DETERMINATION OF ECONOMIC NITROGEN RATE, GROWTH, YIELD AND NITROGEN UPTAKE OF TRANSPLANTED *AUS* VARIETIES

MUNMUN AKTER

MASTER OF SCIENCE

IN

AGRONOMY

DEPARTMENT OF AGRONOMY

SHER-E-BANGLA AGRICULTURAL UNIVERSITY, DHAKA-1207

DECEMBER, 2020

DETERMINATION OF ECONOMIC NITROGEN RATE, GROWTH, YIELD AND NITROGEN UPTAKE OF TRANSPLANTED *AUS* VARIETIES

By

MUNMUN AKTER
REGISTRATION NO. 18-09125

A Thesis

Submitted to the Department of Agronomy,
Sher-e-Bangla Agricultural University, Dhaka,
In partial fulfilment of the requirements for the degree of

MASTER OF SCIENCE

IN

AGRONOMY

SEMESTER: JULY- DECEMBER, 2020

Approved by:

……………………………………… ……………………………………..

(Dr. Sheikh Muhammad Masum) **(Dr. Md. Khairul Alam Bhuiyan)**
Associate Professor

Supervisor **Co-supervisor**

…………………………………

(Prof. Dr. Tuhin Suvra Roy)
Chairman, Examination Committee
Department of Agronomy, SAU

Sher-e-Bangla Agricultural University

Sher-e-Bangla Nagar, Dhaka -1207

DEPARTMENT OF AGRONOMY

CERTIFICATE

This is to certify that the thesis entitled, “**DETERMINATION OF ECONOMIC NITROGEN RATE, GROWTH, YIELD AND NITROGEN UPTAKE OF TRANSPLANTED *AUS* VARIETIES”** submitted to the Faculty of Agriculture, Sher-e-Bangla Agricultural University, Dhaka, in the partial fulfilment of the requirements for the degree of **MASTER OF SCIENCE (M.S.) IN AGRONOMY,** embodies the result of a piece of *bona fide* research work carried out by **MUNMUN AKTER,** Registration No. **18-09125** under my supervision and guidance. No part of the thesis has been submitted for any other degree or diploma.

I further certify that such help or source of information, as has been availed of during the course of this investigation has duly been acknowledged.

(Dr. Sheikh Muhammad Masum)

Associate Professor

Research Supervisor

Advisory Committee

Dated:

Place: Dhaka, Bangladesh

DEDICATED
TO
MY BELOVED
PARENTS

Chapter 1

Introduction

Chapter 2

Review of literature

Chapter 3

Materials and Methods

Chapter 4

Results and Discussion

Chapter 5

Summary and conclusion

References

Appendices

ACKNOWLEDGEMENT

Alhamdulillah, all praises are due to the almighty Allah Rabbul Al-Amin for his gracious kindness and infinite mercy in all the endeavors the author to let him successfully complete the research work and the thesis leading to Master of Science.

The author would like to express his heartfelt gratitude and most sincere appreciations to his Supervisor Dr. Sheikh Muhammad Masum, Associate Professor, Department of Agronomy, Sher-e-Bangla Agricultural University, Dhaka, for his valuable guidance, advice, immense help, encouragement and support throughout the study.

I am deeply grateful to my co-supervisor Dr. Md. Khairul Alam Bhuiyan, Principal Scientific Officer, Agronomy Division, BRRI, Gazipur-1701, for his constructive comments, valuable suggestions, guidelines, planning and carrying out of my research and preparation of the manuscript.

The author would like to express his deepest respect and boundless gratitude to all the respected teachers of the Department of Agronomy, Sher-e-Bangla Agricultural University, Dhaka, for their valuable teaching, sympathetic co-operation, and inspirations throughout the course of this study and research work.

The laboratory and field stuff of the Department of Agronomy, BRRI had offered their consistent support to make the research work successful. I remember their contribution with due admiration. Grateful and thanks to Md. Hira Khan, field assistant, Mosharuf Hossain field assistant, Department of Agronomy, BRRI, Gazipur for their assistance at data collection, sampling and nitrogen analysis of the plant samples during the study. Special thanks to all other friends for their support and encouragement to complete this study.

The author is deeply indebted to her father and grateful to her respectful mother, brother and other relative's for their moral support, encouragement and love with cordial understanding.

Finally the author appreciate the assistance rendered by the scientist and staffs of the Department of Agronomy, Bangladesh Rice Research Institute, Gazipur-1701, Dhaka, who have helped her during the period of study.

The author

ABSTRACT

A field experiment was conducted at the Agronomy field, Bangladesh Rice Research Institute, Gazipur, Dhaka during the period from April to September 2019 to determine growth, yield, and nitrogen uptake and to determine the economic nitrogen application rates for popular transplanted *aus* varieties. The experiment was carried out in a randomized complete block design (RCBD) factorial with two factors. Factor A: three varieties as- BR26, BRRI dhan48, and BRRI dhan82; and Factor B: five levels of nitrogen rates as- 0, 40, 60, 80, 100 kg ha^{-1}. The experimental data shows significance in the individual effect of variety and N rates on the grain yield and yield components but the combined effect of variety and N fertilizer rates was not significant. The grain yields of different varieties in different nitrogen levels would be explained by its panicle density, grains $panicle^{-1}$, and 1000-grain weight. The highest panicle m^{-2} (269.67), grains $panicle^{-1}$ (106.00) was produced in BRRI dhan48 with N_{80} treated plots which the 1000-grain weight (22.85) was produced in BRRI dhan82 with N_{80}. The highest grain yield of 5.52 t ha^{-1} was produced in BRRI dhan48 followed by BRRI dhan82 (4.52 t ha^{-1}) and BR26 (4.51 t ha^{-1}) with N_{80} treated plots. The individual effect of variety and N rate was significant in the case of N concentration, N uptake in grain and straw, and nitrogen harvest index (NHI). Overall, the increased N rate increasing the N concentration of grain and straw irrespective of varieties. The higher N concentration and uptake were observed when N was applied at the rate of N_{60}-N_{100} kg ha^{-1} in all the varieties. Among the varieties, BRRI dhan82 should the higher N uptake (61.23 kg ha^{-1}) in grain. Higher total N uptake was also observed in BRRI dhan48 at the rate of 80 kg N ha^{-1}. NHI ranged from 55 to 72 % in different N levels, indicated 55 to 72% of the absorbed N translocated to the grains, and 45% to 32% remained in the dry matter of the varieties. The estimated economic nitrogen dose for maximum yield was determined by regression analysis and found that N rates of BR26, BRRI dhan48, and BRRI dhan82 were 97, 95, and 55 kg ha^{-1}, respectively. The findings of this study indicated that response of different N rate on three *aus* varieties was linear upto 80 kg N ha^{-1} which might be owing to better N uptake leading to a higher number of panicles and grains $panicle^{-1}$ and that made yield increase, thereafter the response decreased. The study findings of the suggest that variety-specific N fertilization based on soil N status of *aus* rice is the best N management practice to maximize rice yield avoiding the excess use of N fertilizer.

TABLE OF CONTENTS

CONTENTS (CONTD.)

CONTENTS (CONTD.)

CONTENTS (CONTD.)

CONTENTS (CONTD.)

CONTENTS (CONTD.)

CONTENTS (CONTD.)

CONTENTS (CONTD.)

LIST OF TABLES

TABLES (CONTD.)

LIST OF FIGURES

FIGURES (CONTD.)

LIST OF APPENDICES

APPENDICES (CONTD.)

LIST OF PLATES

LIST OF ACRONYMS

AEZ	Agro-Ecological Zone
BARI	Bangladesh Agriculture Research Institute
BBS	Bangladesh Bureau of Statistics
BARC	Bangladesh Agricultural Research Council
SAU	Sher-e-Bangla Agricultural University
BAU	Bangladesh Agricultural University
BSMRAU	Bangabandhu Sheikh Mujibar Rahman Agricultural University
WHO	World Health Organization
IRC	International Rice Commission
FAO	Food and Agriculture Organization
ANOVA	Analysis of variance
DMRT	Duncan’s Multiple Range test
IRRI	International Rice Research Institute
RCBD	Randomized Complete Block Design
cm	Centimeter
CV %	Percent coefficient of variation
DAS	Days after sowing
DAT	Days after transplanting
TDM	Total dry matter
CGR	Crop growth rate
LAI	Leaf area index
V	Variety
cv.	Cultivar
et al.,	And others
wt.	Weight
°C	Degree Celsius
e.g.	exempli gratia (L), for example
etc.	Etcetera
%	Percentage
g	Gram (s)
df	Degree of Freedom
hrs.	Hour (s)
i.e.	id est (L), that is
kg	kilogram (s)
LSD	Least significant difference
m^2	Meter squares
ml	Mili litre
M.S.	Master of Science
No.	Number
var.	Variety

LIST OF ACRONYMS (CONTD.)

HI	Harvest index
NHI	Nitrogen harvest index
mg	Miligram
ha^{-1}	Per hectare (s)
ns	Non-significant
@	at the rate of
t ha^{-1}	Ton per hectare
N	Nitrogen
g m^{-2}	Gram per square meter
Fig.	Figure
viz.	namely
Agric.	Agriculture
Agril.	Agricultural
Agron.	Agronomy
Biol.	Biology
Environ.	Environment
Inst.	Institute
Intl.	International
J.	Journal
Sci.	Science
Uni.	University
MT.	Metric ton

INTRODUCTION

Rice (*Oryza sativa* L.), belongs to the family Poaceae, is the most important cereal crop in the developing world it is the main source of carbohydrate for the people of Bangladesh, and the staple food of more than half of the people in the world as well (BRRI, 2019). Near about 90% of the annual rice is produced and consumed in Asia. The average yield in Bangladesh is low compared to the global mean yield (Haider, 2018). About 35-60% world population derives most of its calories from rice (Tayefe *et al.*, 2014). Globally an increase of rice production in 2017 by 2.9 million tons to total 759.6 million tons (FAO, 2018). The possible way to meet this increases demand by the improvement of rice yield hectare^{-1} (Liu *et al.*, 2016). Bangladesh is the 3rd largest rice-producing country in the world (USDA, 2020). About 75% area and over 80% of the total irrigated area of Bangladesh is covered by rice (Nasim *et al.*, 2017).

Rice plays a significant role in the livelihood of the people of Bangladesh. Rice is planted in mainly three seasons in a year, *aus* (summer rice crop), *aman* crops (rainfed summer rice crop), and *boro* (only winter rice crop).

In Bangladesh, *aus* rice is a significant crop for drought-prone, low water requiring environment, and there are two types of *aus* rice as broadcast/direct seeded *aus* also known as upland *aus* and partially irrigated *aus* or transplanted. Aus is usually planted in March-April and harvested in June-July and the climate is practically combined with hot summer (March-May). Aus rice occupies about 12.53% of the total cultivable area from where modern varieties cover 10.67% and local varieties cover 1.86 % and 7.49% of the total production comes from *aus* rice where modern varieties cover 6.87% and local varieties cover 0.62%. In Bangladesh, the current status of the total area and production of *aus* rice is 1.08 million ha and 2.71 million MT, respectively (BBS, 2018).

Nitrogen fertilizer is required for the growth, development of rice, and grain production. During the *aus* season, deep placement of fertilizer above 52 and 78 kg N ha^{-1} had no significant effects on grain yields rather reduced the N recovery (Islam *et al.,* 2016). Nitrogen fertilizer is the main input in rice production and the optimum rate and profitability of management during the application and stability of the production system (Djaman *et al.*, 2018). By Improving leaf N concentration, photosynthetic rate, delaying leaf senescence, and increasing dry matter for grain filling, the applied nitrogen helps to increase rice productivity (Hasegawa *et al.,* 1994). N can play a significant role in improving panicle size, grain weight, and reducing spikelet sterility, (Fageria, 2009). Application of N fertilizer in rice has also been reported to significantly increase the grain and straw N uptake and N use efficiency (Hassan *et al.*, 2009).

Balanced fertilization is important for the realization of potential grain yield and nutrient uptake than a single application of fertilizer, particularly nitrogen (Talashilker and Vimol, 1986). In general, farmers apply more fertilizers than the recommended amount with the idea that applying nitrogen will always increase the yield which can result in change and negatively affect the sustainability of the production system, and increase production costs (Fan *et al.*, 2012). On the other hand, the application of excess N can result in groundwater pollution, increased production costs, reduced yields and environmental pollution (Djaman *et al.,* 2018), and vegetative growth which makes the plant susceptible to insects, pests, and diseases and ultimately reduces yield (Chamely *et al.*, 2015). The maximum yield of paddy was recorded as a result of the application of 90 to 250 kg nitrogen fertilizer ha^{-1} (Meena *et al.,* 2003).

Optimization of leaf N distribution associated with LAI distribution in rice fields increased canopy photosynthesis by more than 20% during grain filling (Shiratsuchi *et al.,* 2006) when most of the grain dry produced (Yoshida, 1984). So improving the distribution of leaf area index (LAI) and leaf nitrogen content (LNC) in the camp is a desirable way to increase rice yield (Shiratsuchi *et al.,* 2006).

The leaf area index is an important feature that relates to the rate of photosynthesis and dry matter production during the crop growth period. An assessment of LAI may be able to determine the extent of plant growth and explore the factors that limit dry matter production (Hirooka *et al.,* 2017).

In rice, 90% of the grain yield is derived from the photosynthetic production of the leaf after the heading, especially from the flag leaf. Adequate production of dry matter is required for high grain yields. There have been reports of a significant relationship between the yield of grains and the production of dry matter. Dry matter production is an important parameter of plant growth in determining crop yield index which is the ratio of grain yield to total biological yield (Fageria, 2004).

The nitrogen fertilizers are considered to have dominant influences on different agronomic characters of rice such as plant height, tiller number, filled grains panicle^{-1}, spikelet panicle^{-1}, grain yield, straw yield, biological yield, harvest index, etc. Nitrogen also influences the interception of sunlight, leaf area index (LAI), crop growth rate, total dry matter production (TDM), and nitrogen uptake to the plant. Under these circumstances, it is essential to find out the nitrogen responsive stages of plant growth to ensure its maximum requirement to achieve the most effective utilization of the applied nitrogen. Moreover, an economic nitrogen rate is required for the farmers to get maximum profit. Nitrogen fertilizer varies in different locations, ecosystems, and different varieties depending on the initial nitrogen status of the soil (Masum *et al*., 2008)

A suitable combination of variety and rate of nitrogen is required for better grain yield. The Optimum nitrogen rates and method of application reduce the negative environmental impact as well as increase crop productivity and farm income. Therefore, keeping all the points in mind mentioned above, the present piece of research work carried out with the following objectives:

- Observe the growth and yield performance of T. *aus* rice varieties of different N levels
- Observe the varietal difference in nitrogen uptake
- Find out the economic nitrogen rate of T. *aus* rice varieties

REVIEW OF LITERATURE

Rice is the major food crop of the people of Bangladesh. Nitrogen fertilizer is the essential factor for sustainable soil fertility and crop productivity. The variety and nitrogen fertilizer is an important factor as it influences the plant population per unit area, availability of sunlight, nutrient concentration in grain and straw of rice, photosynthesis, respiration, tillering ability, plant height, dry matter production, growth, and development, etc. Research works on various aspects of rice cultivation have been done at home and abroad for the improvement of rice yield. This chapter presents a comprehensive review of literature on the related works which have been done in the country and many other countries of the world with regards to the effect of different nitrogen levels in different varieties of rice cultivation.

2.1 Effect of variety

Variety itself is the genetic factor that contributes a lot to producing yield and yield components. Different researchers reported the effect of rice varieties on yield contributing components and grain yield. Some available information and literature related to the effect of variety on the yield of rice are discussed below.

2.1.1 Effect on growth characters

2.1.1.1 Plant height

An experiment was conducted at Patuakhali Science and Technology University, Dumki, Patuakhali under AEZ-13 by Hossain *et al.* (2018) to optimize the rate of nitrogen in the *aman* season with three aromatic rice varieties of BRRI dhan34, BRRI dhan38, and Sakkorkhora, and four fertilizer treatments were included. The outcome revealed that Sakkorkhora had the longest plant height (157.08 cm). A study was conducted by Sumon *et al.* (2018) to assess the growth, yield, and composition of aromatic rice varieties at the research farm of Sher-e-Bangla Agricultural University, Dhaka, Bangladesh with three aromatic varieties with six levels of nitrogen fertilizer in the subplots and found that the highest plant height was provided by the Raniselute variety.

Chamely *et al.* (2015) experimented and found that the plant height in modern rice varieties BRRI dhan28, BRRI dhan29, and BRRI dhan45 was 80.88 cm, 86.48 cm, 84.01 cm, and 86.48 cm, respectively. Haque *et al.* (2015a) performed an experiment with six hybrid rice varieties and one hybrid, and two Bangladesh Rice Research Institute samples. The varieties were Sonarbangla-1, Jagoron, Hira, Aloron, Richer, BRRI hybrid dhan1 and with two controls were BRRI dhan28 and BRRI dhan29. The maximum plant height was observed 101.5 cm from BRRI dhan28.

Bhuiyan *et al.* (2014) conducted an experiment at BRRI regarding hybrid rice and different nitrogen levels and found that different nitrogen levels differ in plant height at maturity. Jisan *et al.* (2014) conducted and experimented at Bangladesh Agriculture University, Mymensingh to analyze the yield efficiency of some varieties of *aman* rice. The test consisted of four varieties, i.e. BRRI dhan49 BRRI dhan52, BRRI dhan56 BRRI dhan57, and four nitrogen levels. Data revealed that the BRRI dhan52 produced the tallest plant (117.20 cm), while BRRI dhan57 has the lowest plant height. An experiment was performed by Sarkar *et al.* (2014) at Bangladesh Agricultural University, Mymensingh to observe the yield of aromatic fine rice and its consistency. Three fine aromatic rice varieties of BRRI dhan34, BRRI dhan37, and BRRI dhan38 with eight nutrients combinations. Results showed that in BRRI dhan34 produced the tallest plant (142.7 cm).

Masum *et al.* (2008) observed a field experiment and found that plant height of rice affected by varieties in *aman* season and found that Nairshell produces taller height than BRRI dhan44.

2.1.1.2 Tillering pattern

Sumon *et al.* (2018) conducted a study at the research farm of Sher-e-Bangla Agricultural University, Dhaka, Bangladesh to evaluate the growth, yield, and proximate composition of aromatic rice varieties in the *aman* season with six fertilizer levels. They found that BRRI dhan34 gave the maximum number of effective tillers hill^{-1} (12.74).

An experiment was conducted by Sarkar *et al.* (2016) to evaluate the performance of five hybrid rice varieties in the *aman* season, namely Shakti2, Suborna8, Tia, Aloron, and BRRI hybrid dhan2 with an inbred BRRI dhan33. The result showed that the hybrid varieties had dominance over tillers hill^{-1}, and these hybrid varieties showed higher numbers of tiller hill^{-1}.

Jisan *et al.* (2014) conducted an experiment at the Bangladesh Agricultural University, Mymensingh to evaluate the yield performance of some *aman* rice varieties. Four varieties were included in the test, i.e. BRRI dhan49, BRRI dhan52, BRRI dhan56, BRRI dhan57 with four N levels. BRRI dhan52 produced the highest number of effective tillers hill^{-1} (11.28), while BRRI dhan57 produced the lowest. An experiment was conducted by Sarkar *et al.* (2014) at Bangladesh Agricultural University, Mymensingh to observe the yield and quality of 16 fine aromatic rice affected by different nutrients. Results showed that the highest number of tiller hill^{-1} (10.02) was observed in BRRI dhan34.

BRRI (2008) reported an experiment with BRRI modern rice varieties and six levels of nitrogen (0, 30, 60, 90, 120, and 150 kg N ha^{-1}) and reported that tiller production with N @ 120 kg ha^{-1} produced a significantly higher tiller than those of lower N levels.

A field experiment was conducted by Bisne *et al.* (2006) with eight promising varieties using four CMS lines and showed that plant height, tiller number $hill^{-1}$ and grain yield differed significantly among the varieties and Pusa Basmati gave the highest tiller number $hill^{-1}$ and grain yield.

2.1.1.3 Leaf area index

Hasan *et al.* (2017) was carried a field experiment at the Agronomy research field of Bangabandhu Sheikh Mujibur Rahman Agricultural University, Gazipur with five varieties viz. BRRI dhan56, BRRI dhan57, Binadhan-7, BUdhan1, and one advanced line BU-9958-40-5-1 and observed that the highest leaf area index (5.42) in BU-9958-40-5-1 and lowest LAI (4.21) in BRRI dhan57 at 55 DAT.

Das (2015) was carried a field experiment at the agronomy field of Sher-e-Bangla Agricultural University, Dhaka from December 2013 to July 2014 with two rice varieties viz., BRRI dhan28 and BRRI hybrid dhan2, and six levels of fertilizers. Theinteraction effect of different variety × N fertilizer significantly influenced leaf area index of *boro* rice at 25, 50 and 75 DAT and harvest. The highest LAI at 75 DAT was observed in BRRI hybrid dhan2 × 75% Urea of recommended dose (5.29) which was statistically similar with BRRI hybrid dhan2 × 100% Urea of the recommended dose (RD) (5.30). At harvest the highest LAI (4.61) was obtained from BRRI hybrid dhan2 × 100% Urea of RD which was statistically similar with BRRI hybrid dhan2 × 100% Urea of the recommended dose (4.24) and the lowest LAI (2.03) was obtained from BRRI dhan28 × 75% Urea of recommended dose that was statistically similar with BRRI dhan28 × 100% Urea of the recommended dose (2.45).

Zhang *et al.* (2012) evaluated water use Efficiency and physiological response of rice cultivars under alternate wetting and drying conditions and found that the LAI at flowering was significantly higher in high N than low N rates.

Tang *et al.* (2003) conducted by a field test with the super hybrid rice (SHR) combination Liangyoupeijiu with nine treatments that were used, including 0, 60, 120, 130, 160, 180, 225, and 240 kg N ha^{-1}. They reported that higher N fertilizer application observed a higher leaf area index.

2.1.1.4 Total dry matter production

Khatun *et al.* (2020) conducted a field experiment with six rice varieties Binadhan-7, Binadhan-11, Binadhan-16, Binadhan-17, BRRI dhan33, and BRRI dhan39 to determine their growth and yield performance and observed that the maximum dry matter production (34.36 g Plant^{-1}) from Binadhan-17 and minimum (23.2 g Plant^{-1}) from BRRI dhan39 at 68 DAT.

Hasan *et al.* (2017) was carried a field experiment at the agronomy research field of Bangabandhu Sheikh Mujibur Rahman Agricultural University, Gazipur with five varieties viz. BRRI dhan56, BRRI dhan57, Binadhan-7, BUdhan1, and one advanced line BU-9958-40-5-1 and observed that the highest panicle dry weight (398.69 g m^{-2}) was reported from BU-9958-40-5-1 at 55 DAT.

An experiment was conducted by Sarkar *et al.* (2016) to evaluate the performance of five hybrid rice varieties in the *aman* season, namely Shakti2, Suborna8, Tia, Aloron, and BRRI hybrid dhan2 with an inbred BRRI dhan33 as checked. The findings revealed that hybrid varieties displayed dominance over total dry matter hill^{-1} and Tia was observed as the highest hill^{-1} (84.0 g) and BRRI dhan33 was observed as the lowest hill^{-1} (70.10 g).

