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Double Transplanting of Dry Season Rice: A Unique Technology to Optimize Yield of Late Transplanted Rice in Northern Bangladesh

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ABSTRACT

In irrigated condition, double transplanting (DT) of dry season rice in Potato-Rice-Rice cropping pattern emerges as a promising technology to reduce yield losses associated with late-planted dry season rice. A consecutive three-year experiment encompassing three planting dates (20, 28 February and 08 March) and four seedling ages (45, 60, 75 days, and with 75-day for double transplanting- 35 days in the seedbed and 40 days in the first transplanted plot) was conducted to assess the performance of double-transplanted dry-season rice in comparison to conventional transplanting methods. Across the years, the grain yield of dry season rice exhibited a gradual decline with the advancement of planting time. However, the higher grain yield was consistently found from double transplanted dry season rice in all planting times. The yield advantage from double transplanting was 17%, 13%, and 16% for planting times on 20 February, 28 February, and 08 March, respectively compared to conventional transplanting. The system productivity of Potato-Double transplanted dry season rice-wet season rice cropping pattern was higher (1-6%) in all planting times the compared to the cropping pattern with traditional transplanting method. Double transplanting technology was found more stable compared to traditional method in late planting situation. The average added net returns with double transplanted dry season rice over traditional transplanted rice was US$139 to US$187 ha^{-1} 20 February, US$67 to US$117 ha^{-1} 28 February and US$68 to US$171 ha^{-1} 08 March planting. These findings highlight the profitability of adopting double transplanting in the Potato-Rice-Rice cropping system.

Key words: Double transplanting, late planting, productivity, net profit

INTRODUCTION

Rice (*Oryza sativa* L.) in the dry season followed by rice in the wet season is the major cropping pattern in irrigated medium highlands of Southeast Asian countries like India, Nepal, Bangladesh and Myanmar. In Bangladesh, Boro is the dry season irrigated rice and transplanted Aman is the wet season rice which is usually transplanted with 25-35 day old seedling from July to August. T. Aman is harvested from early November to middle of December depending on growth duration, transplanting time and photosensitivity of varieties. Between T. Aman harvest and Boro crop establishment, there is a fallow period of 80-90 days. This wet-dry transition period between T. Aman harvest and Boro crop establishment may be a suitable niche for a non-rice crop. Short duration high value Rabi crops like potato, mustard, edible podded pea can be fitted in

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this transition period in some areas of Bangladesh (Elahi *et al*., 2001; Khan *et al.*, 2004). Introduction of a non-rice crop in between two rice crops may help improve land productivity through a desirable shift in wetland soil ecology in one hand and proper utilization of natural resources to increase system productivity on the other hand. Potato is an important non-rice crop for Asian farmers because of its rich food value and high market price. It contains not only carbohydrate but is also a good source of protein, minerals, vitamin B and vitamin C (Slavin, 2013). It has been established that the total productivity of double rice cropping system could be improved by growing potato in fallow period between two rice (BRRI, 2006). System productivity of Potato-Boro-T. Aman is 29 t/ha whereas the productivity of Boro-Fallow-T. Aman is only 13 t/ha (Khatun *et al.*, 2003). Traditionally, Boro rice cultivation starts with nursery seeding in mid-November to early December. However, farmers intending to grow Boro rice after potatoes typically use older seedlings, which are usually sown in the nursery bed during the last week of December. Seeding of Boro rice in the nursery beds after mid-November produces lower grain yields (Thakur *et al.*, 2003). Boro rice produced higher grain yield upto 25 January transplanting. After 25 January planting, the grain yield declines significantly (BRRI, 1998; Chowdhury and Guha, 2000). The quandary of the productivity of potato and Boro rice may be taken care of by double transplanting of Boro rice. Double transplanting (DT) has been practiced for wet season rice in riverside lands of some Asian countries-India, Bangladesh and Nepal since long time back. It involves growing of seedling in the nursery, followed by transplanting in an intermediate field with closer spacing of 10 × 10 cm using 10-12 seedlings hill^{-1}. After 45 days, tillers from the intermediate field are splitted and transplanted in the main field (Rashid *et al*., 2004). Good prospects of double transplanting technology have also been reported in India (Roy *et al*., 2007). However, there is a dearth of information regarding the performance of double transplanted dry rice in Potato-Rice-Rice cropping system. Recognizing the magnitude of the above-mentioned cause and the importance of potato and dry season rice in the cropping system, the present study was undertaken to evaluate the performance and economic productivity of double transplanting of dry season rice in Potato-Rice-Rice cropping system.

MATERIALS AND METHODS

Experimental site

The study was conducted in the northern region of Bangladesh at the research field of BRRI Regional Station Rangpur (25°41′N and 89°16′ E), Bangladesh, spanning from the dry season 2008 to wet season 2011. The climate of the area is subtropical and exhibits wide seasonal variations in rainfall, temperature and humidity. According to the weather data collected from a nearby weather station (25°43'N and 89°15'E) of Bangladesh Meteorological Department, the hot season commences early in April and extends through July. The maximum temperature observed was about 32 to 36 °C (90 to 97 °F) during the months of May, June, July and August, whereas, the minimum temperature recorded in January ranged from 6 to 17 °C (43 to 63 °F). The average annual rainfall was 159-185 mm, 75–80% of this precipitation occurred during the monsoon season from June to September. Figure 1 depicted the weather pattern observed throughout the study period.

