Impact of Split Foliar Nitrogen Application on Water Use Efficiency and Productivity of Boro Rice in Raised Bed over Conventional Method

M.H.M. Bhuyan[1], M.R. Ferdousi[2] and M.T. Iqbal[1]*

[1]*Department of Agronomy and Agricultural Extension, University of Rajshahi, Rajshahi 6205, Bangladesh*
[2]*Islamia Academy High School & Agriculture College, Bagha, Rajshahi 6280, Bangladesh*

**Corresponding author, Email: toufiq_iqbal@yahoo.com*

Abstract

Introduction of raised bed cultivation system for boro rice production is a major concern now days. A field experiment compared between two cultivation methods: boro (winter, irrigated) rice on raised beds with split foliar spray of N fertilizer and fertilizer broadcasting in conventional planting was conducted in Chuadanga district of Bangladesh. Result showed that foliar spray in raised bed increased grain yield of transplanted boro rice up to 19.54% over conventional planting. Split foliar spray of N fertilizer in raised bed planting increased the number of panicle m^{-2}, number of grains $panicle^{-1}$ and 1000-grain weight of rice over those from the conventional planting method. Better plant growth attribute was observed by foliar spray of N fertilizer in raised bed planting compared to conventional planting. Sterility percentage and weed infestation were lower on foliar spray in raised bed than the conventional planting method. About 40.14% irrigation water and time for application could be saved by foliar spray in raised bed compared to conventional planting. Water use efficiency for grain and biomass production was higher by foliar spray of N in bed planting than the fertilizer broadcasting in conventional method. Similarly, agronomic efficiency of N fertilizer in bed planting was higher than the fertilizer broadcasting in conventional planting. This study concluded that split foliar spray of N fertilizer in raised bed for boro rice is a new approach to get fertilizer and water use efficiency as well as higher yield and less water input compared to conventional cultivation method.

Keywords: split foliar of nitrogen fertilizer application, water use efficiency, agronomic efficiency

Introduction

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

The furrow irrigated raised bed planting system in which crops are sown on ridge or beds .The height of the bed is maintained at about 15 to 20 cm and having a width of about 40 to 70 cm depending on the crops. The furrow width is generally 25 cm. Potential agronomic advantages of beds include improved soil structure due to reduced compaction through controlled trafficking, and reduced water logging and timely machinery operations due to better surface drainage. Beds also provide the opportunity for mechanical weed control and improved fertilizer placement.

Balasubramanian et al. (2003) and Hobbs and Gupta (2003) reported yield of rice transplanted or direct seeded on beds was plus/minus 5-6% of that of puddle transplanted rice, while irrigation water savings averaged about 37-40%. Kukul et al. (2005), however, reported yield reductions of up to 50% and more of rice grown on raised beds compared with puddle transplanted rice. Farmer and researcher trials in the Indo-Gangetic plains suggest irrigation water savings of 12–60% for direct-seeded and transplanted rice on beds, with similar or lower yields for transplanted compared with puddle flooded transplanted rice, and usually slightly lower yields with direct seeded rice (Balasubramanian et al., 2003; Gupta et al., 2003; Hossain et al., 2003; Jehangir et al., 2002*)*.

However, many studies in the northwest Indo-Gangetic plains indicate little effect of rice on beds on water productivity (typically around 0.30–0.35 g kg^{-1}) as the decline in water input was accompanied by a similar decline in yield (Jehangir et al., 2002; Sharma et al., 2003; Singh et al., 2003). Studies in the USA have also shown considerable water savings with furrow-irrigated rice on beds (Tracy et al., 1993; Vories et al., 2002*)*.The raised bed treatment used up to 32% less water than paddy with permanently flooded. Ockerby (1995) grew a commercial rice crop on raised bed using continuous furrow irrigation to form a constant water table 0.13 m below the soil surface. The crop yielded 6.7 t ha^{-1}. Beecher et al. (2006) reported no water saving from the raised bed rice cultivation compared with conventional ponded rice grown on a flat layout. It is also unclear whether the yield of rice crops grown on raised bed has been limited by insufficient crop nitrogen (N). Whereas N supply and uptake of N by paddy rice is well understood, the N transformations in the raised bed system will be complex due to water and N fluxes between the flooded and oxidized soil layers, and these have yet to be studied. Similarly, cultivar traits that may promote yield on raised beds in response to the water and N have not been identified. Our previous study showed that foliar spray of nitrogen fertilizer on raised bed increases yield of transplanted aman rice over conventional method (Bhuyan et al., 2012b). Likewise, another study showed that water use efficiency and grain production werehigher in fertilizer broadcasting on raised bed than fertilizer broadcasting in conventional planting for aman rice (Bhuyan et al., 2012a).However, it was not considered for boro (winter, irrigated) rice with foliar spray of N in raised bed thanfertilizer broadcasting in conventional method. Therefore, this study was undertaken todetermine the effect of foliar spray of N on raised bed than fertilizer broadcasting in conventional planting for boro rice production. It will be hypothesized that foliar spray of N on raised bed receives higher yield and less water inputs than conventional flat planting.

Materials and Methods

Location and Climatic Condition of the Experimental Site

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

Soil Conditions of the Experimental Site

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

Foliar Nitrogen (Urea) Application Pattern

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

Fertilizer Broadcasting in Conventional Planting

The crop was fertilized with N, P, K, S, and Zn at the rates of 120, 14, 36, 8, and 1 kg ha^{-1}, respectively. The sources of N, P, K, S, and Zn were urea, TSP, MP, gypsum, and $ZnSO_4$, respectively. All of the TSP, MP, gypsum, and $ZnSO_4$ were applied at the time of final land preparation as basal dose in the plots with conventional planting. The urea was top dressed in three equal splits at 15, 30, and 50 days after transplanting (DAT) in conventional planting. Fertilizer application pattern is described below in Table 3.

