattarasart, A., Kongchum, M., Runtan, S. (1991). Nitrogen uptake by deepwater rice during the preflood and flooded phases, in relation to dry matter and grain production. *Field Crop Research* **27:** 315-336.

Qin, L. D.,TANG Qi-yuan., ZHANG Yun-bo., QIN Jian-quan., LI Hu., CHEN Li-jun.,YANG Sheng-hai.,ZOUYing-bin., and PENG, Shao-bing.(2012) Effect of Nitrogen Regimes on Grain Yield, Nitrogen Utilization, Radiation Use Efficiency, and Sheath Blight Disease Intensity in Super Hybrid Rice. *Journal of Integrative Agriculture* **11(1)**: 134-143.

Rahman, M.A. (2003). Effect of levels of urea super granules and depth of placement on the growth andyield of transplanted *aman* rice. MS (Ag.) Thesis, Dept. Agron. Bangladesh Agril. Univ. Mymensingh. pp: 100.

Rajput, T. B. S. (2010) Role of Water Management In Improving Agriculture Productivity .IARI, IJF, April, 2010.

Ram, J. Y., Singh, D. S., Kler., Kumar, K., Humphreys, I., and Timsina, J. (2005) "Performance crops and alternative cropping systems on permanent raised beds in the Indo-Gangetic plains of north-western India," in Proceedings of the ACIAR Workshop on Permanent Bed Planting Systems, Griffith, NSW, Australia.

Ram, J.Y., Singh., Kler, D.S., Kumar, K., Humphreys, I., and Timsina, J. (2005) Performance crops and alternative cropping systems on permanent raised beds in the Indo-Gangetic plains of north-western India. Presented in ACIAR Wordshop on Permanent Bed Planting Systems. 1-3 Mar. 2005. Griffith, NSW, Australia.

Ramasamy, C. (2008) Rice cultivation: 'Drip irrigation trials promising**'.** Business Daily from the hindu group of publications, Friday, May 02, 2008.

Ramaswamy, S., Sankaran, S., Velu, V., Athmanathan, V., Rajagopal, T. (1987). Split application of slow release urea. *Newsl. International Rice Research Institute* **12:** 45.

Rao, C.M., Ramaish, N.V., Reddy, S.N., and Reddy, G.V. (1986). Effect of urea and super granules on dry matter accumulation, yield and nutrient uptake in rice (*Oryza sativa*). *Journal Research* **14**: 1-3.

Rashid, M. A., Billah, K .A., Mazid, M.A ., and Jameel, F. (1996) Nitrogen use Efficiency of Urea Super granules and Prilled Urea in Irrigated Rice Cultivation. *Bangladesh Rice journal* **7(1&2)**: 41-44.

Raun, W. R. **(**1999) Improving Nitrogen Use Efficiency for Cereal Production**.** *Agronomy journal* **91(3)**: 357-363.

Rauthan, B. S., and Schnitzer, M. (1981) Effects of a soil fulvic acid on the growth and nutrient content of cucumber (cucumis sativus) plants. *Plant and Soil* **63(3**):491–495.

Reddy, M.D., and Mitra, B.N. (1985). Response of rice to different forms of urea and phosphorus fertilization under intermediate deepwater conditions. *Plant and soils* **84(3):** 431-435.

Reis, J,, Roberto dos A.; Silva, Douglas R. G; Ávila, Fabrício W.; de Ávila, Patrícia A.; Soares, Danilo de A.;Faquin, Valdemar (2012)Productivity and agronomic efficiency of cotton plants in response to nitrogen and sulfur supply *Revista Brasileira de Ciências Agrárias***7(**4): 555-561 octubre-diciembre, Universidade Federal Rural de Pernambuco Pernambuco, Brasil.

Rekha, K. B., Reddy, M. G., and Mahavishnan, K. (2005). Nitrogen and water use efficiency of bhendi (Abelmoschus esculentus L. Moench) as influenced by drip fertigation. *Journal of Tropical Agriculture* **43 (1-2)**: 43-46.

Research Achievement (2009). Bangladesh Rice Research Institute, Technology Development (2009-2010).

Rhoades, J.D. (1982) Cation exchange capacity. In Page, A L. (ed.), Methods of Soil Analysis. Part 2.Chemical and microbiological properties. *America Society of Agronomy*: 149-158 Madison, Wisconsin, USA.

