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Physiological responses of high-yielding rice cultivars to elevated nitrogen levels

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The nitrogen (N) requirement of rice cultivars may differ because of differences in growth duration and N dynamics in the soil. Variability in N utilization, content and uptake by grains affects the physiological aspects and yield. Therefore, a glasshouse experiment was conducted in Bangladesh to investigate the impact of cultivars and N content on growth dynamics, biomass partitioning, yield, and nitrogen-use efficiency (NUE). Ten high-yielding *boro* (dry season irrigated) rice cultivars *viz*. BRRI dhan28, BRRI dhan29, BRRI dhan47, BRRI dhan50, BRRI dhan59, BRRI dhan60, BRRI dhan61, Binadhan-8, Binadhan-10, and Binadhan-14, along with four N concentrations (0, 70, 140, and 210 mg kg^{-1}in the soil) were used. The cultivar Binadhan-8 had a higher yield in all N treatments because of the highest total dry matter (TDM), effective tillers $hill^{-1}$, and grains $panicle^{-1}$.Growth, TDM, yield, and NUE were increased with fertilizer application up to N_{140}, after which declined with increasing N. The highest N content in grain and straw (3.047% and 1.737%) was shown by Binadhan-8. Significant relationships between N concentration and growth dynamics, biomass partitioning, N content, uptake and yield were observed. In addition, excess use of N decreased efficiency, because at a higher concentration of N, absorption exceeds utilization. Therefore, the study was useful in the screening of the most efficient cultivars, which could be used to enhance crop yield and reduce the use of N fertilizer.

Keywords: Nitrogen fertilizer, Modern rice cultivars, Growth dynamics, Total dry matter, Physiological efficiency

INTRODUCTION

Rice is one of the most important crops worldwide, and it is the staple diet of approximately 2.7 billion people. Consequently, 50% more rice than is produced today will be needed by 2050 to cope with the growing demand (Ashikari et al., 2005).The slogan ‘Rice is Life’ is apt for Bangladesh, as this crop plays a vital role in the national food security and is a means of livelihood for millions of rural households in the country. The population of Bangladesh is approximately 160 million and continues to grow by two million persons every year; at this rate, there will an increase of 30 million people over the next 20 years (BPF, 2015).At the current rate of population growth, superior resource management technologies for rice yield will be required to meet the growing demand.

Previously, to achieve better yield, farmers elevated the concentration of N fertilizer, which generally supports growth dynamics. However, regular excessive use of N fertilizers may impair soil health, and will not sustain crop production in the long term. The excessive use of N fertilizers resulted in decreases in physiological nitrogen use efficiency (Jiang et al., 2005). In addition, N is a critical macro-element for plant growth and development, and it is the most yield-limiting nutrient in the rice cropping systems worldwide (Kropff et al., 1993; Cassman et al., 1998; Cole et al., 2008; Lebauer and Treseder, 2008; Sun et al., 2012).

Average rate of N application for rice production in Bangladesh is higher, and the nitrogen use efficiency (NUE) is lower than that of other major rice growing countries. Low NUE of irrigated rice increases environmental pollution through rapid loss of applied N by volatilization, de nitrification, and nutrient leaching from farms (Singh et al., 1995; Singh et al., 1999; Eagle et al. 2000; Liu et al., 2008). The remobilized N was the largest contributor of N to the grain, and total N accumulation during the grain-filling period could be the greatest contributor to yield improvement (Lin et al., 2006).The yield of rice can be improved by optimizing the plant's N uptake through increased N recovery efficiency (Ohnishi et al., 1999; Walker et al., 2008; Thakuria et al. 2009). Therefore, optimizing N use by crops can considerably reduce N losses to the environment without compromising crop yields (Cui et al., 2006; Zheng et al., 2007). In addition, evaluation of rice supplemented with various concentrations of N can aid in the development of high-N-efficient varieties and the screening of appropriate genotypes for all cultivated conditions. Rice genotypes differ significantly in N uptake and utilization efficiency (Fageria, 2007) which also depends on soil texture, land topography, and the agro-ecological region.

Crop harvest and N fertilization are the largest sources of output and input of N, respectively, in an agricultural system. Therefore, the relationship between output and input of N can be used to describe NUE in agricultural production. In a theoretical system without any loss of N to the environment, NUE of 100% would be ideal, because N input would correspond exactly to N output. Practically, this is not possible because agriculture operates in an open environment where there is continuous exchange of nutrients between the soil, environment, water, and air (Robertson et al., 2013).

Rational application of N fertilizer contributes to the efficient use of this nutrient in agricultural systems, but it does not necessarily optimize the NUE. Thus, a conflict occurs between desirable and acceptable levels of N fertilizer application to meet sustainable environmental standards. Farmers, extension workers, fertilizer industries, agricultural researchers, and policymakers rarely take into account issues concerning how much N is being added to the system, what is maintained, and what happens to the excess N. Thus, the sustainable use of N fertilizer is critical not only to increase the NUE, but also to increase crop yield, reduce production costs, and improve environmental quality.

There is information related to N management, required and uses efficiencies for rice cultivars in general, but there is little information on the interaction between N and cultivars for selection of cultivar based on growth and NUE in Asia, and none for Bangladesh, especially for irrigated and high-yield rice (*boro* rice). In Uttarakhand, India, NUE was increased with N concentrations up to 100 kg N ha^{-1} (Singh et al., 2014) infield conditions. Furthermore, the physiological basis of yield gap among N rates has not been studied extensively on the Old Brahmaputra Floodplain of Bangladesh. Such information is vital for identifying the physiological and morphological traits to support the selection and breeding of high-yield rice varieties. Therefore, identification of physiological traits contributing to superior yield performance of crop plants under N management systems will be useful in developing rice varieties. Considering these factors, an experiment was conducted to determine physiological responses, and to use this information to determine the optimum N concentration and the best cultivar for maximum yield. The hypotheses were as follows: (i) cultivars with a higher tendency for N use have the potential for obtaining maximum yield and (ii) there are trade-offs between N concentration and cultivars for maximum yield.

MATERIALS AND METHODS

Experimental site and weather condition

The experiment was conducted (using pots of 12.5-cm diameter) in a glasshouse under controlled conditions in the Agronomy Department, Bangladesh Agricultural University, Mymensingh, Bangladesh (latitude: 24°42΄55΄΄, longitude: 90°25΄47΄΄) during *boro*(dry) seasons of 2014-15 (November to May). The climate is humid subtropical monsoon. Daily rainfall and mean temperature for the experimental period are shown in Fig. 1. The physicochemical properties of the soil before the beginning of the experiment are shown in Table 1.

Table 1. Physicochemical properties of soil before start of the experiments

Soil property	Values
Soil texture	Clay loam
pH–H_2O	5.83
Ec (μs/cm)	143
Organic carbon (%)	1.125
Total N (%)	0.145
Available P (ppm)	23.3
Available K (ppm)	88.64
Available S (ppm)	59.64

Experimental design and treatments

Ten *boro* rice cultivars, BRRI dhan28, BRRI dhan29, BRRI dhan47, BRRI dhan50, BRRI dhan59, BRRI dhan60, BRRI dhan61, Binadhan-8, Binadhan-10, and Binadhan-14, were supplied by the Bangladesh Rice Research Institute (BRRI) and Bangladesh Institute of Nuclear Agriculture (BINA). The selected cultivars were the most popular and high-yielding ones cultivated during the *boro* season. It should be noted that in the *boro* season farmers of Bangladesh are completely dependent on irrigation to grow their crops. The experiment was conducted using a completely randomized design (CRD). The N treatments N_0-0 mg kg^{-1} soil, N_{70}-70 mg kg^{-1} soil, N_{140}- 140 mg kg^{-1}soil, and N_{210}- 210 mg kg^{-1}soil were used in the experiment. The number of pots for each set was 40 (10 × 4) and therefore, the total number of pots was 280 (40×7). Because destructive sampling was needed to record the data for the experiment, seven sets of pots having 40 in each set were maintained to facilitate the sampling program. In each replication, 40 pots were placed side by side while maintaining 10 to 25 cm between them. The replicates were separated by 1 m. The treatments in cultivars (V_1 - BRRI dhan28, V_2 - BRRI dhan29, V_3 - BRRI dhan47, V_4 -BRRI dhan50, V_5 - BRRI dhan59, V_6 - BRRI dhan60, V_7 - BRRI dhan61, V_8 – Binadhan-8, V_9 – Binadhan-10, and V_{10} -Binadhan-14) were randomly arranged to avoid any biasness placement.

Pot preparation and fertilizer application

Each pot was filled with 8 kg of soil and placed in the glasshouse of the Department of Agronomy, BAU, and Mymensingh. Extra water was applied to bring the soil moisture to a suitable level for seedlings because the pots were filled with dry soil. Two liters of water were added to saturate the soil. Fertilizer concentrations for pot experiments were applied as 0.8 g, 1.04 g, 0.9 g, and 0.03 g per pot in the form of Triple Super Phosphate (TSP), Muriate of Potash (MoP), gypsum, and zinc sulfate, respectively. Whole amounts of fertilizers were applied during the final pot preparation. The source of N was urea and was applied as per specified at 15 days after transplanting (DAT), 40 DAT, and 70 DAT.