Table 1 Soil physical and chemical properties.

Location	Chuadanga
Season	Boro
Soil type	Silt loam
pH	7.3
Organic carbon (%)	0.88
Total N (%)	0.11
Available P (mg kg^{-1})	5.68
Exchangeable K (cmol kg^{-1})	0.15
Available S (mg kg^{-1})	12.1
Available Zn (mg kg^{-1})	0.22

Experiment Details

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

Observations Undertaken

Ten randomly selected and tagged plants were used for the measurement of plant height at an interval of 15 days from 15^{th} day after transplanting and ending with just flowering. It was measured from base to tip of the upper most leaves of the main stem. Number of tillers per plant was counted from one meter row length. Leaf area (cm^2) of the functional leaves obtained from samples drawn for dry matter accumulation study was measured by automatic leaf area meter. The effective tiller per row length was recorded just before harvesting the crop and the average values was used to obtain the effective panicles per meter row length. The length of panicle was taken from the 10 panicles from each plot which were randomly selected just before harvesting and mean were calculated.

Table 2 Treatment details for foliar spray in raised bed.

Treatment details	Basal fertilizer application	Spray 1	Spray 2	Spray 3	Total N,P,K,S (kg ha^{-1})
Foliar spray in bed planting	Whole rate of P, K, gypsum and $ZnSo_4$ applied before transplanting on top of the beds	2 % urea at 15 DAT	2 % urea at 30 DAT	2 % urea at 50 DAT	N=30 P=14, K=36 S=8, Zn=1.0

Table 3 Treatment details for conventional planting.

Treatment details	Basal fertilizer application	Split 1	Split 2	Split 3	Total N, P, K, S (kg ha^{-1})
Fertilizer broadcasting in conventional planting	Whole rate of P, K, gypsum and $ZnSo_4$ were applied at the final land preparation.	1/3 of urea at 15 DAT	2/3 of urea at 30 DAT	Rest amount of urea at 50 DAT	N=120, P=14 K=36, S=8 Zn=1

Number of filled and unfilled grains was counted to determine the number of grains per panicle. Thousand grains were counted from the grain yield of each plot and weighed using automatic electronic balance. Biomass yield and grain yield were taken at harvesting from each plot. All the plants from 1 m length were uprooted and weighed to determine the total biomass yield. Digital grain moisture meter was used to record the moisture of the grain. Harvest index (HI) was computed by dividing grain yield with the total dry matter yield.

Irrigation Water Measurements

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

Amount of water applied per plot = Volume of water pan (L) × Time required to irrigate the plot (sec) / Time required to fill the water pan (sec)

Water Use and Agronomic Efficiency Calculation

Water use efficiency for grain production (kg $ha^{-1}cm^{-1}$) = grain yield (kg ha^{-1})/total water required (cm)

Water use efficiency for biomass production (kg $ha^{-1}cm^{-1}$)= [grain yield (kg ha^{-1}) + straw yield (kg ha^{-1})]/ total water required (cm)

Agronomic efficiency (AE) of N fertilizer

AE= GYNA-GYN0/NR

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

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

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

Data Analysis

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 and simple calculation, presentation of table for different comparisons.

Results

Yield Contributing Parameters

Number of panicle per m^2

The number of panicles per m^2 increased with foliar N fertilization. However, the number of panicles per m^2 significantly lowers in fertilizer broadcasting in conventional planting method (Table 4). The increased in the panicle per m^{2}may be attributed due to higher availability of nutrients by foliar spray of urea in raised bed as compared to fertilizer broadcasting in conventional planting. This might have facilitated better utilization of resources by the plants converting majority of the tillers into productive tillers or panicles.

Number of grains per panicle

Perusal of the data revealed significant effect of foliar application of nitrogen on number of grains per panicle (Table 4). Maximum number of grains per panicle was produced by foliar application of N in bed compared to conventional flat planting. This could be attributed to the fact that application of macronutrients may have improved the photosynthetic ability of crop thereby more food material synthesized contributed to the improvement in number of grains per panicle.

Thousand grains weight

Analysis of the data revealed that foliar application of nitrogen solution resulted higher in thousand grains weight (Table 4). This may be due to the foliar application of macro nutrients might have enhanced accumulation of assimilate in the grains and thus resulting in heavier grains of rice. The increase in 1000 grain weight by foliar spray in bed could be attributed to the fact that application of macronutrients may have improved the photosynthesis thus, more food material synthesized contributed to the improvement in 1000 grain weight compared to conventional flat planting.

Grain yield

Planting method had significant effects on grain yield. Grain yield showed a significant response to nitrogen fertilization method (Table 4). Maximum yield was obtained with the foliar nitrogen application on raised bed compared to fertilizer broadcasting in conventional flat method. The lower grain yield obtained by fertilizer broadcasting in conventional flat method. Therefore, the lower yields in conventional planting would be explained by its lower panicle density. Comparatively lower grain yield obtained with conventional flat method could be attributed to poor nutrition to the crop because of insufficient nitrogen uptake.

Growth characters

Plant height

Plant height did not significantly ($P > 0.05$) differ between foliar split nitrogen fertilizer in raised bed and fertilizer broadcasting in conventional planting (Table 5).

Panicle length

Foliar spraying of nitrogen in raised bed increased panicle length by 6.72% compared with fertilizer broadcasting in conventional planting (Table 5). Foliar spraying after transplanting in raised bed enhanced rice plant to higher photosynthesis rate which contributed to higher panicle length. This longer panicle in bed planting might helped in producing higher number of grain per panicle.

