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ARTICLE

Sources of Nitrogen in Combination with Systems of Irrigation Influence the Productivity of Modern Rice (*Oryza sativa* L.) Cultivars during Dry Season in Sub-Tropical Environment

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ABSTRACT

In irrigated agricultural systems, nitrogen (N) and water are the vital resources for sustainability of the crop production in the modern era of climate change. The current study aimed to assess the impact of water and N management on the productivity of irrigated rice cultivars. In the context, a field observation was done at the research farm of Bangladesh Agricultural University, Mymensingh, during dry seasons in consecutive two years (2018–2019 and 2019–2020). The experiments were set up following split-plot design assigning water management in the main plots, nitrogen management in the sub-plots, and the cultivars were approved in the split-split plot with three replications. After two years observation, it was revealed that rice cultivar Binadhan-8 gave the maximum value of leaf area index, number effective tillers hill^{-1} and grains panicle^{-1} which lead to the higher grain yield (GY). Substantial relationships were observed among the concentration of N, growth, total dry matter (TDM) and N content, N uptake, N utilization effectiveness, and GY. However, with little exception, the Combined effect of water and N, cultivars and water management were varied significantly for all parameters. Finally, the results of the current study concluded that application of irrigation at 8 days after the disappearance of ponded water and source of 105 kg N ha^{-1} from PU + Poultry manure are the best management approach for the excellent performance of rice cultivar Binadhan-8.

KEYWORDS

Growth stage; high yielding rice cultivar; internal N use efficiency; water productivity

Nomenclature

AT:	Active tillering
At:	Anthesis
AWD:	Alternate wetting and drying
BRRI:	Bangladesh Rice Research Institute
CGR:	Crop growth rate
d:	days

DAD:	Days after the disappearance of ponded water
Em:	Emergence
FL:	Flowering
GY:	Grain yield
LAI:	Leaf area index
N:	Nitrogen
NAR:	Net assimilation rate
NS:	Non-significant
PH:	Plant height
PI:	Panicle Initiation
PM:	Physiological Maturity
POM:	Poultry manure
PU:	Prilled Urea
RGR:	Relative growth rate
RWC:	Relative water content
TDM:	Total dry matter
USG:	Urea super granule

1 Introduction

Increasing population is one of the significant encounters for food and environmental security across the globe. On the other hand, due to the changing climate, water and N shortage has created a big challenge particularly in the rice growing world. The main restrictive factors for irrigated rice farming are also water and nitrogen. Proficient water and nitrogen management has remained significant for sustainable rice cultivation in irrigated rice farming system. Future rice production will depend greatly on developing approaches and practices that use water and nitrogen efficiently under climate change condition [1]. Considering the water issue, it is imperative to investigate rice-growing substitute methods by utilizing less water for food security [2]. Insufficient water, along with its higher cost, is widespread in rice production. Therefore, farmers and researchers are trying to find alternatives to reduce water usage in rice farming, upgrade its utilization efficiency, and increase rice yield [3]. Production of more rice with less water is quite tricky for crop production; thus, the efficiency of water usage for agriculture should play a vital role in fulfilling future rice needs [4]. Effective utilization of irrigation water to expand crop productivity is the possible solution for water shortage and utilization problems worldwide [5].

Proper management of N fertilizer is vital to improving rice crop development and yields. This is likewise the most restrictive supplement for rice production throughout the planet [6]. To accomplish the harvest's monetary advantage, determination of the suitable level and wellspring of N compost is a significant concern [7]. Rice growers frequently utilize more meaningful levels than those required to keep up with yield due to the difficulty in anticipating the requirements of N manures [8]. Accordingly, evaluating suitable N fertilizer rates and sources for upgrading crop production is also vital. The N accessibility to plants is the most potent factor in rice outputs and its connection to the increment of production components [9,10]. The dry matter partitioning in shoot has been linked with availability of N and that has a positive relation GY [11,12]. The cultivars of irrigated rice contrast in their nitrogen use efficiency (NUE) [10] and GY [13]. In this manner, NUE can be expanded by suitable nitrogen management, and it can likewise further upgrade GY [10]. The proper administration of irrigation water, ideal utilization of fertilizers alongside the utilization of cultivars that are effective in absorbing and utilizing nutrients, particularly N are a portion of the innovations used to increment and support horticultural outcomes in the long run [11,14]. Sustainable and quality production can be ensured by good management of these practices.

For improvement of water productivity and water use efficiency in irrigated rice, various water management systems have been anticipated [15–18]. However, considering the rise in price of chemical fertilizer and enormous competition for water for industrial, domestic and agricultural use, it is necessary to recognize the most proficient water management methods and best possible N fertilizer level for sustainable augment in rice productivity in irrigated rice farming system in Bangladesh. Considering these above facts, the current study aimed to assess the impact of water and N management on the productivity of irrigated rice cultivars in dry season under sub-tropical region.

2 Materials and Methods

2.1 The Characteristics of the Experimental Site

We conducted the field experiment during dry seasons of 2018–2019. The experiment was also repeated in the next season of 2019–2020. The site of experimental was the Agronomy Field Laboratory of Bangladesh Agricultural University, Mymensingh, Bangladesh. Geographically the site lies at the latitude of 24°42′55″N, longitude of 90°25′47″E, and the elevation of 19 m above the sea level. The experimental place experiences the subtropical monsoon climate with humid nature. Before starting the trial the physicochemical properties of the field soils were analyzed and are displayed in Table 1.

Table 1: Physicochemical properties of the soil in the field before starting the observation

Soil characteristics	Values
Soil texture	Clay loam
Soil pH	6.13
Electric conductivity (µs/cm)	649
Organic carbon (%)	1.294
Total nitrogen (N) (%)	0.115
Available form of phosphorus (P) (ppm)	28.2
Available form of potassium (K) (ppm)	83.64
Available form of sulphur (S) (ppm)	25.90

2.2 Experimental Materials, Treatments and Design

Treatments were: (a) three rice cultivars viz., BRRI dhan-28, Binadhan-8 and Binadhan-10; (b) three water management systems, viz., application of irrigation at 8 and 10 days after the disappearance of ponded water (DAD) and Bangladesh Rice Research Institute (BRRI) recommended water application systems (AWD) and (c) three sources of N viz., Prilled Urea (PU) (140 kg N ha^{-1}), Urea Super Granule (USG) (83 kg N ha^{-1}), PU + 3 t ha^{-1} poultry manure (POM) (105 kg N ha^{-1}). All treatments were arranged in a split-plot design where water management treatments were assigned in the main plots and nitrogen management as the sub-plots, and the cultivars were arranged in the split-split plot and all treatments were replicated thrice.

2.3 Field Preparation and Crop Management

The field was prepared by 4-5 ploughing followed by laddering. Except N sources, other fertilizers such as P-K-S-Zn were applied at 20-65-18-1.3 kg ha^{-1}. Nitrogen was applied as per treatments. The source of the nutrients was applied for N as PU (140 kg N ha^{-1}), USG (83 kg N ha^{-1}), PU + 3 t ha^{-1}POM (105 kg N ha^{-1});

for P as triple super phosphate (TSP), for K as muriate of potash (MOP), for S as Gypsum and for Zn as Zinc sulphate fertilizers. Calculation of nutrients was accomplished based on IPNS, and only the required amount was added from the fertilizers. During the final land preparation, entire amounts of P, K, S, Zn fertilizers and poultry manure were applied as basal dose. Two seedlings were transplanted hill^{-1} maintain spacing of 25 cm × 15 cm. USG was applied among every four hills in an alternate row after one week of the transplanting of rice seedling. Urea was used in three equal installments after 15, 40, and 70 days after the crops were transplanted. The unit plot size was 4.0 m × 2.5 m. At the time transplanting the field was with 4 cm of standing water, and the three irrigation treatments were imposed after the disappearance of this ponded water-traditional irrigation at 8, and 10 days after DAD, and BRRI recommended AWD. Free flooding method was used for application of irrigation except AWD. Irrigation water was measured using volumetric method. For AWD method, a 20 cm deep hole was dug in treated plot and a perforated plastic pipe was installed to monitor the level of the water table after irrigation. The practice was continued until flowering starts. 2–4 cm standing water was kept from flowering to dough stage. Polythene sheet was used beneath the soil to prevent seepage from one plot to another.