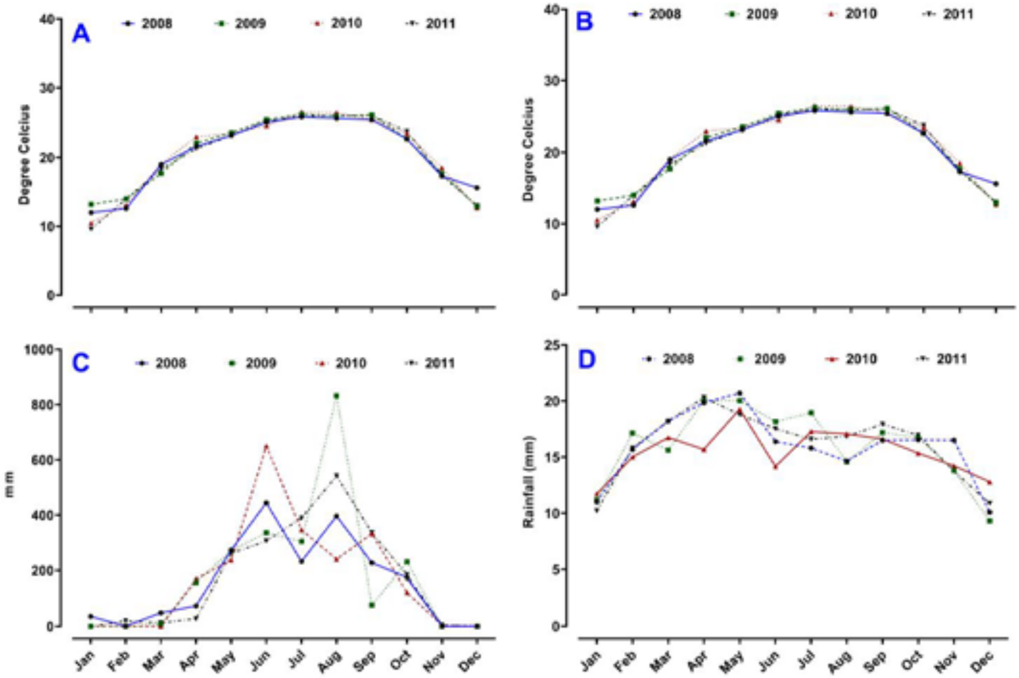

Fig. 1. Monthly average (A) Maximum temperature (B) Minimum temperature (C) Rainfall and (D) Solar radiation at the experimental site, Rangpur, Bangladesh during 2008-2011.

Soil sampling and analysis

The site belongs to Agro-Ecological Region 3 called Tista Meander Floodplain. The soils in this region are rapidly permeable, heavy silt loam or silty clay loam, strongly to slightly acidic, medium in K and CEC content (BARC, 2012). At the commencement of the experiment, soil samples were systematically collected from two distinct depths, i.e., 0 to 15 cm and 15 to 30 cm, using a 5-cm diameter auger. Each sample represented a composite from nine locations within the experimental plot. Subsequently, the freshly collected soil samples were mixed thoroughly, air-dried, crushed to pass through a 2-mm sieve and stored in sealed plastic jars before analysis. The pH of a 1:5 soil water suspension of the soil samples was determined by a portable pH meter. Soil organic C content was analyzed by the Walkley and Black method (Page *et al.*, 1982). The determination of soil total nitrogen (STN) involved the Kjeldahl digestion method applied to air-dried soil samples (Bremner, 1960). Soil phosphorus (P) (0.5 M NaHCO3 extractable) and ammonium acetate (NH_4OAc)-extractable potassium (K) were analyzed following the methods described by Olsen *et al.* (1954) and Page *et al.* (1982), respectively. Plant available sulphate was determined through calcium dihydrogen phosphate extraction method (Page *et al.*, 1982). Table 1 presented The soil chemical properties at different depths of the experimental site.

Table 1. The initial soil status of the experimental plot.

Soil depth (cm)	Soil properties					
	pH	% organic carbon	Total N (%)	Available P (ppm)	Exchangeable K (meq/100g)	Available S (ppm)
0-15	6.65	1.10	0.10	5.67	0.16	5.8
15-30	6.81	0.77	0.07	2.93	0.16	5.2

Experimental design and treatments

The study encompassed twelve treatment combinations, involving three transplanting dates (20 February, 28 February, and 08 March) and four seedling ages (75, 60, 45 days and 75-day double transplanted seedlings) for dry season rice within the potato-dry season rice-wet season rice cropping system. The evaluation spanned three consecutive years: 2008-2009 (year 1), 2009-2010 (year 2), and 2010-2011 (year 3). The experiment was laid out in completely randomized block design (RCBD) with three replications.