Spikelet sterility

Spikelet sterility significantly increased with fertilizer broadcasting in conventional planting compared to foliar spray of nitrogen in bed planting (Table 5). The percentage of filled spikelet was higher by foliar spray of nitrogen in bed planting. The lower sterility in bed might be higher grains per panicle, which directly added to the grain yield.

Straw yield

Foliar spray of nitrogen in raised bed registered significantly higher straw yield compared with fertilizer broadcasting in conventional planting (Table 5). Foliar spray in bed planting provided sufficient nutrient for vegetative growth and also for the reproductive phase which ultimately leads to increased straw yield. Our interpretation is that foliar spray of urea in bed increased the straw yield over conventional planting which might have been due to the effect of roots thereby increasing uptake nutrients from soil ultimately enhancing the vegetative growth.

Table 4 Grain yield and yield components with respect to foliar spray in raised bed and fertilizer broadcasting in conventional planting

Method of Fertilizer application	Yield and yield components			
	panicles (No. m^{-2})	Grains (No panicle^{-1})	1000 grain wt . (g)	Grain yield (t ha^{-1})
Foliar spray in bed planting	470a	128a	25a	5.26a
Fertilizer broadcasting in conventional planting	430b	106b	21.00a	4.40b
LSD at 5%	5.40	3.34	2.93	0.44
Level of significance	**	**	n.s.	*

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

Table 5 Plant biomass with respect to foliar spray in raised bed and fertilizer broadcasting in conventional planting

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

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

Harvest index

Harvest index tended to be higher in foliar spray of nitrogen in bed planting than in conventional method (Table 5). These higher and lower harvest indexes were resulted due to higher and lower grain yield.

Tiller production

Transplanting of Boro rice under different planting method affected the number of tillers per $m^2$of rice. The increasing trend of tiller per m^2 was continued to 40 DAT. At 40 DAT both planting method attained the highest number of tiller per m and then started declining up to 100 DAT. However, both planting method differed significantly ($P \leq 0.01$) from 20 to 100 days after transplanting except 40 and 50 DAT (Table 6). The higher number of tillers per m^2 (147) of rice at maturity was observed from foliar spray of N in bed and the lower (135) in case of fertilizer broadcasting in conventional planting.

Leaf area index

The observed result for foliar spray in bed showed that the leaf area index increased from 20 DAT to 60 DAT and declined towards maturity mainly due to leaf senescence (Table 7). It was observed that the response of LAI on fertilizer broadcasting in conventional planting increased from 20 DAT to 80 DAT and declined towards maturity.

The highest leaf area index was achieved at 60 DAT by foliar spray in bed planting method. After 60 DAT the leaf area index started to decline and continued to 100 DAT by foliar spray. The higher LAI achieved in conventional method at 80 DAT. After 80 DAT the LAI started to decline and continued to 100 DAT by conventional method. However, LAI differs significantly ($P \leq 0.01$) between two methods from 60 to 100 DAT.

Table 6 Effect of tiller production by foliar spray in raised bed and fertilizer broadcasting in conventional planting

Method of Fertilizer application	Tiller (No. m^{-2}) at days after transplanting								
	20	30	40	50	60	70	80	90	100
Foliar spray in bed planting	82a	216a	251a	214a	173a	162a	153a	149a	147a
Fertilizer broadcasting in conventional planting	76b	209b	240a	200a	162b	149b	141b	139b	135b
LSD at 5%	2.07	3.82	10.35	51.87	3.34	2.07	2.93	2.07	4.72
Level of significance	**	*	n.s.	n.s.	**	**	**	**	*

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

Table 7 Effect of leaf area index by foliar spray in raised bed and fertilizer broadcasting in conventional planting

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

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

Dry matter production

Dry matter production (DMP) had a significant response to nitrogen fertilization. In the first date of measurement (20 DAT), it was observed that the foliar spray of urea produced higher dry matter yield than conventional method (Table 8). Likewise, at the final date (100 DAT), higher dry matter production was also recorded in foliar spray in bed compared to conventional method. However, dry matter production differs significantly (*P* ≤ 0.01) at different days after transplanting (DAT) in both planting method (Table 8). Fertilizer broadcasting in conventional planting had lower dry matter production than foliar spray of nitrogen in bed, which could be due to its lower density of tillers and panicles. Variation in DMP at particular stage due to varying water availability resulted in poor yield components and yield.

Dry matter production

Dry matter production (DMP) had a significant response to nitrogen fertilization. In the first date of measurement (20 DAT), it was observed that the foliar spray of urea produced higher dry matter yield than conventional method (Table 8). Likewise, at the final date (100 DAT), higher dry matter production was also recorded in foliar spray in bed compared to conventional method. However, dry matter production differs significantly (*P* ≤ 0.01) at different days after transplanting (DAT) in both planting method (Table 8). Fertilizer broadcasting in conventional planting had lower dry matter production than foliar spray of nitrogen in bed, which could be due to its lower density of tillers and panicles. Variation in DMP at particular stage due to varying water availability resulted in poor yield components and yield.

Crop growth rate

At the initial stage (20 to 40 DAT), the crop growth rate (CGR) by foliar spray in bed planting is lower than conventional method (Table 9). The higher crop growth rate was observed in 50-60 DAT by foliar spray in bed planting method. Similarly, higher crop growth rate was observed in 50-60 DAT by conventional flat planting. However, crop growth rate significantly (*P* ≤ 0.01) differed between both planting methods at all DAT except 40 to 50 DAT.