2.4 Data and Their Measurement Procedures

The plants were sampled from each pot at active tillering stage, panicle initiation stage, flowering stage, and physiological maturity for the measurement of growth parameters includingplant height, leaf area index (LAI), crop growth rate (CGR), relative growth rate (RGR), and net assimilation rate (NAR). For LAI, the leaf blades were isolated from the leaf sheath immediately after sampling the plants then the area of the leaf blades was estimated by using a digital leaf area meter (LI 3100, Licor, Inc., Lincoln NE, USA). After assessing the leaf area, the plant sampled, including leaves used for determining its area, was dried in an electric oven at 65°C for 72 h. Different parameters of growth analysis viz., RGR, CGR, LAI, and NAR were calculated from the dry mass and leaf areas by using the following the standard formulae reported by Radford [19] and Hunt [20].

Water productivity in rice was calculated as follows [21]:

$$\text{Water productivity} = \frac{Y}{\text{WR}}\left(\text{t ha}^{-1}\ \text{cm}^{-1}\right)$$

where, Y, grain yield (t ha^{-1}), WR, total amount of water used (cm).

Relative water content (RWC) was calculated after collection of leaf in turgid condition accordingly [22]:

$$\text{RWC} = \frac{\text{FW} - \text{DW}}{\text{TW} - \text{DW}} \times 100$$

where, FW, fresh leaf weight, TW, turgid leaf weight, and DW, leaf dry weight. For determining the FW, the fresh leaf was cut into small pieces, and afterwards, weighed. the leaf sample (cut pieces) was drenched in distilled water for 4 h in the dim, and afterwards, the turgid leaf weight was determined to measure the TW. The small pieces of leaves were then oven dried at 80°C in an electric oven for 24 h and were weighed to estimate the DW.

The following formula calculates the internal N use efficiency of GY (INUEY):

$$\text{INUE}_Y = \frac{\text{Grain yield}}{\text{Total N uptake}}$$

It is expressed as kg GY/kg N uptake.

Internal N use efficiency of dry biomass (INUE_{DM}) was calculated by the following formula:

$$INUE_{DM} = \frac{\text{Total above ground biomass}}{\text{Total N uptake}}$$

It is expressed as kg biomass/kg N uptake.

2.5 Statistical Analysis of Recorded Data

All recorded data were statistically analyzed by using analysis of variance (ANOVA) and mean separation test was done by following Duncan's multiple range test (DMRT) at 5% level of probability [23].

3 Results

3.1 Climatic Condition during Two Crop Cycles

The weather data were recorded Department of Irrigation and Water Management, Bangladesh Agricultural University, Mymensingh, Bangladesh which are presented in Fig. 1.

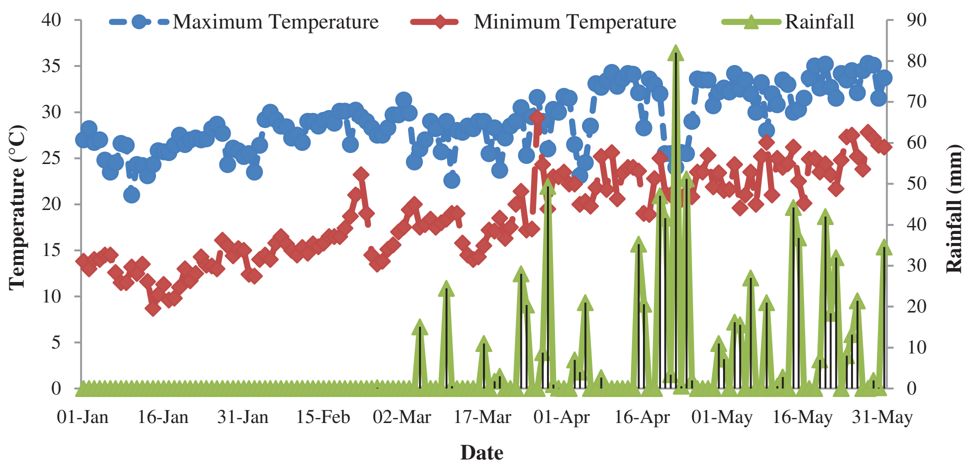

Figure 1: Weather condition during crop growth stages in both years' of observation

In both seasons, the maximum temperatures were varied from 21.0°C to 35.3°C with an average value of 29.1°C, however the minimum temperature ranged from 8.7°C to 29.4°C having a mean value of 18.7°C. Considering the months of observation, March to May was the hottest time, while January to February was the coolest period in both seasons. Daily rainfall ranged from 0 to 82 mm with monthly recorded values (January to May) of 0.0, 0.2, 163.7, 329.5, and 350.2 mm, respectively. No rainfall was happened up to the end of February. Though, rainfall was more regular and steady from the first week of March to onwards. During growth crop stages, 15.3 mm of rainfall was recorded up to panicle initiation (PI) (17 January–08 March), 155.6 mm during PI to flowering (FL) (09 March to 03 April), and 672.7 mm from FL (04 April) to harvest (02 May).

The vegetative growth of plants was completely in fully irrigated condition. On the opposing, they were subjected to equally irrigation and rainfall at PI stage and almost completely grown under rainfed conditions from FL to harvesting stages. From FL to harvest stages the crop received the maximum rainfall. The cultivar and environment had an influence on the duration of crop life cycle. Outline for three cultivars with their phenology are shown in Fig. 2. According to findings of the experiment, the usual duration of the life span of cultivars was 134 days (d). The Em to FL widely ranged between 102 d to 105 d, based on cultivars. The grain-filling period revealed cultivar difference from 28 d for BRRI dhan-28 and 34 for Binadhan-8.

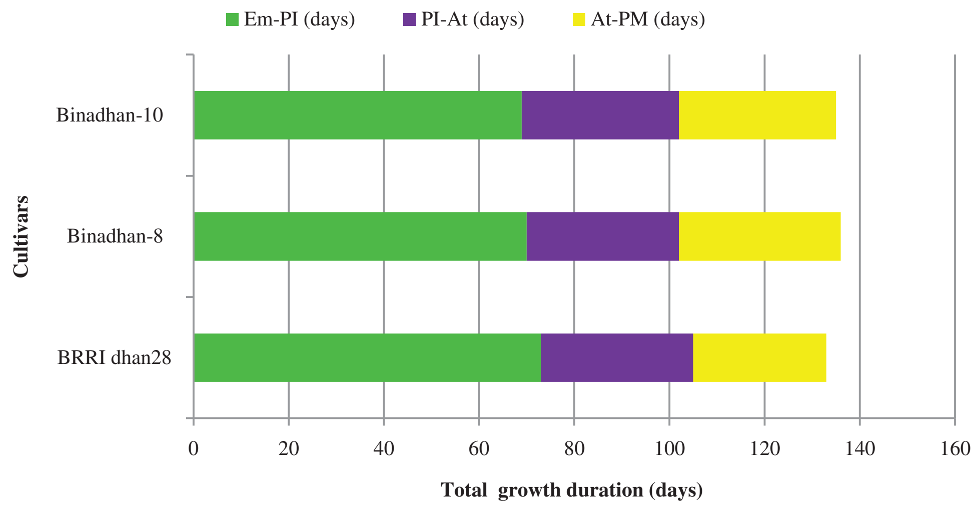

Figure 2: Phenological variation of rice cultivars in both years. The horizontal bar exhibits the duration of each developmental phases: emergence stage, Em; panicle initiation, PI; anthesis, At and physiological maturity, PM. The green bars show emergence Em-PI, violet bars show PI-At, and the yellow bars show At-PM

3.2 Growth Dynamics

A significant dissimilarity for plant height was recorded at different growth stages of all rice cultivars, water and nitrogen treatments (Table 2).