Rice, C.W., and Symth, M.S. (1994) Short-term immobilization of fertilizer N at the surface of no till and plowed soils. *Soil Science Society America Journal* **48**: 295-297.

Rosecrance, R.C., Johnson, R.S., and Weinbaum, S.A. (1998a). The effect of timing of post-harvest foliar urea sprays on nitrogen absorption and partitioning in peach and nectarine trees. *Journal Horticulture Science Biotech* **73**:856-861.

Roy, B. (1988). Coated and modified urea materials for increasing nitrogen use efficiency of lowland rice in heavy clay soils. *Fertilizer Research* **15(2):** 101-109.

Roy, C. K. (2010) Urea Super Granule, A fertilizer of hope. The Daily Star, Tuesday, April 6, 2010.

Rutendo, N. (2012) Effects of Foliar Fertilizer Application during the Seed filling period on Soyabean (Glycine Max (L) Merr.) Grain Yield and Seed Quality. University of Zimbabwe.

RWC. (2002). Agenda notes of the 10th Regional Technical Coordination Committee meeting. New Delhi, 10-14th February 2002. Rice -Wheat Consortium for the Indo-Gangetic Plains, New Delhi.

Rymar, V. T., Udzhurkhu, A. Ch., Parkhomenko, V.D., Pivovarov, A.A., Steba, V.K., and. Smimova, E.S. (1989).Effect of different forms of nitrogen fertilizers on rice yield. *Fiziologiya-i-Biokhimiya-kul' Turnykh-Rastenii* **21(1):** 97-101.

Sagheb, N., and Hobbi, M.S. (2002). Field evaluation of urea fertilizer and water use efficiency by tomato under trickle fertigated and furrow irrigation in the Islamic republic of IRAN. Water balance and fertigation for crop improvement in west Asia, IAEA, Vienna, 2002.

Sahrawat, K.L. (2000): Marco and micronutrients removed by upland and lowland rice cultivars in West Africa. *Communications in Soils Science and Plant Analysis* **31(5 & 6):** 717-723.

Samar, S., Yadav, A., Malik, R.K., and Singh, H. (2002). Long term effect of zero tillage sowing technique on weed flora and productivity of wheat in rice wheat cropping zones of Indo Gangetic plains. In proceedings of International Workshop ”Herbicide Resistance Management and Zero Tillage in Rice-Wheat Cropping System” held at CCS HAU, Hisar.

Samuels, L., Kunst, L., and Jetter, R. (2008). Sealing plant surfaces: Cuticular wax formation by epidermal cells. *Annual Review of Plant Biology* **59:** 683-707.

Sarder, N.A., Shamsuddin, A.M., and Khan, N.H. (1988) Yield and yield components of wetland rice under various sources and levels of nitrogen. *Philippine Journal of Crop Science* **13**.

Sarvanan, A., Velu, V., Ramanathan, K. M .(1988) Effect of source of methods of nitrogen application on volatilization loss of ammonia and yield of rice under submerged of Cauvery Delta, India, *Oryza* **23**: 145-148.

Satsangi, G. P., and Yadav ,Sanjay. (2013). Response of BGA-Urea Fertigation as N2 Source on Growth Parameters and Yield of Paddy (*Oryza sativa* L.) in Agra (India). *World Academy of Science, Engineering and Technology* **79**.

Savant, N. K., and Stangel, P. J. (1990). Deep placement of urea super granules in transplanted rice: Principles and practices. *Fertilizer Research* **25:** 1–83.

Savant, N. K., and Stangel, P. J. (1998). Urea briquettes containing diammonium phosphate: A potential NP fertilizer for transplanted rice. *Fertilizer Research* **51:** 85–94.

Savant, N. K., Ongkingco, P .S., Zarate ,I V., Torrizo, F .M., Stangel, P. J (1991) Urea briquette applicator for transplanted rice. *Fertilizer Research* **28**:323-331.

Savant, N. K., Ongkingco, P. S., Garcia. F D., Dhane, S. S., Khadse, R. R., Chavan, S. A., and Rao, K. S. (1992) Agronomic performance of urea briquette applicator for transplanted rice. *Fertilizer Research* **32**:139-142.

