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Effect of Crop Establishment Methods, Nitrogen and Weed Management Practices on The Performance of Rice Variety

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University of Rajshahi

Dedicated

To my

Father

for whom I am always dying for

and crying my eyes

DECLERATION

I do hereby declare that the whole work submitted as a Dissertation entitled **"Effect of Crop Establishment Methods, Nitrogen and Weed Management Practices on The Performance of Rice Variety"** in the Institute of Biological Sciences, University of Rajshahi, Bangladesh, for the degree of Doctor of Philosophy (PhD) is the result of my own investigation and was carried out under the supervision of **Dr. Aminul Hoque**, Professor, Department of Agronomy and Agricultural Extension, University of Rajshahi, Bangladesh. The Dissertation has not been submitted in the substance for any other degree.

Date: February 2016

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CERTIFICATE

This is to certify that Mrs. Sultana Kaniz Ayesha has worked under my supervision. I am pleased to forward her Dissertation entitled **"Effect of Crop Establishment Methods, Nitrogen and Weed Management Practices on The Performance of Rice Variety"** which is the record of bonafide research carried out at the Institute of Biological Sciences, University of Rajshahi, Bangladesh. She has fulfilled all the requirements of the regulations relating to the nature and prescribed period of research for submission of Dissertation for the award of PhD degree.

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In Him I trust and to Him alone, I turn for help."

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The Author

Abstract

Four experiments were conducted at BRRI Regional Station, Shyampur, Rajshahi to find out the most selective crop establishment method, best application option of N and suitable weed management practices in both *T. aman* and *Boro* season. Popular *T. aman* rice variety BRRI dhan44 and *Boro* rice variety BRRI dhan45 were used as planting materials, where three crop establishment methods (T_1= direct wet seeding by drum seeder, T_2= hand broadcasting and T_3= transplanting) were common treatments for the whole study of N management (N_1= ⅓ at 15 DAT+ ⅓ at 30 DAT +⅓ at PI, N_2= ¼ at basal + ¼ at 15 DAT + ¼ at 30 DAT + ¼ at PI, N_3= LCC based N application and N_4= no nitrogen) for the experiment one and three and weeding options (W_1=Hand weeding, W_2=BRRI weeder + HW, W_3=Herbicide + HW and W_4= no weeding) for the experiment two and for four. The experiment was laid out in RCBD with three replications and means were adjudged by DMRT at 5% level of probability. Data were collected on morpho–physiological, yield and yield attributes where the most of the studied characters were statistically significant due for single effect or their interactions. In experiment one, effect of crop establishment method, the plant population had maximum (143.16) in transplanting methods (T_3) at 60 DAS and highest grain yield (5.05 t ha^{-1}) at than other two crop establishment methods while T_2 (hand broadcasting) obtained the highest BCR (2.34). Among the N management practices, N_2 showed significantly the greater result on plant population (134.11) at 60 DAS and grain yield (4.97 t ha^{-1}) the highest BCR (1.97). For interaction effect between crop establishment and N application methods, plant population had maximum (152.33) in interaction treatment of T_3N_2 at harvest. In experiment two, highest yield (5.12 t ha^{-1}) was obtained in T_3 with highest BCR (2.08) was found in hand broadcasting (T_2). For weed management, superior results found for plant population (139.66) at 60 DAS, grain yield (4.97 t/ha) and BCR (1.47) in hand weeding treatment. On the other hand, the highest PDM (36.20 g) at 60 DAS and yield (6.10 t ha^{-1}) were obtained in T_3W_1. Similarly, in experiment three plant population and PDM had maximum (57.29 and 4.43 g) in T_3 at 60 DAS while T_1 showed the highest BCR (1.47). Incase of N management, N_2 showed the maximum PDM (4.93 g) at 60 DAS and the highest BCR (1.97). The maximum number of plant population (67.16) at 60 DAS was taken in interaction of T_3N_2. For last experiment, transplanting method (T_3) showed significantly the maximum population of plant (61.87) at 60 DAS and highest yield (3.54 t ha^{-1}) however, T_2 showed the highest BCR (1.35). Similarly, maximum plant population (66.44) at 60 DAS, highest straw oven dry weight (31.54 g) at harvest and the highest BCR (1.91) were obtained for hand weeding treatments (W_1). So, the above observation of the whole study, it could be concluded that the transplanting method and N @ ¼ at basal + ¼ at 15 DAT + ¼ at 30 DAT + ¼ at PI singly (T_3 and N_2) or their interaction effect (T_3N_2) would be the most suitable for aman and boro. Considering weed management practices, the interaction of T_3W_1 would be the best option for T-aman (Exp.2) where the interaction effect of T_1W_1 (direct wet seeding by drum seeder × hand weeding) were the most efficient interaction for obtaining the higher yield during *Boro* season.

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ABBREVIATIONS

AEZ	=	Agro-Ecological Zone
ANOVA	=	Analysis of variance
BARC	=	Bangladesh Agricultural Researcher Council
BARC	=	Bangladesh Agricultural Researcher Council
BARI	=	Bangladesh Agricultural Research Institute
BAU	=	Bangladesh Agricultural University
BBS	=	Bangladesh Bureau of Statistics
BINA	=	Bangladesh Institute of Nuclear Agriculture
BRRI	=	Bangladesh Rice Research Institute
DAS	=	Days after sowing
DAT	=	Days after transplanting
DM		Dry matter
DMRT	=	Duncan's Multiple Range Test
e.g.	=	Exempli gratia (by way of example)
et al.	=	And others
FAO	=	Food and Agriculture Organization
i.e.	=	edest (means That is)
IRRI	=	International Rice Research Institute
LCC	=	Leaf colour chart
LSD	=	Least significant difference
mgL^{-1}	=	Milligram per litre
RCBD	=	Randomized Complete Block Design
TDM	=	Total dry matter
TDW	=	Total dry weight
var.	=	Variety
Viz.	=	Namely

CHAPTER 1

INTRODUCTION

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INTRODUCTION

Rice (*Oryza sativa* L) is the staple food for nearly half of the world population (Sellamuthu *et al.*, 2011). More than half of the world's populations depend on rice for calories and especially proteins in the developing countries. In Asia, where 3.1 billion people live, it provides an average 35% of total calories consumed, ranging up to 80% in comdodia (IRRI, 1995). In Bangladesh 76% of the people's average calorie intake and 66% of protein intake comes from rice (FAO, 2000). Majority of food grains come from the rice where 80 percent of its population use as staple food and food security means rice security in Bangladesh. Bangladesh is an agro-based country, earns about 23.46% of her gross domestic products (GDP) from agriculture (Kiron, 2003) and rice contributes 9.05% of the national GDP (BBS, 2004). Geographical and agro climatic conditions of Bangladesh are favorable for rice cultivation. Rice is grown under diverse ecosystem subject to irrigated, rainfed and deep water conditions in three distinct seasons, namely Aus, Aman and Boro. Among the seasons, boro rice covered about 3.94 million hectares with a production of 12.83 million metric tons of rice (BBS, 2004). Rice has strong role in the political stability of the country and provides a sense of food security to the people. Rice covers about 74% of the total cropped area (BBS, 2001) of 13.9 million hectors. Thus farming systems of Bangladesh are essentially rice-based. Bangladesh is one of the major rice growing countries in the world and ranks fourth both in area and production (BBS 2012). Bangladesh has made notable progress in sustaining a respectable growth in rice production over the last three decades. However, the population of Bangladesh is growing at an alarming rate and faces a tremendous challenge for providing food security to the increasing population. With the increase of rapid population in tropical zones in which rice is produced in large scale even a higher production level. Rice plays an important role in the agro-economy and national health of Bangladesh. Therefore, by all means, rice is and will remain the largest single source of income and employment in Bangladesh.

The average yield of rice in Bangladesh is very low, only 2.45 t ha^{-1} (BRRI, 2007). The average yield is almost less than 50% of the world average rice grain yield. On the other hand rice production area is decreasing day by day due to high population pressure. The agricultural land of Bangladesh is being reduced by about 1% per annum (Hossain *et al*, 2006) while the population is increasing at an alarming rate of 1.43% (Economic Review, 2006). The demand of rice will be increasing in future because of increasing population size. The projected population will be about 169 millions by the year 2025. We need to produce about 27.8 million metric tons of clean rice (41 million metric ton paddy) to feed the population by the year 2025, which is about 21% higher than the production level of 2000 (Bhuiyan *et al.,* 1996). To meet the rice demand of the over increasing population and to ensure food security, improvement in agronomic practices along with introduction of high yielding cultivars would be the most logical way to increase the total production at national level (Shnestha and Lodha, 1998; Kundu and Lodha, 1999).

Transplanting has been the major traditional method of rice establishment in Asia. It is the most popular crop establishment method in Asia's irrigated rice growing areas. It involves transplanting of rice seedlings previously grown in nurseries. The traditional manual transplanting is one of the most time consuming, water-using and labourious operations in rice cultivation. Direct seeding is becoming an attractive alternative to transplanting. Rice is direct seeded by essentially two methods (dry and wet seeding) based on physical condition of the field and seed (sprouting or dry). Although transplanting has been a major traditional method of rice establishment in Asia but economic factor and recent changes in rice production technology have improved desirability of direct seeding method. Direct seeded rice required only 34% of total labour requirement of transplanted rice. The economics of broadcast seedling on puddled fields or on dry soils vary greatly in South-East Asia. The significant advantage of direct seeding over transplanting rice is the shorter cropping cycle due to avoidance of transplanting shock, which delays rice growth and development (IRRI, 1987). Rice production system in Southeast Asian countries like

Bangladesh is undergoing changes with the technological advancement and socio-economic conditions. A labour saving culture is indispensable for modern agricultural farming because the less input the more the profit. This is to be done using direct seeding method. Now-a-days, the rising labour costs and need for intensification of rice production through double and triple cropping have been providing the economic incentives for providing a direct seeding method. In wet seeding method, the fields are puddled and sprouted seeds are sown on wet soil by broadcast or line method. It is practiced in irrigated and favourable rainfed lowlands. Direct seeding using a drum seeder, is one of the methods of crop establishment that has potential to deal with this problem. In order to achieve desired performance from direct wet seeded rice seeding has to be done before a cut-off date much earlier than most farmer transplants which leads to crop maturity much before the possible flash flood. In this method, the sprouted seeds of rice are sown on well puddled soil in rows. The application of nitrogen considering proper doses and time either in excess or less than optimum rate affects both yield and quality of rice to a remarkable extent. Hence proper nitrogen management in rice production is of immense value. LCC based nitrogen is newly being introduced indifferent countries for not only N use efficiency but also save nitrogen as well as higher or similar grain yield to the recommended split application of N fertilizer. By taking proper steps in promoting LCC-based nitrogen management potential area, country can be benefited by Tk. 8864 million from additional production and urea saving.

Weed is another major constraint in rice production which share or compete to nutrients, lights and water with rice. In this regard, the climatic as well as edaphic factor of Bangladesh is favourable for weed growth. In boro rice field, weeds of terrestrial, semi-aquatic and aquatic habitats grow throughout the growing season. For their competitive abilities weeds form a serious negative effect in crop production and responsible for marked losses in crop yield (Mamun *et. al.,* 1993). Thus effective weed management system needed to optimize the boro rice yield.

Therefore, the study was undertaken to evaluate alternative crop establishment methods, nitrogen management and weed control options for aman and boro rice with the following objectives:

1. To evaluate the performance of different crop establishment methods on the productivity of aman and boro rice
2. To determine the appropriate time of nitrogen fertilizer application in transplanting aman and boro rice
3. To compare the different weed control methods in transplant aman and boro rice

CHAPTER 2

REVIEW OF LITERATURE

CHAPTER 2

REVIEW OF LITERATURE

The present study was concerned with the different crop establishment methods towards various time and doses of nitrogen and weed management practices. Available literature indicates that a little research has so far been conducted in this aspect. In spite of limited research on this regard, attempt has been made to search out past studies having relevance to the present investigation keeping the major objectives of the study in mind.

2.1 Performance of different nitrogen application options on various characteristics of rice

The different use of fertilizer is recognized as an important factor for rice cultivation but it has always been a problem to raise the utilization rate of rice plant and to increase the efficiency of absorbed N for grain production, irrespective of the amount of N being applied. An adequate nitrogen supply can increase as much as 60% rice production. The low efficiency of N fertilizers is mainly caused by losses of N from the soil-plant system. One way to achieve a higher efficiency is split applications of fertilizers synchronized with the stages of vigorous absorption and efficient nitrogen assimilation by the plant for grain production. Selecting varieties having higher fertilizer use efficiency, placing fertilizers below soil surface, using controlled release fertilizer formulation and using N nitrifications and inhibitors (De Datta 1987) are the key integration for attaining higher yield N use efficiency.

Farmers usually broadcast urea by hand, often providing a surface basal application first followed by one or more top dressing during the growing season. When it is the broadcast on the surface soil and not incorporated, or when broadcast in the floodwater, prilled urea applications have been shown to be highly inefficient with N losses approximately 60-70% of N applied (De Datta and Buresh 1989, Cassman *et al.*, 2002). Such losses represent not only an economic drain for farmers but also have a negative impact on the environment. Since the reactive compounds of N decreases water quality and contribute to global climate change (Galloway *et al.*, 2003). Proper management of N and selection of suitable variety is very important to get the maximum yield and economic profit (Borah and Deka, 1994; Borrel *et al.*, 1998; Singh *et al.*, 1998; Wang *et al.*, 1998).

In Bangladesh, ripen Boro sometimes submerge by flash flood in low lying areas during April-May due to scarcity of labour in Boro season. Through wet seeding of rice, farmers get several benefits: like higher returns, less labour and less water requirement as compared to transplant rice (Sattar 1992). Each of these benefits is attractive for Bangladesh to overcome the scarcity of labour and high cost of water supply.

Sattar and Khan 1994 reported that direct wet-seeded rice required about 20% less water compared with transplant rice, since direct wet-seeded rice is grown initially under saturated condition and they could withstand drought better.

Husain *et al.*, 2004 also reported that manual direct wet-seeding increased grain yield of Boro rice by about 10% and reduced growth duration by about 10 days compared with transplanted rice.

However, research results have clearly showed the superiority of direct seeded rice to conventional transplanting in Bangladesh during Boro season (Khan *et al.*, 1992, Sattar *et al.*, 1996 and Husain *et al.*, 2002.).

It was concluded that direct wet seeding method of Boro rice would: produce around 10% higher yield and reduce maturity by about 10 days. Socio-economic analyses showed that direct seeded crops incurred about Tk. 2000/= ha^{-1} less costs compared to transplanted crops (Husain *et al.*, 2004). In 1993 Boro season an average of 10% water was saved in land preparation for wet seeded rice and average 319 kg ha^{-1} yield benefit was obtained over transplanted rice (Sattar and Khan 1994).

Direct seeding using a drum seeder, is one of the methods of crop establishment that has potential to deal with this problem. In order to achieve desired performance from direct wet seeded rice seedling has to be done before a cut-off date of much earlier than most farmer transplants which leads to crop maturity much before the possible flash flood (Bautista and Gagelonia 1994).

Husain *et al.*, 2003 reported that direct seeing of BRRI dhan28 , BRRI dhan29 and BRRI dhan36 produced about 2-12% higher grain yield than the transplanting method and matured of about 8 days earlier. Higher grain yield of direct seeded crops was associated with higher number of grains m^{-2} which was the product of number of panicles m^{-2} and the number of grains per panicle. The number of grains per panicle and 1000 grain weight were almost stable. Direct seeding of rice may be practiced in the irrigated ecosystem. Husain *et al.*, 2004 reported that direct seeded rice using thick row and double row of drum seeded gave the similar and highest grain yield of about 4.9 t ha^{-1} which was about 22% higher than that of the transplanted rice and about 6% higher than that of the direct seeded thin row rice. Higher yields in all direct seeding methods were resulted from more number of grains per unit area compared to transplanting method. This was revealed by a strong correlation between grain yield and number of grains m^2. All direct seeded rice matured about 10 days (ranged from 7 to 16 days0 earlier than the transplanted rice. Partial budget analysis showed that direct wet seeding by single thick row of the drum seeder would enable the farmers to obtain an additional profit of about Tk. 6116.00 ha^{-1} over transplanting. On an average, direct seeding using single thick row of the seeder produced about 21% higher yield than the transplanting rice.

LCC

Many experiments have been conducted on nitrogen management for rice but little information is available on nitrogen management for direct seeding and transplanting method especially using leaf color chart (LCC). It is a simple, inexpensive and easy to use tool by which a farmer can assess leaf color intensity, which is directly related to leaf chlorophyll content and leaf N status (Balasubramainan *et al.*, 1999). In

Bangladesh, LCC can be used as N management tool like chlorophyll meter in wider scale where the critical threshold value is 3.0-3.5 in both wet and dry seasons (Islam *et al.*, 1998). LCC based N is newly being introduced in different countries for not only N use efficiency but also save nitrogen as well as higher or similar grain yield to the recommended split application of N fertilizer. Khan *et al.*, 2004 reported that leaf color chart (LCC) based N management produced increased grain yields and reduced fertilizer N use over farmers' and recommended fertilizer rates in different regions. By taking proper steps in promoting LCC based N management potential area, country can be benefited by about Tk. 8864 million from additional production and urea saving. For crop need-based N management (using SPAD meter), N fertilizer rates were 90 and 138 kg ha^{-1} in the wet and dry seasons, respectively (Husain *et al.*, 2004). They suggested three equal splits at basal 38 DAT, and 59 DAT (save 30 kg N ha^{-1} in wet season and 45 kg ha^{-1} in dry season). A second top dressing early in the reproductive stage is required for maximum spikelet differentiation, which appears to be a major determinant of storage capacity and grain yield. Norman *et al.,* 1992 reported that use of three-way split application method consistently resulted in either the highest or one of the highest grain yields. Split applications in practically important when higher rate of N are used with a view to consider the ability of the plant to utilize limited amount of N effectively at a particular growth stage. However, most of the research works have been reported on N management, N uptake, N use efficiency, weed management under irrigated transplanted systems but such studies on data in direct-seeded systems are meager. Therefore, the influence of both N including LCC based N and weed management practices under different planting methods and its economic performances are needed to be evaluated under Bangladesh condition.

The experiment of Bekere *et al.*, (2014) was to investigate the effect of split application of nitrogen on growth and yield of NERICA-1 and NERICA-4 rice varieties at Tsukuba International Center, Japan. The result showed that NERICA-1 had significantly greater establishment percentage, SDM, panicle length and 1000–

grain weight than NERICA-4, but its leaves were significantly ($p<0.05$) less green than the latter after 55 days of sowing. It also produced significantly longer panicles than the other two modes of N applications.

Alim (2012) reported that the fertilization of BRRI dhan28 and BRRI dhan36 varieties of rice with 60 kg N ha^{-1} as urea and 60 kg N ha^{-1} as MOC or 50 kg N ha^{-1} as urea with 50 kg N ha^{-1} as MOC was found to be the best nitrogen rate among all the treatment combinations in respect of grain and straw yields.

Haque *et al.*, (2012) investigate the response of different doses of nitrogen application at different growth stages on fine *aman* rice (cv. Kalizira) and reported that different doses of nitrogen had significant positive effect on the most of the vegetative parameters. Plant height, numbers of tiller $hill^{-1}$, leaf $hill^{-1}$, DM $hill^{-1}$ were highest with the increasing rate of nitrogen at all sampling dates excluding final harvest.

Husain *et al.,* (2003) reproduced that direct seeding of method BRRI dhan28, and BRRI dhan36 produced about 2-12% higher grain yield than the transplanting method and matured about 8 days earlier. Higher grain yield of direct seeded crops was associated with the increased product of number of grains m^{-2} which was the product of number of panicle's m^{-2} and number of grains $panicle^{-1}$. The number of grains $panicle^{-1}$ and 1000 grain weight were almost stable. Director seeding of rice may be practiced in the irrigated ecosystem.

Husain *et al.,* (2004) reported that direct seeded rice using thick row and double row of drum seeder gave the similar and highest grain yield of about 4.9 tha^{-1} which was about 22% higher than that of the transplanted rice and about 6% higher than that of the direct seeded thin row rice. Higher yield in all direct seeding methods were result from more number of grains $unit^{-1}$ area compared to transplanting method. This was revealed by a strong correlation between grain yield and number of grains m^{-2}. All direct seeded rice mature about 10 days (ranged from 7 to 16 days) earlier than the transplanted rice. Partial budget analysis showed that direct wet seeding by single thick row of the drum seeder would enable the garners to obtain an additional profit of about Tk. 6116.00 ha^{-1} over transplanting. On an average, direct seeding using single thick row of the seeder produced about 21% higher yield than transplanted rice. However, direct seeding is associated with more seed infestation which may be managed by careful use of herbicides and use of BRRI weedier. The technology is more appropriate in Boro-Fallow-Fallow cropping pattern where seeding can be done early in the season immediately after recession of floodwater. For T.Aman-Boro systems, it can be applicable where the land is ready for seeding within mid-December and irrigation can be applied. Experiments conducted at research farm and on-farm have very clearly demonstrated that irrespective of rice varieties, direct wet seeded rice by drum seeder has 10-15% yield advantage over the conventional transplanted rice. The absolute yield difference between direct wet seeded and transplanted rice. The absolute yield difference between direct wet-seeding methods was only about 30 kg ha^{-1} which is less that 50% of that normally used by the farmers for transplanting. The technology has been tested vigorously both under on-station and on-farm conditions. The current coverage of direct wet seeded rice is about 20000 hectare's, which is increasing day by day.

Among the plant nutrients, nitrogen is the most essential element in determining the yield potentiality of intensified systems (Mae, 1997). Nitrogen plays a key role in supporting plant activity and increasing the rice yield (Subrahmaniyan, 1992). It is essential for the synthesis of protein, which are constituents of protoplasm and chloroplasts. Moreover, it may act as plant growth hormone, since its presence stimulates meristem tic growth and cytokinins biosynthesis. Rice plant requires nitrogen throughout the growing period. But De Datta (1986a) reported that for high yields as optimum nitrogen supply is important at four growth stages. They are: (i) just after rooting, (ii) at the neck-mode differentiation stage, (iii) just before the reduction division stage of pollen mother cell (about 10 days before heading) and (iv) at full heading stage. Nitrogen absorption by the rice plant during tiller intitaition increase the number of total tillers, which later may develop panicles. Nitrogen absorbed during the period from panicle initiation stage to the late stage of spikelet formation maker an effective contribution to spikelet production, whereas nitrogen absorbed after flowering tends to increase the individual grain weight (Mae, 1997). It was also observed that, if soils are well supplied with other nutrients and water is not limiting, rice yield of 3-4 t ha^{-1} could be achieved without adding nitrogen fertilizer (Ladha *et al.,* 1998). Because of microbial biomass accumulation at the soil surface due to associative and free-living nitrogen fixing microorganism and the corresponding enrichment by mineralization are very significant in nitrogen and the corresponding enrichment by mineralization are very significant in nitrogen cycling in wetland rice (Ladha *et al.,* 1998).

The response of rice to nitrogen is largely influenced by variety, soil fertility, environmental factors and management practices. Nitrogen enhances the vegetative growth of plant but the grain yield of rice increases up to a certain level with increase in nitrogen rate (Patnaiki, 1991).

Schnier *et al.,* reported that grain yields obtained from transplanted and direct wet-seeded rice at high levels of nitrogen (120 and 150 kg ha^{-1}) application were statistically similar, indicating that direct-seeded rice had yield potentially similar to that of transplanted rice.

Despite higher growth rates before panicle initiation, the grain yields of broadcast wet seeded growth stages (Peng *et al.,* 1996) BRRI (1993, 1998) reported that nitrogen requirement of modern varieties was 90 to 120 kg N ha^{-1} for the dry season whereas 60 to 90 kg N ha^{-1} for the wet season, depending on the growth duration of rice variety and soil type. Nitrogen is considered as the major yield limiting factor of wet land rice. (De Datta, 1986a) and it is most different to manage it as because a large number of potential transformation pathways are involved in its utilization by rice plants (Fageria, *et al.,* 1997.) Minimizing nitrogen losses from the soil-plant system and maximizing its uptake at critical growth stage are the key points of management of this fertilizer (Mikkelsen *et al.,* 1995). A proper timing of N application, being a precondition for high N use efficiency helps to reduce losses through ammonia volatilization and denitrification. According to Mikkelsen *et al.*, (1995), in tropical areas many farmers split fertilizer N into three doses. The first application is usually made prior to transplanting, desirably with soil incorporation but frequently into stage, whereas the final application is made at or just prior to panicle initiation stage. These split applications are made to maintain the supply of nitrogen for the crops and to maintain minimum losses through volatilization, de-nitrification, leaching or run-off. However, management practices for basal fertilizer N application are similar for both transplanting and broadcast seeding. Many Philippines farmers broadcast the first dose of fertilizer 2-3 week after broadcasting pre-germinated seeds, a practice similar to that followed for transplanted rice (De Datta and Nantasomsarn, 1990). Two-thirds of the fertilizer was broadcast and harrowed into soil before transplanting while one third was broadcast at the panicle initiation stage of the crop. The major disadvantages of applying all nitrogen at planting are the induction of excessive foliage growth and encouragement of excessive weed growth (Grist, 1986). On the other hand, basal application of nitrogen makes the plants more prone to lodge since plants are not established at this time. Shifting the basal dose by 20 DAT is, therefore, advantageous in terms of nitrogen uptake, possibly because nitrogen is applied to the soil when the crop is in active tillering stage and it is in a stage to absorb N vigorously. Thus, N losses are minimized (Mahapatra *et al.*, 1997). According to Mikkelsen *et al.,* (1995), the major nitrogen requirement occurs during early vegetative growth stage and at panicle initiation stage.

Mae (1997) also reported that the nitrogen supply pattern and its uptake process throughout the whole growth cycle of a plant is equally important, because of formation of each yield component strongly depends on the amount of nitrogen supplied at each crucial stage for the particular yield components. Tiller number at maximum tillering and at flowering stage is positively correlated with nitrogen uptake (Krisnakumar and Subramanian, 1992) However, Sheehy *et al.,* (1998) mentioned that nitrogen uptake during the reproductive phase was the most important for final yield. De Datta *et al.,* (1998) evaluated broadcast seeded and transplanted rice under similar N management practices. With applied urea, mean 15 N plant recovery was higher for broadcast seeded rice (47%) than for transplanted rice (37%). Futher, De Datta *et al.,* (1996) mentioned that NH3 volatilization loss could be reduced by 28% of the total N applied using broadcast flooded rice in comparison to transplanted rice. Peng *et al.,* (1996) recommended that the fixed timing N fertilizer rates in Los Banos, Philippines should be 120 and 180 kh N ha^{-1} of irrigated rice in the wet and dry seasons, respectively. They also suggested the fixed timing on N fertilizer as four split applications at final harrowing prior to transplanting, mid-tillering, panicle initiation (PI), and early flowering. Many experiments have been conducted on nitrogen management for rice but little information is available on nitrogen management for direct seeding and transplanting method especially using leaf color chart (LCC). It is a simple, inexpensive and easy to use tool by which a farmer can assess leaf color intensity, which is directly related to leaf chlorophyll content and leaf N status (Balasupramainan *et al.,* 1999). In Bangladesh, LCC can be used as N management tool like chlorophyll meter in wider scale where the critical threshold value is 3.0-3.5 in both wet and dry seasons (Islam *et al.,* 1998).

Khan *et al.,* (2004) reported that leaf colour chart (LCC) based N management produced increased grain yield and reduced fertilizer N use over farmers and recommended fertilizer rates in different regions.

Husain *et al.,* (2004) suggested three equal splits at basal, 38 DAT, and 59 DAT (save 30 kg N ha^{-1} wet season, 45 kg ha^{-1} in dry season). In direct-seeded wetland rice, N topdressing at mid-tillering is a prerequisite for obtaining higher grain yield (Keisers, 1987). A second topdressing early in the reproductive period is required for maximum spikelet differentiation, which appears to be a major determinant of storage capacity and grain yield. Norman *et al.,* (1992) reported that use of the three-way split application method consistently resulted in either the highest or one of the highest grain yield split application important when higher rate of N are used with a view to consider the ability of the plant to utilize limited amount of N effectively at a particular growth stage. However, most of the research works have been reported on N management, N uptake, N use efficiency, weed management under irrigated transplanted systems but such studies on data in direct-seeding systems are meager. Therefore, the influence of both N including LCC based N and weed management practices under planting methods and its economic performances are needed to be evaluated under Bangladesh condition.

2.1.1 Plant height

Nitrogen plays the key role in the growth or rice plant especially for plant height. Lenka and Behara (1967) reported that application of higher doses of N (120 kg ha^{-1}) significantly increased the plant height.

Idris and Matin (1990) found that plant height increased while increasing N dose up to 120 kg N ha^{-1} compared to the control and there after it declined at 140 kg N ha^{-1}. Reddy *et al.,* (1990) observed that nitrogen has positive effect on plant height of rice.

Hussain and Sharma (1991) reported that application of nitrogen up to 140 kg ha^{-1} increased plant height. At 80 kg and 120 kg N ha^{-1}, the change in this parameter was non-significant. The highest plant height was observed from 120 kg N ha^{-1}.

Kumar *et al*., (1995) found that there was a significant effect of increasing levels of nitrogen on the increasing of the plant height. Sahrawat *et al*., (1999) observed that nitrogen level significantly affect plant height. Increasing levels of nitrogen increased the plant height significantly up to 120 kg N ha^{-1}.

2.1.2 Number of tillers hill^{-1}

Nitrogen has strong influences on tiller production of rice. Rao *et al.*, (1986) reported that split application of nitrogen increased total tillers hill^{-1} compared to entire nitrogen applied as basal.

Reddy *et al.*, (1988) observed that nitrogen application in three split from 0 to 120 kg ha^{-1} increase total tillers hill^{-1}. Idris and Matin (1990) noticed that the maximum tillers hill^{-1} was obtained from 140 kg N ha^{-1} which was statistically similar to 60, 80, 100 and 120 kg N ha^{-1} and the minimum tillers hill^{-1} was observed from the control treatment (0 kg ha^{-1}).

Kumar *et al.*, (1995) reported that increasing level of N from 80 to 120 kg N ha^{-1} significantly increased total tillers hill^{-1}. Maske *et al.*, (1997) concluded that number of tillers hill^{-1} increased significantly with increased N level. Sahrawat *et al.* (1999) also noticed that nitrogen level significantly influenced tiller number.

Shah (1998) conducted field experiments at BRRI regional station Habigonj in dry season in 1996 to determine the contribution of tillering times to grain yield as influenced by nitrogen levels and plant densities. Three nitrogen levels as 0, 60 and 120 kg ha^{-1} was used as a treatment and the result showed that 60 N kg^{-1} was optimum for fertile soil.

2.1.3 Number of Effective tillers hill^{-1}

Nitrogen stimulates the cellular activities during panicle formation and development, which lead to increase number of effective tillers hill^{-1}. Balasubramaniyan (1984) summarized that increasing nitrogen application increased the number of effective tillers hill^{-1} with the highest at 120 kg N ha^{-1}

Akanda *et al.*, (1986) reported that nitrogen application in three doses such as 20 kg at basal, 40 kg at active tillering and 20 kg at panicle initiation stage produce the highest number of panicle hill^{-1}. Dubey *et al.*, (1991) noticed that application of 90 kg N ha^{-1} resulted in higher number of effective tillers hill^{-1}. Thakur (1991a) reported that increasing level of nitrogen increase the number of panicle $hill^{-1}$ significantly up to 120 kg ha^{-1}. Thakur (1991b) concluded that the yield attributes like number of effective tillers m^{-2} and (grain weight $panicle^{-1}$ increased with increasing level of nitrogen.

Chander and Pandey (1996) found that application of 120 kg N ha^{-1} resulted in significant increase in number of' effective tillers $hill^{-1}$ compared to 60 kg N ha^{-1}.

Hari *et al*., (1997) carried out a field experiment with rice hybrids PMS2, AIR 30802 to study the effect of different level of nitrogen and observed that productive tillers $hill^{-1}$ increase significantly with increasing level of N from 0 to 150 kg ha^{-1}.

2.1.4 Panicle length

Nitrogen contributes panicle formation and elongation of rice. Kumar *et al*., (1986) noticed that the highest panicle length was observed from 80 kg N ha^{-1} which was significantly superior to 40 kg N ha^{-1}. Sharma and Mishra *et al.,* (1986) reported that maximum length of panicle and maximum number of tillers $hill^{-1}$ was observed from the highest nitrogen rate.

Idris and Matin (1990) noticed that the particle length influenced positively due to the increasing rate of nitrogen. The highest particle length was observed from 60 kg N ha^{-1} and the lowest one from control (0 Kg N ha^{-1}). Singh and Singh (1993) reported that panicles m^{-2}, panicle length and grains $panicle^{-1}$ increased due to application of 60 Kg N ha^{-1}. Azad *et al*., (1995) noticed that panicle length increased significantly with the increasing level of nitrogen from 0 to 75 kg ha^{-1}.

2.1.5 Total spikelets $panicle^{-1}$

Devi and Nair (1984) reported that with the increasing N level from 0 to 40 Kg N ha^{-1} the total spikelets $panicle^{-1}$ in four drought resistant tall upland rice varieties increased. Ghosh *et al*., (1991) noticed that N level increased the total spikelets $panicle^{-1}$. Hussain arid Sharma (1991) reported that the nitrogen application increased total spikelets $panicle^{-1}$ up to 140 Kg N ha^{-1}.

2.1.6 Number of filled grains panicle^{-1}

Hussain *et al.*, (2003) noticed that application of nitrogen increased number of filled spikelets panicle^{-1} up to 80 kg N ha^{-1} and the 120 kg N ha^{-1} did not significantly affect the filled spikelets panicle^{-1}. The highest number of filled spikelets panicle^{-1} produced at 80 kg N ha^{-1} and the lowest was produced in the control. Chander and Pandey (1996) found that a significant increase in filled spikelet panicle^{-1}, tiller m^{-2} and grain yield was obtained from 120 kg N ha^{-1} compared to 60 kg N ha^{-1}.