Haque *et al.* (2015a) conducted field studies including two common *indica* hybrids (BRRI hybrid dhan2 and Heera2) and one elite inbred rice variety (BRRI dhan45).

Both hybrids accumulated higher volumes of biomass and demonstrated greater remobilization of grain-assimilates in early plantings relative to the inbred type.

Jannat (2013) conducted a field experiment with six rice varieties BRRI dhan48, BRRI hybrid dhan1, BRRI hybrid dhan2, ACI hybrid2, Jagoron, Panna1 and observed that the maximum total dry matter hill^{-1} (4.21, 6.62, 11.55 and 10.89 g, respectively) from ACI hybrid2 and minimum (3.21, 5.14, 8.653 and 8.43 g, respectively) from BRRI dhan48 at 30, 45, 60 and 75 DAT.

2.1.1.5 Crop growth rate

Sarkar *et al.* (2017) conducted a field experiment with five water management systems namely, continuous saturation, water applications made 4, 6,8, 10 days after the disappearance of 4 cm ponded water with some varieties viz.; BRRI dhan47, BRRI dhan50, BRRI dhan59, BRRI dhan60, BRRI dhan61, Binadhan8, Binadhan10, and Binadhan14 and observed that the maximum value of CGR (22.60 g cm^{-2} day^{-1}) for Binadhan10 and minimum (7.14, 9.87 and 16.38, respectively) was noted in BRRI dhan61.

Bhuiyan *et al.* (2016) reported that crop growth rate was significantly affected by nitrogen treatments at different stages. The growth rate was lowest during 60 DAS in both the years while the maximum growth occurred at 90 DAS during 2009-10 and at 120 DAS during 2010-11.

2.1.2 Effect on yield contributing characters

2.1.2.1 Panicle m^{-2}, grains panicle^{-1}, 1000-grain weight

An experiment was conducted by Sarkar *et al.* (2016) to evaluate the performance of five hybrid rice varieties in the *aman* season, namely Shakti2, Suborna8, Tia, Aloron, and BRRI hybrid dhan2 with an inbred BRRI dhan33 as checked and these hybrid varieties also showed higher 1000-grain weight over the inbred.

Jisan *et al.* (2014) conducted and experimented with Bangladesh Agricultural University, Mymensingh to examine the yield performance of some varieties of *aman* rice transplants as influenced by different nitrogen levels. The test consisted of four varieties, i.e. BRRI dhan49, BRRI dhan52, BRRI dhan56, BRRI dhan57 and four N levels, respectively. Among the varieties, BRRI dhan52 produced panicle^{-1} (121.5) and 1000-grain weight (23.65 g), whereas BRRI dhan57 produced the lowest values for these parameters.

2.1.3 Effect on grain yield and straw yield

Karmakar *et al.* (2019) conducted an experiment with 4 rice genotypes BR6855-3B-12, BR6855-3B-13, BR6848-3B-12, and BR6976-2B-11-1 along with a check variety BRRI dhan43 and found that the highest grain yield (3.64 t ha^{-1}) was obtained in BR6848-3B-12. Masni and Wasli (2019) conducted an experiment and found that the grain yield and yield components of the red rice variety (MRM 16) were best in 60 kg N ha^{-1}.

Djaman *et al.* (2016) observed that the requirement for nitrogen fertilizer of 90 kg N ha^{-1} for most aromatic rice varieties to achieve maximum yield was 120 kg N ha^{-1} for the optimum nitrogen fertilizer for the non-aromatic rice varieties.

Zohra *et al.* (2013) observed a field experiment to find out the yield performance of three transplant *aman* rice with five levels of N application. It was observed that the straw yield was highest (6.58 t ha^{-1}) in Kalizira and grain yield was highest (5.46 t ha^{-1}) in BRRI dhan46. In most of the cases, it was found that all the varieties performed better for their yield contributing characters with 2 pellets of USG/4 hills compared to any other levels. The findings suggest that BRRI dhan46 can be cultivated to obtain high rice yield in transplant *aman* season.

Azam *et al.* (2012) was carried a field experiment at the agronomy field of Sher-e-Bangla Agricultural University, Dhaka with the influence of variety and different urea fertilizer application method on growth and yield of *boro* rice. They reported that BRRI hybrid dhan2 ×2.7 g size USG placement at 8 DAT showed the highest number of tillers hill^{-1} (28.00), dry weight hill^{-1} (90.59 g), leaf area index (7.87), grains panicle^{-1} (146.20), 1000-grain weight (26.79 g), grain yield (5.41 t ha^{-1}) and straw yield (7.20 t ha^{-1}). Debnath *et al.* (2012) observed a field experiment and found that variety had a significant effect on all the agronomic parameters. BRRI hybrid dhan2 produced the lowest straw yield (4.97 t ha^{-1}) and the highest dry grain yield (5.92 t ha^{-1}), whereas, BRRI dhan29 produced the highest straw yield (6.70 t ha^{-1}) and the lowest grain yield (4.16 t ha^{-1}).

2.2 Effect of Nitrogen fertilizer

Among the factors that are responsible for the growth, yield, and yield contributing characters of rice, nitrogen management is very important for the production of modern varieties of *aus* rice. Some information regarding the effect of nitrogenous fertilizer and their application are reviewed under the following headings:

2.2.1 Effect on growth characters

2.2.1.1 Plant height

Jahan *et al.* (2020) reported that a significant increase in the plant height (98.20 cm) of rice was observed with the application of 175 kg N ha^{-1}.

Mahato *et al.* (2019) conducted a field experiment with 4 levels of nitrogen (0, 80, 100, and 120 kg N ha^{-1}) and observed that the highest plant height was observed (112.2 cm) at the time of harvesting with 120 kg N ha^{-1}.

Adhikari *et al.* (2018) was experimented with four levels of nitrogen in T. *aman* and observed that 80 kg N ha^{-l} gave the highest plant height (113.00 cm) and the lowest plant height (106.00 cm) were recorded from N_0 (no nitrogen fertilizer) treatment. A field experiment was conducted by Hossain *et al.* (2018) to comprised three aromatic rice varieties and four levels of nitrogen viz., 0, 30, 45 and 60 kg ha^{-1}, and found that the highest plant height was observed (152.43 cm) from 45 kg N ha^{-1}.

Saha *et al.* (2017) conducted an experiment with three levels of nitrogen 30, 60 and 90 kg N ha^{-1} and five cultivars namely, MTU-7029, ANNADA, KHANDAGIRI, SATABDI, and GS-3, and observed that, 90 kg N ha^{-l}, and variety Satabdi gave the highest plant height (247.28, 279.84, 212.08 cm, and 205.33 at 20 DAT, 40 DAT, 60 DAT, and at harvest, respectively).

Karim (2011) studied the effect of nitrogen fertilizer (0, 20, 40, 60, 80, 100, 120 kg N ha^{-1}) on high yield and improved seed quality. Growth parameters such as plant height (114.37 cm) and tiller $hill^{-1}$ (15.1) were greater at higher nitrogen levels.

Salem (2006) reported that an increase in nitrogen levels of up to 70 kg ha^{-1} significantly increased leaf area index and plant height. The maximum plant height of the crop was recorded at about 92.81 cm when the rice plants were fertilized with a maximum nitrogen level of 70 kg N ha^{-1}. In contrast, the minimum value of height was recorded around 80.21 cm when the rice plants did not receive the nitrogen fertilizer.

2.2.1.2 Tillering pattern

Adhikari *et al.* (2018) was conducted an experiment with four levels of nitrogen in T. *aman* and observed that 80kg N ha^{-l} gave the maximum number of effective tillers $hill^{-1}$ (6.18) and the minimum number of total tillers $hill^{-1}$ (7.20) were recorded from N_0 (control) treatment.

Saha *et al.* (2017) experimented with three levels of nitrogen with five cultivars and observed that 90 kg N ha^{-1} and variety Satabdi gave the maximum number of tillers (255.20, 280.06, 244.64 and 214.10 at 20, 40, 60 DAT, and at harvest, respectively).

BRRI (2016) reported in an experiment that increasing levels of N increased the number of spikelet $panicle^{-1}$ of rice and the maximum number of spikelet $panicle^{-1}$ (86.2) was obtained with 200 kg N ha^{-1} compared to 90 and 0 kg N ha^{-1}, respectively.

An experiment was conducted by Haque *et al.* (2015b) to investigate the impact of five levels of nitrogen viz. 0, 40, 80, 100, and 140 N kg ha^{-1} and found the longest plant with 100 kg N ha^{-1} followed by 140 kg N ha^{-1} and the highest number of total, effective tillers $hill^{-1}$.

2.2.1.3 Leaf area index

Ajmal *et al.* (2020) conducted a field experiment with 3 levels of nitrogen (120, 140, 160 kg ha^{-1}) and variety JGL-18047. It was observed that the N rate @160 kg N ha^{-1} produced the maximum leaf area index (3.84, 3.63, and 1.75) at 60 DAS, 80 DAS, and harvest and the dose of 120 kg N ha^{-1} lowest LAI (2.99, 2.85, and 1.30) at 60 DAS, 80 DAS and harvest was observed.

Haque and Haque (2016) indicated that the leaf area index (LAI) was significantly affected by the addition of nitrogen fertilizer. The leaf area index increased steadily and reached its maximum value (4.17) 45 days after transplanting when was fertilized with 100 kg N ha^{-1}. On the same planting date, the lowest value (1.90) was recorded in the control treatment.

Masum *et al.* (2008) conducted a field experiment and observed that the effect of four levels of seedling $hill^{-1}$ with two forms of nitrogenous fertilizer in modern and traditional transplant *aman* rice and observed that leaf area index was significantly higher in USG application than prilled urea.

Hamidullah *et al.* (2006) conducted an experiment on growth and yield performance of BINA dhan5 in *boro* season as affected by nitrogen levels viz. 80, 120, and 160 kg N ha^{-1}. They reported that leaf area index was highest at 60 DAT, and decline thereafter, the highest LAI (5.53) was obtained with 160 kg N ha^{-1} at 60 DAT.

Awasthi and Bhan (1993) reported that increasing levels of nitrogen up to 60 kg ha^{-1} influenced LAI and dry matter production of rice.

2.2.1.4 Total dry matter production

Ajmal *et al.* (2020) conducted a field experiment with 3 levels of nitrogen (120, 140, and 160 kg ha^{-1}) with a variety JGL-18047. It was observed that the dose of 160 N kg ha^{-1} produced the maximum dry matter (348 kg ha^{-1}).

Bhuiyan *et al.* (2016) reported that dry matter production significantly increased from tillering stage (45 DAS) to physiological maturity (142 DAS) irrespective of nitrogen treatment. The highest dry matter was recorded by 200 kg N ha^{-1} throughout the growing season followed by 160kg N ha^{-1} treatment. During physiological maturity, 1834 g m^{-2} dry matter was recorded from 200 kg N ha^{-1} followed by 160 kg N ha^{-1} treatment that was highly significant.

Chamely *et al.* (2015) observed that the highest dry matter (69.58 g m^{-2}) was obtained from 200 kg N ha^{-1}.

Xie *et al.* (2007) reported that increased split application of N from control to 140 kg N ha^{-1} increased dry matter accumulation (DMA) of different growth stages of Jinzao22 and Shanyou63 rice varieties and after that dose, the DMA (dry matter accumulation) reduced due to the losses of N by volatilization.

2.2.1.5 Crop growth rate

Ahmed *et al.* (2016) conducted a field experiment with different rates of fertilizer with four genotypes CNI 9012, GSR IRRI I 2, BINA dhan7 and Aloran (BRAC hybrid), and found that the highest crop growth rate (113.8 days) in BINA dhan7 and the lowest (108.8 and 109.4 days) from CNI 9012 and GSR IRRI I 2, respectively. Bhuiyan *et al.* (2016) reported that a rapid increase of CGR of rice was observed from the active tillering stage and reached a peak during booting to the flowering stage and then decreased in all nitrogen treatments.

Das and Panda (2004) conducted a field experiment with the effects of N (0, 60, 120, or 180 kg ha^{-1}) and K (0, 40, 80, or 120 kg ha^{-1}) on the growth rate of hybrid rice 6102. Crop growth rate (CGR) was greater at 40-60 DAT and lower at 20-40 DAT. The increase in the N rate increased CGR. The highest CGR (22.52 g/day/m^2) was obtained with 80 kg K_2O ha^{-1}**.**

2.2.2 Effect on yield contributing characters

2.2.2.1 Panicle m^{-2}, Grains $panicle^{-1}$, 1000-grains weight

Mahato *et al.* (2019) conducted a field experiment with four levels of nitrogen (0, 80, 100, 120 kg N ha^{-1}) and observed that the highest effective tiller m^{-2} (225.0) and the longest panicle length (27.4 cm) was observed with 120 kg N ha^{-1}.

Adhikari *et al.* (2018) experimented with four levels of nitrogen on T. *aman* and 80 kg N ha^{-1} gave the highest panicle length (21.98 cm), number of grains $panicle^{-1}$ (114.20), and the lowest panicle length (20.70 cm), number of grains $panicle^{-1}$ (97.60) were recorded from N_0 (no nitrogen fertilizer control) treatment.

Nori *et al.* (2018) conducted an experiment with an integrated treatment of five nitrogen rates (0, 120, 160, 200, and 240 kg N ha^{-1}) with varieties of MR 211 and MR 219. Increases in the application of nitrogen were reported to increase (P <0.01) grain yield, total spikelets $meter^{-2}$, number of spikelets $panicle^{-1}$.

A field experiment was conducted by Rajesh *et al.* (2017) to comprised six rice genotypes and two level of nitrogen viz., 60 and 120 kg ha^{-1} and found that 120 kg N ha^{-1} gave the maximum number of panicles hill^{-1}, number of filled grains hill^{-1}, filled grain percentage and 1000-grain weight. Rusdiansyah and Saleh (2017) conducted a field experiment with five levels of nitrogen (0, 25, 50, 75, and 100 kg N ha^{-1}) with two cultivars (Nanung and Pance Kuning) in two locations (Petung and Gunung Makmur) observed that Nanung and Pance Kuning showed positive responses to the application of 75 kg N ha^{-1} in Petung for the parameters of tiller number and 1000-grain weight.

Malik *et al.* (2014) discovered that application of N (120 kg ha^{-1}) as urea in four equal splits during transplanting, tillering, panicle initiation, and flowering resulted in the highest number of panicle, number of grains panicle^{-1}, 1000-grain weight, straw yield, and harvest index.

Karim (2011) studied the effect of nitrogen fertilizer (0, 20, 40, 60, 80,100, 120 kg N ha^{-1}) on high yield and improved seed quality. Plants with a moderate level of nitrogen applied showed better yield components of the variety where 60 kg N ha-^{1} found the highest panicle hill^{-1} (11.8), grains panicle^{-1} (140.5), and filled grains panicle^{-1} (130.33).

Kandil *et al.* (2010) found that increased levels of nitrogen fertilizer up to 80 kg N ha^{-1} resulted in marked increases in the tillers numbers m^{-2}, panicle length, panicle weight, grains panicles^{-1} and 1000-grain weight in both seasons. With the addition of 144 or 192 kg N ha^{-1}, the tallest plants and the largest number of panicles m^{-2} were recorded with no significant differences. Mannan *et al.* (2010) conducted a field experiment with four rice varieties viz., Basmati PNR, Basmati 370, Basmati 375 and Basmati-D and five nitrogen levels 0, 25, 50, 75, and 100 kg N ha^{-1} and observed that plant height, tiller number, number of panicles, panicle length, spikelet sterility and straw yield increased with the increase of nitrogen levels upto 75 kg N ha^{-1}.

BRRI (2006) reported in an experiment that increasing levels of N increased the number of spikelet panicle^{-1} of rice, and the maximum number of spikelet panicle^{-1} (82.2) was obtained with 120 kg ha^{-1} compared to 90 and 0 kg ha^{-1}, respectively.

2.2.3 Effect on grain yield and straw yield

A field experiment was conducted by Karim *et al.* (2019) to comprised three varieties viz., BRRI dhan29 and BRRI dhan58, and five level of nitrogen viz., 340, 320, 300, 280, 260, and 165 kg N ha^{-1}. Interaction effect of different variety × 300 kg N ha^{-1} produced the maximum grain yield (6.7 t ha^{-1}) and straw yield (7.91 t ha^{-1}). Mahato *et al.* (2019) conducted a field experiment with 4 levels of nitrogen (0, 80, 100, and 120 kg N ha^{-1}) and observed that the grain yield (4.5 t ha^{-1}), straw yield (5.0 t ha^{-1}) and harvest index (41.5%) with 120 kg N ha^{-1}.

Islam *et al.* (2018) conducted field experiments with 8 levels of nitrogen with BRRI dhan49. Application of USG and 104 kg N ha^{-1} significantly increased the grain yield (5.98 t ha^{-1}).

Ahmed *et al.* (2016) conducted a field experiment with different rates of fertilizer viz., no fertilizer , half of recommendation (90-40-35- 30-5 kg ha^{-1} of Urea-TSP-MoP-Gypsum-ZnSO4), two-third of recommendation (120-53.3-46.6-40- 6.6 kg ha^{-1} of Urea-TSP-MoP-Gypsum-ZnSO4), and recommended rate (180-80-70-60-10 kg ha^{-1} of Urea-TSP-MoP-Gypsum-ZnSO4) besides four genotypes of CNI 9012, GSR IRRI I 2, BINA dhan7, and Aloran (BRAC hybrid) then found that the highest grain yield was recorded in the fertilizer rate of (90-40-35- 30-5 kg ha^{-1} of Urea-TSP-MoP-Gypsum-ZnSO4) (5.0 t ha^{-1}) and the minimum in no fertilizer (4.6 t ha^{-1}) application plots. BRRI (2016) reported in an experiment that the highest grain yield of 5.48 t ha^{-1} and straw yield (t ha^{-1}) 6.65 was obtained with 200 kg ha^{-1} compared to 90 and 0 kg ha^{-1}, respectively. Haque and Haque (2016) conducted an experiment at Bangabandhu

Sheikh Mujibur Rahman Agricultural University, Gazipur, Bangladesh during the rainy season of 2014 and observed that the highest grain yield were (5.36 t ha^{-1}) with 60 kg N ha^{-1}.

A field experiment was conducted by Chamely *et al.* (2015) to comprised three varieties viz., BRRI dhan28, BRRI dhan29 and BRRI dhan45, and five levels of nitrogen viz., control (no fertilizer), 50 kg, 100 kg, 150 kg, and 200 kg N ha^{-1}. Interaction effect of different variety × 200 kg N ha^{-1} produced the maximum grain yield (5.82 t ha^{-1}). Das (2015) was carried a field experiment at the agronomy field of Sher-e-Bangla Agricultural University, Dhaka from December 2013 to July 2014 with two rice varieties viz.; BRRI dhan28 and BRRI hybrid dhan2, and six levels of N fertilizer, and found that the highest grain and straw yield (6.19 t ha^{-1} and 7.74 t ha^{-1}) in BRRI hybrid dhan2 and the lowest (3.53 and 7.70 t ha^{-1}, respectively) in BRRI dhan2 was observed in 100% Urea of the recommended dose was applied as 3 top dressing BRRI hybrid dhan2. Islam *et al.* (2015) was carried a field experiment with BRRI dhan29 and six nitrogen rates: 0, 50, 100, 150, 200, and 250 kg N ha^{-1} and found that 150 kg N ha^{-1} gave the maximum yield of 6.76 t ha^{-1} in 2009 and 6.49 t ha^{-1} in 2010, respectively. A field experiment was conducted by Manzoor *et al.* (2015) with 4 levels of nitrogen (0, 110, 133, 156, 179, and 202 kg N ha^{-1}) and found that the dose of 133 kg N ha^{-1} was optimal for the maximum yield of this rice. Sultana *et al.* (2015) conducted a field experiment with 7 levels of nitrogen (no fertilizer, 0, 50, 60, 70, 80, 90 kg N ha^{-1}) with BRRI dhan49 and observed that the dose of 90 kg N ha^{-1} produced the maximum grain yield (6.17 t ha^{-1}).

The experiment was conducted by Alim (2012) in combinations with three varieties viz., BRRI dhan28 and BRRI dhan36 with some fertilizer treatment. The yields of grain and straw were increased by increasing the nitrogen rate from 120 kg ha^{-1}. BRRI dhan28 produced maximum grain and straw yield.

An experiment was conducted by Fageria (2007) to evaluate the nitrogen significantly improved yield of rice by improving yield components like panicle number, thousand-grain weight, and reduced grain sterility. Also, N also improved grain harvest index, nitrogen harvest index, and plant height which are positively associated with grain yield. For the efficient management of N adequate rate, appropriate source and timing of application during crop growth cycle play an important role.

Fageria and Baligar (2001) have reported that low land rice yield in central Brazil on Varzea soil were significantly higher at 200 kg N ha^{-1} than at 100 kg N ha^{-1}.

2.3 Determination of economic nitrogen fertilizer rate in rice

Sapkota *et al.* (2020) conducted a field experiment and observed that the dose of 120–200 kg N ha^{-1} produced the most economical returns and application rates beyond these ranges would be both economically and environmentally unsustainable.

Rea *et al.* (2019) conducted an experiment on growth and yield performance of BRRIdhan46 as affected by nitrogen levels viz. 0, 52, 78 and 104 kg N ha^{-1} and found that the maximum grain yield of 6.391 t ha^{-1} (54% increases over control) for the dose as USG (104 kg N ha^{-1}) which is statistically similar to the dose USG 78 kg ha^{-1} and NPK briquettes 104 kg ha^{-1}.

Alem *et al.* (2018) conducted a field experiment and observed a significant increase in grain yield as the level of N and P supply increased up to 138 kg N ha^{-1} and 46 kg P_2O_5 ha^{-1} and observed that the dose of 138 N kg ha^{-1} and 46 kg P_2O_5 ha^{-1} produced the maximum grain yield. Djaman *et al.* (2018) observed that a nitrogen rate of 150 kg ha^{-1} was revealed optimum with the best performance achieved by the Hybrid rice AR033H.

Yu *et al.* (2015) reported in an experiment that nitrogen (N) is one of the major nutrients for plant growth increase of the nitrogen use efficiency and the decrease of both the N dose and the fertilizer application rate lead to the economic and environmental benefits.

Mannan *et al.* (2010) also observed the optimum level of nitrogen 69-70 kg N ha^{-1} was estimated through the regression analysis for the cultivation of Basmati fine rice. The variation of grain yield due to the application of nitrogen showed a quadratic regression equation. Among the test genotypes, the short stature Basmati PNR produced the highest grain yield and it was statistically identical with Basmati-D.

Peng *et al.* (1999) reported that curvilinear response of rice yield to nitrogen. Rice yield exhibited a linear response to nitrogen rate below 150 kg N ha^{-1} and a plateau off when the applied N rate is greater than 150 kg N ha^{-1}.