In the case of double transplanting (DT) technology, the rice transplanting process involved two stages. Initially, 35-day-old seedlings were transplanted from nursery beds to a small piece of land with a closer spacing of 10 cm × 10 cm, accommodating 6-8 seedlings per hill. Subsequently, 40 days after the first transplant, tillers were uprooted from the first transplanted plot, splited, and transplanted into the main field following the harvest of potatoes at full maturity (80-90 days of growing period). Tillers from the first transplanted rice cover approximately five times higher than the area of the main field under the second transplanting, necessitating about 2000 sqm of land under the first transplanting to cover one hectare of the main field (BRRI, 2007). Figure 2 illustrates the double transplanting system of dry season rice.

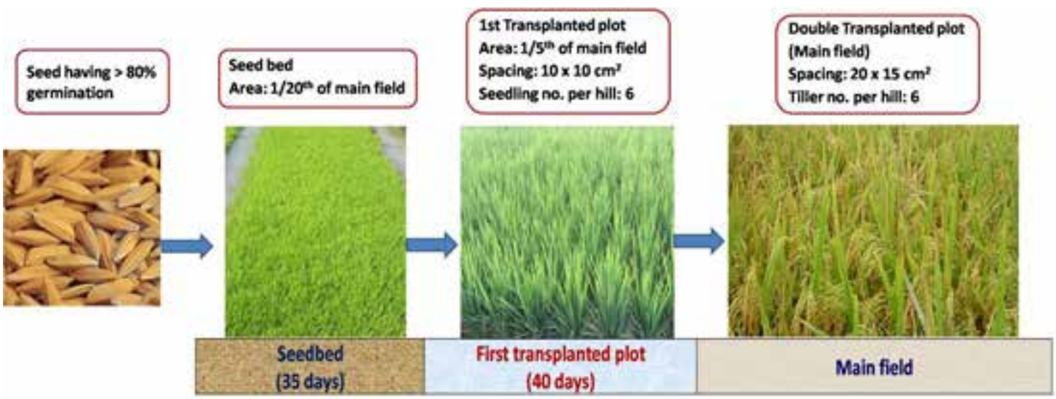

Fig. 2. Double transplanting practice of dry season rice.

Crop husbandry

Potato

A high yielding potato cultivar "Diamont" was manually sown at a seed rate of 1500 kg ha^{-1}on three different dates: 05-10 November, 15-20 November, and 25-30 November during the Rabi season from 2008 to 2010, to align with the three transplanting dates of dry season rice. The seeds were collected from Tuber Crop Research Centre of Bangladesh Agricultural Research Institute (BARI). Each plot received 161 kg N, 44 kg P, 130 kg K, 22 kg S, 5 kg Zn and 2 kg B ha^{-1} for potato cultivation (BARI, 2006). The phosphorus (P) in the form of triple superphosphate, potassium (K) as muriate of potash, sulfur (S) as gypsum, zinc (Zn) as zinc sulfate, and boron (B) as boric acid were applied at the basal level during the final land preparation. Upon land preparation, potatoes were sown with a spacing of 60 cm × 25 cm. Two equal splits of nitrogen (N) as urea were applied at 15 and 30 days after sowing (DAS), just before the earthing-up operation. Surface irrigation was applied immediately after sowing and subsequently as needed by the crop. Hand weeding was performed (one day prior to the application of nitrogen split) at 14 and 29 days after sowing. Other recommended agronomic practices were followed for successful production of potato (BARI, 2006).

Dry season rice

The high-yielding semi-dwarf rice cultivar BRRI dhan29 (160 day seed to seed) was cultivated during the dry seasons from 2009 to 2011. The seeds were collected from Genetic Resources and Seed Division of BRRI. Following the harvest of potato, 75, 60, 45 days old and 75 days DT seedling were transplanted with a spacing of 20 cm × 15 cm on 20 February, 28 February and 08 March, 2009-2011. In the traditional transplanted plots, phosphorus (P), potassium (K), sulphur (S) and Zinc (Zn) were basally applied at the rate of 15-60-15-4 kg ha^{-1} and broadcast prior to the last cultivation. Additionally, 170 kg nitrogen (N) in the form of urea was top dressed in three times. In case of double transplanting plot, 1st transplanted plot received 280 kg N, 15 kg P, 60 kg K, 15 kg S and 4 kg Zn ha^{-1}, while the 2nd transplanted plot received 114 kg N, 15 Kg P, 60 Kg K, 15 Kg S and 4 Kg Zn (BRRI, 2007). The field was irrigated based on the crop's requirements, and other BRRI recommended agronomic practices were followed to ensure the successful production of rice (BRRI, 2008).

Wet season rice

In the wet seasons from 2009 to 2011, the medium-duration semi-dwarf rice cultivar BRRI dhan49, with a seed-to-seed maturity period of 135 days, was cultivated. The transplanting of 30-35-day-old rice seedlings, with 2-3 seedlings per hill, was carried out on 15-20 July. The spacing used for transplantation was 20 cm × 15 cm. For fertilization, the field received 92 kg N, 12 kg P, 33 kg K, and 10 kg S ha^{-1}. Except for urea, all other fertilizers were applied during the final land preparation. Urea was top-dressed in three equal installments: 7-10 days after transplanting, during the tillering stage, and seven days before panicle initiation. All other agronomic practices were executed according by (BRRI, 2008).