Weed population

Bed planting treatments significantly ($P \leq 0.01$) reduced the weed population per m^2 (Table 10) over the conventional planting method. Reduction (128% and 116.07% respectively) in weed density (number m^{-2}) and weed dry biomass (kg ha^{-1}) was recorded in foliar spray in bed compared with fertilizer broadcasting in conventional planting. Less weed population on raised beds because, without disturbance and with drier soil, few weeds would germinate or establish.

Irrigation water use

Amount of water required for different irrigations differed remarkably between the conventional and bed planting methods. The conventional method received the higher amount of water at every irrigation, and total amount was 149.00 cm (Table 11). The total amount of irrigation water received by foliar spray in bed planting was 106.37 cm. Result showed that total water saving by foliar spray in bed over conventional method was 40.14 %.

Table 8 Effect of dry matter production by foliar spray in raised bed and fertilizer broadcasting in conventional planting.

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

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

Table 9 Effect of crop growth rate by foliar spray in raised bed and fertilizer broadcasting in conventional planting

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

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

Table 10 Effect of weed growth by foliar spray in raised bed and fertilizer broadcasting in conventional planting

Method of Fertilizer application	Weed vegetation	
	Weed vegetation population (No. m^{-2})	Dry biomass (kg- ha^{-1})
Foliar spray in bed planting	170b	159.66b
Fertilizer broadcasting in conventional planting	389a	344.98a
LSD at 5%	3.34	2.49
Level of significance	**	**

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

Table 11 Irrigation water savings by foliar spray in raised bed and fertilizer broadcasting in conventional planting

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

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

Water use efficiency

Water use efficiency for grain and biomass production by foliar spray in bed planting was 50.90 kg ha^{-1} cm^{-1} and 99.13 kg ha^{-1} cm^{-1}, respectively (Table.12). In contrast, water use efficiency for grain production and biomass production in conventional planting was 29.53 kg ha^{-1} cm^{-1} and 62.55 kg ha^{-1} cm^{-1}, respectively. The water use efficiency for grain production in raised bed planting was 72.36% higher over conventional planting. Similarly, foliar spray in bed planting produced 58.48% more water use efficiency for biomass production compared to fertilizer broadcasting in conventional planting. The higher water use efficiency in bed planting due to higher grain yield and less water input.

Agronomic efficiency of nitrogen fertilizer

Agronomic efficiency (AE) of fertilizer nitrogen by foliar spray in raised bed was 94.40% (Table 13). On the other hand AE for conventional planting was 22.56 %. Agronomic efficiency of N fertilizer by foliar spray in raised bed was significantly ($P \leq 0.01$) higher than the conventional Planting method.

Discussion

Comparison of Growth Response of Transplanted Boro Rice between Foliar Spray in Raised Bed and Conventional Cultivation

The plant height at maturity tended to be higher in conventional planting compared to that in foliar spray in raised bed planting. Similar result was reported by Hasanuzzaman et al. (2009). They demonstrated that the lowest plant height with foliar spray of urea might be due to the reduced uptake of N through foliage. Alom et al. (2010) also reported same result. They showed that soil and foliar application of urea fertilizer produced plant height of 78.4 cm and 76.5 cm, respectively. They speculated that foliar spray of urea produced lower plant height due to poor performance of N compared to soil application of N fertilizer. Shafiee et al. (2013) differed with these results. They showed that foliar spray produced higher plant height. They stated that foliar fertilization may be increased the level of macro- and micro-nutrients in the leaf, thus it enhanced the net photosynthetic rate of treated rice plant which contributed to higher plant height.

The higher tiller production was observed by foliar spray in raised bed compared to conventional planting. Our results were supported by the findings of Shayganyet al. (2011). They reported that foliar application of different nutrient increased tiller number of rice plant. The panicle length , leaf area index and dry matter production was recorded 25.72 cm, 4.01 and 1315 g m^{-2} by foliar spray in bed planting and 24.10 cm, 3.85 and 1294 g m^{-2} for conventional planting. So, foliar spray in bed planting produced higher panicle length, leaf area index and dry matter than conventional planting. This findings supported by Zayed et al. (2011). They showed that panicle length, leaf area index and dry matter was 21.30 cm, 5.60 and 32.80 g $hill^{-1}$ in foliar spray and 19.35 cm, 4.72 and 26.57 g $hill^{-1}$ in control for rice production. They suggested that foliar spray of micronutrient improved rice growth parameters, as they encouraged rice plants to produce more dry matter as a result of increasing chlorophyll content and optimizing rice canopy with appropriate leaf area index.

Table 12 Water use efficiency by foliar spray in raised bed and fertilizer broadcasting in conventional planting

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

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

Table 13 Agronomic efficiency of fertilizer by foliar spray in raised bed and fertilizer broadcasting in conventional planting

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

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

In our study the biological yield was 10.51 t ha^{-1} by foliar spray in bed planting and 9.3 t ha^{-1} in conventional planting. So, foliar spray in bed planting produced 1.21 t ha^{-1} more biological yield than conventional planting. This result supported by Shaygany et al. (2012). They found that foliar spray produced higher biological yield. This findings also supported by Annadurai and Palaniappan (1994). They observed that 2% Di Ammonium Phosphate spray given more biological yield. Our speculation is that foliar fertilization provides more rapid utilization of nutrients and permits the correction of observed deficiencies in less time than would be required by soil application.

Foliar spray also reduced N losses through denitrification and leaching compared with N fertilizer applications to the soil, the ability to provide N when root activity is impaired. We also speculated that in foliar application, the nutrients penetrate the cuticle of the leaf or the stomata and then enter the cells. Hence, crop response occurs in short time in foliar application compared to soil application which may contributed to better crop growth response by foliar application of fertilizer.