Table 2: The plant height (PH) and leaf area index (LAI) of rice cultivars at different growth stages were varied due to cultivars, water and nitrogen management in both years

Treatments	PH				LAI			
	AT	PI	FL	PM	AT	PI	FL	PM
Cultivars								
BRRI dhan28	28.85b	56.63b	86.68b	87.22b	0.056c	0.97b	3.32c	2.70b
Binadhan-8	29.62a	57.16ab	87.62b	88.16b	0.062a	1.01a	3.51a	2.86a
Binadhan-10	30.24a	57.91a	89.17a	89.72a	0.059b	0.98ab	3.43b	2.74b
CV (%)	4.22	2.81	2.17	2.05	8.35	4.52	4.03	4.98
Water management								
8-DAD	34.84a	62.37a	96.80a	97.40a	0.082a	1.15a	4.21a	3.46a
10-DAD	28.94b	57.53b	87.01b	87.55b	0.057b	0.99b	3.38b	2.62b
AWD	24.94c	51.80c	79.65c	80.14c	0.038c	0.82c	2.67c	2.21c
CV (%)	6.93	2.45	3.63	3.40	8.45	4.52	4.03	4.57
Nitrogen management								
140 kg N ha^{-1} from PU	27.41c	55.64c	84.42c	84.96c	0.052c	0.93c	3.14c	2.49c
83 kg N ha^{-1} from USG	29.45b	57.16b	87.91b	88.46b	0.059b	0.98b	3.40b	2.77b
105 kg N ha^{-1}from PU + 3 t ha^{-1} POM	31.86a	58.90a	91.14a	91.68a	0.067a	1.05a	3.72a	3.04a
CV (%)	8.67	3.41	1.59	1.50	7.48	4.52	3.92	4.71

(Continued)

Table 2 (continued)

Treatments	PH				LAI			
	AT	PI	FL	PM	AT	PI	FL	PM
ANOVA								
Cultivars (V)	**	**	**	**	**	**	**	**
Water management (W)	**	**	**	**	**	**	**	**
Nitrogen management (N)	**	**	**	**	**	**	**	**
V × W × N	NS	NS	NS	NS	NS	NS	NS	NS
CV (%)	4.22	2.81	2.17	2.05	8.35	4.52	4.03	4.98

Note: Within a column, the means with different alphabets were varied significantly at 5% level of probability; ** Significant at 1% level of significance.

Plant height augmented progressively over time reaching the peak level at PM. Binadhan-10 at PM showed longest plant (89.72 cm) height. The longest plant was observed at 8-DAD treatment in view of water management system. The influence of nitrogen management on plant height was also documented (Table 2). The maximum plant height was registered with 105 kg N from PU + 3 t ha^{-1} POM. In respect of cultivars, water and nitrogen management LAI was found significant. In the case of growth stage, LAI was enlarged raucously, attainment a peak at FL and then declining regardless of treatment differentiations. Due to the loss of some leaves through senescence LAI decreased after FL. Maximum LAI (3.51) was found at FL by Binadhan-8. Growing LAI with 8-DAD was recorded at all growth stages. LAI with 8-DAD was significantly higher than 10-DAD and AWD. The levels of nitrogen management had marked variation in LAI (Table 2).

Elevated LAI was registered with the application of 105 kg N from PU + 3 t ha^{-1} POM as compared to 83 kg N ha^{-1} from USG and 140 kg N ha^{-1} from PU. Fig. 3a revealed significant correlation (R^2 = 0.98, $P \leq 0.01$) amongst yield and LAI at FL. More solar radiation was absorbed with higher LAI containing cultivars which resulted in higher photosynthesis and eventually generated higher yields. GY differences for all rice varieties were correlated significantly (R^2 = 0.94, $P \leq 0.01$) with CGR at FL (Fig. 3b).

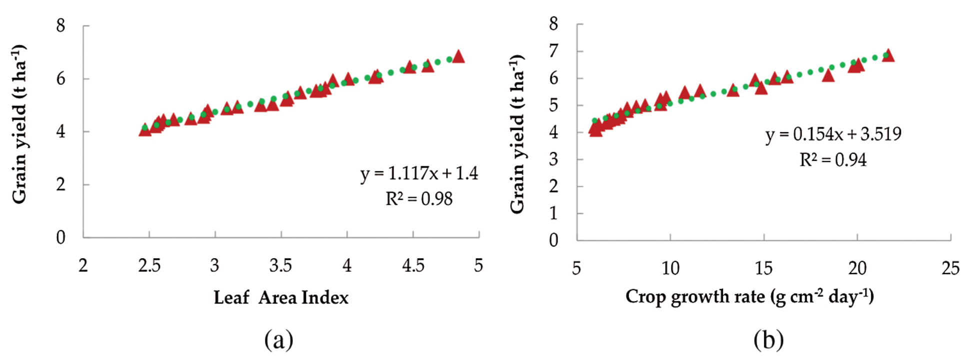

Figure 3: Correlation between GY and LAI (a) and CGR at flowering (b)

CGR improved similarly with the upsurge in leaf area over the time until FL and then declined irrespective of cultivar, water and nitrogen management (Tables 3 and 4). This parameter was significant for interactions between water and nitrogen management, cultivar and water management (Tables 5–8).

CGR was highest (20.51 g cm^{-2} day^{-1}) at 105 kg N from PU + 3 t ha^{-1} POM at FL for 8-DAD and lowest was noted at 140 kg N ha^{-1} from PU for AWD. In the same way, CGR at Binadhan-8 was the highest (18.20 g cm^{-2} day^{-1}) at FL for 8-DAD and the lowest was found at BRRI dhan-28 for AWD. Regardless of treatments, RGR was higher at the premature stage (AT) and demonstrated a retreating tendency with the progression of plant age (Tables 3 and 4). Increment of metabolically active tissue resulted in the decrease of RGR. The use of 105 kg N from PU + 3 t ha^{-1} POM with 8-DAD had the highest RGR (13.78 $g^{-1}g^{-1}$day) at FL (Table 5). Maximum RGR (13.01 $g^{-1}g^{-1}$ day) was obtained from Binadhan-10 along with 8-DAD at FL (Tables 7 and 8) in view of the interaction between cultivars and water management.

Table 3: The CGR and RGR of *boro* rice at different growth stages were varied due to cultivars, water and nitrogen management in both years

Treatments	CGR (g $cm^{-2}day^{-1}$)			RGR ($g^{-1}g^{-1}$day)		
	AT-PI	PI-FL	FL-PM	AT-PI	PI-FL	FL-PM
Cultivars						
BRRI dhan-28	9.71b	10.49c	5.17b	40.13	11.66	4.08a
Binadhan-8	10.75a	11.56a	5.37a	40.07	11.56	3.89c
Binadhan-10	10.04b	10.98b	5.37a	39.79	11.68	3.99b
CV (%)	7.91	7.05	2.46	1.69	2.24	1.77
Water management						
8-DAD	14.05a	17.16a	6.38a	39.37b	12.81a	3.22c
10-DAD	10.21b	9.24b	5.29b	40.20a	10.37c	3.99b
AWD	6.24c	6.62c	4.24c	40.42a	11.72b	4.75a
CV (%)	11.40	7.28	3.72	1.19	3.22	3.36
Nitrogen management						
140 kg N ha^{-1} from PU	8.97c	9.37c	4.80c	40.42a	11.51b	4.22a
83 kg N ha^{-1} from USG	10.23b	10.86b	5.38b	40.02b	11.55b	3.99b
105 kg N $ha^{-1}$from PU + 3 t ha^{-1} POM	11.30a	12.79a	5.73a	39.56c	11.84a	3.75c
CV (%)	3.85	9.85	1.68	1.43	2.62	2.38
ANOVA						
Cultivars (V)	**	**	**	NS	NS	**
Water management (W)	**	**	**	**	**	**
Nitrogen management (N)	**	**	**	**	**	**
V × W × N	NS	NS	**	NS	**	NS
CV (%)	7.91	7.05	2.46	1.69	2.24	1.77

Note: Within a column, the means with different alphabets were varied significantly at 5% level of probability; ** Significant at 1% level of significance.

