Increasing yield and agronomic efficiency of boro rice (*Oryza sativa*) by fertigation with bed planting compared with conventional planting

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Abstract: The fertigation technique with raised bed planting for transplanted boro (winter, irrigated) rice production is a research focus nowadays. A field experiment compared two cultivation methods: the fertigation technique within raised bed planting on boro rice, and fertilizer broadcasting in the conventional planting method. Compared to conventional fertilizer broadcasting, results showed that the new fertigation technique in raised bed planting increased grain yield of transplanted boro rice by up to 17.04%. It yielded a greater number of panicles per square meter, a greater number of grains per panicle, higher 1000-grains weight, and better plant growth attributes. Sterility percentage and weed infestation were lower. Thirty six percent of irrigation water and time for application could be saved. Water use efficiency for grain and biomass production was higher. The agronomic efficiency of nitrogen (N) fertilizer was significantly higher. This study concluded that fertigation in raised bed planting for transplanted boro rice is a new approach with higher yield and higher fertilizer and water use efficiency than the existing agronomic practice in Bangladesh.

Keywords: boro rice, fertigation with bed planting, de-nitrification, water use efficiency, harvest index, irrigated water management

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1 Introduction

Fertigation is the application of water soluble solid fertilizer or liquid fertilizer through the irrigation system[1]. The advantages of the fertigation technique include a slow-release of fertilizer, higher N uptake by the plant to boost leaf and root weight, lower degree of ground water contamination, and higher crop yields[2]. Fertigation technique can also reduce fertilizer application costs by simplifying operation and improving nutrient efficiency. Further, it could conceivably reduce leaching or de-nitrification (gaseous) losses of nitrogen and lower the luxury uptake of nutrients by plants. Fertigation enables users to put the fertilizers in plant root zone or on canopy in desired frequency, amount and concentration at appropriate time[3].

Efficient use of fertilizer requires contact between fertilizer and crop requirements, which could be achieved by applying N fertilizer with furrow irrigation[4]. Thus,

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50% of recommended dose of fertilizer application through fertigation was as effective to produce yield as that of the conventional method of fertilizer application[5] and 25%-50% fertilizer could be saved. Extensive fertigation research on most vegetables crops is available[6]. However, it is unclear how N fertilizer application through fertigation technique behaves for boro rice production on raised bed cultivation method.

Our previous study showed that fertigation in raised bed planting had higher yield and greater water use efficiency than fertilizer broadcasting in the conventional method for transplanted aman rice. Likewise, other studies showed that raised bed planting with fertilizer broadcasting was better than conventional cultivation method[7]. Another study showed that raised bed planting with foliar spray was better than the conventional cultivation method[8]. Another study of ours also showed that split foliar nitrogen application on water use efficiency and productivity of boro rice in raised bed was better than the conventional method[9]. Rice bed planting and foliar fertilization gave higher yield and better growth response than conventional planting[10]. However, no study has been conducted in fertigation technique on raised bed compared with conventional technique for transplanted boro rice (winter irrigated) production. Under this circumstance, the present study was undertaken to achieve the following objectives for transplanted boro rice production: (i) to explore the comparative advantages of using N fertilizer through fertigation in raised bed over N-broadcast in conventional planting, (ii) to examine the differences in yield and growth response between these two techniques, and (iii) to compare the water use efficiency and agronomic efficiency of N using the two ways. It was hypothesized that the fertigation technique in raised bed be more efficient than the conventional flat method for transplanted boro rice production.

2 Materials and methods

The field experiment was carried out on a farm field in the Chuadanga District of Bangladesh, during the boro growth period (December-May).

2.1 Site description

2.1.1 Geographical location

The experimental area was located at 11.5 m above mean sea level. Geographically, it was located at 23°39′N latitude and 88°49′E longitude.

2.1.2 Agro-ecological region

The experimental field belonged to the Agro-ecological Zone (AEZ) of 11- High Ganges river floodplain of Bangladesh.

