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Research Article

Response of Physiological Characteristics and Productivity of Hybrid Rice Varieties under System of Rice Intensification (SRI) over the Traditional Cultivation

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Abstract

Higher and stable yield of the rice is the main bottleneck in Bangladesh due to the use of suboptimal management strategies in rice field. From this perspective, the experiment was carried out to investigate the impact of the system of rice intensification (SRI) on physiological characteristics and productivity of hybrid rice varieties over inbred rice cultivation under traditional system. Results demonstrated that, the SRI cultivation method was more suitable than traditional cultivation method in respect of growth and yield of hybrid rice. Among eight rice varieties, BRRI hybrid Dhan 3 exhibited the best performance in relation to its morpho-physiological characteristics and yield attributes. Consequently, the highest yield (9.77 t ha-1) was obtained from SRI × BRRI hybrid Dhan 3 followed by SRI × Tia (9.19 t ha-1) and SRI × Heera 3 (8.46 t ha-1). Under SRI method, all the studied hybrids showed the higher yield. BRRI hybrid Dhan 3 with SRI method produced highest total dry weight hill-1 (80 g) at maturity, significantly higher number of panicles hill-1 (19.67), highest filled spikelet's panicle-1 (204), 1000-grain weight (28.77 g) and harvest index (45.06 %) whereas under Traditional method, higher grain yield (7.85 t ha-1) was recorded from the hybrid Dhan Tia. Among hybrid and inbred varieties, BRRI Dhan 45 showed the lowest performance under traditional method in term of all studied parameters. So, SRI method was better for cultivation of the hybrid rice varieties compared to traditional method for improving the condition of farming community as a whole.

ABBREVIATIONS

SRI: System of Rice Intensification; RCBD: Randomized Complete Block Design, LA: Leaf Area; TSP: Triple Super Phosphate; MoP: Muriate of Potash, DAT: Days After Transplanting

INTRODUCTION

Rice is the foremost staple food for more than 50% of the world's population [1]. There is an upward shift in demand for rice worldwide due to population increase and urbanization, as people change their eating habits [2], leading to high shelf prices. Between 2006 and 2008, average world prices for rice grew by 217%, compared to wheat which increased by 136%, corn by 125%, and soybeans by 107% [3,4]. Bangladesh is one of the big delta of the world which is densely populated and threatened by floods and storms. About 75% of the total cropped area and more than 80% of the total irrigated area is planted to rice [5]. The country is now producing about 42.3 million tons of clean rice @ 3.78 t ha^{-1} in 11.2 million ha of land. A conservative statistics given by Bhuiyan et al. [6], they indicated that, about 21% higher amount of rice have to be produced to feed the rising population by 2025 than the production in 2000.

There is no opportunity to increase rice area consequently; much of the additional rice required will have to come from higher average yield on existing land. Clearly, it will require adoption of new technology such as high management package, high yielding cultivar, higher input use etc [7]. The System of Rice Intensification (SRI) offers an opportunity to improve food security through increased rice productivity by changing the management of plants, soil, water and nutrients while reducing external inputs like fertilizers and herbicides [8-11]. The system proposes the use of single, very young seedlings with wider spacing, intermittent wetting and drying, use of a mechanical weeder which also aerates the soil, and enhanced soil organic matter [12]. SRI is a technique that is a set of practices and a set of principles rather than as a "technology package" [13]. With SRI, management practices control or modify the microenvironment so that existing genetic potentials can be more fully expressed and realized. The SRI is a production system that emphasize the use of younger seedlings (< 15 days) planted singly and at wider spacing, together with the adoption of intermittent irrigation, organic fertilization, and active soil aeration to the extent possible [14,15]. The SRI system shows that keeping paddy soils moist but not continuously saturated gives better results, both agronomical and economical, than flooding rice throughout its crop cycle. SRI methods enable farmers to reduce their irrigation water by 25-50% while realizing higher and more profitable production [16-20]. Traditional flood irrigated rice ecosystem not only causes wastage of water but also leads to environmental degradation and reduces fertilizer use efficiency. During the last few decades, various new cultivation practices for growing rice have been tried worldwide. The different technologies developed so far to reduce water loss as well as increase water use efficiency of the rice crop are alternate wetting and drying, system of rice intensification and saturated soil culture which partially or totally suppress the need for water in rice field. All these systems have been reported to show high water productivity with no or little compromise on yield. The study was therefore, undertaken to investigate the impact of SRI on productivity of hybrid rice varieties considering the tillering and leaf area development pattern, dry matter accumulation and grain yield of hybrid and inbred rice varieties under SRI (System of rice intensification) and TRC (Traditional rice cultivation) method for the identification of suitable hybrid rice varieties for SRI condition and to generate the information's on physiological behavior of hybrid rice varieties grown in SRI method over tradition methods with inbred variety.

METHODOLOGY

Experimental site and planting materials

The experiment was conducted in the research field of SAU at Boro season, 2015-2016. Popular seven indica hybrids (*viz*, BRRI hybrid Dhan 2, BRRI hybrid Dhan 3, Heera 3, Panna 1, Tia, ACI 6 and Tej) and one inbred (BRRI Dhan 45) were used in this study.

The seeds of the test crop *i.e.,* BRRI hybrid 2, BRRI hybrid 3 and BRRI Dhan 45 were collected from Bangladesh Rice Research Institute (BRRI), Joydebpur, Gazipur. Other elite hybrid varieties were collected from different seed company of Bangladesh.