The movement in NAR was descending based on treatments (Table 3). NAR was significant for interaction between water and nitrogen management and a parallel trend of the result was recorded as achieved in CGR and RGR. The result obtained is related to CGR in view of cultivar and water management.

Table 4: The NAR and RWC of *boro* rice at different growth stages were varied due to cultivars, water and nitrogen management in both years

Treatments	NAR (mg cm^{-2}day^{-1})			RWC (%)			
	AT-PI	PI-FL	FL-PM	AT	PI	FL	PM
Cultivars							
BRRI dhan28	1.279	0.2289c	0.1079a	38.37c	49.84c	64.22b	72.83b
Binadhan-8	1.336	0.2391a	0.0651c	39.76a	51.21a	65.97a	75.20a
Binadhan-10	1.294	0.2334b	0.0874b	39.09b	50.30b	64.86b	73.94b
CV (%)	7.30	11.31	12.59	2.75	1.60	2.73	2.75
Water management							
8-DAD	1.500a	0.3133a	0.0998a	44.86a	57.49a	75.40a	87.88a
10-DAD	1.348b	0.2050b	0.0790c	39.40b	51.40b	64.61b	72.81b
AWD	1.060c	0.1832c	0.0815b	32.96c	42.46c	55.03c	61.27c
CV (%)	10.88	12.09	10.28	2.39	1.60	2.18	3.64
Nitrogen management							
140 kg N ha^{-1} from PU	1.245b	0.2166c	0.0940b	37.22c	48.33c	62.59c	70.70c
83 kg N ha^{-1} from USG	1.315a	0.2336b	0.0978a	39.00b	50.53b	64.80b	73.82b
105 kg N ha^{-1} from PU + 3 t ha^{-1} POM	1.348a	0.2512a	0.0686c	41.00a	52.49a	67.66a	77.44a
CV (%)	6.44	14.17	11.49	2.85	1.64	2.17	3.44
ANOVA							
Cultivars (V)	NS	**	**	**	**	**	**
Water management (W)	**	**	**	**	**	**	**
Nitrogen management (N)	**	**	**	**	**	**	**
V × W × N	NS	**	**	NS	NS	NS	NS
CV (%)	7.30	11.31	12.59	2.75	1.60	2.73	2.75

Note: Within a column, the means with different alphabets were varied significantly at 5% level of probability; ** Significant at 1% level of significance.

Table 5: The CGR and RGR of *boro* rice at different growth stages were varied due to the interaction effect of cultivars, water and nitrogen management in both years

Water management	Nitrogen management	CGR (g cm^{-2}day^{-1})			RGR (g^{-1}g^{-1}day)		
		AT-PI	PI-FL	FL-PM	AT-PI	PI-FL	FL-PM
8-DAD	140 kg N ha^{-1} from PU	12.72c	14.23c	5.66d	39.47c	12.17c	3.50g
	83 kg N ha^{-1} from USG	14.29b	16.74b	6.59b	39.87bc	12.48b	3.21h
	105 kg N ha^{-1} from PU + 3 t ha^{-1} POM	15.15a	20.51a	6.91a	38.78d	13.78a	2.94i
10-DAD	140 kg N ha^{-1} from PU	8.63f	7.84f	4.68f	40.09bc	10.41e	4.14d
	83 kg N ha^{-1} from USG	10.34e	9.19e	5.30 e	40.38b	10.23e	3.97e
	105 kg N ha^{-1} from PU + 3 t ha^{-1} POM	11.65d	10.70d	5.90c	40.13b	10.46e	3.87f

(Continued)

Table 5 (continued)

Water management	Nitrogen management	CGR (g $cm^{-2}day^{-1}$)			RGR ($g^{-1}g^{-1}day$)		
		AT-PI	PI-FL	FL-PM	AT-PI	PI-FL	FL-PM
AWD	140 kg N ha^{-1} from PU	5.56i	6.03g	4.08i	41.69a	11.95c	5.02a
	83 kg N ha^{-1} from USG	6.06h	6.64g	4.25h	39.81bc	11.94c	4.79b
	105 kg N ha^{-1} from PU + 3 t ha^{-1} POM	7.09g	7.17fg	4.39g	39.78bc	11.27d	4.44c
ANOVA							
Water Management (W)		**	**	**	**	**	**
Nitrogen Management (N)		**	**	**	**	**	**
W × N		**	**	**	**	**	**
CV (%)		3.85	9.85	1.68	1.43	2.62	2.38

Note: Within a column, the means with different alphabets were varied significantly at 5% level of probability; ** Significant at 1% level of significance.

Table 6: The NAR and RWC of *boro* rice at different growth stages were varied due to the interaction effect of cultivars, water and nitrogen management in both years

Water management	Nitrogen management	NAR (mg $cm^{-2}day^{-1}$)			RWC (%)			
		AT-PI	PI-FL	FL-PM	AT	PI	FL	PM
8-DAD	140 kg N ha^{-1} from PU	1.44	0.2814c	0.1089a	43.88 b	55.49	73.64b	85.77b
	83 kg N ha^{-1} from USG	1.54	0.3117b	0.1107a	44.40 b	57.37	75.74a	88.30ab
	105 kg N ha^{-1} from PU + 3 t ha^{-1} POM	1.50	0.3467a	0.0798d	46.30a	59.62	76.84a	89.56a
10-DAD	140 kg N ha^{-1} from PU	1.25	0.1909f	0.0862c	36.76e	49.13	61.75e	67.48e
	83 kg N ha^{-1} from USG	1.36	0.2027e	0.0810d	39.32d	51.67	63.39d	71.90d
	105 kg N ha^{-1} from PU + 3 t ha^{-1} POM	1.42	0.2213d	0.0700e	42.11c	53.39	68.68c	79.06c
AWD	140 kg N ha^{-1} from PU	1.03	0.1776h	0.0868c	31.01h	40.37	52.38h	58.86g
	83 kg N ha^{-1} from USG	1.03	0.1863g	0.1019b	33.29g	42.54	55.26g	61.27fg
	105 kg N ha^{-1} from PU + 3 t ha^{-1} POM	1.11	0.1857g	0.0560f	34.58f	44.48	57.47f	63.70f
ANOVA								
Water Management (W)		**	**	**	**	**	**	**
Nitrogen Management (N)		**	**	**	**	**	**	**
W × N		NS	**	**	**	NS	**	**
CV (%)		6.44	14.17	11.49	2.85	1.64	2.17	3.44

Note: Within a column, the means with different alphabets were varied significantly at 5% level of probability; ** Significant at 1% level of significance.

Table 7: The CGR and RGR of *boro* rice at different growth stages were varied due to the interaction effect of cultivars, water and nitrogen management in both years

Water management	Cultivars	CGR (g $cm^{-2}day^{-1}$)			RGR ($g^{-1}g^{-1}$day)		
		AT-PI	PI-FL	FL-PM	AT-PI	PI-FL	FL-PM
8-DAD	BRRI dhan28	13.46	16.24c	6.16c	39.32cd	12.67b	3.31
	Binadhan-8	15.03	18.20a	6.39b	39.88bc	12.75b	3.09
	Binadhan-10	13.67	17.04b	6.61a	38.91d	13.01a	3.25
10-DAD	BRRI dhan28	9.71	8.69e	5.16e	40.18b	10.33e	4.09
	Binadhan-8	10.71	9.73d	5.45d	40.25ab	10.38e	3.92
	Binadhan-10	10.20	9.30de	5.27e	40.18b	10.40e	3.97
AWD	BRRI dhan28	5.97	6.52f	4.20f	40.90a	11.98c	4.84
	Binadhan-8	6.49	6.74f	4.27f	40.09b	11.54d	4.65
	Binadhan-10	6.25	6.59f	4.25f	40.29ab	11.64d	4.76
ANOVA							
Water Management (W)		**	**	**	**	**	**
Cultivar (V)		**	**	**	NS	NS	**
W × V		NS	*	**	*	**	NS
CV (%)		7.91	7.05	2.46	1.69	2.24	1.77

Note: Within a column, the means with different alphabets were varied significantly at 5% level of probability; ** Significant at 1% level of significance.