Rajarathinam and Balasubrananiyan (1999) reported that there was no remarkable change in filled spikelets panicle^{-1} due to higher dose of N above 150 kg ha^{-1}. They also noticed that an appreciable reduction in filled spikelets panicle^{-1} at 250 Kg N ha^{-1}.

2.1.6 Grain yield

Nitrogen has remarkable influence both on yield and yield attributes of rice. Grain yield increased significantly at each successive level of N, due to increase in the number of panicles m^{-2}, length of particle, spikelets panicle^{-1} and weight of 1000 grain (Dalai and Dixit, 1987). Mishra *et al.*, (1988) concluded that N rates at 0, 30 and 60 Kg N ha^{-1} produced aus rice yield of 3.46, 4.84 and 5.24 t ha^{-1}, respectively and no further increase in yield was achieved by N application up to 90 kg ha^{-1}.

Islam *et al.*, (1990) observed that the grain yield of rice increased significantly up to 80 Kg N ha^{-1} but decrease at 120 Kg N ha^{-1}. Sadeque *et al.*, (1990) carried out a field experiment to study the effect of different levels of N (50, 100 and 200 kg ha^{-1}) on transplant aman rice (cv. BR11) and observed that N had on significant effect on grain yield. Pandey *et al.*, (1991) reported that significant increased in yield with increased in N level.

BRRI (1992) reported that grain yield of rice increased positively up to 80 Kg N ha^{-1}, Nitrogen application from 120 Kg to 160 Kg ha^{-1} significantly reduced the yield which was assumed to be due to excessive vegetative growth followed by lodging after flowering. Thakur (1993a) noticed that increasing levels of N increased the growth and yield attributes of rice significantly. Thakur (1993 b) concluded that most of the yield contributing characters specially panicles m^{-2} and spikelets $panicle^{-1}$ increased with increase N level and followed this trend to the grain yield.

Singh and Pillai (1994) observed that grain yield increased significantly up to 90 Kg ha^{-1} nitrogen application and after which it declined. Hussain *et al*., (1995) found that application of nitrogen up to 120 Kg ha^{-1} increased the grain yield of rice. Increased in yield with 40, 80 and 120 Kg N ha^{-1} over the control was 24, 33 and 34%, respectively. They noticed significantly higher yield was obtained with 80 and 120 Kg N ha^{-1} than 0 and 40 Kg N ha^{-1}. Hari *et al*., (1996) pointed out that grain yield increased as nitrogen application increased from 0 to 150 Kg ha^{-1}, although a further increase up to 200 Kg ha^{-1} did not increase grain yield.

Muthukrishnan *et al*., (1997) showed that incremental dose of N increased the grain yield by up to 80 kg N ha^{-1} (4.5 t ha^{-1}), Singh *et al*., (1999) evaluated the performance of three F_1 hybrid rice cultivars (KRH1, Pro. Agro. 103 and MGR1) using Jaya and Rasi as standard checks giving four levels of N (0, 60, 120, 180 kg, ha^{-1} and noticed that grain yield increased linearly with increased N levels up to 120 Kg ha^{-1}, Gopal *et al*., (1999) found that rice yield cv. Yerramallelu increased with N up to 100 kg N ha^{-1} and then decreased with 140 kg N ha^{-1}. Yield was not significantly affected by different split application. Sahrawat *et al*., (1999) noted that N level significantly affected the grain and straw yields. Chopra and chopra (2000) reported that nitrogen application at the rate of 80 kg ha^{-1} improved the entire yield attributes compared with control.

Sarker *et al*., (2001) investigated the effect of N level on the yield, yield contributing characters, physiological parameters of Iratom-24 rice variety and observed significant effect of N on yield and other crop characters. The highest grain yield (6.45 t ha^{-1}), 1000 grain weight (27.49 g) and number of grains $panicle^{-1}$ were produced at 120 kg N ha^{-1} for Iratom-24 rice variety.

2.1.7 Harvest index

Prasad (1981) noticed that the increasing rate of N application from 0 to 120 and 200 kg ha^{-1} increased biological yield but decreased harvest index. Similar observation was also noted by Park (1987).

Pandey (1999) conducted a field experiment with 6 rice cultivars fertilized with 0, 40, 80, 120, 160 Kg N ha^{-1} and observed that harvest index and yield were the highest in cv. IET 7633. Grain yield increased with increasing N rates, while harvest index decreased. Mondal and Swamy (2003) concluded that application of N (120 Kg ha^{-1}) as urea in four equal splits during transplanting, tillering, panicle initiation and flowering resulted in the highest number of panicles, number of grains $panicle^{-1}$, 1000 grain weight, straw yield and harvest index.

Balasubramanian (2003), Hill and Fujisaka *et.al.,* (1993) reported that Asian rice farmers are shifting from transplanting to direct seeding rice culture to reduce cost of labour input, water use, time (early harvest) and cultivation cost.

Ho and Ramah (2002) reported that 92% of Muda farmers in Indonesia found superior yield of direct seeded rice to that of transplanted rice.

Suh *et al.*, (2000) reported that the technology of direct seeding in rice cultivation is an innovation mainly induced by factors in market economy and is rapidly diffused among individual farm house.

Prasad *et al.,* (1992) observed that line sowing gave a higher number of panicles per unit area and fertile spikelets per panicle than broadcasting. Dingkhun *et al.,* (1990) reported that early production of a large vegetative biomass, leaf area and tiller number ere characteristics of direct seeded flooded rice.

De Datta and Gautam (1988) cited in this regard that land preparation and water control costs become higher for broadcast seeded than transplanted rice. But the net effect favors direct seeded rice.

Khan *et al.*, (1992) reported that direct seeded rice reduces the growth duration by about 15 days compared with conventional transplanted rice to overcome the shock due to uprooting.

Elahi *et al.*, (1997) reported that direct seeding either broadcast or line sowing gave significantly higher grain yield than transplanting under proper management. Coxhead (1984) stated that an alternative method of crop establishment is wet seeding in which sprouted seeds are directly sown in pudded land. Balasubramanian and Hill (2002) and Smith and Shaw (1996) recommended wet seeding of rice to reduce the high wages and scarcity of labour.

Gupta *et al.*, (2002) described that rice could also be established by dry seeding or by wet seeding and mentioned the direct seeding as an alternative to puddled transplanted rice. Sattar and Khan (1994) reported that there was a possibility to adopt wet seeded rice in irrigated areas because of 10% yields increase of direct wet seeded rice compared with transplanting during Boro season. They also reported that direct wet seeded rice required about 20% less water compared with transplanted rice. Hussain *et al.*, (2004) also reported that manual direct wet seeding increased grain yield of BORO rice by about 10% and reduced growth duration by about 10 days compared with transplanted rice. Balasubramanian *et al.*, (2003) stated that dry seeded rice on flat land with reduced or zero tillage produced rice yields similar to or higher than that of transplanted rice on puddeled soil. Sayre (2000) reported that the potential advantages of zero or reduced tillage system, reduced erosion, fossil fuel use, production costs, increased crop turn around period and land use efficiency, reduced drudgery in planting ,especially for female members, improved crop water use (for both irrigation and irrigated conditions), improved soil physical, chemical and biological characteristics, enhanced carbon sequestration, enhanced flora and fauna biodiversity and reduced incidence of many annual grass and broad leaf weed species. Hobbs and Gupta (2003) mentioned that the benefits could be accrued when zero till or bed planting is combined with rice establishment without puddling the soil.

PhilRice (2002) reported that seed rate of 40-60 kg per hectare was enough for direct wet seeding method with drum seeder to avoid too close spacing that resulted in mutual l shading, less tiller and lanky plants that are susceptible to lodging.

Haque *et al.,* (2005) reported that direct wet seeding by drum seeder in single thin row gave the highest grain yields of 7.04 and 8.31 t ha^{-1} for line BR4828-54-4-1-4-9 and BRRI dhan29, respectively with the corresponding increase of 264 and 17.9% over transplanting methods. Higher yields in direct wet seeding by drum seeder in single thin row were associated with higher number of panicle per square meter (Ahmed *et al.,* 2008).

Hussain *et al.,* (2003) reported that direct wet seeding by drum seeder in different rice varieties of about 2-12% higher grain yield than the transplanting method and matured about 8 days earlier.

Hussain *et al.,* (2004) reported that direct seeded rice using thick row and double row of drum seeded gave the similar and highest grain yield of about 4.9 t ha^{-1} which was about 22% higher than that of the transplanted rice and about 6% higher than that of the direct seeded thin row rice.

2.2 Performance of different weed management practices on various characteristics of rice

The reduction in grain yield depends on the cultural system, cropping season, plant spacing, amount of fertilizer applied, ecological and climatic conditions, and duration, time, type and intensity of weed infestation (Moody, 1991 and De Datta, 1991). Weed infestation in direct-seeded fields has caused 30-100% yield loss (Ho, 1994). Moody (1991) reported that three hand weeding were needed for optimum grain yield. In directly sown rice, the major challenges for farmers in effective weed management. Wet and dry sown rice cv. Sarju-52 establishment methods were listed on farmers' fields in Uttaranchal, India during 2000-02 and compared to the traditional practice of transplanting. Experiments showed that yield were comparable across all establishment systems. Competition from weeds was removed. However, potential yield losses due to weeds were greater in directly sown rice.

The effects of crop establishment (transplanting, broadcasting or line sowing) along with manual (plots were kept weed-free up to the maximum tillering stage) or chemical (1.25 kg butachlor ha^{-1} at 4 to 6 days after sowing signal or in combination with 0.80 kg 2.4-D ha^{-1} at 21 days after sowing) control treatments on the yield of rice cv. Jyothi were studied in Pattambi, kerala, India during the rabi season of 1996-97, 1997-98 and 1998-99 (Johnkutty *et al.,* 2002)

Mamun *et al.,* (1991) stated in this regard that, the traditional methods of weed control still used by the farmers of Bangladesh are land tillage and hand weeding and generally, 2 to 3 hand weedings are required for growing a normal rice crop. This method of weed control is time consuming and expensive. It involves a large number of labourers, which during peak period is very difficult to hire even a higher wages. Therefore, a cheaper, speedier and convenient method for controlling weeds is an utmost needed for Bangladesh. In the recent years, the use of herbicide in the field of agriculture has brought about a revolution in the method of seed control (Barari, D. 2005).

Chowdhury *et al.,* (1998) showed that Ronstar significantly reduced weed infestation, increased the grain yield and nutrient uptake by rice irrespective of the doses used. Trivedi *et al.,* (1985) tested several herbicides alone or in combination with one hand weeding for seed control in rice plots and showed that Oxadizon (1.0 kg ha^{-1}) applied pre-emergence gave excellent seed control (83%) efficiency but combining one hand weeding with 0.75 kg Oxadiazon ha^{-1} did not increase grain yield significantly compared with Oxadiazon alone BRRI (1996) had conducted several experiments and showed that the performance of hand weeding and herbicide were similar in terms of grain yield but cost of production was higher in hand weeding method. Weed infestation vary in their growth habit and life cycle and no single method of seed control is applicable to all cases.

Singh and Singh (1985) reported that the efficacy of different herbicides followed by one hand weeding was similar to that of two hand weedings. Herbicides alone gave higher yield of 2.17 t ha^{-1} in comparison to 1.08 t ha^{-1} in control pots (weedy plots). But, herbicide Thiobencarb + one hand weeding was the most effective. Karim *et al.,* (2004) reported that although a number of sulfonylurea herbicides have been found as suitable alternatives to the old herbicide 2, 4-D; an integrated weed management program must be developed in order to reduce the problem of herbicide resistance in weeds.

Weeds are one of the major concern in dry seeded rice, aerobic soil condition, dry tillage practice, besides alternate weeding and drying conditions as of the component of SRI are conducive for germination and growth of highly competitive weeds which causes 40–100% loss in grain yield (Choubey *et al*., 2001); Bahar and Singh, 2004). Hand weeding twice at 21 and 42 DAT is better than herbicide application but in case of where labor is either costly or not availability, the use of herbicide may be a better substitute provided herbicide hazards are considered (Thapa and Jha, 2004).

CHAPTER 3

MATERIALS AND METHODS

CHAPTER 3
MATERIALS AND METHODS

The experiments were conducted at Bangladesh Rice Research Institute (BRRI), Regional Station, Rajshahi located in $24^{0}69^{/}$ North latitude, $88^{0}30^{/}$East longitude. The experimental details are presented in this chapter.

3.1 Site description

3.1.1 Location

The field experiment was carried out on the experimental field of the Bangladesh Rice Research Institute (BRRI) at Regional Station, Shyampur, Rajshahi.

3.1.2 Soil

The experimental field was in High Gangetic River Floodplain soil belongs to an Agro–ecological zone (AEZ) 26 (BARC 2005).

3.1.3 Collection of soil sample

Soil samples were taken randomly by soil Auger from different spots in the experimental field at a depth of 0–20 cm before starting the experiment. The collected soils were mixed thoroughly to make a composite sample. The initial soil of the experimental field (0–20 cm layer) was analyzed for physical and chemical properties before set up the experiment. Physical and chemical properties of soils are presented in tabular form.

Sl.No.	Analyzed character	Content/Value	Soil fertility level
1.	pH	8.50	Slightly alkaline
2.	Organic matter (OM)%	1.37	Low
3.	Total nitrogen%	0.07	Very low
4.	Available phosphorus (µg g $soil^{-1}$)	10.0	Low
5.	Exchangeable potassium (meq 100g $soil^{-1}$)	0.19	Medium
6.	Available sulphur (µg g $soil^{-1}$)	9.80	Low
7.	Available zinc (µg g $soil^{-1}$)	0.40	Very low

3.1.4 Climate

Bangladesh has a tropical monsoon climate. The mean annual rainfall around the experimental area varies from 1000–1200 mm which was less than the country average. The maximum precipitation occurred during May to September (About 90%). Summer is hot and winter is cool and dry. Monthly average relative humidity ranges from 60–70 % in dry season (November–May) and 80–90 % in wet season (June–October). Some meteorological data like temperature, rainfall, relative humidity, sunshine hour and solar radiation during experimental period have been presented in Appendix–IX. The data were collected from nearby weather station distance from one and half kilometer from experimental field.

3.2 Cropping season

There are three major cropping season in Bangladesh like Rabi, Kharif–I and Kharif–II. Rabi season extends from middle of October to middle of March, Kharif–I from middle of March to end of June and Kharif–II from July to middle of October. The experimental material, rice were grown in Aman (Kharif–II) and Boro (Kharif–I) season.

3.3 Crop

3.3.1 Aman rice

The popular aman rice variety developed by Bangladesh Rice Research Institute, BRRI dhan44 was used in the experiment for growing season of Kharif–II.

3.3.2 Boro rice

The popular boro rice variety developed by Bangladesh Rice Research Institute, BRRI dhan45 was used in the experiment for growing season of Kharif–I.

3.4 Seed rate

For both direct seeding and transplanting 30–35 kg seeds per hectare were used.

3.5 Land preparation

The experimental area was prepared using animal drawn country plough and power tiller followed by laddering several times. This land preparation was started at least 10–15 days ahead of seeding time.

3.6 Experimental treatment and layout

The Experiment was laid out in a split–plot design with methods in the main plot and combination of N and weed management in the subplot. The treatments were replicated thrice. Four experiments were conducted and in each year two experiments were done: one in dry (Boro) and one in wet (Aman) season.

3.6.1 Crop establishment technique

3.6.1.1 Direct wet seeding by drum seeder

The IRRI–designed Drun seeder is a simple machine made of high density plastic. It can accommodate 6 to 8 cm diameter. Each drum has a pair of rows of holes (8 to 9 mm diameter) on each side. It is suitable for seedling of sprouted rice seeds in rows on well prepared puddle soils. Inside the drum, a device pushes the seeds towards the holes as the drum rotates. It weighs only about 10 kg when and portable. When loaded with sprouted seeds, it weighs 20 to 22 kg. Two persons could sown one hectare of land in a day. However, for direct–seeded rice, sprouted seeds were sown in the main field in the 1st week of July.

3.6.1.2 Hand broadcasting

Sprouted seeds were sown by hand broadcasting at uniform level on the saturated soil throughout the main field after the final leveling. For both methods (either direct–seeded or transplanted rice) of crop establishment, seeds were soaked on the same day.

3.6.1.3 Transplanting

The seedlings were raised in a wet seedbed method. Clean seeds of each variety with more than 85% germination were soaked in water for 24 hours and incubated for 48 hours for the wet season experiments and at least 72 hours for the dry season experiments. Then the pregerminated seeds were sown uniformly on thoroughly puddled, leveled and raised seed bed at the rate of 100g m^{-2} and at the same time. In case of transplanting, 28 day–old seedlings were used during wet season.

3.7 Fertilizer

Fertilizer other than nitrogen was applied before seeding or transplanting. All plots received a blanket dose of 75, 90, 60 & 7.5 kg ha^{-1} of TSP, MP, Gypsum & $ZnSO^4$ respectively. After application the fertilizers were thoroughly incorporated with the soil (BARC, 2005). Urea at the rate of 180 kg ha^{-1} was used for Aman season, but sometimes urea was applied less or equal when LCC (leaf color chart) based urea was used. Urea was applied according to treatments.

3.8 Research methodology: experimental technique/experiments conducted

The research programme was carried out at the Bangladesh Rice Research Institute (BRRI) farm, Regional Station, Shyampur, Rajshahi.

3.8.1 Experiment–1: Effect of crop establishment method and time of nitrogen application on productivity of transplant aman rice

The treatments were

Factor A: Crop establishment method (3)

1. T_1= Direct wet seeding by Drum Seeder
2. T_2= Hand broadcasting
3. T_3= Transplanting

Factor B: N management practices (4)

1. N_1= ⅓ at 15 DAT + ⅓ at 30 DAT + ⅓ at PI.
2. N_2= ¼ at basal + ¼ at 15 DAT + ¼ at 30 DAT + ¼ at PI
3. N_3= LCC based N application
4. N_4= No nitrogen

Design: Split–plot method of planting in the main plot and combination of N and weed management in the subplot.

Replication: 3

Variety: BRRI dhan44

Spacing: Sprouted seeds were sown uniformly in line by drum seeder for line sowing method and transplanting was done at 15cm×25cm spacing

3.8.2 Experiment–2: Effect of crop establishment and weed control method on productivity of transplant aman rice

Factor A: Crop establishment method (3)

1. T_1= Direct wet seeding by Drum Seeder
2. T_2= Hand broadcasting
3. T_3= Transplanting

Factor B: Weeding options (3)

1. W_1= Hand weeding (HW)
2. W_2= BRRI weeder +HW
3. W_3= Herbicide +1HW
4. W_4= No weeding

Design: Split–plot method of planting in the main plot and combination of N and weed management in the subplot.

Replication: 3

Variety: BRRI dhan44

Spacing: Sprouted seeds were sown uniformly in line by drum seeder for line sowing method and transplanting was done at 15cm×25cm spacing

3.8.3 Experiment–3: Effect of crop establishment method and time of nitrogen application on productivity of boro rice

Factor A: Crop establishment method (3)

1. T_1= Direct wet seeding by Drum Seeder
2. T_2= Hand broadcasting
3. T_3= Transplanting

Factor B: N management practices (4)

5. N_1= ⅓ at 15 DAT + ⅓ at 30 DAT + ⅓ at PI
6. N_2= ¼ at basal + ¼ at 15 DAT + ¼ at 30 DAT + ¼ at PI
7. N_3= LCC based N application
8. N_4= No nitrogen

Design: Split–plot method of planting in the main plot and combination of N and weed management in the subplot.

Replication: 3

Variety: BRRI dhan45

Spacing: Sprouted seeds were sown uniformly in line by drum seeder for line sowing method and transplanting was done at 15cm×25cm spacing

3.8.4 Experiment–4: Effect of crop establishment and weed control method on the productivity of boro rice

Factor A: Crop establishment method (3)

1. T_1= Direct wet seeding by Drum Seeder
2. T_2= Hand broadcasting
3. T_3= Transplanting

Factor B: Weeding options (3)

5. W_1= Hand weeding (HW)
6. W_2= BRRI weeder +HW
7. W_3= Herbicide +1HW
8. W_4= No weeding

Design: Split–plot method of planting in the main plot and combination of N and weed management in the subplot.

Replication: 3

Variety: BRRI dhan45

Spacing: Sprouted seeds were sown uniformly in line by drum seeder for line sowing method and transplanting was done at 15cm×25cm spacing

Date of seeding: First week of July

Date of transplanting: 31 July

Seeding method: Sprouted seeds were sown directly in the main field for direct seeded method but on the same day, sprouted seeds were sown in the seedbed for transplanting method i.e. seeding date remained same in different planting methods.

Seedling age: 25 days for transplanting method with 2 seedlings $hill^{-1}$.

Fertilizer rate: 180, 75, 90, 60 & 7.5 kg ha^{-1} of Urea, TSP, MP, Gypsum & $ZnSO_4$ respectively.

Plot size: 3m × 3.5m

Intercultural operations

Intercultural cultural operations were done to ensure normal growth of the crops. The experimental fields were irrigated whenever water required. In case of transplanted aman rice first and second hand weeding were done 21 DAT and 42 respectively. On the other hand weeding was done at 28 DAT in herbicide applied plots of transplanted aman rice and all the dirt seeded rice plots.

Harvesting

The crops were harvested at full maturity. Six m^2 areas in each plot were harvested to record grain and straw yield. The data for yield contributing parameters were recorded from another one m^2 area from 10 randomly selected plants. Grain yield was adjusted with moisture meter having the moisture content of 14 % for both aman and boro rice varieties.

3.9 Data collection details

3.9.1 Morpho–physiological

* Plant population
* Above ground plant dry weight
* Plant height at vegetative and reproductive stage

3.9.2 Yield and Yield components

* Number of effective tillers hill^{-1}
* Number of panicle hill^{-1}
* Number of filled grains panicle^{-1}
* Thousand grain weight
* Straw sub sample weight
* Straw oven dry weight
* Straw weight
* Grain weight

3.10 Procedures of sampling and data collection

Plant population density

At 20 DAS rice seedlings of direct–seeded method were counted inside a quadrate measuring 50 cm × 50 cm placed at random in two spots per plot.

Above ground dry matter (DM)

Plant samples were collected from the outside of the grain yield harvested area but away from the border crops. Similar to plant height during first year, DM was taken at different growth stages of rice plant but in the following consecutive years, plant samples were collected at 20 day intervals staring from 20 DAT to 60 DAT.

Plant height

In the first year, plant height was taken at different growth stages of rice plant but in the following consecutive years, plant height was taken from 5 randomly selected crop plants of a plot at 15 day intervals starting from 30 DAS/20 DAT.

Number of effective tillers hill^{-1}

The panicles which had at least one grain was considered as effective tiller. The number of effective tillers of 5 hills was recorded and expressed as effective tillers number hill^{-1}.

Number of panicles hill^{-1}

Number of panicle hill^{-1} data was recorded from the randomly selected five hill of middle portion of the plot and then converted into panicle hill^{-1}.

Number of filled grains panicle^{-1}

Recording filled grains hill^{-1} data converted into filled grains panicle^{-1} by the following formula: total filled grains hill^{-1} / number of total panicle hill^{-1}

Thousand–grain weight (g)

One thousand cleaned dried seeds were counted randomly from each sample and weighed by using a digital electric balance at the stage the grain retained 12% moisture and the mean weight were expressed in gram.

Grain yield (t ha^{-1})

Grain yield was determined from the central 5 m^2 of the plot and expressed as t ha^{-1} on 12% moisture basis. Grain moisture content was measured by using a digital moisture tester.

Straw yield (t ha^{-1})

Straw yield was determined from the central 5 m^2 of each plot. After threshing, the sub–sample was oven dried to a constant weight and finally converted to t ha^{-1}.

Yield and yield components

For both the methods, quadrate of five (2.Sm x 2.Um) square meter all rice plants inside were harvested respectively in the middle portion of each plot to estimate grain and straw yields. Border areas of all sides of the plot were excluded to avoid border competition effects. All the plants from harvested area were counted. After threshing and cleaning, fresh weight and moisture content of the grains were recorded. The grain and straw were dried in the sun before weighing. The grain yield was adjusted to 14% moisture content using moisture meter and was expressed as ton per hectare using following formula:

$$\text{Adjusted weight} = \frac{100 - M_1}{100 - M_2} \times W$$

Where W is the fresh weight of grains and M_1 and M_2 are the fresh and adjusted moisture percents of grain, respectively. The straw was oven dried and the dry weight of the straw was recorded. Both the grain and straw yields were expressed in ton per hectare.

Straw and grain analysis

The plant samples were cut at soil surface level at harvest in an individual plot and then dried in the sun. Five hundred gm straw of each sample was taken and grinded them in a machine and kept in a polythene bag for N analysis. For grain analysis, 200 gm was taken, dried them and kept in a polythene bag.

3.11 LCC (leaf color chart) reading

Leaf N status was assessed by LCC; a heavy plastic ruler (a Japanese prototype) was 4 shades from yellowish, green to dark green on it to simulate the color of rice leaves. The LCC values were recorded from the middle portion of the fully expanded upper most leaves of 10–15 hills, especially for LCC treatment. The color strips are fabricated with veins resembling rice leaves. Farmers can determine the right time of application of urea or N fertilizer in rice by matching the leaf color with the color strips of LCC. Farmers can decide to apply N fertilizer when leaf color measurement by LCC falls below the LCC critical value of a particular rice variety.

3.12 Economic analysis

A simple economic analysis was done based on the different operational (variable) costs of cultivation under reach planting methods from seeding to harvesting but no fixed cost was considered. Cost of land preparation, labour, inputs, irrigation, intercultural operations etc. and price of the produces were collected from the farmers and local markets to compute total variable costs, gross return, gross margin and benefit–cost ratio (BCR). The gross margin and BCR were computed as follows:

Gross margin= Gross return – total variable cost.

$$BCR = \frac{Grossreturn}{\text{Total variable cost}}$$

3.13 Statistical analysis

The data recorded for different characters from all the experiments were compiled and tabulated in proper form and subjected to proper statistical analyses were done as per standard procedure using M–STAT, EXCEL and IRRISTAT programmes. The outline of ANOVA (Gomez and Gomez, 1084) has been presented in Appendices I to VII. Mean separation was done by Duncan Multiple Range Test (DMRT).

CHAPTER 4

RESULTS AND DISCUSSION

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RESULTS AND DISCUSSION

The present study was accomplished through four field experiments. Results of the effect of different crop establishment methods as direct wet seeding by drum seeder, hand broadcasting and transplanting along with nitrogen and weed management practices and their interactions on the growth, yield and yield attributing components of modern rice varieties BRRI dhan44 (aman) and BRRI dhan45 (boro) have been presented and discussed in this chapter.

4.1 Experiment 1: Effect of crop establishment method and time of nitrogen application on productivity of *T. aman* rice

4.1.1 Effect of crop establishment methods

4.1.1.1 Performance study of morpho–physiology at vegetative stage

Plant population

Different crop establishment methods affect significantly on plant population in a particular area. The number of plant population in a certain area of experimental plot varied from 27-72 for 20 DAS, 98-124 for 40 DAS and 115-143 for 60 DAS, respectively (Table 1). Highest number of plant populations was found in transplanting method for 20, 40 and 60 days after sowing as compared to other methods such as direct wet seeding by drum seeder and hand broadcasting. Results showed that irrespective of different crop establishment methods, plant populations (No.s) increased with the passage of time and reached to its maximum number at maturity stage. Considering three different establishment methods (direct wet seeding, hand broadcasting and transplanting), the number of plant population was lowest in 20 DAS and highest in 60 DAS. It grows rapidly at early vegetative stage. Haque *et al.*, (2012) also investigate the response of different doses of nitrogen application at different growth stages (split application) on fine *aman* rice (cv. Kalizira) and reported that different doses of nitrogen had significant positive effect on the most of the vegetative parameters like plant population.

Plant dry matter

The results have been presented in Table 1. The Table 1 showed that total dry matter accumulation increased with the increasing of sowing date and reached to its maximum at maturity. In transplanting method production of total dry matter showed significantly higher than the method of direct wet seeding by drum seeder and hand broadcasting (Table 1) throughout the growing period. Dry matter production of all methods was low in 20 DAS and higher in 60 DAS. Thereafter, considering three methods, dry matter production slowly increased up to 60 DAS and quickly increased up to maturity. At 60 DAS, hand broadcasting and transplanting method did not differed significantly dry matter production but in direct wet seeding by drum seeder method and it was found significantly lower than other two methods (Table 1). Mean of dry matter accumulation ranges from 1.63 to 31.10 g. Its values are 1.63g, 9.1g to 17.0g for 20, 40 and 60 DAS as well. And the mean values for direct wet seeding by drum seeder, hand broadcasting and transplanting was found 9.67g, 15.95g and 17.03g respectively regarding the parameter dry matter accumulation. Plant dry matter production for 20 DAS and 40 DAS, it was found highest in transplanting method but with 60 DAS the similar performance was in hand broadcasting and transplanting system (Table 1). The trend of dry matter accumulation more rapidly increased in hand broadcasting method than other two practices. The investigation of Haque *et al.*, (2012) for nitrogen application option at different growth stages on fine *aman* rice (cv. Kalizira) had similar performances at vegetative stage excluding final harvest.

Plant height

Different crop establishment methods at different DAS affect the plant height in aman growing season. Plant height ranges from 22.04 cm to 73.48 cm for different crop establishment methods at different DAS. Among all crop establishment methods, transplanting system produced higher plant height (73.48 cm) compared to direct wet seeding by drum seeder and hand broadcasting considering 20, 40 and 60 DAS. The method direct wet seeding by drum seeder produced the lowest plant height of 22.04 cm followed by 24.92 cm of hand broadcasting. Regarding the mean performance of plant height (Table 1) in three crop establishment methods, average highest value (50.44) was in transplanting and lowest value (43.59) was in direct wet seeding by drum seeder. It might be due to maintain proper distance from hill to hill and proper management in line sowing as compared to other methods. This result also similar with the findings of Haque *et al*., (2012) for most of the vegetative parameters like plant height.

Table 1. Effect of crop establishment method on plant population, plant dry matter and plant height of *T aman* rice at different days after sowing (DAS)

Treatments	Plant population at different DAS			Plant dry matter (g) at different DAS			Plant height (cm) at different DAS		
	20	40	60	20	40	60	20	40	60
T_1	26.79c	98.16c	132.00b	1.02b	6.43c	20.96b	22.04c	42.79b	65.95c
T_2	40.87b	109.70b	114.50c	1.12b	10.78b	35.94a	24.927b	47.91a	70.44b
T_3	71.79a	123.87a	143.16a	2.75a	11.93a	36.40a	29.095a	48.76a	73.48a
CV (%)	**5.41**	**4.35**	**4.23**	**3.97**	**11.27**	**9.60**	**4.11**	**4.74**	**4.93**
Level of sig.	**	**	**	**	**	**	**	**	**

T_1: Direct wet seeding by drum seeder; T_2: Hand broadcasting and T_3: Transplanting
CV= Co–efficient of variation and **= significant at 1% level of probability

4.1.1.2 Performance study of growth and yield attributes at reproductive stage

Plant height

The result presented in Table 2 or Fig. 1 and it revealed that different crop establishment methods had the significant role on plant height. Among three systems, tallest plant found by using the method transplanting but it did not significantly differed with direct wet seeding by drum seeder unlike by the system of hand broadcasting. Shortest plant (106.5 cm) was in hand broadcasting (Table 2 or Fig. 1). The average of plant height with three systems varied from 106.52 cm to 117.18 cm. This was similar to the results of Chowdhury *et al*. (1995).

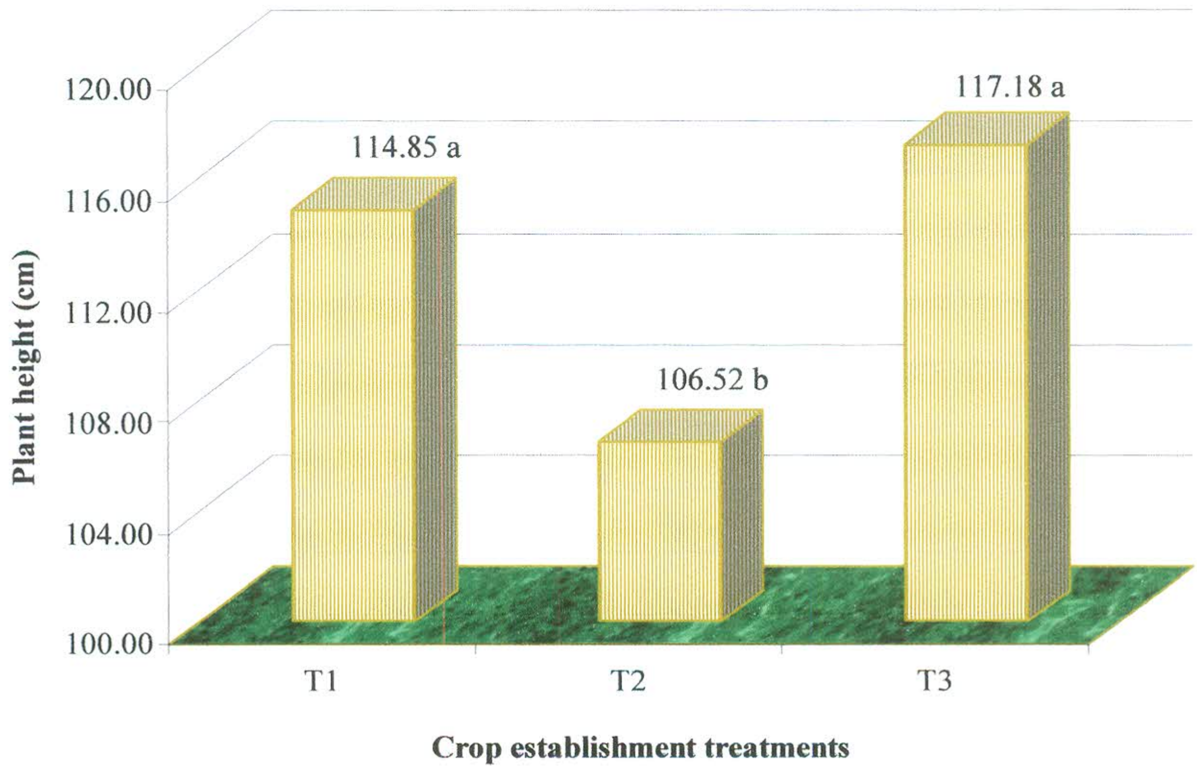

Fig. 1. Effect of crop establishment treatments on plant height of *T. aman* rice at harvest

Number of tillers

It found from the Table 2 that the number of tillers ranged from 8.31 to 10.64. These three methods significantly differed from each other having the highest (10.64 per hill) number in transplanting system while the lowest (8.31 per hill) number using direct wet seeding by drum seeder. The reason behind the lower number of tiller production may be due to higher rate of tiller abortion in direct wet seeding by drum seeder method. The result of this type of tiller production trend in rice was similar with the findings of Pirdashty *et al.,* (2000).