Crop management

Forty days old seedlings (previously grown in the seedbed) of the cultivars were transplanted in the pot on January 15, 2015. During the growth period, especially in the early stages, sometimes weeds were observed and uprooted by hand. No major insects were noticed except rice hispa during the growth period. The infestation was controlled by applying insecticides (Fenitrothion 50 EC) in each pot at the tillering stage. Soil moisture was maintained at about field capacity during the experimentation.

Plant and growth dynamics measurement

In the experiment, phenological observations were made weekly. The anthesis date of rice was recorded using the decimal code scale proposed by Zadoks et al., (1974). Anthesis dates were recorded when 50% of the plants reached this stage in each plot. Observations on growth dynamics were made at active tillering (AT), panicle initiation (PI), flowering (FL), and physiological maturity (PM). The parameters to assess growth dynamics, such as plant height, leaf area index (LAI), crop growth rate (CGR), relative growth rate (RGR), and net assimilation rate (NAR) were recorded for each pot through destructive sampling. For each destructive sample, a plant was uprooted and washed with water. The leaf blades were separated from the leaf sheath and leaf area was measured by a leaf area meter (LI 3100, Licor, Inc., Lincoln NE, USA). Leaf area index was accordingly calculated from leaf area data. After measurement of leaf area, the plant samples were dried in an electric oven at 65°C for 72 hour until they reached at constant weight, and their dry weights were recorded. LAI, CGR, RGR, and NAR were calculated following the standard formulae (Radford, 1967; Hunt, 1978).

Table 2. Definitions and methods of calculating nutrient use efficiency

Nutrient efficiency	Definitions and formulas for calculation
Agronomic efficiency (AE)	The agronomic efficiency is defined as the economic production obtained per unit of nutrient applied. It can be calculated by: AE (mg mg^{-1}) = $G_f – G_u/N_a$, where G_f is the grain yield of the fertilized pot (mg), G_u is the grain yield of the unfertilized pot (mg), and N_a is the quantity of nutrient applied (mg)
Physiological efficiency (PE)	Physiological efficiency is defined as the biological yield obtained per unit of nutrient uptake. It can be calculated by: PE (mg mg^{-1}) = $BY_f – BY_u/N_f – N_u$, where, BY_f is the biological yield (grain plus straw) of the fertilized pot (mg), BY_u is the biological yield of the unfertilized plot (mg), N_f is the nutrient uptake (grain plus straw) of the fertilized pot, and N_u is the nutrient uptake (grain plus straw) of the unfertilized pot (mg)
Agro-physiological efficiency (APE)	Agro-physiological efficiency is defined as the economic production (grain yield in case of annual crops) obtained per unit of nutrient uptake. It can be calculated by: APE (mg mg^{-1}) = $G_f – G_u/N_{uf} – N_{uu}$, where, G_f is the grain yield of fertilized pot (mg), G_u is the grain yield of the unfertilized pot (mg), N_{uf} is the nutrient uptake (grain plus straw) of the fertilized pot (mg), N_{uu} is the nutrient uptake (grain plus straw) of unfertilized pot (mg)
Apparent recovery efficiency (ARE)	Apparent recovery efficiency is defined as the quantity of nutrient uptake per unit of nutrient applied. It can be calculated by: ARE (%) = ($N_f – N_u/N_a$) × 100, where, N_f is the nutrient uptake (grain plus straw) of the fertilized plot (mg), N_u is the nutrient uptake (grain plus straw) of the unfertilized pot (mg), and N_a is the quantity of nutrient applied (mg).

Biomass partitioning measurement

Biomass partitioning in the form of sheath weight, leaf weight, root weight, and total dry matter was calculated for each N treatment level for all cultivars. The sheath, leaf, and root dry weight was calculated during AT, PI, FL, and PM by placing the plant samples in the oven at 65°C for 72 h. Total dry matter of the plant was determined by adding shoot dry matter, including leaf blade, leaf sheath, Culm, and panicle (when applicable) and root dry matter.

Estimation of NUE indicators

NUE indicators were calculated according to Fageria et al. (2010), and are shown in Table 2.

Measurement of yield and yield components

Maturity date was identified when 90% of grains had matured. At maturity, the whole plant was cut at the ground level with a sickle. The harvested crop from each pot was bundled separately and tagged appropriately. After recording data for plant height and panicle length for each plant, plant materials were sun dried for grain collection. Finally, grain and straw yield and yield contributing parameters were recorded separately.

Data analysis
Data on crop growth, NUE indicators, yield components, and yield of rice were compiled and tabulated for statistical analysis. Analysis of variance was conducted with the computer package MSTAT-C. Means were tested using Duncan's Multiple Range Test (Gomez and Gomez, 1984)

RESULTS

Crop Phenology and environmental conditions during crop cycle
Crop duration was interactively determined by the cultivar and environment. Patterns for 10 cultivars with different phenology are shown in Fig. 2. In the present study, the average length of life cycle of cultivars was 141 days (d). The greatest difference between the minimal and maximal crop duration for cultivars was 28 d and the smallest difference was 13 d. Crop duration from emergence to FL varied from 95 d to 119 d depending on the cultivar. Grain filling duration exhibited variation based on cultivar from 27 d for Binadhan-14 to 34 for Binadhan-8.Daily mean temperature for the effective grain-filling period was constant for all cultivars because of the relative stable temperature after FL (Fig. 1). Considering phenology, during transplanting, PI, and FL daily mean temperatures were 17°C, 21°C, and 24°C, respectively. At the early stage of crop growth, there was no rainfall; however, at the grain-filling stage and onward, rainfall began, and maximum rainfall (46.6 mm) was recorded during the grain-filling period (Fig.1)

Growth dynamics
Significant effects of different cultivars and N fertilization on plant height and LAI are presented in Table 3.Plant height increased progressively over time attaining the greatest height at PM. The rate of increase, however, varied depending on the growth stage. A significant variation in plant height was caused by the cultivars and N concentrations, except at AT and PI. The greatest plant height (109.3 cm) at FL was measured for Binadhan-10,and the lowest (57.73 cm) for Binadhan-14.Plant height increased with increasing concentrations of N fertilizer up to N_{140}, then declined at higher concentrations at PM(from 67.53 cm to 97.57 cm at N_0 level and 76.60 cm to 114.0 cm at N_{140} level).

LAI is the basic physiological parameter, which indicated the size the crop assimilated per unit area.LAI of rice with different concentrations of N fertilizer and cultivars showed substantial differences across the growth stages. LAI at lower nitrogen concentrations was less than at higher ones. As the N levels increased, LAI also gradually increased from N_0 to $N_{140}$and was greatest at N_{140} for all cultivars. Considering the growth stage, LAI increased sharply, reaching a peak at FL and then decreased irrespective of treatment differences. The rate of decrease of LAI after attaining its peak was more rapid. Maximum LAI (6.16) was attained at FL by Binadhan-8. LAI decreased after FL reflecting the loss of some existing leaves through senescence. A significant relationship (R^2=0.79, p<0.01) between grain yield and LAI at FL is shown in Fig 3a. Cultivars having a greater LAI could possibly absorb more solar radiation, photosynthesize more, and ultimately produce higher yields.

Regarding LAI and CGR, it was observed that CGR increased parallel with the increase in leaf area over the time until FL and then decreased (Table 4).CGR at N_{140} remained higher irrespective of cultivar and attained a maximum of 27.45 g cm^{-2} day^{-1}at FL for Binadhan-8 and a minimum was noted at N_0. CGR for Binadhan-8 receiving N_{70}, N_{140}, and N_{210} was 79, 81, and 80% higher, respectively, than those receiving no N fertilizer. Grain yield variations for cultivars were significantly and positively correlated (R^2=0.77, p<0.01) with CGR at FL (Fig. 3b).

The pattern of RGR changes at different N concentrations was similar, but the computed RGR at higher N concentrations was greater than at the concentration below it up to N_{140} (Table 4). Irrespective of treatments, RGR was greater at the early stage (AT) and showed a decreasing trend with the advancement of plant age. The decrease in RGR was probably caused by increased metabolically active tissue, which contributed less to plant growth. Based on the trend for RGR in rice cultivars,

Figure1. Maximum and minimum temperatures (°C) and total rainfall (mm) at the experimental site (Mymensingh, Bangladesh) during the experimental period

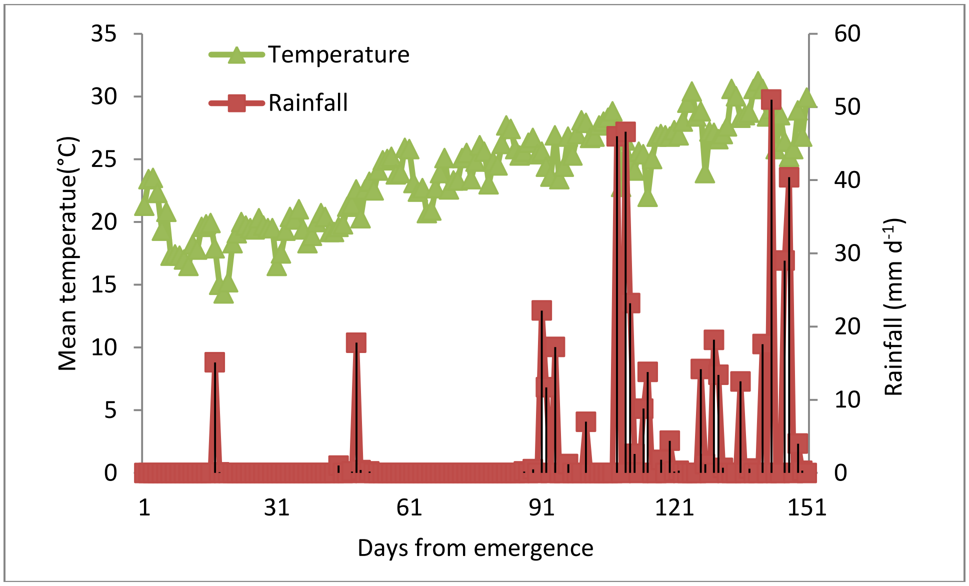


Figure 2.Crop phenology of high-yield rice cultivars of Bangladesh. Bar shows the length of each developmental phase: Emergence(Em), panicle initiation (PI)(green bars), PI-anthesis(At)(black bar), and At-physiological maturity(PM)(red).