Savant, N. K., Stangel, P. J. (1990). Deep placement of urea supergranules in transplanted rice: Principles and practices. *Nutrient. 09/1990* **25(1):**1-83.

Savant, N.K., and Stangel, P.J. (1985). Special publication SP-6, *International Fertilizer Development Centre, Muscle shoals, Albama, USA:* 133-134.

Sayre, K.D., Mezzalama, M., and Martinez, M. (2001). Tillage, Crop Rotation and Crop-Residue Management: Effect on Maize and Wheat Production for Rainfed Conditions in Altiplano of Central Mexico. CIMMYT, Mexico.

Schnier, H.F., Dingkuhn, M., De Datta, S.K., Marqueses, E.P., and Faronilo, J.E. (1988). Nitrogen use efficiency, flood water properties, and nitrogen balance in transplanted lowland rice as affected by liquid urea band placement. *Fertilizer Research* **16**:241-255.

Shafiee, M. I., Boycea, A. N., Khandakera, M. M., Johari, M., Saadb., Aziz, T. A., Mispana, M. S., Anuara, M. S. M.,and Bakar, B. H. (2013) Pilot Studies on Rice Yield Enhancement with Foliar Application of SBAJA in Sungai Besar, Selangor, Malaysia .*Life Science Journal* **10(1)** .

Shah, K.H., Aslam, M., Memon, M.Y., Siddiqui, S.H., Imtiaz, M., and Khan, P. (2003). A comparison of the efficiency of fertigation technique versus conventional methods of P application in berseem. *Pakistan Journal of Soil Science* **22(4):** 76-80.

Shah, K.H., Memon, M.Y., Siddiqui ,S.H., Imtiaz, M. and Aslam, M. (2003). Response of Wheat to Foliarly Applied Urea at Different Growth Stages and Solution Concentrations. *Plant Pathology Journal* **2**: 48-55.

Shah, K.H., Memon, M.Y., Siddiqui, S.H. and Aslam, M. (2001). Response of wheat to broadcast and fertigation technique for P application. *Pakistan Journal of Biology Science* **4**: 543-545.

Sharma, K.I., Vittal, K.P.R., Ramakrishna, Y.S., Srinivas, K., Warlu, B. V., and Kausuma, J. G. (2007).Fertilizer use constraints and Management in rainfed area with special emphasis on N use efficiency. *I .k. International Publishing House Pvt. Ltd*. New Delhi: 121-138.

Sharma, P. K., and De Datta, S. K. (1986). “Physical properties and process of puddled rice soil,” *Advances in Soil Science* **5:**139–178.

Sharma, P. K., Bhushan, L., Ladha, J. K., Naresh, R. K., Gupta, R. K., Balasubramanian, B. V., and Bouman, B. A. M. (2003). Crop–water relations in rice–wheat cropping under different tillage systems and water-management practices in a marginally sodic, medium-textured soil. In ‘‘Water-Wise Rice Production’’ (B. A. M. Bouman, H. Hengsdijk, B. Hardy, P. S. Bindraban, T. P. Tuong, and J. K. Ladha, Eds.). pp. 223–235. Proceedings of a Thematic Workshop on Water-Wise Rice Production, 8–11 April 2002 at IRRI Headquarters in Los Ban˜ os, Philippines. International Rice Research Institute, Los Ban˜ os, Philippines.

Sharma, P.K., Ladha, J.K., and Bhushan, L .(2003). Soil physical effects of puddling in rice-wheat cropping systems. In Improving productivity and Sustainability of rice- wheat systems; Issues and impact. *American Society of Agronomy Spec.Publ* **65**: 97-113.

Sharpe's Soil Service Ltd (2013). www.sharpes.ca.

Shaygany., Jamshid., Peivandy., Noura., Ghasemi., Seyedhadi. (2012). Increased yield of direct seeded rice (*Oryza sativa* L.) by foliar fertilization through multi-component fertilizers. *Archives of Agronomy and Soil Science* **58 (10)**:1091-1098.

Shayganya, J., Peivandy, N., and Ghasemi, S. (2011). Increased yield of direct seeded rice (*Oryza sativa* L.) by foliar fertilization through multicomponent fertilizers. *Archives of Agronomy and Soil Science* **2011**: 1-8.