Soil analysis data from the treatment combination

Treatment combination	Total N (%) before planting	Total N (%) after harvest
Variety	**Traditional X**	
BRRI hy. Dhan2	0.070	0.062
BRRI hy. Dhan3	0.071	0.063
Heera 3	0.071	0.068
Panna1	0.075	0.071
Tia	0.073	0.074
ACI 6	0.071	0.071
Tej	0.073	0.067
BRRI Dhan45	0.072	0.069
Variety	**SRI system X**	
BRRI hy. Dhan2	0.074	0.074
BRRI hy. Dhan3	0.081	0.069
Heera 3	0.070	0.067
Panna1	0.074	0.069
Tia	0.072	0.071
ACI 6	0.070	0.069
Tej	0.072	0.068
BRRI Dhan45	0.073	0.070

Treatments details

The experiment comprised of two factors *i.e.*, factor a: cultivation methods; T_1 = Traditional method; Plant spacing, S_1 (15cm × 25cm) + Regular irrigation, I_1 and T_2 = SRI method; Plant spacing, S_2 (20cm × 20cm) + Controlled irrigation, I_2 whereas factor b: variety-8 varieties *i.e.*, V_1 = BRRI hybrid Dhan 2, V_2 = BRRI hybrid Dhan 3, V_3 = Heera 3, V_4 = Panna1, V_5 = Tia, V_6 = ACI 6 and V_7 = Tej) and V_8 = BRRI Dhan45 (inbred). The experiment was laid out in Randomized Complete Block Design (RCBD) with three replications. There were 16 treatment combinations. The total numbers of unit plots were 48. The size of unit plot was 3m × 1.5m. The distances between each plots and replications were 1m.

Crop husbandry

Seed sprouting: Healthy seeds were selected by specific gravity method and then immersed in water bucket for 24 hours and then those were kept tightly in gunny bags. The seeds started sprouting after 48 hours and were sown after 72 hours.

Preparation of tray and seed bed for growing seedling: As per BRRI recommendation seedbed was prepared with 1 m wide adding nutrients as per the requirements of soil. Seed were sown in the seed bed @ 70 g m^{-2} on 1 January, 2016 for traditional system but for SRI system sprouted seed were sown in tray grown with intensive care and 12 days old seedling were transplanted in the main field.

Preparation of the experimental plot: The plot selected for the experiment was opened in 10 December 2015 with a power tiller, and was exposed to the sun for a week, after which the land was harrowed, ploughed and cross-ploughed several times followed by laddering to obtain a good tilth. Weeds and stubble were removed from the plots and finally plots were leveled properly by wooden plank. The field layout was made as per treatments immediately after final land preparation.

Fertilizers and manure application: The N, P, K, S, Zn and B in the form of urea, TSP, MoP, gypsum, zinc sulphate and borax fertilizer, respectively were applied @ 150-100-100-10-60-10 kg ha^{-1} respectively. The entire amount of TSP, MoP, gypsum, zinc sulphate and borax were applied during the final preparation of each plot. Mixture of cowdung was applied @ 10 t/ha at 15 days before of transplantation. Urea was applied in three equal installments at after recovery, tillering and before panicle initiation.

Transplanting of seedlings in the field: The seedlings were transplanted in the main field on January 01, 2016 and the rice seedlings were transplanted in lines. Spacing of plantation was maintained as per treatment. Two different spacing were used as 15cm × 25cm for TRC method and 20cm × 20cm for SRI.

Application of irrigation water and drainage: Irrigation was given done as per treatment. Two water regimes namely, controlled irrigation and regular irrigation were used for the experiment.

A. Controlled irrigation: Water was applied just to saturate the soil (no flood) throughout the growing period of the crop. Irrigation was done when it is needed.

B. Regular irrigation: Flood irrigation was done. Irrigation was provided to maintain a constant level of standing water up to 6 cm. Plots were equipped with drainage irrigation system for continuous flood irrigation (up to 5-6 cm depth) throughout the rice-growing season.

Intercultural operations: Intercultural operations were done to ensure the normal growth of the crops. Gap filling was furnished within 7 days using the seedling from same source. The plots were irrigated whenever required. Weeding was done as and when necessary. Plant protection measures *viz.* insecticide and fungicide were sprayed as required to keep the crop free from insect and pathogen attack. Top dressing of urea was done as per schedule.

Data collection

Plant sampling: Data pertaining to dry matter accumulation and leaf area (LA) were taken through destructive sampling method. Keeping 5 m^2 undisturbed areas in one side for yield data, plant hills were selected from third rows during first sampling and more two rows or three hills had been left at final sampling to minimize the border or side effect.

Leaf area and dry matter accumulation: Eight sample hills were uprooted from each plot at heading and at maturity, and roots were removed. Then, plant hills were partitioned into green leaf, dead leaf, stem (culm + leaf sheath) and panicles (if present). Green leaf area (LA) was measured by an automatic leaf area meter (Model: LI-3100, Li-COR, Lincoln, NE, USA.) just after removal of leaves to avoid rolling and shrinkage and transformed into leaf area index (LAI). The segmented plant samples were kept in separated envelopes and were oven dried at 70^0C for 72 hours. Dry weight of each component was determined with a digital balance and means were calculated. Finally total dry matter (TDM) was calculated adding the weight of different plant parts at pre-anthesis and at maturity.

Shoot reserve remobilization to the grain: The shoot (culm + leaf sheath + leaf blade) reserve translocation was calculated by net loss in dry weight of vegetative organs between pre-anthesis and maturity.

$$\text{Shoot reserve translocation (\%)} = \frac{A-M}{A} \times 100$$

Where, A = Total shoot dry matter at pre-an thesis, g m^{-2}

M = Total shoot dry matter at maturity, g m^{-2}

Yield components: At maturity, the number of panicles $hill^{-1}$ was counted. Twenty panicles from those hills were threshed. Filled and un-filled spikelet's were separated by a seed sorter (Kiya Seisakusho LDT, model 1973, Tokyo, Japan). After separation, the filled and unfilled spikelet's were counted by an automatic counter (Nagoga, model DC 1-O, Japan) and then number of spikelet's $panicle^{-1}$ spikelet's filling percentage (%) and 1000 grains weight were calculated.