Number of panicles

Significantly higher number of panicles found in transplanting system. There was no significant difference between two methods like hand broadcasting and direct weight seeding by drum seeder (Table 2). Number of panicles per hill varied from 7.46 to 8.62. Similarly, Prassad *et al.* (1999) and Ali (2005) also found significant variation in number of panicle due to crop establishment method.

Yield of grain

The lowest yield of grain (3.30 t ha^{-1}) was in the methods of direct wet seeding by drum seeder while the highest yield of grain (5.05 t ha^{-1}) found by using transplanting system (Table 2). Yield of grain with hand broadcasting did not differed significantly with the yield of grain of transplanting methods. Director seeding of rice may be practiced in the irrigated ecosystem. The findings of Husain *et al.* (2003) confirmed with this result for higher grain yield in direct wet seeding by drum seeder compared to other transplanting system.

Yield of straw

Yield of straw in direct wet seeding by drum seeder significantly lower (3.96 t ha^{-1}) than other two crop establishment methods (hand broadcasting and transplanting). However, the highest yield of straw found in transplanting method (6.06 t ha^{-1}) followed by using the method hand broadcasting (5.94 t ha^{-1}). This value with three crop establishment method ranged from 3.96 to 6.06 t ha^{-1} (Table 2). This was similar to the reports of Dingkuhn *et al*. (1990).

Straw sub sample weight

Straw sub sample weight was significantly affected by crop establishment methods (Table 2). The mean value of straw sub sample weight varied from 100.9g to 132.8g. Transplanting method gave the highest straw sub sample weight. The other two methods as hand broadcasting and direct wet seeding by drum seeder did not give significant differences with each other's.

Straw oven dry weight

In transplanting method, it found that the highest straw oven dry weight as compared to direct wet seeding by drum seeder and hand broadcasting. This value ranged from 34.2g to 44.8g (Table 2). The other two methods as hand broadcasting and direct wet seeding by drum seeder did not give significant differences with each other's.

Table 2. Effect of crop establishment method on yield and yield attributes of *T. aman* rice at harvest

Treatments	Plant height (cm)	No. of tillers $hill^{-1}$	No. of panicles $hill^{-1}$	Grain yield ($t\ ha^{-1}$)	Straw yield (t ha)	Straw sub sample weight (g)	Straw oven dry weight (g)	No. of filled grains $panicle^{-1}$	1000-yield of grain (g)
T_1	114.85a	8.31c	69.50c	3.30c	3.96c	100.9c	34.2b	89.89b	26.9b
T_2	106.52b	9.72b	74.58b	4.95b	5.94b	111.0b	36.7b	97.30a	27.4ab
T_3	117.18a	10.60a	86.16a	5.05a	6.06a	132.8a	44.8a	96.88a	28.7a
CV (%)	**3.34**	**9.06**	**6.21**	**9.40**	**10.95**	**14.54**	**7.77**	**12.44**	**11.47**
Level of sig.	**	**	**	**	**	**	**	**	**

T_1: Direct wet seeding by drum seeder; T_2: Hand broadcasting and T_3: Transplanting
CV= Co–efficient of variation and **= significant at 1% level of probability

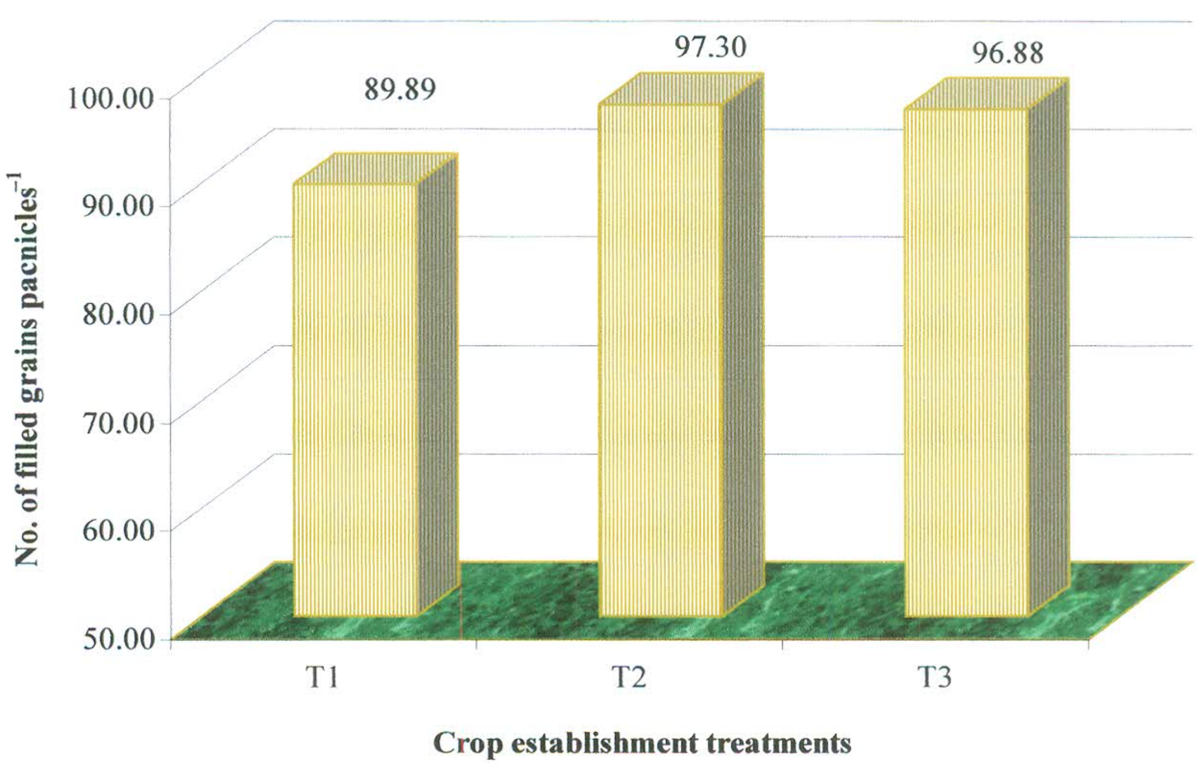

Fig. 2. Effect of crop establishment method on number of filled grains panicles^{-1} of *T. aman* rice at harvest

Number of filled grains

Filled grain numbers per panicles was significantly affected by the crop establishment methods. It ranged from 89.89 to 97.30 (Fig. 2). The highest number of filled grain (Table 2 or Fig. 2) produced with hand broadcasting followed by transplanting method where the lowest number of filled grain found in direct wet seeding by drum seeder. This result was confirmed with the findings of Ali (2005).

Thousand–yield of grain

The 1000–yield of grain did not differed significantly from each other by crop establishment methods. Similar grain size may be the reason behind it. This mean value ranged from 26.9 g to 28.7 g (Table 2). Transplanting method gave the highest 1000–yield of grain and the method direct wet seeding by drum seeder gave the lowest 1000–yield of grain. The result also similar with (Reddy, G.R. S., Reddy, G. V., Ramaiah, N.V. and Reddy, G. B. 1990) for the producing of Thousand–yield of grain.

4.1.1.3 Cost of production and economic performance of T. aman growing season as affected by crop establishment methods in presence of N fertilizer

Considering N management practices, the economic performance of different crop establishment methods were evaluated in terms of cost return and benefit cost ratio (Table 3). The cost of production, net return after marketing and benefit cost ratio of unit plots were converted into ton per hectare. The treatment wise cost and return with BCR for different crop establishment methods are shown in Table 4. By economic analysis it was observed that the maximum cost of planting method was involved in transplanting.

Variable cost

The total variable costs associated with the different crop establishment methods. The variable cost incurred by transplanting (T_3) method was the highest of Tk. 52,590/– ha^{-1} while it was the lowest in the treatment of direct wet seeding by drum seeder with Tk. 45,490/– (Table 3 and 4). It might be due to escaping of labour costs for uprooting at seedling stage. This was similar to the result of Balsabramanian and Hill (2002). The total variable costs for hand broadcasting (T_2) had lower than the transplanting (T_3) while similar finding was found by Balsabranian and Hill (2002).

Table 3. Production cost of T. aman rice as affected by different crop establishment methods in presence of N fertilizer

Crop establishment methods	Different operational cost in Taka							Total variable cost (Tk. ha^{-1})
	Land preparation	Seed	Irrigation	Fertilizer	Labor	Herbicide	Insecticide	
T_1	4200	1800	1500	6090	30400	600	900	45490
T_2	4200	1800	1500	6090	28500	600	900	43590
T_3	5400	2000	1800	6090	35800	600	900	52590

T_1: Direct wet seeding by drum seeder; T_2: Hand broadcasting and T_3: Transplanting
Seed= Tk. 35 kg^{-1}, Urea= Tk. 16 kg^{-1}, TSP= Tk. 30 kg^{-1}, MP= Tk. 20 kg^{-1}, Gypsum= Tk. 10 kg^{-1}, Zinc sulphate= Tk. 190 kg^{-1}, Irrigation 1500 $season^{-1}$ ha^{-1},, Wage rate= Tk. 250 man day^{-1}.

Table 4. Gross return, net return and benefit cost ratio of T. aman rice as affected by different crop establishment methods in presence of N fertilizer

Treatments	Total variable cost (Tk. ha^{-1})	Gross return (Tk. ha^{-1})			Net return (Tk. ha^{-1})	BCR
		Grain*	Straw*	Total		
T_1	45490	66000	1980	67980	22490	1.49
T_2	43590	99000	2970	101970	58380	2.34
T_3	52590	101000	3030	104030	51440	1.98

T_1: Direct wet seeding by drum seeder; T_2: Hand broadcasting and T_3: Transplanting
*Mean yield of 3 replications; Price of paddy= Tk. 20 ka^{-1} and Price of straw= Tk. 0.50 ka^{-1}
All prices indicated here just after harvesting period

Gross return

It was found that highest return (58,380/–) was in the method of hand broadcasting (T_2) due to its lowest production cost and above average grain and straw yield. By this planting method economic efficiency with BCR (2.34) was the highest as compared to other techniques (Table 4). This was confirmed with the result of Ali (2005) and Ampong and De Datta (1991).

Net return (Tk. ha^{-1})

The treatment wise costs and their return in margin for different planting techniques of rice cultivation are shown in Table 4 for aman season. It was highest (58,380/–) in broadcasting method for its higher grain and straw yield. Lowest return (22,490/–) was found in direct wet seeding by drum seeder which is opposite to transplanting method of Tk. 22,498/– having the lowest BCR value of 1.49.

Benefit cost ratio (BCR)

The benefit cost was higher in broadcasting method (2.34) among three treatments. The lowest BCR (1.49) was found in direct seeding method which was also lower than hand broadcasting (1.98). Thus, it was found that direct net seeding method was less costly than other planting methods. However, transplanting practice was a better option for its higher BCR (Table 4). This was similar to the reports of Utomo *et al*. (1996) and BRRI (1985). It may be concluded that lower cultivation cost with higher marginal profit indicating the best crop establishment method for aman rice.

4.1.2 Effect of different nitrogen management practices

4.1.2.1 Performance study of morpho–physiology at vegetative stage

Plant population

Results of effect of nitrogen management options on plant population presented in Table 5. The effects of application with different nitrogen management practices affect the plant population within a certain unit plot area of land for producing plant population. In general, lowest number of plant population found with control (no nitrogen) treatment. In 20 DAS, N2 (¼ at basal + ¼ at 15 DAS + ¼ at 30 DAS + ¼ at panicle initial stage) gave the highest number of plant population (Table 2). Similar trend was found in 40 and 60 DAS. However, mean number (104.6) of plant population in all DAS was highest in N2 management followed by N1 (⅓ at 15 DAS + ⅓ at 30 DAS + ⅓ at panicle initial stage). Ranges of plant population varied from 41.0 to 134.1 (Table 5). In 60 DAS there is no significant difference for different nitrogen management practices except control treatment. Plant population for LCC based nitrogen application was lower (93.57) in their mean performance of different nitrogen management practices. In Bangladesh, LCC can be used as N management tool like chlorophyll meter in wider scale where the critical threshold value is 3.0-3.5 in both wet and dry seasons (Islam *et al.*, 1998).

Plant dry matter accumulation

Results showed that four splits of nitrogen management options (including control) also gave the same trend throughout the whole growing period in respect to dry matter production. Leaf color chart (LCC) based nitrogen application produced lower (13.55) dry matter compared to N1 (15.04) and N2 (15.87). Dry matter accumulation was lowest in 20 DAS (1.35g) and highest in 60 DAS (34.78g). The mean production of dry matter till 60 DAS, ranges from 12.12g to 15.87g. The highest dry matter produced in N2 (¼ at basal + ¼ at 15 DAS + ¼ at 30 DAS + ¼ at panicle initial stage) followed by N1 (⅓ at 15 DAS + ⅓ at 30 DAS + ⅓ at panicle initial stage) (Table 5).

Table 5. Effect of application time and level of N on plant population, plant dry matter and plant height of *T aman* rice at different days after sowing (DAS)

Treatments	Plant population at different DAS			Plant dry matter (g) at different DAS			Plant height (cm) at different DAS		
	20	40	60	20	40	60	20	40	60
N_1	50.72a	116.77b	129.22a	1.72a	10.29ab	33.12a	25.63a	47.79a	72.11a
N_2	54.83a	124.77a	134.11a	1.95a	10.89a	34.78a	25.97b	47.25a	73.09a
N_3	41.00b	106.22c	133.50a	1.49c	9.09b	30.08b	25.23a	47.77a	70.98a
N_4	39.39b	94.55d	122.72b	1.35c	8.58c	26.42c	24.58b	43.14b	63.65b
CV (%)	**5.41**	**4.35**	**4.23**	**3.97**	**11.27**	**9.60**	**4.11**	**4.74**	**4.93**
Level of sig.	**	**	**	**	**	**	**	**	**

N_1: ⅓ at 15 DAT + ⅓ at 30 DAT + ⅓ at PI; N_2: ¼ at basal + ¼ at 15 DAT, + ¼ at 30 DAT + ¼ at PI; N_3: Leaf color chart (LCC) based N application and N_4: no nitrogen
CV= Co–efficient of variation and **= significant at 1% level of probability

Nitrogen application with three splits

Experimental field with no nitrogen

Plant height

Results reveal that nitrogen management options had no remarkable differences in plant height for 20, 40 and 60 DAS. Considering four options, plant height ranged from 43.79 cm to 48.77 cm till 60 DAS (Table 3). Similar effect found in N_1, N_2 and N_3 for different DAS at their mean plant height. At 20 DAS, dwarf plant found in N2 (¼ at basal + ¼ at 15 DAS + ¼ at 30 DAS + ¼ at panicle initial stage) and other two options had the similar height except no nitrogen application (Table 5).

4.1.2.2 Performance study of growth and yield attributes at reproductive stage

Plant height

The effect of nitrogen management method on plant height in aman rice was presented in Table 6 or Fig. 3. It revealed that there were no significant differences on plant height by using various doses of nitrogen application except no nitrogen. But it is observed that numerically when nitrogen application with splitting into ⅓ at 15 DAS + ⅓ at 30 DAS + ⅓ at panicle initial (N1) stage produced higher plant height (115.79 cm) followed by LCC based N application (115.04 cm). The value of mean nitrogen application ranged from 106.18 cm to 115.79 cm where the lowest plant height in no nitrogen application.

Number of tillers

Tiller production was highly affected by different treatment of nitrogen application. By using nitrogen with splitting at ¼ at basal + ¼ at 15 DAS + ¼ at 30 DAS + ¼ at panicle initiation stage (N_2) gave the highest number (10.61) of number of tillers followed by the splitting use of ⅓ at 15 DAS + ⅓ at 30 DAS + ⅓ at panicle initial (N1) stage and LCC based nitrogen application was the lowest (9.00) number of tiller production. It ranged from 8.61 to 10.61 (Table 6).

Number of panicles

Significantly higher number of panicles (82.27) found in using nitrogen of ¼ at basal + ¼ at 15 DAS + ¼ at 30 DAS + ¼ at panicle initiation stage (N_2). There was no significant difference between two applications like LCC based nitrogen application and no nitrogen (Table 6). Number of panicles per hill for different nitrogen treatments varied from 71.22 to 82.27. Generally, lower tillers were in without nitrogen. However, among other three applications, it found that the more the splitting of nitrogen application the more the tiller production.

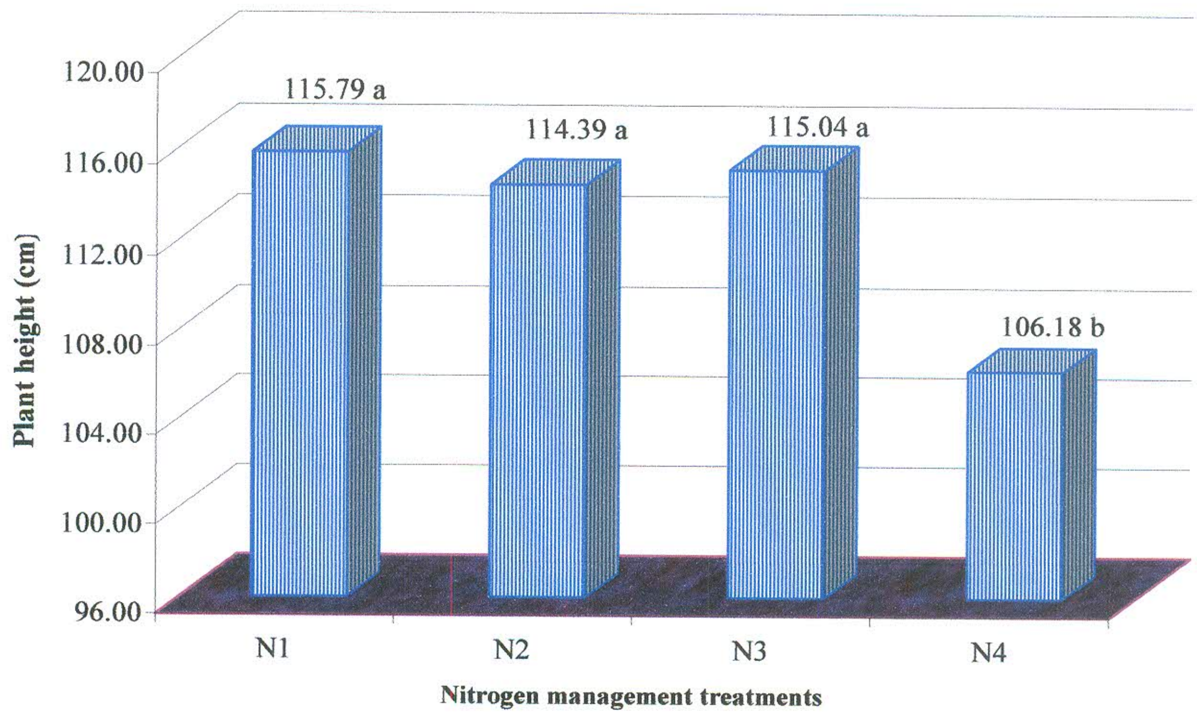

Fig. 3 Effect of nitrogen management practices on plant height of *T. aman* rice at harvest

Grain yield

Generally, there were not significant differences found in different nitrogen application. The lowest yield of grain (3.50 t ha^{-1}) was in the methods no nitrogen while the highest yield of grain (4.97 t ha^{-1}) found by applying the nitrogen in four splits of ¼ at basal + ¼ at 15 DAS + ¼ at 30 DAS + ¼ at panicle initiation stage (N_2). The overall yield of grain ranged from 3.50 to 4.97 t ha^{-1} (Table 6) The response of rice to nitrogen is largely influenced by variety, soil fertility, environmental factors and management practices. Nitrogen enhances the vegetative growth of plant but the yield of grain/yield of rice increases up to a certain level with increase in nitrogen rate (Patnaiki, 1991).

Straw yield

There were no significant differences for nitrogen application in respect to yield of straw. But numerically, it ranged from 4.20 to 5.96 t ha^{-1}. Higher yield of straw (5.96 t ha^{-1}) was in the splitting use of ¼ at basal + ¼ at 15 DAS + ¼ at 30 DAS + ¼ at panicle initiation stage (N_2) followed by the use of ⅓ at 15 DAS + ⅓ at 30 DAS + ⅓ at panicle initiation stage (N_1) (5.72 t ha^{-1}). These two values were very close to each other (Table 6).

Straw sub sample weight

Significantly highest (139.6g) straw sub sample weight found in application of ¼ at basal + ¼ at 15 DAS + ¼ at 30 DAS + ¼ at panicle initiation stage (N_2) followed by ⅓ at 15 DAS + ⅓ at 30 DAS + ⅓ at panicle initiation stage (N1). Straw sub sample weight varied from 101.2g to 102.6g. LCC based nitrogen application approximately similar with no nitrogen application (N4). Among other three N application treatments, the lowest straw sub sample weight found in applying LCC based application (Table 6). This finding was also similar with Suh *et al.,* (2000).

Straw oven dry weight

Straw oven dry weight was also significantly affected by nitrogen applications system. Application of N2 gave the highest of straw oven dry weight (Table 4). It valued from 31.4g to 50.5g. The highest straw oven dry weights found with the N application of four splits while the lowest in no nitrogen application. When application of total nitrogen made four splits then it gave higher straw oven dry weight than the application two or more times.

Number of filled grains

Filled grain numbers per panicles was significantly affected by the application of nitrogen at different times and doses. It was ranges from 83.54 to 110.83 where the highest number of filled grains found in N2 (¼ at basal + ¼ at 15 DAS + ¼ at 30 DAS + ¼ at panicle initiation stage) nitrogen application system followed by N1 (⅓ at 15 DAS + ⅓ at 30 DAS + ⅓ at panicle initiation stage) application (Table 6 or Fig. 4). Among all nitrogen application, the lowest number of filled grains was in no nitrogen treatment. This result was confirmed with the findings of Ali (2005).

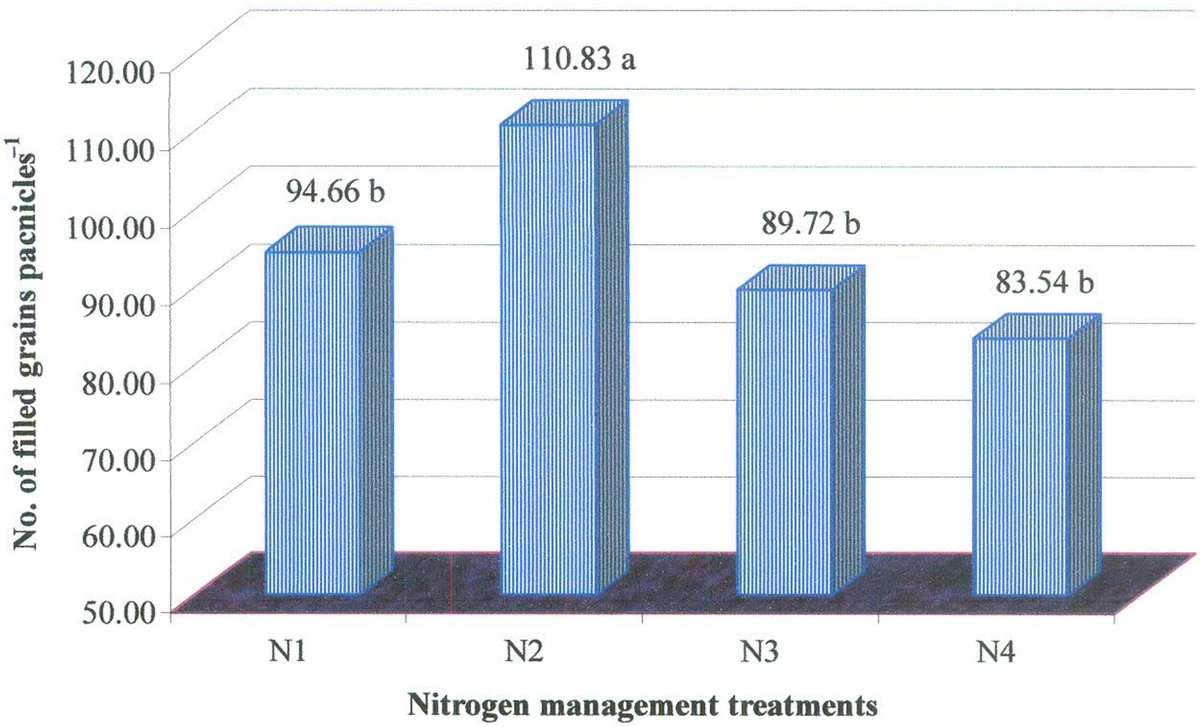

Fig. 4. Effect of nitrogen management practices on number of filled grains panicles^{-1} of *T. aman* rice at harvest

Thousand–yield of grain

The 1000–yield of grain did not differed significantly from each other with different nitrogen management practices. Similar grain size may be the reason behind it. This mean value ranged from 25.7g to 31.7g (Table 4). But numerically, nitrogen application with four splits {N2, (¼ at basal + ¼ at 15 DAS + ¼ at 30 DAS + ¼)} at panicle initiation stage) gave the highest 1000–yield of grain among all N applications. According to Mikkelsen *et al.*, (1995), in tropical areas many farmers split fertilizer N into three doses.

The first application is usually made prior to transplanting, desirably with soil incorporation but frequently into stage, whereas the final application is made at or just prior to panicle initiation stage. These split applications are made to maintain the supply of nitrogen for the crops and to maintain minimum losses through volatilization, de-nitrification, leaching or run-off. Management practices for basal fertilizer N application are similar for both transplanting and broadcast seeding.

Table 6. Effect of application time and level of N on yield and yield attributes of *T. aman* rice at harvest

Treatments	Plant height (cm)	No. of tillers $hill^{-1}$	No. of panicles $hill^{-1}$	Grain yield ($t\ ha^{-1}$)	Straw yield ($t\ ha^{-1}$)	Straw sub sample weight (g)	Straw oven dry weight (g)	No. of filled grains $panicle^{-1}$	1000–grain weight (g)
N_1	115.79a	10.0a	7.86ab	4.77ab	5.72ab	116.2b	38.6b	946.6b	27.6b
N_2	114.39a	10.6a	8.23a	4.97a	5.96a	139.6a	50.5a	1108.3a	31.7a
N_3	115.04a	9.0b	7.49bc	4.50bc	5.40bc	102.6c	33.9c	897.2b	25.9b
N_4	106.18b	8.6b	7.12c	3.50c	4.20c	101.2c	31.4d	835.4b	25.7b
CV (%)	**3.34**	**9.06**	**6.21**	**9.40**	**10.95**	**14.54**	**7.77**	**12.44**	**11.47**
Level of sig.	**	**	**	**	**	**	**	**	**

N_1: ⅓ at 15 DAT + ⅓ at 30 DAT + ⅓ at PI; N_2: ¼ at basal + ¼ at 15 DAT, + ¼ at 30 DAT + ¼ at PI; N_3: Leaf color chart (LCC) based N application and N_4: no nitrogen
CV= Co–efficient of variation and **= significant at 1% level of probability

4.1.2.3 Cost of production and economic performance of T. aman growing season as affected by N management practices

A budget along with total cultivation cost among different nitrogen management practices in aman/boro season are provided in Table 7.

Table 7. Economic performance with BCR of different N–management treatments during T. aman season

Treatments	Cost of production (Tk. ha^{-1})			Yield ($t\ ha^{-1}$)		Gross return (Tk. ha^{-1})			Net return (Tk. ha^{-1})	BCR
	Fixed cost	N–application cost	Total Tk.	Gain	Straw	Grain	Straw	Total		
N_1	47190	3200	50390	4.77	5.72	95400	2860	98260	47870	1.95
N_2	48690	3200	51890	4.97	5.96	99400	2980	102380	50490	1.97
N_3	46100	2900	49000	4.50	5.4	90000	2700	92700	43700	1.89
N_4	36890	0	36890	3.50	4.2	70000	2100	72100	35210	1.95

N_1: ⅓ at 15 DAT + ⅓ at 30 DAT + ⅓ at PI; N_2: ¼ at basal + ¼ at 15 DAT, + ¼ at 30 DAT + ¼ at PI; N_3: Leaf color chart (LCC) based N application and N_4: no nitrogen
Price of un–husked rice= Tk. 20 kg^{-1} and price of straw= Tk. 0.50 kg^{-1}

Treatment wise economic performance of various N–application approach were evaluated in terms of cost, return and benefit cost ratio (Table 7). The total cost and gross returns from unit plot were converted into t ha^{-1}. The variable cost of production varied from 36,890/– (N_4: no nitrogen) to 51,890/– (N_2: ¼ at basal + ¼ at 15 DAT, + ¼ at 30 DAT + ¼ at PI). When means of grain and straw yield were considered it was noticed that the highest gross and net return (Tk. 1,02,380/– and 50,490/–) were found in 4 split of N (N_2: ¼ at basal + ¼ at 15 DAT, + ¼ at 30 DAT + ¼ at PI) along with highest BCR 1.97 (Table 7). However, very lowest return (35,210/–) from N_4 treatment means that there was no nitrogenous fertilizer cost during conducting the experiment. But, the lowest BCR (1.89) was obtained from N_3 (Leaf color chart (LCC) based N application) which might be due to the much higher cost of production than control or no nitrogen (N_4). Highest return strand from higher grain and straw yield as well as the four split N–application gave the highest BCR value. Such the same observation was also obtained by the findings of De Datta and Ampory (1988).

4.1.3 Interaction effect of crop establishment methods and N application

4.1.3.1 Performance study of morpho–physiology at vegetative stage

Plant population

Interaction effect of establishment methods and time and dose of N application had highly significant in respect of plant population (Appendix I and Table 8). From the observation Table 5, it was found that the plant populations varied from 25.50 in T_1N_4 to 89.50 in T_3N_2 at 20 DAS, 85.83 in T_1N_4 to 141.00 in T_3N_2 at 40 DAS and 99.00 in T_2N_4 to 152.00 in T_3N_2 at 60 DAS. These result revealed that transplanting methods with the application of ¼ at basal + ¼ at 15 DAS + ¼ at 30 DAS + ¼ at panicle initiation stage (T_3N_2) had highly significant for germinate the more seeds which resulted the maximum plant population in this study. Considering all combinations of interactions, the mean performance of plant population also varied from 79.33 in T_2N_4 to 127.61 in T_3N_2 (Table 8).

Plant dry matter

Effect of interaction treatments of different crop establishment methods along with various nitrogen application options varied significantly at 20 and 60 DAS while all the interactions treatments did not differed significantly at 40 DAS. As a result, the highest weight of plant dry matter (3.56 and 42.81 g) was registered from the transplanting system along with the application of ¼ at basal + ¼ at 15 DAS + ¼ at 30 DAS + ¼ at panicle initiation stage (T_3N_2) followed by T_3N_2 (2.68 and 39.58 g) at 20 and 60 DAS, respectively (Table 8). On the other hand, the lowest weight of dry matter (0.75 and 19.96 g) was taken from the direct wet seeding by drum seeder while N fertilizer was absent (T_1N_4) at those stages, respectively.

Table 8. Interaction effect between crop establishment method and application time and level of N on plant population, plant dry matter and plant height of *T aman* rice at different days after sowing (DAS)

Treatments	Plant population at different DAS			Plant dry matter (g) at different DAS			Plant height (cm) at different DAS		
	20	40	60	20	40	60	20	40	60
T_1N_1	27.16de	101.50	118.66d	1.18de	6.68	20.88e	22.22	43.62cd	67.62
T_1N_2	27.83de	115.66	135.00c	1.26d	8.31	22.56e	22.39	42.46d	68.38
T_1N_3	26.66e	89.66	138.16bc	0.88ef	5.73	20.43e	22.07	44.22cd	65.55
T_1N_4	25.50e	85.83	136.16c	0.75f	5.00	19.96e	21.50	40.87d	62.26
T_2N_1	41.83c	110.33	121.00d	1.31d	11.66	38.90ab	25.67	48.82ab	72.68
T_2N_2	47.16c	117.66	115.00d	1.01def	11.85	38.98ab	25.70	51.85a	74.64
T_2N_3	37.13c	109.00	123.00d	1.13de	10.20	35.10bc	24.80	48.95ab	72.54
T_2N_4	37.16cd	101.83	99.00e	1.01def	9.43	30.80cd	23.53	42.02d	61.91
T_3N_1	83.16a	138.50	148.00ab	2.68b	12.53	39.58ab	28.99	50.92ab	76.02
T_3N_2	89.50a	141.00	152.33a	3.56a	12.51	42.81a	29.84	47.44bc	76.26
T_3N_3	59.00b	120.00	139.33bc	2.46bc	11.35	34.71bc	28.82	50.15ab	74.85
T_3N_4	55.50b	96.00	133.00c	2.28c	11.33	28.50d	28.72	46.54bc	66.79
CV (%)	**5.41**	**4.35**	**4.23**	**3.97**	**11.27**	**9.60**	**4.11**	**4.74**	**4.93**
Level of sig.	**	ns	**	**	ns	**	ns	**	ns

T_1: Direct wet seeding by drum seeder; T_2: Hand broadcasting and T_3: Transplanting
N_1: ⅓ at 15 DAT + ⅓ at 30 DAT + ⅓ at PI; N_2: ¼ at basal + ¼ at 15 DAT, + ¼ at 30 DAT + ¼ at PI; N_3: Leaf color chart (LCC) based N application and N_4: no nitrogen
CV= Co–efficient of variation; **= significant at 1% level of probability and ns= not significant

Plant height

Analysis of variance data on plant height have been presented in Appendix I indicated significantly difference at 40 DAS while recording data at 20 and 60 DAS did not vary significant due to all the interaction treatments of various crop establishment methods and nitrogen application options. As a result, plant height significantly varied from 40.87 cm (shortest) in T_1N_4 to 51.85 cm (tallest) in T_2N_2 at 40 DAS. Considering all combinations of interactions, the mean performance of plant height varied from 34.74 cm in T_1N_2 to 51.98 cm in T_3N_1 cm (Table 8). These result revealed that transplanting methods with the application of ⅓ at basal (15 DAS) + ⅓ at 30 DAS + ⅓ at panicle initiation stage (T_3N_1) had highly significant for better development of plant than other interaction treatment.