Shukla, R .K., Sharma, R. S., and Chipde, S. J. (1993) Improvement of N use efficiency in transplanted rice. *Oryza* **30**: 259-261.

Sinclair, T. R., Tanner, C. B., and Bennett, J.M. (1984). Water use efficiency in crop production. *Bioscience* **34:** 36-40.

Singh, A. K., Choudhury, B. U., and Bouman, B. A. M. (2003). Effects of rice establishment methods on crop performance, water use, and mineral nitrogen. In ''Water-Wise Rice Production'' (B. A. M. Bouman, H. Hengsdijk, B. Hardy, P. S. Bindraban, T. P. Tuong, and J. K. Ladha, Eds.). pp. 223– 235. Proceedings of a Thematic Workshop on Water- Wise Rice Production, 8–11 April 2002 at IRRI Headquarters in Los Ban˜ os, Philippines. *International Rice Research Institute, Los Ban˜os, Philippines.*

Singh, A., Aggarwal, N., Singh, G. A. and Hundal, R. K. (2012) Ways to Maximize the Water Use Efficiency in Field Crops – A review .*Greener Journal of Agricultural Sciences* **2(4):**108-129.

Singh, B.K., and Singh, R.P. (1986). Effect of modified urea materials on rain fed low land transplanted rice and their residual effect on succeeding wheat crop. *Indian Journal of Agronomy* **31(2):** 198-200.

Singh, G., Singh, Y., Singh, V.P., Singh, R.K., Singh, P., Mortimer, M., Johnson, D.E., and Orr, A .(2003) . Direct seeding as an alternative to transplanting rice for the rice-wheat systems of the Indo-Gangetic Plain: Sustainability issues related to weed management. British crop science congress. (In press).

Singh, J. R., Kler, D. S., Kumar, K., Humphreys, I., and Timsina, J. (2005) "Performance crops and alternative cropping systems on permanent raised beds in the indo-gangetic plains of north-western India," in Proceedings of the ACIAR Workshop on Permanent Bed Planting Systems, Griffith, NSW, Australia, March 2005.

Singh, S., Chhokar, R.S., Gopal, R., Kumar, V., and Singh, M. (2009). Integrated weed management – A key for success of direct seeded rice.

Singh, S., Chhokar, R.S., Gopal, R., Kumar, V., Singh, M. (2009) Integrated weed management –A key for success of direct seeded rice in the Indo-Gangetic Plains. *International Rice Research Institute (IRRI),* Los Baños, Laguna (Philippines).

Singh, S., Ladha, J. K., Gupta, R. K., Bhushan, L., and Rao, A. N. (2008). "Weed management in aerobic rice systems under varying establishment methods," *Crop Protection* **27(3–5)**: 660– 671.

Singh, U., and Allgood ,J. H. (2013) Ag Sector Council Seminar, Fertilizer Deep Placement Technology: A Useful Tool in Food Security Improvement .Ronald Reagan Building ,1300 Pennsylvania Ave Public Information Center (Room M17/M18) Washington, DC United States ,April 24, 2013.

Singh, U., Cassman, K. G., Ladha, J. K., Bronson, K. F. (1995) Innovative nitrogen management strategies for lowland rice system. Pages 230-254 in *Fragile lives in fragile ecosystem*. Proceedings of the international Rice Research Conference, 13-17 Feb 1995. International Rice Research Institute, P.O. Box 933, Manila, Philippines.

Singh, U.P. (2002). Boro Rice in Eastern India. Rice-Wheat Consortium Regional Technical Coordination Committee Meeting. 10-14 February 2002. Rice-Wheat Consortium for the Indo-Gangetic Plains, New Delhi, India.

Singh, U.S., Dar, M.H., Singh, S., Zaidi, N.W., Bari, M.A., Mackills, D.J., Collard, B.C.Y., Singh, V.N.,Singh, J.P., Reddy, J.N., Singh, R.K., and Ismail, A.M. (2013). Field performance, dissemination, impact and tracking of submergence tolerant (Sub1) rice varieties in south Asia. *SABRAO Journal of Breeding and Genetics* **45 (1)** 112-131.