Grain yield: The crops were harvested according to maturity from the undisturbed sample area of 5 m^2 of each unit plot. After threshing, cleaning and sun drying, the grain weight were recorded and adjusted to 14% moisture content (MC) using the following formula.

100 - Sample MC (%)

Grain yield at 14% MC = --------------------------------- x weight of the grains at harvest

100 - 14

Source-sink ratios

Ratio of spikelet's number to leaf area (at heading): It was calculated as spikelet's number to cm^{-2} LA at heading according to [21].

Spikelet's no.cm^{-2}

Ratio of spikelet's no. to LA (at heading) =

LAI (at heading)

Ratios of yield sink to leaf area (at heading): It was determined following the formula expressed by [21] as follows-

Yields sink (mg cm^{-2})

Ratio of yield sink to LA (at heading) =

LAI (at heading)

Ratio of grain dry matter from current photosynthate to average leaf area (heading to maturity): It was calculated used the following formula-

Ratio of grain dry matter from current photosynthate (GDMCPn) to average

Yield sink - (panicle dry weight at heading + remobilization)

LA (heading to maturity) = ----------------------------- (mgcm^{-2})

LAI (heading to maturity)

Percentage of grain dry matter from current photosynthate: Percentage of grain dry matter from current photosynthate (GDMCPn%) was estimated using following formula-

Yield sink - (panicle dry weight at heading + remobilization)

GDMCPn (%) = --- × 100

Grain weight

Statistical analysis

Collected data on different parameters were analyzed statistically using the analysis of variance (ANOVA) technique with the help of computer package MSTAT-C [22], and mean differences was adjudged by DMRT. Raw data management, correlation and regression analysis was done by using Microsoft Excel spread sheet whenever it was needed. Graphical presentation was made by Microsoft Excel.

RESULTS AND DISCUSSION

Number of tillers hill^{-1}

Number of tillers hill^{-1} was significantly influenced by cultivation methods at different days after transplanting (Table 1). It was found that till 50 DAT, the highest number of tillers hill^{-1} was found by traditional cultivation methods but after 50 DAT to at harvest SRI method gave the highest number of tillers hill^{-1} (19.32, 16.9, 14.57 and 13.29 at 60, 70, 80 DAT and at harvest, respectively). The lowest number of tillers hill^{-1} was found by traditional cultivation methods at 60, 70, 80 DAT and at harvest. This finding is in agreement with [23], also found the highest number of tillers hill^{-1} at saturated condition.

The production of tillers hill^{-1} was significantly influenced by the tested varieties (Table 1). BRRI hybrid Dhan 3 showed the highest tillers hill^{-1} (11.09, 20.25, 15.72, 15.14 and 14.67 at 50, 60, 70, 80 DAT and at harvest, respectively) followed by hybrid variety Tia at harvest. The minimum tillers hill^{-1} (9.28, 13.65, 12.08, 11.07 and 9.92 at 50, 60, 70, 80 DAT and at harvest, respectively) was recorded from BRRI Dhan 45. Islam et al., Chowdhury et al., Akbar, Bhowmick and Nayak [24-27], reported similar trend of tillering habits with different varieties of rice. The combined effect of cultivation methods and variety had significant effect on number of tillers hill^{-1} at 30, 40, 50, 60, 70, 80 DAT and at harvest (Table 1). Results signified that SRI ×BRRI hybrid Dhan 3 treatment combination gave the highest number of tillers hill^{-1} (12.40, 23.60, 20.29, 20.27, 19.67 at 50, 60, 70, 80 DAT and at harvest, respectively) followed by SRI × BRRI hybrid 2 and SRI × Tia at harvest.

On the other hand, the lowest number of tillers hill^{-1} (8.13, 11.83, 8.43, 7.63 and 7.50 at 50, 60, 70, 80 DAT and at harvest, respectively) was found from SRI × ACI 6, Traditional × Tia, Traditional × ACI 6 (both at 70 and 80 DAT) and Traditional × BRRI Dhan 45 treatment combination, respectively.

Shoot dry matter accumulation and its remobilization to grain

Significantly varied results were observed in terms of shoot dry matter accumulation as influenced by different cultivation system in *Boro* rice at flowering and maturity stages (Table 2).

Table 1: Effect of different varieties and cultivation methods on number of tillers hill^{-1} at different days after transplanting of rice in *Boro* season.