4.1.3.2 Performance study of growth and yield attributes at reproductive stage

Plant height

The interaction effect of crop establishment methods and time with doses of nitrogen application showed significant variation on plant height at harvest (Appendix II and Table 9). Data revealed that the interaction of transplanting methods with nitrogen application of ¼ at basal + ¼ at 15 DAS + ¼ at 30 DAS + ¼ (T_3N_2) produced the tallest plant (121.46 cm) followed by the direct wet seeding by drum seeder methods grown under LCC based N application (120.76 cm). On the other hand, the shortest plant (101.98 cm) was observed in T_2N_4 (hand broadcasting × no nitrogen).

Yield of straw

Yield of straw was significantly affected by the interaction of crop establishment methods and nitrogen application option at harvest (Appendix II and Table 9). Data from the Table 6 revealed that the hand broadcasting method with nitrogen application of ¼ at basal + ¼ at 15 DAS + ¼ at 30 DAS + ¼ (T_2N_2) obtained the highest yield of straw (6.76 t ha^{-1}) while the lowest yield of straw (2.50 t ha^{-1}) was found in interaction of T_1N_4 (direct wet seeding with drum seeder × no nitrogen).

Following results for other parameters

Rest of the observation parameters such as number of tillers, number of panicles, yield of grain, straw sub sample weight, straw sub sample dry weight, filled grains panicles^{-1} and 1000–yield of grain did not vary significant due to interaction effect of crop establishment methods and various application option of N. However, number of tillers varied from 75.50 (T_1N_4) to 122.83 (T_3N_2); number of panicles varied from 61.33 (T_1N_4) to 92.66 (T_3N_2), yield of grain varied from 2.08 (T_1N_4) to 5.63 t ha^{-1} (T_2N_2), straw sub sample weight varied from 83.8 g (T_1N_4) to 138.8 g (T_3N_2), straw sub sample dry weight varied from 25.00 g (T_1N_4) to 53.90 g (T_1N_2), filled grains varied from 82.77 (T_1N_4) to 114.90 (T_3N_2) and 1000–yield of grain varied from 25.50 g (T_1N_4) to 35.90 g (T_3N_2) (Table 9).

Table 9. Interaction effect between crop establishment method and application time and level of N on yield and yield attributes of *T. aman* rice at harvest

Treatments	Plant height (cm)	No. of tillers hill^{-1}	No. of panicles hill^{-1}	Grain yield (t ha^{-1})	Straw yield (t ha^{-1})	Straw sub sample weight (g)	Straw oven dry weight (g)	No. of filled grains panicle^{-1}	1000–grain weight (g)
T_1N_1	119.47ab	8.83	7.41de	3.85	4.62 e	96.9e	30.0	90.1	26.8
T_1N_2	113.84c	8.97	7.56de	4.00	4.80 e	131.8c	53.9	100.3	29.5
T_1N_3	120.78ab	7.90	6.68g	3.25	3.90 f	91.4f	28.2	86.4	26.1
T_1N_4	105.31f	7.55	6.13h	2.08	2.50 g	83.8g	25.0	82.7	25.5
T_2N_1	107.91e	9.68	7.56de	5.22	6.26 b	121.2d	40.7	96.5	28.6
T_2N_2	107.86e	10.58	7.85d	5.63	6.76 a	148.2a	49.6	117.3	29.6
T_2N_3	108.34e	9.30	7.38e	4.93	5.92 c	94.3ef	29.2	87.6	25.8
T_2N_4	101.98g	9.35	7.03f	4.02	4.82 e	80.5h	27.6	87.7	25.6
T_3N_1	120.00ab	11.53	8.58b	5.22	6.26 b	130.7c	45.2	97.4	27.3
T_3N_2	121.46a	12.28	9.26a	5.27	6.32 b	138.8b	48.3	114.9	35.9
T_3N_3	116.00b	9.80	8.41b	5.30	6.36 b	122.2d	44.4	95.1	26.0
T_3N_4	111.26d	8.93	8.20c	4.38	5.26 d	139.4b	41.6	80.1	25.9
CV (%)	**3.34**	**9.06**	**6.21**	9.40	10.95	**14.54**	**7.77**	**12.44**	**11.47**
Level of sig.	**	ns	**	ns	**	**	ns	ns	ns

T_1: Direct wet seeding by drum seeder; T_2: Hand broadcasting and T_3: Transplanting
N_1: ⅓ at 15 DAT + ⅓ at 30 DAT + ⅓ at PI; N_2: ¼ at basal + ¼ at 15 DAT, + ¼ at 30 DAT + ¼ at PI; N_3: Leaf color chart (LCC) based N application and N_4: no nitrogen
CV= Co–efficient of variation; **= significant at 1% level of probability and ns= not significant

4.2 Experiment 2: Effect of crop establishment method and weed management on productivity of *T. aman* rice

4.2.1 Effect of crop establishment methods

4.2.1.1 Performance study of morpho–physiology at vegetative stage

Plant population

Establishment methods of *T. aman* rice exerted significant difference regarding number of plant population in a specific area at every data recording stages (Appendix III and Table 10). From the Table 7 it was found that the number of plant population significantly varied from 27.41 to 79.95 at 20 DAS, 103.29 to 147.91 at 40 DAS and 110.00 to 142.91 at 60 DAS. It is evident form the Table 10 that the maximum number of plant populations was noted in transplanting method (T_3) at every data recording stages as compared to direct wet seeding by drum seeder and hand broadcasting methods (T_1 and T_2, respectively) while direct wet seeding by drum seeder method exhibited the poorer effect on plant population. The above results revealed that the number of plant population significantly increase with the advancement of the study period, however population number increased rapidly from 20 DAS to 40 DAS and thereafter it increase gradually as well as the maximum plant population would be found at maturity or reproductive stage. Gopal *et al.*, (1999) found that rice yield cv. Yerramallelu increased with N up to 100 kg N ha^{-1} and then decreased with 140 kg N ha^{-1}. Dry matter accumulation was not significantly affected by different split application.

Plant dry matter

Analysis of variance data on plant dry matter have been presented in Appendix III indicated significant difference at 20, 40 and 60 DAS where plant dry matter significantly increase with the increase of the study period (Table 10). From the Table 10, it was showed that the plant dry matter significantly varied from 0.96 to 1.06 g $hill^{-1}$, 7.26 to 12.47 g $hill^{-1}$ and 22.57 to 32.79 g $hill^{-1}$ at 20, 40 and 60 DAS, respectively where the highest weight of dry matter were obtained from the crop establishment method of Transplanting (T_3) while it was lowest in direct wet seeding by drum seeder method (T_1) at all the data recording stages (Table 10). Mean of dry matter accumulation ranges from 10.26 to 15.88 g $hill^{-1}$ where transplanting methods (T_3) perform better than direct wet seeding by drum seeder method and hand broadcasting. From the above result, it was found that the transplanting method had more significant than other crop establishment methods in case of the tallest plant and maximum number of plant population were also obtained under this study which ultimately ensure the maximum dry matter weight.

Plant height

A significant variation regarding plant height was found due to various crop establishment methods at 20, 40 and 60 DAS where plant height varied from 22.78 to 28.26 cm, 42.80 to 51.08 cm and 69.05 to 74.08 cm at 20, 40 and 60 DAS, respectively (Appendix III and Table 10). Among the different crop establishment methods, the tallest plant (28.26, 51.08 and 74.08 cm) was exhibited in transplanting method (T_3) followed by hand weeding (T_2) method (25.00, 47.84 and 73.01 cm) while the shortest plant (22.78, 42.80 and 69.05 cm) was recorded in direct wet seeding by drum seeder method (T_1) at 20, 40 and 60 DAS, respectively. Regarding the mean performance of plant height due to crop establishment methods, average highest value (51.44 cm) was in transplanting and lowest value (44.88 cm) was in direct wet seeding by drum seeder method. The above result indicated that the plant height significantly increase with the advancement of the present study concerning all crop establishment methods. This was similar to the results of Chowdhury *et al.* (1995).

Table 10. Effect of crop establishment method on plant population, plant dry matter and plant height of *T aman* rice at different days after sowing (DAS)

Treatments	Plant population at different DAS			Plant dry matter (g) at different DAS			Plant height (cm) at different DAS		
	20	40	60	20	40	60	20	40	60
T_1	27.41c	103.29b	110.00c	0.96b	7.26c	22.57b	22.78c	42.80c	69.05b
T_2	36.37b	111b.08a	128.00b	1.06b	9.39b	30.69a	25.00b	47.84b	73.01a
T_3	79.95a	147.91	142.91a	2.38a	12.47a	32.79a	28.26a	51.08a	74.077a
CV (%)	**4.97**	**7.43**	**4.47**	**11.91**	**5.87**	**5.46**	**5.62**	**4.36**	**3.18**
Level of sig.	**	**	**	**	**	**	**	**	**

T_1: Direct wet seeding by drum seeder; T_2: Hand broadcasting and T_3: Transplanting
CV= Co–efficient of variation
**= significant at 1% level of probability

4.2.1.2 Performance study of growth and yield attributes at reproductive stage

Plant height

The result of plant height at harvest presented in Table 11 revealed that the different crop establishment methods had significant while it was significantly varied from 108.98 to 120.38 cm (Appendix IV and Table 11 or Fig. 5). Among three crop establishment methods, tallest plant was exhibited from the transplanting methods followed by hand broadcasting (111.75 cm). On the other hand, the shortest plant was in direct wet seeding by drum seeder method (T_1). These results revealed that transplanting method had highly significant than other method of crop establishment. This was similar to the results of Chowdhury *et al.* (1995).

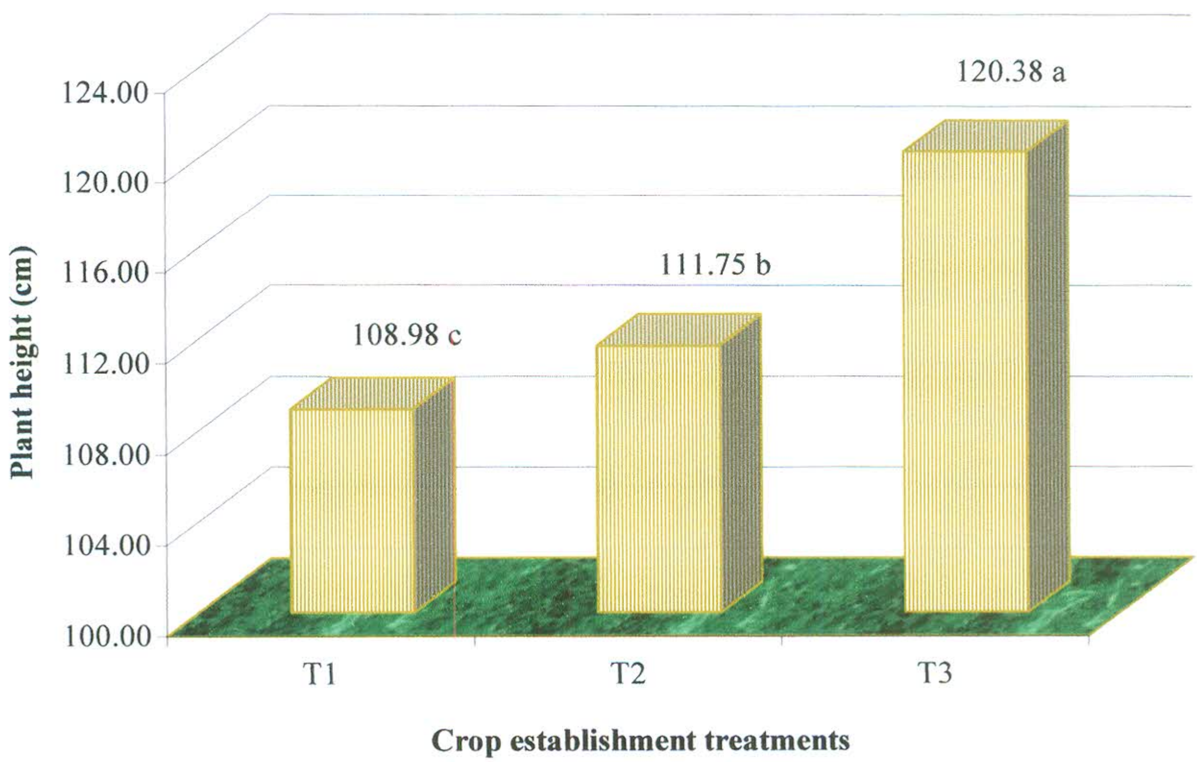

Fig. 5. Effect of establishment methods on plant height of *T. aman* rice at harvest

Number of tillers

A significant variation due to crop establishment methods was obtained in respect of number of tillers per hill (Appendix IV and Table 11). Among the crop establishment methods, transplanting method showed significantly the maximum tillers (12.32) than hand broadcasting method (9.58) and direct wet seeding by drum seeder method (8.76) method. Transplanting method had highly significant than other methods might be due to the proper growth of plant with specific space were obtained which ultimately produce the maximum tillers than other methods. Hussain *et al.,* (2003) reported that direct wet seeding by drum seeder in different rice varieties of about 2-12% higher tiller number than the transplanting method and matured about 8 days earlier.

Number of panicles

Number of panicles per hill had highly significant due to crop establishment method at harvest (Appendix IV and Table 11). Among the crop establishment methods, the maximum number of panicles (8.74) was established in transplanting method while minimum (6.32) was for direct wet seeding by drum seeder method. So, the panicle numbers per hill varied from 6.32 to 8.74. The above result of the present study was also showed similarity with the research reports of Prassad *et al.* (1999) and Ali (2005) where they also found significant variation due to crop establishment method.

Yield of grain

The data on yield of grain had also significant due to various establishment methods of crop where it was significantly varied from 3.45 to 5.12 t ha^{-1} (Appendix IV and Table 11). From the Table 8, it was evident that the highest yield of grain was found in transplanting method (T_3) followed by hand broadcasting (4.40 t ha^{-1}) while the lowest yield of grain (4.45 t ha^{-1}) was in the methods of direct wet seeding by drum seeder (Table 11). The above results indicated that the yield of grain had highest for transplanting methods might be due to the tallest plant; more number of tillers and panicles and maximum filled grains were taken under these methods which ultimately resulted the greater yield. Moody (1991) reported that three hand weeding were needed for optimum grain yield.

Yield of straw

Yield of straw of *T. aman* rice had highly significant due to crop establishment methods where the highest yield of straw (6.14 t ha^{-1}) was obtained in transplanting method while it did not differed significantly with the hand broadcasting method (5.28 t ha^{-1}) (Appendix IV and Table 11). On the other hand, significantly the lowest yield of straw (4.14 t ha^{-1}) was taken in direct wet seeding by drum seeder method (T_1). So, the above result showed the straw yield ranged from 13.36 to 9.66 due to crop establishment methods. Sahrawat *et al*., (1999) noted that N level and application option significantly affected the grain and straw yields.

Straw sub sample weight

Sub–sample yield of straw showed significant variation due to crop establishment methods at harvest and it was varied from 144.00 to 115.65 g (Appendix IV and Table 11). The highest yield of straw sub sample weight was obtained by using the transplanting method (T_3) followed by direct wet seeding by drum seeder (T_1) method while it was lowest in hand broadcasting method (T_2). Transplanting method gave the highest straw sub sample weight which might be due to the tallest plant and maximum tillers were establishment under this method which ensures the highest yield of straw sub sample.

Straw oven dry weight

Effect of crop establishment methods was significantly influence on straw over dry weight where it was significantly varied from 33.13 to 50.71 g (Appendix IV and Table 11). The highest yield of straw oven dry was for transplanting method while it was the lowest for direct wet seeding by drum seeder method. Hand broadcasting method obtained the average medium yield of straw over dry (37.25 g).

Number of filled grains

A significant variation was also found due to crop establishment methods in respect of filled grains (Appendix IV and Table 11 or Fig. 6). Filled grain numbers 10–

panicles^{-1} ranged from 87.08 to 92.79 where the maximum number of filled grains 10–panicles^{-1} was produced by transplanting method while h direct wet seeding by drum seeder method noted the minimum filled grains.

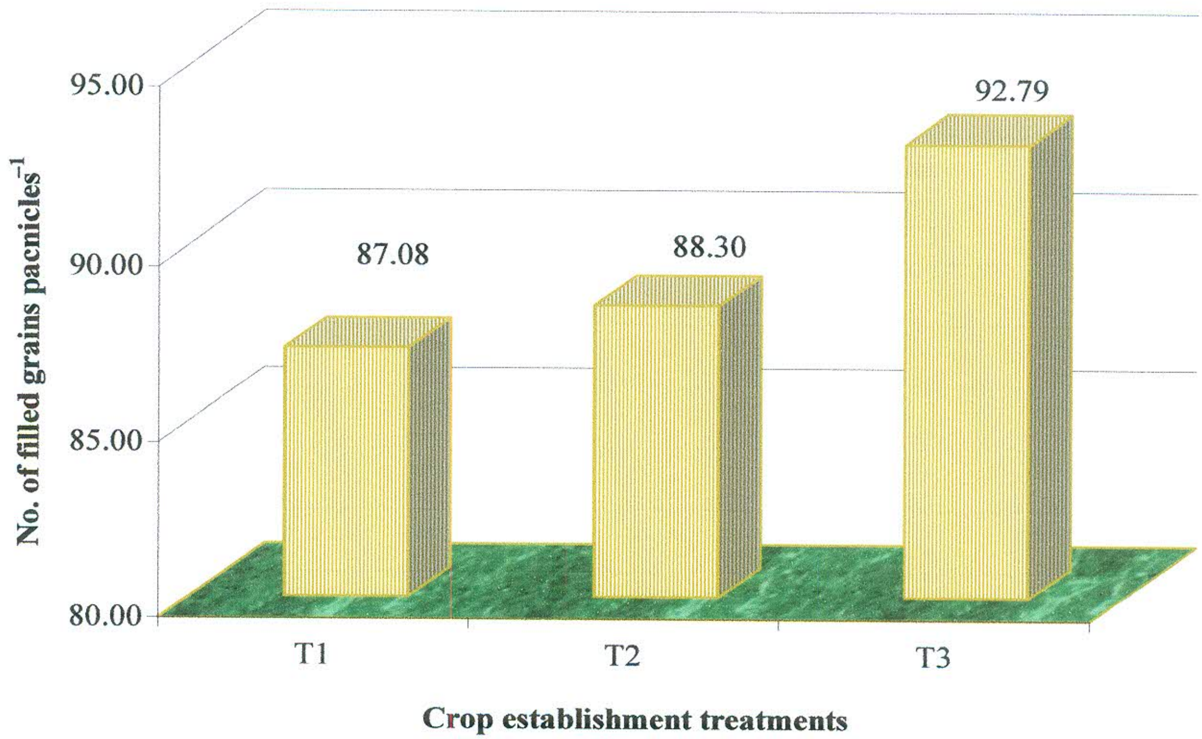

Fig. 6. Effect of establishment methods on filled grains panicles^{-1} of *T. aman* rice at harvest

Thousand–yield of grain

Weight of 1000–grain varied significantly due to crop establishment methods (Appendix IV and Table 11). Weight of 1000–grain had highest (27.95 g) in transplanting method (T_3) followed by direct wet seeding by hand broadcasting method (T_2) while direct wet seeding by drum seeder obtained the lowest weight of 1000–grain (24.87 g). This result indicated that the 1000–yield of grain varied from 24.87 to 27.95 g. Hussain *et al.*, (2004) reported that direct seeded rice using thick row and double row of drum seeded gave the similar and highest grain yield of about 4.9 t ha^{-1} which was about 22% higher than that of the transplanted rice and about 6% higher than that of the direct seeded thin row rice.

Table 11. Effect of crop establishment method on yield and yield attributes of *T. aman* rice at harvest

Treatments	Plant height (cm)	No. of tillers $hill^{-1}$	No. of panicles $hill^{-1}$	Grain yield ($t\ ha^{-1}$)	Straw yield ($t\ ha^{-1}$)	Straw sub sample weight (g)	Straw oven dry weight (g)	No. of filled grains $panicle^{-1}$	1000–grain weight (g)
T_1	108.98c	8.76c	6.32c	**3.45 c**	**4.14 c**	118.54b	33.13b	87.1c	24.87c
T_2	111.75b	9.58b	7.80b	**4.40 b**	**5.28 b**	115.65b	37.25b	88.3b	26.30b
T_3	120.38a	12.31a	8.74a	**5.12 a**	**6.14 a**	144.00a	50.71a	92.8a	27.95a
CV (%)	**3.25**	**5.63**	**5.32**	**7.86**	**6.60**	**3.70**	**5.24**	**6.68**	**5.87**
Level of sig.	**	**	**	**	**	**	**	**	**

T_1: Direct wet seeding by drum seeder; T_2: Hand broadcasting and T_3: Transplanting
CV= Co–efficient of variation and **= significant at 1% level of probability

4.2.1.3 Cost of production and economic performance of T. aman growing season as affected by crop establishment methods in presence of weed management practices

A partial budget showing cost of cultivation among direct wet seeding by drum seeder (T_1), hand broadcasting (T_2) and transplanting (T_3) methods in aman growing season regarding the various weed management practices are presented in Table 12.

Table 12. Production cost of T. aman rice as affected by different crop establishment methods in presence of weed management practices

Crop establishment methods	Different operational cost in Taka (ha^{-1})							Total variable cost (Tk. ha^{-1})
	Land preparation	Seed	Irrigation	Fertilizer	Labor	Herbicide	Insecticide	
T_1	4200	1800	1500	6090	30400	600	900	45490
T_2	4200	1800	1500	6090	28500	600	900	43590
T_3	5400	2000	1800	6090	35800	600	900	52590

T_1: Direct wet seeding by drum seeder; T_2: Hand broadcasting and T_3: Transplanting
Seed= Tk. 35 kg^{-1}, Urea= Tk. 16 kg^{-1}, TSP= Tk. 30 kg^{-1}, MP= Tk. 20 kg^{-1}, Gypsum= Tk. 10 kg^{-1}, Zinc sulphate= Tk. 190 kg^{-1}, Irrigation 1500 $season^{-1}$ ha^{-1},, Wage rate= Tk. 250 man day^{-1}.

Table 13. Gross return, net return and benefit cost ratio of T. aman rice as affected by different crop establishment methods in presence of weed management practices

Treatments	Total variable cost (Tk. ha^{-1})	Gross return (Tk. ha^{-1})			Net return (Tk. ha^{-1})	BCR
		Grain*	Straw*	Total		
T_1	45490	69000	2070	71070	25580	1.56
T_2	43590	88000	2640	90640	47050	2.08
T_3	52590	102400	3070	105470	52880	2.01

T_1: Direct wet seeding by drum seeder; T_2: Hand broadcasting and T_3: Transplanting
*Mean yield of 3 replications; Price of paddy= Tk. 20 ka^{-1} and Price of straw= Tk. 0.50 ka^{-1}
All prices indicated here just after harvesting period

Variable cost

The variable cost was similar to N–management practices for different crop establishment methods. But it varies in benefit cost ratio and net return because of their different production of grain and straw (Table 12 and 13).

Gross return

Highest gross return found for transplanting method (Tk. 1,05,470/–) followed by hand broadcasting (Tk. 90,640/–) in aman season regarding weed management practices (Table 13). This trend similar with the previous nitrogen management practices followed in aman growing season.

Net return (Tk. ha^{-1})

Among three planting techniques, the highest (52,880/–) and the lowest (25,580/–) marginal return found in the crop establishment method of transplanting (T_3) and direct wet seeding by drum seeder (T_1), respectively (Table 13).

BCR

In aman season, following weed management practices hand broadcasting method (T_2) gave the highest benefit cost ratio (2.07) where for direct wet seeding by drum seeder (T_1) and transplanting methods (T_3) showed the BCR or 1.56 and 2.01, respectively where $T_3 > T_1$ (Table 13).

4.2.2 Effect of different weed management practices

4.2.2.1 Performance study of morpho–physiology at vegetative stage

Plant population

Effect of weed management practices on number of plant population in a selected unit area of plot was statistically significant at 20 and 40 days after sowing while it did not vary significant at 60 DAS (Appendix II and Table 14). At 20 DAS, the maximum plant population (53.88) was exhibited from the hand weeding (W_1) followed by herbicide management and single hand weeding (W_3) (48.55) while the minimum plant population (43.05) was obtained in no weeding (W_4) management practices. In another observation at 40 DAS, weed management practices of hand weeding W_1, W_2 and W_3 did not vary significant in plant population of plant as well as they produce statistically identical maximum plant population (128.55, 120.00 and 125.44 cm, respectively) while now weeding showed the minimum plant population (109.05 cm). Among the weed management treatments, plant population were statistically similar at 60 DAS, however it was varied from 108.33 in W_4 to 139.66 in W_1 while mean of plant population during the study was varied from 86.81 to 107.40 where the maximum value was for hand weeding (W_1) and the lowest value was for no weeding (W_4).

Plant dry matter accumulation

Plant dry matter at 20, 40 and 60 DAS had also significant due to weed management practices where it was ranges between 1.34 to 1.54 g, 7.67 to 11.66 g and 24.19 to 31.66 g, respectively with and average mean ranges from 11.07 to 14.95 g during the study (Appendix III and Table 14). From the Table 14, it was found that the hand weeding management (W_1) noted the highest dry matter weight (1.54, 11.66 and 31.66 g) at 20, 40 and 60 DAS, respectively while hand weeding including herbicide application (W_3) showed the statistically identical highest plant dry matter weight (1.53 and 30.40 g) at 20 and 60 DAS, respectively. On the other hand, plant dry matter weight had lowest (1.34, 7.67 and 24.19 g) in without weeding (W_4) which was statistically differed from other weeding treatments.

T. aman plot following hand weeding

T. aman plot following no weeding

Plant height

Plant height at different days after sowing exerted significant due to weed management practices of *T. aman* rice (Appendix III and Table 14). Results reveal that the hand weeding management remarkable in plant height at 20, 40 and 60 DAS (26.28, 49.16 and 74.43 cm, respectively) while hand weeding including herbicide application (W_3) did not different significantly at 20 and 60 DAS (26.43 and 72.92 cm, respectively) and it was statistically close at 40 DAS (48.03 cm). However, BRRI weeder and hand weeding (W_2) also showed statistically identical tallest plant at 60 DAS (72.16 cm). On the other hand, no weeding management of *T. aman* rice consider as shortest plant producer (23.83, 45.24 and 68.68 cm) at those stages, respectively while weed management treatment W_2 showed the statistically similar shortest plant (24.85 cm) at 20 DAS and it was statistically close at 40 DAS (46.53 cm).

Table 14. Effect of weed management practices on plant population, plant dry matter and plant height of *T aman* rice at different days after sowing (DAS)

Treatments	Plant population at different DAS			Plant dry matter (g) at different DAS			Plant height (cm) at different DAS		
	20	40	60	20	40	60	20	40	60
W_1	53.88a	128.55a	139.66	1.54a	11.66a	31.66a	26.28a	49.15a	74.43a
W_2	46.16c	120.00a	126.94	1.45ab	8.80c	28.48b	24.85b	46.53bc	72.16a
W_3	48.55b	125.44a	132.94	1.53a	10.70b	30.40a	26.43a	48.03ab	72.92a
W_4	43.05d	109.05b	108.33	1.34b	7.67d	24.19c	23.83b	45.24c	68.68b
CV (%)	**4.97**	**7.43**	**4.47**	**11.91**	**5.87**	**5.46**	**5.62**	**4.36**	**3.18**
Level of sig.	**	**	ns	**	**	**	**	**	**

W_1: Hand weeding (HW), W_2: BRRI weeder + HW, W_3: Herbicide + HW and W_4: no weeding
CV = Co–efficient of variation; **= significant at 1% level of probability and ns= not significant

4.2.2.2 Performance study of growth and yield attributes at reproductive stage

Plant height

The effect of weed management practices on plant height had highly significant where it was varied from 110.78 to 115.98 cm (Appendix IV and Table 15 or Fig. 7). It is evident from the Table 15 that there were no significant differences in plant height between the weed management practices treatments of hand weeding (W_1) and herbicide application including hand weeding techniques (W_3) (115.98 and 115.11 cm, respectively) while those treatments was also statistically close to BRRI weeder + hand weeding (W_2) (112.95 cm) at harvest. As a result, no weeding management produced significantly the shortest plant (110.78 cm) at harvest which was also statistically close to weed management treatment of W_2.

Number of tillers

The production of total tillers in this study affected significantly due to different treatments on weed management practices where number of tillers per hill significantly varied from 9.04 to 11.20 (Appendix IV and Table 15). Among the weed management treatments, the maximum number of tillers was found from hand weeding treatment (W_1) than W_3 (10.69) and W_2 (9.94) while no weeding treatment registered the minimum number of tiller in this study (Table 15).

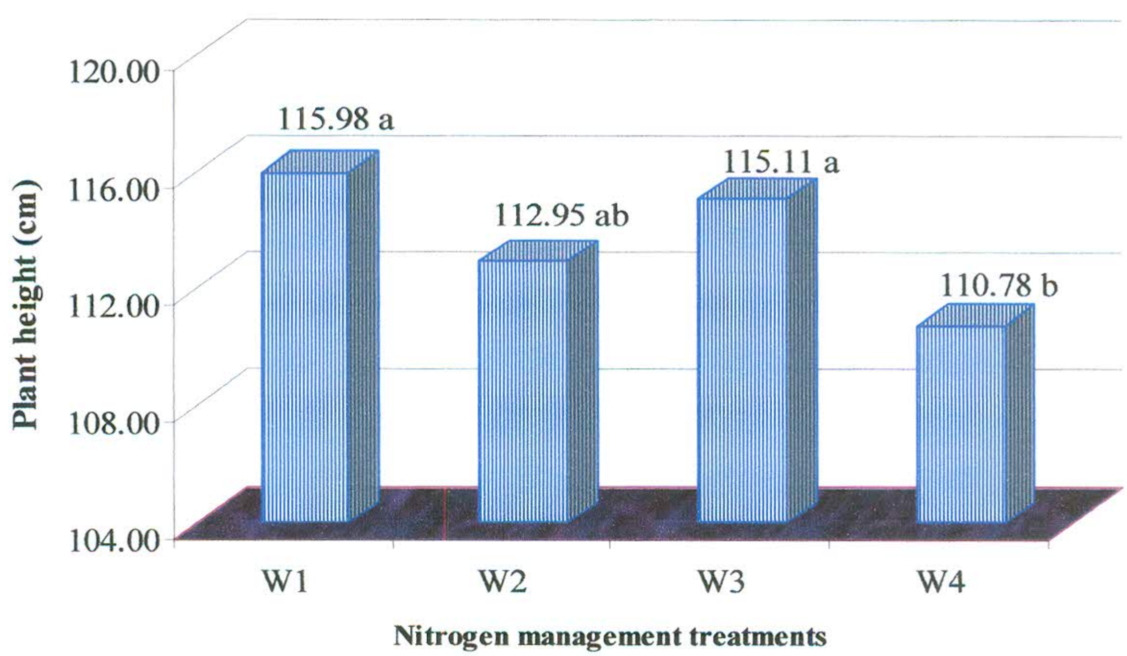

Fig. 7. Effect of nitrogen management practices on plant height of *T. aman rice* at harvest

Number of panicles

Significant variation was also found due to the various treatments of weed management practices in respect of number of panicles per hill (Appendix IV and Table 15). From the Table 15, it was found that the number of panicle ranges from 6.65 to 8.52 at harvest where maximum number was for hand weeding treatment (W_1) and minimum was for no weeding treatment (W_4). Among other weed management treatments, W_3 produce of 8.11 and W_2 produce of 7.45 number of panicle where all the treatments were statistically differed from each other.

Yield of grain

There was a significant variation due to weed management practices treatment regarding yield of grain where yield of grain ranges from 3.45 to 4.97 t ha^{-1} (Appendix IV and Table 15). It is evident from the Table 15 that hand weeding treatment (W_1) produced significantly the highest yield of grain (4.97 t ha^{-1}) while grain yield had lowest (3.45 t ha^{-1}) in no weeding treatment. However, there was no significant differences between the weed management practices treatments of BRRI weeder + hand weeding (W_2) and herbicide application + hand weeding (W_3) (4.33 and 4.53 t ha^{-1}, respectively).

Yield of straw

A significant variation was also found due to weed management practices treatment regarding yield of straw at harvest (Appendix IV and Table 15). The highest yield of straw (5.96 t ha^{-1}) was for the treatment W_1 (hand weeding) while it was lowest (4.14 t ha^{-1}) was for the treatment W_4 (no weeding). On the other hand, the yield of straw of 5.44 and 5.20 t ha^{-1} were produce from the W_3 (herbicide + hand weeding) and W_2 (BRRI weeder + hand weeding) which was statistically different from each other and also differed from other treatments.

Straw sub sample weight

Sub sample yield of straw at harvest had also significant due to weed management practices treatments where the highest weight of sub sample straw (133.21 g) found in no weeding treatment (W_4) while it was lowest (118.97 g) in herbicide + hand weeding treatment (W_3) (Appendix IV and Table 15). However, weed management practices treatments of W_1 (hand weeding) and W_2 (BRRI weeder + HW) produce of 125.08 and 126.98 g while both treatments were statistically identical.