Yield and Yield Components

Foliar spray of urea in raised bed significantly ($P<0.01$) increased grain yield compared to conventional planting (Table 1). Yield contributing parameter such as panicle m^{-2}, grain $panicle^{-1}$ and 1000-grain weight was also observed higher by foliar spray in raised bed planting over conventional planting (Table 1). Likewise, Shaygany et al. (2012) showed that a significant increased in number of panicle m^{-2}, 1000 grain weight, biological yield and grain yield with foliar application of nutrient. They concluded that five foliar applications of balanced amounts of fertilizers at the seedling stage (two sprays), tillering (single spray) and at panicle initiation and panicle differentiation (two sprays) helped in enhancing yield and yield components of rice.

Similar results had also been obtained by Badole et al. (1999) reported that the yield of rice increased significantly with the application of 50, 50 and 50 kg ha^{-1}(N:P:K) as a basal rate and foliar spray of urea at the three growth stages. This treatment also recorded the highest values of the yield attributing characters. They suggested that 2% urea 3 times at the tillering, panicle initiation and grain filling stages gave highest yield and yield components on transplanted rice. Similar findings regarding significant effect of foliar urea application have also been obtained by Duraisami et al. (2002). They demonstrated that urea foliar spray gave the highest chaff per panicle (12.4), harvest index (43.64%) and number of grains per panicle.They suggested that 100% P and K rates and 2.5% urea foliar spray at active tillering, panicle initiation, mid-heading, first flowering and 50% flowering stages provided better yield attributing parameters. Subramanianet al.(1980) reported that split foliar spray of N fertilizer significantly increased grain yield of transplanted rice. They speculated that 50% N in the soil at transplanting, 25% N as foliar spray at tillering and 25% N as foliar spray at panicle initiation gave higher yield over 90 kg N ha^{-1} in a single dose at transplanting .

Our speculation is that foliar spraying of urea after transplanting enhance rice plant to be more availability of N, increased photosynthesis rate and yield components of rice leading to high grain yield. Foliar application of macronutrients might raise dry matter transformation from store parts to sink part. It was observed that foliar application was effective in improving rice growth and subsequently main yield components such as filled grains per panicle, panicle weight and 1000-grain weight. We also speculated that at early growth stage when plant roots are not well developed, foliar fertilization is more advantageous in absorption compared to soil application. Soil application method is more common and most effective for nutrients, which required in higher amounts.

However, under certain circumstances, foliar fertilization is more economic and effective. Foliar nutrients are mobilized directly into plant leaves, which are the goal of fertilization to begin with, increasing the rate of photosynthesis in the leaves, and by doing so stimulate nutrient absorption by plant roots. Foliar feeding is an effective method for correcting soil deficiencies and overcoming the soil's inability to transfer nutrients to the plant under low moisture conditions. Foliar spray of nutrients should be avoided at high temperature during the day to avoid leaf burning. Similarly, windy days may drift the applied nutrient solution and rain immediately after application may washout the sprayed material and reduces its efficiency.

In contrast Alam et al. (2010) found that soil application of urea (282 kg urea ha^{-1}) and 2% foliar spray of urea produced grain yield 5.34 t ha^{-1} and5.04 t ha^{-1}, respectively. They also recorded that effective tiller hill^{-1} (number), grains panicle^{-1} (number) and 1000-grain weight (g) was 12.1, 134.4, 22.20 in soil application of urea and 10.0, 137.10 and 22.00 for foliar spray of urea, respectively. They suggested that 2% urea solution (92 kg N ha^{-1}) gave a statically comparable yield with soil application of 130 kg N ha^{-1}.When foliar spray is applied 38 kg N (82 kg urea) could be saved and it could be alternative of soil application.

Hasanuzzaman et al. (2009) also differed with our findings. They demonstrated that conventional urea application with 3 equal splits produced grain yield of transplanted boro rice 7.0 t ha^{-1} and 5.1 t ha^{-1} by foliar spray of urea. They also showed that panicle hill^{-1} (number), grains panicle^{-1} (number) and 1000-grain weight (g) was 8.1, 94.5 and 22.30 for conventional urea (200 kg ha^{-1}) at 3 equal splits and 6.9, 81.2 and 20.9 in 1% foliar spray of urea.

Variation between Conventional and Foliar Method in Relation to Water Use Efficiency

Total irrigation required by conventional planting was significantly (P< 0.05) higher over foliar spray in bed planting. Bed planting consumed 40.14% less water than conventional planting. Similarly, water use efficiency for grain production by foliar spray in bed planting was significantly (P < 0.05) higher over conventional planting. Water use efficiency for biomass production by foliar spray in bed planting was also significantly higher (P< 0.05) over conventional planting.

In our study water use efficiency was 29.53 kg ha^{-1}cm^{-1} for conventional transplanted rice. Jha et al. (1988) reported that water use efficiency was 2.53 kg ha^{-1}mm^{-1} for continuous flooding (7 cm water) rice cultivation. They suggested that scheduling 7 cm irrigation water 6 days after disappearance of water gave a net savings of 38-47 % irrigation water and 60 to 80 % increase in water use efficiency. Pathaket al. (2011) showed that water productivity was 0.40 kg grain m^{-3} for conventional puddle rice. They stated that transplanted rice with continuous standing water has relatively high water inputs which contributed low water productivity. Singh et al. (2006) found that water productivity for conventional puddle rice was 29 kg ha^{-1} cm^{-1}. They stated that if irrigation is applied one day after drainage or two days after drainage, precious water can be saved without any adverse impact in water productivity.