Singh, Y., Humphreys, E., Kukal, S. S. (2009). "Crop performance in permanent raised bed rice-wheat cropping system in Punjab, India," *Field Crops Research* **110(1):**1–20.

Sirisena,D.N., Wickramasinghe, W.M.A.D.B., and Ranatunge, R.A.N.D. (2002) performance of different form of urea in rice cultivation. Short Communication.

Sivanappan, R.K. (2006) Fertigation useful to increase crop yield .The Hindu, September 2006,Tamil Nadu, India.

Sivanappan, R.K. (1985). In: Drip irrigation in Action **II** *ASAE*, *Michigan* 736-740.

Soltanpour, P.N., and Workman, S. (1979) Modification of the NH4HC03 -DTPA soil test to omit carbon black. *Communication Soil Science Plant Analysis* **10:**1411-1420.

Soman, P. (2012) D2S6b PPT Drip Irrigation and Fertigation Technology for Rice Cultivation. Source -Scribd, Subject-Business & Law.

Stangel, P. J. (1989) Urea supergranule for transplanted rice. *IFDC Research Review*: 1-9 in soil fertility and fertilizer use. Vol. 3. Virendra Kumar al (Eds.) Indian farmers Fertilizer Cooperative Limited.new Delhi.

Starek, J., McCann, C., Westermann, I.R., Izadi, D.T., and Tisdall, T.A. (1993). Potato response to split N timing with varying amount of excessive irrigation. *American Potato Journal* **70**: 765-777.

Stevens, Gene., Heiser, Jim., Rhine, Matt., and Dunn, David .(2008) Nitrogen Fertilization for Sprinkler Irrigated Rice. University of Missouri-Delta Center.

Subramanian, S., Venkataramanan, C. R. (1980). A note on the time and mode of nitrogen application to rice (IR 20). *Madras Agricultural Journal* **67 (8)**:546-547.

Sudjadi, M., Prawirasumantri, J., Brrien, D.T.O., and Irawan (1984).Evaluation of nitrogen fertilizer efficiency trials in rice conducted in Indonesia under the NSFFER guidelines. In proceedings of the workshop under deep placement technique. Centre for Soil Research, Bogor, Indonesia, September.27-28, 1984.

Suwanarit A., and Sestapukdee, M. (1989). Stimulating effects of foliar k-fertilizer applied at the appropriate stage of development of maize: a new way to increase yield and improve quality *Plant and Soil* **120(1):**111–124.

Tabbal, D.F., Bouman, B.A.M., Bhuiyan, S.I., Sibayan, E.B., Sattar, M.A. (2002). On-farm strategies for reducing water input in irrigated rice: case studies in the *Philippines Agriculture Water Management* **56**:93-112.

Taha, M.H., Abdel-Hadi, A.H. and Shadr, M.S. (1996) Efficiency of some N and P sources on some crops in Egypt. International Workshop on Technology and Equipment of Compound Fertilizers, China, May - June, 96.

Taiz, L.,and Zeiger, E. (1998) Plant physiology. Second edition, Sinamer Associates, Inc, Publishers *Sunderland Massachusetts, USA* **1998:** 113-124.

Talukder, A.S.M.H.M., Meisner, C A., Sarkar, M.A.R., and Islam, M.S. (2010) Effect of water management, tillage options and phosphorus rates on rice in an arsenic-soil-water system.19th World Congress of Soil Science, Soil Solutions for a Changing World, 1 – 6 August 2010, Brisbane, Australia.

Tandon, H.L.S. (1987). Phosphorus Research and Agricultural Production in India. Fertilizer Development and Consultation Organization, New Delhi, Indian, pp: 160.

Tang, Y. L., Zheng, J. G., and Huang, G. (2005) "Studies on permanentbed- planting with double zero tillage for rice and wheat in sichuan basin," *Southwest China Journal of Agricultural Sciences***18(1)**: 25–28.

Tarfa, B., And Kiger,B.G. (2013) UDP and Rice production in Nigeria: "Guiding Investments in Sustainable Intensification in Africa" Abuja, Nigeria – June18, 2013.

Tattini, M., Chiarini, A., Tafani, R. and Castagneto, M. (1990) "Effect of humic acids on growth and nitrogen uptake of containergrown olive (*Olea europea* L. Maurino)," *ISHS Acta Horticulturae*, **286:**125–128.