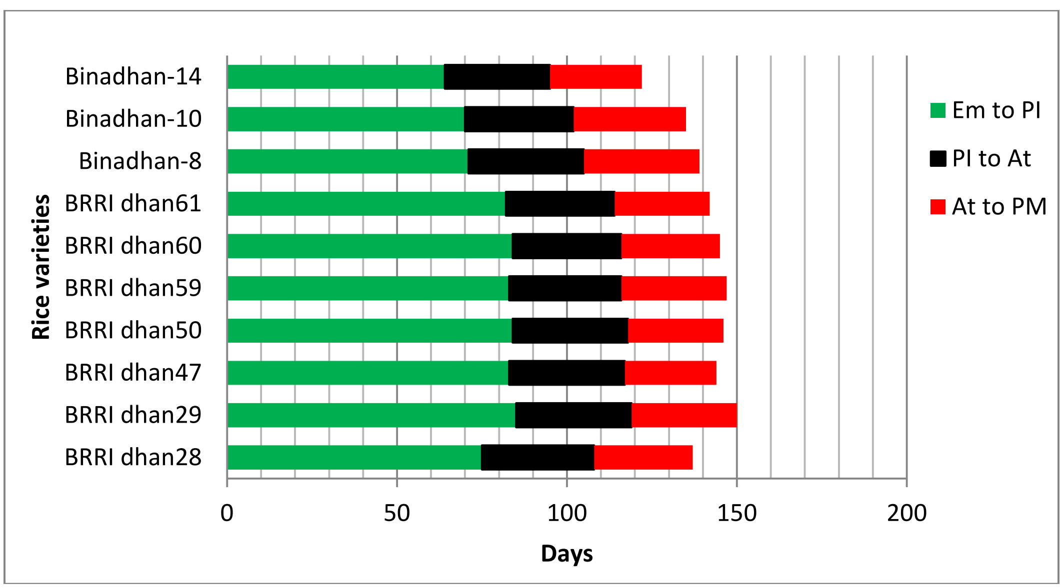


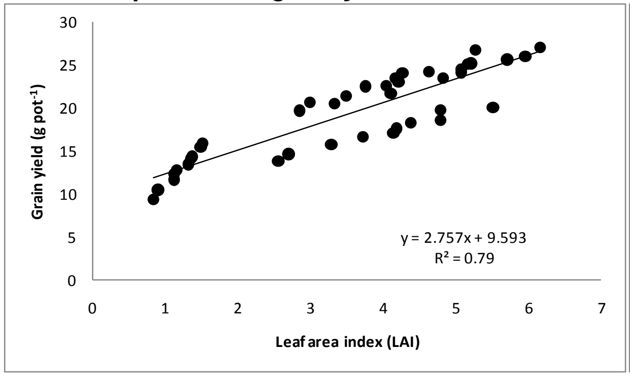
Table 3. Plant height and leaf area index of 10 *boro* rice cultivars at different nitrogen concentrations

Cultivars	N rate (mg kgsoil^{-1})	Plant height (cm)				Leaf area Index (LAI)			
		AT	PI	FL	PM	AT	PI	FL	PM
BRRI dhan28	0	23.13	63.17	79.73 i-l	84.47 pq	0.07 h-k	0.64 lm	1.31 nop	1.22 r
	70	24.17	64.57	106.9 ab	109.0 a-e	0.08 g-j	0.69 kl	4.18 fg	3.89 j
	140	24.07	65.03	108.0 a	113.4 ab	0.07 h-k	0.77 hij	4.63 e	4.36 h
	210	26.13	64.77	104.3 abc	108.0 b-f	0.06 jkl	0.75 ij	4.83 e	4.57 fg
BRRI dhan29	0	21.80	57.10	72.03 lmn	82.90 qr	0.09 c-g	0.75 ij	1.36 no	1.34 qr
	70	20.07	60.70	96.97 cde	98.87 hij	0.10 b-e	0.88 de	4.79 e	4.52 g
	140	21.60	62.03	98.93 bcd	102.0 f-i	0.11 a-d	0.92 d	5.21d	5.00 d
	210	21.17	60.73	94.23 d-g	96.77 i-l	0.10 c-f	0.86 def	5.08 d	4.76 e
BRRI dhan47	0	21.60	65.57	77.80 jkl	93.70 j-n	0.05 lm	0.32 t	0.89 q	0.89 t
	70	22.43	71.07	99.80 bcd	104.7 d-g	0.06 jkl	0.44 qrs	2.69 lm	2.63 o
	140	23.13	72.73	104.9 abc	110.7 a-d	0.08 f-i	0.49 opq	3.49 i	3.17 mn
	210	23.97	74.53	99.57 bcd	106.7 c-f	0.08 f-i	0.50 op	3.33 ij	3.28 lm
BRRI dhan50	0	19.50	57.60	65.40 n-q	74.20 s	0.04 m	0.41 s	1.11 p	1.03 s
	70	17.57	60.97	84.90 hij	92.10 l-o	0.06 i-l	0.47 o-r	3.28 j	3.12 n
	140	20.90	63.10	87.47 ghi	97.20 i-l	0.07 h-k	0.51 o	4.04 g	3.87 j
	210	21.30	63.07	86.27 ghi	89.00 nop	0.08 e-h	0.48 o-r	4.10 g	3.82 j
BRRI dhan59	0	21.83	53.90	67.87 mno	83.60 pq	0.08 g-j	0.74 jk	1.34 no	1.22 r
	70	23.23	55.67	85.27 hij	90.23 mno	0.08 e-h	0.86 ef	4.38 f	4.31 h
	140	22.87	58.80	90.43 e-h	92.40 k-o	0.09 c-g	0.90 de	5.16 d	4.98 d
	210	22.10	56.60	88.17 f-i	92.20 l-o	0.09 d-g	0.84 efg	5.07 d	4.70 ef
BRRI dhan60	0	19.27	54.03	75.33 klm	77.67 rs	0.06 jkl	0.62 mn	1.15 op	1.02 s
	70	17.17	56.40	86.53 ghi	87.23 opq	0.07 h-k	0.68 lm	4.14 g	3.88 j
	140	19.60	59.07	87.40 ghi	98.43 h-k	0.06 jkl	0.76 ij	4.26 fg	4.07 i
	210	20.17	57.87	83.93 hij	95.93 i-m	0.06 jkl	0.73 jk	4.21 fg	4.13 i
BRRI dhan61	0	17.23	51.10	69.60 mno	78.03 rs	0.05 lm	0.44 p-s	1.11 p	1.00 s
	70	19.47	54.47	84.47 hij	97.10 i-l	0.06 klm	0.49 opq	3.72 h	3.61 k
	140	21.87	58.40	87.43 ghi	99.37 g-j	0.05 lm	0.58 n	4.16 fg	4.03 i
	210	22.63	58.07	83.30 h-k	94.97 j-n	0.05 lm	0.49 opq	3.75 h	3.40 l
Binadhan -8	0	15.80	68.60	81.73 ijk	97.57 i-l	0.10 b-e	0.80 ghi	1.50 n	1.45 q
	70	13.43	70.73	95.67 def	104.1 e-h	0.12 ab	1.07 c	5.51 c	5.29 c
	140	17.43	71.17	98.27 cde	114.0 a	0.11 abc	1.13 ab	6.16 a	5.81 a
	210	18.80	70.87	97.53 cde	110.3 a-d	0.11 a-d	1.06 c	5.96 a	5.62 b
Binadhan -10	0	21.60	70.10	80.60 ijk	97.30 i-l	0.11 abc	0.82 fgh	1.48 n	1.35 qr
	70	22.47	76.80	104.4 abc	107.8 b-f	0.12 a	1.10 bc	4.79 e	4.60 fg
	140	23.60	78.23	109.3 a	112.4 abc	0.12 ab	1.17 a	5.27 d	4.90 d
	210	22.60	76.63	106.9 ab	105.6 def	0.11 a-d	1.13 ab	5.71 b	5.42 c
Binadhan-14	0	15.00	46.37	59.03 pq	67.53 t	0.04 m	0.29 t	0.83 q	0.80 t
	70	14.63	47.80	63.47opq	74.43 s	0.06klm	0.42rs	2.55 m	2.26 p
	140	16.40	49.33	66.37nop	76.60 s	0.06klm	0.47os	2.99 k	2.77 o
	210	15.17	49.20	57.73 q	75.33 s	0.05 lm	0.41 s	2.84 kl	2.66 o
ANOVA									
Cultivars (V)		**	**	**	**	**	**	**	**
Nitrogen treatment		*	**	**	**	**	**	**	**

(N)									
V × N		NS	NS	**	**	**	**	**	**
CV (%)		14.30	3.59	5.07	3.39	10.97	5.12	3.50	2.56

Within a column, means followed by same letters are not significantly different at 5 % probability level by Duncan's Multiple Range Test (DMRT)
AT active tillering, *PI* panicle imitation, *FI* flowering, *PM* physiological maturity
* Significant difference at P ≤ 0.05, ** Significant difference at P ≤ 0.01, NS- Non-significant

Figure 3.Relationship between grain yield and leaf area index (a), crop growth rate (b), and total dry matter (c) at flowering.