	Number of tillers hill^{-1}						
	30 DAT	**40 DAT**	**50 DAT**	**60 DAT**	**70 DAT**	**80 DAT**	**At harvest**
Cultivation methods							
Traditional	3.63 a	8.19 a	10.49 a	15.0 b	10.9 b	10.34 b	9.44 b
SRI system	2.33 b	6.38 b	9.54 b	19.32 a	16.9 a	14.57 a	13.29 a
Varieties							
BRRI hy. Dhan 2	2.75 d	6.80 d	9.87 cd	17.27 c	13.03 bc	11.75 d	10.42 e
BRRI hy. Dhan 3	2.79 cd	7.22 c	11.09 a	20.25 a	15.72 a	15.14 a	14.67 a
Heera 3	3.50 a	8.57 a	9.94 cd	16.14 d	13.30 b	11.57 d	10.92cd
Panna1	3.08 bc	7.19 c	9.53 de	17.77 b	12.92 bcd	12.10 c	10.58 de
Tia	2.79 d	5.97 e	10.37 b	17.79 b	12.52 de	12.29 c	12.17 b
ACI 6	2.68 d	7.10 cd	9.90 cd	17.92 b	15.69 a	13.30 b	11.34 c
Tej	3.10 b	7.77 b	10.15 bc	16.52 d	12.70 cd	12.44 c	10.94 cd
BRRI Dhan 45	3.14 b	7.69 b	9.28 e	13.65 e	12.08 e	11.07 e	9.920 f
Interaction							
Traditional X							
BRRI hy. Dhan 2	2.67 de	6.27 h	9.17 fg	13.43 h	9.630 i	9.43 g	8.67 h
BRRI hy. Dhan 3	3.00 d	7.07 f	11.67 b	17.33 e	13.57 e	12.00 de	10.83 ef
Heera 3	4.43 ab	10.60 a	10.73 c	15.40 g	10.47 hi	9.97 fg	8.67 h
Panna1	3.43 c	7.40 e	9.73 e	14.93 g	10.67 hi	10.63 f	9.83 g
Tia	4.20 b	7.73 d	9.83 de	11.83 i	11.00 h	10.90 ef	9.67 g
ACI 6	3.33 c	8.27 c	9.70 e	13.17 h	8.43 j	7.63 h	10.17 fg
Tej	4.57 a	9.77 b	11.43 b	17.00 ef	12.23 fg	11.87 e	10.20 fg
BRRI Dhan 45	3.37 c	8.47 c	10.00 de	16.90 ef	11.17 gh	10.53 f	7.50 i
SRI system X							
BRRI hy. Dhan 2	2.83 de	7.33 e	10.57 c	21.10 b	16.43 c	14.07 bc	14.33 b
BRRI hy. Dhan 3	2.57 e	7.37 e	12.40 a	23.60 a	20.29 a	20.27 a	19.67 a
Heera 3	2.57 e	6.57 g	9.77 e	20.17 bc	16.13 cd	13.17 c	11.17 e
Panna1	2.73 de	6.97 f	9.33 f	20.60 b	15.17 d	13.57 bc	11.33 de
Tia	1.37 g	4.20 j	8.73 h	15.47 g	14.03 e	13.67 bc	13.50 b
ACI 6	2.03 f	5.93 i	8.13 i	18.50 d	17.80 b	14.60 b	11.10 e
Tej	1.63 g	5.77 i	8.87 gh	16.03 fg	13.17 ef	13.00 cd	11.67 cde
BRRI Dhan 45	2.90 de	6.90 f	10.17 d	19.10 cd	15.73 cd	14.50 b	12.17 cd
CV(%)	6.22	8.55	7.38	8.52	9.38	7.11	8.55

Within a column for each site, values followed by the same letter (s) are not significantly different at 5% level of probability as per DMRT.

Results showed that the highest shoot dry matter accumulation was recorded by SRI system (42.33g at flowering). At maturity stage, the highest shoot dry matter accumulation was also recorded by SRI system (33.47g). But, the highest shoot reserve translocation was recorded from traditional cultivation method (25.39%). The shoot dry matter accumulation was significantly varied due to varietal differences (Table 2). The highest shoot dry matter accumulation (41.44 g) at flowering stage was obtained from BRRI hybrid Dhan 3 followed by ACI 6, Tej and Tia respectively. There was no significance difference in shoot dry matter accumulation at maturity stage among the varieties. Interaction effect of cultivation system and variety was significantly influenced by shoot dry matter accumulation at flowering and maturity stage (Table 2). Results indicated that the highest shoot dry matter accumulation (56.10 g at flowering) was obtained from SRI × BRRI hybrid Dhan 3. At maturity stage, the highest shoot dry matter accumulation (36.43 g) was also recorded from SRI × BRRI hybrid Dhan 3 treatment combination. On the other hand, the lowest shoot dry matter accumulation was recorded from SRI × BRRI Dhan 45 (21.00 g) at maturity. The shoot reserve translocation was highest (43.60 %) in Traditional × Heera 3 treatment combination followed by SRI × BRRI hybrid Dhan 3 treatment combination and the lowest was (17.37%) in SRI × BRRI Dhan 45.

Total dry matter hill^{-1}

Significantly varied results were observed in terms of dry weight hill^{-1} as influenced by different cultivation systems in *Boro* rice at two different growth stage (Table 2). Results showed that, at both growth stages the highest dry weight hill^{-1} was recorded by SRI system (46.27 and 68.87 g at pre-anthesis and maturity stage, respectively). The results obtained from Traditional cultivation method showed the lowest total dry weight hill^{-1} (43.87 and 45.73 g at pre-anthesis and maturity stage, respectively). The highest total dry matter (48.44 g) at pre-anthesis stage was obtained from BRRI hybrid Dhan 3. The variety BRRI hybrid Dhan 3 also

Table 2: Influence of different varieties and cultivation methods on shoot dry matter accumulation at pre-anthesis and at maturity, shoot reserve translocation and total dry matter accumulation at pre-anthesis and at maturity of rice in *Boro* season.