Table 8: The NAR and RWC of *boro* rice at different growth stages were varied due to the interaction effect of cultivars, water and nitrogen management in both years

Water management	Cultivars	NAR (mg $cm^{-2}day^{-1}$)			RWC (%)			
		AT-PI	PI-FL	FL-PM	AT	PI	FL	PM
8-DAD	BRRI dhan28	1.47	0.3039c	0.1337a	44.20	56.79	74.70	87.04
	Binadhan-8	1.56	0.3242a	0.0588g	45.47	58.11	76.30	88.72
	Binadhan-10	1.46	0.3117b	0.1069b	44.90	57.57	75.21	87.87
10-DAD	BRRI dhan28	1.31	0.1982f	0.0858c	38.54	50.83	63.69	70.96
	Binadhan-8	1.37	0.2103d	0.0693f	40.17	52.19	65.67	74.82
	Binadhan-10	1.35	0.2063e	0.0820d	39.48	51.17	64.47	72.66
AWD	BRRI dhan28	1.04	0.1847g	0.1040b	32.36	41.90	54.27	60.50
	Binadhan-8	1.07	0.1827g	0.0672f	33.64	43.34	55.94	62.04
	Binadhan-10	1.06	0.1822g	0.0735e	32.88	42.15	54.89	61.28
ANOVA								
Water Management (W)		**	**	**	**	**	**	**
Cultivar (V)		NS	**	**	**	**	**	**
W × V		NS	**	**	NS	NS	NS	NS
CV (%)		7.30	11.31	12.59	2.75	1.60	2.73	2.75

Note: Within a column, the means with different alphabets were varied significantly at 5% level of probability; ** Significant at 1% level of significance.

RWC was significantly influenced by cultivars, water and nitrogen management. The tolerance levels of cultivars were higher to drought conditions having elevated RWC (%). At FL, the maximum RWC (65.97%) was exhibited by Binadhan-8. Most of the cultivars had a slight change in RWC at FL and PM and related patterns of RWC as before were documented. The interaction effect of water and nitrogen management was significant for RWC. The highest RWC (76.84%) at FL was recorded from 105 kg N from PU + 3 t ha^{-1} POM with 8-DAD which is statistically similar to 83 kg N ha^{-1} from USG and 8-DAD.

3.3 Total Dry Matter, Grain yield and Yield Components

TDM increased significantly from AT to PM (TDM at FL only presented, Table 9). It was maximum ($P < 0.05$) in Binadhan-8 followed by Binadhan-10 and BRRI dhan28. TDM varied from 12.70 to 30.78 g plant^{-1}with water management treatments. Highest TDM was recorded at 8-DAD compared to 10-DAD and AWD. In respect of nitrogen management, maximum TDM was found in 105 kg N from PU + 3 t ha^{-1} POM. TDM was significant for combined effect of water and nitrogen management (Table 10). Use of 105 kg N from PU + 3 t ha^{-1} POM with 8-DAD treatment produced highest TDM (35.13 g plant^{-1}). In addition, interaction effect of cultivar and water management was also significant for this parameter (Table 11).

Table 9: Yield attributes and yield of rice as influenced by cultivar, water and nitrogen management systems

Treatments	Effective tillers hill^{-1}	Grains panicle^{-1}	1000 grain weight (g)	TDM at FL (g plant^{-1})	Grain yield (t ha^{-1})[a]	Straw yield (t ha^{-1})[a]	Harvest index (%)
Cultivars							
BRRI dhan28	12.22b	76.78c	21.13	19.96c	5.12c	5.63c	47.59
Binadhan-8	13.22a	80.24a	21.57	22.03a	5.34a	5.88a	47.63
Binadhan-10	12.64b	78.24b	21.32	20.78b	5.20b	5.75b	47.60
CV (%)	6.12	2.03	4.29	2.24	1.48	1.10	1.19
Water management							
8-DAD	16.41a	95.49a	23.68a	30.78a	6.13a	6.87a	47.20b
10-DAD	12.20b	76.53b	20.87b	19.29b	5.14b	5.61b	47.71a
AWD	9.47c	63.24c	19.46c	12.70c	4.40c	4.78c	47.91a
CV (%)	5.23	1.56	4.32	2.51	1.48	1.23	0.86
Nitrogen management							
140 kg N ha^{-1} from PU	11.45c	73.14c	20.64c	18.12c	4.93c	5.39c	47.70
83 kg N ha^{-1} from USG	12.64b	78.23b	21.34b	20.84b	5.19b	5.76b	47.53
105 kg N ha^{-1}from PU + 3 t ha^{-1} POM	13.99a	83.89a	22.04a	23.81a	5.54a	6.11a	47.59
CV (%)	5.85	2.72	3.75	2.34	1.21	1.10	1.18
ANOVA							
Cultivars (V)	**	**	NS	**	**	**	NS
Water management (W)	**	**	**	**	**	**	**
Nitrogen management (N)	**	**	**	**	**	**	NS
V × W × N	NS	NS	NS	NS	*	NS	NS
CV (%)	6.12	2.03	4.29	2.24	1.48	1.10	1.19

Note: Within a column, the means with different alphabets were varied significantly at 5% level of probability, [a]Grain yield and straw yield with the moisture content of 14%.

Table 10: Interaction between water and nitrogen management on yield attributes and yield of rice (two year means)

Water management	Nitrogen management	Effective tillers hill^{-1}	No. of grains panicle^{-1}	1000 grain weight (g)	TDM at FL (g plant^{-1})	Grain yield (t ha^{-1})[a]	Straw yield (t ha^{-1})[a]	Harvest index (%)
8-DAD	140 kg N ha^{-1} from PU	14.39c	88.61c	22.62	26.63c	5.72c	6.35c	47.44
	83 kg N ha^{-1} from USG	16.35b	95.73b	23.67	30.60b	6.06b	6.91b	46.84
	105 kg N ha^{-1} from PU + 3 t ha^{-1} POM	18.50a	102.1a	24.77	35.13a	6.61a	7.35a	47.33
10-DAD	140 kg N ha^{-1} from PU	11.06f	70.84f	20.26	16.34f	4.88 f	5.26f	47.77
	83 kg N ha^{-1} from USG	12.12e	76.14e	20.84	19.37e	5.09e	5.60e	47.79
	105 kg N ha^{-1} from PU + 3 t ha^{-1} POM	13.41d	82.59d	21.52	22.16d	5.44d	5.98d	47.56
AWD	140 kg N ha^{-1} from PU	8.91h	59.97i	19.05	11.40i	4.19i	4.56i	47.88
	83 kg N ha^{-1} from USG	9.45gh	62.82h	19.50	12.56h	4.42h	4.78h	47.97
	105 kg N ha^{-1} from PU + 3 t ha^{-1} POM	10.07g	66.94g	19.84	14.13g	4.57g	5.00g	47.87
ANOVA								
Water Management (W)		**	**	**	**	**	**	**
Nitrogen Management (N)		**	**	**	**	**	**	NS
W × N		**	**	NS	**	**	**	NS
CV (%)		5.85	2.72	3.75	2.34	1.21	1.10	1.18

Note: Within a column, the means with different alphabets were varied significantly at 5% level of probability; [a] Grain yield and straw yield with the moisture content of 14%.