2.4 Nitrogen concentration and uptake

Jahan *et al.* (2020) observed that the applied N rates significantly affected nutrient uptake of BRRI dhan58 and BRRI dhan75 in *boro* and T. *aman* seasons, respectively. In *boro* season, the grain N uptake by BRRI dhan58 significantly increased with N rates up to 125 kg N ha^{-1}. The straw N uptake by BRRI dhan58 increased with the increase of N rates. The total N uptake by BRRI dhan58 ranged between 24.52 and 138.58 kg ha^{-1}. The highest total N uptake (138.58 kg ha^{-1}) by BRRI dhan58 in *boro* season was observed with 125 kg N ha^{-1} which was similar to N_{150}. In T. *aman* season, the grain and straw N uptake of BRRI dhan75 varied from 42.30 to 64.60 kg ha^{-1} and 24.45–50.05 kg ha^{-1}, respectively. The highest grain and straw N uptakes by BRRI dhan75 were found with 75 and 100 kg N ha^{-1}, respectively. The total N uptake by BRRI dhan75 varied from 75.53 to 114.66 kg ha^{-1} and the highest was with 100 kg N ha^{-1}.

A greenhouse experiment was conducted by Fageria and Santos (2014) to evaluate N responses to 12 lowland rice genotypes. The N rates used were 0 mg kg^{-1} (low) and 300 mg kg^{-1} (high) of soil. Plant height, straw yield, grain yield, panicle density, 1000-grain weight, and root dry weight were significantly increased with the addition of N fertilization. These growth, yield, and yield components were also significantly influenced by genotype treatment. Grain yield had significant linear or quadratic association with shoot dry weight, panicle number and 1000-grain weight based on grain efficiency index genotypes were classified as efficient, moderately efficient and inefficient in N use. The N efficient genotypes were 'BRS Tropical', 'BRS Jaçanã', 'BRA 02654', 'BRA 051077', 'BRA 051083', 'BRA 051108', 'BRA 051130' and 'BRA 051250'. Remaining genotypes fall into moderately efficient group. None of the genotypes were grouped as inefficient in N use efficiency.

Metwally *et al*. (2011) reported nitrogen uptake by grains increased significantly with the increase in the rate of applied nitrogen up to 250 kg ha^{-1} in Egyptian soil. Results of the study showed that N uptake in the grains, straw and NHI is strongly related to grain, straw and total dry matter yield depending on N levels across years.

Artacho *et al*. (2009) reported N uptake in grain and total N uptake had a significant quadratic response to N fertilization but total N uptake increased significantly and linearly with N levels. The authors also reported that N uptake in straw had a significant linear increase between 0 to 300 kg N ha^{-1} and grain yield was significantly and quadratically related with N uptake in grain and with total N uptake indicated that, in most cases, higher grain yield would be due to higher N uptake. In the recent study, it was found almost 100% of the variation in total dry matter production was explained by N uptake in both years in different rates. Artacho *et al.*

(2009) also reported that response in grain yield to total N uptake was up to 200 kg N ha^{-1}

Fageria (2004) reported a positive significant (P<0.01) correlation of dry matter production with grain yield of low land rice from active tillering to physiological maturity.

Fageria and Baligar (2001) reported significant increase in grain yield of rice yield with higher N accumulation in the grain.

Fageria and Baligar (1999) found that Nitrogen concentration and N uptake in the dry matter and grains were significantly affected by N treatments in lowland rice.

Based on the above research findings, it is revealed that nitrogen levels play a significant role in different rice varieties cultivation.

MATERIALS AND METHODS

This chapter presents a brief description of the experimental period, site description, climatic condition, crop or planting materials, treatments, experimental design and layout, crop growing procedure, fertilizer application, uprooting of seedlings, intercultural operations, data collection, and statistical analysis.

3.1 Experimental period

The experiment was conducted during the period from April to September 2019 in T. *aus* season.

3.2 Site description

The experiment was carried out at the agronomy field, Bangladesh Rice Research Institute, Gazipur, Dhaka, during the period from April to September 2019. The location of the site is situated at 23^{0}99' N latitude and 90^{0}40'E longitudes with an elevation of 8.2 m from sea level (Appendix I).

3.3 Weather and Climate

The experimental field was under subtropical climate characterized by heavy rainfall during April to September and scanty rainfall during October to March. The monthly means of daily maximum, minimum and average temperature, relative humidity, total rainfall, and sunshine hours during the period of the experiment was collected from the weather station of Bangladesh Rice Research Institute, Gazipur, Dhaka, and has been presented in Appendix II.

3.4 Soil

The soil of the experiment site was clay loam of shallow brown Terrace soils under the Madhupur tract (AEZ-28). The experimental field is classified as a chhiata clay loam, hypothermic erotic endoaquept. The physicochemical properties of the status are shown in Appendix III.

3.5 Plant Material

Four varieties of *aus* rice viz., BR26 (Sraboni), BRRI dhan48, and BRRI dhan82 were used as test crops in the experiment. The salient feature of rice varieties are given below;

BR26 (Sraboni):

BR26, a high yielding variety of *aus* rice was developed by the Bangladesh Rice Research Institute and was released in 1993. It is a photo-insensitive variety. Its average plant height is 115 cm. This variety takes 115-120 days to mature. Grain is long with whitish color, low amylase content. It can give a grain yield of 4.0 t ha^{-1}.

BRRI dhan48:

BRRI dhan48 is a high yielding variety of *aus* rice developed by the Bangladesh Rice Research Institute and was released in 2008. It is a photo-insensitive variety. Its average plant height is 105 cm. This variety takes 110-115 days to mature. Grain medium bold, low amylase content. It can give a grain yield of 5.5 t ha^{-1}.

BRRI dhan82:

BRRI dhan82 is a short duration *aus* rice variety released in 2017. The average height of BRRI dhan82 is 110 cm. The variety is well adapted to the climatic condition of Bangladesh. Grain medium size with whitish. The average yield capacity is 4.5-5.5 t ha^{-1}.

3.6 Experimental treatments

The experiment was consisted of two factors. The treatments followed varieties and N rates, where varieties are considered as Factor A and different nitrogen levels considered as Factor B.

Factor A: Variety (3)

V_1= BR26

V_2 =BRRI dhan48

V_3= BRRI dhan82

Factor B: Nitrogen levels (5)

N_0= 0 (Control)
N_1 = 40 kg ha^{-1}
N_2= 60 kg ha^{-1}
N_3= 80 kg ha^{-1}
N_4= 100 kg ha^{-1}

3.7 Experimental design and layout

The experiment was laid out in 2 factors randomized complete block design factorial with 3 replications. There were 45 unit plots in the experiment. Each replication was divided into 15 unit plots where the treatment combinations were allocated at random. The size of each unit plot was (2.5m × 4.0m =10m^2). The spacing between block to block and plot to the plot was 0.6 m and 0.4 m, respectively.

3.8 Seedbed preparation and raising of seedlings

Seeds of the above three varieties were selected by a specific gravity method and sprouted by immersing in water in a bucket for 24 hours and then seeds were taken out of the water and kept thickly in gunny bags. A piece of medium high land was puddled well with country plough followed by cleaning and leveling with a ladder. Sprouted seeds were sown in the wet nursery bed on 10 April 2019. Proper care was taken to raise healthy seedlings in the seedbed. Weeding irrigation was done when was necessary.

3.9 Land preparation

The land of the experimental plot was opened on 08 April 2019 with a power tiller. Later on, the land was ploughed and cross-ploughed three times followed by laddering to level the field. The corners of the land were spaded and weeds and stubble were removed from the field. The land was thus made ready for transplanting. The layout of the experimental field was done on 20 April 2019.

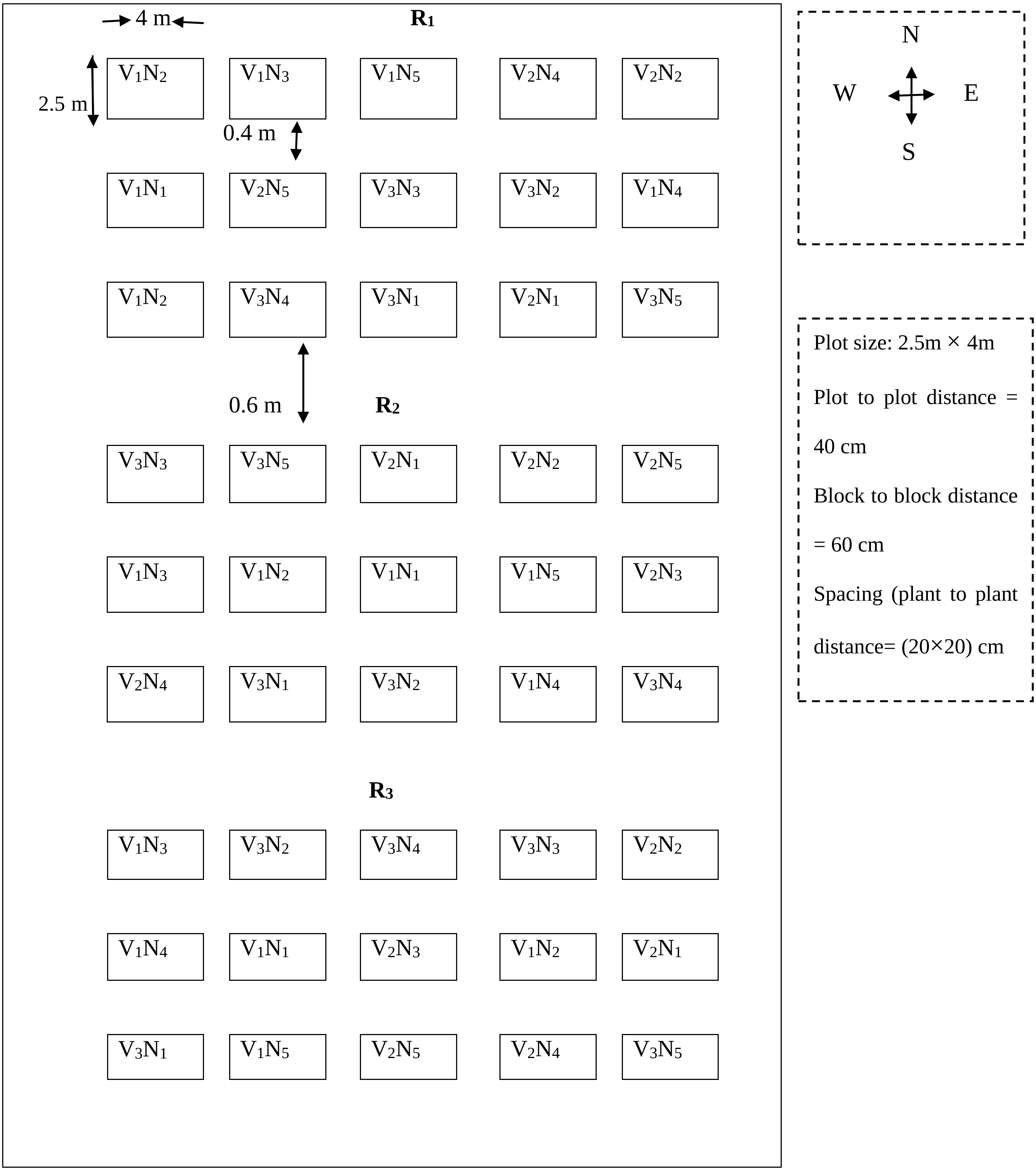

Fig 1: Treatment combinations with RCBD factorial experiment design.

3.10 Fertilizer application

The fertilizers N, P, K, S, Zn, and B in the form of urea, TSP, MoP, and gypsum, respectively were applied. The entire amount of TSP, MP, and gypsum was applied during the final preparation of plot land. Urea was applied in three equal installments. The application of fertilizer in the experiment is shown in Table 1.

Table 1. Application of fertilizer in the experimental plot

Treatment	Fertilizer (kg ha^{-1})	Application of fertilizer in the experimental plot (g)			
		Total ($10\ m^2$)	1^{st} installment ($10\ m^2$)	2^{nd} installment ($10\ m^2$)	3^{rd} installment ($10\ m^2$)
N_0	N_0	0	0	0	0
N_1	N_{40}	87	29	29	29
N_2	N_{60}	130	43.3	43.3	43.3
N_3	N_{80}	174	58	58	58
N_4	N_{100}	217	72.3	72.3	72.3
TSP	53	53	53	0	0
MoP	82	82	82	0	0
Gypsum	28	28	28	0	0

3.11 Uprooting and Transplanting of seedlings

Twenty days old seedlings were uprooted carefully and were kept in soft mud in shade. The seedbeds were made wet by application of water in the previous day before uprooting the seedlings to minimize mechanical injury of roots. Before transplanting, the land isle was made so that nitrogen cannot move from one plot to another. Seedlings were then transplanted as per experimental treatment on the well-puddled plots on 30 April 2019. In each plot, spacing (plant to plant and row to row) were 20×20 cm with 2 seedlings/hill.

3.12 Intercultural operations

3.12.1 Gap filling

After seven days of transplanting, a minor gap filling was done where it was necessary to use the seedling from the same source. Plot to plot distance 40 cm. Block to block distance 60 cm.

3.12.2 Weeding

During the plant growth period two hand weeding were done, first weeding was done at 15 DAT (days after transplanting) followed by second weeding at 35 DAT.

3.12.3 Application of irrigation water

Irrigation water was applied to every plot according to the crop growth stage. Irrigation was done up to 6 cm.

3.12.4 Plant protection measures

Plants were infested with *Scirpophaga incertulus* (rice stem borer) and *Nephotettix nigropictus* (leafhopper) to some extent which was successfully controlled by applying one time of Suntap Plus 500WP (Cartap hydrochloride 47.5% + Fipronil 2.5%) on 20 May 2019. But any fungal and bacterial disease was not observed. The grain was protected from birds during the grain-filling period.

3.13 General observation of the experimental field

The field was investigated from time to time to detect the visual difference among the treatment and any kind of infestation by weeds, insects, and diseases so that considerable losses by pests were minimized. The field looked beautiful with normal green color plants (Plate 5).

3.14 Recording of data

A. Crop growth characters

Plant height (cm) (15 days interval starting from 15 DAT)

Number of tillers hill^{-1} (15 days interval starting from 15 DAT)

Leaf area index (15 days interval starting from 15 DAT)

Dry matter weight (g m^{-2}) of plant (15 days interval starting from 15 DAT)

Crop growth rate (g/m^2/d) (15 days interval starting from 15 DAT)

B. Nitrogen concentration (N %)

Nitrogen concentration in rice plants

Nitrogen content in grain

C. Nitrogen uptake

Nitrogen uptake in rice plants

Nitrogen content in grain

D. Yield contributing characters

Number of panicle m^{-2}

Number of grains panicle^{-1}

1000-grain weight (g)

E. Yield

Grain yield (t ha^{-1})

Straw yield (t ha^{-1})

Biological yield (t ha^{-1})

Harvest index (%)

E. Relationship

Relationship of grain yield and leaf area index (LAI) and total dry matter production

Relationship of grain yield and leaf area index (LAI) and total dry matter production

Correlation of grain yield with panicle m^{-2}, grains $panicle^{-1}$, 1000-grain weight

F. Determination of optimum and economic of N doses

3.15 Experimental measurements

Experimental data collection began at 15 days after transplanting and continued until harvest. The necessary data on yield contributing characters were collected from twelve selected hills (2x2) x3 from each plot in the field and at the harvest plot yield was harvested from a 5 m^2 plot.

3.15.1 Plant height

Plant height was measured at 15 days interval and continued until harvest. The height of the plant was determined by measuring the distance from the soil surface to the tip of the leaf before heading, and to the tip of the panicle after heading.

3.15.2 Number of tiller $hill^{-1}$

Number of tiller $hill^{-1}$ were counted at 15 days interval up to harvest from pre-selected hills and finally averaged as their number $hill^{-1}$.

3.15.3 Leaf area index (LAI)

Leaf area index was estimated by measuring the length and width of the leaf and multiplying by a factor of in green leaf 0.75 or brown leaf 0.67 followed by Yoshida, 1981.

3.15.4 Dry matter weight of plant

The sub-samples of 4 hills $plot^{-1}$ uprooting from 2^{nd} line were oven-dried until a constant dry weight from which the weight of above-ground dry matter were recorded at 15 days interval up to harvest.

3.15.5 Crop growth rate

Crop growth rate (CGR) is the gain in dry matter production on a unit of land in a unit of tune. It was calculated with the following formula:

$$CGR = \frac{W_2 - W_1}{t_2 - t_1}$$

Where,

W_1= dry weight per unit area at t_1,

W_2= dry weight per unit area at t_2,

t_1 = first sampling,

t_2= second sampling.

3.15.6 Panicle length

Measurement of panicle length was taken from the basal node of the rachis at the top of each panicle. Each observation was an average of 11 panicles.

3.15.7 Number of grains panicle^{-1}

At least one fertile grain was considered as an effective tiller.

3.15.8 1000-grain weight

One thousand clean and sun-dried grains were calculated from the seed stock and weighed by an electronic balance.

3.15.9 Grain yield

Grain yield was determined from the central 5 m^2 area of the plot and expressed as t ha^{-1}. The grain moisture content of the filled grains was measured with a digital moisture tester and grain yield was calculated at 14% moisture content (MC) as follows.

$$\text{Grain yield at 14\% MC} = \frac{100 - SampleMC\%}{100 - 14} \times \text{fresh weight of grains at harvest}$$

3.15.10 Straw yield

Straw yield was determined from the central 5 m^2 area of each plot. After threshing, the sub-sample was oven dried to fixed weight and finally converted to t ha^{-1}.

3.15.11 Biological yield

Grain yield (economic yield) and straw yield together were regarded as biological yield. It was calculated with the following formula;

Biological yield= Grain yield + Straw yield

3.15.12 Harvest index

Harvest index (%) was calculated from the economic (Grain) yield and biological yield (grain+ straw) of rice for each plot. It was calculated with the following formula (Gardner *et al*., 1985).

$$\text{Harvest index (\%)} = \frac{\text{Grain yield}}{\text{Biological yield}} \times 100$$

3.15.13 Nitrogen content and Nitrogen uptake by rice plants

Experimental data measured began at 15 days after transplanting and continued until harvest. After harvest grain and straw, samples were taken from respective plots and all samples were oven-dried at 70°C for 72h, weighed, ground, and then subsamples were taken for N determination. N content in the grains and straw was measured by the standard micro-Kjeldahl procedure (Bremner and Mulvaney, 1982). N uptake in grain and straw was calculated by following formulae.

$$\text{Nitrogen uptake by grain (kg ha}^{-1}) = \frac{\text{\% N in grain} \times \text{Grain yield (kg ha}^{-1})}{100}$$

$$\text{Nitrogen uptake by straw (kg ha}^{-1}) = \frac{\text{\% N in straw} \times \text{straw yield (kg ha}^{-1})}{100}$$

3.16 Statistical Analysis

The data obtained for different characters were statistically analyzed with the computer-based software CROP STAT 7.2 and mean separation have been done by least significance difference test (LSD) at a 5% level of significance. Regression analyses were done to determine the economic nitrogen rates of the respective varieties.

RESULTS AND DISCUSSION

The experiment was conducted to compare the performance of the *aus* rice variety with different nitrogen levels. Data on different growth parameters and yield of rice, nitrogen concentration in grain and straw, and characteristics pre and post-harvest soil was recorded. The data have been presented in the form of different tables and figures. The result obtained from the present study have been presented and discusses wad in this chapter.

4.1 Growth parameters

4.1.1 Plant height

4.1.1.1 Effect of variety

Plant height of the varieties measured at 15, 30, 45, 60, 75 DAT (days after transplanting) and maturity showed statistically significant variations due to different rice varieties (Fig. 2). At 15, 30, 45, 60, 75 DAT and maturity, the tallest plant (36.93, 53.66, 94.46, 115.32, 127.93 and 122.38 cm, respectively) was recorded from BRRI dhan48 which was followed (36.16, 53.30, 93.16, 115.30, 126.25 and 121 cm, respectively) by BRRI dhan82 and they were statistically similar, whereas the shortest plant (35.65, 53.12, 89.92, 113.80, 125.55 and 120.36 cm, respectively) was found from BR26. Similarly, many researches recorded different sizes of plant height earlier for different rice varieties (Masum *et al*., 2008, Chamely *et al.,* 2015, Sumon *et al.,* 2018).

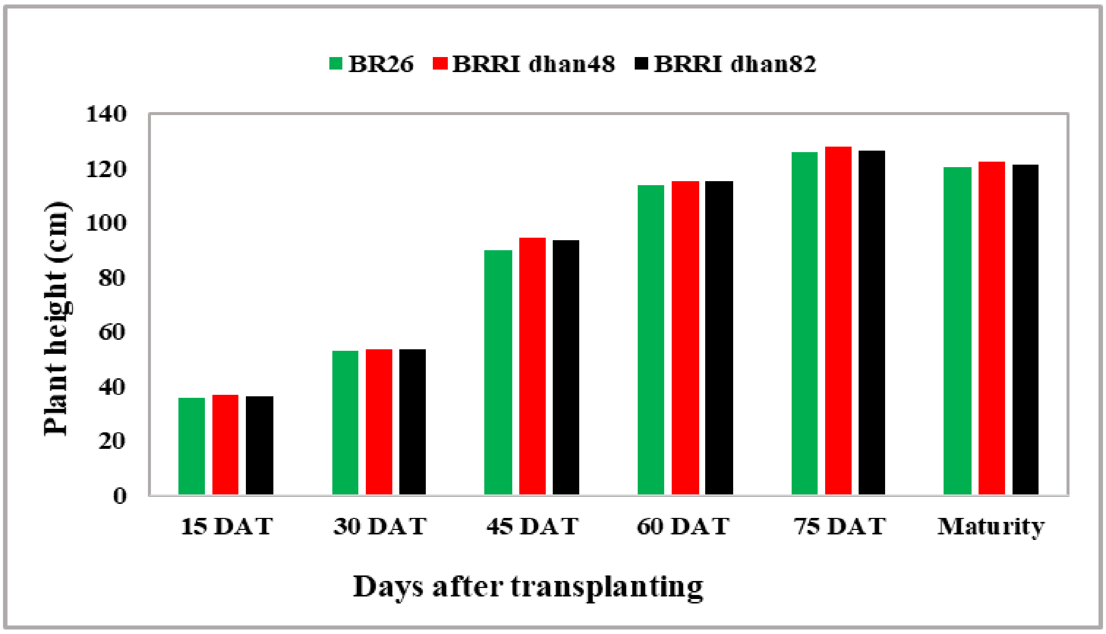

Figure 2. Plant height of *aus* varieties at different days after transplanting during *aus* 2019 at BRRI, Gazipur [LSD $_{(0.05)}$ for variety (V), 15 DAT (ns), 30 DAT (ns), 45 DAT (0.66), 60 DAT (1.11), 75 DAT (ns), at maturity (1.47)]

4.1.1.2 Effect of nitrogen fertilizer

The plant height was significantly influenced due to application of nitrogen level irrespective growth stages. The amount of nitrogen applied affects the photosynthesis of plants. Plants grow under nitrogen stress often with little nitrogen fertilizer. However, it should be noted that more nitrogen fertilizer also causes effects on the plant growth (Lv *et al.*, 2017; Paul *et. al.*, 2017; Li *et al.*, 2019a). Plant height of the varieties was measured at 15, 30, 45, 60, 75 DAT (days after transplanting) and maturity showed statistically significant variations due to different levels of nitrogen (Fig. 3). At 15, 30, 45, 60, 75 DAT and maturity, the tallest plant (38.99, 57.28, 96.06, 120.36, 131.17 and 124.71 cm, respectively) was observed from N_{80} (80.0 kg N ha^{-1}) which was followed (36.95, 54.21, 93.95, 116.53, 126.92 and 122.29 cm, respectively) by N_{100} (100 kg N ha^{-1}) similar with (35.98, 53.46, 92.43, 114.58, 126.11 and 122.18 cm, respectively) by N_{60} (60 kg N ha^{-1}) and also (34.62, 51.97, 91.47, 113.28, 124.17 and 120.48 cm, respectively) by N_{40} (40 kg N ha^{-1}), while the shortest plant (33.02, 49.87, 88.65, 109.28, 121.91 and 118.23 cm, respectively) was found from N_0 (0 kg N ha^{-1}). Similar research finding was also reported by Chamely *et al.* (2015). Plant height increased rapidly at the early and middle tillering stages (30-45 DAT) (Fig. 3). This was probably due to higher uptake of applied nitrogen and greater availability of soil nutrients. The result supported by the findings of Fageria and Wilcox (1977), Thakur and Singh (1987) and Sigh *et al.* (1996). Devaraju *et al.* (1998) opined that an adequate supply of plant nutrients influenced plant height. Nitrogen increases the chlorophyll content at all growth stages as it is a constituent and might have increased the photosynthesis and resulted in increased plant height (Gill and Singh, 1985). Chou *et al.* (2020) reported that, nitrogen fertilizer would lead to the elongation of various internodes of rice stems, especially the basal internodes, thus increased plant height.