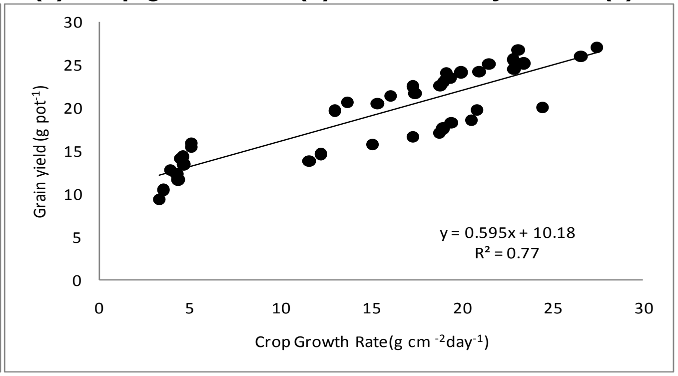


Figure. 3 (a) **Fig. 3 (b)**

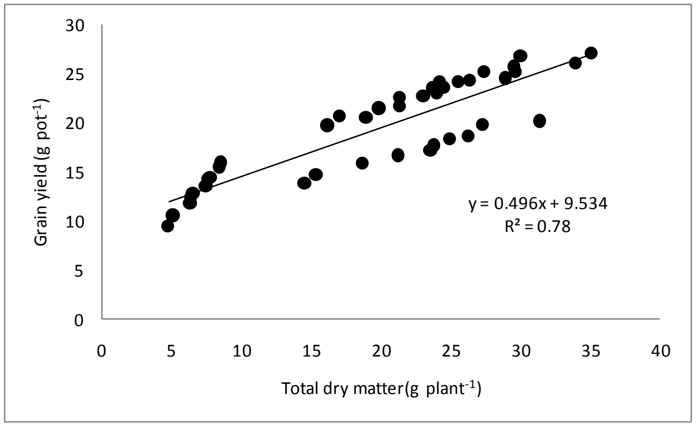


Fig. 3(c)

Table4 Effect of different nitrogen concentrations on CGR, RGR and NAR of rice cultivars at different growth stages

Cultivars	N rate (mg kg soil^{-1})	CGR (g cm $^{-2}$day^{-1})			RGR (g^{-1}g^{-1}day)			NAR (mg cm^{-2}day^{-1})		
		AT-PI	PI-FL	FL-PM	AT-PI	PI-FL	FL-PM	AT-PI	PI-FL	FL-PM
BRRI dhan28	0	1.80 ij	4.64 pq	0.98 mn	44.49	21.14 l	2.42 jkl	0.3050 a-j	0.2148 o	0.0338 i-l
	70	1.92 hi	18.95 i	3.09 e-h	43.49	40.08 c-i	2.38 j-m	0.2978 c-l	0.4244 efg	0.0333 i-l
	140	2.14 efg	20.97 ef	3.75 def	42.36	39.88 c-i	2.59 g-k	0.3155a-g	0.4221 efg	0.0362 f-j
	210	2.10 efg	19.39 hi	3.14 eh	43.84	39.09 d-j	2.35 k-n	0.3297ab	0.3836 jk	0.0291 klm
BRRI dhan29	0	2.07 fgh	4.58 pq	1.47 j-m	41.61	19.12 l	3.37 c	0.2846 g-m	0.1933 p	0.0473 b
	70	2.45 d	20.54 fg	4.85 b	42.89	37.54 f-j	3.29 cde	0.2937d-m	0.3862 jk	0.0453 bcd
	140	2.55 d	23.43 d	4.83 b	42.72	38.95 d-j	2.94 d-h	0.2925 d-m	0.4115 fgh	0.0412 b-f
	210	2.49 d	22.88 d	3.94 cde	42.63	38.93 d-j	2.49 ijk	0.3097 a-g	0.4173 e-h	0.0348 g-k
BRRI dhan47	0	0.87 p	3.52 rs	0.83 mn	40.36	26.70 k	2.95 c-h	0.2654mno	0.2747 m	0.0413 b-f
	70	1.20 mno	12.23 no	2.80 ghi	40.24	40.31 a-h	3.26 cde	0.2746 j-n	0.4270 ef	0.0457 bc
	140	1.33 lmn	16.08 k	1.26 lm	39.53	42.97 a-d	1.20 rs	0.2536 no	0.4575 abc	0.0164 qr
	210	1.26 l-o	15.34 kl	0.95 mn	39.01	43.05 a-d	0.95 s	0.2409 o	0.4469 cd	0.0125 r
BRRI dhan50	0	1.15 o	4.33 pqr	0.55 mn	43.00	25.93 k	1.64 opq	0.3054 a-i	0.2664 mn	0.0224 op
	70	1.29 l-o	15.07 l	2.88 f-i	40.35	42.47 a-e	2.80 f-j	0.2750 i-n	0.4519 bcd	0.0392 d-i
	140	1.40 l	18.81 i	0.14 n	39.53	44.63 a	0.12 t	0.2693 k-o	0.4768 a	0.0015 s
	210	1.30 l-o	17.43 j	1.29 lm	38.96	44.60 ab	1.15 rs	0.2487 no	0.4489 cd	0.0142 r
BRRI dhan59	0	2.07 fgh	4.50 pq	0.85 mn	45.22	19.15 l	2.05 l-o	0.3099 a-g	0.1937 p	0.0287 k-n
	70	2.43 d	19.42 hi	4.70 bc	46.00	37.00 f-j	3.36 cd	0.3160 a-f	0.3893 ij	0.0470 b
	140	2.51d	21.49 e	6.71 a	44.66	38.00 e-j	4.25ab	0.3067 a-h	0.3831 jk	0.0574 a
	210	2.44 d	19.97 gh	6.58 a	44.91	37.31 f-j	4.44 a	0.3153 a-g	0.3677 kl	0.0585 a
BRRI dhan60	0	1.74 j	3.89 qrs	0.56mn	45.77	19.47 l	1.63 pq	0.3145 a-g	0.1971 op	0.0227 nop
	70	1.89 i	18.78 i	3.27efg	44.35	40.29 a-h	2.53 h-k	0.3042 a-j	0.4267 ef	0.0354 f-j
	140	2.12 efg	19.14 hi	3.86cde	44.98	38.79 d-j	2.87 e-i	0.3321 a	0.4097 fgh	0.0402 c-h
	210	2.04 gh	18.99 i	3.55 efg	44.09	39.23 d-j	2.69 f-k	0.3310 ab	0.4147 fgh	0.0370 e-j
BRRI dhan61	0	1.23 mno	4.27 pqr	0.62 mn	43.93	24.97 k	1.85 opq	0.3011 b-j	0.2559 n	0.0257 m-p
	70	1.35 lm	17.28 j	3.64 d-g	42.85	44.14 abc	3.08 c-f	0.2939 d-m	0.4711 ab	0.0431b-e
	140	1.58 k	19.18 hi	2.31hij	41.23	43.15 a-d	1.82 opq	0.3200 a-e	0.4596 abc	0.0245 m-p
	210	1.41l	17.32 j	4.88 b	40.78	43.32 a-d	4.00 b	0.3269 abc	0.4704 ab	0.0594 a
Binadhan -8	0	2.23 e	5.08 p	1.41 klm	39.97	19.33 l	2.98 c-g	0.2899 e-m	0.1980 op	0.0417 b-f
	70	3.08 bc	24.44c	5.04 b	44.07	36.79 g-j	2.90 e-i	0.3095 a-g	0.3907 ij	0.0405 c-h
	140	3.27 a	27.45 a	5.05 b	43.77	37.62 f-j	2.62 g-k	0.3212 a-d	0.4015 hij	0.0367 e-j
	210	3.14 abc	26.59 b	4.89 b	43.87	37.73 f-j	2.62 g-k	0.3273 abc	0.4064 ghi	0.0367 f-j
Binadhan -10	0	2.20 ef	5.08 p	0.90 mn	41.71	19.56 l	1.98 m-p	0.2679 l-o	0.1956 p	0.0277 l-o
	70	3.00 c	20.85f	4.48 bcd	43.94	34.78 j	2.96 c-h	0.2940 d-m	0.3607 l	0.0414 b-f
	140	3.15 ab	23.12 d	3.90 cde	43.63	35.53 ij	2.38 j-m	0.3006 b-j	0.3678 kl	0.0333 i-l
	210	3.02 bc	22.84 d	3.11 e-h	43.64	35.99 hij	1.96 nop	0.3037 a-j	0.3507 l	0.0243 m-p
Binadhan-14	0	0.79 p	3.31 s	0.77 mn	39.44	27.15 k	2.93 e-h	0.2693 k-o	0.2797 m	0.0411 b-g
	70	1.15 o	11.57 o	1.18 m	40.51	40.08 b-i	1.52 qr	0.2770 h-n	0.4243 efg	0.0212 pq
	140	1.29 l-o	13.67m	2.11 i-l	41.97	41.15 a-g	2.28 k-n	0.2869 f-m	0.4366 de	0.0318 jkl
	210	1.18 no	13.00 mn	2.19 ijk	40.55	41.55 a-f	2.48 ijk	0.2988 c-k	0.4491 cd	0.0347 h-k
ANOVA										