In our experiment water use efficiency was 50.90 kg ha^{-1} cm^{-1} in raised bed and 29.53 kg ha^{-1} cm^{-1} in conventional planting. So, raised bed increased water use efficiency by 72.36 % over conventional planting .This result supported by Tabbal et al. (2002). They showed that water productivity for transplanted rice in flooded condition was 1.06 g grain kg^{-1} water and 1.81 g grain kg^{-1} water for saturated soil condition (raised bed). Saturated soil condition increased water productivity by 70.75 % compared to conventional planting.

Kahlown et al. (2004) showed that water use efficiency in raised bed and traditional transplanting on puddle soil was 0.33 kg m^{-3} and 0.20 kg m^{-3}, respectively. Raised bed contributed 65% higher water use efficiency compared to conventional planting. They stated that if the furrows in bed planting refill with water, on the day after free water left the furrows. This change in irrigation practice almost doubled the water productivity. Bably et al. (2008) demonstrated that field water use efficiency in bed and traditional planting were 11.69 and 7.22 kg grain mm^{-1}, respectively. Bed planting method increased field water use efficiency by 65.8% more than traditional planting. They suggested that higher field water use efficiency in bed planting due to higher productivity of rice. But Kukul et al. (2010) differed with our findings. They demonstrated that puddle transplanted rice on sandy loam soil increased 11% irrigation water productivity than transplanted raised bed planting. Irrigation water productivity of transplanted rice on permanent beds decreased mainly due to declining grain yield as the beds aged. Cabangon et al. (2005) found that water productivity in bed (centre to centre spacing of 65 cm) was 0.65 kg m^{-3} and 0.45 kg m^{-3} for conventional flat planting. So, raised bed provided 44.45% more water productivity than conventional flat planting. They speculated that low water stress contributed higher water productivity in raised bed planting.

Our speculation is that the soil water of raised bed planting changes gradually, that is the ratio of gain and loss is balanced. The soil water of flat planting, however, changes more markedly and does not increase as much with increase in soil depth. Raised bed planting has the benefit of better distributing the limited water in the soil and thus creating a more stable soil water environment for the growing root system. We can conclude that an increase in water consumption led to a decrease in soil moisture in the flat planting, and that the range in soil water content of traditional flat planting is greater than that of raised bed planting which contributed to water use efficiency.

Foliar Split Urea Fertilizer Application on Raised Bed is Agronomical more Efficient than Conventional Flat Method

In our study the agronomic efficiency of N fertilizer by foliar spray in bed and conventional planting was 94.40% and 22.56%, respectively. The agronomic efficiency of N fertilizer of foliar spray in bed planting significantly (P< 0.05) increased over conventional planting. Agronomic efficiency for N fertilizer (120 kg ha^{-1}N) in conventional flat planting was 22.56 %. Similarly, Qin et al. (2012) found that agronomic N use efficiency (AE_N) in farm practice fertilizer (FFP) was 12.5. They demonstrated that earlier application of high N rate of farm practice fertilizer (FFP) led to low agronomic N use efficiency. Artacho et al. (2009) reported that agronomic N use efficiency for 150 kg ha^{-1} N was 24 kg kg^{-1} and 19 kg kg^{-1} in site 1 and site 2, respectively for flooded rice. They suggested that variation in agronomic N use efficiency between cropping sites, would reflect site specific difference in temperature and solar radiation.

Raun et al. *(*1999) supported our results. They stated that world nitrogen use efficiency (NUE) for cereal production is approximately 33 %. They suggested that increased cereal NUE is unlikely, unless asystems approach is implemented that uses varieties with high harvestindex, incorporated NH_4–N fertilizer, application of prescribed rates consistent with in-field variability using sensor-based systems within production fields, low N rates applied at flowering, and forage production system. They showed that total N applied 120 kg ha^{-1} in conventional planting rice gave agronomic efficiency of N was 21.0 kg grain kg^{-1} N^{-1}. FAO(2003c) reported that agronomic N use efficiency for rice in Bangladesh is low (35% and lower). These findings also similar to our results.FAO suggested that the enhancement of N use to medium levels, coupled with efficiency improvement measures, is important for the Bangladesh. In our research the agronomic efficiency of N was recorded 94.40% for foliar spray in bed and 22.56% for conventional planting. Alam et al. (2010) supported our findings. They demonstrated that agronomic efficiency of N was 80% in foliar application and 16.49% for soil application of urea fertilizer. They pointed out that the higher agronomic efficiency of N fertilizer in foliar application might be a lower level of nitrogen for a successful plant growth.

Our speculation is that the higher agronomic efficiency of N fertilizer by foliar spray in bed planting may be the immediate uptake of the nutrient applied which facilitated minimum loss due to leaching, deep percolation, denitrification and ammonia volatilization. Agronomic efficiency of N fertilizer may be improved by minimizing the fertilizer losses from the soil that are caused by poor water management, for example leaching or denitrification. The agronomic efficiency of N fertilizer can also be improved by ensuring that lack of water does not at any stage retard crop growth or nutrient uptake appreciably. Excess water can be a cause of nutrient losses, and insufficient water at a critical stage can limit growth and yield.

Conclusions

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

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

Acknowledgements

The authors are thankful to the farmer who leases his land for this experiment. The author also thanks to the pump operator for his kind help to irrigate the land. The authors are deeply indebted to the authorities of Bangladesh Rice research institute (BRRI), Local weather office, Chuadanga and seed processing unit, Bangladesh Agricultural Development Corporation (BADC), Chuadnaga for their assistance and constructive suggestion.

References

Alam, S.S., A.Z.M. Moslehuddin, M.R. Islam and A.M. Kamal. 2010. Soil and foliar application of nitrogen for Boro rice (BRRIdhan 29). J. Bangladesh Agric. Univ. 8: 199-202.