2.1.3 Climate

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

2.1.4 Soil

Soil samples (0-15 cm depth) were collected from the field for physico-chemical analysis (Table 1) one week before transplanting. Soil samples were analyzed for particle size distribution by the hydrometer method[11]. Soil pH was measured in water (Soil water ratio 1:1) and electrical conductivity of the soil suspension was measured using conductivity meter. The concentrations of phosphorus (P), potassium (K) and zinc (Zn) were determined by the AB-DTPA method[12]. For the concentration determination of K from plant samples, the wet digestion method (nitric acid + perchloric acid in 2:1 ratio) and flame photometer[13] was used. The data of the initial analysis of soil samples concerning organic carbon, pH, available N, P and K are shown in Table 1.

Table 1 Soil physical and chemical properties (Initial analysis)

Location	Season	Soil type	pH	Organic carbon /%	Total N /%	Available P /ppm	Exchangeable K /meq·100 g^{-1}	Available S /ppm	Available Zn /ppm
Chuadanga	Boro	Silt loam	7.3	0.88	0.11	5.68	0.15	12.10	0.22

2.2 Details of the experiment

2.2.1 Experimental design

The experiment was laid out in a randomized complete block design (RCBD) with three replications. The entire experimental area was divided into three blocks representing three replications to reduce soil heterogenic effects and each block was divided into three unit plots with raised bunds as per treatments. Thus the total number of unit plots was 9. The size of each unit plot was 4 m × 3.5 m. Plots were separated from one another by ails of 0.25 m. Each unit block was separated from others by 1 m drains. Treatments were randomly distributed within the blocks. One control treatment with three replications was undertaken in this study. However, only yield data were undertaken to calculate agronomic efficiency. The overall treatments structure of this experiment were mentioned as below in Table 2.

Table 2 Treatments setting for this experiment

Treatments details	Number of replications	Fertilizer application
Fertigation in raised bed planting irrigation	Three	Urea was applied through water in three equal splits
Fertilizer broadcasting in conventional planting land	Three	Basal doses were applied at final preparation
Control	Three	No fertilizer added

2.3 Crop/planting material

Rice variety BRRI dhan 28 was used as a testing plant material.

2.3.1 Description of variety: BRRI dhan 28

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

2.4 Land preparation

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

2.5 Bed preparation

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

2.6 Transplanting of rice seedlings

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

2.7 Fertilizer application in conventional planting

Fertilizer was applied at the following rates: N=120, P=14, K=36, Sodium (S)=1.0 kg/ha applied as urea, Triple Super-Phosphate (TSP), Murate of Potash (MP), gypsum and Zinc Sulphate ($ZnSO_4$), respectively. TSP, MP, gypsum and $ZnSO_4$ were applied as a whole at the final land preparation as basal dose in the plots with the conventional treatment. Urea was broadcasted in three equal splits at the 15th, 30th, and 50th day after rice transplanting in the conventional planting method.

2.8 Fertilizer application in fertigation technique with raised bed planting

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

2.9 Weeding

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

2.10 Plant protection measures

The rice was infested by stem borer at tillering stage and rice bug at grain filling stage. Furadon 5G at the rate of 10 kg/ha was applied at the 40th day after transplanting and Malathion 57 EC 5G at the rate of 1 L/ha was applied at grain filling stage to control stem borer and rice bug, respectively.

2.11 Detailed procedures of data collection

2.11.1 Plant height and tiller number observation

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

2.11.2 Leaf area index

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

$$\text{Leaf area index (LAI)} = \text{Leaf area/Ground area}$$

2.11.3 Yield attributed characters of rice

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

2.11.4 Biomass yield and grain yield

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

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

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

2.11.5 Harvest index

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

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

2.11.6 Irrigation water measurement

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

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

2.11.7 Water use efficiency calculation

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

Water use efficiency for grain production (kg/ha·cm) = grain yield (kg/ha)/total water required (cm)

Water use efficiency for biomass production (kg/ha·cm) = [grain yield (kg/ha) + straw yield (kg/ha)]/total water required (cm)

2.11.8 Agronomic efficiency of fertilizer calculation

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

$$A_E = GYN_A - GYN_0/N_R$$

where, GYN_A= Grain yield (kg/ha) with addition of nutrient; GYN_0= Grain yield (kg/ha) without addition of nutrient; N_R= Rate of added nutrient (kg/ha).