Data collection and analysis

Potato tuber yield was assessed from 6 m^2 harvest area in each plot at harvestable maturity. Grain yields (rough rice) were obtained from 6 m^2 harvest area in each plot at 80% maturity and reported at 0.14 g H_2O g^{-1} fresh weight of grain. Human labour used for different management practices and their wage rate were documented. The time required for each field operation was expressed as person-days ha^{-1}, with eight hours considered equivalent to one person-day. The irrigation cost, farm-gate price of potato and rough rice, prices of fertilizer and crop seed were also recorded. Total productivity of Potato-Rice-Rice systems was compared in terms of rice equivalent yield (REY) (Rashid *et al.*, 2004). The REY of potato was computed by the following formula:

$$REY = \frac{\text{potato yield (kg) x potato price (US\$ kg}^{-1})}{\text{Unit price of paddy (US\$ kg}^{-1})}$$

Economic analysis of double transplanting technology was conducted based on added net return relative to traditional transplanting, which is the difference between added gross return and added cost for double transplanting treatment as compared with traditional transplanting. Added gross return equaled additional yield as rough rice (yield of DT treatment - average yield of traditional transplanting) multiplied by the price of yield. Added cost equaled the sum of costs for differences in labour determined as [(labor for 1st and 2nd transplanting, uprooting from 1st and 2nd transplanted plot and weeding of the DT treatment - labour for uprooting, transplanting and weeding of traditional transplanting) × wage rate] and costs for differences in fertilizer and irrigation determined as (fertilizer and irrigation costs of DT treatment - fertilizer and irrigation costs of traditional transplanting). The prices of seeds, fertilizer, irrigation, potato, rough rice, and labour wage were as follows: rice seed = US$ 0.45 kg^{-1}, potato seed = US$ 0.32 to 0.36 kg^{-1}, P fertilizer = US$ 0.28 to 0.51 kg^{-1}, K fertilizer = US$ 0.19 to 0.45 kg^{-1}, S fertilizer = US$ 0.06 to 0.08 kg^{-1}, Zn fertilizer = US$ 1.29 to 1.54 kg^{-1}, B fertilizer = US$ 1.93 to 2.57 kg^{-1}, urea = US$ 0.15 to 0.26 kg^{-1}, irrigation cost of double transplanting = US$ 242.89 to 271.71 ha^{-1}, irrigation cost of traditional transplanting = US$ 240.10 to 268.91 ha^{-1}, potato = US$ 0.09 to 0.13 kg^{-1}, rough rice = US$ 0.22 to 0.23 kg^{-1}, and labour wage = US$ 1.93 to 2.57 person-day^{-1} (US$1 = Bangladesh Taka 77.78).

Analysis of variance (ANOVA) of the treatment means were compared using least significant difference (LSD) at the 5% level of probability (Gomez and Gomez, 1984). Descriptive statistics such as means, range, 25% quartile, and 75% quartile were used to determine the variability of parameters. Productivity and stability of the cropping system were analyzed according to Conway, 1987.

RESULTS AND DISCUSSION

Grain yield and yield components of dry season rice

The grain yield exhibited significant variability in respect of planting time ($P \leq 0.001$), seedling age ($P \leq 0.001$), and year ($P \leq 0.001$), while the interaction effect among these factors was not statistically significant. Notably, the double transplanting treatment consistently yielded the highest grain yield compared to the other treatments across all planting times and years (Table 2). Irrespective of seedling age, grain yield was gradually decreased with the progress of the planting time in all years. On average, rice transplanted on 20 February yielded about 7% and 23% higher grain than those transplanted on 28 February and 08 March, respectively. The findings revealed a decrease in grain yield at a rate of 66 kg^{-1} ha^{-1} day^{-1} from 20 February to 08 March planting. Previous research underscored the importance of completing transplanting for dry season rice by 25 January to avoid a significant decline in grain yield (Chowdhury and Guha, 2000). A gradual rise in both average maximum and minimum temperatures observed as transplanting time advanced in the study area (Fig. 1) could potentially impact rice yield. According to Baker *et al.* (1992), there was a 7–8% decrease in rice yield for each 1°C increase in daytime maximum/nighttime minimum temperature within the range of 28/21 to 34/27 °C. Among different seedling ages, the 75-day-old double-transplanted seedlings consistently yielded higher grain compared to other age groups across all planting times and years. This result was supported by Roy *et al.* (2007), who observed higher grain yield with double-transplanted rice compared to

Table 2. Grain yield (t ha^{-1}) of BRRI dhan29 under different planting times and seedling ages in BRRIRS Farm, Rangpur, Bangladesh.