Straw oven dry weight

A significant variation due to weed management practices were found in respect of straw over dry weight (Appendix IV and Table 15). Among the weed management treatments, treatment W_1 (hand weeding) and W_3 (herbicide + HW) produced statistically highest yield of straw of over dry (42.31 and 41.96 g, respectively) while lowest yield of straw of oven dry (37.66 g) was obtained from no weeding treatment.

Number of filled grains

Filled grain numbers panicles^{-1} was significantly affected by various treatments on weed management where it was varied from 72.22 to 105.33 (Appendix IV and Table 15 or Fig. 8). Weed management treatment of hand weeding (W_1) produced significantly the maximum filled grains and no weeding (W_4) showed the minimum filled grains panicles^{-1}. Another two treatments of weed management, W_2 produced of 85.97 and W_3 produced of 94.03 filled grains in this study (Table 15 or Fig. 8).

Thousand–yield of grain

Weight of 1000–grain varied significantly among the weed management practices treatments where Weight of 1000–grain ranges from 24.57 to 28.92 g. (Appendix IV and Table 15). From the above values it was found that the maximum was for hand weeding (W_1) and minimum was for no weeding (W_4) while BRRI weeder + HW (W_2) and herbicide + HW (W_3) showed statistically identical weight of 1000–grain (25.85 and 26.16 g, respectively).

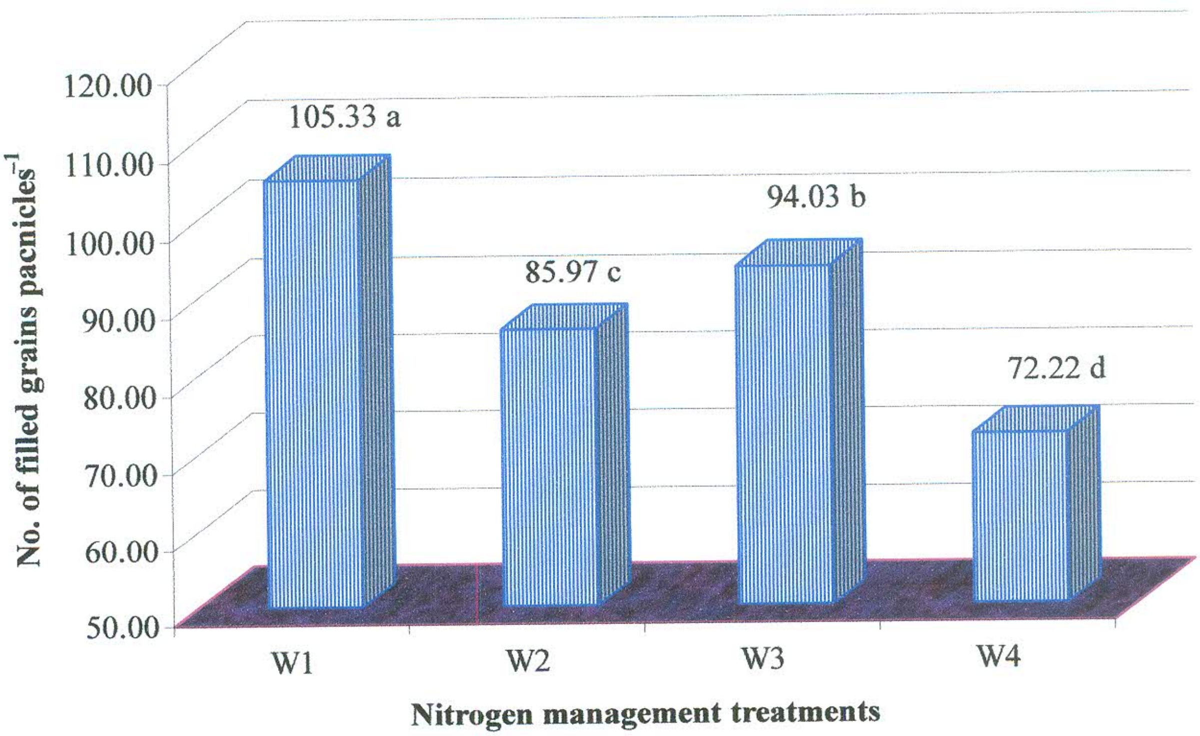

Fig. 8. Effect of weed management practices on filled grains panicles^{-1} of *T. aman rice* at harvest

Table 15. Effect of weed management practices on yield and yield attributes of *T. aman* rice at harvest

Treatments	Plant height (cm)	No. of tillers hill^{-1}	No. of panicles hill^{-1}	Grain yield (t ha^{-1})	Straw yield (t ha^{-1})	Straw sub sample weight (g)	Straw oven dry weight (g)	No. of filled grains panicle^{-1}	1000–grain weight (g)
W_1	115.98a	11.20a	8.52a	**4.97 a**	**5.96**	125.08b	42.31a	105.3a	28.92a
W_2	112.95ab	9.94c	7.45c	**4.33 c**	**5.20**	126.98b	39.52b	85.9c	25.85b
W_3	115.11a	10.69b	8.11b	**4.53 b**	**5.44**	118.97c	41.96a	94.0b	26.16b
W_4	110.78b	9.04d	6.65d	**3.45 d**	**4.14**	133.21a	37.66c	72.2d	24.57b
CV (%)	**3.25**	**5.63**	**5.32**	**7.86**	**6.60**	**3.70**	**5.24**	**6.68**	**5.87**
Level of sig.	**	**	**	**	**ns**	**	**	**	**

W_1: Hand weeding (HW), W_2: BRRI weeder + HW, W_3: Herbicide + HW and W_4: no weeding
CV= Co–efficient of variation; **= significant at 1% level of probability and ns= not significant

4.2.2.3 Cost of production and economic performance of T. aman growing season as affected by weed management practices

Different weed management practices affect the grain and straw yield and thus cultivation cost and economic returns different each other are furnished in Table 16.

Table 16. Economic performance with BCR of different weed management (means of 3 yields)

Treatments	Cost of production (Tk. ha^{-1})			Yield (t ha^{-1})		Gross return (Tk. ha^{-1})			Net return (Tk. h^{a-1})	BCR
	Fixed cost	W–management cost	Total Tk.	Gain	Straw	Grain	Straw	Total		
W_1	38800	1600	40400	4.97	5.96	99400	2980	102380	51990	2.03
W_2	33800	1600	35400	4.33	5.2	86600	2600	89200	37310	1.72
W_3	31300	4000	35300	4.53	5.44	90600	2720	93320	44320	1.90
W_4	2930	0.00	29300	3.45	4.14	69000	2070	71070	34180	1.93

W_1: Hand weeding (HW), W_2: BRRI weeder + HW, W_3: Herbicide + HW and W_4: no weeding
Price of un–husked rice= Tk. 20 kg^{-1} and price of straw= Tk. 0.50 kg^{-1}

Due to differences of cost of weed control among four treatments, the total cost of production was varied in this experiment. The treatment W_1 involved the maximum cost of production (40,400/–) along with highest BCR of 2.03 where the lowest cost of production (29,300/–) was involved in W_4 (Table 16). The net return from rice cultivation was found to be the maximum (51,990/–) with the weed control practices in hand weeding (W_1) followed by W_3 (44,320). The economic return when there was no weeding throughout the growing season due to lower grain and straw yield having the lowest net return of 34,180/– along with higher BCR value of 1.93 than W_2 (1.72). BRRI weeder + HW (W_2) showed lower BCR might be due to more or less similar net return and higher cost of production than that of no weeding (Table 16).

It may therefore be concluded that the hand weeding approach whenever necessary was the best treatment than others. As the similarity with W_1, it may be mentioned that the use of herbicide is an alternative in controlling weeds by hand weeding. The results correlated with the findings of Ahmed *et al.* (2005).

4.2.3 Interaction effect of crop establishment methods and N application

4.2.3.1 Performance study of morpho–physiology at vegetative stage

Plant population

A significant variation was found due to interaction effect of establishment methods and various types of N application at 20 DAS where the maximum number of plant population (94.66) was noted from the interactions between transplanting methods and hand weeding (T_3W_1) followed by transplanting methods and BRRI weeder + hand weeding (T_3W_2) at 20 DAS (Appendix III and Table 17). On the other hand, plant population had minimum (25.50) in T_1W_4 (direct wet seeding by drum seeder × no weeding) while statistically similar minimum number of plant population (28.33, 27.66 and 8.16) were obtained in T_1W_1, T_1W_2 and T_1W_3, respectively at 20 DAS. The plant population at 40 and 60 DAS was statistically similar due to whole interaction treatments due to its non significant variation. In case of mean performance, plant population varied from 61.11 (T_1W_4) to 134.38 (T_3W_1) considering the whole studied period (20, 40 and 60 DAS).

Plant dry matter

However, plant dry matter was significantly affected due to crop establishment methods along with various nitrogen applications at 40 and 60 DAS but it did not differed significantly at 20 DAS (Appendix III and Table 17). As a result, all the interactions treatments had statistically identical for observing the plant dry matter at 20 DAS. At 40 and 60 DAS, the highest weight of plant dry matter (15.23 and 17.52 g, respectively) was found in T_3W_1 (transplanting method × hand weeding) while interaction treatments of T_3W_2 (transplanting method × BRRI weeder + hand weeding) and T_3W_3 (transplanting method × herbicide + one hand weeding) obtained the statistically highest weight of plant dry matter (16.12 and 16.85 g, respectively) at 60 DAS. On the other hand, the lowest weight of dry matter (5.58 and 8.70 g) was recorded in T_1W_4 (direct wet seeding by drum seeder × no weeding) at 40 and 60 DAS, respectively.

Plant height

All the treatment combinations of crop establishment methods and nitrogen application options were produced statistically similar height of rice plant incase of the interaction effect did not vary significant regarding plant height at 20, 40 and 60 DAS (Appendix III and Table 17). However, plant height varied from 20.58 to 28.33 cm at 20 DAS, 40.95 to 52.84 cm at 40 DAS and 64.63 to 76.47 cm at 60 DAS. In case of mean performance regarding plant height varied from 41.98 to 52.55 cm where least value was obtained from T_1W_4 and highest value was recorded from T_3W_1.

Table 17. Interaction effect between crop establishment method and weed management practices on plant population, plant dry matter and plant height of *T aman* rice at different days after sowing (DAS)

Treatments	Plant population at different DAS			Plant dry matter (g) at different DAS			Plant height (cm) at different DAS		
	20	40	60	20	40	60	20	40	60
T_1W_1	28.33g	115.66	124.66	1.08	8.70ef	24.45bd	24.78	44.71	72.29
T_1W_2	27.66g	98.16	110.16	1.85	7.10g	22.51d	21.66	41.68	68.97
T_1W_3	28.16g	110.50	116.16	1.00	7.68fg	23.70d	24.10	43.85	70.33
T_1W_4	25.50g	88.83	89.00	0.91	5.58h	19.62e	20.58	40.95	64.63
T_2W_1	38.66e	115.83	140.00	0.93	11.05cd	35.80a	25.72	49.90	74.52
T_2W_2	35.66ef	110.66	129.00	1.11	7.50g	26.75b	24.78	47.19	74.41
T_2W_3	37.50ef	112.66	132.50	1.20	10.31d	33.46a	25.40	48.95	73.21
T_2W_4	33.66f	105.16	110.50	1.00	8.70ef	26.75b	24.10	45.34	69.91
T_3W_1	94.66a	154.16	154.33	2.61	15.23a	34.73a	28.33	52.84	76.47
T_3W_2	75.16c	151.16	141.66	2.38	11.80c	36.20a	28.12	50.71	73.10
T_3W_3	80.00b	153.16	150.16	2.41	14.10b	34.05a	29.79	51.30	75.24
T_3W_4	70.00d	133.16	125.50	2.11	8.75e	26.20b	26.82	49.45	71.49
CV (%)	**4.97**	**7.43**	**4.47**	**11.91**	**5.87**	**5.46**	**5.62**	**4.36**	**3.18**
Level of sig.	**	ns	ns	ns	**	**	ns	ns	ns

T_1: Direct wet seeding by drum seeder; T_2: Hand broadcasting and T_3: Transplanting
W_1: Hand weeding (HW), W_2: BRRI weeder + HW, W_3: Herbicide + HW and W_4: no weeding
CV = Co–efficient of variation; **= significant at 1% level of probability and ns= not significant

4.2.3.2 Performance study of growth and yield attributes at reproductive stage

Number of panicles

A significant variation was found due to interaction effect of crop establishment method and application time and date of N at harvest (Appendix IV). The data on number of panicles per hill significantly varied from 5.90 to 9.82 which were obtained from the treatment combinations of T_1W_4 (direct wet seeding by drum seeder × no weeding) and T_3W_1 (transplanting method × hand weeding), respectively at harvest (Table 18). Similarly, Prassad *et al.* (1999) and Ali (2005) also found significant variation due to crop establishment method which was fully supported the present findings.

Yield of grain

The grain varied significantly from 2.55 to 6.10 t ha^{-1} due to interaction effect of crop establishment method and application time and date of N at harvest (Appendix IV and Table 18). Among the treatment combinations, yield of grain had highest (6.10 t ha^{-1}) in T_3W_1 (transplanting method × hand weeding) followed by T_3W_3 (transplanting method × herbicide + hand weeding) (5.17 t ha^{-1}) while yield of grain had lowest in T_1W_4 (direct wet seeding by drum seeder × no weeding) (2.55 t ha^{-1}).

Number of filled grains

Number of filled grains $panicles^{-1}$ was significantly affected by the interaction effect of crop establishment methods and N treatments at harvest (Appendix IV and Table 18). The maximum number of filled grains (108.50) was observer in T_3W_1 (transplanting method × hand weeding) while the treatment combinations of T_2W_1 (hand broadcasting method × hand weeding) obtained the statistically similar maximum filled grains (107.00) followed by T_1W_1 (direct wet seeding by drum seeder × hand weeding) and T_2W_3 (hand broadcasting method × herbicide + hand weeding) (100.50 and 97.60, respectively). On the other hand, filled grains had minimum (70.37) in T_1W_4 (direct wet seeding by drum seeder × no weeding).

Weight of 1000–grains

Weight of 1000–grain significantly varied from 22.00 to 28.86 g due to interaction effects of crop establishment methods and application time and level of N (Appendix IV and Table 18). From the Table 18, it was found that the highest Weight of 1000–grain (29.30 g) was found in T_1W_1 (direct wet seeding by drum seeder method × hand weeding) while the interaction treatments of T_3W_1 (transplanting method × hand weeding), T_2W_1 (hand broadcasting method × hand weeding) and T_3W_3 (transplanting method × herbicide + one hand weeding) obtained the statistically similar identical Weight of 1000–grain (28.86, 28.60 and 28.56 g, respectively). Similarly, yield of grain of 1000–grain had lowest (22.20 g) was recorded in T_1W_4 (direct wet seeding by drum seeder × no weeding).

Table 18. Interaction effect between crop establishment method and weed management practices on yield and yield attributes of *T. aman* rice at harvest

Treatments	Plant height (cm)	No. of tillers hill^{-1}	No. of panicles hill^{-1}	Grain yield (t ha^{-1})	Straw yield (t ha^{-1})	Straw sub sample weight (g)	Straw oven dry weight (g)	No. of filled grains panicle^{-1}	1000–grain weight (g)
T_1W_1	111.08	9.73	6.92e	3.92 d	4.70	107.96	35.33	100.5ab	29.30a
T_1W_2	108.04	8.45	5.90f	3.63 de	4.36	101.16	33.36	88.1c	25.00bc
T_1W_3	110.90	8.80	6.53ef	3.72 de	4.46	104.12	35.26	89.4bc	23.00c
T_1W_4	105.92	8.05	5.92f	2.55 f	3.06	160.90	28.56	70.4d	22.20c
T_2W_1	114.01	10.78	8.83cd	4.92 bc	5.90	119.06	39.86	107.0a	28.60a
T_2W_2	110.00	9.13	7.93d	4.63 c	5.56	138.06	34.66	75.3d	25.03bc
T_2W_3	113.23	10.37	8.32cd	4.72 bc	5.66	107.40	39.43	97.6bc	26.93ab
T_2W_4	109.78	8.05	68.83e	3.33 e	4.00	98.10	35.03	73.3d	24.66bc
T_3W_1	122.86	13.10	9.82a	6.10 a	7.32	148.23	51.73	108.5a	28.86a
T_3W_2	120.80	12.23	8.51cd	4.75 bc	5.70	141.73	50.53	94.5bc	27.53ab
T_3W_3	121.20	12.92	9.48ab	5.17 b	6.20	145.40	51.20	95.1bc	28.56a
T_3W_4	116.66	11.03	7.15e	4.50 c	5.40	140.63	49.40	73.0d	26.86ab
CV (%)	**3.25**	**5.63**	**5.32**	**7.86**	**6.60**	**3.70**	**5.24**	**6.68**	**5.87**
Level of sig.	**ns**	**ns**	**	**	**ns**	**ns**	**ns**	**	**

T_1: Direct wet seeding by drum seeder; T_2: Hand broadcasting and T_3: Transplanting
N_1: ⅓ at 15 DAT + ⅓ at 30 DAT + ⅓ at PI; N_2: ¼ at basal + ¼ at 15 DAT, + ¼ at 30 DAT + ¼ at PI
N_3: Leaf color chart (LCC) based N application and N_4: no nitrogen
CV= Co–efficient of variation; **= significant at 1% level of probability and ns= not significant

Non significant variation result

Among other yield and yield contributing characters *viz.* plant height (cm), number of tillers per hill, yield of straw (kg 6 m^{-2}), straw sub sample weight (g) and straw sub sample dry weight (g) were statistically identical due to all interaction treatments between crop establishment methods and various application option of N. However, plant height varied from 105.92 (T_1W_4) to 122.86 (T_3W_1), number of tillers varied from 8.05 (T_1W_4) to 13.08 (T_3W_1); yield of straw varied from 3.06 (T_1W_4) to 7.32 t ha^{-1} (T_3W_1), straw sub sample weight varied from 98.10 g (T_2W_4) to 148.23 g (T_3W_1) and straw oven dry weight varied from 28.56 g (T_1W_4) to 51.73 g (T_3W_1) (Table 18).

4.3 Experiment 3: Effect of crop establishment method and time of nitrogen application on productivity of *Boro* rice

4.3.1 Effect of crop establishment methods

4.3.1.1 Performance study of morpho–physiology at vegetative stage

Plant population

Effect of different crop establishment methods showed significant difference in respect of plant population at different days after sowing during *Boro* season (Appendix V and Table 19). It is evident from the Table 13 that the number of plant populations had maximum (38.20, 35.37 and 57.29) in transplanting methods at 20, 40 and 60 DAS, respectively while hand broadcasting method obtained the statistically similar maximum plant population (33.79) at 40 DAT. On the other hand, direct wet seeding by drum seeder showed significantly the minimum number of plant population (15.75, 15.75 and 33.87) at those stages, respectively. From the above results it was found that the mean performance of plant population varied from 21.79 for direct wet seeding by drum seeder to 43.62 for transplanting method. Results showed that irrespective of different crop establishment methods, plant populations (Nos.) increased with the passage of time and reached to its maximum number at maturity stage. Considering three different establishment methods (direct wet seeding, hand broadcasting and transplanting), the number of plant population was lowest in 20 DAS and highest in 60 DAS. It grows rapidly at early vegetative stage. This result was confirmed with the findings of Ali (2005).

Plant dry matter

At *Boro* season, the data on plant dry matter affected significantly due to crop establishment methods at 20 and 60 DAS where it was significantly varied from 0.26 to 4.43 during the study (20 t o60 DAS) (Appendix V and Table 19). Among the crop establishment treatments, transplanting methods showed significantly the highest weight of plant dry matter (0.50 and 4.43 g) than hand broadcasting method (0.35 and 3.04 g) and direct wet seeding by drum seeder (0.26 and 2.22 g) at 20 and 60 DAS, respectively. At 40 DAS, all the crop establishment treatments recorded statistically similar plant dry matter due to non-significant variation. However, mean of dry matter accumulation ranges from 1.25 to 2.10 g for direct wet seeding by drum seeder and hand broadcasting, respectively. The trend of dry matter accumulation more rapidly increased in transplanting method than other two crop establishment methods.

Plant height

Analysis of variance data on plant height revealed that it was significantly affected due to different crop establishment methods at 20 and 60 DAS while a non significant variation was observed at 40 DAS during the *Boro* season (Appendix V and Table 19). As a result, direct wet seeding by drum seeder (T_1), hand broadcasting (T_2) and transplanting (T_3) method showed statistically similar height of *Boro* rice plant at 40 DAS. In another observation at 20 and 60 DAS, transplanting method produced significantly the tallest plant (13.56 and 2.51 cm, respectively) with an average mean values of 19.31 cm compared to hand broadcasting (9.78 and 28.60 cm) with an average mean values of 17.26 and direct wet seeding by drum seeder (8.94 and 24.93 cm) with an average mean values of 15.53 cm considering 20, 40 and 60 DAS. It might be due to maintain proper distance from hill to hill and proper management in line sowing as compared to other methods. Reddy *et al.,* (1990) observed that nitrogen has positive effect on plant height of rice.

Table 19. Effect of crop establishment method on plant population, plant dry matter and plant height of *Boro* rice at different days after sowing (DAS)

Treatments	Plant population at different DAS			Plant dry matter (g) at different DAS			Plant height (cm) at different DAS		
	20	40	60	20	40	60	20	40	60
T_1	15.75c	15.750b	33.875c	0.267c	1.28	2.225c	8.947b	12.717	24.925c
T_2	35.83b	33.792 a	45.625b	0.357b	1.28	3.042b	9.782b	13.408	28.597b
T_3	38.20a	35.375 a	57.292 a	0.500 a	1.36	4.433 a	13.565 a	14.847	29.514 a
CV (%)	**7.02**	**8.27**	**6.52**	**7.11**	**26.11**	**4.63**	**4.65**	**3.67**	**2.74**
Level of sig.	**	**	**	**	**ns**	**	**	**ns**	**

T_1: Direct wet seeding by drum seeder; T_2: Hand broadcasting and T_3: Transplanting
CV= Co–efficient of variation; **= significant at 1% level of probability and ns= not significant

4.3.1.2 Performance study of growth and yield attributes at reproductive stage

Number of tillers

It is evident from the Appendix VI that there was a significant variation due to crop establishment methods (Table 20). From the Table 20 or Fig. 13, it was found that the transplanting method produced significantly more tillers per hill (7.20) than hand broadcasting (6.25) and direct wet seeding by drum seeder (6.25) where hand broadcasting and direct wet seeding did not vary significant between them. The reason behind the lower number of tiller production may be due to higher rate of tiller abortion in direct wet seeding by drum seeder method.

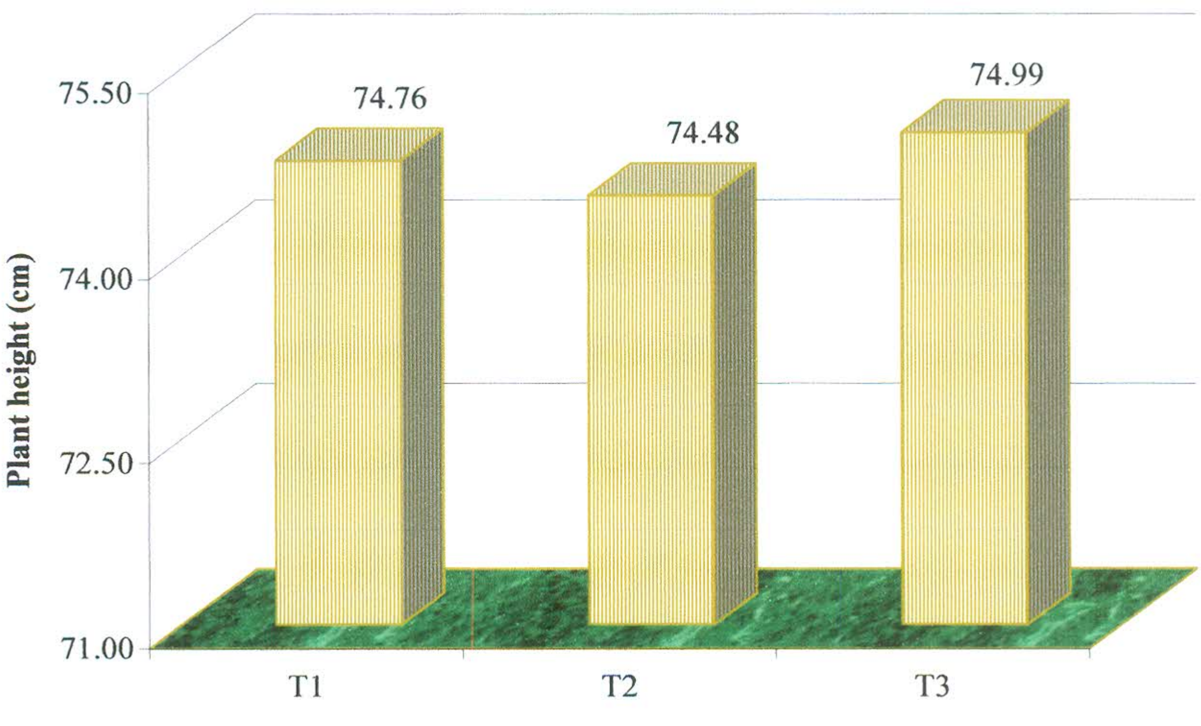

Fig. 9. Effect of crop establishment method on plant height of Boro rice at harvest

Number of filled grains

A significant variation was found due to crop establishment method where transplanting method obtained the maximum filled grains per hill (7.07) than hand broadcasting (T_2) and direct wet seeding by drum seeder (T_1) treatments (6.16 and 5.96, respectively) where t_2 and T_1 were statistically similar for obtaining the filled grains (Appendix VI and Table 20 or Fig. 10). Ali (2005) also recorded the same trend which was confirmed with the findings of this result.

Thousand–yield of grain

The data on Thousand–yield of grain had significant due to crop establishment method (Appendix VI and Table 20). However, transplanting method registered the highest Weight of 1000–grain(20.15 g) but Thousand–yield of grain with hand broadcasting (16.20 g) and direct wed seeding by drum seeder (16.05 g) did not differed significantly (Table 20).

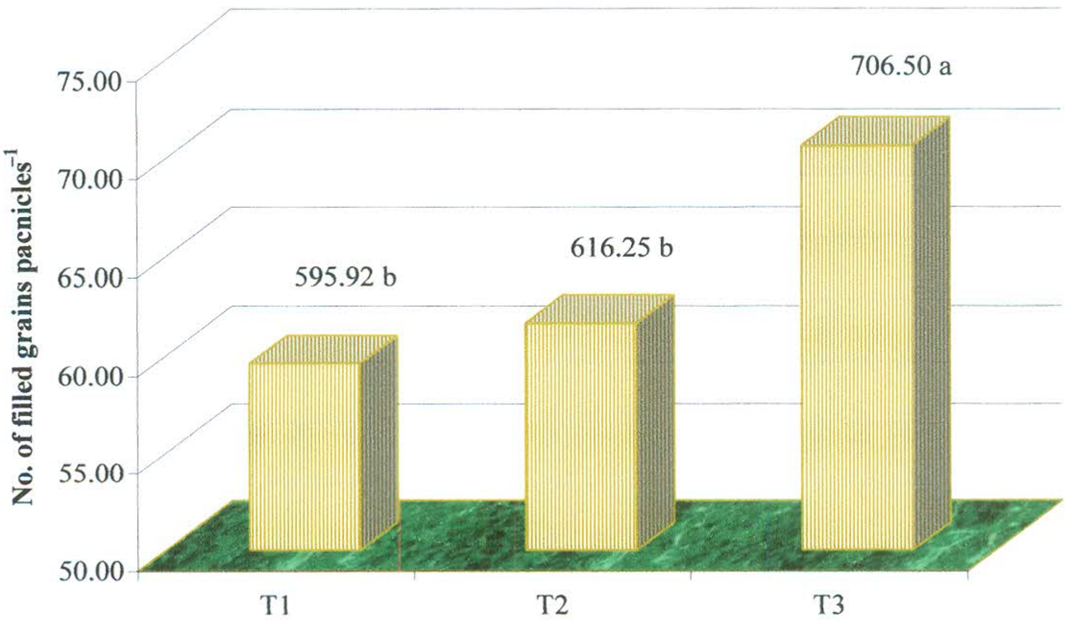

Fig. 10. Effect of crop establishment method on filled grains panicles^{-1} of Boro rice at harvest

Non significant variation result

From the Table 14, it was also found that the yield and yield attributes such as plant height (cm) (Table 20 or Fig. 9), number of panicles per hill, yield of grain (t ha^{-1}), yield of straw (t ha^{-1}), straw sub sample weight (g) and straw oven dry weight (g) of transplanting method (74.98 cm, 5.57, 3.75 t ha^{-1}, 4.50 t ha^{-1}, 111.75 g and 29.05 g, respectively) did not differed significantly with hand broadcasting method (74.48 cm, 5.26, 3.71 t ha^{-1}, 4.45 t ha^{-1}, 97.66 g and 28.36 g, respectively) and direct wet seeding by drum seeder (74.76 cm, 5.34, 3.50 t ha^{-1}, 4.20 t ha^{-1}, 96.08 g and 27.59 g, respectively). In case of the above whole parameters of the study at *Boro* season did not vary significant due to studied whole crop establishment methods.

Table 20. Effect of crop establishment method on yield and yield attributes of *Boro* rice at harvest

Treatments	Plant height (cm)	No. of tillers hill^{-1}	No. of panicles hill^{-1}	Grain yield (t ha^{-1})	Straw yield (t ha^{-1})	Straw sub sample weight (g)	Straw oven dry weight (g)	No. of filled grains panicle^{-1}	1000–grain weight (g)
T_1	74.762	6.25b	5.38	**3.50**	**4.20**	96.083	27.592	59.5b	16.050b
T_2	74.483	6.25b	5.25	**3.71**	**4.45**	97.667	28.367	61.6b	16.209b
T_3	74.987	7.19a	5.57	**3.75**	**4.50**	111.750	29.058	70.7a	20.158a
CV (%)	**1.26**	**1.82**	**4.53**	**7.23**	**7.36**	**3.90**	**2.37**	**4.70**	**6.80**
Level of sig.	**ns**	**	**ns**	**ns**	**ns**	**ns**	**ns**	**	**

T_1: Direct wet seeding by drum seeder; T_2: Hand broadcasting and T_3: Transplanting
CV= Co–efficient of variation; **= significant at 1% level of probability and ns= not significant

4.3.1.3 Cost of production and economic performance of Boro growing season as affected by crop establishment methods in presence of N fertilizer

Production cost in Boro season for different methods and their returns are presented in Table 21 and 22.

Table 21. Production cost of T. aman rice as affected by different crop establishment methods in presence of N fertilizer

Crop establishment methods	Different operational cost in Taka							Total variable cost (Tk.)
	Land preparation	Seed	Irrigation	Fertilizer	Labor	Herbicide	Insecticide	
T_1	4200	1800	2400	9550	31500	750	750	51950
T_2	4200	1800	2400	9550	32400	750	750	51850
T_3	5400	2100	2600	9550	45000	750	750	66150

T_1: Direct wet seeding by drum seeder; T_2: Hand broadcasting and T_3: Transplanting
Seed= Tk. 40 kg^{-1}, Urea= Tk. 16 kg^{-1}, TSP= Tk. 30 kg^{-1}, MP= Tk. 20 kg^{-1}, Gypsum= Tk. 10 kg^{-1}, Zinc sulphate= Tk. 190 kg^{-1}, Irrigation 1500 season^{-1} ha^{-1},, Wage rate= Tk. 250 man day^{-1}.

Table 22. Gross return, net return and benefit cost ratio of T. aman rice as affected by different crop establishment methods in presence of N fertilizer

Treatments	Total variable cost (Tk. ha^{-1})	Gross return (Tk. ha^{-1})			Net return (Tk. ha^{-1})	BCR
		Grain*	Straw *	Total		
T_1	51950	70000	2100	72100	20150	1.39
T_2	51850	74200	2225	76425	24575	1.47
T_3	66150	75000	2250	77250	11100	1.17

T_1: Direct wet seeding by drum seeder; T_2: Hand broadcasting and T_3: Transplanting
*Mean yield of 3 replications; Price of paddy= Tk. 20 ka^{-1} and Price of straw= Tk. 0.50 ka^{-1}
All prices indicated here just after harvesting period

The total variable cost ranged from Tk. 51950/– (T_1: direct seeding by drum seeder method) to 66,150/– (T_2: hand broadcasting) (Table 21 and 22). It was found that almost similar cultivation costs were in direct wet seeding by drum seeder and hand broadcasting. Similar input cost may be the reason behind it. Due to higher land preparation and labor cost (Tk. 66150/–) for transplanting (T_3) system and maximization of the total cost was found in it.

Gross return

Among all crop establishment method, a little bit higher gross return in T_3 system. However, statistically insignificant difference with them. Producing same yield was the other reason behind it (Table 22).

Net return (Tk. ha^{-1})

By economic analysis, hand broadcasting gave the higher marginal/net return of Tk. 24,575/- ha^{-1} for bor cultivation period. Although there were insignificant yield differences found between two methods of hand broadcasting and transplanting. The lowest net return (11,100/–) was in transplanting (Table 22)..

BCR

Highest net return with similar production cost maximized the BCR value of 1.47 for hand broadcasting method followed by direct wet seeding by drum seeder (1.39). The lowest BCR was in transplanting (T_3) method (1.17) (Table 22).