2.11.9 Statistical analysis

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

3 Results

3.1 Yield attributing parameters

3.1.1 Number of panicles per square meter

Substantial differences were found in the number of panicles per square meter between the fertigation in bed planting and conventional planting from the analysis results (Table 3). Fertigation in bed planting produced a significantly (≤0.001) higher number of panicles per square meter than fertilizer broadcast in conventional planting for transplanted boro rice. The higher number of panicles per square meter in fertigation of bed planting contributed to the higher grain yield of the fertigation treatment.

Table 3 Grain yield and yield components with respect to fertigation in raised bed and fertilizer broadcasting in conventional planting

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

Note: LSD means least significant difference. Where * and ** represent probability of ≤ 0.001 and ≤ 0.01, respectively. Values were means of three replicates.

3.1.2 Number of grains per panicle

Bed planting with fertigation produced significantly (≤0.01) higher number of grains per panicle than fertilizer broadcast in conventional planting for transplanted boro rice (Table 3). Fertigation in raised bed planting had 18 more grains per panicle than the conventional planting method.

3.1.3 Thousand grains weight

Weight of 1 000 grains was significantly (≤0.001) higher in fertigation with bed planting compared to conventional planting. Fertigation in bed planting had 4 g more in 1 000 grains wt than the conventional method (Table 3). The higher grain weight directly contributed to the higher grain yield in fertigation with bed planting.

3.1.4 Grain yield

Planting methods apparently affected the grain yield of transplanted boro rice. Fertigation in bed planting produced significantly (≤0.01) higher grain yield than conventional planting (Table 3). The yield increase by fertigation in bed planting over conventional planting was 17.04%. The higher grain yield in fertigation with bed planting was related to a higher number of panicles per square meter, a higher number of grains per panicle and higher individual grain weight. The grain yield of conventional planting was lower due to a smaller number of panicles per square meter, a smaller number of grains per panicle and lower individual grain weight.

3.2 Plant growth parameters

3.2.1 Plant height

Plant height was not significantly different ($P \geq 0.05$) between the fertigation in bed planting and fertilizer broadcast in conventional planting for transplanted boro rice. However, plant height tended to be higher with fertigation technique (Table 4).

Table 4 Plant biomass with respect to fertigation in raised bed and fertilizer broadcasting in conventional planting

Method of fertilizer application	Plant height /cm	Panicle length (cm)	Non-bearing tiller $/number\cdot m^{-2}$	Sterility /%	Straw yield $/t\cdot ha^{-1}$	Harvest index
Fertigation in bed planting	84.82 a	25.65 b	57 b	12.25 b	5.20 a	0.497 b
Fertilizer broadcasting in conventional planting	87.34 a	24.10 b	102 a	16.21 a	4.92 a	0.47 b
LSD at 5%	2.910	1.507	2.618	2.364	0.190	0.013
Level of significance	n.s.	n.s.	**	*	n.s.	n.s.

Note: LSD means least significant difference. Where n.s.,* and ** represent probability of >0.05, ≤0.001, and ≤0.01, respectively. Values were means of three replicates.

3.2.2 Panicle length

Panicle length was not significantly affected by planting methods. It was observed that the fertigation in bed planting produced longer panicles compared to conventional planting (Table 4). Panicles of shorter length were found in conventional planting than fertigation in bed planting. Longer panicle length might be matched up to a higher number of grains per panicle in the fertigation of bed planting treatment.

3.2.3 Non-bearing tiller

Planting methods influenced the number of non-bearing tillers of transplanted boro rice. The number of non-bearing tillers per square meter was significantly lower in fertigation of raised bed planting than the conventional planting method (Table 4).

3.2.4 Sterility

Influence of planting methods on sterility of transplanted boro rice is presented in Table 4. It was revealed that fertigation in bed planting significantly ($P\leq0.01$) reduced the sterility percentage. The lower sterility in fertigation of bed planting might be a cause of a high number of grains per panicle.