Table 11: Interaction between water management and cultivars on yield attributes and yield of rice (two year means)

Water management	Cultivar	Effective tillers hill^{-1}	Grains panicle^{-1}	1000 grain weight (g)	TDM at FL (g plant^{-1})	Grain yield (t ha^{-1})[a]	Straw yield (t ha^{-1})[a]	Harvest index (%)
8-DAD	BRRI dhan28	15.65	93.17	23.37	29.31c	6.01b	6.71c	47.23
	Binadhan-8	17.17	97.74	24.02	32.73a	6.31a	7.02a	47.22
	Binadhan-10	16.42	95.56	23.67	30.32b	6.08b	6.87b	47.16
10-DAD	BRRI dhan28	11.76	74.94	20.67	18.25f	5.03e	5.49f	47.65
	Binadhan-8	12.73	78.48	21.11	20.27d	5.24c	5.75d	47.77
	Binadhan-10	12.09	76.16	20.84	19.33e	5.14d	5.59e	47.70

(Continued)

Table 11 (continued)

Water management	Cultivar	Effective tillers hill^{-1}	Grains panicle^{-1}	1000 grain weight (g)	TDM at FL (g plant^{-1})	Grain yield (t ha^{-1})^a	Straw yield (t ha^{-1})^a	Harvest index (%)
AWD	BRRI dhan28	9.260	62.24	19.34	12.31h	4.31h	4.70i	47.89
	Binadhan-8	9.766	64.49	19.59	13.08g	4.47f	4.86g	47.89
	Binadhan-10	9.406	63.00	19.47	12.70gh	4.40g	4.79h	47.94
ANOVA								
Water Management (W)		**	**	**	**	**	**	**
Cultivar (V)		**	**	NS	**	**	**	NS
W × V		NS	NS	NS	**	*	**	NS
CV (%)		6.12	2.03	4.29	2.24	1.48	1.10	1.19

Note: Within a column, the means with different alphabets were varied significantly at 5% level of probability; ** Significant at 1% level of significance, [a]Grain yield and straw yield with the moisture content of 14%.

The highest TDM (32.73 g plant^{-1}) was recorded in Binadhan-8 and 8-DAD treatment. TDM was greatly responsible for GY variations among cultivars ($R^2 = 0.98$, $P < 0.01$) to (Fig. 4a). Table 9 showed the ANOVA of GY and yield components and their mean relationship. The highest number of effective tillers hill^{-1} was observed in Binadhan-8 followed by Binadhan-10 and BRRI dhan28. Effective tillers hill^{-1} had a strong correlation with GY ($R^2 = 0.98$, $P < 0.01$) (Fig. 4b). Moreover, number of grains panicle^{-1}, GY and straw yield was higher in Binadhan-8. There was a positive relationship ($R^2 = 0.98$, $P < 0.01$) between grains panicle^{-1} and GY (Fig. 4c). Yield attributes and yield differed significantly with water management (Table 9). GY of rice under 8- DAD and 10- DAD treatments was 39.32% and 16.82 % higher than AWD. GY was also significantly affected by nitrogen management. 105 kg N from PU + 3 t ha^{-1} POM produced maximum GY (5.54 t ha^{-1}) followed by 83 kg N ha^{-1} from USG and 140 kg N ha^{-1} from PU. Combined effect of water and nitrogen management demonstrated significant response in terms of yield components and yield (Table 10). The top value related to GY (6.61 t ha^{-1}) was recorded from application of 105 kg N from PU + 3 t ha^{-1} POM with 8-DAD while the minimum was established in 140 kg N ha^{-1} from PU with AWD. Binadhan-8 with 8-DAD treatment produced highest GY (6.31 t ha^{-1}) (Table 11). Besides lowest GY (4.31 t ha^{-1}) was obtained from BRRI dhan28 along with AWD treatment. There was a distinct variation in GY due to interaction effect among cultivar, water and nitrogen management (Fig. 5).

3.4 Water Use and Productivity

Table 12 figured out the water consumption and water productivity with different water management treatments.

Three water management systems had distinct amount of water. Full water under 10-DAD and AWD was lesser than that of 8-DAD. The amount of water was 108.4 cm for 8-DAD and 104.4 cm for that of 10-DAD and AWD. Water productivity was the maximum (0.057 t ha^{-1} cm^{-1}) in 8-DAD due to higher yield and was found to be least (0.042 t ha^{-1} cm^{-1}) in AWD.

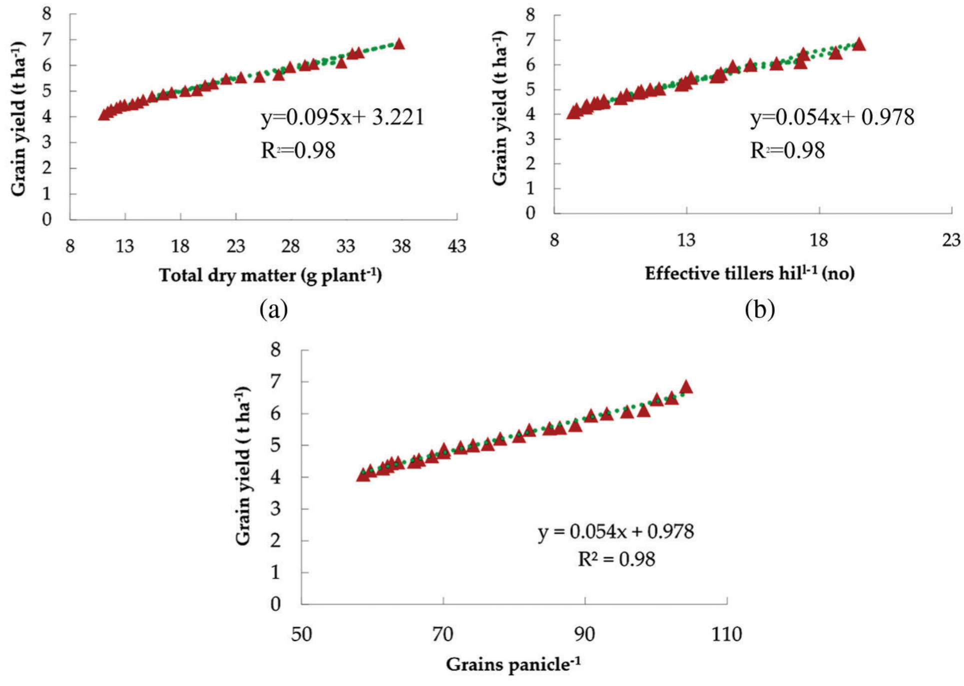

Figure 4: Relationship between GY and total dry matter (a), effective tillers hill^{-1} (b), and grains panicle^{-1} (c)

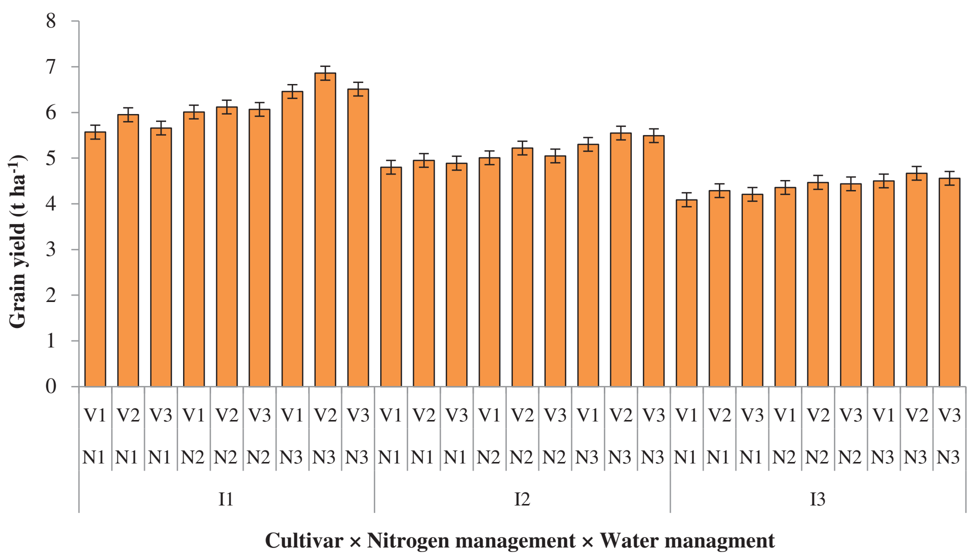

Figure 5: Interaction among cultivar, water and nitrogen management for GY

Table 12: Water use and water productivity under different water management systems (two year means)

Treatments	Irrigations (number)	Frequency of water application (DAT)	Water used for crop establishment (cm)	Irrigation water applied (cm)	Rain water (cm)	Total water use (cm)	Grain yield (t ha^{-1})	Water productivity (t ha^{-1} cm^{-1})	% yield increase over AWD
8-DAD	6	30,40,50,60,70,80	4	24	84.4	108.4	6.13a	0.057	39.32
10-DAD	5	30,42,54, 66,78	4	20	84.4	104.4	5.14b	0.049	16.82
AWD	5	30,43,56,69, 82	4	20	84.4	104.4	4.40c	0.042	–
F-test (0.05)							**		
CV (%)							1.48		

Note: Within a column, the means with different alphabets were varied significantly at 5 % level of probability; ** Significant at 1% level of significance.