Cultivars (V)		**	**	**	**	**	**	**	**	**
Nitrogen treatment (N)		**	**	**	NS	**	**	**	**	**
V × N		**	**	**	NS	**	**	**	**	**
CV (%)		4.21	3.30	17.25	4.31	2.07	8.95	5.20	2.89	9.55

Table 5. Grain yield and yield components of ten *boro* rice cultivars at different nitrogen concentrations

Cultivars	N rat(mg kgsoil^{-1})	Grain yield(g pot^{-1})^{a}	Effective tillers hill^{-1}	Panicle length (cm)	No. of grainspanicle^{-1}	1000 grain weight (g)
BRRI dhan28	0	13.50	3.83	18.57	99.10	19.33
	70	17.67	11.47	21.24	108.30	20.40
	140	24.30	14.45	23.68	116.00	21.87
	210	23.57	13.47	22.64	112.80	21.47
BRRI dhan29	0	14.40	4.23	19.75	106.20	21.30
	70	18.67	12.30	22.06	115.20	21.57
	140	25.27	15.33	24.60	122.68	22.33
	210	24.57	14.30	23.46	119.70	22.03
BRRI dhan47	0	10.50	3.17	17.03	92.60	24.17
	70	14.67	9.63	19.53	101.60	25.47
	140	21.48	12.70	22.07	109.07	26.87
	210	20.57	11.63	20.93	106.10	26.23
BRRI dhan50	0	11.70	3.27	18.52	93.53	16.10
	70	15.83	10.47	20.97	102.67	17.13
	140	22.70	13.50	23.31	110.12	18.15
	210	21.73	12.47	22.37	107.17	17.47
BRRI dhan59	0	14.20	4.08	19.62	103.65	20.08
	70	18.33	11.97	22.16	112.50	20.35
	140	25.17	14.90	24.77	120.20	22.03
	210	24.23	13.97	23.56	117.00	20.67
BRRI dhan60	0	12.80	3.77	18.29	97.71	21.87
	70	17.17	11.30	20.92	106.90	23.00
	140	24.17	14.33	23.42	114.56	23.97
	210	23.07	13.30	22.32	111.40	23.27
BRRI dhan61	0	12.38	3.62	18.57	96.60	20.15
	70	16.67	10.80	20.91	105.47	20.57
	140	23.55	13.87	23.77	113.10	21.43
	210	22.57	12.80	22.31	109.97	20.57
Binadhan -8	0	15.93	4.83	19.63	112.70	26.10
	70	20.17	12.97	22.16	121.73	27.20
	140	27.10	16.20	25.03	129.70	27.77
	210	26.07	14.97	23.56	126.23	27.33
Binadhan -10	0	15.50	4.75	20.31	107.97	24.42
	70	19.83	12.63	22.86	117.37	25.33
	140	26.83	15.83	25.41	125.43	27.07
	210	25.73	14.63	24.26	121.87	26.27
Binadhan-14	0	9.43	3.00	16.41	91.19	20.33

	70	13.83	9.47	18.95	100.47	20.73
	140	20.72	12.57	21.50	108.10	21.50
	210	19.73	11.47	20.35	104.97	20.93
ANOVA						
Cultivars (V)		**	**	**	**	**
Nitrogen treatment (N)		**	**	**	**	**
V × N		NS	NS	NS	NS	NS
CV (%)		6.58	8.10	6.18	3.30	5.01

Within a column, means followed by same letters are not significantly different at 5 % probability level by Duncan's Multiple Range Test (DMRT)
** Significant difference at P ≤ 0.01, NS- Non-significant
[a]Grain yield is at 14 % moisture content

Table 6. Content and uptake of nitrogen in the grain and straw of 10*boro* rice cultivars at different nitrogen concentrations

Cultivars	N rate(mg kg soil^{-1})	N content in grain (%)	N uptake in grain (mg pot^{-1})	N content in straw (%)	N uptake in straw (mg pot^{-1})
BRRI dhan28	0	1.170 w	159.7 tuv	0.463 p	58.78 qrs
	70	1.647 tu	291.0 opq	1.133 l	189.7 mn
	140	2.023 opq	489.1h-k	1.230 jk	301.6 ghi
	210	2.090 nop	492.4 h-k	1.297ij	307.4 ghi
BRRI dhan29	0	1.767 rst	259.3 pqr	0.586 mn	80.37 pqr
	70	2.383 jk	444.8 jkl	1.390 gh	245.9 kl
	140	2.847 cde	716.8 bc	1.540 cde	392.4 bc
	210	2.920 bcd	717.4 bc	1.617 bc	399.3 b
BRRI dhan47	0	1.313 v	140.4 uv	0.433 p	45.52 rs
	70	1.810 r	265.6 pqr	1.173 kl	170.6 no
	140	2.417 ijk	511.5 hij	1.337 hi	298.4 ghi
	210	2.513 ghi	516.8 g-j	1.413 fgh	304.4 ghi
BRRI dhan50	0	1.593 u	188.2 s-v	0.466 p	47.53 rs
	70	2.143 mno	339.1 no	1.217 jk	172.4 no
	140	2.370 jk	529.1f-i	1.477 ef	325.1e-h
	210	2.447 hij	531.5 fgh	1.467 efg	310.7 f-i
BRRI dhan59	0	1.677 tu	240.9 qrs	0.553 no	69.52 p-s
	70	2.330 jkl	427.3 klm	1.343 hi	222.1lm
	140	2.763 e	686.4 cd	1.470 efg	357.6 cde
	210	2.850 cde	690.8 cd	1.600 bc	376.7 bcd
BRRI dhan60	0	1.580 u	208.1 r-u	0.460 p	56.45 qrs
	70	2.150 mn	369.0 mn	1.197 kl	193.8 mn
	140	2.647 f	626.4 de	1.407fgh	337.7 d-g
	210	2.793 de	644.5 de	1.510 e	350.1def

BRRI dhan61	0	1.677 stu	212.3 rst	0.510 op	61.17 p-s
	70	2.300 kl	383.5 lmn	1.237 jk	197.7 mn
	140	2.553 fgh	591.5 ef	1.460efg	347.8def
	210	2.590 fg	584.4 efg	1.520 de	350.0 def
Binadhan -8	0	2.013 pq	325.0 nop	0.656 m	99.75 p
	70	2.530 f-i	510.9 hij	1.517de	291.4 hij
	140	2.953 abc	787.5 a	1.667 ab	450.2 a
	210	3.047 a	794.0 a	1.737a	455.2 a
Binadhan -10	0	1.800 rs	286.0 opq	0.610 mn	93.99 pq
	70	2.423 ijk	480.7h-k	1.420 fgh	277.5 ijk
	140	2.900 bcd	763.3 ab	1.593 bcd	435.1 a
	210	2.997 ab	771.3 ab	1.657 b	440.2 a
Binadhan-14	0	1.267 vw	123.9 v	0.446 p	36.89 s
	70	1.960 q	270.9 o-r	1.197 kl	145.7 o
	140	2.227 lm	453.1jk	1.280 ij	256.2 jkl
	210	2.320 jkl	458.1ijk	1.347 hi	258.8 jkl
ANOVA					
Cultivars (V)		**	**	**	**
Nitrogen treatment (N)		**	**	**	**
V × N		**	*	**	**
CV (%)		3.22	8.42	3.43	8.75

Within a column, means followed by same letters are not significantly different at 5 % probability level by Duncan's Multiple Range Test (DMRT)

* Significant difference at P ≤ 0.05, ** Significant difference at P ≤ 0.01

It appears that the BRRI dhan50 cultivar had the highest RGR up to FL, and the BRRI dhan59 cultivar had the highest RGR at PM.

The trend in NAR based on N concentration was relatively equal and downward (Table 4). The percentage of increase in NAR for N_{70}, N_{140}, and N_{210} were 49%, 51%, and 51%, respectively, compared to the control for Binadhan-8 at FL. With LAI increasing, NAR was lower in all the treatments and this could have occurred because of more tillering and greater leaf area development at higher N concentrations.

Biomass partitioning

The impacts of elevated N rates on biomass partitioning in the form of sheath weight, leaf weight, root weight, and TDM was investigated (data not shown). The sheath weight (g plant^{-1}) improved with higher concentrations of N fertilizer throughout the plant's life and it was highest during FL, followed by PI and AT. During AT, the sheath weight was highest for the rice cultivarBinadhan-10, whereas it was lowest for BRRI dhan47 and Binadhan-14. The maximum sheath weight during PI was recorded for Binadhan-10, followed by Binadhan-8, BRRI dhan61, and BRRI dhan29. The highest sheath weight among the 10 rice cultivars throughout FL and PM was recorded inBinadhan-8, followed by Binadhan-10, and BRRI dhan61. The leaf weight (g plant^{-1}) followed a similar pattern as sheath weight. Leaf weight increased with increasing N fertilizer up to N_{140}, and this was observed during all four stages among the 10 rice cultivars. The cultivarBinadhan-10 had the greatest leaf weight during AT and PI, whereas it was lowest for Binadhan-14. During FL and PM, Binadhan-8had the highest leaf weight, followed by Binadhan-10 and BRRI dhan61.