	Shoot dry matter at pre-anthesis (g hill^{-1})	**Shoot dry matter at maturity (g hill^{-1})**	**Shoot reserve translocation (%)**	**Total dry matter**	
				at pre-anthesis (g hill^{-1})	**at maturity (g hill^{-1})**
Cultivation methods					
Traditional	39.93 a	29.79 b	25.39 a	43.87 b	45.73 b
SRI system	42.33 a	33.47 a	20.93 b	46.27 a	68.87 a
Variety					
BRRI hy. Dhan2	34.00 ab	27.33	19.62 c	45.67 ab	61.76 ab
BRRI hy. Dhan3	41.44 a	28.58	31.03 a	48.44 a	63.89 a
Heera 3	34.00 ab	27.34	19.59 c	43.98 ab	58.58 bc
Panna1	34.00 ab	28.46	16.29 c	39.56 ab	58.78 bc
Tia	36.78 ab	28.56	22.35 b	45.56 ab	61.56 ab
ACI 6	38.22 a	27.44	28.21 ab	43.78 ab	54.22 cd
Tej	36.88 ab	28.48	22.78 c	40.06 ab	53.52 d
BRRI Dhan45	32.44 b	29.96	17.64 d	37.89 b	53.22 d
Interaction					
Traditional X					
BRRI hy. Dhan2	46.08 bc	33.11 b	28.15 bc	52.33 b	49.63 cd
BRRI hy. Dhan3	56.00 a	36.41 a	34.98 b	48.10 b	77.77 a
Heera 3	45.78 bc	25.82 c	43.60 a	40.20 c	65.47 abc
Panna1	38.33 cde	33.41 b	17.84 d	43.67 c	71.33 ab
Tia	33.00 egf	25.92 c	21.45 c	40.00 c	65.67 abc
ACI 6	41.00 cde	27.74 c	32.34 b	48.00 b	77.67 a
Tej	33.10 egf	22.91 cd	30.79 bc	52.73 b	49.83 cd
BRRI Dhan45	45.33 bc	32.45 bc	28.41 bc	52.33 b	49.67 cd
SRI system X					
BRRI hy. Dhan2	32.67 efg	23.67 cd	27.55 bc	38.00 cd	72.67 ab
BRRI hy. Dhan3	56.10 a	36.43 a	35.06 b	63.00 a	80.00 a
Heera 3	49.63 ab	33.96 b	31.57 bc	56.03 ab	49.87 cd
Panna1	37.33 cde	26.89 c	27.97 bc	44.33 c	73.00 ab
Tia	49.33 ab	33.96 b	31.16 bc	56.33 ab	49.67 cd
ACI 6	42.00 bcd	33.66 b	19.86 d	47.33 b	55.00 bcd
Tej	49.43 ab	26.99 c	45.40 a	56.23 ab	49.77 cd
BRRI Dhan45	22.67 h	21.00 cd	17.37 e	28.33 e	38.67 d
CV(%)	5.89	5.56	8.73	9.93	10.33

Within a column for each site, values followed by the same letter (s) are not significantly different at 5% level of probability as per DMRT.

showed highest total dry matter (63.89 g) at harvest. At pre-anthesis stage the lowest total dry matter hill^{-1} (37.89 g) was obtained from BRRI Dhan 45. The lowest total dry matter was also produced in BRRI Dhan 45 (53.22 g) at harvest. The results uphold with the findings of Islam et al., Amin et al., Patnaik et al., [24,28,29], who reported that dry matter accumulation capacity depends mainly on varietal performance. Interaction effect of cultivation system and variety had significant influence on total dry matter hill^{-1} at different growth stages (Table 2). Results indicated that the highest total dry weight hill^{-1} (63.00 and 80.00 g at pre-anthesis and maturity respectively) was with SRI × BRRI hybrid Dhan 3 which was statistically similar with Traditional× BRRI hybrid Dhan 2 at maturity.

The results recorded from SRI × BRRI Dhan 45 showed the lowest total dry weight hill^{-1} (28.33 and 38.67 g at pre-anthesis and at maturity respectively). The results obtained from all other treatments at different growth stages showed significantly differences compared to the highest and the lowest values of total dry weight hill^{-1}.

Leaf area index

Significantly varied result was observed in case of leaf area index as influenced by cultivation system and variety of *Boro* rice (Table 3). Result showed that the highest leaf area index was recorded by SRI system (4.13) and the results obtained from Traditional cultivation system showed the lowest leaf area index (3.73). Leaf area index was significantly influenced by the different tested varieties (Table 3). Rice variety of BRRI hybrid 3 showed the highest leaf area index (4.28), which was statistically similar with Tia followed by Panna 1. The minimum leaf area index was found in BRRI Dhan 45 (3.56) which was statistically identical with ACI 6 and Tej. Interaction effect of cultivation system and variety significantly influenced the leaf area index at different growth stages (Table 3). Results indicated that the highest leaf area index (4.68) was with SRI × BRRI hybrid Dhan 3 which was statistically similar with Traditional × BRRI hybrid Dhan 3 but lowest leaf area index (3.36) was with Traditional × BRRI Dhan 45.