Annadurai, K.A and S.P. Palanniappan. 1994. Effect of phosphorus levels and DAP spray on low land rice yield. Madras Agric. J. 81: 633-634.

Bably, A.Z.E., M.E. Meleha, A.A.A. Allah and W.M. El-Khoby. 2008. Increasing rice productivity, water use efficiency, water saving and rice productivity in North Delta, Egypt. The 3rd International Conference on Water Resources and Arid Environments (2008) and the 1st Arab Water Forum.

Balasubramanian, V., J.K. Ladha, R.K. Gupta, R.K. Naresh, R.S. Mehla, R.S. Bijay-Singh and R.S. Yadvinder-Singh. 2003. Technology options for rice in the rice–wheat system in South Asia, pp. 1–25. In J.K. Ladha, J.E. Hill, J.M. Duxbury, R.K. Gupta and R.J. Buresh, eds, Improving the Productivity and Sustainability of Rice–Wheat Systems: Issues and Impacts. ASA Special Publication 65. SSSAInc., Madison, WI.

Beecher, H.G., B.W. Dunn, J.A. Thompson, E. Humphreys, S.K. Mathews and J. Timsina. 2006. Effect of raised beds, irrigation and nitrogen management on growth, water use and yield of rice in south-eastern Australia. Australian J. Experimental Agric. 46:1363-1372.

Bhuyan, M.H.M, M.R. Ferdousi and M.T. Iqbal. 2012a. Yield and growth response to transplanted aman rice under raised bed over conventional cultivation method. ISRN Agronomy (doi:10.5402/2012/646859).

Bhuyan, M.H.M, M.R. Ferdousi and M.T. Iqbal. 2012b. Foliar spray of nitrogen fertilizer on raised bed increases yield of transplanted aman rice over conventional method. ISRN Agronomy (doi:10.5402/ 2012/184953).

Badole, W.P. and A.H. Narkhede. 1999. Effect of concentration and time of foliar spray of urea on growth and economic yield of rice (*Oryza sativa*). Indian J. Agron. 44: 705-709.

BARC. 2005. Bangladesh Agricultural Research Council, Fertilizer Recommendation Guide. Ministry of Agriculture, Governments of the People's Republic of Bangladesh, Dhaka, Bangladesh.

Bouyouscos, G.J. 1962. Hydrometer method improved for making particle size analysis of soils. Agron. J. 54: 464-465.

Burkhardt, J., S. Dreitz, H.E. Goldbach and T. Eichert. 1999. Stomatal uptake as an important factor for foliar fertilization, pp. 63–72. In Technology and Application of Foliar Fertilizers: Proceedings of the Second International Workshop on Foliar Fertilization. Soil and Fertilizer Society of Thailand. Bangkok: Soil and Fertilizer Society of Thailand.

Cabangon, R.J and T.P. Tuong. 2005. Effect of water regime on grain yield, water input and water productivity of rice grown on raised beds. Presented in ACLAR Workshop on Permanent Bed Planting Systems. 1-3 Mar.2005. Griffith, NSW, Australia.

Duraisami, V.P. and A.K. Mani. 2002. Yield maximization and economics in rice grown during winter season under irrigated condition. Mysore J. Agric. Sci. 36: 212-217.

Eichert, T. and J. Burkhardt. 2001. Quantification of stomatal uptake of ionic solutes using a new model system. J. Experimental Bot. 52: 771–781.

Eichert, T., E.H. Goldbach and J. Burkhardt. 1998. Evidence for the uptake of large anions through stomatal pores. Botanica Acta 111: 461-466.

FAO, 2003. The State of Food Insecurity in the World 2003. Food and Agriculture Organization of the United Nations, Vialedelle Terme di Caracalla, Rome, Italy.

Gupta, R.K. and M.A. Gill. 2003. Reclamation and management of alkaline soil, pp. 199-204. In Addressing Resource Conservation Issues in Rice-Wheat Systems of South Asia: A Resource Book. Rice-Wheat Consortium for the Indo-Gangetic Plains Intl. Maize and Wheat Impr. Cent., New Delhi, India.

Gooding, M.J. and W.P. Davies. 1992. Foliar urea fertilization of cereals: A review. Fertilizer Research 32: 209–222.

Hobbs, P.R. and R.K. Gupta. 2003. Resource-conserving technologies for wheat in the rice-wheat system, pp. 149–171. In Improving Productivity and Sustainability of Rice-Wheat Systems: Issues andImpact. American Society of Agronomy Special Publication 65, American Society of Agronomy, Madison, Wi, USA.

Hossain, M.Z., S.M.A. Hossain, M.P. Anwar, M.R.A. Sarker and A.A. Mamun. 2003. Performance of BRRI Dhan 32 in SRI and Conventional Methods and Their Technology Mixes. Pakistan J. Agron. 2: 195-200.

Jha, K.P. and N. Sahoo. 1988. Influence of various water regimes on yield attributed of rice under Mahanadi delta condition. Oryza 25: 32-37.

Jehangir, W.A., H. Murrayy-Rust, I. Masihand K. Shimizu. 2002. Sustaining Crop and Water Productivity in the Irrigated Rice-Wheat System. Paper presented at, National Workshop on Rice –Wheat Cropping System Management, Pakistan Agricultural Research Council Rice-Wheat consortium for Indo-Gangetic Plains. December 11-12, 2002, Islamabad, Pakistan.

Jamal, Z., M. Hamayun, N. Ahmad and M.F.Chaudhary. 2006. Effect of soil and foliar application of different concentrations of NPK and foliar application of $(NH_4)_2SO_4$ on different parameters in wheat. J. Agron. 5: 251-256.