Planting time	Seedling age				
	75 days	60 days	45 days	75 days (DT)	Mean for PT
			2008-09		
20 Feb	5.27	5.50	5.01	6.27	5.51
28 Feb	4.98	5.11	4.61	5.36	5.01
08 Mar	3.98	4.00	3.94	4.90	4.21
Mean for SA	4.74	4.87	4.52	5.51	
			2009-10		
20 Feb	5.65	5.91	5.04	6.31	5.73
28 Feb	5.37	5.57	5.20	5.96	5.52
08 Mar	4.77	5.10	4.71	5.50	5.02
Mean for SA	5.26	5.53	4.99	5.92	
			2010-11		
20 Feb	5.57	5.62	4.92	6.29	5.60
28 Feb	5.05	5.25	4.58	5.86	5.19
08 Mar	4.47	4.53	4.03	4.76	4.45
Mean for SA	5.03	5.13	4.51	5.64	
LSD (5%)					
Planting time (P)					0.20**
Seedling age (S)					0.23**
Year (Y)					0.20**
P×Y					0.35^{ns}
S×Y					0.41^{ns}
P×S					0.41^{ns}
P×S×Y					0.70^{ns}

DT=Double transplanting, SA= Seedling age, PT= Planting time
ns and ** = Not significant, significant at 1% level respectively

traditional transplanting. Traditional transplanting with 60-day-old seedlings resulted in a higher grain yield than both 75-day-old and 45-day-old seedlings. Lower grain yield with 45-day-old seedlings aligns with the findings of Channabasappa *et al.* (1998) who reported better performance of older seedlings compared to younger ones under late-transplanted conditions. Moreover, spikelet sterility and seedling mortality was decreased with transplanting of older seedlings (Murty and Saha, 1979; Rashid *et al.*, 1990). The adoption of double transplanting practices could lead to a yield advantage of 17%, 13%, and 16% compared to traditional transplanting when conducted on 20 February, 28 February, and 08 March, respectively. Across three years, the grain yield with double transplanting practice on 20 February, 28 February and 08 March was higher by 0.90, 0.65, and 0.66 t ha^{-1}, respectively, than that achieved with traditional transplanting. This aligns with reports from other authors who observed higher grain yields in double-transplanted rice from early sown nursery beds in Assam and North Bihar (Singh *et al.* 2003 and Thakur *et al.*, 2003). Additionally, our results are consistent with a study reporting the benefits of adopting double transplanting for PA 6201 hybrid rice, considering its higher grain yield compared to the standard practice of single planting (Rataray, 2006).

All the yield components measured in the present study were significantly affected by planting time ($P \leq 0.001$; except panicle m^{-2} and 1000-grain weight), seedling age ($P \leq 0.001$; except 1000-grain weight), however in-significantly affected by year except panicle m^{-2} ($P \leq 0.05$). Interaction effect of all yield components was non-significant except panicle m^{-2}. The interaction between planting time and seedling age significantly affects the number of panicle m^{-2} ($P \leq 0.05$).

Traditional transplanted rice consistently showed a significantly higher number of panicles m−2 compared to double transplanted rice across all the years. Regardless of the year and planting times, 45-day-old seedlings produced significantly more panicles per square meter than seedlings from other age categories. The lower number of panicles m^{-2} in double transplanted rice may be due to insufficient time for split tillers to develop secondary tillers after the second transplanting.

In contrast, the number of spikelets per panicle in double transplanted rice was significantly higher than in the other treatments across all the planting times and years, except for the February 20 treatment in 2008-09. Furthermore, double transplanted rice exhibited significantly higher grain filling percentages than traditional transplanted rice across all years, seedling ages, and planting times, which likely contributed to the higher grain yield of double transplanted rice. However, grain weight remained unaffected by planting time, seedling age, or year (Table 3).

Table 3. Yield components of dry season rice across different treatments and years in BRRI-RS Farm, Rangpur, Bangladesh.

Seedling age	Panicles m^{-2}			Grain $panicle^{-1}$			1000-grain weight (g)			Grain filling %		
	20 Feb	28 Feb	08 Mar	20 Feb	28 Feb	08 Mar	20 Feb	28 Feb	08 Mar	20 Feb	28 Feb	08 Mar
2008-2009												
75 days	304	282	295	101	116	94	22.0	21.3	21.7	74.5	66.3	66.1
60 days	300	284	301	126	113	85	21.0	21.7	21.3	67	68.9	70.9
45 days	307	315	328	119	106	98	22.0	22.0	21.3	60.7	58.9	55.5
75 days (DT)	275	270	269	121	127	126	22.0	21.3	21.0	79.4	71.1	64.9
2009-2010												
75 days	314	312	303	101	106	107	22.7	22.3	21.6	73.1	69.8	64.4
60 days	305	296	304	122	108	101	22.4	22.9	22.7	69.7	72.6	70.1
45 days	313	322	317	102	104	101	22.4	21.9	22.7	66.5	67.4	60.5
75 days (DT)	274	269	259	140	134	136	21.4	22.3	22.5	74.8	72.4	65.9
2010-2011												
75 days	309	302	295	111	122	107	21.7	22.3	21.7	70.6	58.5	62.6
60 days	305	295	294	110	126	108	22.4	21.6	20.6	72.1	63.9	63.9
45 days	318	315	316	104	145	105	22.6	20.9	21.3	64.2	47.4	55.1
75 days (DT)	270	267	263	127	128	120	22.4	22.3	21.6	74.9	71.6	65
LSD (5%)												
Planting time (P)	4.85^{ns}			7.08**			0.35^{ns}			3.23**		
Seedling age (S)	5.60**			8.18 **			0.41^{ns}			3.73**		
Year (Y)	4.85^{ns}			7.08^{ns}			0.30^{ns}			3.23*		
P×Y	8.40^{ns}			12.27^{ns}			0.61^{ns}			5.60^{ns}		
S×Y	9.70^{ns}			14.17^{ns}			0.71^{ns}			6.47^{ns}		
P×S	9.70*			14.17^{ns}			0.71^{ns}			6.47^{ns}		
P×S×Y	16.80^{ns}			24.55^{ns}			1.23^{ns}			11.20^{ns}		