Source-sink relation

Cultivation method, variety and their interaction significantly influenced the ratio of spikelet's number to leaf area (at heading), yield sink to leaf area (at heading) and grain dry matter accumulated from current photosynthetic assimilation to leaf area (heading to maturity) (Table 3). These three parameters were used to explain the source-sink relation in the studied cultivation method and varieties. Irrespective of varieties, the ratio of spikelet's number to leaf area (LA) was differed significantly among the test varieties in the *Boro* season. The ratio of spikelet's number to LA (at heading) was significantly affected by cultivation method. SRI cultivation method showed upward trend in ratio of yield sink to LA (at heading) and ratio of spikelet's number to LA (at heading). BRRI hybrid Dhan 3, BRRI hybrid Dhan 2, Heera 3, Tej, Tia and BRRI Dhan 45 (0.57, 0.56, 0.56, 0.55, 0.54 and 0.56 mg cm^{-2} respectively) were statistically identical but different from Panna1 and ACI 6 (0.47 and 0.45 mg cm^{-2}) in case of spikelet's number to LA (at heading) ratio. The highest ratio of yield sink to LA (at heading) was recorded from BRRI hybrid Dhan 3 (16.47 mg cm^{-2}) with SRI cultivation system. In traditional cultivation system, ratio of yield sink to LA (at heading) was significantly decreased, irrespective of varieties. Table 3 showed that ratio of grain dry matter accumulated from current photosynthetic assimilation to LA (heading to maturity) was significantly higher in BRRI hybrid Dhan 3 (5.94 mg cm^{-2}) which was statistically similar with Heera 3, Tej and Tia (5.91, 5.86, 5.46 mg cm^{-2}) respectively. In SRI cultivation system, all hybrid variety showed superiority over test inbred BRRI Dhan 45 in respect of post-heading photosynthetic assimilation per unit LA (at heading). It was indicated that the studied hybrids had higher source use efficiency in SRI cultivation system and resulted higher yield sink per unit LA (at heading). BRRI hybrid Dhan 3 produced higher grain yield based on the shoot reserve remobilization and greater leaf area. But in Traditional cultivation system, the ratio of grain dry matter accumulated from current photosynthetic assimilation to leaf area (heading to maturity) decreased in all test hybrid varieties and provided lower yield sink per unit leaf area (at heading) in comparison to inbred BRRI Dhan 45. The varieties have a significant variation on these traits. Due to the genetical traits of each varieties they differ one another. These data of present study are in agreement with those reported by El-Refaee [30]. The uptakement of the nutrients from soil is the main pioneer of the higher growth and development of the plant. Under present study it is said that, SRI system provide the higher spacing for easy and better utilization of plant essential nutrients than TCM. The higher the source of rice plant (leaf area) higher the sink (grain) from the better compartmentalization of plant dries matter to sink through photosynthesis. These results were in agreement with that obtained by [31,32]. Ali and Izhar [33], also reported that, SRI increased plant height, total tillers per m^2 and leaf area index indicating higher chlorophilic area improving photosynthesis efficiency of plant which in turn resulted in higher dry matter accumulation per m^2 and better yield sink to leaf area, higher grain dry matter from current photosynthates to leaf area. The peak tiller production time was enhanced in system of rice intensification than conventional cultivation method of cultivation resulting in higher number of tiller per m^2 [33]. As that system of rice intensification increased supplying capacity of the soil which in turn resulted in higher leaf growth rate and higher leaf area index. The higher leaf area index might be due to higher no of tiller putting forth more leaves resulted higher leaf area index. SRI promotes more vigorous growth leaf area index than the normal planting system [33].

Yield components

Panicles hill^{-1}: Significantly varied results were observed in case of panicles hill^{-1} as influenced by cultivation method of *Boro* rice at harvest (Table 4). Results showed that at harvest the highest number of panicles hill^{-1} (13.29) was recorded by SRI method where the lowest panicles hill^{-1} (9.44) was recorded by Traditional method. This finding is in agreement with Anwar et al, [23]. The production of panicles hill^{-1} was significantly influenced by different rice varieties (Table 4). Rice variety of BRRI hybrid Dhan 3 showed the highest number of panicles hill^{-1} (14.67) followed by hybrid rice variety Tia. The minimum panicles hill^{-1} (9.92) at harvest was found in hybrid rice variety Heera 3 which was closely followed by BRRI hybrid Dhan 2. Interaction effect of cultivation systems and variety significantly influenced the

Table 3: Influence of different varieties and cultivation methods on leaf area idex, source-sink relationship, percentage of grain dry matter accumulation from current photosynthate of rice in *Boro* season.

	Leaf area index	Ratio of spikelet's no. to LA* (cm^{-2})	Ratio of yield sink to LA*(mg cm^{-2})	Ratio of grain DM from current Pn to LA**(mg cm^{-2})	Grain DM from Current Pn (%)
Cultivation methods					
Traditional	3.73 b	0.482 b	10.978 b	4.2837 b	78.08 b
SRI system	4.13 a	0.592 a	14.104 a	5.9390 a	82.19 a
Variety					
BRRI hy. Dhan 2	4.00 b	0.569 a	13.570 ab	3.26 c	79.70 ab
BRRI hy. Dhan 3	4.28 a	0.579 a	14.079 a	5.94 a	81.62 a
Heera 3	4.03 b	0.569 a	13.490 ab	5.91 a	80.30 ab
Panna1	4.13 ab	0.456 b	12.707 b	3.20 c	80.00 ab
Tia	4.20 a	0.540 a	13.020 b	5.46 a	80.03 ab
ACI 6	3.65 c	0.476 b	12.507 b	4.97 b	79.37 ab
Tej	3.61 c	0.558 a	13.00 b	5.86 a	77.98 b
BRRI Dhan 45	3.56 c	0.561 a	9.410 c	5.04 b	77.88 b
Interaction					
Traditional X					
BRRI hy. Dhan 2	4.32 ab	0.431 d	11.201 cd	2.937 f	80.88 c
BRRI hy. Dhan 3	4.53 a	0.537 bc	11.602 c	4.830 d	85.77 a
Heera 3	4.23 ab	0.494 cd	11.903 c	4.730 d	81.69 bc
Panna1	4.25 ab	0.469 cd	8.786 e	2.877 f	82.85 abc
Tia	3.93 b	0.479 cd	11.321 cd	4.164 de	80.78 c
ACI 6	3.40 c	0.466 cd	8.867 e	5.255 cd	81.59 bc
Tej	3.83 b	0.531 bc	11.680 c	4.430 de	80.88 c
BRRI Dhan 45	3.36 c	0.476 cd	11.983 c	5.155 cd	74.49 d
SRI system X					
BRRI hy. Dhan 2	4.35 ab	0.480 cd	15.088 ab	3.589 ef	81.00 c
BRRI hy. Dhan 3	4.68 a	0.654 a	16.479 a	7.506 a	85.98 a
Heera 3	4.35 ab	0.645 a	15.078 ab	6.6723 ab	81.50 bc
Panna1	4.38 ab	0.588 ab	10.039 de	5.983 bc	80.84 c
Tia	4.25 ab	0.602 a	14.719 b	6.1890 b	81.83 bc
ACI 6	3.96 b	0.596 ab	14.202 b	6.723 ab	81.40 bc
Tej	3.98 b	0.639 a	14.212 b	7.3063 a	80.78 c
BRRI Dhan 45	3.48 c	0.592 ab	10.033 de	5.938 bc	70.67 e
CV(%)	5.68	6.84	6.83	11.69	7.33