3.2.5 Straw yield

The straw yield of transplanted boro rice was not significantly different between fertigation in bed planting and conventional planting (Table 4). The higher straw yield was found in fertigation of raised bed planting compared to fertilizer broadcast in conventional planting. The higher number of panicles per square meter might be responsible for higher straw yield in fertigation of raised bed planting.

3.2.6 Harvest index

Planting methods did not significantly influenced the harvest index of transplanted boro rice. Harvest index was increased by 5.43% at fertigation in bed planting over conventional planting (Table 4). The lower harvest index in the conventional planting than fertigation in bed planting may be the result of lower grain yield and straw yield.

3.3 Tiller production

Different planting methods of transplanted boro rice affected the number of tillers per square meter. At the start (20 days after transplanting), the number of tillers per square meter was higher in conventional planting than fertigation in bed planting (Table 5). However, at final counting (the 100th day) fertigation in bed planting produced a higher number of tiller per square meter than conventional planting. Likewise, in fertigation with raised bed planting, the highest tiller production was observed 40 days after transplanting (DAT). After 40 days, the number of tiller was started to decline and continued to the 100th day. Similarly, in conventional planting method the highest number of tillers per square meter was recorded at the 40th day. The results pointed out that the number of tillers per square meter for both treatments were highest at the 40th day after transplanting and after that started to decrease due to death of some tertiary tillers, which continued up to maturity.

Table 5 Effect on tiller production by fertigation in raised bed and fertilizer broadcasting in conventional planting

Method of fertilizer application	Tiller (number·m^{-2}) at DAT								
	20	30	40	50	60	70	80	90	100
Fertigation in bed planting	61b	205a	224b	203a	162b	157a	148b	145c	141a
Fertilizer broadcasting in conventional planting	76a	209a	240b	200a	162b	149b	141b	139c	135a
LSD at 5%	2.069	4.984	13.08	9.662	8.738	2.618	9.438	10.347	10.35
Level of significance	**	n.s.	n.s.	n.s.	n.s.	**	n.s.	n.s.	n.s.

Note: LSD means least significant difference. Where n.s., and ** represent probability of >0.05 and ≤0.01, respectively. Values were means of three replicates.

3.4 Leaf area index

The leaf area index of transplanted boro rice was measured at different DAT varied by the fertigation and conventional planting. At early stage (20 DAT), the conventional planting resulted higher leaf area index than fertigation in bed planting (Table 6). However, at maturity stage (100 DAT) fertigation in bed planting gave higher leaf area index than conventional planting. The highest leaf area index was found by fertigation in bed planting at 60 DAT. On the other hand, the highest leaf area index was found in conventional planting at 80 DAT.

Table 6 Effect on leaf area index by fertigation in raised bed and fertilizer broadcasting in conventional planting

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

Note: LSD means least significant difference. Where n.s., and ** represent probability of >0.05, and ≤0.01, respectively. Values were means of three replicates.

3.5 Dry matter production

The planting method significantly affected dry matter production of transplanted boro rice at different DAT. At 20 DAT conventional planting produced significantly higher dry matter than fertigation in bed planting (Table 7). After 20 DAT fertigation in bed planting gave significantly higher dry matter production (except 50 DAT) up to 90 DAT than conventional planting. The highest dry matter production was found in fertigation at 90 DAT. Similarly, in the conventional planting method the highest dry matter production was found at 90 DAT.

Table 7 Effect on dry matter production by fertigation in raised bed and fertilizer broadcasting in conventional planting

Method of fertilizer application	Dry matter production ($g\cdot m^{-2}$) at different DAT							
	20	30	40	50	60	70	80	90
Fertigation in bed planting	56b	225b	502a	621b	913a	1057a	1294a	1312a
Fertilizer broadcasting in conventional planting	61a	257a	492b	619b	903b	1049b	1282b	1294b
LSD at 5%	2.62	4.98	2.62	9.30	3.93	2.42	4.14	11.71
Level of significance	*	**	**	n.s.	*	**	**	*

Note: LSD means least significant difference. Where n.s.,* and ** represent probability of >0.05, ≤0.001 and ≤0.01, respectively. Values were means of three replicates.