Total dry matter, grain yield and yield components

There was no significant interaction between cultivars and N concentrations on TDM at AT. However, after AT, changes were more visible. TDM increased significantly with increasing N concentration up to N_{140} with no further increase at higher N concentrations at PI, FL, and PM (TDM at FL only presented, Fig. 3c). TDM at FL increased from 4.74 g plant^{-1} to 8.54 g plant^{-1}for $N_0$and 19.44 g plant^{-1} to 40.76 g plant^{-1}for N_{140}. The rice cultivar Binadhan-8 had greatest value for total dry matter during all stages (data not presented).

The ANOVA for grain yield and yield components, and their mean comparisons is shown in Table 5. Response of cultivars and N rates on grain yield was not significant. Grain yield increased with increasing N concentration up to N_{140} and then declined at the higher concentration (from 9.43 g pot^{-1} to 15.93 g pot^{-1} at $N_0$and 20.72 g plant^{-1} to 27.10 g plant^{-1} at N_{140}). Among the cultivars, because Binadhan-8 had higher physiological indices, it had the highest yield.

There were no significant interactions between cultivars and N concentration on any yield component. Effective tillers hill^{-1} increased with increases in N concentration up to N_{140}. Effective tillers hill^{-1} with N_{70}, N_{140}, and N_{210} for Binadhan-8 were 63, 70, and 68% higher, respectively, than with no N fertilizer. Grain yield variations for cultivars were significantly positively correlated (R^2=0.86, p<0.01) with effective tillers hill^{-1} (Fig. 4a). Number of grains panicle^{-1} increased with increases in N concentration up to N_{140}, and then decreased with increasing N concentration. This trait was increased by 13% when N concentration increased from N_0 to N_{140} and there was a significant positive correlation (R^2=0.79, p<0.01) between grains panicle^{-1} and grain yield (Fig. 4b). There was no significant effect of cultivars or N concentration for 1,000 grain weight, which ranged from 17.13 to 27.77g.

N response to yield from different rice cultivars is shown in Fig. 5. The relationship was almost quadratic, in which the grain yield increase relative to N fertilizer increased as each increment in N concentration was added. That is, the grain yield increase with each increment of N fertilizer concentration was less than it had been at the previous increment in N. Ultimately, the yield plateau and additional N did not result in a yield increase, and at that point, N was no longer rate-limiting.

N content (%) and uptake (mg pot^{-1})

N content (%) and uptake in grain was significantly influenced by N and cultivar treatments (Table6). The grain N content (%) varied from 1.17% to 3.047%. Binadhan-8 had the highest N content (%) among cultivars. Increasing grain N content (%) and uptake with elevated N concentration was marked, which increased rice grain yield. In the straw, N content (%) varied from 0.433% to 1.737%. and varied from 36.89 to 455.2 mg pot^{-1}. N uptake in straw was also lower than that of grain. N content in grain had a highly significant positive association with grain yield (R^2= 0.82, p<0.01) as is shown in Fig. 6a. Hence, increasing N concentration in grain can increase rice grain yield.

Figure 4. Relationship between grain yield and effective tillers hill^{-1} (a), and grains panicle^{-1} (b).

Fig. 4 (a)

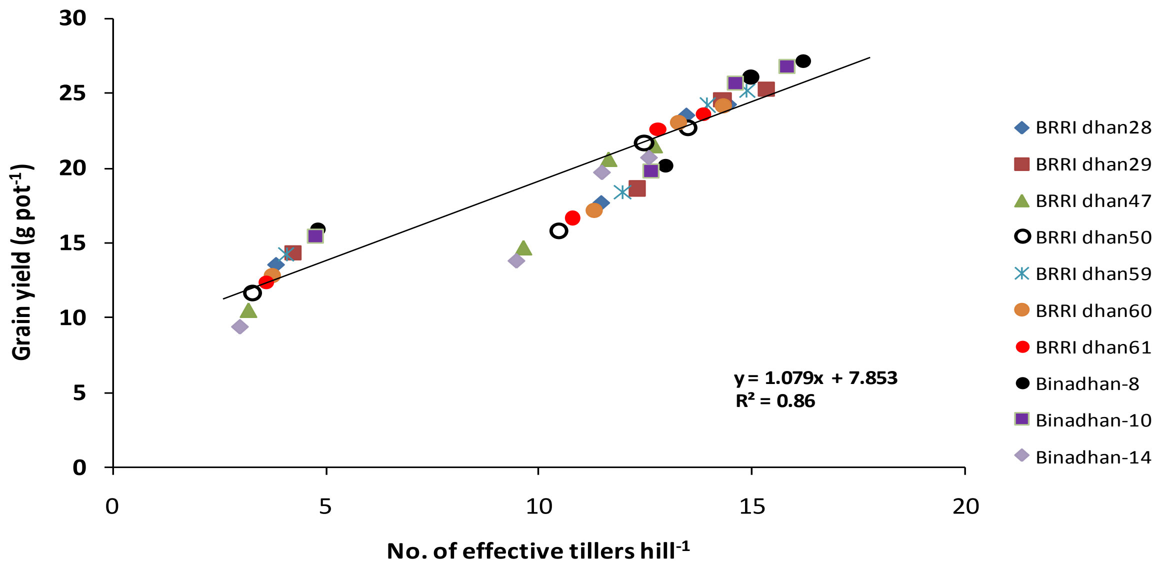
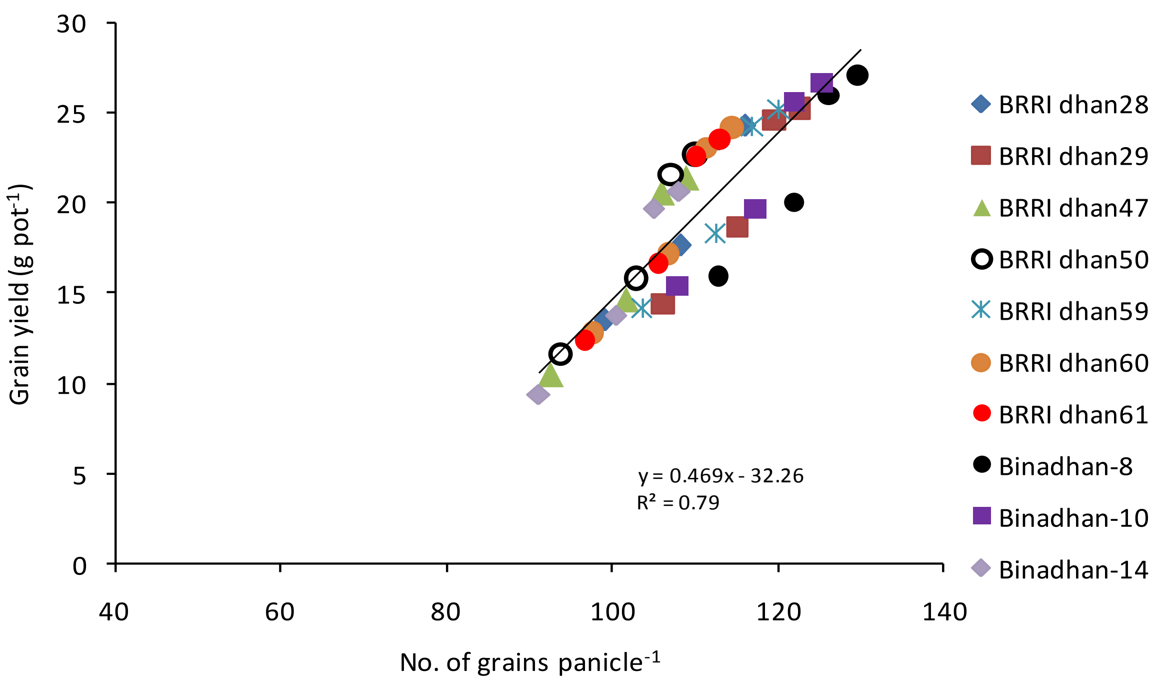


Fig. 4 (b)