4.3.2 Effect of different nitrogen management practices

4.3.2.1 Performance study of morpho–physiology at vegetative stage

Plant population

Number of plant population affected significantly during *Boro* season due to the effects of application time and levels of N at 20 and 40 DAS while various treatments on the application time and levels of N did not vary significant at 60 DAS (Appendix V and Table 23). Among the different treatments on nitrogen management practices, plant population within a certain unit plot area of land had maximum (36.50 and

34.00) in ¼ at basal + ¼ at 15 DAS + ¼ at 30 DAS + ¼ at panicle initial stage (N_2) at 20 and 40 DAS, respectively followed by ⅓ at 15 DAS + ⅓ at 30 DAS + ⅓ at panicle initial stage (N_1) (29.38 and 28.38, respectively). In general, minimum number of plant population (29.38 and 28.38) found with control treatment (without nitrogen) at 20 and 40 DAS, respectively. At 60 DAS, N_1, N_2, N_3 and N_4 were statistically similar for obtaining the plant population. Mean performance of plant population varied from 27.35 (N_4: no nitrogen) to 42.31 (N_2: ¼ at basal + ¼ at 15 DAS + ¼ at 30 DAS + ¼ at panicle initial stage) considering 20, 40 and 60 DAS.

Plant dry matter accumulation

Split application of Nitrogen fertilizer at different levels affect the plant dry matter at different dates after sowing (20, 40 and 60 DAS) with an average mean values of 1.67 (N_1), 2.33 (N_2), 1.55 (N_3) and 0.99 (N_4) (Appendix V and Table 23). Among the N treatments, N_2 (¼ at basal + ¼ at 15 DAS + ¼ at 30 DAS + ¼ at panicle initial stage) produced significantly the highest weight of plant dry matter (0.42, 1.65 and 4.93 g with an average mean values of 2.33) followed by N_1 (⅓ at 15 DAS + ⅓ at 30 DAS + ⅓ at panicle initial stage) (0.38, 1.33 and 3.30 g with a mean value of 1.67) at 20, 40 and 60 DAS, respectively (Table 15). Likewise, without application of N (no nitrogen) noted the lowest weight of plant dry matter (0.32, 1.06 and 1.58 g with a mean value of 0.99 g) at those stages, respectively.

Plant height

Analysis of variance data on plant height have been presented in Appendix V indicated significant difference at all the data recording stages (Appendix V and Table 15). Considering the various management practices of N application, plant height varied from 10.00 (N_3) to 30.79 cm (N_2) while mean value varied from 15.82 (N_4) to 19.74 cm (N_2) considering 20 to 60 DAS (Table 23). Among the N treatments, N_2 (¼ at basal + ¼ at 15 DAS + ¼ at 30 DAS + ¼ at panicle initial stage) produced significantly the tallest plant (12.28, 16.15 and 19.74 cm) at 20, 40 and 60 DAS, respectively while shortest plant was taken from N_3 (LCC: Leaf color chart based N application) at 20 DAS (10.00 cm) and N_4 (without nitrogen) at 40 and 60 DAS (12.27 and 24.26 cm, respectively). Results reveal that nitrogen management options had remarkable differences in plant height at 20, 40 and 60 DAS where N_2 treatment had highly significant than other N treatments.

Table 23. Effect of application time and level of N on plant population, plant dry matter and plant height of *Boro* rice at different days after sowing (DAS)

Treatments	Plant population at different DAS			Plant dry matter (g) at different DAS			Plant height (cm) at different DAS		
	20	40	60	20	40	60	20	40	60
N_1	29.38b	28.389b	49.056	0.389b	1.333ab	3.300b	10.133c	13.347b	28.284b
N_2	36.50a	34.000a	55.889	0.422a	1.656a	4.933a	12.280a	16.144[a]	30.789 a
N_3	20.88bc	26.222bc	45.944	0.367b	1.167b	3.111c	10.000c	12.873b	27.084c
N_4	25.94c	24.611c	31.500	0.320c	1.067c	1.589d	10.644b	12.265c	24.556d
CV (%)	**7.02**	**8.27**	**6.52**	**7.11**	**26.11**	**4.63**	**4.65**	**3.67**	**2.74**
Level of sig.	**	**	**ns**	**	**	**	**	**	**

N_1: ⅓ at 15 DAT + ⅓ at 30 DAT + ⅓ at PI; N_2: ¼ at basal + ¼ at 15 DAT, + ¼ at 30 DAT + ¼ at PI
N_3: Leaf color chart (LCC) based N application and N_4: no nitrogen
CV= Co–efficient of variation; **= significant at 1% level of probability and ns= not significant

4.3.2.2 Performance study of growth and yield attributes at reproductive stage

Plant height

There was a significant variation due to nitrogen management practices in respect of plant height in *Boro* rice (Appendix VI and Table 24 or Fig. 11). It is evident from the Table 16 that the tallest plant (78.29 cm) was exhibited from the treatment N_2 (¼ at basal + ¼ at 15 DAS + ¼ at 30 DAS + ¼ at panicle initiation stage) followed by N_1 (⅓ at 15 DAS + ⅓ at 30 DAS + ⅓ at panicle initial) (76.48 cm) while no nitrogen treatment produced the shortest plant (69.27 cm) at harvest.

Number of tillers

Production of tillers per hill also affected significantly due to nitrogen management practices during the *Boro* season at harvest (Appendix VI and Table 24). From the Table 24 it was found that the number of tillers per hill varied from 4.38 to 7.83 where the maximum number was produced by using nitrogen with splitting at ¼ at basal + ¼ at 15 DAS + ¼ at 30 DAS + ¼ at panicle initiation stage (N_2) and the minimum number of tillers was found by the without application of nitrogen. Rao *et al.*, (1986) also reported that split application of nitrogen increased total tillers $hill^{-1}$ compared to entire nitrogen applied as basal. Reddy *et al.*, (1988) observed that nitrogen application in three split from 0 to 120 kg ha^{-1} increase total tillers $hill^{-1}$.

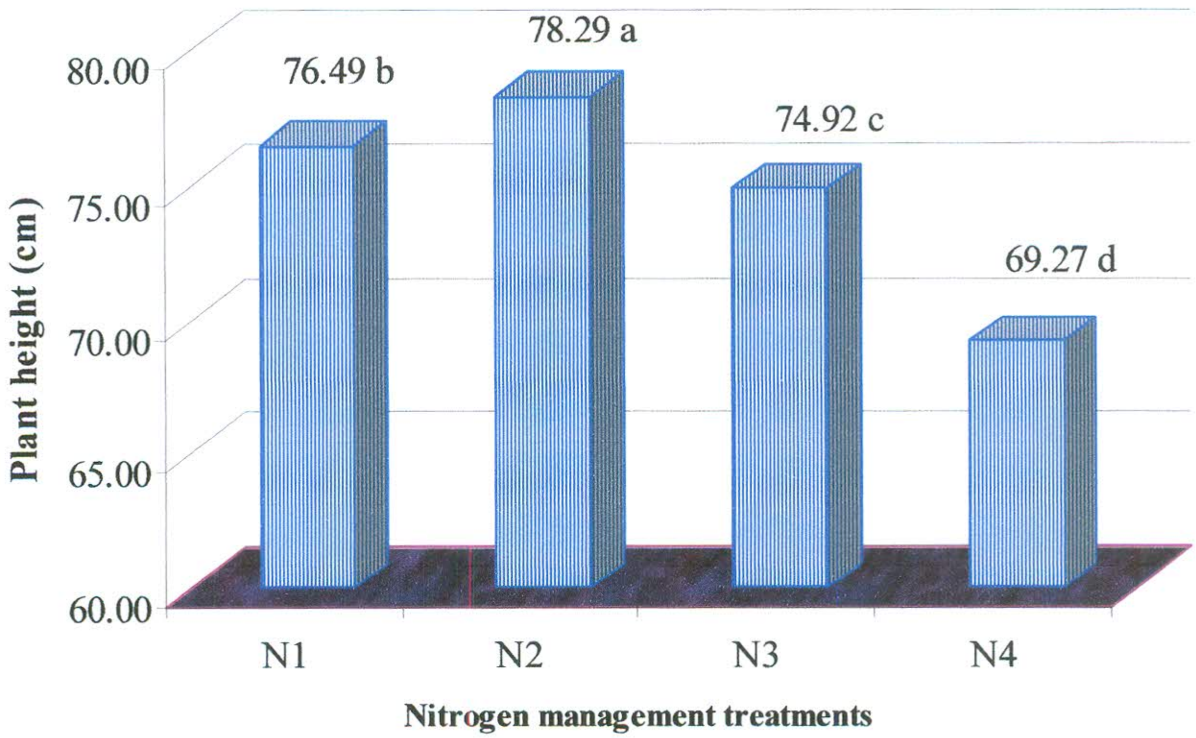

Fig. 11. Effect of nitrogen management practices on plant height of Boro rice at harvest

Number of panicles

Number of panicles per hill at harvest varied significantly due to N management practices (Appendix VI and Table 24). Maximum number of panicles (6.73) was found from the nitrogen of ¼ at basal + ¼ at 15 DAS + ¼ at 30 DAS + ¼ at panicle initiation stage (N_2) while there was no significant difference (6.12) with N_1 (⅓ at 15 DAS + ⅓ at 30 DAS + ⅓ at panicle initial) treatment. No nitrogen showed the minimum number of panicles per hill (3.49) and it was statistically differed from other N treatments. So, the panicle numbers for different nitrogen treatments in a particular unit area varied from 3.49 to 6.73. Generally, lower tillers were in without nitrogen. However, among other three applications, it found that the more the splitting of nitrogen application ensured the more tiller production.

Nitrogen application with three splits

Experimental field with no nitrogen

Yield of grain

Yield of grain affected significantly due to different time and levels of nitrogen application during *Boro* season (Appendix VI and Table 24). Yield of grain had highest (4.91 t ha^{-1}) in four splits of ¼ at basal + ¼ at 15 DAS + ¼ at 30 DAS + ¼ at panicle initiation stage (N_2) followed by N_1 (⅓ at 15 DAS + ⅓ at 30 DAS + ⅓ at panicle initial) (4.20 t ha^{-1}) and N_3 (LCC: Leaf color chart based N application) (3.48 t ha^{-1}) while the lowest yield of grain (2.02 t ha^{-1}) was in no nitrogen practices. From the above overall yield of grain observation it was found that the yield of grain ranged from 2.02 to 4.91 t ha^{-1}.

Yield of straw

Analysis of variance regarding yield of straw at harvest had statistically significant due to nitrogen application management option (Appendix VI and Table 24). From the Table 24, it was appeared that the numerically highest yield of straw (5.89 t ha^{-1}) was in the splitting use of ¼ at basal + ¼ at 15 DAS + ¼ at 30 DAS + ¼ at panicle initiation stage (N_2) followed by N_1 (⅓ at 15 DAS + ⅓ at 30 DAS + ⅓ at panicle initiation stage) (5.04 t ha^{-1}) while it was lowest (2.42 t ha^{-1}) in N_4 treatment (no nitrogen). So, the yield of straw ranges from 2.42 to 5.89 t ha^{-1}.

Straw sub sample weight and oven dry weight

Both the studied characters (straw sub sample weight and oven dry yield of straw) were statistically similar (non–significant) due to various treatments of N application (Appendix VI and Table 24). In that case all the treatments produce same weight regarding both characters, however, straw sub sample weight ranges from 86.44 (N_4) to 115.55 t ha^{-1} (N_2) and straw oven dry weight ranges from 24.93 (N_4) to 31.43 t ha^{-1} (N_2).

Number of filled grains

Filled grain $panicles^{-1}$ had highly significant due to the application of nitrogen at different times and doses (Appendix VI and Table 24 or Fig. 12). The maximum number of filled grains (78.88) was obtained in N_2 (¼ at basal + ¼ at 15 DAS + ¼ at

30 DAS + ¼ at panicle initiation stage) followed by N_1 (⅓ at 15 DAS + ⅓ at 30 DAS + ⅓ at panicle initiation stage) application (66.58). Among other nitrogen treatment, the minimum number of filled grains (48.42) was found in no nitrogen treatment. Hussain *et al.,* (2002) noticed that application of nitrogen at different DAT as top dressing increased number of filled spikelets panicle^{-1} up to 80 kg N ha^{-1}.

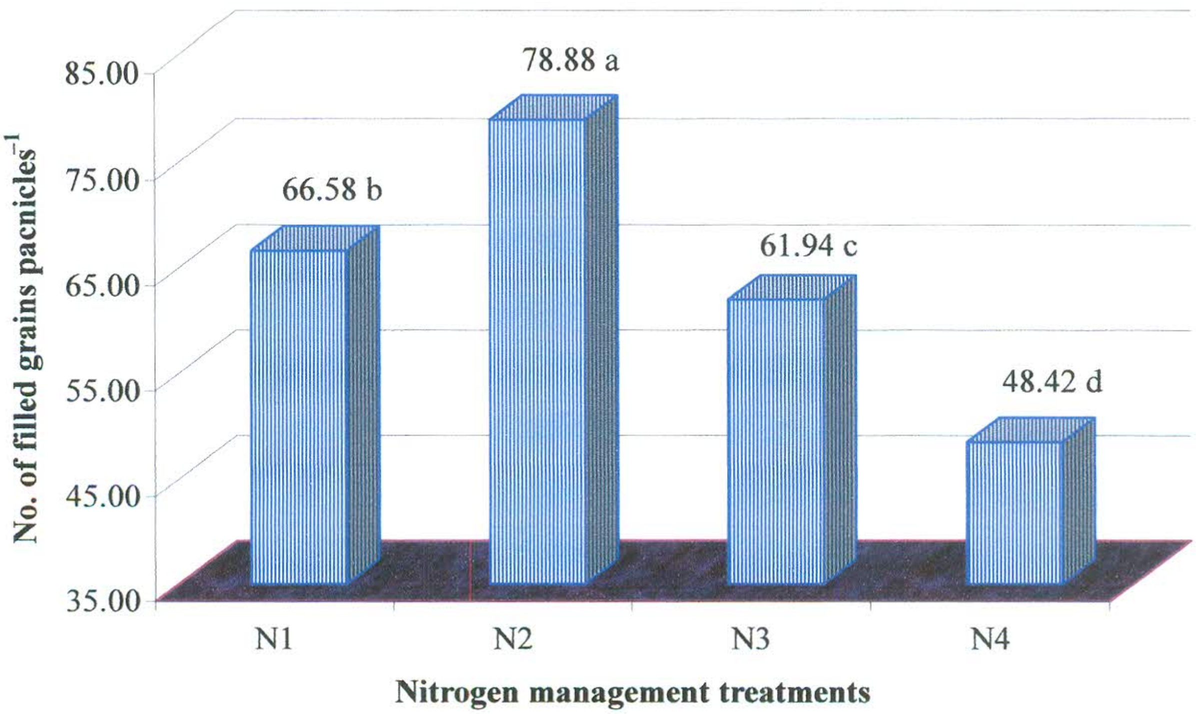

Fig. 12. Effect of nitrogen management practices method on filled grains panicles^{-1} of *Boro* rice at maturity.

Thousand–yield of grain

The Weight of 1000–grain varied significantly due to different treatments on nitrogen management practices where it was varied from 13.71 to 20.91 g (Appendix VI and Table 24). Significant difference regarding Weight of 1000–grain revealed that numerically the highest Weight of 1000–grain was obtained in four splits application of N (N_2: ¼ at basal + ¼ at 15 DAS + ¼ at 30 DAS + ¼ at panicle initiation stage) while 1000–yield of grain had lowest in N_4 treatment (no nitrogen).

Table 24. Effect of application time and level of N on yield and yield attributes of *Boro* rice at harvest

Treatments	Plant height (cm)	No. of tillers $hill^{-1}$	No. of panicles $hill^{-1}$	Grain yield ($t\ ha^{-1}$)	Straw yield ($t\ ha^{-1}$)	Straw sub sample weight (g)	Straw oven dry weight (g)	No. of filled grains $panicle^{-1}$	1000–grain weight (g)
N_1	76.49b	7.56b	6.12a	**4.20 b**	**5.04 b**	108.556	29.422	66.6b	18.634b
N_2	78.29a	7.83a	6.73a	**4.91 a**	**5.89 a**	115.556	31.433	78.9a	20.911a
N_3	74.92c	6.54c	5.22b	**3.48 c**	**4.18 c**	96.778	27.567	61.9c	16.633c
N_4	69.27d	4.38d	3.49c	**2.02 d**	**2.42 d**	86.444	24.933	48.4d	13.711d
CV (%)	**1.26**	**1.82**	**4.53**	7.23	7.36	**3.90**	**2.37**	**4.70**	**6.80**
Level of sig.	**	**	**	**	**	**ns**	**ns**	**	**

N_1: ⅓ at 15 DAT + ⅓ at 30 DAT + ⅓ at PI; N_2: ¼ at basal + ¼ at 15 DAT, + ¼ at 30 DAT + ¼ at PI
N_3: Leaf color chart (LCC) based N application and N_4: no nitrogen
CV= Co–efficient of variation; **= significant at 1% level of probability and ns= not significant

4.3.2.3 Cost of production and economic performance of Boro growing season as affected by N management practices

A detail budget regarding cost of production of Boro rice as influenced by different nitrogen management practices are presented in Table 25.

Table 25. Economic performance with BCR of different N–management treatments during boro season

Treatments	Cost of production ($Tk.\ ha^{-1}$)			Yield ($t\ ha^{-1}$)		Gross return ($Tk.\ ha^{-1}$)			Net return ($Tk.\ ha^{-1}$)	BCR
	Fixed cost	N–application cost	Total Tk.	Gain	Straw	Grain	Straw	Total		
N_1	47190	3200	50390	4.20	5.04	84000	2520	86520	36130	1.72
N_2	48690	3200	51890	4.91	5.89	98200	2945	101145	49255	1.95
N_3	46100	2900	49000	3.48	4.18	69600	2090	71690	22690	1.46
N_4	36890	0.00	36890	2.02	2.42	40400	1210	41610	4720	1.13

N_1: ⅓ at 15 DAT + ⅓ at 30 DAT + ⅓ at PI; N_2: ¼ at basal + ¼ at 15 DAT, + ¼ at 30 DAT + ¼ at PI; N_3: Leaf color chart (LCC) based N application and N_4: no nitrogen
Price of un–husked rice= Tk. 20 kg^{-1} and price of straw= Tk. 0.50 kg^{-1}

From the above economic performance of Boro rice as influenced by N management practices, it was found that the highest variable cost of production (51,890/–) had for the treatment N_2 (¼ at basal + ¼ at 15 DAT, + ¼ at 30 DAT + ¼ at PI) while it was the lowest (36,890/–) for the treatment N_4 or control (no nitrogen). Similarly, the highest gross and net return (Tk. 1,01,145/– and 49,255/–) were obtained from 4 split of N (N_2: ¼ at basal + ¼ at 15 DAT, + ¼ at 30 DAT + ¼ at PI) while similar treatment also obtained the highest BCR (1.95) (Table 25). Very lowest return (4,720/–) along with lowest BCR (1.13) were obtained from no nitrogenous fertilizer which might be due to the much lower production of grain and straw as compared other N management practices. Highest return strand from higher grain and straw yield as well as the four split N–application gave the highest BCR value. Such the same observation was also obtained by the findings of De Datta and Ampong (1988).

4.3.3 Interaction effect of crop establishment methods and N application

4.3.3.1 Performance study of morpho–physiology at vegetative stage

Plant population

Analysis of variance Appendix V indicated significant different regarding plant population due to Interaction effect of establishment methods and application time and dose of N (Appendix V and Table 26). It is evident from the Table 26 found that the plant populations varied from 14.83 to 47.50 at 20 DAS, 14.50 to 43.66 at 40 DAS and 25.33 to 67.16 at 60 DAS. However, T_2N_2 (hand broadcasting × N application of ¼ at basal + ¼ at 15 DAS + ¼ at 30 DAS + ¼ at panicle initiation stage) showed the maximum population at 20 DAS but the transplanting methods with the application of ¼ at basal + ¼ at 15 DAS + ¼ at 30 DAS + ¼ at panicle initiation stage (T_3N_2) registered the maximum population at 40 and 60 DAS. On the other hand, T_1N_4 (direct wet seeding by drum seeder and no nitrogen) produced significantly the minimum plant population (14.83, 14.50 and 25.33) at 20, 40 and 60 DAS, respectively. Among the all treatment combinations of interactions, the mean performance of plant population varied from 18.22 to 52.10 in T_1N_4 and T_3N_2, respectively (Table 26).

Plant dry matter

The data on plant dry matter collected at 20, 40 and 60 DAS where statistically significant variation was found at 20 DAS and 60 DAS and non significant variation at 40 DAS due to the effect of interaction treatments between crop establishment methods and nitrogen application options (Appendix V and Table 26). As a result, the highest weight of plant dry matter (0.56 and 7.16 g) was found from the transplanting system along with the application of ¼ at basal + ¼ at 15 DAS + ¼ at 30 DAS + ¼ at panicle initiation stage (T_3N_2) while it was lowest (0.23 and 1.66 g) in direct wet seeding by drum seeder with no N fertilizer (T_1N_4) at those stages, respectively at 20 and 60 DAS, respectively. From the mean performance considering the all data recording period (20, 40 and 60 DAS) it was varied from 0.98 (T_1N_4) to 3.08 g (T_3N_2).

Table 26. Interaction effect between crop establishment method and application time and level of N on plant population, plant dry matter and plant height of *Boro* rice at different days after sowing (DAS)

Treatments	Plant population at different DAS			Plant dry matter (g) at different DAS			Plant height (cm) at different DAS		
	20	40	60	20	40	60	20	40	60
T_1N_1	16.167e	16.167	35.333e	0.267fg	1.433	2.400e	8.580e	12.607	25.807ef
T_1N_2	16.500e	16.333	42.333d	0.300ef	1.433	2.467e	10.313d	14.847	27.540cd
T_1N_3	15.500e	16.000	32.500e	0.267fg	1.167	2.367e	8.567e	12.207	24.527f
T_1N_4	14.833e	14.500	25.333f	0.233g	1.067	1.667f	8.327e	11.208	21.827g
T_2N_1	33.333c	34.500	46.667d	0.367cd	1.167	3.133d	9.213f	13.173	28.133c
T_2N_2	47.500a	42.000	58.167c	0.400c	2.000	5.167b	11.680c	16.047	31.847ab
T_2N_3	33.500c	29.667	44.333d	0.333de	1.033	2.600e	9.167e	12.280	27.827cd
T_2N_4	29.000d	29.000	33.333e	0.327de	0.933	1.267g	9.067e	12.133	26.580de
T_3N_1	38.667b	34.500	65.167ab	0.533ab	1.400	4.367c	12.607b	14.260	30.913b
T_3N_2	45.500a	43.667	67.167a	0.567a	1.533	7.167a	14.847a	17.540	32.980a
T_3N_3	34.667c	33.000	61.000bc	0.500b	1.300	4.367c	12.267bc	14.133	28.900c
T_3N_4	34.000c	30.333	35.833e	0.400c	1.200	1.833f	14.540a	13.453	25.261ef
CV (%)	**7.02**	**8.27**	**6.52**	**7.11**	**26.11**	**4.63**	**4.65**	**3.67**	**2.74**
Level of sig.	**	ns	**	**	ns	**	**	ns	**

T_1: Direct wet seeding by drum seeder; T_2: Hand broadcasting and T_3: Transplanting
N_1: ⅓ at 15 DAT + ⅓ at 30 DAT + ⅓ at PI; N_2: ¼ at basal + ¼ at 15 DAT, + ¼ at 30 DAT + ¼ at PI
N_3: Leaf color chart (LCC) based N application and N_4: no nitrogen
CV= Co–efficient of variation; **= significant at 1% level of probability and ns= not significant

Plant height

Plant height data had also significant at 20 and 60 DAS while it did not vary significant at 40 DAS (Appendix V and Table 26). As a result, plant height varied from 11.20 cm in T_1N_4 to 17.54 cm in T_3N_2 at 40 DAS but they were statistically same. At 20 and 60 DAS, treatment T_3N_2 exhibited the tallest plant (14.84 and 32.98 cm, respectively) while it was followed by T_3N_1 at 20 DAS (12.60) and T_2N_2 at 60 DAS (31.84 cm) while it was shortest in T_1N_4 (8.32 and 21.82 cm, respectively). Considering all combinations of interactions, the mean performance of plant height varied from 13.78 cm in T_1N_4 to 21.78 cm in T_3N_2 cm (Table 26).

4.3.3.2 Performance study of growth and yield attributes at reproductive stage

Plant height

The plant height varied significantly from 65.66 cm to 80.49 cm due to interaction effect between crop establishment methods and time with doses of nitrogen application (Appendix VI and Table 27). From the Table 18, it was found that the tallest plant (80.49 cm) was taken from the interaction of transplanting methods with nitrogen application of ¼ at basal + ¼ at 15 DAS + ¼ at 30 DAS + ¼ (T_3N_2) while direct wet seeding by drum seeder method with similar N treatment produced statistically identical tallest plant (79.88 cm). Consequently, the shortest plant (65.66 cm) was obtained in T_1N_4 (direct wet seeding by drum seeder × no nitrogen). So, the above result showed that the plant height at harvest varied from 65.66 to 80.49 cm.

Number of tillers

Production of total tillers per hill at harvest due to interaction effect between crop establishment methods and nitrogen management practices were statistically significant where it was varied from 3.33 to 8.83 (Appendix VI and Table 27). The tiller production had maximum in crop establishment method of transplanting with nitrogen application of ¼ at basal + ¼ at 15 DAS + ¼ at 30 DAS + ¼ (T_3N_2) followed by the similar methods with nitrogen application of ⅓ at 15 DAS + ⅓ at 30 DAS + ⅓ at panicle initiation stage (T_3N_1). Similarly, tiller production had minimum in interaction of direct wet seeding by drum seeder and without nitrogen (T_1N_4) which was statistically differed from other interactions (Table 27).

Number of panicles

Panicle number also varied significantly due to interaction effect of crop establishment method and nitrogen treatments (Appendix VE and Table 27). It is evident from the Table 27 that the number of panicles hill^{-1} had maximum (7.73) in transplanting method with nitrogen application of ¼ at basal + ¼ at 15 DAS + ¼ at 30 DAS + ¼ (T_3N_2) followed by the direct wet seeding by drum seeder with similar nitrogen treatment (T_1N_2). Among other interaction treatments, number of panicles had minimum (2.77) in direct wet seeding by drum seeding methods with no nitrogen treatment (T_1N_4) which was statistically differed from other interactions (Table 27). So, the panicle number at harvest varied from 2.77 to 7.73 due to interaction treatments. A significant variation for number of panicle due to crop establishment methods was also found by Prassad *et al.* (1999) and Ali (2005).

Yield of straw

Yield of straw was also significantly affected by the interaction effect of crop establishment methods and nitrogen application option (Appendix VI and Table 27). Data from the Table 18 revealed that the direct wet seeding by drum seeder method with nitrogen application of ¼ at basal + ¼ at 15 DAS + ¼ at 30 DAS + ¼ (T_1N_2) showed the highest straw yield (6.00 t ha^{-1}) while it was statistically close (5.87) to T_2N_2 (hand broadcasting method × nitrogen application of ¼ at basal + ¼ at 15 DAS + ¼ at 30 DAS + ¼). On the other hand, the lowest yield of straw (2.33 t ha^{-1}) was found in interaction of T_3N_4 (transplanting method × no nitrogen) which was statistically identical (2.40 6m^{-2}) to T_2N_4 (hand broadcasting × no nitrogen).

Number of filled grains

Number of filled grains panicles^{-1} at harvest affected significantly due to interaction effects of crop establishment methods and nitrogen management treatments where it was varied from 42.90 to 83.47 (Appendix VI and Table 27). The maximum number of filled grains (834.66) was observer in T_3N_2 (transplanting method × nitrogen application of ¼ at basal + ¼ at 15 DAS + ¼ at 30 DAS + ¼) which was statistically differed from other interaction treatments. On the other hand, filled grains had minimum (42.90) in T_1N_4 (direct wet seeding by drum seeder × no nitrogen) which was also statistically differed from other interaction treatments.

Non significant variation result

Among other observation parameters such as yield of grain $6m^{-2}$, straw sub sample weight, straw sub sample dry weight Thousand–yield of grain did not vary significant due to interaction effect of crop establishment methods and various application option of N. However, yield of grain varied from 1.95 (T_3N_4) to 5.00 t ha^{-1} (T_1N_2), straw sub sample weight varied from 81.00 g (T_2N_4) to 124.00 g (T_3N_2), straw sub sample dry weight varied from 23.83 g (T_1N_4) to 32.70 g (T_1N_2) and 1000–yield of grain varied from 11.63 g (T_1N_4) to 22.46 g (T_3N_2) (Table 27).

Table 27. Interaction effect between crop establishment method and application time and level of N on yield and yield attributes of *Boro* rice at harvest

Treatments	Plant height (cm)	No. of tillers $hill^{-1}$	No. of panicles $hill^{-1}$	Grain yield (t ha^{-1})	Straw yield (t ha^{-1})	Straw sub sample weight (g)	Straw oven dry weight (g)	No. of filled grains $panicle^{-1}$	1000–grain weight (g)
T_1W_1	77.35bc	7.77c	6.50bc	3.61	4.33 ef	99.667	28.067	66.8c	18.200
T_1W_2	79.88a	7.68c	6.65b	5.00	6.00 a	108.667	32.700	68.2bc	18.667
T_1W_3	76.16cd	6.30f	5.43ef	3.28	3.93 g	91.667	25.767	60.6d	15.700
T_1W_4	65.66g	3.33i	2.78j	2.11	2.53 hi	84.333	23.833	42.9e	11.633
T_2W_1	74.17ef	6.68e	6.10cd	4.50	5.40 d	112.000	30.000	59.8d	15.703
T_2W_2	74.51def	6.98d	5.80de	4.89	5.87 c	114.000	30.767	84.9a	21.600
T_2W_3	73.66f	5.73g	4.93g	3.45	4.13 f	83.667	27.733	58.1d	14.533
T_2W_4	75.59de	5.60g	4.27h	2.00	2.40 i	81.000	24.967	43.6f	13.000
T_3W_1	77.95b	8.27b	5.75de	4.50	5.40 b	114.000	30.200	73.1b	22.000
T_3W_2	80.50a	8.83a	7.73a	4.83	5.80 b	124.000	30.833	83.5a	22.467
T_3W_3	74.94def	7.58c	5.28fg	3.72	4.47 e	115.000	29.200	67.2c	19.667
T_3W_4	66.57g	4.20h	3.50i	1.95	2.33 i	94.000	26.000	58.8d	16.500
CV (%)	**1.26**	**1.82**	**4.53**	**7.23**	**7.36**	**3.90**	**2.37**	**4.70**	**6.80**
Level of sig.	**	**	**	ns	**	ns	ns	**	ns

T_1: Direct wet seeding by drum seeder; T_2: Hand broadcasting and T_3: Transplanting
N_1: ⅓ at 15 DAT + ⅓ at 30 DAT + ⅓ at PI; N_2: ¼ at basal + ¼ at 15 DAT, + ¼ at 30 DAT + ¼ at PI
N_3: Leaf color chart (LCC) based N application and N_4: no nitrogen
CV= Co–efficient of variation; **= significant at 1% level of probability and ns= not significant

4.4 Experiment 4: Effect of crop establishment method and weed management on productivity of *Boro* rice

4.4.1 Effect of crop establishment methods

4.4.1.1 Performance study of morpho–physiology at vegetative stage

Plant population

Number of plant population in a specific area at different DAS exerted significant difference due to crop establishment methods during *Boro* season where mean performance varied from 26.39 to 44.16 while every data recording stages were considered (Appendix VII and Table 28). The number of plant population had maximum (36.79, 33.83 and 61.87) in transplanting method (T_3) at 20, 40 and 60 DAS, respectively while hand broadcasting method showed statistically similar maximum number of plant population (32.20) at 40 DAS. Similarly, number of plant population had minimum (23.37, 19.29 and 36.50) in direct wet seeding by drum seeder (T_1) at those stages, respectively.

Plant dry matter

Analysis of variance data on plant dry matter during *Boro* season showed significant difference at 20 and 60 DAS while 40 DAS did not vary significant due to crop establishment methods (Appendix VII and Table 28). From the Table 28, it was found that the mean of plant dry matter was 2.30 g for transplanting method (highest), 1.86 g for hand broadcasting method (average medium) and 1.22 for direct wet seeding by drum seeder (lowest) while all the data recording period (20, 40 and 60 DAS) were considered. From the Table 19, it was also found that the plant dry matter significantly highest (0.59 and 5.04 g) at 20 and 60 DAS, respectively while it was minimum (0.28 and 2.25 g) in direct wet seeding by drum seeder (T_1) at those stages, respectively. Idris and Matin (1990) reported that the influence of both N including LCC based N and weed management practices under planting methods and its economic performances are needed to be evaluated under Bangladesh condition.

Table 28. Effect of crop establishment method on plant population, plant dry matter and plant height of *Boro* rice at different days after sowing (DAS)

Treatments	Plant population at different DAS			Plant dry matter (g) at different DAS			Plant height (cm) at different DAS		
	20	40	60	20	40	60	20	40	60
T_1	23.375c	19.292b	36.500c	0.283c	1.117	2.250c	8.972b	11.861	26.288
T_2	34.000b	32.208a	54.125b	0.308b	1.208	4.058b	9.150b	12.818	27.232
T_3	36.792a	33.833[a]	61.875a	0.592a	1.283a	5.042a	18.145a	13.777	27.670
CV (%)	**9.05**	**7.97**	**5.26**	**11.95**	**12.29**	**10.84**	**5.55**	**7.60**	**5.68**
Level of sig.	**	**	**	**	**ns**	**	**	**ns**	**ns**

T_1: Direct wet seeding by drum seeder; T_2: Hand broadcasting and T_3: Transplanting
CV= Co–efficient of variation; **= significant at 1% level of probability and ns= not significant

Plant height

The plant height at 20 DAS showed significant difference due to crop establishment method while plant height at 40 and 60 DAT were statistically identical among the crop establishment method (Appendix VII and Table 28). As a result, the tallest plant (18.14 cm) was exhibited in transplanting method (T_3) followed (9.15) by hand broadcasting (T_2) while the shortest plant (8.97 cm) was recorded in direct wet seeding by drum seeder method (T_1) at 20 DAS. Among other observation, plant height varied from 11.86 cm (T_1) to 13.77 cm (T_3) at 40 DAS and 26.28 cm (T_1) to 27.67 cm (T_3) at 60 DAS. This was similar to the results of Chowdhury *et al.* (1995) who found that the mean performance of 15.71 cm for T_1 (direct wet seeding by drum seeder), 16.40 for T_2 (hand broadcasting) and 19.86 for T_3 (transplanting).