Thakur, R.B. (1991). Relative efficiency of prilled urea and modified urea fertilizers on rainfed lowland rice. *Indian Journal of Agronomy* **36(1):** 87-90.

Thomas, J., and Prasad, R. (1982). On the nature of mechanism responsible for the higher efficiency of the urea super granules for rice. *Plant and Soil* **69**: 127-130.

Thompson, J., Griffin, D., and North, S. (2003). "Improving the water use efficiency of rice," Final Report 1204, Yanco, Co-Operative Research Centre for Sustainable Rice Production, New South Wales, Australia, 2003.

Thompson, J., Griffin, D., and North, S. (2003). Improving the water use efficiency of rice. Final report Project No. 1204, Cooperative Research Centre for Sustainable Rice Production, Yanco, New South Wales.

TNAU. (2013). Nutrient Management: Tips for Better Fertilizer Use Efficiency. TNAU, Agritech Portal.

Tompson, J. (1999). Methods for increasing rice water use efficiency workshop proceedings. Yanco (Australlia): *CRC for Sustainable Rice Production*: 45-46.

Tracy, P., Sims, B.D., Hefner, S.G., and Cairns, J.P. (1993). Guidelines for producing rice using furrow irrigation. (Department of Agronomy, University of Missouri, Columbia USA).

Tran, D.V.,and Marathée, J.P., (1994). Major Issues in Asian Rice-Wheat Production Systems. Sustainability of Rice-Wheat Production Systems in Asia. RAPA Publication**11:** 61-67.

Treeby, M., Falivene, S., and Skewes, M. (2011). Fertigation: delivering fertiliser in the irrigation water. Primefact 1089: NSW Primary Industries.

Tumbare, A.D. (1999) Effect of liquid fertilizer through drip irrigation on growth and yield of Okra (*Hibiscus esculentus*). *Indian Journal of Agronomy* **44(1):** 176-178.

Tuong, T.P. (2003). Strategies for increasing water productvity in rice irrigation system: water saving irrigation technologies. In proceedings of the international conference on increasing water use efficiency in lowland rice cultivation . setember 15-19 , 2003. Iksan, Korea . Rural Development Adminstration, Republic of Korea: 39-65.

Tuong, T.P., Bouman, B.A.M., and Mortimer, M. (2004). More Rice, Less Water—Integrated Approaches for Increasing Water Productivity in Irrigated Rice-Based Systems in Asia. Crop Science- ICSC2004

Upadhaya, B.P. (2005).Climate and agriculture. [Online].Available: http://www.gorkhapatra.org. np /index.php.

Utomo, W. H., Prastowo, B., Adisarwanto, T., Dacanay, E. V., Kirchhof, G. S., and So, H. B. (1994). "Soil puddling and rice growth," in Management of Clay Soil for Lowland Rice-Based Cropping Systems, *G. S. Kirchhof and H. B. So, Eds*., vol**. 70** of *ACIAR* Proceedings, pp. 90–94, Australian Centre for International Agricultural Research, Canberra. Australia.

Venkatesh, K., Singh, S.K., Mamrutha, H.M., Tiwari, V., Gupta, O.P., and Sharma, I. (2013) Best management practices for safe and economic use of Nitrogenous fertilizer. Krishisewa- *Agriculture information Hub.*

Venugoplan, M. V., Tarhalkar, P. P., and Singh, J. (1995) "Efficacy of phosphate carriers as foliar fertilizer on rainfed upland cotton (*Gossypium hirsutum*)," *Indian Journal of Agricultural Science* **65 (5)**: 320–328.

Vethaiya, B., Ladha, J.K., Gupta, K.R., Naresh, R.K., Mehla, R.S., and Yadvinder, S. (2003). Technology options for rice in the rice wheat system in South Asia. Improving the productivity and sustainability of rice wheat system: issues and impacts proceedings of an international symposium, USA, 22 October, 115-147.

Vories E.D., Counce, P.A., and Keisling, T.C. (2002) Comparison of flooded and furrow irrigated rice on clay. *Irrigation Science* **21**: 139-144.

Vories, E., Counce, E. P., and Keisling, T. C. (2002). "Comparison of flooded and furrow-irrigated rice on clay. *Irrigation Science* **21(3):** 139–144.