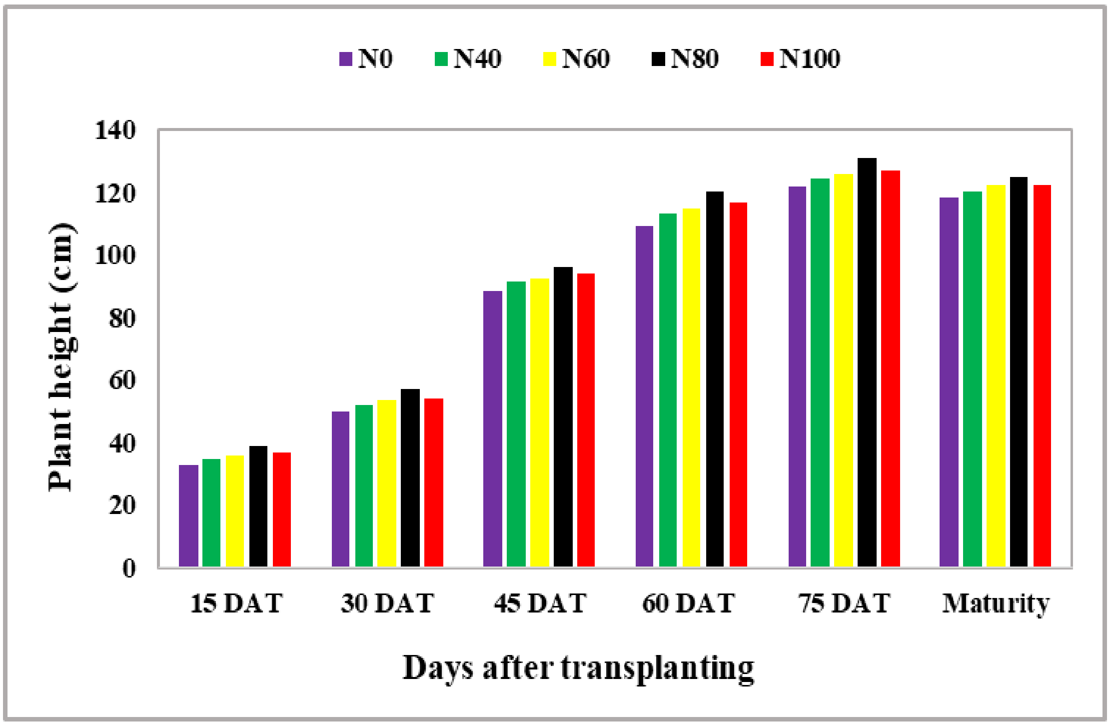

Figure 3. Plant height of different nitrogen rates at different days after transplanting during *aus* 2019 at BRRI, Gazipur [LSD $_{(0.05)}$ for nitrogen rate (N), 15 DAT (0.64), 30 DAT (1.21), 45 DAT (0.85), 60 DAT (1.44), 75 DAT (1.24), at maturity (1.89)]

4.1.1.3 Interaction effect of variety and different nitrogen rates

Interaction effect of variety and different rates of nitrogen application did not influence significantly the plant height at different growth stages of *aus* rice (Table 2). However, at 15, 30, 45, 60, 75 DAT and maturity, the highest plant (39.30, 58.58, 97.67, 121.08, 131.75 and 126.88 cm, respectively) was found from BRRI dhan48 × N_{80} (80 kg ha^{-1}), while the lowest plant (32.79, 49.67, 86.42, 108.67, 121.75 and 108.00 cm, respectively) was recorded from BR26 × N_0 (0 kg ha^{-1}) treatment combination. The results obtained from all other treatments at different growth stages on plant height gave insignificantly different results. The increase in plant height in response to application of N fertilizers is probably due to enhanced availability of nitrogen which enhanced more leaf area resulting in higher photo assimilates and thereby resulted in more dry matter accumulation (Chaturvedi, 2005). Similarly, many researches recorded different scale of plant height earlier for different rice varieties with nitrogen rate (Mandal *et al.*, 1992; Rupp and Hubner, 1995).

Table 2. Interaction effect of variety (BR26, BRRI dhan48, and BRRI dhan82) and nitrogen rates on plant height (cm) at BRRI farm, Gazipur

Treatment		Days after transplanting					
		15 DAT	30 DAT	45 DAT	60 DAT	75 DAT	Maturity
BR26	N_0	32.79	49.67	86.42	108.67	121.75	118.00
	N_{40}	34.14	51.00	89.67	112.08	124.08	119.83
	N_{60}	35.17	52.79	88.83	113.17	125.17	120.39
	N_{80}	38.66	56.42	93.17	119.50	130.08	121.83
	N_{100}	36.72	54.06	91.52	115.58	126.42	121.67
BRRI dhan48	N_0	33.17	50.00	90.96	109.67	122.07	118.38
	N_{40}	34.98	52.50	93.50	114.17	124.25	120.58
	N_{60}	36.43	53.99	94.58	115.33	126.75	122.88
	N_{80}	39.30	58.58	97.67	121.08	131.75	126.88
	N_{100}	37.12	54.50	95.59	117.17	127.50	123.57
BRRI dhan82	N_0	33.08	49.94	88.58	109.50	121.92	118.29
	N_{40}	34.74	52.41	91.26	113.58	124.17	120.46
	N_{60}	36.34	53.59	93.88	115.25	126.42	122.34
	N_{80}	39.00	56.83	97.33	120.50	131.67	125.42
	N_{100}	37.00	54.08	94.75	116.83	126.83	123.14
$LSD_{(0.05)}$ for V × N rate		ns	ns	1.47	ns	ns	ns
CV (%)		1.8	2.3	0.9	1.3	1.0	1.6

Note: ns= Non significant; N_0= 0 (Control), N_1= 40 kg ha^{-1}, N_2 60 kg ha^{-1}, N_3= 80 kg ha^{-1}, N_4= 100 kg ha^{-1}

4.1.2 Number of tillers hill^{-1}

4.1.2.1 Effect of variety

The number of total tillers hill^{-1} at 15, 30, 45, 60, 75 DAT (days after transplanting) and maturity showed statistically significant differences due to different *aus* rice varieties (Fig. 4). At 15, 30, 45, 60, 75 DAT and maturity, the maximum number of tillers hill^{-1} (6, 12, 16, 21, 22 and 19, respectively) were found from BRRI dhan48 which was followed (5, 11, 15, 20, 21 and 18, respectively) by BRRI dhan82 and the minimum number (5, 11, 14, 19, 20 and 18, respectively) were recorded from BR26. Khalifa (2009) reported that modern rice variety surpassed other varieties in the case of tillers $hill^{-1}$. The results indicate that tillering pattern of different varieties differed due to genetic potentiality of the varieties (Chamely *et al.*, 2015). BRRI (1985) and Babiker (1986) also reported differences in tillering in the modern and traditional varieties of rice.

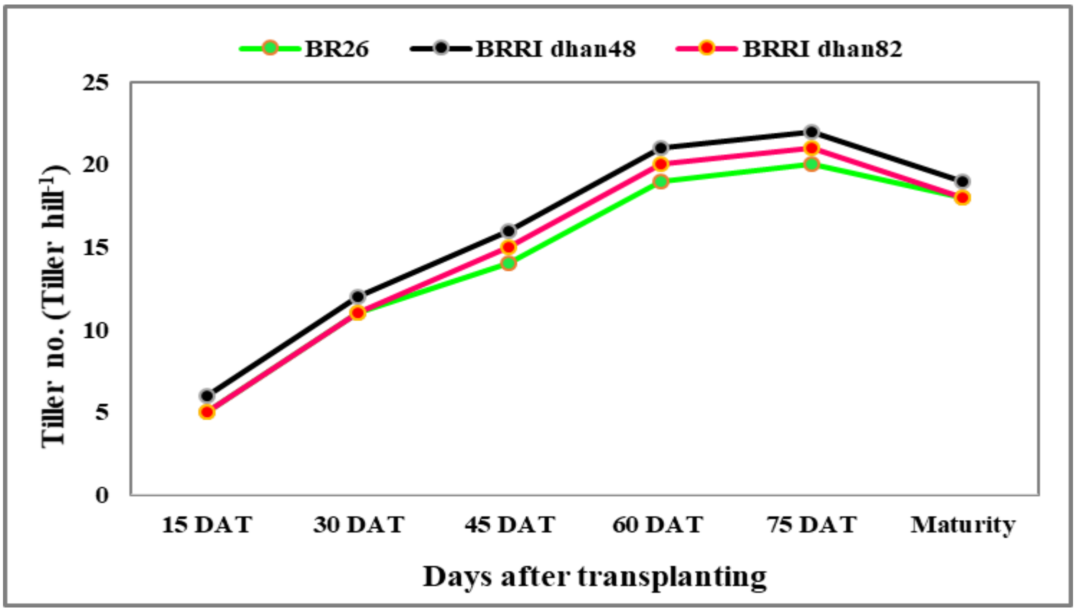

Figure 4. Tillering pattern (Tiller $hill^{-1}$) of *aus* varieties at different days after transplanting during *aus* 2019 at BRRI, Gazipur [LSD $_{(0.05)}$ for variety (V), 15 DAT (ns), 30 DAT (0.48), 45 DAT (ns), 60 DAT (ns), 75 DAT (0.58), at maturity (ns)]

4.1.2.2 Effect of nitrogen fertilizer

The application of N fertilizer may increase the number of productive tillers (Budhar and Palaniappan, 1996; Wilhelm, 1998). However, not every tiller contributes similarly to high productivity (Sahu *et al.*, 2004). Different levels of nitrogen showed statistically significant variations in terms of the number of tillers $hill^{-1}$ of *aus* rice at 15, 30, 45, 60, 75 DAT (days after transplanting) and maturity (Fig. 5). At 15, 30, 45, 60, 75 DAT and maturity, the maximum number of tillers $hill^{-1}$ was recorded by N_{80} (7, 13, 18, 22, 23 and 20, respectively) which was the same results obtained from N_{40} and N_{100} at maturity. The results obtained from N_0 showed the lowest number of tillers $hill^{-1}$ (4, 9, 14, 16, 17 and 16 at 15, 30, 45, 60, 75 DAT and maturity, respectively) which was same results obtained from N_{60}, N_{40} at 45 DAT and maturity. Similarly, Qurashi *et al.* (2013) and Paul *et al.* (2017), reported that the number of tillers hill^{-1} was significantly influenced by the dose of nitrogen. Tiller number increased with nitrogen supply. Yoshida *et al.* (1972), Shanmugam (1983) and Rajput *et al.* (1988) reported that, as the amount of nitrogen absorbed by the crop increases, there is an increase in the number of tillers m^{-2}.

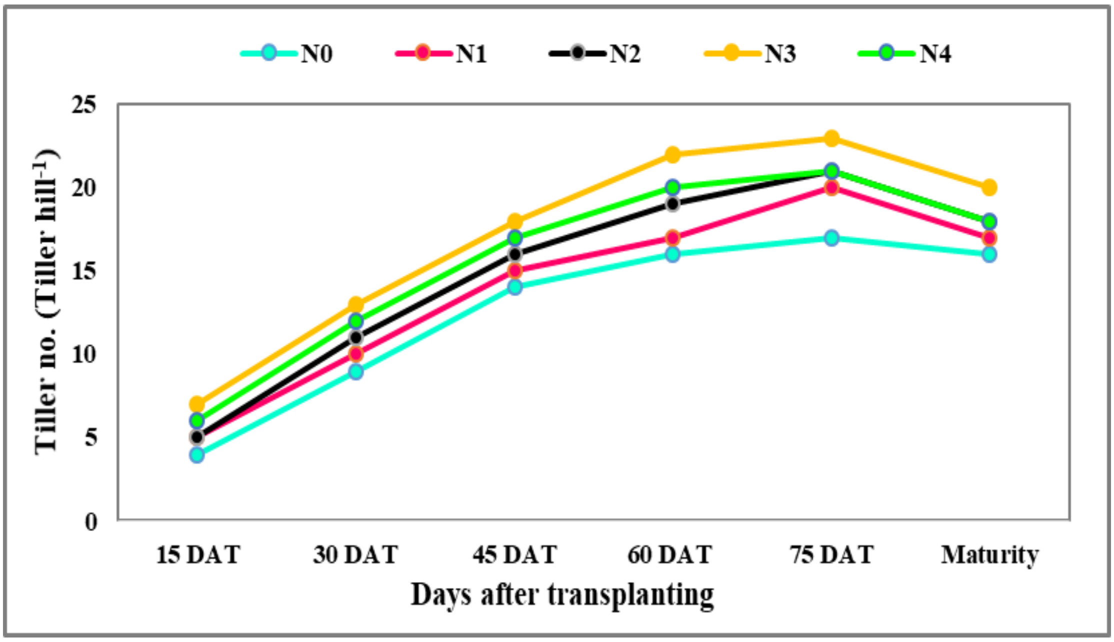

Figure 5. Tillering pattern (Tiller hill^{-1}) of different nitrogen rates at different days after transplanting during *aus* 2019 at BRRI, Gazipur [LSD $_{(0.05)}$ for nitrogen rate (N), 15 DAT (0.65), 30 DAT (0.61), 45 DAT (0.78), 60 DAT (0.89), 75 DAT (0.75), at maturity (0.49)]

4.1.2.3 Interaction effect of variety and different nitrogen rates

Interaction effect of variety and different rates of nitrogen application showed statistically insignificant differences on number of tillers hill^{-1} of *aus* rice at 15, 30, 45, 60, 75 DAT (days after transplanting) and maturity (Table 3). At 15, 30, 45, 60, 75 DAT and maturity, the maximum number of tillers hill^{-1} (8, 14, 18, 23, 24 and 21, respectively) was observed from BRRI dhan48 × N_{80} (80 kg ha^{-1}) and the minimum number (3, 9, 14, 18, 19 and 17, respectively) was recorded from BR26 × N_0 (0 kg ha^{-1}) treatment combination. Similarly, many researches recorded different numbers of tiller hill^{-1} for different rice varieties with nitrogen rate (Hossain *et al.*, 2002; Tunio *et al.*, 2002; Rahman *et al.*, 2007; Sowmyalatha *et al.*, 2012; Songyikhangsuthor *et al.*, 2014).

Table 3. Interaction effect of variety (BR26, BRRI dhan48, and BRRI dhan82) and nitrogen rates on total tiller pattern (Tiller hill^{-1}) at BRRI farm, Gazipur

Treatment		Days after transplanting					
		15 DAT	**30 DAT**	**45 DAT**	**60 DAT**	**75 DAT**	**Maturity**
BR26	N_0	3	9	14	18	19	17
	N_{40}	4	10	15	19	20	17
	N_{60}	5	11	16	20	20	18
	N_{80}	7	13	17	21	22	19
	N_{100}	6	12	16	20	21	18
BRRI dhan48	N_0	4	10	14	19	20	17
	N_{40}	4	11	16	21	22	18
	N_{60}	5	12	16	21	22	19
	N_{80}	8	14	18	23	24	21
	N_{100}	6	13	17	21	22	19
BRRI dhan82	N_0	3	8	14	19	20	17
	N_{40}	5	10	15	20	21	18
	N_{60}	5	11	15	21	22	18
	N_{80}	7	13	18	22	23	20
	N_{100}	6	12	16	20	21	18
LSD $_{(0.05)}$ for variety (V) × N rate (N)		ns	ns	ns	ns	ns	ns
CV (%)		13.3	5.6	5.2	4.5	3.7	2.8

Note: ns= Non significant; N_0= 0 (Control), N_1= 40 kg ha^{-1}, N_2 60 kg ha^{-1}, N_3= 80 kg ha^{-1}, N_4= 100 kg ha^{-1}

4. 1.3 Leaf Area Index (LAI)

4.1.3.1 Effect of variety

The plant communities of higher population density adjusted their leaves with greater LAI from an early stage of growth (Ali *et al.*, 2017). Leaf area index (LAI) was significantly influenced by different varieties used in the present study (Fig. 6). At 15, 30, 45, 60, 75 DAT and maturity, the maximum number of leaf area index (0.28, 0.98, 0.173, 2.30, 3.07 and 2.84, respectively) was found from BRRI dhan48 which was followed (0.27, 0.97, 1.73, 2.29, 3.04 and 2.83, respectively) by BRRI dhan82 and the minimum number (0.25, 0.95, 1.68, 2.27, 3.02 and 2.71, respectively) was recorded from BR26. These findings could be due to the proper mechanism of nutrient supply from the soil to the plants, the light intensity and light holding capacity of a variety, and above all, the variety's phenotypic characteristics. At the initial stage, LAI was low and over time it increased and maximum at 75 DAT, then tens to decrease. These results corroborate the findings of Kim *et al.* (1987) and Paul *et al.* (2013), who reported that LAI increased with an increase in plant density.

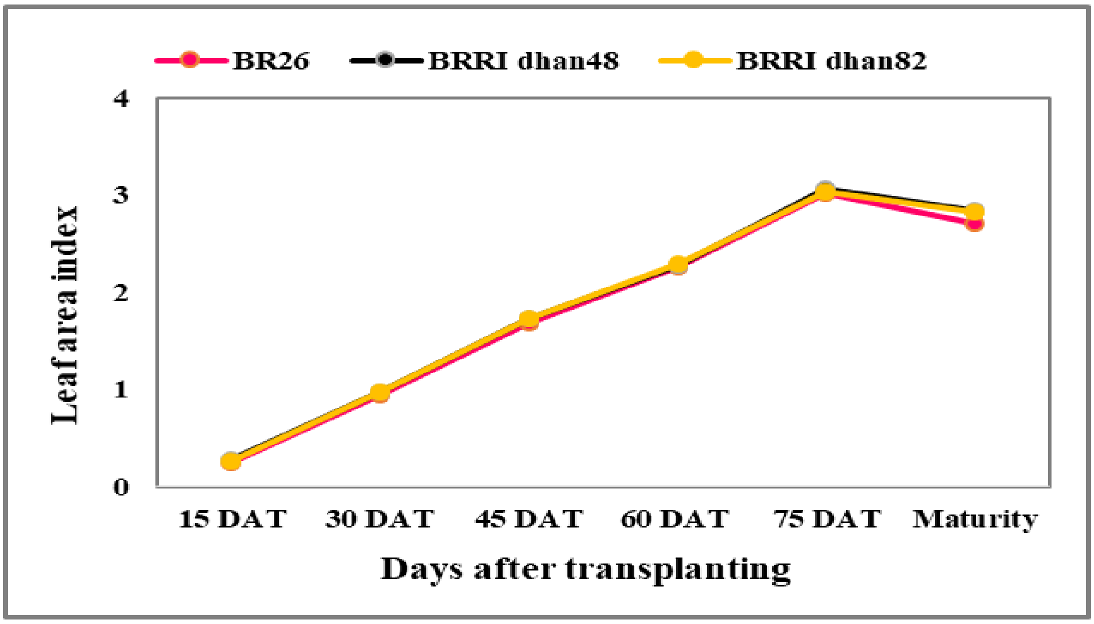

Figure 6. Leaf area index of *aus* varieties at days after transplanting during *aus* 2019 at BRRI, Gazipur [(LSD $_{(0.05)}$ for variety (V), 15 DAT (0.51), 30 DAT (ns), 45 DAT (0.48), 60 DAT (0.52), 75 DAT (ns), at maturity (ns)]

4.1.3.2 Effect of nitrogen fertilizer

Different levels of nitrogen showed statistically not significant variations in terms of leaf area index of *aus* rice at 15, 30, 45, 60, 75 DAT (days after transplanting), and maturity (Fig. 7). At 15, 30, 45, 60, 75 DAT, and maturity, the maximum leaf area index was recorded by N_{80} (0.30, 0.99, 1.79, 2.34, 3.09 and 2.88, respectively), which was followed (0.28, 0.96, 1.74, 2.30, 3.05 and 2.84, respectively) by N_{100} (100 kg N ha^{-1}) similar with (0.27, 0.95, 1.73, 2.29, 3.04 and 2.83, respectively) by N_{60} (60 kg N ha^{-1}) and also (0.26, 0.95, 1.72, 2.28, 3.03 and 2.82, respectively) by N_{40} (40 kg N ha^{-1}), while the shortest plant (0.24, 0.93, 1.70, 2.26, 3.02 and 2.80, respectively) was found from N_0 (0 kg N ha^{-1}). A similar finding was also reported by Paul *et al.* (2014). Ray *et al.* (2015) also stated that high nitrogen levels (80 kg N ha^{-1}) resulted in higher LAI in rice. Zhang *et al.* (2020) reported that the leaf area index increased with the increase of nitrogen application amount and the occurrence of maximum leaf area index showed a trend of delay in the rice growth period with the increase of nitrogen application amount.