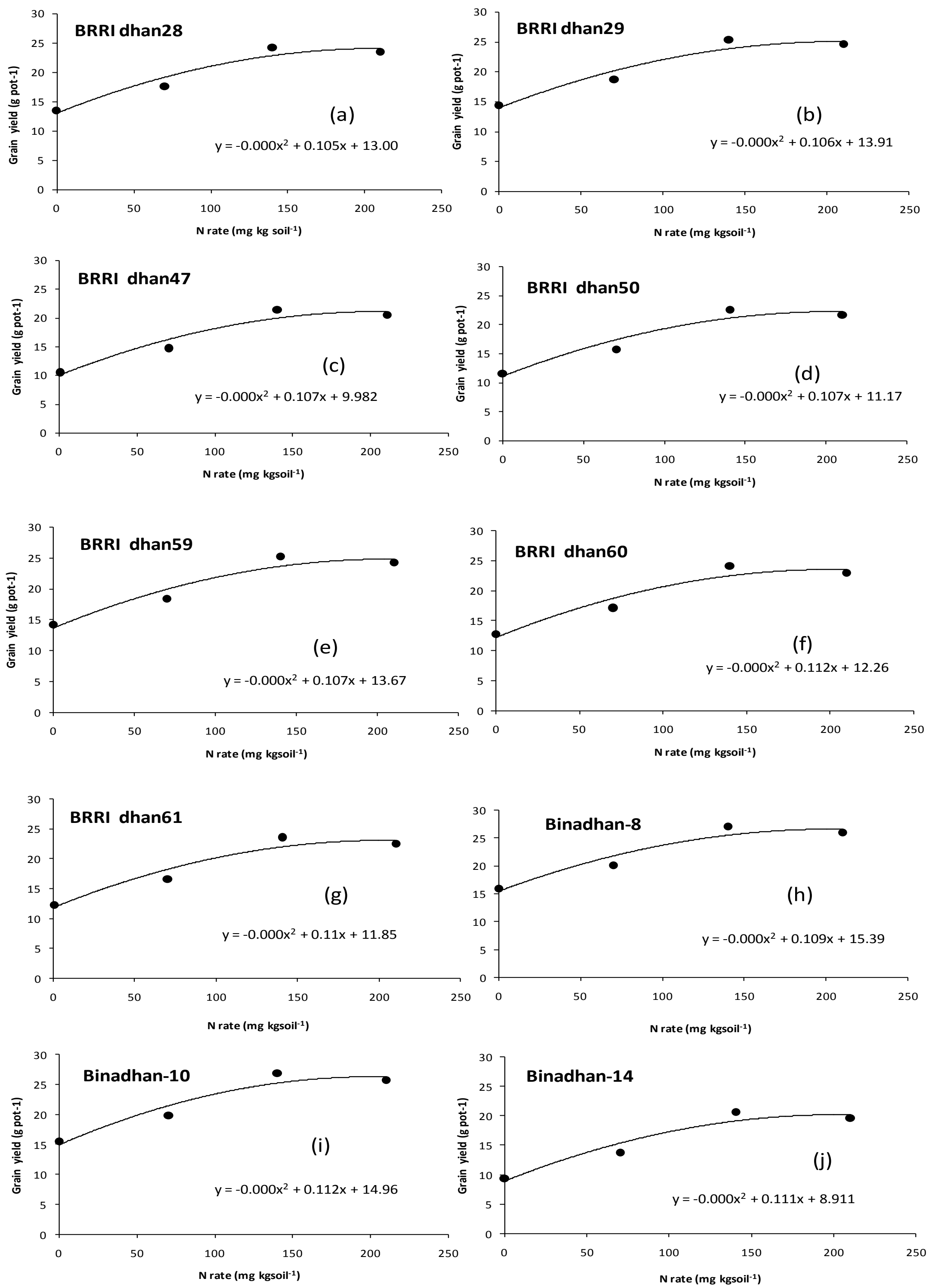


Figure 5.Relationship between grain yield and concentration of nitrogen for the cultivars (a) BRRI dhan28, (b)BRRI dhan29, (c) BRRI dhan47, (d) BRRI dhan50, (e) BRRI dhan59, (f) BRRI dhan60, (g) BRRI dhan61, (h) Binadhan-8, (i) Binadhan-10, and(j) Binadhan-14.

Figure. 6 (a)

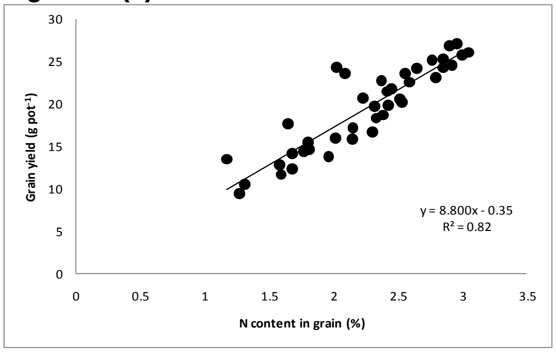


Figure. 6 (b)

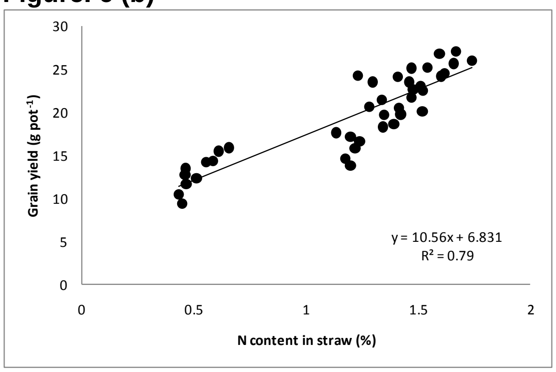


Figure. 6 (c)

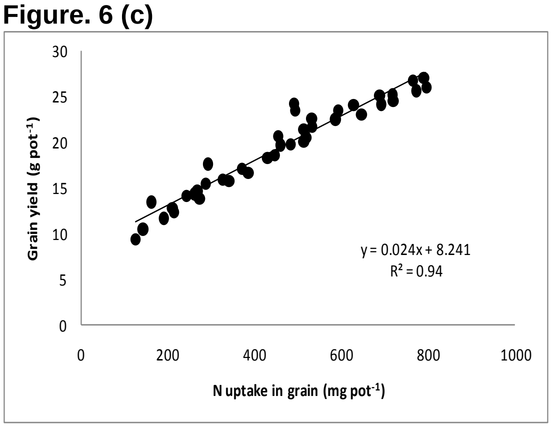


Figure. 6 (d)

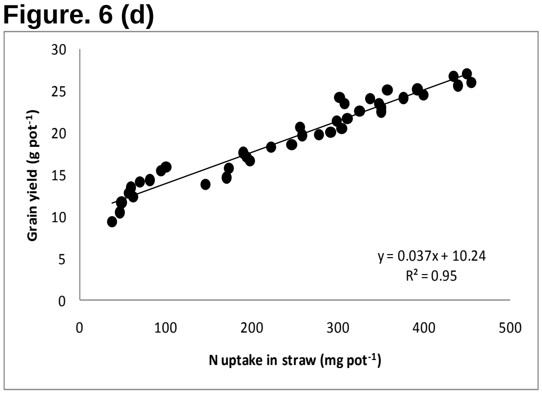


Figure 6. Relationship between grain yield and N content in grain (a), N content in straw (b), N uptake in grain (c), and N uptake in straw (d).

A similar trend was also observed for N content in straw and grain yield (Fig. 6b).Uptake of N in the grain and straw followed dry matter yield of these two plant parameters. Uptake of N in grain (R^2= 0.94, p<0.01) as well as in straw (R^2 = 0.95, p<0.01) had a highly significant association with grain yield (Fig. 6c and 6d).

N use efficiencies indicators

N use efficiencies defined in Table 2 were calculated for all cultivars (Table 7). Results showed that most of the indexes for N use efficiency and cultivars were significantly affected by N application. N harvest index (NHI) was defined as the percent of grain N uptake to total plant N uptake. NHI of rice cultivars decreased with increased N application. This indicated that the N ratio in straw was enhanced with increasing N application and it led to the excessive N uptake by the rice plant.

Agronomical efficiency (AE) was used to explain the ability of yield increase per kilogram pure N and it was non-significant for N application among the cultivars (data not shown). Physiological efficiency (PE), agro-physiological efficiency (APE), and apparent recovery efficiency (ARE) were also varied among cultivars and showed statistically significant differences among cultivars. Physiological efficiency (PE) revealed the use efficiency of N absorbed by the rice plant.PE of all cultivars increased significantly with increasing N application up to N_{140} and tended to decline at N_{210} (Table 7). This showed that yield increased per kilogram of N accumulated in rice plant, and was decreased with increasing N application after a certain rate. Thus, it obeyed the descending reward rule. The APE varied from 10.66 to 19.21 mg with an average value of 14.47 mg grain produced per mg N accumulated in grain and straw. ARE was the main index used to describe the characteristics of N uptake and utilization in rice. Most researchers consider this parameter is in accord with rice production.

In this study, ARE increased with increasing of N application at first, reached to the maximum at N_{140}, and then declined significantly at N_{210}. The average of ARE was 49.15%. The highest yield producing genotype, Binadhan-8, had reasonably good values for PE, APE, and ARE.