3.6 Crop growth rate

The crop growth rate of transplanted boro rice measured at different DAT was different between fertigation and conventional planting. At early stage (20-30 DAT) crop growth rate was significantly higher in conventional planting than fertigation in bed planting (Table 8). At maturity stage (80-90 DAT) the fertigaion in bed planting had significantly higher crop growth rate than conventional planting. The highest crop growth rate was found during 50-60 DAT by fertigaion in bed planting. Similarly, in the conventional planting method the highest crop growth rate was recorded during 50-60 DAT.

Table 8 Effect on crop growth rate by fertigation in raised bed and fertilizer broadcasting in conventional planting

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

Note: LSD means least significant difference. Where n.s.,* and ** represent probability of > 0.05, ≤ 0.001 and ≤ 0.01, respectively. Values were means of three replicates.

3.7 Weed vegetation

Weed population and dry biomass were greatly influenced by different planting methods of transplanted boro rice. Fertigation in the bed planting method reduced weed populations resulting in lower dry biomass than conventional planting. The conventional method had significantly ($P \le 0.01$) higher weed vegetation than fertigation in the raised bed method (Table 9).

3.8 Irrigation requirement

Different planting methods affected the irrigation water requirement. The total irrigation water required by fertigation in bed planting was 94.86 cm (Table 10). On the other hand the conventional method received 149.00 cm irrigation water. Result showed that the total water savings by fertigation in bed planting over conventional planting was 36.33%.

Table 9 Effect of weed growth by fertigation in raised bed and fertilizer broadcasting in conventional planting.

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

Note: LSD means least significant difference. Where * and ** represent probability of ≤0.001 and ≤0.01, respectively. Values were means of three replicates.

Table 10 Irrigation water savings by fertigation in raised bed and fertilizer broadcasting in conventional planting

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

Note: LSD means least significant difference. Where n.s., and ** represent probability of >0.05, and ≤0.01, respectively. Values were means of three replicates.

3.9 Water use efficiency

Water use efficiency for grain and biomass production by fertigation in bed planting was 54.29 and 109.10 kg/ha·cm, respectively (Table 11). In contrast, water use efficiencies for grain production and biomass production in conventional planting were 29.53 and 62.55 kg/ha·cm, respectively. However, water use efficiencies for grain production and biomass production by fertigation in bed planting were 83.81% and 74.44 % higher than those by conventional planting, respectively.

Table 11 Water use efficiency by fertigation in raised bed and fertilizer broadcasting in conventional planting

Method of fertilizer application	Water use efficiency saving by fertigation in bed planting and Fertilizer broadcasting in conventional planting	
	Water use efficiency for grain production /kg·ha^{-1}·cm^{-1}	Water use efficiency for biomass production /kg·ha^{-1}·cm^{-1}
Fertigation in bed planting	54.29a	109.10a
Fertilizer broadcasting in conventional planting	29.53b	62.55b
LSD at 5%	1.86	2.11
Level of significance	**	**

Note: LSD means least significant difference. Where, ** represents probability of ≤0.01. Values were means of three replicates.

3.10 Agronomic efficiency of N fertilizer

The agronomic efficiency of N fertilizer for fertigation in bed planting was 27.08% (Table 12).

Table 12 Agronomic efficiency of N fertilizer by fertigation in raised bed and fertilizer broadcasting in conventional planting

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

Note: LSD means least significant difference. Where, * represents probability of ≤0.01. Values were means of three replicates.