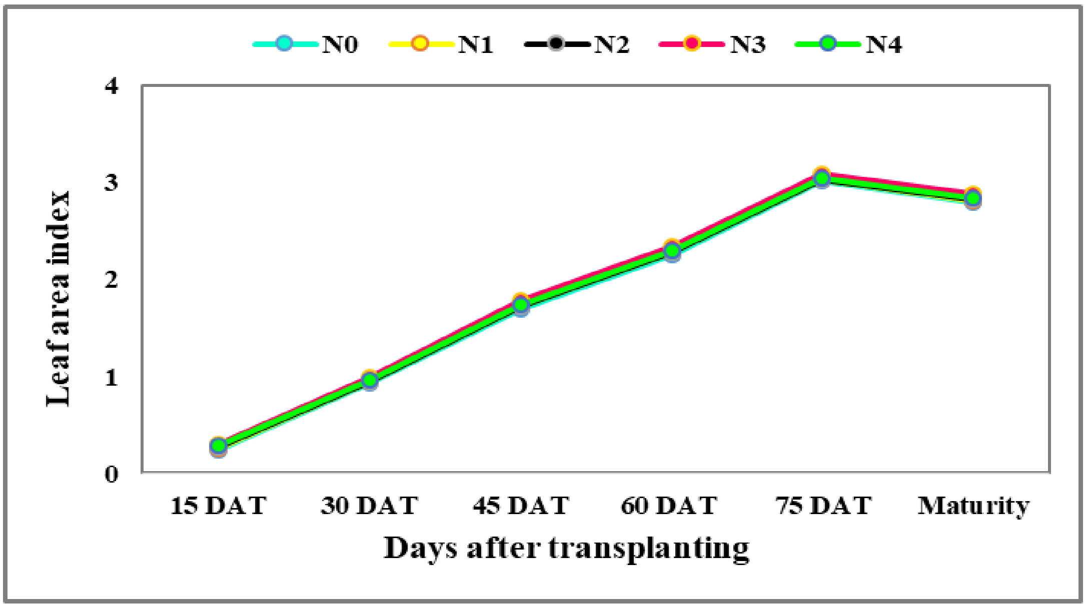

Figure 7. Leaf area index of different nitrogen rates at days after transplanting during *aus* 2019 at BRRI, Gazipur [LSD $_{(0.05)}$ for nitrogen rate (N), 15 DAT (0.65), 30 DAT (0.59), 45 DAT (0.61), 60 DAT (0.67), 75 DAT (0.48), at maturity (ns)]

4.1.3.3 Interaction effect of variety and different nitrogen rates

Interaction effect of variety and different nitrogen rates had no significant influence on leaf area index at different growth stages of the three *aus* rice varieties (Table 4). Therefore, at 15, 30, 45, 60, 75 DAT (days after transplanting), and maturity, the highest leaf area index (0.33, 0.98, 1.77, 2.33, 3.09 and 2.88, respectively) was observed from BRRI dhan48 × N_{80} (80 kg ha^{-1}) and the lowest number of (0.22, 0.92, 1.68, 2.24, 3.01 and 2.80, respectively) was recorded from BR26 × N_0 (0 kg ha^{-1}) treatment combination. Similarly, many researches recorded a different number of leaf area index for different rice varieties with nitrogen rate (Tang *et al.*, 2003; Zhang *et al.*, 2012; Das, 2015).

Table 4. Interaction effect of variety (BR26, BRRI dhan48, and BRRI dhan82) and nitrogen rates on leaf area index at BRRI farm, Gazipur

Treatment		Days after transplanting					
		15 DAT	**30 DAT**	**45 DAT**	**60 DAT**	**75 DAT**	**Maturity**
BR26	N_0	0.22	0.92	1.68	2.24	3.01	2.80
	N_{40}	0.24	0.93	1.70	2.25	3.02	2.82
	N_{60}	0.25	0.94	1.71	2.26	3.03	2.83
	N_{80}	0.29	0.95	1.75	2.30	3.05	2.83
	N_{100}	0.27	0.95	1.72	2.28	3.04	2.84
BRRI dhan48	N_0	0.25	0.92	1.70	2.26	3.02	2.80
	N_{40}	0.27	0.94	1.72	2.28	3.03	2.82
	N_{60}	0.26	0.95	1.74	2.29	3.05	2.84
	N_{80}	0.33	0.98	1.77	2.33	3.09	2.88
	N_{100}	0.28	0.96	1.75	2.30	3.06	2.85
BRRI dhan82	N_0	0.25	0.94	1.71	2.24	3.02	2.79
	N_{40}	0.27	0.95	1.72	2.26	3.03	2.81
	N_{60}	0.28	0.95	1.74	2.27	3.04	2.83
	N_{80}	0.30	0.97	1.76	2.31	3.06	2.86
	N_{100}	0.27	0.96	1.75	2.29	3.05	2.85
LSD $_{(0.05)}$ for V × N rate		ns	ns	ns	ns	ns	ns
CV (%)		2.5	6.6	5.4	7.3	4.2	13.3

Note: ns= Non significant; N_0= 0 (Control), N_1= 40 kg ha^{-1}, N_2 60 kg ha^{-1}, N_3= 80 kg ha^{-1}, N_4= 100 kg ha^{-1}

4.1.5 Total dry matter production

4.1.5.1 Effect of variety

Dry matter is the material that was dried to a constant weight. Total dry matter production indicates the production potential of a crop. A high total dry matter production is the first prerequisite for high yield. The increase of total dry matter production depends on the leaf area production (Tanaka, 1983). Total dry matter of leaves, leaf sheath + stem and or panicles of plants data were measured at 15, 30, 45, 60, 75 DAT (days after transplanting), and maturity (Fig. 8). At 15, 30, 45, 60, 75 DAT and maturity, the highest total dry matter production (87.60, 228.93, 431.40, 620.33, 804.95, 692.87 g m^{-2}) was found in BRRI dhan48 and the lowest total dry matter production (772.89 g m^{-2}) was found in BR26. At maturity, BRRI dhan48 gave the numerically highest (692.87 g m^{-2}) total dry matter production whereas BR26 gave the lowest (648.00 g m^{-2}) total dry matter production. The significant variation in total dry matter production among the varieties was also reported by Masum *et al.* (2008), Jannat (2013), Hasan *et al.* (2017) and Khatun *et al.* (2020).

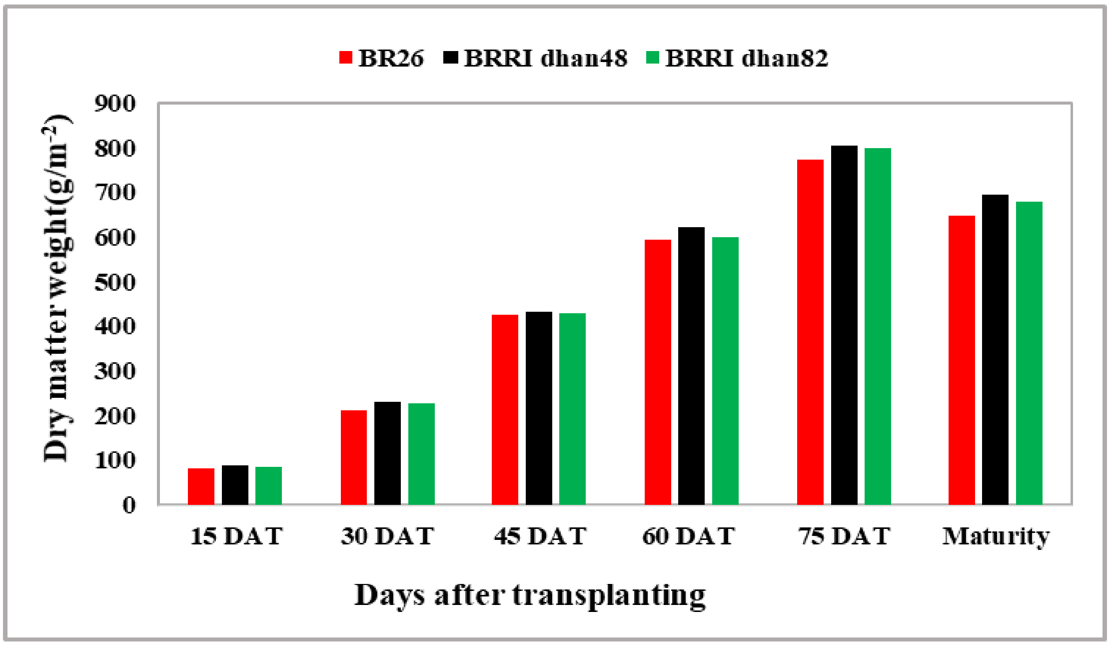

Figure 8. Dry matter production (g m^{-2}) of *aus* varieties at different days after transplanting during *aus* 2019 at BRRI, Gazipur [LSD $_{(0.05)}$ for variety (V), 15 DAT (1.84), 30 DAT (6.12), 45 DAT (5.19), 60 DAT (22.03), 75 DAT (17.33), at maturity (11.43)]

4.1.5.2 Effect of nitrogen fertilizer

Dry matter accumulation increases significantly with N-fertilizer application in rice at all the growth stages of the crop (Kirrilov and Pavlov *et al.*, 1989; Chaturvedi, 2005). Different levels of nitrogen showed statistically significant variations in terms of total dry matter production of *aus* rice at 15, 30, 45, 60, 75 DAT (days after transplanting) and maturity (Fig. 9). At 15, 30, 45, 60, 75 DAT and maturity, the maximum amount of total dry matter production was recorded by N_{80} (97.22, 243.22, 456.00, 654.67, 838.84 and 748.56 g m^{-2}, respectively), which was statistically similar (89.67, 228.11, 434.56, 624.56, 812.76 and 715.11 g m^{-2}, respectively) by N_{100} (100 kg N ha^{-1}) closely followed (88.33, 228.44, 431.67, 616.33, 809.53 and 706.33 g m^{-2}, respectively) by N_{60} (60 kg N ha^{-1}) and also (79.78, 211.33, 415.78, 575.33, 756.69 and 609.56 g m^{-2}, respectively) by N_{40} (40 kg N ha^{-1}), while the minimum (73.22, 19.33, 402.00, 549.22, 740.49 and 560.89 g m^{-2}, respectively) was found from N_0 (0 kg N ha^{-1}). Siddaram *et al*. (2010) reported that higher growth indices recorded in rice had a positive association with higher dry matter accumulation. Apart from that, nitrogen might have involved in various physiological activities like increased photosynthetic activity and better light interception, in turn, resulted in higher dry matter accumulation.

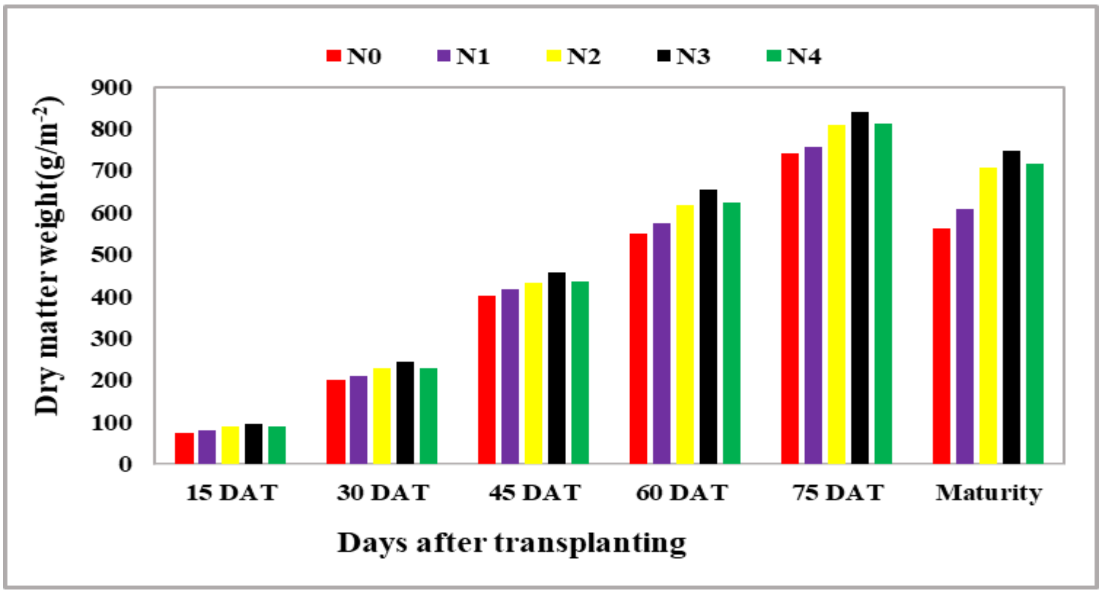

Figure 9. Dry matter production (g m^{-2}) different nitrogen rates at different days after transplanting during *aus* 2019 at BRRI, Gazipur [LSD $_{(0.05)}$ for nitrogen rate (N), 15 DAT (2.38), 30 DAT (7.91), 45 DAT (6.71), 60 DAT (28.44), 75 DAT (22.38), at maturity (14.76)]

4.1.5.3 Interaction effect of variety and different nitrogen rates

Interaction effect of variety and different rates of nitrogen application showed statistically insignificant differences on total dry matter production of *aus* rice except during 30 DAT. Thereafter (Table 5) at 15, 30, 45, 60, 75 DAT and maturity, the maximum amount of total dry matter production (99.67, 256.00, 460.33, 700.33, 870.20, and 760.67 g m^{-2}, respectively) was observed from BRRI dhan48 × N_{80} (80 kg ha-^{1}), which were as par (97.67, 254.33, 459.00, 636.00, 832.67 and 752.01 g m^{-2}, respectively) by BRRI dhan82 × N_{80} (80 kg ha^{-1}) and the minimum (69.33, 189.67, 397.33, 537.33, 734.60 and 546.33 g m^{-2}, respectively) were recorded from BR26 × N_0 (0 kg ha^{-1}) treatment combination. Higher dry matter production was perhaps due to the higher leaf dry weight and stem dry weight recorded at different stages. As nitrogen could enhance tillers production and leaf area development, naturally total dry matter production also increased with increased levels of nitrogen (Siddaram *et al.,* 2010; Ajmal *et al.*, 2020).

Table 5. Interaction effect of variety (BR26, BRRI dhan48, and BRRI dhan82) and nitrogen rates on total dry matter production (g m^{-2}) at BRRI farm, Gazipur

Treatment		Days after transplanting					
		15 DAT	30 DAT	45 DAT	60 DAT	75 DAT	Maturity
BR26	N_0	69.33	189.67	397.33	537.33	734.60	546.33
	N_{40}	76.67	207.00	415.78	563.33	751.53	578.00
	N_{60}	87.00	222.67	430.67	605.00	782.33	691.67
	N_{80}	94.33	219.33	448.67	647.67	813.67	733.00
	N_{100}	87.33	221.00	427.67	605.67	782.33	695.33
BRRI dhan48	N_0	75.03	206.00	407.00	557.67	744.60	569.04
	N_{40}	82.33	217.33	416.00	585.67	764.87	631.33
	N_{60}	89.00	233.00	431.67	626.00	826.47	717.67
	N_{80}	99.67	256.00	460.33	700.33	870.20	760.67
	N_{100}	91.67	231.67	433.33	638.00	827.60	727.00
BRRI dhan82	N_0	75.33	202.33	401.67	552.67	742.27	569.33
	N_{40}	80.33	216.67	415.67	577.00	753.67	619.33
	N_{60}	89.00	229.67	430.67	618.00	819.80	709.67
	N_{80}	97.67	254.33	459.00	636.00	832.67	752.01
	N_{100}	90.00	231.67	441.67	630.00	828.33	723.00
LSD $_{(0.05)}$ for variety (V) × N rate (N)		ns	13.69	ns	ns	ns	ns
CV (%)		2.9	3.7	1.6	4.9	2.9	2.3

Note: ns= Non significant; N_0= 0 (Control), N_1= 40 kg ha^{-1}, N_2 60 kg ha^{-1}, N_3= 80 kg ha^{-1}, N_4= 100 kg ha^{-1}

4.1.4 Crop growth rate

4.1.4.1 Effect of variety

The crop growth rate is a measure of the increase of dry matter over a while. In many cases, the increase can be plotted as a logarithmic or exponential curve (Gardner *et al.,* 1985). Crop growth rate (CGR) was significantly influenced by different varieties used in the present study (Fig. 10). At 15-30 DAT, the highest crop growth rate was recorded by BRRI dhan48 (9.46 g/m^2/d). The results obtained from BR26 showed the lowest crop growth rate (8.60 g/m^2/d). On 30-45 DAT, the highest crop growth rate was recorded by BRRI dhan48 (12.79 g/m^2/d) and lowest (11.16 g/m^2/d) from BR26. At 45-60 DAT, the highest crop growth rate was recorded by BRRI dhan48 (14.16

g/m^2/d) and the lowest (13.49 g/m^2/d) from BR26 and at 60-75 DAT, the highest crop growth rate (13.15 g/m^2/d) was obtained from BRRI dhan48 and the lowest (12.01 g/m^2/d) from BR26. Similar research finding was also reported by Bhuiyan *et al.* (2016) and Sarkar *et al.* (2017).

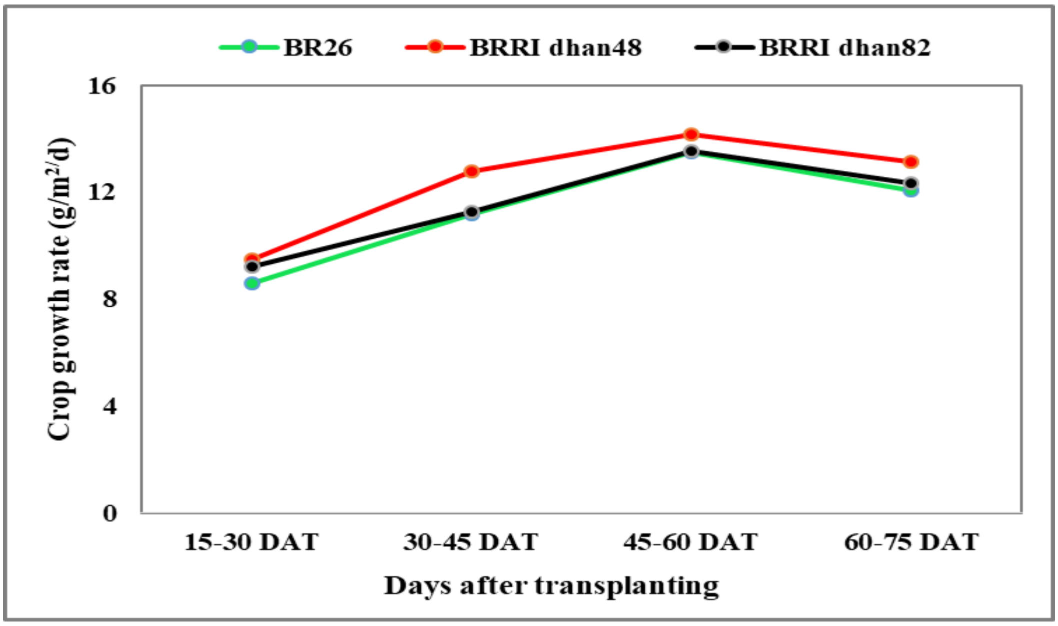

Figure 10. Crop growth rate (g/m^2/d) of *aus* varieties at different days after transplanting during *aus* 2019 at BRRI, Gazipur [LSD $_{(0.05)}$ for variety (V), 15-30 DAT (0.32), 30-45 DAT (1.37), 45-60 DAT (0.43), 60-75 DAT (ns)]

4.1.4.2 Effect of nitrogen fertilizer

Different levels of nitrogen showed statistically significant variations in terms of the number of crop growth rate (CGR) of *aus* rice at 15-30, 30-45, 45-60 (days after transplanting), and 60-75 DAT (Fig. 11). At 15-30 DAT, the results obtained from N_0 (0 kg ha^{-1}) showed the lowest crop growth rate (9.41 g/m^2/d). On 30-45 DAT, the highest crop growth rate (13.24 g/m^2/d) was recorded by N_{80} (80 kg ha^{-1}) and the lowest (11.64 g/m^2/d) from N_0. At 45-60 DAT, the highest crop growth rate (14.19 g/m^2/d) was recorded by N_{80} (80 kg ha^{-1}) and the lowest (13.51 g/m^2/d) from N_0 (0 kg ha^{-1}) and at 60-75 DAT, the highest crop growth rate (12.88 g/m^2/d) was obtained from N_{80} (80 kg ha^{-1}) and the lowest (12.08 $g/m^2/d$) from N_0 (0 kg ha^{-1}). Bhuiyan *et al.* (2016) reported that crop growth rate was significantly affected by nitrogen treatments at different stages. Das and Panda (2004) also reported similar results.

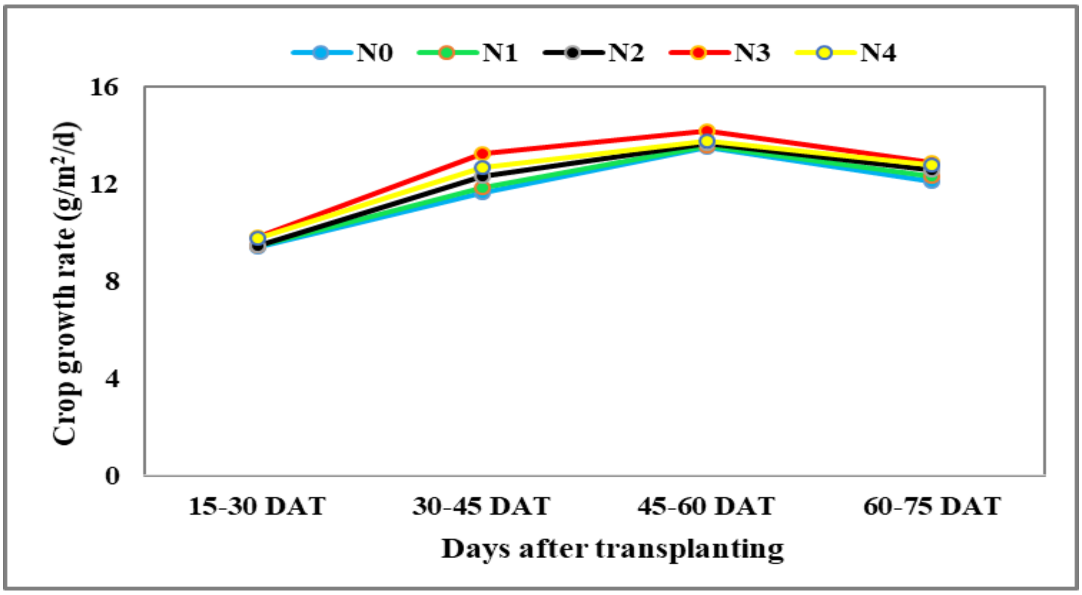

Figure 11. Crop growth rate ($g/m^2/d$) of different nitrogen rates at different days after transplanting during *aus* 2019 at BRRI, Gazipur [LSD $_{(0.05)}$ for nitrogen rate (N), 15-30 DAT (0.41), 30-45 DAT (1.77), 45-60 DAT (ns), 60-75 DAT (ns)]

4.1.4.3 Interaction effect of variety and different nitrogen rates

Interaction effect of variety and different nitrogen rates application had no significant influence on the crop growth rate at different growth stages of the three varieties of *aus* rice (Table 6) except 15-30 DAT. Thereafter, at 45-60 DAT, the highest crop growth rate (15.29 $g/m^2/d$) was observed from BRRI dhan48 × N_{80} (80 kg N ha^{-1}). At 15-30 DAT, the lowest crop growth rate (8.47 $g/m^2/d$) was found from the combination of BR26 × N_0 (0 kg N ha^{-1}). Similarly, many researches recorded different crop growth rate for different rice varieties with nitrogen rate (Parashivamurthy *et al.*, 2012; Kumar *et al.*, 2017; Jahan *et al.*, 2020).