3.5 N Content (%) and Uptake (kg ha^{-1})

N content (%) and uptake of grain and straw were influenced by cultivar, water and nitrogen management (Table 13).

Table 13: Effect of cultivar, water and nitrogen management on content and uptake of nitrogen in the grain and straw, internal N use efficiency of boro rice (two year means)

Cultivars	N content in grain (%)	N uptake in grain (kg ha^{-1})	N content in straw (%)	N uptake in straw (kg ha^{-1})	Internal N use efficiency of grain yield (kg grain yield/kg N uptake)	Internal N use efficiency of dry biomass (kg biomass/kg N uptake)
Cultivars						
BRRI dhan28	1.26b	65.71b	0.941b	55.27c	45.37a	49.51
Binadhan-8	1.30a	71.06a	1.007a	61.53a	43.00c	48.57
Binadhan-10	1.28ab	67.91b	0.973ab	58.30b	44.16b	48.98
CV (%)	3.49	5.99	6.49	4.20	3.98	4.63
Water management						
8-DAD	1.46a	90.37a	1.263a	87.10a	34.75c	49.40a
10-DAD	1.27b	65.91b	0.985b	55.66b	42.65b	47.04b
AWD	1.09c	48.40c	0.672c	32.34c	55.13a	50.63a
CV (%)	4.28	4.12	9.18	6.49	4.10	5.59
Nitrogen management						
140 kg N ha^{-1} from PU	1.21c	60.83c	0.881c	49.44c	47.85a	50.10a
83 kg N ha^{-1} from USG	1.27b	67.35b	0.965b	57.79b	44.21b	49.28a
105 kg N ha^{-1}from PU + 3 t ha^{-1} POM	1.35a	76.50a	1.075a	67.89a	40.47c	47.68b
CV (%)	2.47	5.89	6.49	4.30	3.16	4.45
ANOVA						
Cultivars (V)	**	**	**	**	**	NS
Water management (W)	**	**	**	**	**	*

(Continued)

Table 13 (continued)

Cultivars	N content in grain (%)	N uptake in grain (kg ha^{-1})	N content in straw (%)	N uptake in straw (kg ha^{-1})	Internal N use efficiency of grain yield (kg grain yield/kg N uptake)	Internal N use efficiency of dry biomass (kg biomass/kg N uptake)
Nitrogen management (N)	**	**	**	**	**	**
V × W × N	NS	NS	NS	NS	NS	NS
CV (%)	3.49	5.99	6.49	4.20	3.98	4.63

Note: Within a column, the means with different alphabets were varied significantly at 5% level of probability; ** Significant at 1% level of significance, *Significant at 5% level of significance.

The grain N content (%) in cultivar ranged from 1.26% to 1.30%. Binadhan-8 had the highest N content (%) whereas that content was superior in 8-DAD and 105 kg N from PU + 3 t ha^{-1} POM. Increment of rice GY is the outcome of superior grain N content (%) and uptake. In respect of straw, N content (%) varied from 0.941% to 1.007% for cultivar, 0.672% to 1.263% for water management and 0.881% to 1.075% for nitrogen management. Irrespective of treatments, N uptake in straw varied from 32.34 to 87.10 kg ha^{-1}. Straw N uptake was also inferior to that of grain. A well significant positive association was observed between grain N content and GY ($R^2 = 0.98$, $P < 0.01$) Fig. 6a. Parallel tendency of result was also recorded for N content in straw and GY (Fig. 6b). Uptake of N in grain ($R^2 = 0.99$, $P < 0.01$) and straw ($R^2 = 0.99$, $P < 0.01$) had a greatly significant relationship with GY (Figs. 6c and 6d). Combined effect of water and nitrogen management was significant for all those parameters apart from N content in grain (%).

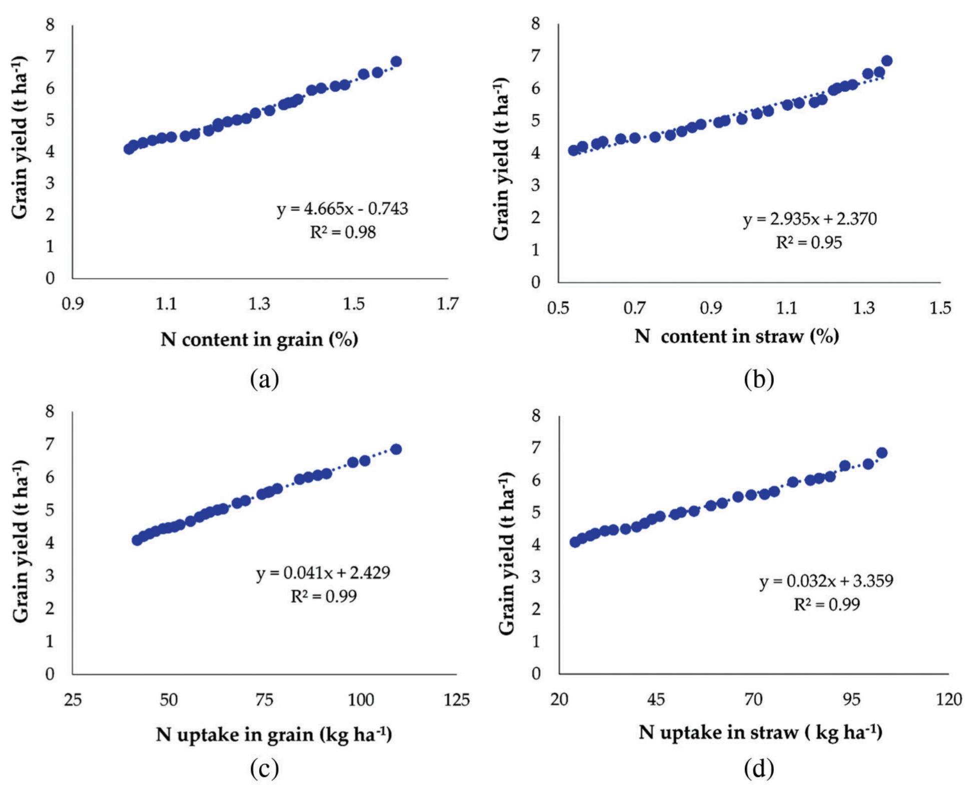

Figure 6: Relationship between GY and N content in grain (a), N content in straw (b), N uptake in grain (c) and N uptake in straw (d)

3.6 N Use Efficiencies Indicators

The analyzed data of internal N use efficiency was presented in Table 13. $INUE_Y$ and $INUE_{DM}$ were affected by cultivar, water and nitrogen management. The $INUE_Y$ varied from 34.75 to 55.13 kg grain/kg N and $INUE_{DM}$ from 47.04 to 50.63 kg biomass/kg N. $INUE_Y$ and $INUE_{DM}$ were declined due to more use of water. Similarly, $INUE_Y$ and $INUE_{DM}$ tended to decrease with application of POM with PU. Combinations of water and nitrogen management interacted significantly along with these parameters (Table 14).