DT=Double transplanting

ns, * and ** = Not significant, significant at 5% and 1% level respectively

The grain filling percentage exhibited the highest significant positive correlation (r = 0.61, $P \leq 0.01$) with grain yield, followed by spikelets per panicle (r = 0.47; $P \leq 0.05$) (Table 4). This indicated that higher filled grain from higher spikelets panicle^{-1}contributes to the higher yields in double transplanting practice. These findings align with previous research, where a higher number of filled grains per panicle was reported in double-transplanted rice compared to the traditional system, leading to an overall enhancement in yield (Roy *et al.*, 2007).

Table 4. Correlation coefficients (*r*) between grain yield and yield components across different treatments and years in double and traditional transplanting.

Trait	Grain yield	Panicle m^{-2}	Spikelet panicle^{-1}	Grain filling %	1000-grain weight
Grain yield	1				
Panicles m^{-2}	0.33^{ns}	1			
Spikelets panicle^{-1}	0.47*	-0.08^{ns}	1		
Grain filling %	0.61**	0.36^{ns}	-0.34^{ns}	1	
1000-grain weight	0.13^{ns}	-0.09^{ns}	0.002^{ns}	-0.13^{ns}	1

ns = Not significant. Number of observations = 27

* Significant difference at $P \leq 0.05$, ** Significant difference at $P \leq 0.01$

Growth and field duration of dry season rice

Figure 3 depicted the growth and primary field duration of dry season rice. Regardless of seedling age, dry season rice physiologically matured earlier with the advancement of planting time over the three years. A previous study also concluded that delayed transplanting of Boro rice results in a shortened growing period (Roy *et al.*, 2007). Regarding different seedling ages, it was observed that 45-day-old seedling-transplanted rice achieved physiological maturity earlier than the thers, while transplanting with 75-day-old seedlings required more time for maturation. Double transplanting with 75-day-old seedlings matured 4-10 days earlier compared to traditional transplanting with the same seedling age. In the case of double transplanting, the crop was likely to obtain additional space for vegetative growth in the intermediate 1st transplanted field, potentially contributing to the earlier maturity of double-transplanted rice compared to traditionally transplanted rice with the same seedling age. BRRI also reported that double-transplanted rice matures 7-10 days earlier than the traditionally transplanted rice with older seedlings in late situations (BRRI, 2015).

The main field duration of crops is crucial not only for introducing a new crop into the existing cropping pattern but also for resilience against biotic and abiotic stresses in certain cases. The main field duration was higher when using 45-day-old seedling-transplanted rice. In all instances, the practice of double transplanting facilitated a reduction in the main field duration. Compared with normal transplanted rice, the field duration decreased with double-transplanted rice, ranging from 4 to 13 days during the dry season. BRRI earlier reported that double transplanting technology minimizes the main field duration of rice (BRRI, 2015).

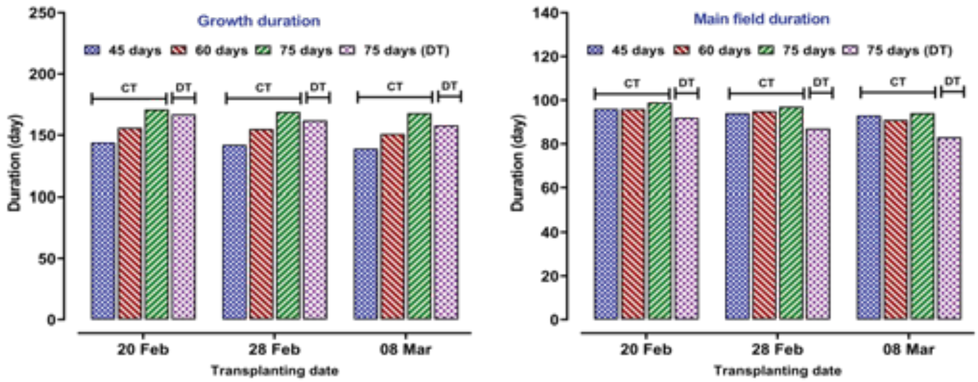

Fig. 3. Growth and main field duration of dry season rice transplanted with varying seedling age on different transplanting date.