4.4.1.2 Performance study of growth and yield attributes at reproductive stage

Plant height

Plant height at harvest exerted significant difference due to crop establishment methods while it was significantly varied from 71.63 to 75.88 cm (Appendix VIII and Table 29 or Fig. 13). Among three crop establishment methods, transplanting method had taller (75.88 cm) than hand broadcasting method (74.84 cm) and direct wet seeding by drum seeder (71.63 cm). These results revealed that transplanting method had highly significant than other method of crop establishment. This was similar to the results of Chowdhury *et al.* (1995).

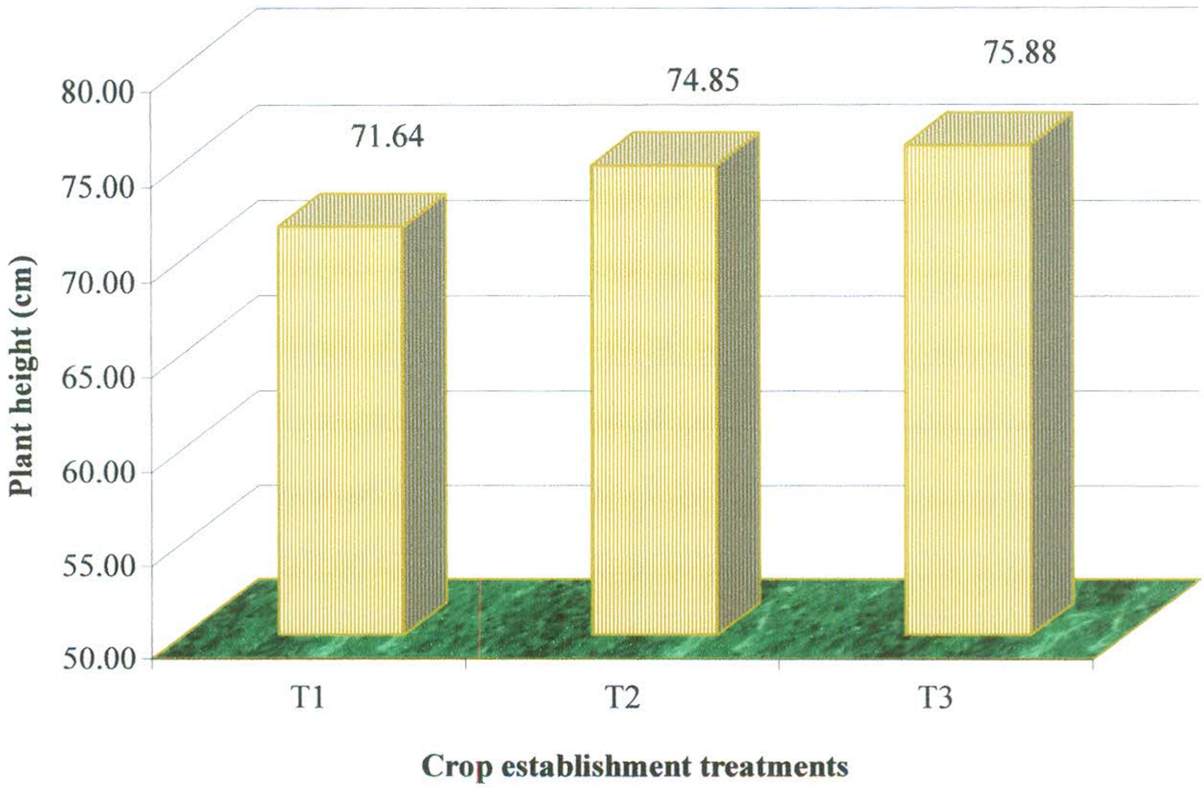

Fig. 13. Effect of crop establishment method on plant height of Boro rice at harvest

Number of tillers

Number of tillers per hill at harvest was significantly influenced by the crop establishment methods during *Boro* season where transplanting and hand broadcasting method were statistically identical to produce maximum tillers (7.22 and 6.87, respectively) while direct wet seeding by drum seeder showed the minimum tiller (48.50) (Appendix VIII and Table 29).

Number of panicles

A significant variation was also found due to crop establishment method in respect of panicles number per hill at harvest (Appendix VIII and Table 29). From the Table 29, it was found that the establishment methods of both transplanting and hand broadcasting showed significantly the maximum panicles per hill (6.02 and 5.49, respectively) while direct wet seeding by drum seeder method obtained the minimum panicles (4.32). So, the panicle numbers for a particular unit area varied from 4.32 to 6.02. Prassad *et al.* (1999) and Ali (2005) also found significant variation in number of panicle among the different crop establishment method.

Yield of grain

The yield of grain at harvest had significant due to crop establishment methods (Appendix VIII and Table 29). Among the crop establishment methods, transplanting method (T_3) had highest (3.54 t ha^{-1}) than hand broadcasting (3.40 t ha^{-1}) and direct wet seeding by drum seeder (3.26 t ha^{-1}). The above results indicated that the yield of grain had highest for transplanting methods might be due to the tallest plant, more number of tillers and panicles with maximum filled grains were taken under this method which ultimately showed the greater yield. This was confirmed with the reports of Tabbal *et al*. (2002) and Elahi *et al*. (1997).

Yield of straw

Yield of straw of *Boro* rice had statistically significant due to crop establishment methods where the highest yield of straw (4.25 t ha^{-1}) was observed in transplanting method while hand broadcasting method showed the lowest (4.08 t ha^{-1}) (Appendix IV and Table 29). This was similar to the reports of Dingkuhn *et al*. (1990).

Number of filled grains

A significant variation was found on the production of filled grains at harvest due to crop establishment methods where filled grains had maximum (87.10) in direct wet seeding by drum seeder method (T_1) than T_2: hand broadcasting (40.34) and T_3: transplanting method (71.96) while t_2 and T_3 were statistically identical (Appendix VIII and Table 29 or Fig. 14).

Thousand–yield of grain

Weight of 1000–grain at harvest also varied significantly due to crop establishment methods where it was the highest (23.33 g) in transplanting method (T_3) and the lowest (18.85 g) in direct wet seeding by drum seeder (Appendix VIII and Table 29). This result indicated that the 1000–yield of grain varied from 18.85 to 23.33 g.

Following results for other parameters

Among other yield and yield contributing characters *viz*. plant height (cm), straw sub sample weight (g) and straw sub sample dry weight (g) were statistically identical due to all interaction treatments between crop establishment methods and various application option of N. However, plant height varied from 71.63 cm (T_1) to 75.88 cm (T_3), straw sub sample weight varied from 97.18 g (T_1) to 110.58 g (T_3) and straw sub sample dry weight varied from 28.82 g (T_1) to 30.70 g (T_2) in this study during *Boro* season (Table 29).

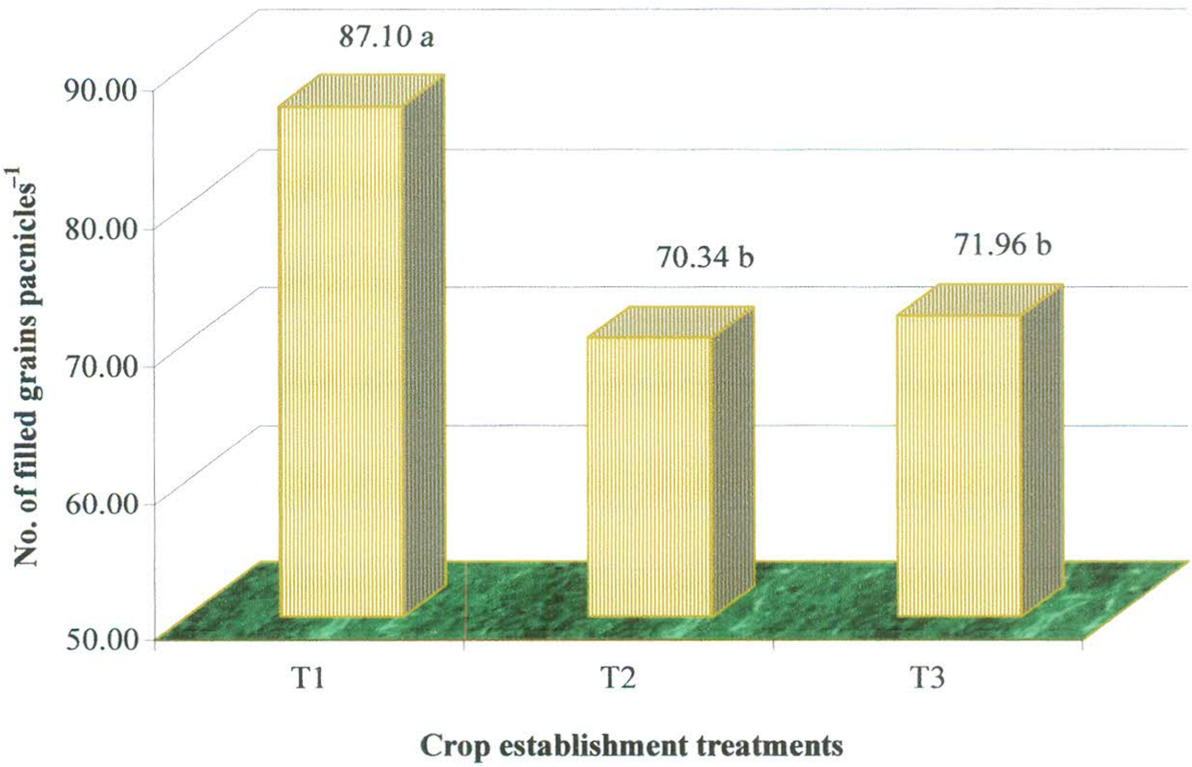

Fig. 14. Effect of crop establishment method on filled grains panicles^{-1} of Boro rice at harvest

Table 29. Effect of crop establishment method on yield and yield attributes of *Boro* rice at harvest

Treatments	Plant height (cm)	No. of tillers hill^{-1}	No. of panicles hill^{-1}	Grain yield (t ha^{-1})	Straw yield (t ha^{-1})	Straw sub sample weight (g)	Straw oven dry weight (g)	No. of filled grains panicle^{-1}	1000–grain weight (g)
T_1	71.637	4.85b	4.32b	**3.26 c**	**3.92 c**	97.183	28.825	87.1a	18.850c
T_2	74.847	6.87a	5.49a	**3.40 b**	**4.08 b**	104.500	30.700	70.3b	19.825b
T_3	75.880	7.21a	6.02a	**3.54 a**	**4.25 a**	110.583	30.225	71.9b	23.333a
CV (%)	**4.47**	**5.77**	**9.60**	**16.50**	**11.48**	**3.47**	**3.55**	**4.01**	**11.11**
Level of sig.	**ns**	**	**	**	**	**ns**	**ns**	**	**

T_1: Direct wet seeding by drum seeder; T_2: Hand broadcasting and T_3: Transplanting
CV= Co–efficient of variation; **= significant at 1% level of probability and ns= not significant

4.4.1.3 Cost of production and economic performance of Boro growing season as affected by crop establishment methods in presence of weed management practices

In boro season, treatment wise production cost and their economic efficiency were furnished in Table 30 and 31. The cost and output were converted in to t ha^{-1}.

Table 30. Production cost of T. aman rice as affected by different crop establishment methods in presence of weed management practices

Crop establishment methods	Different operational cost in Taka							Total variable cost (Tk.)
	Land preparation	Seed	Irrigation	Fertilizer	Labor	Herbicide	Insecticide	
T_1	4200	1800	2400	9550	31500	750	750	51950
T_2	4200	1800	2400	9550	32400	750	750	51850
T_3	5400	2100	2600	9550	45000	750	750	66150

T_1: Direct wet seeding by drum seeder; T_2: Hand broadcasting and T_3: Transplanting
Seed= Tk. 40 kg^{-1}, Urea= Tk. 16 kg^{-1}, TSP= Tk. 30 kg^{-1}, MP= Tk. 20 kg^{-1}, Gypsum= Tk. 10 kg^{-1}, Zinc sulphate= Tk. 190 kg^{-1}, Irrigation 1500 $season^{-1}$ ha^{-1},, Wage rate= Tk. 250 man day^{-1}.

Table 31. Gross return, net return and benefit cost ratio of Boro rice as affected by different crop establishment methods in presence of weed management practices

Treatments	Total variable cost (Tk.)	Gross return (Tk. ha^{-1})			Net return (Tk. ha^{-1})	BCR
		Grain*	Straw *	Total		
T_1	51950	65200	1960	67160	15210	1.29
T_2	51850	68000	2040	70040	18190	1.35
T_3	66150	70800	2125	72925	6775	1.10

T_1: Direct wet seeding by drum seeder; T_2: Hand broadcasting and T_3: Transplanting
Mean yield of 3 replications; Price of paddy= Tk. 20 ka^{-1} and Price of straw= Tk. 0.50 ka^{-1}
All prices indicated here just after harvesting period

Variable cost

Total cost of production in hand broadcasting method (51,850/–) and drum seeder method (51,950/–) is lower than transplanting method (66,150/–) in this study (Table 30 and 31). However, the profit (grain margin) was move higher in transplanting compared to other two methods.

Gross return (Tk. ha^{-1})

Gross return also highest (72,925/--) in transplanting method for its better yield (Table 31). On the other hand, though there was a lower yield found in hand broadcasting but for its lower cultivation cost (51,850/–) indicating the highest net profit (18,190/–).

Net return (Tk. ha^{-1})

The overall higher net return (18,190/–) was found in hand broadcasting method compared direct wet seeding by drum seeder (15,210/–) while transplanting method found to be the lowest net return (6,775/–). Hand broadcasting showed the highest net return might be due to higher yield (Table 31). This is an agreement with the findings of Islam and Uddin (1987), where they observed that transplanted BRRI rice gave the highest net income under both irrigated and rainfed conditions.

BCR

The benefit cost ration was little bit higher in hand broadcasting (1.35) than other crop establishment methods and it indicates greater profit. As association of more labor and land preparation cost in transplanting method, its return (6,775/–) and BCR (1.10) is low even after gaining the higher grain and straw yields (Table 31).

4.4.2 Effect of different weed management practices

4.4.2.1 Performance study of morpho–physiology at vegetative stage

Plant population

Effect of weed management on the number of plant population in a certain area was statistically significant at 20, 40 and 60 days after sowing with a mean values of 45.25 for W_1, 33.92 for W_2, 37.87 for W_3 and 30.52 for W_4 (Appendix VII and Table 32). At 20 DAS, the plant population had maximum (36.05, 32.33 and 66.44) was obtained in W_1 (hand weeding) at 20, 40 and 60 DAS, respectively while it was followed by W_3 at 20 and 60 DAS (31.66 and 52.00, respectively) and W_4 at 40 DAS (32.17). On the other hand, no weeding treatment (W_4) observed the minimum plant population at 20 and 60 DAS (28.38 and 39.27, respectively) and W_2 at 40 DAS (26.73). In the recent years, the use of herbicide in the field of agriculture has brought about a revolution in the method of weed control (Barari, D. 2005).

Plant dry matter accumulation

Plant dry matter at 20, 40 and 60 DAS exerted significant variation due to weed management practices where the mean performance of plant dry matter during study was 2.36 g for W_1, 1.63 for W_2, 1.73 for W_3 and 1.43 for W_4 (Appendix VII and Table 32). From the Table 32, it was found that the hand weeding management (W_1) noted the highest plant dry matter weight (1.36 and 5.22 g) at 40 and 60 DAS, respectively while BRRI weeder + HW (W_2) had highest at 20 DAS (0.59 g). On the other hand, plant dry matter weight had lowest (0.26, 1.04 and 3.00 g) in without weeding (W_4) at 20, 40 and 60 DAS, respectively which was statistically differed from other weeding treatments.

Plant height

Plant height had highly significant at 20 and 60 DAS while 40 DAS did not vary significant due to weed management practices during *Boro* season (Appendix VII and Table 32). Results reveal that the hand weeding management showed the tallest plant (12.85 and 29.09 cm) at 20 and 60 DAS followed by herbicide + HW (W_3) (12.23 and 27.13 cm, respectively). On the other hand, no weeding management of *Boro* rice exhibited the shortest plant (11.39 and 25.31 cm) at those stages, respectively (Table 32).

Table 32. Effect of weed management practices on plant population, plant dry matter and plant height of *T aman* rice at different days after sowing (DAS)

Treatments	Plant population at different DAS			Plant dry matter (g) at different DAS			Plant height (cm) at different DAS		
	20	40	60	20	40	60	20	40	60
W_1	36.056a	33.222a	66.444a	0.511b	1.367a	5.222a	12.856[a]	14.113	29.089a
W_2	29.444bc	26.722c	45.611c	0.367a	1.156bc	3.367bc	11.871bc	12.771	26.720bc
W_3	31.667b	29.944b	52.000b	0.433c	1.244ab	3.544b	12.236ab	12.653	27.133b
W_4	28.389c	23.889a	39.278d	0.267d	1.044c	3.000c	11.393c	11.737	25.311c
CV (%)	**9.05**	**7.97**	**5.26**	**11.95**	**12.29**	**10.84**	**5.55**	**7.60**	**5.68**
Level of sig.	**	**	**	**	**	**	**	ns	**

W_1: Hand weeding (HW), W_2: BRRI weeder + HW, W_3: Herbicide + HW and W_4: no weeding
CV = Co–efficient of variation; **= significant at 1% level of probability and ns= not significant

4.4.2.2 Performance study of growth and yield attributes at reproductive stage

Plant height

Effect of weed management on plant height at harvest had highly significant where W_1 (hand weeding) had taller (78.82 cm) than W_3: herbicide + HW (76.04 cm), W_2: BRRI weeder +HW (74.17 cm) while W_4 (no weeding) had shorter (67.43 cm) in this study (Appendix VIII and Table 33 or Fig. 15).

Number of tillers

Number of tillers per hill at harvest exerted significant variation due to different treatments of weed management practices where number of tillers per hill significantly varied from 4.31 to 8.01 (Appendix VIII and Table 33). Among the weed management treatments, hand weeding (W_1) showed significantly the maximum number of tillers than W_3 (6.83) and W_2 (6.10) while no weeding (W_4) treatment registered the minimum number of tiller (Table 22).

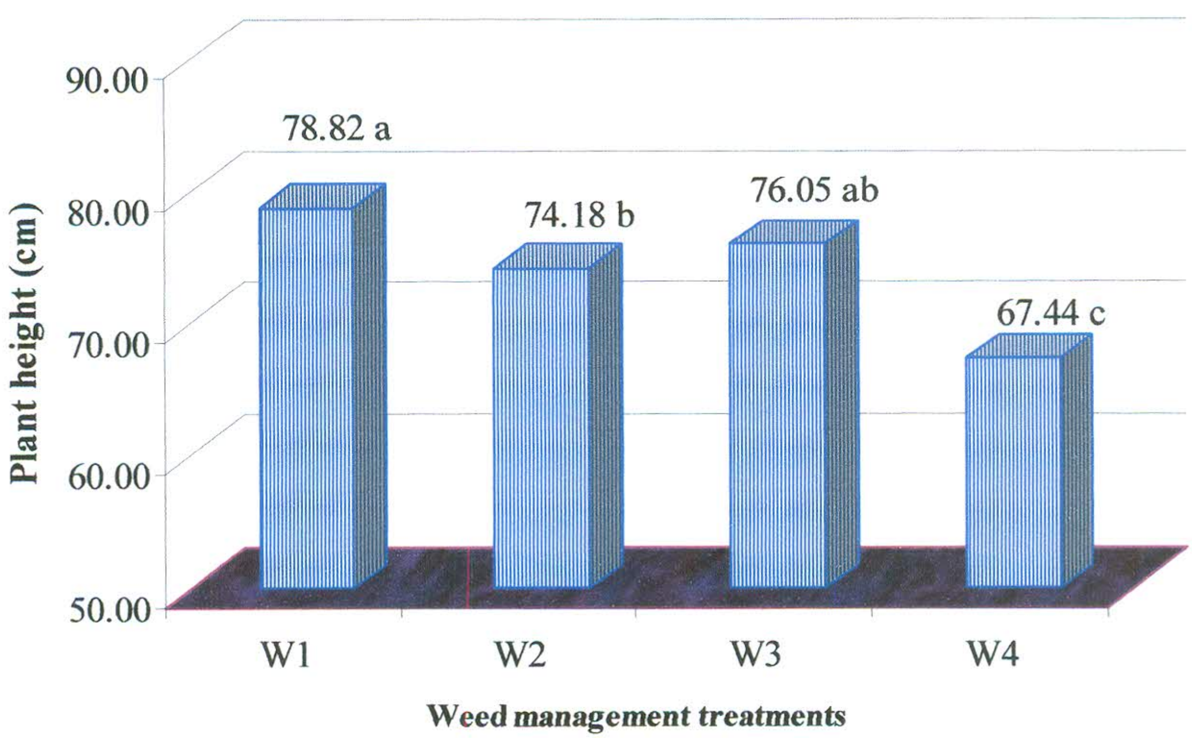

Fig. 15. Effect of weed management practices on plant height of Boro rice at harvest

Number of panicles

Panicle number at harvest had also significant due to various treatments of weed management practices (Appendix VIII and Table 33). From the Table 33, it was clear that the hand weeding (W_1) treatment showed the maximum panicles followed by W_3: herbicide + HW (5.67) and W_2: BRRI weeder + HW (4.95) while no weeding had minimum in this study.

Yield of grain

Yield of grain due to weed management practices also found significant variation where yield of grain varied from 2.00 to 4.67 t ha^{-1} (Appendix VIII and Table 33). It is evident from the Table 33 that hand weeding treatment (W_1) produced significantly the highest yield of grain (4.67 t ha^{-1}) than herbicide + HW treatment (W_2) (3.32 t ha^{-1}) and W_3: BRRI weeder +HW (3.63 t ha^{-1}) while grain yield had lowest (2.00 t ha^{-1}) in no weeding treatment. Singh and Pillai (1994) observed that grain yield increased significantly up to 90 Kg ha^{-1} nitrogen application along with weed control properly at vegetative stage of rice in its growing period.

Yield of straw

A significant variation was also found due to weed management practices treatment on the subject of yield of straw at harvest (Appendix VIII and Table 33). The highest yield of straw (5.60 t ha^{-1}) was found from the treatment W_1 (hand weeding) while it was lowest (2.40 t ha^{-1}) was taken from the treatment W_4 (no weeding). On the other hand, the yield of straw of 4.36 and 3.98 t ha^{-1} were produce from W_3 (herbicide + hand weeding) and W_2 (BRRI weeder + hand weeding), respectively.

Straw sub sample and oven dry weight

Both the characters *viz.* straw sub sample and over dry weight did not vary significant due to weed management practices as well as all the treatments were produced statistically similar weight of stray sub sample and oven dry yield of straw during *Boro* season in this study (Appendix VIII and Table 33).

Number of filled grains

Filled grain numbers panicles^{-1} was significantly affected due to various treatments on weed management where it was varied from 64.82 to 84.09 (Appendix VIII and Table 33 or Fig. 16). Number of filled grains had maximum in hand weeding (W_1) followed by both W_3 (herbicide + HW) and W_2 (BRRI weeder + HW) (79.56 and 77.40, respectively) where W_2 and W_3 were statistically similar. Another treatment (W_4: no weeding) produced minimum filled grains which was statistically differed from other treatments. Karim *et al.,* (2004) reported that although a number of sulfonylurea herbicides have been found as suiTable alternatives to the old herbicide 2,4-D; an integrated weed management program must be developed in order to reduce the problem of herbicide resistance in weeds.

Thousand–yield of grain

Weight of 1000–grain varied significantly due to weed management practices where Weight of 1000–grain varied from 17.57 for W_4: no weeding (minimum) to 22.00 for W_1: hand weeding (maximum) while W_3 and W_2 were also produced statistically similar maximum weight of 1000 grain (21.97 and 21.11, respectively) (Table 33).

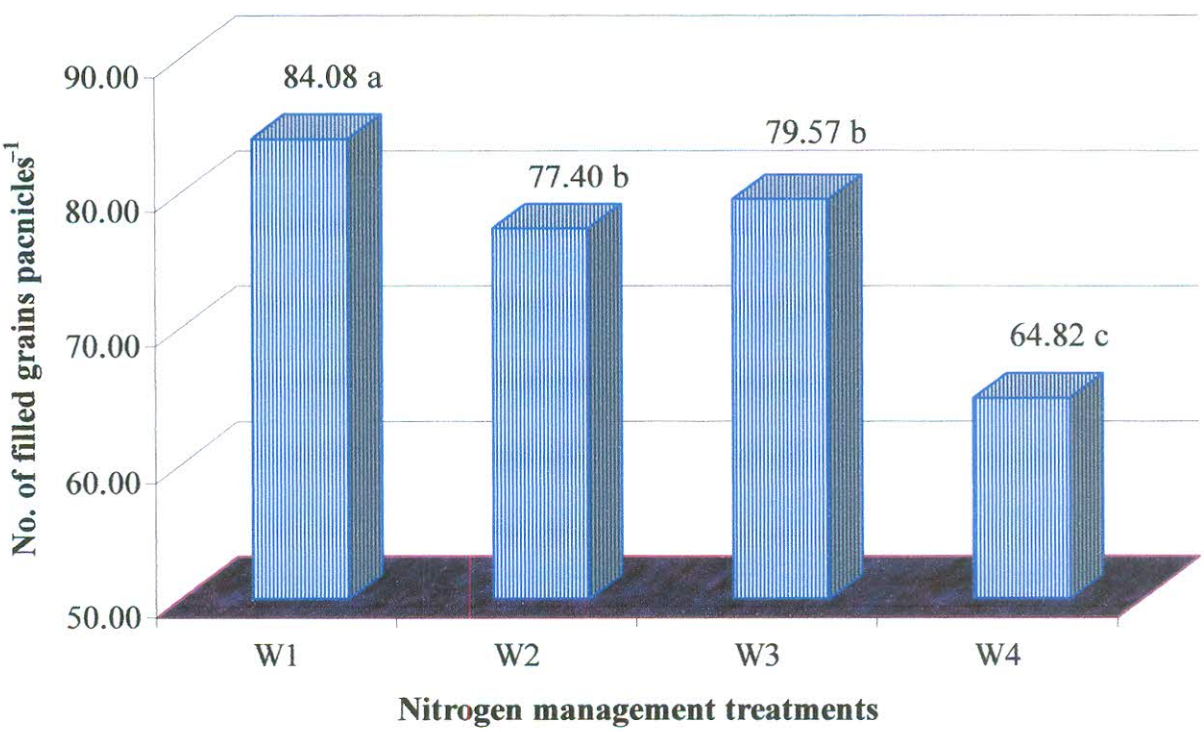

Fig. 16. Effect of weed management practices method on filled grains panicles^{-1} of Boro rice at harvest

Table 33. Effect of weed management practices on yield and yield attributes of *Boro* rice at harvest

Treatments	Plant height (cm)	No. of tillers $hill^{-1}$	No. of panicles $hill^{-1}$	Grain yield ($t\ ha^{-1}$)	Straw yield ($t\ ha^{-1}$)	Straw sub sample weight (g)	Straw oven dry weight (g)	No. of filled grains $panicle^{-1}$	1000–grain weight (g)
W_1	78.82a	8.02a	6.76a	4.67 a	5.60 a	108.778	31.544	84.08a	22.011a
W_2	74.18b	6.10c	4.95c	3.32 c	3.98 c	103.000	29.500	77.40b	21.111a
W_3	76.05ab	6.83b	5.67b	3.63 b	4.36 b	107.778	31.022	79.57b	21.978a
W_4	67.44c	4.31d	3.72d	2.00 d	2.40 d	96.800	27.600	64.82c	17.578b
CV (%)	**4.47**	**5.77**	**9.60**	**16.50**	**11.48**	**3.47**	**3.55**	**4.01**	**11.11**
Level of sig.	**	**	**	**	**	ns	ns	**	**

W_1: Hand weeding (HW), W_2: BRRI weeder + HW, W_3: Herbicide + HW and W_4: no weeding
CV= Co–efficient of variation; **= significant at 1% level of probability and ns= not significant

4.4.2.3 Cost of production and economic performance of Boro growing season as affected by weed management practices

The cost of production along with its gross and net return and its benefit cost ration were evaluated in this section and the obtained values were presented in Table 34.

Table 34. Economic performance with BCR of different weed management (means of 3 yields)

Treatments	Cost of production ($Tk.\ ha^{-1}$)			Yield ($t\ ha^{-1}$)		Gross return ($Tk.\ ha^{-1}$)			Net return ($Tk.\ ha^{-1}$)	BCR
	Fixed cost	W–management cost	Total Tk.	Gain	Straw	Grain	Straw	Total		
W_1	38800	1600	40400	4.67	5.6	93400	2800	96200	45810	1.91
W_2	33800	1600	35400	3.32	3.98	66400	1990	68390	16500	1.32
W_3	31300	4000	35300	3.63	4.36	72600	2180	74780	25780	1.53
W_4	2930	0.00	29300	2.00	2.4	40000	1200	41200	4310	1.12

W_1: Hand weeding (HW), W_2: BRRI weeder + HW, W_3: Herbicide + HW and W_4: no weeding
Price of un–husked rice= Tk. 20 kg^{-1} and price of straw= Tk. 0.50 kg^{-1}

Among four treatments, the total cost of production was varied in this experiment where the treatment W_1 (hand weeding) required more cost of production (40,400/–). However, this treatment returned the highest gross and net income (96,200/– and

45810/–, respectively) as well the higher BCR of 1.91. This was found might be due to the higher production of grain and straw. Similarly, the lowest cost of production (29,300/–) was involved in W_4 while this treatment also showed the lowest gross and net income (41,200/– and 4,310/–, respectively) also with the lowest BCR (1.12) in this study (Table 34).

It may therefore be concluded that the hand weeding approach whenever necessary was the best treatment than others. The results correlated with the findings of Ahmed *et al.* (2005).

4.4.3 Interaction effect of crop establishment methods and N application

4.4.3.1 Performance study of morpho–physiology at vegetative stage

Plant population

The data on plant population at different DAS varied significantly due to interaction effect of establishment methods and various types of N application (Appendix VII and Table 35). Among the interaction treatments, plant population had minimum in T_3W_1: transplanting method with hand weeding (46.00 and 44.00, respectively) at 20 and 40 DAS while the interaction treatment of T_2W_1: hand broadcasting with transplanting method obtained the maximum plant population at 60 DAS (83.66) whereas all the interaction treatments were statistically differed from other treatment at all the data recording stages. Among other interaction treatments, plant population had minimum (21.50, 16.50 and 32.33) in direct wet seeding by drum seeder method with no weeding treatment (T_1W_4) at 20, 40 and 60 DAS, respectively while the mean performance of plant population varied from 23.44 (T_1W_4) to 55.27 (T_3W_1). Another finding was also recorded that weed infestation in direct-seeded and without weed control fields has caused 30-100% yield loss (Ho, 1994).

Plant dry matter

A significant variation was found on plant dry matter due to crop establishment methods along with various nitrogen applications at 20 and 60 DAS but it did not differed significantly at 40 DAS (Appendix VII and Table 35). As a result, all the interactions treatments had statistically identical for observing the plant dry matter at 40 DAS. The highest weight of plant dry matter (0.93 g) was found in T_2W_2 (hand broadcasting method × BRRI weeder + HW) at 20 DAS while interaction treatments of T_3W_1 (transplanting method × hand weeding) obtained the highest weight of plant dry matter (7.13 g) at 60 DAS. On the other hand, the lowest weight of dry matter (0.20 and 1.66 g) was recorded in T_1W_4 (direct wet seeding by drum seeder × no weeding) at 20 and 60 DAS, respectively.

Table 35. Interaction effect between crop establishment method and weed management practices on plant population, plant dry matter and plant height of *Boro* rice at different days after sowing (DAS)

Treatments	Plant population at different DAS			Plant dry matter (g) at different DAS			Plant height (cm) at different DAS		
	20	40	60	20	40	60	20	40	60
T_1W_1	25.67d	21.167e	39.833gh	0.333de	1.167	3.667de	9.053d	13.620	30.093
T_1W_2	22.50e	19.500e	35.833hi	0.267ef	1.100	1.800g	8.967d	12.680	25.660
T_1W_3	23.83de	20.000f	38.000gh	0.333de	1.133	1.867g	9.027d	10.147	25.933
T_1W_4	21.50e	16.500g	32.333i	0.200f	1.067	1.667g	8.840d	10.997	23.467
T_2W_1	36.50b	34.500c	83.667a	0.400d	1.333	4.867c	10.627c	13.660	28.280
T_2W_2	32.00c	31.833c	42.500fg	0.267a	1.200	4.433cd	8.567d	12.820	27.367
T_2W_3	35.67b	33.667bc	51.500e	0.333de	1.233	2.800f	8.960d	13.313	27.707
T_2W_4	31.83c	28.833b	38.833gh	0.233f	1.067	4.133d	8.447d	11.480	25.573
T_3W_1	46.00a	44.000a	75.833b	0.800b	1.600	7.133ª	18.887a	15.060	28.893
T_3W_2	33.83bc	28.833d	58.500d	0.567c	1.167	3.867de	18.080a	12.813	27.133
T_3W_3	35.50c	36.167b	66.500c	0.633c	1.367	5.967b	18.720a	14.500	27.760
T_3W_4	31.83c	26.333d	46.667f	0.367d	1.000	3.200ef	16.893b	12.733	26.893
CV (%)	**9.05**	**7.97**	**5.26**	**11.95**	**12.29**	**10.84**	**5.55**	**7.60**	**5.68**
Level of sig.	**	**	**	**	ns	**	**	ns	ns

T_1: Direct wet seeding by drum seeder; T_2: Hand broadcasting and T_3: Transplanting
W_1: Hand weeding (HW), W_2: BRRI weeder + HW, W_3: Herbicide + HW and W_4: no weeding
CV = Co–efficient of variation; **= significant at 1% level of probability and ns= not significant

Plant height

Interaction effect between crop establishment methods and nitrogen application options were statistically similar height of *Boro* rice plant at 40 and 60 DAS due to non-significant variation, however, plant height varied from 10.14 cm (T_1W_3) to 15.06 cm (T_3W_1) at 40 DAS and 23.46 cm (T_1W_4) to 28.89 cm (T_3W_1) at 60 DAT while interaction effect showed significant variation at 20 DAS (Appendix VII and Table 35). At 20 DAS, plant height varied from 8.44 cm (T_2W_4: hand broadcasting × no weeding) to 18.88 cm (T_3W_1: transplanting method × hand weeding).