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

4 Discussion

4.1 Rice yield

Fertigation techniques facilitated higher grain yields of transplanted boro rice than the conventional cultivation method. The boro rice yield for the fertigation technique in raised bed planting was 5.15 t/ha, whereas boro rice yield for fertilizer broadcasting in the conventional cultivation method was 4.40 t/ha (Table 3). We also found that yield components including the number of panicles per square meter, grains per panicle and 1000-grains weight were significantly (P>0.05) higher by fertigation in bed planting than fertilizer broadcasting in the conventional planting method. Therefore, fertigation in raised bed planting significantly increased rice yield compared to the fertilizer broadcasting in conventional planting. Bouyouscos[15] also found that rice yield under fertigation was 3.8 t/ha, whereas 3.1 t/ha for flooded irrigation. He speculated that keeping the soil wet alone and not providing standing water resulted in yields comparable or more than that in flooded (with standing water) condition. Likewise, Kumar et al.[16] found that soil application of fertilizer produced 4.163 t/ha grain yield of Rabi (winter) rice. On the other hand, fertigation in raised bed planting gave 4.338 t/ha rice yield of Rabi (winter) rice. This study revealed that higher grain yield by fertigation in bed planting over soil application of fertilizer due to higher number of productive tillers per hill. Similarly, Govindan and Grace[17] indicated that fertigation in the raised bed system accelerated the pace of rice production. They speculated that fertigation was an integrated approach to soil-water-plant nutrient management at the plant root zone. Fertigation is the direct application of water and nutrient to plants through irrigation system which increased rice production. Biswas[1] indicated that fertigation technique provided better yield and quality of products. He observed that fertigation allowed optimization of nutrient balance in soils by supplying nutrients directly to the effective root zones as per the requirement which might contribute to yield. International Rice Research Institute (IRRI) conducted a study to determine the most suitable time and the proper method of fertilizer application for rice cultivation. IRRI[18] proposed that fertigation was a tool that can increase rice yield. In addition, Sivanappan[19] reported that fertigation increased crop yield. He pointed out that fertigation was a useful technology by which inorganic fertilizer could be applied to crops through the drip irrigation system. Moreover, Anbumozhi[20] estimated that fertigation condition (9 cm) improved paddy yield compared to too shallow or too deep ponding water depth. Similarly, Ramasamy[21] stated that fertigation technology for rice cultivation in raised bed with furrow irrigation would be futuristic and have great impact on rice yield. Another study[22] found same results. They observed that fertigation treatments yielded higher than the flooded dry urea for rice cultivation.

We speculated that a higher number of panicles per square meter were in the fertigation treatment because fertilization with N resulted in more luxury consumption than with other nutrients that contribute to the healthy growth of rice plants. Higher 1000-grains weight in fertigation was possible since in the initial stage, a greater number of panicles may be developed due to urea application but due to the excessive number of panicles, only healthier and stronger panicles could survive. Less healthy or strong panicles would diminish due to their weak structure or other factors. Our speculation was that the increase in grain yield by fertigation might be attributed to a higher level of N utilization in the plant system, hence more intense chlorophyll synthesis and more efficient translocation of assimilates to reproductive parts. We observed that in fertigation nutrients are placed at very low concentrations through water and move down into the lower soil layers where the absorptive roots exist and may contribute to grain yield. We also speculated that in fertigation plant enjoys continuous nutrition because nutrients are directed to the active root zone which enables optimal match between plant requirements and nutrients supply. This may be another cause of higher boro rice yield in fertigation than the conventional cultivation method. Fertigation was shown to enhance overall root activity, improve the mobility of nutritive elements and their uptake, as well as increased yield of boro rice. We also observed that higher yield in the fertigation treatment than conventional planting may be obtained by the supply of nitrogen at each growing stage of boro rice. Under the conventional fertilization method, plant nitrogen at every sensitive stage may cause decrease in the yield of rice.

4.2 Rice growth attributes

Fertigation in bed planting has a greater effect on growth parameters of transplanted boro rice than conventional cultivation method (Table 4). Our findings revealed higher plant height, greater panicle length and better harvest index in fertigation under bed planting than conventional planting. Similar results were found in another study that fertigation in bed produced taller plant than soil application of fertilizer as it was estimated that plant height of rice was 96.4 cm under fertigation and 84.3 cm under soil application of fertilizer[16]. The same study speculated that plant height was high in the fertigated plots due to higher uptake of nutrient from the fertilizers. Likewise, reported that urea fertigation produced plant height of 78.33 cm and 43.33 cm by control[23]. Similarly, Taha et al. found that fertigation improves plant growth parameters[24]. They speculated that fertigation enhanced nutrient uptake and limits nutrient losses which may contributed to better growth attribute. Higher number of tillers per square meter was observed with fertigation and broadcasting fertilizer in conventional planting produced fewer tillers per square meter (Table 5). Fertilizer application practice showed varied response in vegetative and reproductive characteristics. The significant effect of fertigation in bed planting was observed in non-bearing tiller and sterility percentage over conventional planting (Table 4). Other growth parameters measured, including plant height, panicle length, straw yield and harvest index in conventional planting, were not different under fertigation and conventional irrigation conditions. The dry matter production at the early growth stage in the conventional planting was higher, but significantly ($P \geq 0.05$) lower than that from the fertigation in bed planting at maturity (Table 7). This indicates that infiltration irrigation had better gas exchange and higher temperature, which facilitated root growth and longevity.