CT= Conventional transplanting, DT=Double transplanting

Potato yield

Potato yield remained unaffected by the year, while it exhibited significant variation with planting times ($P \leq 0.001$), with a non-significant interaction effect. Among the treatments, potato yield from 05-10 November sowing was significantly higher than in other treatments across all the years. There was a gradual decrease in potato yield with the progress of planting time. The potato yield planted during November 05-10 was 12% and 41% higher than that planted during 15-20 November and 25-30 November, respectively (Table 5). Previous studies reported higher yields for potato planted on 15 November, showing an increase of 34.29% compared to those planted on 30 November (Haque *et al.*, 2013).

Table 5. Potato tuber yield across different planting time and year in BRRI Farm, Rangpur, Bangladesh.

Planting time	Yield (t ha^{-1})		
	2008-09	2009-10	2010-11
Nov 05-10	22.98	25.42	25.83
Nov 15-20	20.06	22.22	24.27
Novr 25-30	15.98	18.13	18.55
LSD (5%)			
Planting time (P)		2.64**	
Year (Y)		2.63^{ns}	
P×Y		4.56^{ns}	

ns, ** = Not significant, significant at 1% level, respectively

Wet season rice yield

The grain yield of wet season rice was not significantly affected by year. The yield ranged from 4.49 to 4.84 t ha^{-1} across different years (Fig. 4). Biswash *et al.* (2015) also reported similar grain yield of BRRI dhan49 in Northern Bangladesh.

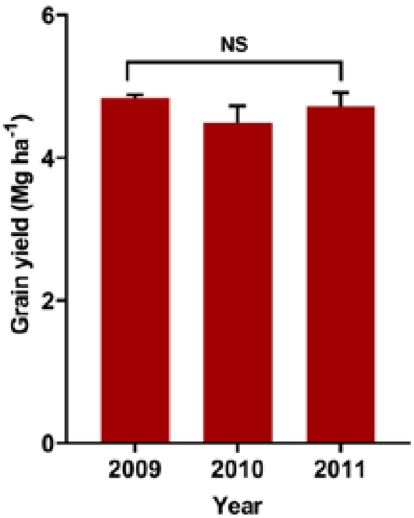

Fig. 4. Year wise grain yield of wet season rice in Northern Bangladesh.

System productivity of Potato-Rice-Rice cropping system

The system productivity of Potato-Dry season rice-Wet season rice cropping system varied significantly among planting times ($P \leq 0.001$), seedling age ($P \leq 0.001$) and years ($P \leq 0.001$), whereas their interaction effect was non-significant expect planting time × year ($P \leq 0.001$). Double transplanting practice consistently turned out the highest system productivity regardless of the planting time, seedling age and years (Table 6). Across different seedling ages, the system productivity of the double transplanting treatment was significantly higher than the other treatments in all the years. This increase in system productivity was attributed to the consistent improvement in grain yield of double-transplanted dry-season rice. System productivity gradually decreased with the progress of planting time, as evidenced by decreased yields of potato and dry-season rice. Additionally, the lower price of potatoes with seasonal progression significantly impacted system productivity. In the year 2008-09, system productivity was notably lower due to the cheap price of potato compared to other years. The introduction of double transplanting for dry-season rice in Potato-Rice-Rice cropping system demonstrated its effectiveness, resulting in higher productivity of the Potato-double transplanted dry-season rice-wet season rice cropping system compared to the traditional one. These findings are in agreement with earlier studies by Roy *et al.* (2007) and Khatun *et al.* (2007).

Table 6. Rice equivalent yield (t ha^{-1}) of Potato-Rice-Rice cropping system across different treatments in BRRI-RS Farm, Rangpur, Bangladesh.

Planting time	Seedling age				
	75 days	60 days	45 days	75 days (DT)	Mean for PT
			2008-09		
20 Feb	21.32	21.56	21.06	22.32	21.57
28 Feb	18.48	18.61	18.11	18.86	18.51
08 Mar	15.80	15.82	15.76	16.73	16.03
Mean for SA	18.53	18.66	18.31	19.30	
			2009-10		
20 Feb	25.09	25.36	24.49	25.75	25.17
28 Feb	19.01	19.21	18.84	19.60	19.17
08 Mar	16.73	17.05	16.67	17.46	16.98
Mean for SA	20.28	20.54	20.00	20.94	
			2010-11		
20 Feb	23.20	23.25	22.55	23.93	23.23
28 Feb	20.55	20.76	20.08	21.37	20.69
08 Mar	16.99	17.05	16.55	17.28	16.97
Mean for SA	20.25	20.35	19.72	20.86	
LSD (5%)					
Planting time (P)					0.20**
Seedling age (S)					0.23**
Year (Y)					0.20**
P×Y					0.35**
S×Y					0.41^{ns}
P×S					0.41^{ns}
P×S×Y					0.70^{ns}

DT=Double transplanting

ns, ** = Not significant, significant at the 1% level, respectively

A comparative analysis was also conducted to assess the advantage of using double transplanting practice over traditional transplanting in terms of productivity and stability. Stability measured by the coefficient of variation in productivity, determined from a time series of productivity measurements (Conway, 1987). The superior productivity with double transplanting practice across all planting times confirmed its benefits over traditional transplanting. Additionally, the higher stability of the double transplanting technology, particularly evident on 08 March, suggests its feasibility in later conditions (Fig. 5).