Table 14: Interaction between water and nitrogen management on content and uptake of nitrogen in the grain and straw, internal N use efficiency of boro rice (two year means)

Water management	Nitrogen management	N content in grain (%)	N uptake in grain (kg ha^{-1})	N content in straw (%)	N uptake in straw (kg ha^{-1})	Internal N use efficiency of grain yield (kg grain yield/kg N uptake)	Internal N use efficiency of dry biomass (kg biomass/ kg N uptake)
8-DAD	140 kg N ha^{-1} from PU	1.38	79.58c	1.190	75.96c	36.81g	49.62bc
	83 kg N ha^{-1} from USG	1.46	88.78b	1.250	86.87b	34.57h	49.50bc
	105 kg N ha^{-1} from PU + 3 t ha^{-1} POM	1.55	102.7a	1.330	98.47a	32.88i	49.07bcd
10-DAD	140 kg N ha^{-1} from PU	1.21	59.44f	0.881	46.42f	46.13d	46.52e
	83 kg N ha^{-1} from USG	1.27	64.92e	0.978	54.92e	42.60e	47.82cde
	105 kg N ha^{-1} from PU + 3 t ha^{-1} POM	1.34	73.36d	1.090	65.65d	39.21f	46.77de
AWD	140 kg N ha^{-1} from PU	1.03	43.46i	0.567	25.92i	60.62a	54.14a
	83 kg N ha^{-1} from USG	1.09	48.35h	0.660	31.56h	55.45b	50.52b
	105 kg N ha^{-1} from PU + 3 t ha^{-1} POM	1.16	53.38g	0.790	39.55g	49.32c	47.21cde
ANOVA							
Water Management (W)		**	**	**	**	**	*
Nitrogen Management (N)		**	**	**	**	**	**
W × N		NS	NS	**	**	**	**
CV (%)		2.47	5.89	6.49	4.30	3.16	4.45

Note: Within a column, the means with different alphabets were varied significantly at 5% level of probability;** Significant difference at $P \leq 0.01$, * Significant difference at $P \leq 0.05$, NS-Non significant.

4 Discussion

Study on individual effect of cultivar, irrigation scheduling and nitrogen management on diverse interference in rice is well recognized in the literature. Studies on physiological development, yield, water productivity and NUE of exclusively high yielding cultivars in relation to different water and nitrogen management are still inadequate. In fact, the effect of water and N source on high yielding rice subsisted in production. According to association between water and nitrogen management, appropriate rate of water and source of N use aiming at improving water productivity, NUE could be increased by N utilization and amplify rice GY. In our study, cultivars varied in respect of performance under different water and nitrogen management. The dissimilarity in the performance may be connected to crop length, growth, TDM and NUE indicators variation.

In our study grain filling time influenced GY. The involvement of grain filling period to rice GY exhibited that GY of diverse cultivars was fixed by grain-filling period [24]. The rice cultivars having loner grain filling time have created higher yield. The maximum days (34) from anthesis to physiological maturity were required for Binadhan-8 which has influence in accomplishing supreme GY. Utilization of more climatic parameters like temperature and light for extended grain grow this related with extension of more grain-filling period.

Our study revealed that plant height, LAI, CGR, RGR and NAR improved distinctly in crop grown at 8-DAD and 10-DAD over those of severe AWD. Moisture insufficiency raised from severe AWD and rice plant suffered from water stress in dry season. Thus it declined maximum growth attributes at different developmental stages. It specified that rice crop desires optimal saturation rather than AWD for its optimum growth in dry season. For improving growth parameters of summer rice, use of irrigation at saturation might produce positive condition compared to AWD [25].

In our study, the growth variables of *boro* (irrigated) rice were greatly influenced by sources of nitrogen. Use of 105 kg N from PU + 3 t ha^{-1} POM distinctly increase plant height, LAI, CGR, RGR and NAR of the crop compared to 83 kg N ha^{-1} from USG and 140 kg N ha^{-1} from PU. Integrated application of inorganic and organic N is superior than solitary inorganic source (PU) on rising rice yield components and GY [26–28]. This may be due to the truth that N is simply obtainable from chemical fertilizer at the early growth stage in rice and organic fertilizers are mineralized at the later growth stages in rice. The mutual application of organic and inorganic sources of N is better than sole application of urea as N source for grain and straw yield because organic manures can trim down N loss [27] and maintain the N supply to rice plants for longer period [26,28].

Effective tillers $plant^{-1}$, grains $panicle^{-1}$ and TDM were higher in Binadhan-8 contrasted to Binadhan-10 and BRRI dhan28. Binadhan-8 finally created higher GY over those of Binadhan-10 and BRRI dhan28. Differential production potentiality is accountable for differences in productivity of rice cultivars [29].

The crop grown at 8-DAD treatment results in more effective tillers $plant^{-1}$, grains $panicle^{-1}$, TDM, 1000 grain weight that these attributes produced influential role in producing higher grain and straw yield. 8-DAD increased GY by 39.32% over AWD. Decline in tillering at AWD directed to decrease panicle fabrication, grain formation and development which ultimately reduced crop yield under dry condition.

Our study reflected significant variation on growth, yields attributes and yield due to combined application of water and N source. In the highest irrigation treatment (8-DAD), using 105 kg N from PU + 3 t ha^{-1} POM provided significantly higher yield. However, use of 105 kg N from PU + 3 t ha^{-1} POM with the lower irrigation treatments 10-DAD and AWD gave significantly lower yield. The considerable and reliable interactions between irrigation and N might be due to the little variation among the water management treatments and the low level of soil moisture stress [30]. The system in which high yielding rice showed improved yield performance and higher WUE under water-saving irrigation is not completely understood. A number of probable clarifications could be made based on previous findings. Firstly, it is assumed that a large root biomass of high yielding cultivars of rice is responsible for large aboveground biomass production [31–34]. Secondly, higher dry matter produced by high yielding rice showed mid and late growth periods. We observed that, CGR from PI to FL (flowering) and FL to PM, were significantly different under various DAD and AWD-based irrigation. It is proposed that a high dry matter production capability at the mid growth stage can generate large sink size by encouraging spikelet differentiation, declining spikelet degeneration, and escalating proliferation of endosperm cells at the early seed-development stage [35–38]. Therefore, better yield performance and higher WUE for high-yielding rice are the outcome of stronger ability of dry-matter production during the mid- and late-growth stage under various DAD and AWD-based irrigation. Combined effect between cultivar and N management was non significant for most of the parameters. This might be due to similar type of N necessities of the cultivars under studied. Finally, interaction among cultivars, water and N management was significant for GY. The higher yield was come with higher LAI, effective tillers plant^{-1}, grains panicle^{-1} and higher TDM.

The levels of internal crop N use-efficiency for high-yielding irrigated rice were determined by our study. The use of N fertilizer must be optimized to maximize economic returns although farmers are struggling for higher N use-efficiency. Hence, use of 140 kg N ha^{-1} fertilizer produced a $INUE_Y$ level of 47.85 kg grain/kg crop N uptake and $INUE_{DM}$ level of 50.10 kg biomass/kg crop N uptake. It was reported $INUE_Y$ of 46 kg rice grain/kg crop N uptake was found [39]. In comparison, 105 kg N from PU + 3 t ha^{-1}POM application recorded $INUE_Y$ level of 40.47 kg grain/kg crop N uptake and $INUE_{DM}$ level of 47.68 kg biomass/kg crop N uptake. Low $INUE_Y$ and $INUE_{DM}$ resulted from extreme N fertilizer utilization [40].

5 Conclusions

Results from the research exposed that *boro* rice yield differed significantly ($P < 0.05$) across the various N and water treatments. Physiological and yield contributing parameters were more influential for 8-DAD treatments compared to 10-DAD and AWD. The highest water productivity was also observed in 8-DAD treatment. N application through PU along with POM was found more advantageous in terms of higher yield components, yield and N use efficiency. 8-DAD treatment showed more water productivity and yield increase over AWD and it was more efficient to produce rice than the rest of the water management methods. This indicates that continuous submergence is not a requirement in rice production and farmers could apply 8-DAD treatment and PU along with poultry manure to decrease water use, enhance water and N productivity which will reduce cost of production. So, it may be accomplished that Binadhan-8 at 8-DAD with 105 kg N from PU + 3 t ha^{-1} POM be adapted for improving growth and productivity of *boro* rice under sub-tropical condition of Bangladesh.

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