Within a column for each site, means followed by the same letters are not significantly different at 5% level of probability as per DMRT.
Abbreviations: DM=Dry Matter, Pn=Photosynthesis, LA= Leaf Area, *= at heading and ** = average from heading to maturity

Table 4: Effect of cultivation method and variety on yield contributing and yield parameter of rice in *Boro* season.

	Yield contributing and yield data						
Cultivation methods	**Panicles hill^{-1}**	**Filled spikelet's panicle^{-1}**	**Unfilled spikelet's panicle^{-1}**	**Spikelet filling percentage**	**1000-grain weight (g)**	**Grain yield (t ha^{-1})**	**Harvest index (%)**
Traditional	9.44 b	144.90 b	9.21 b	94.02 a	26.49	6.59 b	41.19 b
SRI system	13.29 a	160.67 a	17.69 a	90.08 b	26.25	7.62 a	42.22 a
Variety							
BRRI hy. Dhan 2	10.42 de	154.30 d	22.92 b	87.06 d	25.82 d	6.44 e	41.34 c
BRRI hy. Dhan 3	14.67 a	149.50 d	6.09 f	96.08 a	28.67 a	8.52 a	43.26 a
Heera 3	9.920 e	142.50 e	8.67 e	94.26 b	25.67 d	8.03 b	42.89 ab
Panna1	10.58 d	151.30 d	10.17 d	93.70 bc	26.47 c	7.60 c	42.47 b
Tia	12.17 b	159.80 c	12.35 c	92.82 bc	27.16 b	8.14 b	43.23 a
ACI 6	11.34 c	179.30 a	26.58 a	93.55 bc	21.91 e	6.67 d	41.37 c
Tej	10.94 cd	167.30 b	7.67 e	93.12 bc	27.50 b	6.30 f	41.07 c
BRRI Dhan 45	10.92 cd	118.20 f	3.17 g	90.54 c	27.75 b	5.19 g	38.02 d
Interaction							

Traditional X							
BRRI hy. Dhan 2	8.67 h	134.70 g	6.50 ghi	95.39 a	25.60 ef	6.39 hi	41.25 ef
BRRI hy. Dhan 3	8.67 h	146.30 f	4.67 hi	96.90 a	28.56 a	6.51 g	41.46 ef
Heera 3	7.50 i	137.80 g	4.03 i	97.15 a	26.57 cd	7.60 de	42.65 cd
Panna1	9.83 g	135.80 g	12.67 de	91.46 b	25.63 ef	7.18 f	42.04 de
Tia	10.83 ef	172.80 b	13.87 d	92.56 ab	28.52 a	7.85 d	42.83 bcd
ACI 6	10.17 fg	154.70 e	6.83 ghi	95.77 a	22.24 g	6.13 j	40.73 f
Tej	10.20 fg	165.00 d	6.00 ghi	96.49 a	26.70 cd	5.93 j	40.64 f
BRRI Dhan45	9.67 g	112.00 i	18.33 c	85.93 c	28.08 ab	5.16 k	37.94 g
SRI system X							
BRRI hy. Dhan2	12.17 d	169.70 c	9.33 efg	94.78 a	26.04 de	6.48 gh	41.43 ef
BRRI hy. Dhan3	19.67 a	173.80 b	39.33 b	95.31 a	28.77 a	9.77 a	45.06 a
Heera 3	11.17 e	147.20 f	12.50 de	92.17 ab	24.76 f	8.46 c	43.12 bc
Panna1	11.33 e	166.80 cd	7.67 fgh	95.60 a	27.30 bc	8.01 d	42.90 bc
Tia	13.50 c	146.80 f	10.83 def	93.12 ab	25.80 de	9.19 b	43.62 b
ACI 6	12.50 d	204.00 a	46.33 a	81.49 d	21.58 h	7.20 f	42.01 de
Tej	11.67 de	152.70 e	7.50 fghi	81.54 d	28.30 a	6.66 g	41.50 ef
BRRI Dhan 45	14.33 b	124.30 h	8.00 fgh	93.95 ab	27.41 bc	5.22 k	38.10 g
CV(%)	5.389	11.267	8.319	4.3	6.684	6.671	8.274

Within a column for each site, values followed by the same letter (s) are not significantly different at 5% level of probability as per DMRT.

number of panicles hill^{-1} at harvest (Table 4). Results indicated that the highest number of panicles hill^{-1} (19.67) was with SRI ×BRRI hybrid Dhan 3 followed by SRI × BRRI Dhan 45. The results recorded from Traditional × Heera 3 showed the lowest number of panicles hill^{-1} (7.50) at harvest.