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

4.3 Water use efficiency

Fertigation in bed planting had favorable and marked influence on water use efficiency (WUE) of transplanted boro rice. Our findings revealed that fertigation in bed planting provided significantly higher WUE efficiency (54.29 kg/ha·cm) than conventional cultivation method. The lower WUE of 29.53 kg/ha·cm was observed on fertilizer broadcasting in conventional planting (Table 11). Similarly, Kuma et al. estimated that WUE in fertigation was 6.04 kg/ha·mm and 6.04 kg/ha·mm under soil application of fertilizer[16]. They stated that higher quantity of irrigation water saving coupled with higher water and nutrient use efficiencies indicated the practical feasibility of adopting fertigation for sustainable rice production. Higher consumptive use of water up to 149 cm was registered in fertilizer broadcasting of conventional planting than fertigation in bed planting. The low consumptive use of water at 94.86 cm was observed under fertigation in bed planting (Table 10). Our study revealed that fertigation in bed planting saved 36.33% irrigation water compared to the conventional planting method (Table 10). Likewise, Soman found that fertigation technique consume irrigation water of 3.2 million litre/ac for rice production. Flood irrigation consumes 9.5 million litre/ac irrigation water[15]. So, fertigation saved 50.79% water compared to flood irrigation in conventional planting. Regardless of that, it was stated that fertigation technique for rice cultivation saved water use by 50% than conventional planting[25]. In addition, Govindan stated that fertigation in raised bed was a water saving irrigation technique that required less irrigation water for the same yield than the traditional method for rice cultivation[17].

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

4.4 Weed vegetation

Substantial differences were observed in the weed vegetation per square meter under the conditions of fertigation in raised bed and conventional planting (Table 9). Higher weed vegetation was observed in the conventional fertilizer broadcast. Low weed vegetation was observed in fertigation on raised bed planting (Table 9). Similarly, Kafkafi et al. found that fertigation decreased weed infestation[26]. He stated that fertigation was able to reduced fluctuation of nutrient concentration in the soil, which might cause less weed infestation. Likewise, Soman demonstrated that weeds in fertigation could be managed and reduced easier than in conventional flood planting[15]. He also speculated that weeds in the fertigation system may be controlled by mulching the seedbed with rice husk at planting and manual weeding or by minimum herbicide application. Moreover, Haifa Group reported that fertigation reduced weed population[27]. They speculated that fertigation enabled optimal match between plant requirements and nutrients supply which facilitated better crop plant growth relative to weeds. Our study also revealed that conventional fertilizer broadcast produced significantly higher dry biomass of weeds than the fertigation treatment (Table 9). Similarly, Mollah found lower weed dry biomass in raised bed than conventional planting[28], which might be due to the dry top surface of beds that inhibited the weed growth. In addition, Ram et al. also found that lower weed biomass in raised beds than the conventional planting[29].