Table 6. Interaction effect of variety (BR26, BRRI dhan48, and BRRI dhan82) and nitrogen rates on crop growth rate ($g/m^{2/}d$) at BRRI farm, Gazipur

Treatment		Days after transplanting			
		15-30 DAT	30-45 DAT	45-60 DAT	60-75 DAT
BR26	N_0	8.47	9.29	13.29	12.64
	N_{40}	8.53	9.84	13.27	11.75
	N_{60}	9.31	11.49	13.24	12.85
	N_{80}	10.41	10.47	13.62	11.07
	N_{100}	9.34	12.49	13.44	12.64
BRRI dhan48	N_0	8.77	10.07	13.84	12.78
	N_{40}	8.93	11.31	13.91	11.82
	N_{60}	9.38	12.96	13.84	13.83
	N_{80}	10.44	16.01	15.29	14.44
	N_{100}	9.38	13.64	14.07	13.22
BRRI dhan82	N_0	8.73	9.31	13.40	12.36
	N_{40}	9.09	10.56	13.71	11.78
	N_{60}	9.60	11.49	13.40	12.99
	N_{80}	10.42	13.27	13.64	13.42
	N_{100}	9.44	11.87	14.01	13.15
LSD $_{(0.05)}$ for variety (V) × N rate (N)		0.71	ns	ns	ns
CV (%)		4.7	15.6	4.3	12.5

Note: ns= Non significant; N_0= 0 (Control), N_1= 40 kg ha^{-1}, N_2 60 kg ha^{-1}, N_3= 80 kg ha^{-1}, N_4= 100 kg ha^{-1}

4.1.6 Nitrogen concentration (N %)

4.1.6.1 Effect of variety

Nitrogen concentration (N %) in plant was significantly influenced by different varieties used in the present study (Table 7). At 15 DAT, in BR26 the nitrogen concentration was recorded 0.41. The results obtained from BRRI dhan48 showed the lowest nitrogen concentration (0.35). On 30 DAT, the highest nitrogen concentration was recorded by BRRI dhan82 (1.13) and the lowest (1.01) from BR26. At 45 DAT, the highest nitrogen concentration was recorded by BRRI dhan82 (1.22) and the lowest (1.16) from BR26. At 60 DAT, the highest nitrogen concentration (0.98) was obtained from BRRI dhan48 and the lowest (0.56) from BRRI dhan82. At 75 DAT, the highest nitrogen concentration (0.69) was obtained from BRRI dhan48 and BR26 and the lowest (0.65) from BRRI dhan82. At maturity, the highest nitrogen concentration (0.63) was obtained from BRRI dhan48 and the lowest (0.59) from BR26. Nitrogen concentration in plant parts increased over time due to the application of nitrogenous fertilizer and plant demand. Thereafter it seems to decline trend towards maturity. Similar research findings was also reported by Zhang *et al.* (2009), Haque *et al.* (2015b), and Djaman *et al.* (2016).

Table 7. Nitrogen concentration (%) of BR26, BRRI dhan48, and BRRI dhan82 as affected by nitrogen rates at BRRI farm, Gazipur

Treatment	Days after transplanting					
	15 DAT	**30 DAT**	**45 DAT**	**60 DAT**	**75 DAT**	**Maturity**
Variety						
BR26	0.41	1.01	1.16	1.01	0.69	0.59
BRRI dhan48	0.35	1.03	1.18	0.98	0.69	0.63
BRRI dhan82	0.36	1.13	1.22	0.93	0.65	0.60
LSD $_{(0.05)}$ for variety (V)	0.52	0.98	ns	0.56	ns	ns
Nitrogen rate						
N_0	0.23	0.51	0.54	0.52	0.24	0.21
N_1	0.29	0.83	0.90	0.85	0.60	0.53
N_2	0.39	1.07	1.17	1.04	0.79	0.69
N_3	0.47	1.29	1.60	1.14	0.84	0.78
N_4	0.49	1.58	1.73	1.32	0.89	0.84
LSD $_{(0.05)}$ for N rate (N)	0.68	0.13	0.11	0.72	0.66	0.60
CV (%)	18.6	12.4	9.5	7.7	10.1	10.2

Note: ns= Non significant; N_0= 0 (Control), N_1= 40 kg ha^{-1}, N_2 60 kg ha^{-1}, N_3= 80 kg ha^{-1}, N_4= 100 kg ha^{-1}

4.1.6.2 Effect of nitrogen fertilizer

Nitrogen is the only nutrient that has not a common soil mineral source. Nitrogen in beneficial forms of plants is probably the most limited nutrient for plant growth. Most of the nutritional dynamics and supply rates of plants are related to Model N. Different levels of nitrogen application showed statistically significant variations in nitrogen concentration (N %) of *aus* rice at 15, 30, 45, 60, 75 DAT (days after transplanting), and maturity (Table 7). At 15 DAT, the highest nitrogen concentration (0.49) was recorded by N_{100} (100 kg ha^{-1}) closely followed (0.47) by N_{80} (80 kg N ha^{-1}). The results obtained from N_0 (0 kg ha^{-1}) showed the lowest nitrogen concentration (0.23). On 30 DAT, the highest nitrogen concentration (1.58) was recorded by N_{100} (0 kg ha^{-1}) and the lowest (0.51) from N_0 (0 kg ha^{-1}). At 45 DAT, the highest nitrogen concentration (1.73) was recorded by N_{100} (100 kg ha^{-1}) and the lowest (0.54) from N_0 (0 kg ha^{-1}). At 60 DAT, the highest nitrogen concentration (1.32) was obtained from N_{100} (100 kg ha^{-1}) and the lowest (0.52) from N_0 (0 kg ha^{-1}). At 75 DAT, the highest nitrogen concentration (0.89) was obtained from N_{100} (100 kg ha^{-1}) and the lowest (0.24) from N_0 (0 kg ha^{-1}). At maturity, the highest nitrogen concentration (0.84) was obtained from N_{100} (100 kg ha^{-1}) and the lowest (0.21) from N_0 (0 kg ha^{-1}). Perez *et al.* (1996), Cassman *et al.* (2003), and Djaman *et al.* (2018) reported that improvement in crop yields is attributed to the increase in fertilizer use, especially nitrogen fertilizer.

4.1.6.3 Interaction effect of variety and different nitrogen rates

Interaction effect of variety and different nitrogen rates application had insignificant influence on nitrogen concentration at different growth stages of the three varieties of *aus* rice (Table 8). However, at 45 DAT, the highest nitrogen concentration (1.74) was observed from BRRI dhan82 and BR26 × N_{100}, (100 kg ha^{-1}). At maturity, the lowest nitrogen concentration (0.20) was found from the combination of BR26 × N_0 (0 kg ha^{-1}). Similarly, many researcher recorded nitrogen concentration for different rice varieties with nitrogen rate (Peng *et al.,* 2004; Djaman *et al.,* 2016; Djaman *et al.,* 2018).

Table 8. Interaction effect of variety (BR26, BRRI dhan48, and BRRI dhan82) and nitrogen rates on nitrogen concentration N% at BRRI farm, Gazipur

Treatment		Days after transplanting					
		15 DAT	30 DAT	45 DAT	60 DAT	75 DAT	Maturity
BR26	N_0	0.25	0.47	0.52	0.57	0.29	0.20
	N_{40}	0.34	0.84	0.89	0.90	0.67	0.48
	N_{60}	0.45	1.01	1.14	1.07	0.79	0.69
	N_{80}	0.50	1.16	1.52	1.18	0.83	0.79
	N_{100}	0.52	1.54	1.74	1.31	0.87	0.82
BRRI dhan48	N_0	0.23	0.53	0.55	0.46	0.22	0.21
	N_{40}	0.26	0.76	0.92	0.84	0.59	0.59
	N_{60}	0.39	1.02	1.15	1.05	0.83	0.70
	N_{80}	0.43	1.31	1.58	1.15	0.88	0.81
	N_{100}	0.45	1.54	1.70	1.39	0.91	0.87
BRRI dhan82	N_0	0.21	0.53	0.53	0.49	0.21	0.23
	N_{40}	0.29	0.88	0.90	0.80	0.55	0.52
	N_{60}	0.34	1.18	1.22	1.01	0.75	0.69
	N_{80}	0.46	1.41	1.71	1.09	0.83	0.76
	N_{100}	0.52	1.65	1.74	1.25	0.91	0.82
$LSD_{(0.05)}$ for variety (V) × N rate (N)		ns	ns	ns	ns	ns	ns
CV (%)		18.6	12.4	9.5	7.7	10.1	10.2

Note: ns= Non significant; N_0= 0 (Control), N_1= 40 kg ha^{-1}, N_2 60 kg ha^{-1}, N_3= 80 kg ha^{-1}, N_4= 100 kg ha^{-1}

4.1.7 Nitrogen uptake

4.1.7.1 Effect of variety

Nitrogen uptake (NUP) was significantly influenced by different varieties used in the present study (Table 9) during 15, 30, and 60DAT. At 15 DAT, the highest nitrogen uptake was recorded by BR26 (3.85 kg ha^{-1}). The results obtained from BRRI dhan48 showed the lowest nitrogen uptake (2.99 kg ha^{-1}). On 30 DAT, the highest nitrogen uptake was recorded by BRRI dhan82 (26.29 kg ha^{-1}) and the lowest (23.18 kg ha^{-1}) from BR26. At 45 DAT, the highest nitrogen uptake was recorded by BRRI dhan82 (53.67 kg ha^{-1}) and lowest (50.50 kg ha^{-1}) from BR26. At 60 DAT, the highest nitrogen uptake (63.58 kg ha^{-1}) was obtained from BR26 and the lowest (56.26 kg ha^{-1}) from BRRI dhan82. At 75 DAT, the highest nitrogen uptake (56.33 kg ha^{-1}) was obtained from BR26 and the lowest (52.66 kg ha^{-1}) from BRRI dhan82. At maturity, the highest nitrogen uptake (42.63 kg ha^{-1}) was obtained from BRRI dhan48 and the lowest (42.05 kg ha^{-1}) from BR26. Arthanari *et al.* (2007) reported that response of rice to nutrient uptake may vary with varieties. Similar research findings was also reported by Koutroubas and Ntanos (2003) and Artacho *et al.* (2009).

Table 9. Nitrogen uptake (kg ha^{-1}) of BR26, BRRI dhan48, and BRRI dhan82 as affected by nitrogen rates at BRRI farm, Gazipur

Treatment	Days after transplanting					
	15 DAT	**30 DAT**	**45 DAT**	**60 DAT**	**75 DAT**	**Maturity**
Variety						
BR26	3.85	23.18	50.50	63.58	56.33	42.05
BRRI dhan48	2.99	22.22	50.67	58.94	53.60	42.63
BRRI dhan82	3.22	26.29	53.46	56.26	52.66	42.36
LSD $_{(0.05)}$ for variety (V)	0.45	2.25	ns	3.63	ns	ns
Nitrogen rate						
N_0	1.67	10.11	21.51	27.79	17.85	11.95
N_1	2.38	17.45	37.47	48.79	45.75	32.12
N_2	3.49	24.49	50.50	64.32	63.93	49.22
N_3	4.54	31.47	73.09	74.74	70.78	58.62
N_4	4.69	35.97	75.14	82.34	72.67	59.82
LSD $_{(0.05)}$ for N rate (N)	0.59	2.91	4.56	4.68	5.46	4.35
CV (%)	18.1	12.6	9.2	8.1	10.4	10.6

Note: ns= Non significant; N_0= 0 (Control), N_1= 40 kg ha^{-1}, N_2 60 kg ha^{-1}, N_3= 80 kg ha^{-1}, N_4= 100 kg ha^{-1}

4.1.7.2 Effect of nitrogen fertilizer

Nitrogen use efficiency is largely influenced by grain yield, N fertilizer input and N uptake (Qiao *et al.*, 2012). Different levels of nitrogen showed statistically significant variations in terms of the number of nitrogen uptake (NUP) of *aus* rice at 15, 30, 45, 60, 75 DAT (days after transplanting), and maturity (Table 9). At 15 DAT, the highest nitrogen uptake (4.69 kg ha^{-1}) was recorded by N_{100} (100 kg ha^{-1}) closely followed (4.59 kg ha^{-1}) by N_{80} (80 kg N ha^{-1}). The results obtained from N_0 (0 kg ha^{-1}) showed the lowest nitrogen uptake (1.67 kg ha^{-1}). On 30 DAT, the highest nitrogen uptake (35.97 kg ha^{-1}) was recorded by N_{100} (0 kg ha^{-1}) and the lowest (10.11 kg ha^{-1}) from N_0 (0 kg ha^{-1}). At 45 DAT, the highest nitrogen uptake (75.14 kg ha^{-1}) was recorded by N_{100} (100 kg ha^{-1}) and the lowest (21.51 kg ha^{-1}) from N_0 (0 kg ha^{-1}). At 60 DAT, the highest nitrogen uptake (82.34 kg ha^{-1}) was obtained from N_{100} (100 kg ha^{-1}) and the lowest (48.79 kg ha^{-1}) from N_0 (0 kg ha^{-1}). At 75 DAT, the highest nitrogen uptake (72.67 kg ha^{-1}) was obtained from N_{100} (100 kg ha^{-1}) and the lowest (17.85) from N_0 (0 kg ha^{-1}). At maturity, the highest nitrogen uptake (59.82 kg ha^{-1}) was obtained from N_{100} (100 kg ha^{-1}) and the lowest (11.95 kg ha^{-1}) from N_0 (0 kg ha^{-1}). Present research results indicate that total N uptake by rice plants increased with increased N rates up to a certain level than it decreased. Yesuf and Balcha (2014) also reported similar findings. Sharma and Mittra (1990), Paikaray *et al.* (2001), Dobermann (2005), Jahan *et al.* (2014), Islam *et al.* (2015) and Hussain *et al.* (2016) reported that use of an optimum dose of nitrogen might have helped for good vegetative growth and root system, which increased the higher N uptake by plants and hence increased yield and yield components of rice.

4.1.7.3 Interaction effect of variety and different nitrogen rates

Interaction effect of variety and different nitrogen rates application had a non-significant influence on nitrogen uptake (NUP) at different growth stages of the three varieties of *aus* rice (Table 10). Therefore, at 60 DAT, the highest nitrogen uptake (84.39 kg ha^{-1}) was observed from BRRI dhan82 × N_{100} (100 kg ha^{-1}) closely followed (83.69 kg ha^{-1})) by N_{100} (100 kg N ha^{-1}) from BR26. At 15 DAT, the lowest nitrogen uptake (1.52 kg ha^{-1}) was found from the combination of BRRI dhan82 × N_0 (0 kg ha^{-1}) closely followed (1.57 kg ha^{-1}) by N_0 (0 kg N ha^{-1}) from BRRI dhan48. Similar research findings was also reported by Paikaray *et al.* (2001) and Jahan *et al.* (2014).

Table 10. Interaction effect of variety (BR26, BRRI dhan48, and BRRI dhan82) and nitrogen rates on nitrogen uptake (kg ha^{-1}) at BRRI farm, Gazipur

Treatment		Days after transplanting					
		15 DAT	**30 DAT**	**45 DAT**	**60 DAT**	**75 DAT**	**Maturity**
BR26	N_0	1.92	9.45	21.04	31.71	21.79	11.57
	N_{40}	2.82	17.72	36.89	52.71	51.19	30.32
	N_{60}	4.03	23.31	49.23	67.11	64.79	49.24
	N_{80}	5.02	29.73	69.81	82.70	71.95	59.19
	N_{100}	5.47	35.69	75.52	83.69	71.89	59.93
BRRI dhan48	N_0	1.57	9.99	21.85	24.55	16.15	11.30
	N_{40}	1.99	15.73	38.11	47.49	44.54	33.95
	N_{60}	3.39	22.73	49.76	63.55	64.75	48.46
	N_{80}	4.09	28.66	70.86	74.70	71.58	59.17
	N_{100}	3.89	33.99	72.76	84.39	70.99	60.26
BRRI dhan82	N_0	1.53	10.89	21.64	27.09	15.62	12.97
	N_{40}	2.30	18.91	37.42	46.18	41.51	32.09
	N_{60}	3.06	27.42	52.51	62.29	62.25	49.97
	N_{80}	4.51	36.04	78.59	66.80	68.79	57.49
	N_{100}	4.71	38.23	77.13	78.94	75.11	59.26
LSD $_{(0.05)}$ for variety (V) × N rate (N)		ns	ns	ns	ns	ns	ns
CV (%)		18.1	12.6	9.2	8.1	10.4	10.6

Note: ns= Non significant; N_0= 0 (Control), N_1= 40 kg ha^{-1}, N_2 60 kg ha^{-1}, N_3= 80 kg ha^{-1}, N_4= 100 kg ha^{-1}

4.2 Yield contributing characters

4.2.1 Number of panicle m^{-2}

4.2.1.1 Effect of variety

The number of panicles was significantly influenced by different varieties used in the present study (Table 11). The highest number of panicle m^{-2} (253.80) was recorded by BRRI dhan48. The results obtained from BR26 showed the lowest number of panicle m^{-2} (249.80). Many plant researches also reported that panicle length varied among rice varieties (Diaz *et al.,* 2000; Chamely *et al.,* 2015; Murshida *et al.,* 2017; Zhang *et al.,* 2019; Li *et al.,* 2020).

Table 11. Yield contributing characters of BR26, BRRI dhan48, and BRRI dhan82 as affected by nitrogen rates at BRRI farm, Gazipur

Treatment	Days after transplanting		
	Panicle m^{-2}	**Grains $panicle^{-1}$**	**1000-grain weight (g)**
Variety			
BR26	249.80	84.40	20.55
BRRI dhan48	253.80	96.33	22.24
BRRI dhan82	231.33	90.00	22.41
LSD $_{(0.05)}$ for variety (V)	14.98	7.77	0.55
Nitrogen rate			
N_0	235.11	75.56	21.14
N_1	234.44	88.67	21.48
N_2	238.56	91.44	21.95
N_3	261.56	99.89	22.11
N_4	255.22	95.67	21.99
LSD $_{(0.05)}$ for N rate	19.34	10.03	0.71
CV (%)	8.2	11.5	3.4

Note: ns= Non significant; N_0= 0 (Control), N_1= 40 kg ha^{-1}, N_2 60 kg ha^{-1}, N_3= 80 kg ha^{-1}, N_4= 100 kg ha^{-1}

4.2.1.2 Effect of nitrogen fertilizer

Different levels of nitrogen showed statistically significant variations in terms of the number of panicle m^{-2} of *aus* rice (Table 11). The highest number of panicle m^{-2} (261.56) was recorded by N_{80} (80 kg N ha^{-1}). The results obtained from N_0-N_{40} (40 kg ha^{-1}) showed the lowest number of panicle m^{-2} (234-235). Similarly, many researches recorded different the panicle number and yield increase with the increase of nitrogen application in a certain range nitrogen levels (Yoseftabar, 2013; Gewaily *et al.,* 2018; Zhang *et al.,* 2019; Li *et al.,* 2020).

4.2.1.3 Interaction effect of variety and different nitrogen rates

Interaction effect of variety and different nitrogen application had no significant influence on panicle m^{-2} (Table 12). However, the highest number of panicle m^{-2} (269.67) was observed from BRRI dhan48 × N_{80} (80 kg ha^{-1}) and the lowest number of panicle m^{-2} (217.00) was found from the combination of BRRI dhan82 × N_{100} (100 kg N ha^{-1}). Higher rates of N produced huge ineffective tiller, crop got lodging and infestation by insect and pest (Kulagod *et al.*, 2011).

Table 12. Interaction effect of rice variety (BR26, BRRI dhan48, and BRRI dhan82) and nitrogen rates on yield contributing characters at BRRI farm, Gazipur

Treatment		Days after transplanting		
		Panicle m^{-2}	Grains $panicle^{-1}$	1000-grain weight (g)
BR26	N_0	232.00	66.67	20.33
	N_{40}	243.67	80.00	20.38
	N_{60}	251.67	89.67	20.53
	N_{80}	265.00	95.67	20.81
	N_{100}	256.67	90.00	20.70
BRRI dhan48	N_0	234.33	82.67	21.23
	N_{40}	242.67	88.33	22.08
	N_{60}	260.00	102.33	22.55
	N_{80}	269.67	106.00	22.69
	N_{100}	262.33	102.33	22.66
BRRI dhan82	N_0	239.00	77.33	21.86
	N_{40}	217.00	97.67	21.98
	N_{60}	249.00	94.00	22.77
	N_{80}	250.00	98.00	22.85
	N_{100}	201.67	83.00	22.60
LSD $_{(0.05)}$ for variety (V) × N rate (N)		ns	ns	ns
CV (%)		8.2	11.5	3.4

Note: ns= Non significant; N_0= 0 (Control), N_1= 40 kg ha^{-1}, N_2 60 kg ha^{-1}, N_3= 80 kg ha^{-1}, N_4= 100 kg ha^{-1}

4.2.2 Number of grains $panicle^{-1}$

4.2.2.1 Effect of variety

The number of grains $panicle^{-1}$ was significantly influenced by different varieties used in the present study (Table 11). The highest number of grains $panicle^{-1}$ was recorded by BRRI dhan48 (96.33). The results obtained from BR26 showed the lowest number of panicle m^{-2} (84.40). Differences in number of grains $panicle^{-1}$, due to varieties were reported by BRRI (1994). Similar findings was also reported by Chamely *et al.* (2015), Ali *et al.* (2017) and Murshida *et al.* (2017).

4.2.2.2 Effect of nitrogen fertilizer

The filled grains panicle^{-1} was significantly influenced by N rates. The increase in the number of filled grain with the increase in N rates indicates that N fertilization is important for both sources and sinks development (Jahan *et al.*, 2020). Different levels of nitrogen showed statistically significant variations in terms of number of grains panicle^{-1} of *aus* rice at days after transplanting (Table 11). The highest number of grains panicle^{-1} (99.89) was recorded by N_{80} (80 kg ha^{-1}). The results obtained from N_0 (0 kg ha^{-1}) showed the lowest number of grains panicle^{-1} (75.56). Yesuf and Balcha (2014), Chamely *et al.* (2015) and Zhang *et al.* (2020) reported that nitrogen fertilizer significantly affected the grain length and width of head rice.

4.2.2.3 Interaction effect of variety and different nitrogen rates

Interaction effect of variety and different nitrogen rates application had no significant influence on the number of grains panicle^{-1} at different growth stages of the three varieties of *aus* rice (Table 12). However, the highest number of grains panicle^{-1} (106.00) was observed from BRRI dhan48 × N_{80} (80 kg ha^{-1}) and the lowest number of grains panicle^{-1} (66.67) was found from the combination of BR26 × N_0 (0 kg ha^{-1}). A similar finding was also reported by Chamely *et al.* (2015).

4.2.3 Weight of 1000-grain

4.2.3.1 Effect of variety

The weight of 1000-grain was significantly influenced by different varieties used in the present study (Table 11). The highest weight of 1000-grain was recorded from BRRI dhan48 (22.24 g). The results obtained from BR26 showed the lowest weight of 1000-grain (20.55 g). Weight of the grain in a variety is controlled by its genetic character (Zhang *et al.*, 2020). Hence 1000-grain weight was varied differently in different varieties. A similar finding was also reported by (Murshida *et al.*, 2017).

4.2.3.2 Effect of nitrogen fertilizer

Different levels of nitrogen showed statistically significant variations in terms of weight of 1000-grain of *aus* rice at days after transplanting (Table 11). The highest weight of 1000-grain (22.11 g) was recorded by N_{80} (80 kg ha^{-1}). The results obtained from N_0 (0 kg ha^{-1}) showed the lowest weight of 1000-grains (21.14 g). Kirrilov *et al.* (1989), Kausar *et al.* (1993), and Chaturvedi (2005) reported that the application of nitrogen increased the protein percentage, which in turn increased the 1000-grain weight.

4.2.3.3 Interaction effect of variety and different nitrogen rates

Thousand grains weight, an important yield-determining component, is a genetic character and least influenced by environment (Saha *et al*., 2017). Interaction effect of variety and different nitrogen rates application had no significant influence on the weight of 1000-grain at different growth stages of the three varieties of *aus* rice (Table 12). A similar non-significant interaction also reported by Chamely *et al.* (2015). However, numerically the highest weight of 1000-grain (22.85 g) was observed from BRRI dhan82 × N_{80} (80 kg ha^{-1}) and the lowest weight of 1000-grain (20.33 g) was found from the combination of BR26 × N_0 (0 kg ha^{-1}).