Wabel, M.I., Jaloud, A.A., Hussain, G., and Karimulla, S. (2002). Fertigated for improved water use efficiency and crop yield. Water balance and fertigation for crop improvement in west Asia, IAEA, Vienna, 2002.

Wells, B. R., Vories, E., Norman, R. J., Kamputa, D. (1990) Nitrogen management of furrow-irrigated rice. *Research Series - Arkansas Agricultural Experiment Station* **398**:43-44.

Welselaar, R. (1985) Deep point placed urea in a flooded soil: a Mechanistic view. Special Publication SP 6: 7-14. *International Fertilizer Development Centre*, Muscle Shoals, USA.

Wetsellar, R. (1985). Deep point-placed urea in a flooded soil: a mechanistic view. Special Publications, *International fertilizer Development Centre* (IFDC), U.S.A. special publication **6:**7-14.

Will, S., Eichert, T., Fernandez, V., Moehring, J., Mueller, T., and Roemheld, V. (2011). Absorption and mobility of foliar-applied boron in soybean as affected by plant boron status and application as a polyol complex. *Plant and Soil* **344**:283-293.

Witter, S.H., Bukovac, M.J., and Tukey, H.B. (1963). In "Fertiliser Technology and Usage". (Eds McVicar, M.H., Bridges, G.L. and Nelson, L.B.) (*Soil Sci. Soc. Amer. Madison*).

Wilson, N. D. (2000) Foliar feeding crops. ViTech Industries, Inc. P.O. Box 604 Maricopa, Az 85139 520-568-4313.

World Bank. (1997). Staff appraisal report, Pakistan National Drainage Project. Report No. 1531U, pp 3–4, Rural Development Sector Management Unit, South Asia Region.

Yadav, A., Malik, R. K., Chouhan, B. S. (2002). Feasibility of raising wheat on furrow irrigated raised beds in South-Western Haryana in Proceedings of the International Workshop on, Herbicide Resistance Management and Zero Tillage in Rice-Wheat. 83.

Yamada, Y., Ahmed, A., Alcantara, A., Khan, H. (1979) Nitrogen efficiency study under flooded paddy conditions. Pages 39-74 in proceedings of the final INPUTS Review Meeting. East West Center, Honolulu, Hawii.

Yang, J., Liu, K., Wang, Z., Du, Y., and Zhang, J. (2007) Water-saving and high-yielding irrigation for lowland rice by controlling limiting values of soil water potential. *Journal of Integrated Plant Biology* **49**:1445-1454.

Yoshida, S., Forno, D.A., Cock, J.H., Gomez, K.A. (1976) Laboratory manual for physiological studies of rice. International Rice Research Institute, Philippines, P.83.

Young, R.D., and Hargett, N.L. (1984). History, growth and status. In: Fluid fertilizer. J.M. Potts (eds.) Tennessee Valley Authority (TVA), Bull. Y-185.

Zaman, S. K., Razzaque, M. A., Karim, S. M. R., and Ahmed, A. U. **(**1993).Evaluation of Prilled Urea and Urea Supergranules as Nitrogen Sources for Upland Aus Rice. *Bangladesh rice journal* **4(1 &2):** 42-46.

Zayed, B.A., Salem, A.K.M. and Sharkawy, H.M. El. (2011). Effect of Different Micronutrient Treatments on Rice (*Oriza sativa* L.) Growth and Yield under Saline Soil Conditions. *World Journal of Agricultural Sciences* **7 (2)**: 179-184.

Zhang, T. Q., Tan, C. S., Liu, K., Drury, C. F., Papadopoulos, A. P., and Warner, J. (2009). Yield and Economic Assessments of Fertilizer Nitrogen and Phosphorus for Processing Tomato with Drip Fertigation. *Agronomy Journal* 102 (2): 774-780.

Zhongming, M., and Fahong, W. (2005). "Raised bed-planting system for irrigated spring wheat in hexi corridor," in Proceedings of the ACIAR Workshop on Permanent Bed Planting Systems, Griffith, March 2005.

Zia, M. S., Aslam M., and Gill, M. A. (1992). Nitrogen management and fertilizer use efficiency for lowland rice in Pakistan. Soil Science and Plant Nutrition **38(2).**