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

4.5 Agronomic efficiency of N

Agronomic efficiency was significantly affected by N placement methods of transplanted boro rice (Table 12). Higher agronomic efficiency of N was found on fertigation in raised bed planting. Our study revealed that agronomic efficiency of N was 27.08% in raised bed planting and 22.56 % for conventional planting (Table 12). Similarly, Mollah et al. found that agronomic efficiency of N was 27 kg grain/kg N in raised bed planting and 17.5 kg grain/kg N for conventional flat planting[30]. They revealed that the bed planting system could use N more efficiently and thus have higher agronomic efficiency of N than the conventional method. Statistically, lower agronomic efficiency of N was found with conventional fertilizer broadcast (Table 12). Similarly, Qin et al. found lower agronomic N use efficiency (AE_N) at 12.5 kg grain/kg N in farm practice fertilizer (FFP)[31], demonstrating that earlier application of high N rate of farm practice fertilizer (FFP) led to low agronomic N use efficiency. We also observed that fertigation in bed planting enhanced agronomic efficiency of N than fertilizer broadcast in conventional planting (Table 12). Likewise, Biswas reported that the fertigation system provided higher fertilizer use efficiency[1]. He speculated that increased fertilizer use efficiency in fertigation due to improved availability of nutrients and their uptake by crops. Moreover, Rajput showed that nitrogen use efficiency in fertigation was 95% whereas broadcast fertilizer produced 40%[32]. He speculated that higher nitrogen use efficiency in fertigation over broadcast fertilizer due to proper dose and time of fertilizer application. In addition, Kafkafi indicated that the fertigation technique improve fertilizer use efficiency[26]. He demonstrated that in the fertigation system nutrients are applied only to the active root zone, which reduced losses of nutrients through leaching or soil fixation and enhanced fertilizer use efficiency.

We speculated that fertigation provided an opportunity to use nutrients more efficiently through better timing and placement. In fertigation, synchronizing fertilizer N application to rice with crop N demand can result in reduction of N losses and increase in agronomic efficiency of N. In the conventional planting method, nitrogen is applied too early, holding the risk of losing it through leaching before the crop could take up, especially during rains. The best approach, in such cases is to split the nitrogen application with fertigation, where most of the nitrogen fertilizer is applied just before the crop's maximum demand. We revealed that the lower agronomic efficiency of N in conventional planting was because the applied nutrients could not be fully utilized by plant roots as they moved laterally over long distances. Fertigation can improve N utilization and there are reduced losses through nitrate leaching. At the same time plants take up more N by fertigation than broadcast and the uptake of nutrients is also enhanced agronomic efficiency of N. In addition, fertigation was shown to enhance overall root activity, improve the mobility of nutritive elements and their uptake. The fertigation technique is used mainly with N fertilizer. We suggested that in fertigation systems, the best practice would be to frequently apply small amounts of N fertilizer to meet real-time crop requirements.

5 Conclusions

This research demonstrated that fertigation with bed planting increased grain yield by 17.04% for boro (winter, irrigated) rice compared to fertilizer broadcasting with the conventional planting method. Fertigation in raised bed produced a higher number of panicles per unit area, a higher number of grains per panicle and greater 1 000-grain weight for transplanted boro rice which ultimately gave a higher grain yield than the conventional fertilizer broadcasting. This study also concluded that fertigation in raised bed planting proved more beneficial than conventional planting, especially with respect to grain yield, yield attributes, agronomic efficiency of N and water use efficiency. Fertigation in raised bed planting is considered the most effective method to decrease N losses and thereby to increase fertilizer use efficiency. Compared to conventional fertilizer broadcasting, fertigation in raised bed planting saved irrigation water by 36.33% and increased irrigation efficiency. Bed planting with fertigation provided less weed density and lower dry biomass than the conventional cultivation method. These findings conclude that water use efficiency for grain and biomass production was higher in fertigation with bed planting than fertilizer broadcasting of the conventional method. The agronomic efficiency of N fertilizer was also significantly higher in fertigation of bed planting than the conventional way.

It was found from our previous study that fertigation in the bed planting system for transplanted aman (summer, no irrigated) rice achieved higher yield than fertilizer broadcasting in the conventional flat method. The potential gains from growing boro rice on raised bed planting with fertigation are considered to be associated with better agronomic management than fertilizer broadcasting in the conventional method. It is likely that the raised bed planting will have long term soil physical benefits without sacrificing yield. The boro rice-based farming system that incorporated fertigation in raised bed planting offers many advantages. Based on the findings of this experiment, high yielding boro rice (winter, irrigated) crops have been successfully grown using fertigation with raised bed planting. There is a good prospect of utilizing this technology to benefit rice farmers. More studies are needed to fully establish bed planting with fertigation, a better planting method for boro rice cultivation in Bangladesh as well as other countries in the world.

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