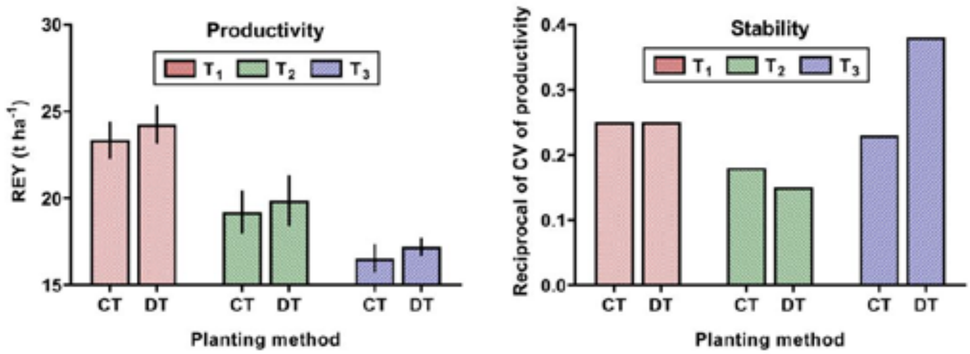

Fig. 5. Productivity and stability of double and conventional transplanted rice in Potato-Rice-Rice cropping systems in Northern Bangladesh.

* Error bar showing confidence interval at 0.05

T_1 = Transplanting at 20 February, T_2 = Transplanting at 28 February, T_3 = Transplanting at 08 March, CT = Conventional transplanting, DT = Double transplanting

Economic analysis

Added costs and net returns associated with double transplanting were analyzed in comparison to traditional transplanting technique to assess the profitability of the double transplanting technique (Table 7). Across the years, the average additional costs for double transplanting practice on 20 February, 28 February, and 08 March ranged from \$30 to \$34 ha^{-1}, \$28 to \$34 ha^{-1}, and \$28 to \$33 ha^{-1} respectively. These added costs were primarily attributed to the extra application of P, K, S, Zn fertilizers, additional land preparation and labour requirements in the first transplanted plot. On the other hand, the average added net returns with double transplanting ranged from US\$ 22 to 439 ha^{-1} on 20 February, US\$ 17 to 325 ha^{-1} on 28 February and from US\$ 25 to 272 ha^{-1} on 08 March across different years. The highest added net return was observed with double transplanting on 20 February compared to other treatments over three years. Overall, the average added net returns were higher with double transplanting practice across all planting times, indicating its profitability compare to traditional transplanting. On average per dollar net return (added net return divided by added cost) was the highest on 20 February transplanting (\$ 5.36) followed by 08 March transplanting (\$ 3.94) and it was the lowest in 28 February transplanting (\$ 3.74). These results suggest that double transplanting of dry season rice was more profitable on 20 February transplanting. Moreover, the positive added net returns with double transplanting practice in all the planting times confirmed that the technology is ready for wide-scale evaluation and promotion in Bangladesh. Previous studies have similarly concluded that, despite the higher cost associated with double-transplanted technology, this system yielded a higher gross margin (net profit) than the conventional approach (Khatun *et al.*, 2007; Roy *et al.*, 2007).

Table 7. Added costs and added net returns of double transplanted dry season rice compared to traditional transplanted rice under different planting time in Northern Bangladesh.

Planting time	Added cost (US$ ha^{-1})	Added net return (US$ ha^{-1})			
		Mean	Range	25% quartile	75% quartile
		2008-09			
20 Feb	34	187	15 to 439	89	264
28 Feb	34	67	15 to 228	38	62
08 Mar	33	171	8 to 272	154	202
		2009-10			
20 Feb	30	139	22 to 306	54	233
28 Feb	28	98	17 to 213	53	165
08 Mar	28	112	33 to 212	59	175
		2010-11			
20 Feb	31	183	15 to 387	95	226
28 Feb	30	179	11 to 325	140	198
08 Mar	28	68	25 to 180	11	103

CONCLUSION

In the study, double transplanting practice demonstrated its superiority over the traditional transplanting system in late situation. This technology has effectively intensified the double rice cropping system by ensuring the harvest of potato after full maturity during the wet-dry transition period between dry and wet season rice. Simultaneously, it minimized the yield loss of dry season rice resulting from late transplanting after potato cultivation. The shorter main field duration of double-transplanted rice can also mitigate the impact of abiotic risks such as hailstorms, unusual rains, and higher temperatures at maturity. Consequently, double-transplanting of dry season rice following potato cultivation emerges as a promising technology for enhancing yield and income. Implementing a comprehensive program one to demonstrate and promote this practice in areas with Rabi crops-Rice-Rice cropping pattern could significantly improve the productivity of the existing system.

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