Filled and unfilled spikelet's panicle^{-1}: Cultivation systems had significant effect on filled and un-filled spikelet's panicle^{-1} (Table 4). Results showed that the highest filled spikelet's panicle^{-1} was recorded by SRI system (160.67) where the lowest (144.90) was obtained from Traditional cultivation system. The highest un-filled spikelet's panicle^{-1} was also recorded by SRI system (17.69) where the lowest (9.21) was obtained from Traditional cultivation system. The result under the present study was similar with the findings of Bouman et al, [34]. Performance of test varieties under the present study showed a significant difference in respect of spikelet's panicle^{-1} (Table 4). The highest filled spikelet's panicle^{-1} (179.30) was observed in variety of ACI 6 where the lowest filled spikelet's panicle^{-1} (118.20) was observed in variety of BRRI Dhan 45. Again, the highest un-filled spikelet's panicle^{-1} (26.58) was observed in variety of ACI 6 where the lowest un-filled spikelet's panicle^{-1} (3.17) was observed in variety of BRRI Dhan 45. The results obtained by [25,27,35], was in agreement with findings of present study. Combined effect of cultivation methods and varieties under the present study showed a significant difference in respect of spikelet's panicle^{-1} (Table 4). Results denoted that the highest filled spikelet's panicle^{-1} (204.00) was observed in SRI × ACI 6 followed by SRI ×BRRI hybrid Dhan 3 where the lowest filled grains panicle^{-1} (112.00) was observed in Traditional × BRRI Dhan 45 followed by SRI × BRRI Dhan 45. Again, the highest un-filled spikelet's panicle^{-1} (46.33) was observed in SRI × ACI 6 followed by SRI × BRRI hybrid 3 where the lowest un-filled spikelet's panicle^{-1} (4.03) was observed in Traditional × Heera 3.

Spikelet filling percentage: The spikelet filling percentage varied among the cultivation methods and tested varieties. All the test hybrid varieties contained the significantly higher number of spikelet filling percentage over BRRI Dhan 45. The magnitude of decrease in grain filling percentage was more or less similar in all studied varieties under traditional cultivation method.

1000-grain weight (g): Cultivation methods had not significant effect on 1000-grain weight of *Boro* rice (Table 4). Significant influence of different varieties was observed on 1000-grain weight (Table 4). It is attained that the highest 1000-grain weight (28.67 g) was in BRRI hybrid Dhan 3 treatment followed by BRRI Dhan 45, Tej and Tia. The lowest 1000-grain weight (21.91 g) was observed in ACI 6. The results are in agreement with the findings of Chowdhury et al and Rahman et al. [25,36], who observed varied 1000-grain weight among different varieties of rice. Combined effect of cultivation methods and varieties had significant influence on 1000-grain weight of rice (Table 4). Results indicated that the highest 1000-grain weight (28.77 g) was with SRI × BRRI hybrid Dhan 3 which was statistically identical with SRI × Tej, Traditional × BRRI hybrid 3, and Traditional × Tia and closely followed by Traditional × BRRI Dhan 45. On the other hand, the lowest result 1000-grain weight (21.58 g) was recorded from SRI × ACI 6 followed by Traditional × ACI 6. The results obtained from all other treatment combinations were significantly different compared to the highest and the lowest 1000-grain weight.

Grain yield: Cultivation methods had significant effect on grain yield of *Boro* rice (Table 4). It was found that the highest grain yield was from SRI method (7.62 t ha^{-1}) where the lowest was from traditional method (6.59 t ha^{-1}). Different varieties significantly produced variable grain yield (Table 4). The highest grain yield was recorded by BRRI hybrid Dhan 3 (8.52 t ha^{-1}) followed by Heera 3 and Tia whereas the lowest grain yield (5.19 t ha^{-1}) was obtained from BRRI Dhan 45 followed by Tia and Heera 3. The results are in agreement with the findings of Islam et al, Siddiquee et al and Chowdhury et al. [24,37,25], whose stated that, the grain yield differed significantly among the varieties. Combined effect of cultivation methods and varieties had significant influence on grain yield (Table 4). The highest grain yield (9.77 t ha^{-1}) was with SRI × BRRI hybrid Dhan 3 followed by SRI × Tia. The lowest result was recorded from Traditional × BRRI Dhan 45 (5.16 t) which was statistically identical with SRI × BRRI Dhan 45. The results obtained from the rest of the treatment combinations showed intermediate level of grain yield compared to the highest and the lowest grain yield.

Harvest index: Cultivation methods had significant effect on harvest index (Table 4). It was found that the highest harvest index was from SRI method (42.22%) where the lowest was from traditional method (41.19%). Different varieties significantly produced variable harvest index. The highest harvest index was recorded by BRRI hybrid Dhan 3 (43.26%) which was statistically similar with variety Tia and Heera 3 whereas the lowest harvest index (38.02%) was obtained from BRRI Dhan 45 followed by ACI 6 and Tej. Combined effect of cultivation methods and varieties had significant influence on harvest index (Table 4). The highest harvest index (45.06) was with SRI × BRRI hybrid Dhan 3 followed by SRI × Heera 3 and SRI × Tia. The lowest result was recorded from Traditional × BRRI Dhan 45 (37.94%) which was statistically identical with SRI × BRRI Dhan 45.

CONCLUSION

The SRI cultivation method was more suitable than traditional cultivation method in respect of growth and yield of hybrid rice. Among eight rice varieties, BRRI hybrid Dhan 3 exhibited the best performance in relation to its morpho-physiological characteristics and yield attributes. Consequently, the highest yield (9.77 t ha^{-1}) was obtained from SRI × BRRI hybrid Dhan 3 followed by SRI × Tia (9.19 t ha^{-1}) and SRI × Heera 3 (8.46 t ha^{-1}). Under SRI method, all the studied hybrids exhibited the higher yield than inbred BRRI Dhan 45.

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