4.4.3.2 Performance study of growth and yield attributes at reproductive stage

Number of tillers

Tiller production at harvest due to interaction effect of crop establishment method and application time and date of N had highly significant where it was varied from 2.78 to 8.83 (Appendix VIII and Tale 36). From the above results it was found that the number of panicles per hill had maximum in interaction treatment of T_3W_1 (transplanting method × hand weeding) and minimum in interaction treatment of T_1W_4 (direct wet seeding by drum seeder × no weeding).

Number of panicles

A significant variation was found due to interaction effect of crop establishment method and application time and date of N in respect of panicles number per hill at harvest (Appendix VIII and Table 36). The data on number of panicles per hill significantly varied from 2.37 to 6.93 which were obtained from the interaction treatments of T_1W_4 (direct wet seeding by drum seeder × no weeding) and T_1W_1 (direct wet seeding by drum seeder method × hand weeding), respectively (Table 36). However, transplanting method with hand weeding (T_3W_1) also showed statistically similar maximum panicles (6.73) at harvest but the interaction treatment of T_2W_1 (hand broadcasting × hand weeding), T_3W_3 (transplanting method × herbicide + HW) and T_2W_3 (hand broadcasting method × herbicide + HW) produced statistically close maximum panicles (6.60, 6.45 and 6.18, respectively).

Yield of grain

The data on yield of grain at harvest varied significantly from 1.72 to 4.72 t ha^{-1} due to interaction effect of crop establishment method and N management treatments (Appendix VIII and Table 36). Among the interaction treatments, yield of grain had highest in T_2W_1 (hand broadcasting method × hand weeding) while statistically similar highest yield of grain were also obtained by T_1W_1 (direct wet seeding by drum seeder × hand weeding) and T_3W_1 (transplanting method × hand weeding) at harvest (4.67 and 4.62 t ha^{-1}, respectively) followed by T_3W_3 (transplanting method × herbicide + hand weeding) (4.28 t ha^{-1}) while yield of grain had lowest in T_3W_4 (transplanting method × no weeding) (1.72 t ha^{-1}).

Table 36. Interaction effect between crop establishment method and weed management practices on yield and yield attributes of *Boro* rice at harvest

Treatments	Plant height (cm)	No. of tillers hill^{-1}	No. of panicles hill^{-1}	Grain yield (t ha^{-1})	Straw yield (t ha^{-1})	Straw sub sample weight (g)	Straw oven dry weight (g)	No. of filled grains panicle^{-1}	1000–grain weight (g)
T_1W_1	74.60	7.52c	6.93a	4.67 a	5.60	99.67	30.00	9.45a	21.33
T_1W_2	70.98	4.13f	3.58ef	2.95 cde	3.54	96.33	28.80	83.87b	19.93
T_1W_3	72.13	4.97e	4.38e	3.17 cd	3.80	98.67	29.23	89.47ab	20.17
T_1W_4	68.83	2.78g	2.37g	2.28 def	2.74	94.07	27.27	80.53bc	13.97
T_2W_1	80.05	7.68bc	6.60ab	4.72 a	5.66	112.33	32.40	78.70bc	21.53
T_2W_2	75.39	6.55d	5.77bcd	3.45 bc	4.14	102.00	30.07	71.70d	19.83
T_2W_3	76.13	7.30c	6.183bcd	3.45 bc	4.14	108.00	32.23	71.93d	21.13
T_2W_4	67.81	5.95d	3.45f	2.00 ef	2.40	95.67	28.10	59.03e	16.80
T_3W_1	81.82	8.83a	6.73a	4.62 a	5.54	114.33	32.23	79.00bc	23.17
T_3W_2	76.16	7.62bc	5.55cd	3.55 bc	4.26	110.67	29.63	76.63cd	23.57
T_3W_3	79.88	8.23ab	6.45abc	4.28 ab	5.14	116.67	31.60	77.30cd	24.63
T_3W_4	65.66	4.20f	5.33d	**1.72 f**	**2.06**	100.67	27.43	54.90e	21.97
CV (%)	**4.47**	**5.77**	**9.60**	**16.50**	**11.48**	**3.47**	**3.55**	**4.01**	**11.11**
Level of sig.	**ns**	**	**	**	**ns**	**ns**	**ns**	**	**ns**

T_1: Direct wet seeding by drum seeder; T_2: Hand broadcasting and T_3: Transplanting
N_1: ⅓ at 15 DAT + ⅓ at 30 DAT + ⅓ at PI; N_2: ¼ at basal + ¼ at 15 DAT, + ¼ at 30 DAT + ¼ at PI
N_3: Leaf color chart (LCC) based N application and N_4: no nitrogen
CV= Co–efficient of variation; **= significant at 1% level of probability and ns= not significant

Number of filled grains

Number of filled grains panicles^{-1} at harvest was significantly affected by the interaction effect between crop establishment methods and application time and level of N (Appendix VIII and Table 36). The maximum number of filled grains (94.53) was observer in T_1W_1 (direct wet seeding by drum seeder method × hand weeding) while the treatment combinations of T_1W_3 (direct wet seeding by drum seeder method × herbicide + HW) obtained the statistically similar maximum filled grains (89.476) followed by T_1W_2 (direct wet seeding by drum seeder × BRRI weeder + hand weeding) (83.87). On the other hand, filled grains had minimum (54.90) in T_3W_4 (transplanting method × no weeding).

Non significant variation result

Yield and yield contributing characters such as plant height (cm), yield of straw (kg 6 m^{-2}), straw sub sample weight (g), straw oven dry weight (g) and Weight of 1000–grain were statistically identical due to interaction treatments between crop establishment methods and various application option of N. However, plant height varied from 65.66 (T_3W_4) to 81.82 (T_3W_1), yield of straw varied from 2.06 (T_3W_4) to 5.66 (T_2W_1), straw sub sample weight varied from 94.06 g (T_1W_4) to 116.66 g (T_3W_3), straw oven dry weight varied from 27.26 g (T_1W_4) to 32.40 g (T_2W_1) (Table 36).

CHAPTER 5

SUMMARY AND CONCLUSION

CHAPTER 5

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5.1 Summary

One year evaluation under four experiments regarding both *T. aman* and *Boro* season were conducted at the experiment field of the Bangladesh Rice Research Institute (BRRI) at Regional Station, Shyampur, Rajshahi. Popular *T. aman* rice variety cv. BRRI dhan–44 and *Boro* rice variety cv. BRRI dhan–45 developed by BRRI were used as planting materials for the present study where three types of crop establishment methods such as T_1= hand broadcasting, T_2=direct wet seeding by drum seeder and T_3= transplanting were common treatments for the whole study while four N management practices including control (no N fertilizer) *viz.* N_1=1/3 at 15 DAT + ⅓ at 30 DAT + ⅓ at PI, N_2= ¼ at basal + ¼ at 15 DAT + ¼ at 30 DAT + ¼ at PI, N_3= LCC based N application and N_4= No nitrogen were used as fertilizer treatments for the experiment one the three (one for *T. aman* season and one for *Boro* season). Besides, four weeding options including control (no weeding) namely W_1=Hand weeding (HW), W_2=BRRI weeder +HW, W_3=Herbicide +1HW and W_4=No weeding were also used for the experiment two and four (one for *T. aman* season and one for *Boro* season). The experiment was laid out in two factors RCBD with three replications for each experiment and analysis was done by the MSTAT-C package program whereas means were adjudged by DMRT at 5% level of probability. Data were also collected on various morpho–physiological, yield and yield attributing characters concerning whole study where the summary and conclusion of overall result were presented under the following individual experiment.

5.1.1 Experiment 1

Incase of the experiment 1, most of the studied characters were statistically significant among the studied whole characters due to the main performance of singly or their interaction effects of various crop establishment methods and N management practices treatments. From the result observation it was found that the plant population, plant dry matter and plant height significantly increase with the advancement of the study as well as those were highest at 60 DAS.

Incase of the effect of crop establishment method, the plant population had maximum (143.16) in transplanting methods (T_3) at 60 DAS while similar methods also showed significantly the highest plant dry matter (36.40 g) at 60 DAS, tallest plant (117.18 cm), maximum panicle (86.16), highest yield of grain (5.05 t ha^{-1}), highest yield of straw (6.06 t ha^{-1}) at harvest than other two crop establishment methods whereas hand broadcasting method (T_2) had minimum for plant population (114.50) at 60 DAS and plant height (106.52 cm) at harvest and direct wet seeding (T_1) had lowest for plant dry matter (20.96 g) at 60 DAS, panicles number (69.50), grains weight (3.30 t ha^{-1}) and yield of straw (3.96 t ha^{-1}). In case of cost and economic performance, treatment T2 (hand broadcasting) obtained the highest net return (Tk. 58380) and BCR (2.34) with lowest cost of production (Tk. 43,590) while T_3 confirm the highest gross return (Tk. 1,04,030/–) along with higher production cost (Tk. 52,590). Net return and BCR were lowest (Tk. 22,490/– and 1.49, respectively) were recorded in T_1. Among other characters of the study were statistically identical due to crop establishment method.

Among the N management practices, N_2 showed significantly the greater result on plant population (134.11) at 60 DAS, PDM (34.78) at 60 DAS, number of tillers (106.11), number of panicles (82.27), grain and straw yield (4.97 and 5.96 t ha^{-1}, respectively), filled grains (1108.30) and weight of 1000–grain (31.70 g) at harvest while tallest plant (115.79 cm) and highest yield of straw (13.60 t ha^{-1}) were taken in N_1. All the above studied characters significantly perform lower when N fertilizer did not apply (N_4: no nitrogen). N effect also showed that the treatment N_2 required the highest cost for production (Tk. 51,890) while gross and net return (Tk. 1,02,380 and Tk. 50,490, respectively) and BCR (1.97) were also highest in this treatment. Similarly, minimum cost for production, gross and net return (Tk.

36,890, Tk. 72,100 and Tk. 35,107, respectively) were also found in N4 (No. nitrogen) while N_3 showed lowest BCR (1.89). Rest of the studied characters was statistically non–significant due to N management practices treatment.

In case of interaction effect between crop establishment and N application methods, plant population had maximum (152.33) in interaction treatment of T_3N_2 while this treatment also produces the highest PDM (19.62 g) at 60 DAS and tallest plant (121.46 cm) at harvest whereas plant population and plant height had lower (99.00 and 101.98 cm, respectively) in T_2N_4 and PDM had lower in T_1N_4 (8.57 g) and maximum number of panicles (92.66) were taken in T_3N_2 while highest yield of straw (6.76 t ha^{-1}, respectively) and highest weight of sub sample straw (148.20 g) were found in T_2N_2. Similarly, T_1N_4 observed the minimum panicles (61.33) and lowest yield of straw (2.50 t ha^{-1}) while lowest weight of sub sample straw (80.50 g) was taken in T_2N_4. A non–significant variation due to interaction treatments were also found among other characters of the studied.

5.1.2 Experiment 2

Incase of the experiment 2, performance study of crop establishment methods and weed management practices singly or their interaction were statistically significant among the maximum characters of the study where population number, PDM and plant height increase in increasing study period.

Among the crop establishment methods, maximum population (142.91) at 60 DAS, highest PDM (12.47 g) at 60 DAS, tallest plant (120.38 cm), maximum tillers (123.16), maximum panicles (87.41), highest yield of grains (5.12 t ha^{-1}), highest yield of straw (6.14 t ha^{-1}), highest weight of sub sample and over dry straw (144.00 and 50.71 g, respectively), maximum filled grains (927.91) and highest weight of 1000–grain (27.95 g) were registered in T_3 (transplanting methods) at harvest while those characters were significantly lower in T_1. Hand broadcasting (T_2) required lowest cost for production (Tk. 43,590) while highest BCR (2.08) was also found in

T_2. However, highest cost of production (Tk. 52,590) was required for treatment T_3 but highest gross and net return (Tk. 1,05,470 and Tk. 52,880, respectively) were also obtain in treatment T_3. Treatment T_1 gave the lowest gross and net return (Tk. 71,070 and Tk. 25,580, respectively) along with lowest BCR (1.56).

Incase of the main effect of weed management, hand weeding (W_1) showed superior results on plant population (139.66) at 60 DAS, PDM (31.66 g) at 60 DAS, plant height (115.98 cm), tillers (112.00), panicles (85.22), straw oven dry weight (42.31 g), grain yield (4.97 t ha^{-1}), filled grains (1053.33), and weight of 1000–grain (28.92 g) at harvest while straw sub sample weight had highest (133.21 g) in W_4 (no weeding). On the other hand, plant population (108.33) at 60 DAS, PDM (24.19 g) at 60 DAS, plant height (110.78 cm), tillers (90.44), panicles (66.50), grain yield (3.45 t ha^{-1}), straw oven dry weight (37.66 g), filled grains (722.22), and weight of 1000–grain (24.57 g) at harvest were lower in W_4 while straw sub sample weight had lowest (118.97 g) in W_3 (herbicide + HW). Hand weeding (W_1) further recorded the highest gross and ret return (Tk. 1,02,380 and Tk. 51,990, respectively) as well as the highest BCR (2.03) while this treatment also required the highest cost for production (Tk. 40,400). However, no weeding (W_4) required lowest cost (Tk. 2,930) for production along with lowest gross and net return (Tk. 71,070 and Tk. 34,180, respectively) but it also showed the highest BCR (1.93) compared W_2 (1.72).

Incase of interactions, the highest PDM (36.20 g) at 60 DAS, maximum panicles (98.16), highest yield of grain (6.10 t ha^{-1}) and maximum filled grains (1085.00) were obtained in T_3W_1 (transplanting method × hand weeding) while highest weight of 1000–grain (29.30) was found in T_1W_1 whereas above indicating all characters were significantly lowest in T_1W_4 (direct wet seeding by drum seeder × no weeding).

5.1.3 Experiment 3

Incase of the experiment 3, maximum characters of the study had significant due to the singly or interaction effects of various crop establishment methods and N management practices treatments where plant population, plant dry matter and plant height significantly increase up to harvest.

Among the crop establishment method, plant population and PDM had maximum (57.29 and 4.43 g) in T_3 (transplanting method) at 60 DAS while direct wet seeding by drum seeder (T_1) showed the lowest plant population and PDM (33.87 and 2.22 g, respectively) at 60 DAS. At harvest, maximum tillers and filled grains (71.95 and 706.50, respectively), and highest weight of 1000–grain (20.15 g) were also found under transplanting methods (T_3). Similarly, minimum tillers and panicle and lowest weight of 1000–grain were in T_1 (direct wet seeding by drum seeder). Hand broadcasting also showed the highest BCR (1.47) while it required lowest cost for production (Tk. 51,850) along with the highest net return (TK. 24,575). The highest gross return and production cost (Tk. 77,250 and Tk. 66,150. respectively) and lowest BCR (1.17) were recorded for transplanting method (T_3). However, lowest gross return (Tk. 72,100) was obtained from T_1. Other characteristics (plant height, panicles (no.), grain and yield of straw, weight of sub sample and oven dry yield of straw) of the study had statistically identical among the whole treatments of crop establishment due to non–significant variation.

Incase of N management, N_2 showed the maximum population (34.00) at 40 DAS, highest PDM (4.93 g) at 60 DAS, tallest plant (78.29 cm), maximum number of tillers, panicles and filled grains (78.33, 67.27, 788.77), highest yield of grains, straw and 1000–grain (4.91 t ha^{-1}, 5.89 t ha^{-1} and 20.91 g, respectively) at harvest while minimum population (24.61) at 40 DAS, lowest PDM (1.06 g), shortest plant (69.27 cm), minimum number of tillers, panicles, and filled grains (43.77, 34.94 and 484.22, respectively), lowest yield of grains and straw (2.02 and 2.42 t ha^{-1}, respectively) were found in without N application treatment (T_4). The highest BCR

(1.97) was also found in N_2 while this treatment required highest cost (Tk. 51,890) for production and returned the highest gross and net Tk. of 1,01,145 and Tk. 49,255, respectively. In every cases, such as production cost (Tk. 36,890), gross return (Tk. 41,610), net return (Tk. 4,720) as well as the BCR (1.13) were lowest in N_4 (no nitrogen). Plant population at 60 DAS, straw sub sample and oven dry weight were statistically same due to non significant variation among the N management treatments.

The maximum number of plant population (67.16) at 60 DAS, highest PDM (7.16 g) at 60 DAS, tallest plant (80.49 cm), maximum number of tillers, panicles and filled grains (88.33, 77.33 and 834.66, respectively) were taken in interaction of T_3N_2 (transplanting method × ¼ at basal + ¼4 at 15 DAT + ¼ at 30 DAT + ¼ at PI) while minimum plant population (32.33) at 60 DAS, lowest PDM (1.06 g), shortest plant (65.66 cm), minimum number of tillers, panicles and filled grains (33.33, 27.66 and 429.00, respectively) were found in interaction of T_1N_4 (direct wet seeding by drum seeder × no nitrogen). Similarly, T_1N_2 (direct wet seeding by drum seeder × ¼ at basal + ¼4 at 15 DAT + ¼ at 30 DAT + ¼ at PI) produced the highest yield of straw (6.00 t ha^{-1}) while it was the lowest (2.33 t ha^{-1}) in T_3N_4. Among other characters of the study were statistically similar due to non significant variation of interaction treatments.

5.1.4 Experiment 4

Incase of the Most of the studied characters were also statistically significant due to singly or their interaction effect between crop establishment methods and weed management practices. Incase of the main effect of crop establishment methods, transplanting method (T_3) showed significantly the maximum population of plant (61.87) at 60 DAS, highest PDM (5.04 g) at 60 DAS, maximum tillers (72.70), maximum panicles (60.16), highest yield of grains (3.54 t ha^{-1}), highest yield of straw (4.25 t ha^{-1}) and maximum filled grains (719.58) were recorded in T_3 (transplanting methods) at harvest while those characters were significantly lower in T_1. Similarly, treatment T_2 (hand broadcasting) showed the highest BCR (1.35) and net return (Tk. 18,190) while T_3 (transplanting method) showed highest gross of Tk. 72,925 and lowest net return of Tk. 67,775 and lowest BCR (1.10). The lowest gross return (Tk. 67,160) was recorded in T_1. Rest of the studied characters did not vary significant due to crop establishment method in this study.

Similarly, maximum plant population (66.44) at 60 DAS, highest PDM (5.22 g) at 60 DAS, tallest plant (78.82 cm), maximum number of tillers, panicles and filled grains (80.11, 67.55 and 840.77, respectively), highest yield of grains, straw, straw oven dry weight and 1000–grain weight (4.67 t ha^{-1}, 5.60 t ha^{-1}, 31.54 g and 22.0 g, respectively) at harvest were for hand weeding treatments (W_1) while all the above representing characters were statistically lower in W_4 (no weeding). The highest BCR (1.91) along with highest gross and net (Tk. 96,200 and T. 45,810, respectively) were obtained in W_1 while this treatment also need highest cost for production of Tk. 40,400. Similarly, lowest cost for produciton (Tk. 2,930) and BCR (1.12) were obtained in W_4 (no weeding) while minimum gross and net (TK. 41,200 and Tk. 4,310, respectively) were also recorded in W_4. However, weeding management treatments were produced statistically identical results on straw sub sample and oven dry weight at harvest due to non–significant variation.

However, the maximum population of plant (83.66) and highest yield of grains (4.72 t ha^{-1}) were found in T_2W_1 (hand broadcasting × hand weeding); highest PDM (3.17 g) at 60 DAS and maximum number of tillers (88.33) at harvest were observed in T_3W_1 (transplanting methods) but the maximum number of panicles and filled grains (69.33 and 945.33, respectively) was obtained in T_1W_1 and minimum filled grains (549.00) was found in T_3W_4.

From the above result observation of the whole study, it could be concluded that the transplanting method and split application of N @ ¼ at basal + ¼ at 15 DAT + ¼ at 30 DAT + ¼ at PI (T_3N_2) singly or their interaction effect showed the understanding superiority for obtaining the greater yield of *T. aman* (experiment one) and *Boro* (experiment three) rice under the studied area. Similarly, transplanting method and hand weeding management singly or their interaction treatments also perform better than other singly of their interaction treatments in case of the experiment two (*T. aman* season). However, singly effect of transplanting method and hand weeding had most productive during *Boro* season (experiment four) but the interaction effect of direct wet seeding and hand weeding (T_1W_1) were the most productive interaction treatment incase of the experiment four. So, the above observation of the whole study, it could be concluded that the transplanting method and N @ ¼ at basal + ¼ at 15 DAT + ¼ at 30 DAT + ¼ at PI singly (T_3 and N_2) or their interaction effect (T_3N_2) would be the most productive treatments in case of the experiment one and three, while effects of transplanting method and hand weeding singly (T_3 and W_1) or their interaction (T_3W_1) would be the most productive during aman (expt. two) and boro (expt. four) season except the experiment four incase of interaction effect where the interaction effect of T_1W_1 (direct wet seeding by drum seeder × hand weeding) were the most efficient interaction for obtaining the higher yield during *Boro* season.

5.2 Conclusion

Based on the findings of all experiments, the following conclusion on crop establishment methods, nitrogen and weed management practices could be drawn.

1. Transplanting technique is the best option for rice cultivation for both T-aman and boro growing season and economically confirm the highest gross return with this method.
2. In case of nitrogen application in rice field among four options, more split application gave greater grain and straw yield having the highest economic efficiency.
3. The combined approach of T_3N_2 is the most suitable for both season.
4. Grain yield, straw yield along with gross margin performed better in hand weeding approach for T-aman and boro.

5.3 Recommendation

Following recommendations are formulated for the whole study:

1. Transplanting method along with nitrogen application @ $^1/_4$ at basal +$^1/_4$ at 15 DAT + $^1/_4$ at 30 DAT +$^1/_4$ at PI stage or their interaction would be the most productive package for Bangladesh perspective.
2. Same treatment with hand weeding practices were suitable for farmers package in case of aman and boro.
3. It needs to incorporate other yield attributing traits and it should repeat other AEZ of Bangladesh for better confirmation of the findings.

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APPENDICES

Appendix I. Analysis of variance (ANOVA) for plant population, plant dry matter and plant height of *T aman* rice at different days after sowing (DAS) as influence by crop establishment method and N application option (Experiment 1)

SV	DF	Plant population at different DAS			Plant dry matter (g) at different DAS			Plant height (cm) at different DAS		
		20	40	60	20	40	60	20	40	60
Rep	2	2.114	8.215	0.174	0.105	0.115	2.688	3.015	10.144	20.494
Fac A	2	150.69**	4005.93**	2505.44**	11.308**	101.043**	926.311**	150.693**	125.05**	172.06**
Error	4	0.760	85.194	70.892	0.626	0.301	1.063	3.207	5.780	1.211
Fac B	3	3.207**	4670.33**	248.019**	0.291**	10.140**	121.837**	0.568**	42.312**	165.79**
A×B	6	0.568**	0.769ns	287.296**	0.047**	0.748ns	21.857**	2.791ns	13.736**	8.685ns
Error	18	1.882	416.542	30.218	0.217	1.200	8.907	2.693	4.848	11.916

SV= Source of variation, DF= Degrees of freedom
Fac A= Crop establishment method and Fac B= Nitrogen management
**= significant at 1% level of probability and ns= not significant

Appendix II. Analysis of variance (ANOVA) for yield and yield attributes of *T. aman* rice at harvest as influence by crop establishment method and N application option (Experiment 1)

SV	DF	Plant height (cm)	No. of tillers hill^{-1}	No. of panicles hill^{-1}	Grain yield (t ha^{-1})	Straw yield (t ha^{-1})	Straw sub sample weight (g)	Straw oven dry weight (g)	No. of filled grains panicle^{-1}	Thousand grain weight (g)
Rep	2	33.882	90.528	123.083	0.034	6.164	249.909	13.757	2504.083	1.947
Fac A	2	376.780**	1647.5**	875.58**	4.194**	39.627**	3168.83**	370.252**	20788.1**	10.70**
Error	4	4.392	49.622	16.917	0.095	0.969	315.494	9.991	5950.667	6.693
Fac B	3	180.653**	758.21**	202.90**	1.381**	40.610**	2848.53**	651.390**	122853**	68.261**
A×B	6	29.065**	102.26ns	14.787**	0.078ns	3.993**	698.859**	109.470ns	6869.16ns	10.975ns
Error	18	14.231	74.979	22.741	0.063	30.977	279.441	9.006	13870.32	10.113

SV= Source of variation, DF= Degrees of freedom
Fac A= Crop establishment method and Fac B= Nitrogen management
**= significant at 1% level of probability and ns= not significant

Appendix III. Analysis of variance (ANOVA) for plant population, plant dry matter and plant height of *T aman* rice at different days after sowing (DAS) as influence by crop establishment method and weed management practices (Experiment 2)

SV	DF	Plant population at different DAS			Plant dry matter (g) at different DAS			Plant height (cm) at different DAS		
		20	40	60	20	40	60	20	40	60
Rep	2	3.146	36.111	44.778	0.033	0.378	1.368	4.922	8.438	15.934
Fac A	2	9480.8**	6817.6**	42.12**	7.547**	82.160**	349.79**	91.392**	208.92**	83.95**
Error	4	13.448	115.257	1632.676	0.033	0.399	3.978	1.078	2.528	15.130
Fac B	3	188.31**	660.86**	10.398ns	0.079**	29.235**	96.183**	13.756**	26.306**	53.435**
A×B	6	84.826**	67.275ns	53.649ns	0.060ns	4.049**	21.311**	2.052ns	0.615ns	3.434ns
Error	18	5.681	80.588	32.192	0.031	0.325	2.450	2.027	4.250	5.243

SV= Source of variation, DF= Degrees of freedom
Fac A= Crop establishment method and Fac B= Weed management
**= significant at 1% level of probability and ns= not significant

Appendix IV. Analysis of variance (ANOVA) for yield and yield attributes of *T. aman* rice at harvest as influence by crop establishment method and weed management practices (Experiment 2)

SV	DF	Plant height (cm)	No. of tillers hill^{-1}	No. of panicles hill^{-1}	Grain yield (t ha^{-1})	Straw yield (t ha^{-1})	Straw sub sample weight (g)	Straw oven dry weight (g)	No. of filled grains panicle^{-1}	Thousand grain weight (g)
Rep	2	29.946	2.340	1.271	0.061	0.119	33.674	0.066	281.028	4.820
Fac A	2	423.8**	4162.7**	1849.8**	3.042**	46.55**	2919.53**	1014.94**	10871.2**	28.568**
Error	4	4.647	12.580	5.083	0.020	0.294	9.737	0.259	3679.028	1.203
Fac B	3	48.78**	793.9**	602.69**	1.317**	7.997ns	309.400**	43.032**	1760.68**	10.09**
A×B	6	2.318ns	40.935ns	52.46**	0.097**	0.472ns	1516.47ns	6.752ns	9744.42**	6.352**
Error	18	13.671	33.130	16.683	0.042	0.616	21.714	4.472	3560.917	2.401

SV= Source of variation, DF= Degrees of freedom
Fac A= Crop establishment method and Fac B= Weed management
**= significant at 1% level of probability and ns= not significant

Appendix V. Analysis of variance (ANOVA) for plant population, plant dry matter and plant height of *Boro* rice at different days after sowing (DAS) as influence by crop establishment method and N application option (Experiment 3)

SV	DF	Plant population at different DAS			Plant dry matter (g) at different DAS			Plant height (cm) at different DAS		
		20	40	60	20	40	60	20	40	60
Rep	2	0.924	0.924	13.861	0.001	0.074	0.023	0.486	0.688	0.082
Fac A	2	1826.7**	1426.3**	1645.1**	0.166**	0.025ns	14.961**	72.680**	14.165ns	70.754**
Error	4	1.997	7.455	4.517	0.002	0.060	0.099	0.764	2.615	0.526
Fac B	3	190.53**	151.27**	950.19ns	0.017**	0.599**	16.841**	9.882**	26.508**	60.436**
A×B	6	44.623**	29.650ns	71.602**	0.002**	0.140ns	2.845**	1.331**	0.271ns	2.406**
Error	18	4.417	5.481	8.826	0.001	0.116	0.022	0.251	0.252	0.577

SV= Source of variation, DF= Degrees of freedom
Fac A= Crop establishment method and Fac B= Nitrogen management
**= significant at 1% level of probability and ns= not significant

Appendix VI. Analysis of variance (ANOVA) for yield and yield attributes of *Boro* rice at harvest as influence by crop establishment method and N application option (Experiment 3)

SV	DF	Plant height (cm)	No. of tillers hill^{-1}	No. of panicles hill^{-1}	Grain yield (t ha^{-1})	Straw yield (t ha^{-1})	Straw sub sample weight (g)	Straw oven dry weight (g)	No. of filled grains panicle^{-1}	Thousand grain weight (g)
Rep	2	1.505	6.049	0.882	0.091	0.172	14.250	2.005	270.028	0.619
Fac A	2	0.765ns	359.4**	30.13ns	0.078ns	0.488ns	892.583ns	6.460ns	41574.4**	64.999**
Error	4	1.985	3.309	6.819	0.023	0.079	24.708	0.740	456.903	0.406
Fac B	3	136.83**	2183.4**	1782.3**	4.944**	17.765**	1487.59ns	68.830ns	142463.3**	84.079**
A×B	6	46.44**	245.1**	157.1**	0.092ns	0.374**	133.954ns	5.581ns	9469.25**	5.895ns
Error	18	0.886	1.426	5.970	0.025	0.102	15.778	0.452	902.833	1.411

SV= Source of variation, DF= Degrees of freedom
Fac A= Crop establishment method and Fac B= Nitrogen management
**= significant at 1% level of probability and ns= not significant

Appendix VII. Analysis of variance (ANOVA) for plant population, plant dry matter and plant height of *Boro* rice at different days after sowing (DAS) as influence by crop establishment method and weed management practices (Experiment 4)

SV	DF	Plant population at different DAS			Plant dry matter (g) at different DAS			Plant height (cm) at different DAS		
		20	40	60	20	40	60	20	40	60
Rep	2	3.861	4.882	10.021	0.004	0.044	0.363	0.486	0.067	4.794
Fac A	2	601.38**	761.88**	2029.2**	0.352**	0.084ns	24.061**	330.18**	11.011ns	5.982ns
Error	4	4.392	7.247	3.646	0.003	0.133ns	0.177	1.362	0.525	2.024
Fac B	3	103.91**	146.39**	1217.6**	0.097**	0.168**	8.744**	3.422**	8.629ns	21.888**
A×B	6	21.678**	37.215**	260.52**	0.014**	0.038ns	3.169**	1.054**	2.876ns	3.781ns
Error	18	8.067	5.134	7.141	0.002	0.022	0.168	0.450	0.950	2.364

SV= Source of variation, DF= Degrees of freedom
Fac A= Crop establishment method and Fac B= Weed management
**= significant at 1% level of probability and ns= not significant

Appendix VIII. Analysis of variance (ANOVA) for yield and yield attributes of *Boro* rice at harvest as influence by crop establishment method and weed management practices (Experiment 4)

SV	DF	Plant height (cm)	No. of tillers hill^{-1}	No. of panicles hill^{-1}	Grain yield (t ha^{-1})	Straw yield (t ha^{-1})	Straw sub sample weight (g)	Straw oven dry weight (g)	No. of filled grains panicle^{-1}	Thousand grain weight (g)
Rep	2	42.267	116.869	18.340	0.036	0.023	0.004	1.068	772.333	1.947
Fac A	2	58.76ns	1964.8**	908.17**	0.083**	0.678**	540.201ns	11.402ns	102545.1**	10.697**
Error	4	19.604	39.704	28.569	0.012	0.073	9.320	3.327	1229.917	68.261
Fac B	3	211.6**	2162.6**	1465.2**	3.914**	9.264**	269.721ns	28.237ns	61200.96**	10.98**
A×B	6	20.02ns	249.65**	192.60**	0.160**	0.383ns	28.194ns	1.104ns	4775.05**	9.491ns
Error	18	10.953	13.295	25.604	0.113	0.251	13.078	1.127	939.019	0.517

SV= Source of variation, DF= Degrees of freedom
Fac A= Crop establishment method and Fac B= Weed management practices.
**= significant at 1% level of probability and ns= not significant

Appendix IX. Monthly temperature, relative humidity, sunshine hour and rainfall of experimental site during the study period

Year	Month	Air temperature (^{o}C)			**Rainfall (mm)	*Relative humidity	**Sunshine (hrs)
		Maximum	Minimum	Average			
2007	July	29.6	18.5	24.1	001	77.33	169.3
	August	26.9	14.0	20.5	000	74.33	147.5
	September	24.3	10.7	17.5	000	76.03	76.6
	October	26.2	15.5	20.9	018	76.25	141.4
	November	33.2	20.4	26.8	027	66.37	234.4
	December	32.9	23.3	28.1	028	73.33	182.8
2008	January	35.5	25.2	30.4	092	71.67	240.5
	February	30.6	19.1	24.9	0.15	76.33	225.80
	March	26.0	13.0	19.5	000	77.00	147.00
	April	24.1	12.5	18.3	027	80.33	102.80
	May	25.9	13.1	19.5	000	72.33	163.10
	June	30.5	19.9	25.2	022	74.33	154.20

* Monthly average; ** Monthly total
Source: Regional Inspection Centre, Bangladesh Meteorological Department, Rajshahi