4.3 Yield

4.3.1 Grain yield

4.3.1.1 Effect of variety

Grain yield was significantly influenced by different varieties used in the present study (Table 13). The highest grain yield was recorded by BRRI dhan48 (4.47 t ha^{-1}).

The results obtained from BR26 showed the lowest grain yield (3.74 t ha^{-1}). The significant variation in grain yield among the varieties was also reported by Azam *et al.* (2012), Murshida *et al.* (2017), and Ndebeh *et al.* (2018).

Table 13. Grain yield, straw yield, biological yield and harvest index of BR26, BRRI dhan48, and BRRI dhan82 as affected by nitrogen rates at BRRI farm, Gazipur

Treatment	Days after transplanting			
	Grain yield (t ha^{-1})	**Straw yield (t ha^{-1})**	**Biological yield (t ha^{-1})**	**Harvest index**
Variety				
BR26	3.74	4.76	8.50	0.44
BRRI dhan48	4.47	5.47	9.93	0.45
BRRI dhan82	3.85	4.99	8.84	0.43
LSD $_{(0.05)}$ for variety (V)	0.49	0.52	0.99	0.11
Nitrogen rate				
N_0	2.88	3.99	6.87	0.42
N_1	3.66	4.80	8.47	0.43
N_2	4.58	5.58	10.16	0.45
N_3	4.87	5.74	10.61	0.46
N_4	4.10	5.25	9.36	0.44
LSD $_{(0.05)}$ for N rate (N)	0.64	0.67	1.29	0.15
CV (%)	16.4	13.6	14.6	3.5

Note: ns= Non significant; N_0= 0 (Control), N_1= 40 kg ha^{-1}, N_2 60 kg ha^{-1}, N_3= 80 kg ha^{-1}, N_4= 100 kg ha^{-1}

4.3.1.2 Effect of nitrogen fertilizer

Different levels of nitrogen showed statistically significant variations in terms of grain yield of *aus* rice (Table 13). The highest grain yield (4.87 t ha^{-1}) was recorded by N_{80} (80 kg ha^{-1}). The results obtained from N_0 (0 kg ha^{-1}) showed the lowest grain yield (2.88 t ha^{-1}). Tayefe *et al.* (2014), Moro *et al.* (2015), Pan *et al.* (2017), Rea *et al.* (2019), Chen *et al.* (2020a), and Zhang *et al.* (2020) reported that the application of nitrogen increased the grain yield thus resulting in higher yields.

4.3.1.3 Interaction effect of variety and different nitrogen rates

Grain yield is a function of the interplay of various yield components such as the number of productive tillers, panicle length, percentage of grain filling and 1000-grains weight (Hossain *et al.,* 2002; Li *et al.,* 2019b), and it was found that this main yield component is greatly affected by both variety and nutrient management (Garcia *et al.*, 2015). Grain yield varied significantly from variety to variety. Interaction effect of variety and different nitrogen rates application had no significant influence on grain yield of the three varieties of *aus* rice (Table 14). Numerically the highest grain yield (5.57 t ha^{-1}) was observed from BRRI dhan82 × N_{80} (80 kg N ha^{-1}) and the lowest grain yield (2.63 t ha^{-1}) was found from the combination of BR26 × N_0 (0 kg N ha^{-1}). A similar research findings was also reported by Tang *et al.* (2014), Chamely *et al.* (2015), Chen *et al.* (2020b), and Liu *et al.* (2020), .

Table 14. Interaction effect of variety (BR26, BRRI dhan48, and BRRI dhan82) and nitrogen rates on grain yield, straw yield, biological yield and harvest index at BRRI farm, Gazipur

Treatment		Days after transplanting			
		Grain yield (t ha^{-1})	Straw yield (t ha^{-1})	Biological yield (t ha^{-1})	Harvest index
BR26	N_0	2.63	3.55	6.18	0.43
	N_{40}	3.26	4.39	7.65	0.43
	N_{60}	4.22	5.21	9.43	0.45
	N_{80}	4.51	5.39	9.90	0.46
	N_{100}	4.09	5.26	9.36	0.44
BRRI dhan48	N_0	2.92	4.08	6.99	0.42
	N_{40}	3.69	4.76	8.45	0.44
	N_{60}	5.26	6.06	11.32	0.46
	N_{80}	5.57	6.39	11.97	0.47
	N_{100}	4.88	6.04	10.93	0.45
BRRI dhan82	N_0	3.09	4.36	7.45	0.42
	N_{40}	4.04	5.26	9.30	0.43
	N_{60}	4.26	5.46	9.72	0.44
	N_{80}	4.52	5.44	9.96	0.46
	N_{100}	3.33	4.46	7.79	0.43
LSD $_{(0.05)}$ for variety (V) × N rate (N)		ns	ns	ns	ns
CV (%)		16.4	13.6	14.6	3.5

Note: ns= Non significant; N_0= 0 (Control), N_1= 40 kg ha^{-1}, N_2 60 kg ha^{-1}, N_3= 80 kg ha^{-1}, N_4= 100 kg ha^{-1}

4.3.2 Nitrogen concentration (N %)

4.3.2.1 Effect of variety

Nitrogen concentration in grain was significantly influenced by different varieties used in the present study (Table 15). The highest nitrogen concentration (N %) of grain was recorded by BRRI dhan48 (0.93). The results obtained from BR26 showed the lowest nitrogen concentration (N %) in grain (0.82).

4.3.2.2 Effect of nitrogen fertilizer

Different levels of nitrogen showed statistically significant variations in terms of nitrogen concentration (N %) of grain of *aus* rice (Table 15). The highest nitrogen concentration (N %) of grain (1.08) was recorded by N_{100} (100 kg ha^{-1}) which was closely followed (1.07) by N_{80} (80 kg N ha^{-1}). The results obtained from N_0 (0 kg ha^{-1}) showed the lowest nitrogen concentration (N %) of grain (0.52).

4.3.2.3 Interaction effect of variety and different nitrogen rates

Interaction effect of variety and different nitrogen rates application had no significant influence on grain of the three varieties of *aus* rice (Table 16). The highest nitrogen concentration (N %) of grain (1.12) was observed from BRRI dhan48 × N_{100} (100 kg ha^{-1}) and BRRI dhan82 × N_{80} (80 kg ha^{-1}) and the lowest nitrogen concentration (N %) of grain (0.47) was found from the combination of BRRI dhan82 × N_0 (0 kg ha^{-1}).

4.3.3 Nitrogen uptake of grain

4.3.3.1 Effect of variety

Nitrogen uptake of grain was significantly influenced by different varieties used in the present study (Table 15). The highest nitrogen uptake of grain was recorded by BRRI dhan48 (43.31 kg N ha^{-1}). The results obtained from BR26 showed the lowest nitrogen uptake of grain (31.93 kg ha^{-1}).

4.3.3.2 Effect of nitrogen fertilizer

Different levels of nitrogen showed statistically significant variations in terms of nitrogen uptake by grain of *aus* rice (Table 15). The highest nitrogen uptake of grain (52.36 kg ha^{-1}) was recorded by N_{80} (80 kg ha^{-1}). The results obtained from N_0 (0 kg ha^{-1}) showed the lowest nitrogen uptake of grain (14.96 kg ha^{-1}).

4.3.3.3 Interaction effect of variety and different nitrogen rates

Interaction effect of variety and different nitrogen application had no significant influence on nitrogen uptake of grain of the three varieties of *aus* rice (Table 16). The highest nitrogen uptake of grain (61.48 kg ha^{-1}) was observed from BRRI dhan48 × N_{80} (80 kg ha^{-1}) and the lowest nitrogen uptake of grain (12.51 kg ha^{-1}) was found from the combination of BR26 × N_0 (0 kg ha^{-1}).

4.3.4 Straw yield

4.3.4.1 Effect of variety

Straw yield was significantly influenced by different varieties used in the present study (Table 13). The highest straw yield was recorded by BRRI dhan48 (5.47 t ha^{-1}). The results obtained from BR26 showed the lowest straw yield (4.76 t ha^{-1}). A similar findings was also reported by Paul *et al.* (2014) and Murshida *et al.* (2017).

4.3.4.2 Effect of nitrogen fertilizer

Different levels of nitrogen showed statistically significant variations in terms of straw yield of *aus* rice (Table 13). The highest straw yield (5.74 t ha^{-1}) was recorded by N_{80} (80 kg ha^{-1}). The results obtained from N_0 (0 kg ha-^{1}) showed the lowest straw yield (3.99 t ha^{-1}). Jahan *et al.* (2020) stated that nitrogen fertilization improve rice vegetative growth in terms of plant height and tiller number leading to increase straw yield. Chaturvedi (2005) reported that the application of nitrogen increased the grain yield thus resulting in higher yields. With the increase in the grain yield, the straw yield has increased.

4.3.4.3 Interaction effect of variety and different nitrogen rates

Interaction effect of variety and different nitrogen application rates had no significant influence on straw yield of the three varieties of *aus* rice (Table 14). The highest straw yield (6.39 t ha^{-1}) was observed from BRRI dhan82 × N_{80} (80 kg ha^{-1}) and the lowest straw yield (3.55 t ha^{-1}) was found from the combination of BR26 × N_0 (0 kg N ha^{-1}). As plant height, number of tillers, and biomass production increased, straw yield increased.

4.3.5 Nitrogen concentration (N %)

4.3.5.1 Effect of variety

Nitrogen concentration of straw was significantly influenced by different varieties used in the present study (Table 15). The highest nitrogen concentration of straw was recorded by BR26 (0.41). The results obtained from BRRI dhan82 showed the lowest nitrogen concentration of straw (0.33).

Table 15. Nitrogen concentration (N %) and nitrogen uptake (kg N ha^{-1}) of BR26, BRRI dhan48, and BRRI dhan82 as affected by nitrogen rates at BRRI farm, Gazipur

Treatment	Days after transplanting						
	N (%) in grain	**N (%) in straw**	**N (%) in grain + straw**	**N uptake grain (kg ha^{-1})**	**N uptake in straw (kg ha^{-1})**	**N uptake (grain+ straw) (kg ha^{-1})**	**Nitrogen harvest index (%)**
Variety							
BR26	0.82	0.41	1.22	31.93	19.91	51.84	60.41
BRRI dhan48	0.93	0.34	1.27	43.31	19.03	62.34	68.15
BRRI dhan82	0.89	0.33	1.21	35.04	16.38	51.42	66.68
LSD $_{(0.05)}$ for variety (V)	0.58	0.22	ns	5.13	2.43	7.11	2.36
Nitrogen rate							
N_0	0.52	0.26	0.78	14.96	10.13	25.09	59.43
N_1	0.72	0.33	1.06	26.49	16.03	42.52	62.17
N_2	0.99	0.37	1.36	45.37	20.47	65.83	68.52
N_3	1.07	0.41	1.48	52.36	23.24	75.60	69.12
N_4	1.08	0.43	1.51	44.61	22.35	66.95	66.15
LSD $_{(0.05)}$ for N rate (N)	0.75	0.28	0.74	6.63	3.14	9.18	3.05
CV (%)	8.9	8.1	6.2	18.7	17.6	17.2	4.8

Note: ns= Non significant; N_0= 0 (Control), N_1= 40 kg ha^{-1}, N_2 60 kg ha^{-1}, N_3= 80 kg ha^{-1}, N_4= 100 kg ha^{-1}

4.3.5.2 Effect of nitrogen fertilizer

Different levels of nitrogen showed statistically significant variations in terms of nitrogen concentration of straw of *aus* rice (Table 15). The highest nitrogen concentration of straw (0.43) was recorded by N_{100} (100 kg ha^{-1}). The results obtained from N_0 (0 kg ha^{-1}) showed the lowest nitrogen concentration of straw (0.26).

4.3.5.3 Interaction effect of variety and different nitrogen rates

Interaction effect of variety and different nitrogen application had no significant influence on nitrogen concentration of straw of the three varieties of *aus* rice (Table 16). The highest nitrogen concentration of straw (0.48) was observed from BR26 × N_{80} (80 kg ha^{-1}) and the lowest nitrogen concentration of straw (0.22) was found from the combination of BRRI dhan82 × N_0 (0 kg ha^{-1}).

4.3.6 Nitrogen uptake (NUP) of straw

4.3.6.1 Effect of variety

Nitrogen uptake of straw was significantly influenced by different varieties used in the present study (Table 15). The highest nitrogen uptake of straw was recorded by BR26 (19.91 kg ha^{-1}). The results obtained from BRRI dhan82 showed the lowest nitrogen uptake of straw (16.38 kg ha^{-1}).

4.3.6.2 Effect of nitrogen fertilizer

Different levels of nitrogen showed statistically significant variations in terms of nitrogen uptake of straw of *aus* rice at days after transplanting (Table 15). The highest nitrogen uptake of straw (23.24 kg ha^{-1}) was recorded by N_{80} (80 kg ha^{-1}). The results obtained from N_0 (0 kg ha^{-1}) showed the lowest nitrogen uptake of straw (10.23 kg ha^{-1}).

Table 16. Interaction effect of variety (BR26, BRRI dhan48, and BRRI dhan82) and nitrogen rates on yield components of nitrogen concentration (N %) and nitrogen (N) uptake (kg ha^{-1}) in grain and straw at BRRI farm, Gazipur

Treatment		Days after transplanting						
		N(%) in grain	N(%) in straw	N(%) in grain + straw	N uptake grain (kg ha^{-1})	N uptake in straw (kg ha^{-1})	N uptake (grain+ straw) (kg ha^{-1})	Nitrogen harvest index (%)
BR26	N_0	0.48	0.29	0.76	12.51	10.10	22.61	55.38
	N_{40}	0.68	0.38	1.06	22.24	16.82	39.06	57.20
	N_{60}	0.89	0.42	1.31	37.58	21.86	59.44	63.01
	N_{80}	1.01	0.48	1.49	45.27	26.01	71.28	63.70
	N_{100}	1.02	0.47	1.49	42.03	24.77	66.80	62.75
BRRI dhan48	N_0	0.61	0.26	0.87	17.89	10.69	28.58	62.84
	N_{40}	0.79	0.34	1.13	29.29	16.23	45.52	64.19
	N_{60}	1.01	0.34	1.36	53.39	20.82	74.21	71.89
	N_{80}	1.10	0.37	1.47	61.48	23.46	84.94	72.37
	N_{100}	1.12	0.39	1.52	54.49	23.96	78.46	69.44
BRRI dhan82	N_0	0.47	0.22	0.69	14.48	9.60	24.08	60.06
	N_{40}	0.70	0.28	0.98	27.94	15.04	42.98	65.12
	N_{60}	1.06	0.34	1.40	45.14	18.72	63.85	70.67
	N_{80}	1.12	0.37	1.48	50.34	20.25	70.59	71.29
	N_{100}	1.10	0.41	1.51	37.29	18.31	55.59	66.24
LSD $_{(0.05)}$ for Variety (V) × N rate (N)		ns	ns	ns	ns	ns	ns	ns
CV (%)		8.9	8.1	6.2	18.7	17.6	17.2	4.8

Note: ns= Non significant; N_0= 0 (Control), N_1= 40 kg ha^{-1}, N_2 60 kg ha^{-1}, N_3= 80 kg ha^{-1}, N_4= 100 kg ha^{-1}

4.3.6.3 Interaction effect of variety and different nitrogen rates

Interaction effect of variety and different nitrogen application had no significant influence on nitrogen uptake of straw of the three varieties of *aus* rice (Table 16). The highest nitrogen uptake of straw (26.01 kg ha^{-1}) was observed from BR26 × N_{80} (80 kg ha^{-1}) and the lowest nitrogen uptake of straw (9.60 kg ha^{-1}) was found from the combination of BRRI dhan82 × N_0 (0 kg ha^{-1}).

4.3.7 Biological yield

4.3.7.1 Effect of variety

Biological yield was significantly influenced by different varieties used in the present study (Table 13). The highest biological yield was recorded by BRRI dhan48 (9.93 t ha^{-1}). The results obtained from BR26 showed the lowest biological yield (8.50 t ha^{-1}).

4.3.7.2 Effect of nitrogen fertilizer

Different levels of nitrogen showed statistically significant variations in terms of biological yield of a*us* rice (Table 13). The highest biological yield (10.61 t ha^{-1}) was recorded by N_{80} (80 kg ha^{-1}). The results obtained from N_0 (0 kg ha^{-1}) showed the lowest biological yield (6.87 t ha^{-1}).

4.3.7.3 Interaction effect of variety and different nitrogen rates

Interaction effect of variety and different nitrogen rates application had no significant influence on biological yield of the three varieties of *aus* rice (Table 14). The highest biological yield (11.97 t ha^{-1}) was observed from BRRI dhan82 × N_{80} (80 kg ha^{-1}) and the lowest biological yield (6.18 t ha^{-1}) was found from the combination of BR26 × N_0 (0 kg ha^{-1}).

4.3.8 Nitrogen concentration (%)

4.3.8.1 Effect of variety

Nitrogen concentration of grain + straw was significantly influenced by different varieties used in the present study (Table 15). The highest nitrogen concentration of grain +straw was recorded by BRRI dhan48 (1.27). The results obtained from BRRI dhan82 showed the lowest nitrogen concentration (1.21).

4.3.8.2 Effect of nitrogen fertilizer

Different levels of nitrogen showed statistically significant variations in terms of nitrogen concentration of grain + straw of *aus* rice (Table 15). The highest nitrogen concentration of grain + straw (1.51) was recorded by N_{100} (100 kg ha^{-1}). The results obtained from N_0 (0 kg ha^{-1}) showed the lowest nitrogen concentration (0.78).

4.3.8.3 Interaction effect of variety and different nitrogen rates

Interaction effect of variety and different nitrogen application rates had no significant influence on nitrogen concentration of grain +straw at of the three varieties of *aus* rice (Table 16). The highest nitrogen concentration of grain + straw (1.52) was observed from BRRI dhan48 × N_{100} (80 kg ha^{-1}) and the lowest nitrogen concentration of grain + straw (0.76) was found from the combination of BR26 × N_0 (0 kg ha^{-1}).

4.3.9 Nitrogen uptake

4.3.9.1 Effect of variety

Grain yield was significantly influenced by different varieties used in the present study (Table 15). The highest nitrogen uptake of grain +straw was recorded by BRRI dhan48 (62.34 kg ha^{-1}). The results obtained from BRRI dhan82 showed the lowest nitrogen uptake of biological yield (51.42 kg ha^{-1}).

4.3.9.2 Effect of nitrogen fertilizer

Different levels of nitrogen showed statistically significant variations in terms of nitrogen uptake of grain + straw of *aus* rice (Table 15). The highest nitrogen uptake of grain +straw (75.60 kg ha^{-1}) was recorded by N_{80} (80 kg ha^{-1}). The results obtained from N_0 (0 kg ha^{-1}) showed the lowest nitrogen uptake (25.09 kg ha^{-1}).

4.3.9.3 Interaction effect of variety and different nitrogen rates

Interaction effect of variety and different nitrogen rates application had significant influence on nitrogen uptake of biological yield at different growth stages of the three varieties of *aus* rice (Table 16). The highest nitrogen uptake of biological yield (84.94 kg ha^{-1}) was observed from BRRI dhan48 × N_{80} (80 kg ha^{-1}) and the lowest nitrogen uptake of biological yield (22.61 kg ha^{-1}) was found from the combination of BR26 × N_0 (0 kg ha^{-1}).

4.4 Harvest index

4.4.1 Effect of variety

Harvest index was significantly influenced by different varieties used in the present study (Table 13). The highest harvest index was recorded by BRRI dhan48 (0.45). The results obtained from BRRI dhan82 showed the lowest harvest index (0.43).

4.4.2 Effect of nitrogen fertilizer

Different levels of nitrogen showed statistically significant variations in terms of harvest index of *aus* rice at days after transplanting (Table 13). The highest harvest index (0.46) was recorded by N_{80} (80 kg ha^{-1}). The results obtained from N_0 (0 kg ha^{-1}) showed the lowest harvest index (0.42). Murshida *et al.* (2017) reported that the application of nitrogen increased the grain yield thus resulting in higher yields. With the increase in the grain yield, the harvest index has increased.

4.4.3 Interaction effect of variety and different nitrogen rates

Interaction effect of variety and different nitrogen application had no significant influence on harvest index at of the three varieties of *aus* rice (Table 14). The highest harvest index (0.47) was observed from BRRI dhan82 × N_{80} (80 kg ha^{-1}) the lowest harvest index (0.42) was found from the combination of BRRI dhan48 and BRRI dhan82 × N_0 (0 kg ha^{-1}). Similar research findings was also reported by Tang *et al.* (2014), Chamely *et al.* (2015), Chen *et al.* (2020a) and Liu *et al.* (2020).

4.4.4 Nitrogen harvest index

Nitrogen harvest index explained by N accumulation in grains /N accumulation in grains plus dry matter/ straw).

4.4.4.1 Effect of variety

Nitrogen harvest index was significantly influenced by different varieties used in the present study (Table 15). The highest nitrogen harvest index was recorded by BRRI dhan48 (68.15%). The results obtained from BR26 showed the lowest nitrogen harvest index (60.41%).

4.4.4.2 Effect of nitrogen fertilizer

Different levels of nitrogen showed statistically significant variations in terms of nitrogen harvest index of *aus* rice (Table 15). The highest nitrogen harvest index (69.12) was recorded by N_{80} (80 kg ha^{-1}). The results obtained from N_0 (0 kg ha^{-1}) showed the lowest nitrogen harvest index (59.43).

4.4.4.3 Interaction effect of variety and different nitrogen rates

Interaction effect of variety and different nitrogen rates had no significant influence on nitrogen harvest index of the three varieties of *aus* rice (Table 16). The highest nitrogen harvest index (72.37%) was observed from BRRI dhan48 × N_{80} (80 kg ha^{-1}) and the lowest nitrogen harvest index (55.38%) was found from the combination of BR26 × N_0 (0 kg ha^{-1}).