Kukal, S.S., Y. Singh. E. Humphreys, S.S. Dhillon and B. Singh. 2005. Soil water dynamics and crop performance in rice-wheat on permanent beds in Indo-Gangetic Plains of India. Presented in ACIAR Workshop on Permanent Bed Planting Systems. 1-3 Mar. 2005. Griffith, NSW, Australia.

Kukal, S.S., E. Humphreys, S. Yadav and Y. Singh. 2010. Irrigation water productivity of rice grown with resource conservation technologies. 19th World Congress of Soil Science, Soil Solutions for a Changing World 28, 1–6 August 2010, Brisbane, Australia. Published on DVD.

LI, D., T. Qi-yuan, Z. Yun-bo, Q. Jian-quan, L. Hu, C. Li-jun, Y. Sheng-hai, Z. Ying-bin and P. Shao-bing. 2012. Effect of nitrogen regimes on grain yield, nitrogen utilization, radiation use efficiency, and sheath blight disease intensity in super hybrid rice. J. Integrative Agric. 11: 134-143.

Mirza, H., K. Nahar, M.M. Alam, M.Z. Hossain and M.R. Islam. 2009. Response of transplanted rice to different application methods of urea fertilizer. Intern. J. Sustain. Agric. 1: 1-5.

Mohd, I.S., A.N. Boyce, M.M. Khandaker, J.M. Saad, T.A. Aziz, M.S. Mispana, M.S.M. Anuara and B.H. Bakar. 2013. Pilot studies on rice yield enhancement with foliar application of SBAJA in Sungai Besar, Selangor, Malaysia. Life Sci. J. 10: 329-335.

Muhammad, A.K. and A. Raoof. 2004. Efficient water application methods for growing paddy in the Indus basin. Innovative Technologies and Management for Water Saving in Agriculture.

Ockerby, S.E. 1995. On farm development of a tropical irrigated rice-soybean cropping system. Final report for the Rural Industries Research and Development Corporation and the Grains Research and Development Corporation. Queensland Department of Primary Industries, Mareeba, Qld (ISSN 0727-6281).

Pamela, A., C. Bonomelli and F. Meza.2009. Nitrogen application in irrigated rice grown in Mediterranean conditions: Effects on grain yield, dry matter production, nitrogen uptake, and nitrogen use efficiency. J. Plant Nutrition 32: 1574-1593.

Pathak, H. 2010. Mitigating greenhouse gas and nitrogen loss with improved fertilizer management in rice: quantification and economic assessment. Nutr. Cycl. Agroecosyst. 87:443-454.

Rhoades, J.D. 1982. Cation exchange capacity, pp. 149-158. In A L. Page, ed. Methods of Soil Analysis. Part 2. Chemical and microbiological properties. Am. Soc. of Agron., Madison, Wisconsin, USA.

Shaygany, J., P. Noura and G. Seyedhadi. Increased yield of direct seeded rice (*Oryza sativa* L.) by foliar fertilization through multi-component fertilizers. Archives Agron. Soil Sci. 58: 1091-1098.

Shayganya, J., N. Peivandy and S. Ghasemi. Increased yield of direct seeded rice (*Oryza sativa* L.) by foliar fertilization through multicomponent fertilizers. Archives Agron. Soil Sci.: 1-8.

Soltanpour, P.N. and S. Workman. 1979. Modification of the NH_4HCO_3 -DTPA soil test to omit carbon black. Commun. Soil Sci. Plant Analysis. 10: 1411-1420.

Sharma, P.K., J.K. Ladha and L. Bhushan. 2003. Soil physical effects of puddling in rice-wheat cropping systems. In Improving productivity and Sustainability of rice- wheat systems; Issues and impact. Amer. Soc. Agron. Spec. Publ. 65: 97-113.

Singh, G., Y. Singh, V.P. Singh, R.K. Singh, P. Singh, M. Mortimer, D.E. Johnson and A. Orr. 2003. Direct seeding as an alternative to transplanting rice for the rice-wheat systems of the Indo-Gangetic Plain: Sustainability issues related to weed management. British crop science congress.

Subramanian, S. and C.R. Venkataramanan. 1980. A note on the time and mode of nitrogen application to rice (IR 20). Madras Agri. J. 67: 546-547.

Tabbal, D.F., B.A.M. Bouman, S.I. Bhuiyan, E.B. Sibayan and M.A. Sattar 2002. On-farm strategies for reducing water input in irrigated rice: case studies in the Philippines. Agric. Water Manage. 56: 93-112.

Thind, H.S., Bijay-Singh, R.P.S. Pannu, Y. Singh, V. Singh, R.K. Gupta, M. Vashistha, J. Singh, A. Kumar. 2009. Relative performance of neem (Azadirachtaindica) coated urea vis-a`-vis ordinary urea applied to rice on the basis of soil test or following need based nitrogen management. Nutri. Cycl. Agroecosyst.

Tracy, P., B.D. Sims, S.G. Hefner and J.P.Cairns. 1993. Guidelines for Producing Rice using Furrow Irrigation. Department of Agronomy, University of Missouri, Columbia, USA.

Vories, E.D., P.A. Counce and T.C. Keisling. 2002. Comparison of flooded and furrow irrigated rice on clay. Irrigation Sci. 21: 139-144.

William, R.R. 1999. Improving nitrogen use efficiency for cereal production. Agron. J. 91: 357-363.

Zayed, B.A., A.K.M. Salem and H.M.E.Sharkawy.2011. Effect of different micronutrient treatments on rice (*Oryza sativa* L.) growth and yield under saline soil conditions. World J. Agri. Sci. 7: 179-184.

Manuscript received 15 May 2013, accepted 23 December 2015