Table7. Nitrogen use efficiency of 10*boro* rice cultivars at different nitrogen concentrations

Cultivars	N rate (mg kg soil^{-1})	NHI (%)	PE (mg mg^{-1})	APE (mg mg^{-1})	ARE (%)
BRRI dhan28	0	0.73	-	-	-
	70	0.61	30.74 f-j	15.37 fgh	43.70 klm
	140	0.62	39.06 ab	18.39 ab	47.68 ijk
	210	0.62	35.99 cd	17.04 cd	32.30 op
BRRI dhan29	0	0.76	-	-	-
	70	0.64	22.82 pq	11.41 no	58.50 def
	140	0.65	29.00 i-m	13.66 i-l	64.13 abc
	210	0.64	26.92 lmn	12.75 lmn	43.18 klm
BRRI dhan47	0	0.76	-	-	-
	70	0.61	32.04 efg	16.02 def	41.71 lm
	140	0.63	35.74 cd	16.83 cde	52.00 ghi
	210	0.63	32.91 efg	15.59 e-h	35.30 op
BRRI dhan50	0	0.80	-	-	-
	70	0.66	29.10 h-l	14.55 g-j	45.97 jkl
	140	0.62	36.17 cd	17.04 cd	51.54 hi
	210	0.63	34.51 de	16.35 def	33.69 op
BRRI dhan59	0	0.78	-	-	-
	70	0.66	23.62 opq	11.81 mno	56.49 efg
	140	0.66	30.41 g-k	14.32 h-k	61.13 cde
	210	0.65	27.62 k-n	13.09 klm	42.06 lm
BRRI dhan60	0	0.79	-	-	-
	70	0.66	26.93 lmn	13.47 jkl	49.71 ij
	140	0.65	31.94 e-h	15.04 fgh	58.30 def
	210	0.65	28.68 j-m	13.58 jkl	40.55 mn
BRRI dhan61	0	0.78	-	-	-
	70	0.66	26.10 mno	13.05 klm	51.29 hi
	140	0.63	33.53 def	15.79 d-g	55.48 fgh
	210	0.62	31.63 e-i	14.98 f-i	36.72 no
Binadhan -8	0	0.76	-	-	-
	70	0.64	21.40 q	10.70 o	62.92 bcd
	140	0.64	27.48 lmn	12.94 klm	67.75 ab
	210	0.64	25.40 nop	12.03 mno	45.80 jkl
Binadhan -10	0	0.75	-	-	-
	70	0.64	21.32 q	10.66 o	63.03 bcd
	140	0.63	27.29 lmn	12.85 lm	68.20 a
	210	0.64	25.26 nop	11.97 mno	46.19 jkl
Binadhan-14	0	0.77	-	-	-
	70	0.65	31.33 f-j	15.66 d-h	42.63 klm
	140	0.64	40.80 a	19.21a	45.71 j-m
	210	0.64	37.72 bc	17.87bc	30.90 p
ANOVA					
Cultivars (V)		NS	**	**	**
Nitrogen treatment (N)		**	**	**	**
V × N		NS	**	**	**
CV (%)		5.27	7.03	7.50	3.33

DISCUSSION

Studies on rational application of N and use efficiency for rice, which have a direct relationship with physiological processes and yield, have been conducted by many researchers (Fageria and Barbosa Filho, 2001; Fageria and Baligar, 2001; Saito et al. 2006; Quanbao et al. 2007, Fageria et al. 2010; Singh et al. 2014). However, all of them used upland and lowland cultivars and some under different soil conditions. Studies on physiological process, yield, and NUE of exclusively high-yield cultivars were still limited. In fact, the effect of N concentrations on high-yield rice and N utilization existed in rice production. According to the relationship between N utilization and rice production, the appropriate concentration of N with a goal of improving N utilization could increase NUE and rice grain yield. In the present study, the performance of cultivars varied under different N concentrations. The difference in the performance might be related to crop duration, growth, TDM, and NUE variation.

Association of grain filling duration and rate with grain yield shows different patterns depending on crop species. Studies on the contribution of the grain-filling period to grain yield in rice showed that grain yield of different cultivars was determined by grain-filling duration(Yang et al. 2008). In the present study, it was observed that grain-filling duration had a positive effect on grain yield. The rice cultivars having higher grain-filling durations produced higher yield. Extension of grain-filling duration provided rice plants with more climatic resources, such as temperature and solar radiation, for prolonged grain growth.

LAI is used as a photosynthetic system measurement, and is related to biological and economic yields. Increases in LAI cause higher yields (Singh et al. 2009). In the present study, maximum LAI was obtained in the FL stage, and then it decreased because of leaf senescence. The trend of CGR under N fertilizer concentration and rice cultivars illustrated that there was a significant difference among treatments. Because leaves are the main factor of photosynthesis and dry matter increments in unit area can be expected, similar to the results of this experiment, the treatment with higher LAI had more CGR. In the present study, maximum RGR was observed in the early stage of crop growth and with increments of time, it decreased linearly. Singh et al. (2009) reported similar results concerning RGR changes with N fertilizer concentrations. At higher LAI, increases in respiration cause a reduction in NAR. The reason for the severe reduction in NAR at the higher N concentration was the acceleration in leaf production and early closure of canopy. In this condition, less solar radiation is absorbed by the leaves and as a result, NAR is reduced.

In the present study, TDM did not vary significantly until AT among the four concentrations of N and the growth of plants was slight. Likely, in this period, leaf extension and total dry weight follow carbon increments and the role of urea is negligible (Fageria and Baligar 2001). However, afterwards changes were more noticeable. It was revealed that N is necessary for increments of dry matter because of enhanced yield components, specially, the number of panicles and panicle length. Shibuet al. (2010) and Azarpouret al. (2011) reported that, with increased concentration of N in rice, TDM increased. In the present study, it was observed that TDM increased up to N_{140} and then tended to decrease. Because the concentration of N requirement varies depending on the crop, as well as its growth stage, high N concentrations may be beneficial during early growth stages, but may cause losses during later flowering and fruiting stages (Ayres and Westcot, 1994). These reasons might partially explain the lower TDM with higher N fertilizer concentration. In addition, maximum TDM accumulation in each cultivar occurred at PM. Differences in N content in different rice cultivars at PM emphasizes that increases in N are necessary for dry matter production (Fageria and Baligar, 2001; Fageria and Baligar, 2005; Fageria, 2007). The present study showed that grain yield was significantly (R^2=0.78) related to the TDM at FL, which explains grain yield variation. In the present study, among the studied cultivars, Binadhan-8 produced more dry matter along with highest yield. This result is consistent with that of Horie et al. (2001).

In relation to grain yield components, the present study clearly showed that, grain yield was closely related to the number of effective tillers hill^{-1} and grains panicle^{-1}. These types of responses are in line with the most commonly reported studies in small grain cereals, where grain number m^{-2} is the main yield component explaining changes in yield caused by genetic and management factors (Slafer et al. 2005). In agreement with the findings of this study, Kariali and Mohapatra (2007) also supported the theory that grain yield is highly dependent on the number of effective tillers. In the present study, maximum grain yield (27.10 g pot^{-1}) was obtained from N_{140}concentration. Minimum grain yield was related to the N_0 treatment (10.50 g pot^{-1}) because non-application of nitrogen fertilizer decreased yield components and physiological indices. Regarding the N effect on grain yield of rice, different research indicates that with increasing nitrogen content grain yield considerably increased to a certain extent (Zhang et al. 2008; Lin et al. 2009; Rezaee et al., 2009; Lampayan et al., 2010).

The highest grain yield in Binadhan-8 can be explained by higher concentration of N in grain. N content was lower in straw than in grain. Nitrogen concentration is always higher in the grain of rice than in the stover (Kiniry et al., 2001). Because there are strong relationships among grain N content, straw N content, and grain yield, this indicates that increasing N accumulation in both straw and grain can improve rice yield.

Estimation of NUE indicators in crop plants is important for assessing the fate of applied N and its role in improving maximum economic yield through efficient absorption and utilization by the plant. In the present study, AE, PE, APE, and ARE increased up to N_{140} and then tended to decrease. The decreasing trend of NUE indicators at higher N rates suggests that rice plants were unable to absorb or utilize N at higher rates or the rate of N uptake by plant could not keep up with the loss of N (Fageria and Baligar, 2005). Nitrogen loss usually occurs by means of ammonia volatilization, de-nitrification, surface runoff, and leaching in the soil floodwater system (Vlek and Byrnes,1986), and causes significant problems in terms of environmental pollution, increased production costs, grain yield reduction, and global warming (Li et al., 2012). Nonetheless, the magnitude and nature of N losses vary depending on the timing, rate, and method of N application, source of N fertilizer, soil chemical and physical properties, climatic conditions, and crop status (Zhu, 1997). Decreases in N uptake efficiency at higher N rates have also been reported by Timsina et al., (2001) and Mae et al. (2006).

CONCLUSION

There are wide variations in physiological parameters, as well as growth dynamics, biomass partitioning, and NUE among cultivars under different N concentrations. The Binadhan-8 cultivar had the highest yield and was the most N-efficient cultivar, followed by Binadhan-10, BRRI dhan29, and BRRIdhan59. They had higher TDM, more panicles, and more grains panicle^{-1} than other cultivars. These characteristics are considered important for cultivars with increased yields. Our results also showed that the response of different rice cultivars to N application was not the same. Significant genetic differences existed among yield increases with N concentrations, NUE, and N accumulation in rice. Rational N application, as an important factor affecting rice yield and quality, has always been an important aspect in rice research. However, in the recent practices of rice production, genetic differences in rice N nutrition are typically neglected when N fertilizers are applied, inevitably making N application and demand unbalanced, reducing production efficiency, and wasting resources. Therefore, studies on the differences in N nutrition originated from rice cultivars are urgently required for the purpose of proper fertilization, reduction in resource loss, and protection of the environment.

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CONFLICT OF INTEREST

The authors declared that present study was performed in absence of any conflict of interest”.

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AUTHOR CONTRIBUTIONS

UKS, MRU, MARS and MAS designed and performed the experiment. UKS and MRU analyzed the data and wrote the manuscript. MRU, MARS, AKS and SUP reviewed the manuscript.All authors read and approved the final version.

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