4.5 Relationship of grain yield and leaf area index (LAI) and total dry matter production

Grain yield increased with increasing leaf area index of individual leaves within rice canopy until an optimal value of leaf area index (Ying *et al.*, 1998; Sinclair and Sheehy, 1999; Mae *et al.*, 2006). Regression analysis was found to quantify the relationship between leaf area index at 75 DAT and grain yield. Grain yield and leaf area index have a significant effect on rice production. In these graphs observed that grain yield also changes with the change in leaf area index. Grain yield (4.51 t ha^{-1}) of BR26 at the rate of N_{80} (80 kg ha^{-1}) and leaf area index (3.05) were significantly and linearly related (R^2 = 0.8748^*) [Fig. 12(A)], indicating that the highest grain yield would be due to the highest leaf area index and the lowest grain yield (2.63 t ha^{-1}) was found by lower leaf area index (3.01) BR26 at the rate of N_0 (0 kg ha^{-1}). In these graphs, grain yield (5.57 t ha^{-1}) of BRRI dhan48 at the rate of N_{80} (80 kg ha^{-1}) and leaf area index (3.09) were significantly and linearly related (R^2 = 0.8075^*) [Fig. 12(B)], indicating that the highest grain yield would be due to the highest leaf area index and the lowest grain yield (2.92 t ha^{-1}) was found by leaf area index (3.02) BRRI dhan48 at the rate of N_0 (0 kg ha^{-1}) also grain yield (4.52 t ha^{-1}) of BRRI dhan82 at the rate of N_{80} (80 kg ha^{-1}) and leaf area index (3.06) were significantly and linearly related (R^2 = 0.3079^{ns}) [Fig. 12(C)], indicating that the highest grain yield would be due to the highest leaf area index and the lowest grain yield (3.09 t ha^{-1}) was found by the lowest leaf area index (3.02) BRRI dhan82 at the rate of N_0 (0 kg ha^{-1}). Grain yield (4.51 t ha^{-1}) of BR26 at the rate of N_{80} (80 kg ha^{-1}) and total dry matter production (9.90 t ha^{-1}) were significantly and linearly related (R^2 = 0.9929^{**}) [Fig. 12(D)], indicating that the highest grain yield would be due to the highest total dry matter production and the lowest grain yield (2.63 t ha^{-1}) was found by lower total dry matter production (6.18 t ha^{-1}) BR26 at the rate of N_0 (0 kg ha^{-1}). In these graphs, grain yield (5.57 t ha^{-1}) of BRRI dhan48 at the rate of N_{80} (80 kg ha^{-1}) and dry matter production (11.97 t ha^{-1}) were significantly and linearly related (R^2 = 0.9965^{**}) [Fig. 12(E)], indicating that the highest grain yield would be due to the highest dry matter production and the lowest grain yield (2.92 t ha^{-1}) was found by dry matter production (6.99 t ha^{-1}) BRRI dhan48 at the rate of N_0 (0 kg ha^{-1}) also grain yield (4.52 t ha^{-1}) of

BRRI dhan82 at the rate of N_{80} (80 kg ha^{-1}) and dry matter production (9.96 t ha^{-1}) were significantly and linearly related ($R^2 = 0.9909^{**}$) [Fig. 12(F)], indicating that the highest grain yield would be due to the highest dry matter production and the lowest grain yield (3.09 t ha^{-1}) was found by the lowest dry matter production (7.45 t ha^{-1}) BRRI dhan82 at the rate of N_0 (0 kg ha^{-1}).

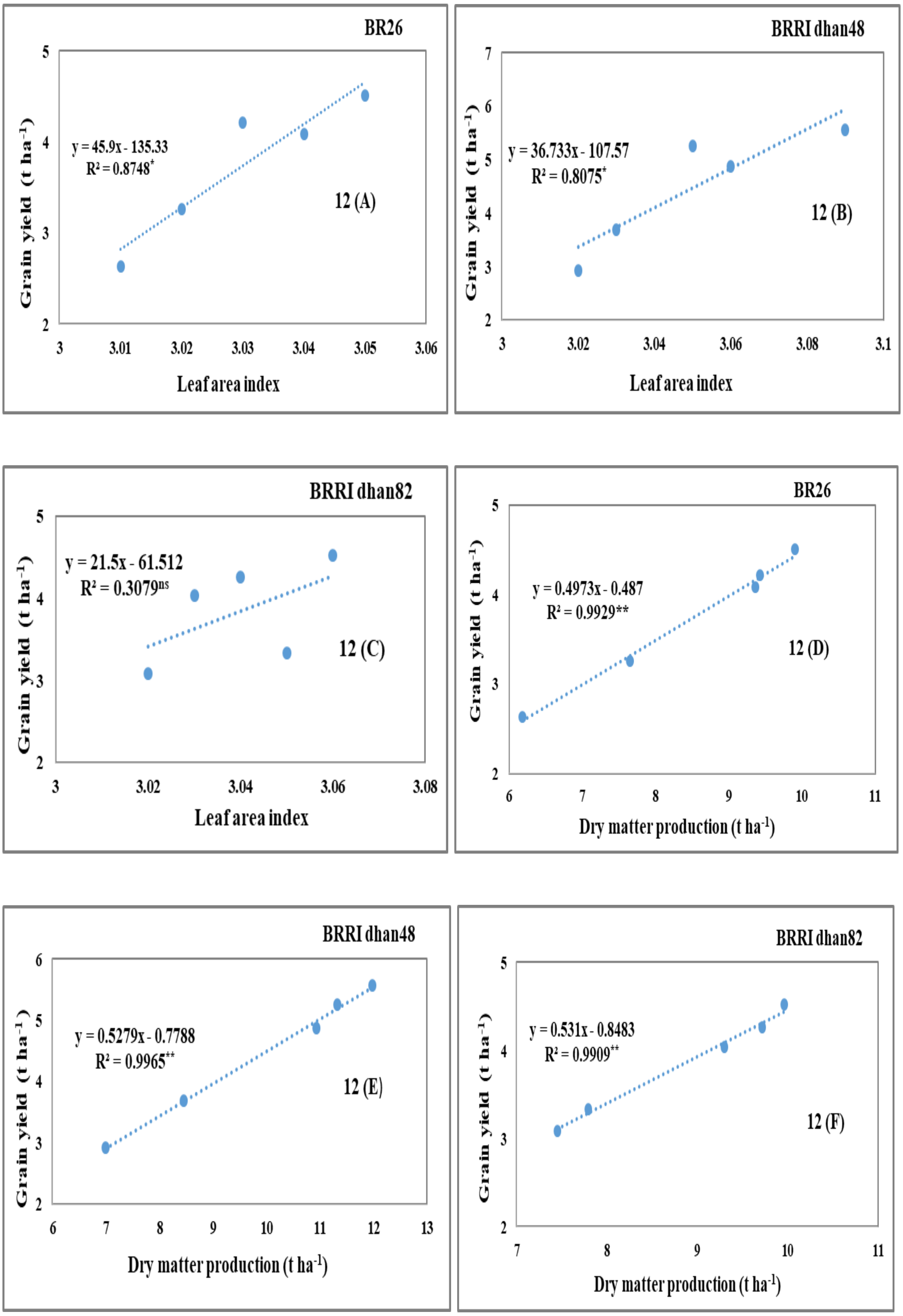

Figure 12. Dependent of grain yield on leaf area index (LAI) and total dry matter production of different varieties during *aus* 2019 at BRRI, Gazipur
(*=significant at 5% level, **= significant at 1% level, ns=not significant)

4.6 Relationship between grain yield and grain N uptake and grain yield with total N uptake

Grain yield of varieties and N uptake in grain and total N uptake were significantly and linearly related (R^2 = 0.8863** and 0.8619**) (Fig. 13 "A, B"), indicating that higher grain yield would be due to higher N uptake.

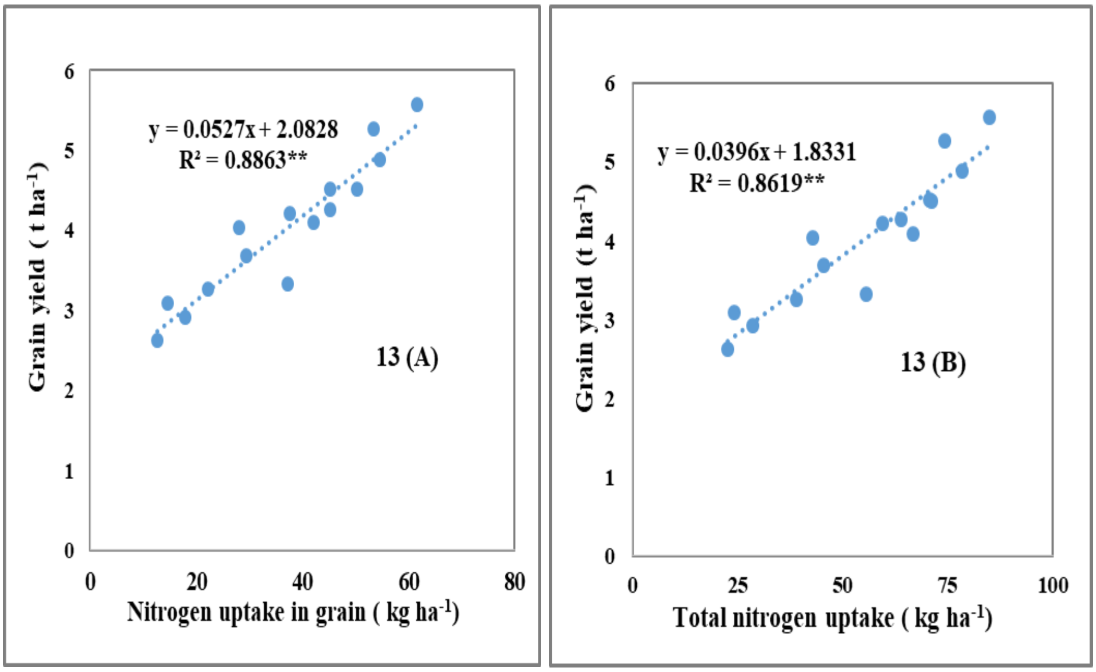

Figure 13. Relationship between grain yield and grain N uptake and grain yield with total N uptake (*=significant at 5% level, **= significant at 1% level, ns=not significant)

4.7 Correlation of grain yield with panicle m^{-2}, grains panicle^{-1}, 1000-grain weight (g)

The correlation analysis between grain yields with panicle m^{-2} were statistically significant by different varieties used in the present study. In this graphs observed that grain yield also changes with the change in panicle m^{-2}. For BR26, the highest grain yield (4.51 t ha^{-1}) and panicle m^{-2} (265.00) were significantly and linearly related (R^2 = 0.928**) [Fig. 14 (A)] was found by N_{80} (80 kg ha^{-1}) and lowest grain yield (2.63 t ha^{-1}) was found by panicle m^{-2} (232.00) from N_0 (0 t ha^{-1}). For BRRI dhan48, the highest grain yield (5.57 t ha^{-1}) and panicle m^{-2} (269.67) were significantly and linearly related (R^2 = 0.9646**) [Fig. 14 (D)] was found by N_{80} (80 kg ha^{-1}) and lowest grain yield (2.92 t ha^{-1}) was found by panicle m^{-2} (234.33) from N_0 (0 t ha^{-1}). For BRRI dhan82, the highest grain yield (4.52 t ha^{-1}) and panicle m^{-2} (250.00) were significantly and linearly related (R^2 = 0.2617^{ns}) [Fig. 14 (G)] was found by N_{80} (80 kg ha^{-1}) and lowest grain yield (3.90 t ha^{-1}) was found by panicle m^{-2} (239.00) from N_0 (0 t ha^{-1}). Grain yield (4.51 t ha^{-1}) of BR26 at the rate of N_{80} (80 kg ha^{-1}) and grains panicle^{-1} (95.67) were significantly and linearly related (R^2 = 0.9762**) [Fig. 14 (B)], indicating that the highest grain yield would be due to the highest grains panicle^{-1} and the lowest grain yield (2.63 t ha^{-1}) was found by lower grains panicle^{-1} (66.67) BR26 at the rate of N_0 (0 kg ha^{-1}). In these graphs, grain yield (5.57 t ha^{-1}) of BRRI dhan48 at the rate of N_{80} (80 kg ha^{-1}) and grains panicle^{-1} (106.00) were significantly and linearly related (R^2 = 0.9814**) [Fig. 14 (E)], indicating that the highest grain yield would be due to the highest grains panicle^{-1} and the lowest grain yield (2.92 t ha^{-1}) was found by grains panicle^{-1} (82.67) BRRI dhan48 at the rate of N_0 (0 kg ha^{-1}) also grain yield (4.52 t ha^{-1}) of BRRI dhan82 at the rate of N_{80} (80 kg ha^{-1}) and grains panicle^{-1} (98.00) were significantly and linearly related (R^2 = 0.9027**) [Fig. 14 (H)], indicating that the highest grain yield would be due to the highest grains panicle^{-1} and the lowest grain yield (3.09 t ha^{-1}) was found by the lowest grains panicle^{-1} (77.33) BRRI dhan82 at the rate of N_0 (0 kg ha^{-1}). Grain yield (4.51 t ha^{-1}) of BR26 at the rate of N_{80} (80 kg ha^{-1}) and 1000-grain weight (20.81) were significantly and linearly related (R^2 = 0.916^{ns}) [Fig. 14 (C)], indicating that the highest grain yield would be due to the highest 1000-grain weight and the lowest grain yield (2.63 t ha^{-1}) was found by lower 1000-grain weight (20.33) BR26 at the rate of N_0 (0 kg ha^{-1}). In these graphs, grain yield (5.57 t ha^{-1}) of BRRI dhan48 at the rate of N_{80} (80 kg ha^{-1}) and 1000-grain weight (22.69) were significantly and linearly related (R^2 = 0.9387**) [Figure 14 (F)], indicating that the highest grain yield would be due to the highest 1000-grain weight and the lowest grain yield (2.92 t ha^{-1}) was found by 1000-grains weight (21.23) BRRI dhan48 at the rate of N_0 (0 kg ha^{-1}) also grain yield (4.52 t ha^{-1}) of BRRI dhan82 at the rate of N_{80} (80 kg ha^{-1}) and 1000-grain weight (22.85) were significantly and linearly related (R^2 = 0.9027**) [Fig. 14 (I)], indicating that the highest grain yield would be due to the highest 1000-grain weight and the lowest grain yield (3.09 t ha^{-1}) was found by the lowest 1000-grain weight (21.86) BRRI dhan82 at the rate of N_0 (0 kg ha^{-1}).

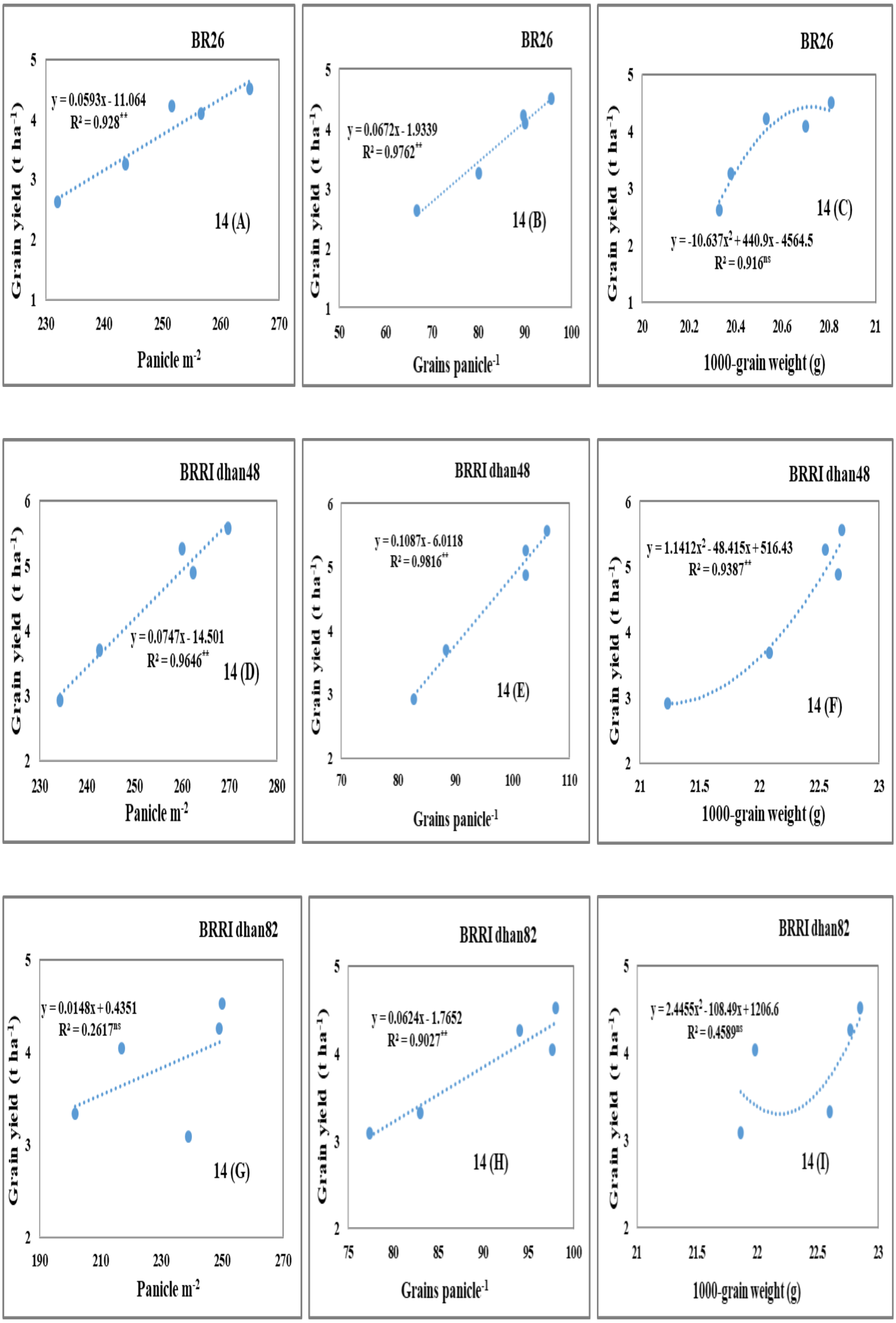

Figure 14. Correlation of grain yield with panicle m^{-2}, grains panicle^{-1}, 1000-grain weight (g) during *aus* 2019 at BRRI, Gazipur (*=significant at 5% level, **= significant at 1% level, ns=not significant)

4.8 Determination of optimum and economic of N doses

The optimum N dose for the tested *aus* rice variety was determined by regression the grain yield with the N rates: $Y = a + bN + cN_2$ Where, Y is rice yield (kg ha^{-1}), N is nitrogen dose (kg ha^{-1}), a is intercept (estimated yield without N application), b and c are coefficients, respectively. Differentiating Y with respect to N of the equation gives the nitrogen dose for the maximum yield. The optimum nitrogen dose for maximum yield calculated by $N= -b/2c$ and the equation of economic N rate is $x= (E_N-b)/2c$. where, $E_N= p_f/p_y$. Here, p_f indicates price of N fertilizer (18 Tk./kg and p_y indicates price of paddy(Tk /kg).The variation of grain yield of BR26, BRRI dhan48 and BRRI dhan82 at different nitrogen rates was determined through regression equation (Fig. 15). Differentiating the quadratic equation of yield response with respect to applied different N doses the optimum N rate appeared as 99, 95 and 57 kg ha^{-1} for BR26, BRRI dhan48 and BRRI dhan82, respectively. Considering economic N rate would be 97, 93 and 55 kg ha^{-1} for BR26, BRRI dhan48 and BRRI dhan82 respectively. Fageria and Santos (2014) also found efficient and moderately efficient rice varieties in N use efficiency, and none of the varieties were grouped as inefficient.

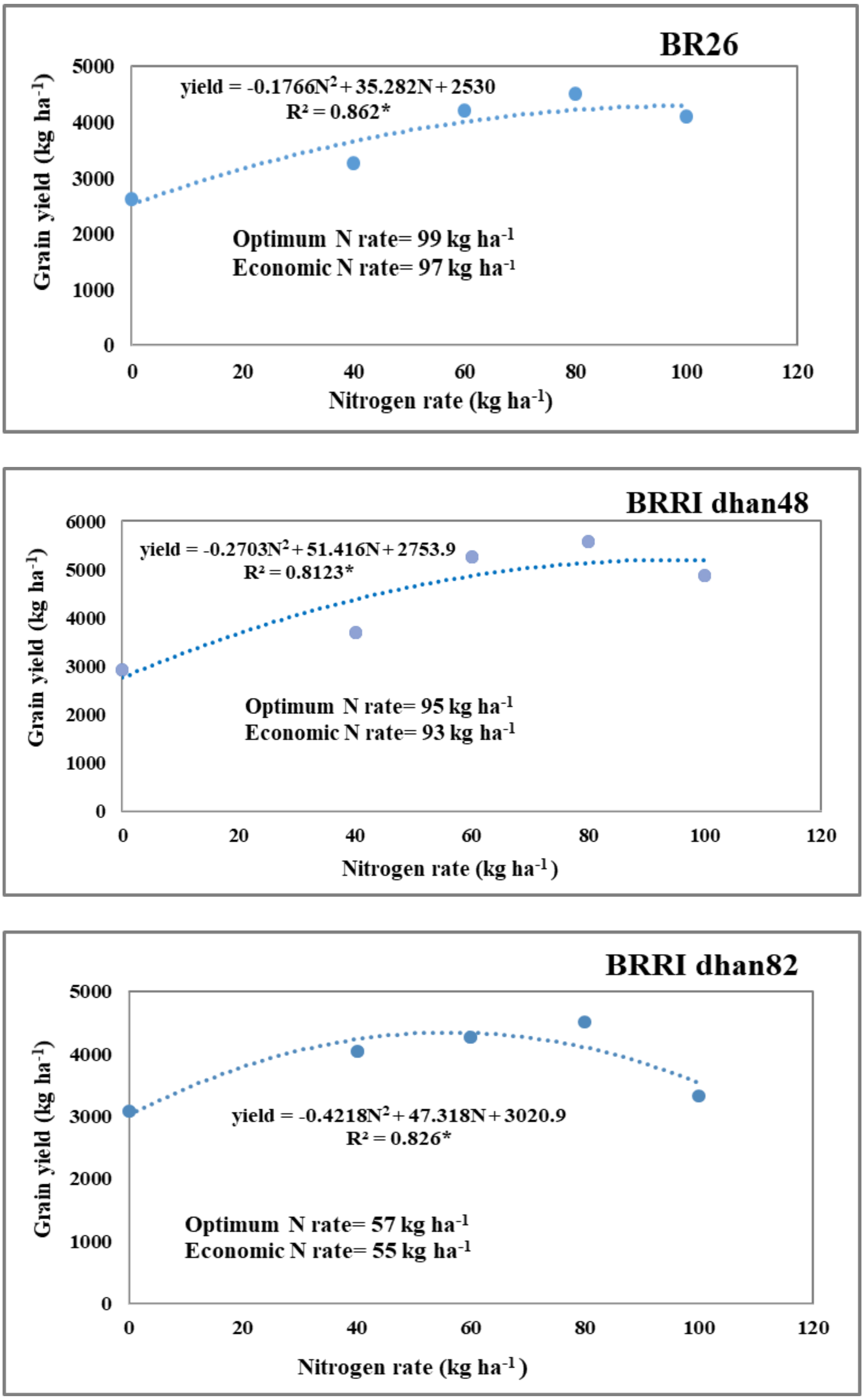

Figure 15. Grain yield responses to N fertilization and determination of optimum and economic N doses in different *aus* varieties during *aus* 2019 at BRRI, Gazipur (*=significant at 5% level)

SUMMARY AND CONCLUSIONS

A field experiment was conducted at the Agronomy field, Bangladesh Rice Research Institute, Gazipur, Dhaka during the period from April to September 2019 to find out growth, yield, and nitrogen uptake of popular *aus* varieties and to determine the optimum and economic nitrogen rate for popular transplanted *aus* varieties. The experiment was carried out in a randomized complete block design (RCBD), where two factors were considered as variety and nitrogen rates. The size of each unit plot was (2.5m × 4.0m = 10m^2). The plots were replicated thrice and thus the total number of plots was 45. BRRI released three *aus* varieties (BR26, BRRI dhan48, and BRRI dhan82) and five N rates (0, 40, 60, 80, and 100 kg ha^{-1}) were selected as treatments.

Data were collected on growth parameters likes plant height (cm), number of tillers hill^{-1}, leaf Area index (LAI), crop growth rate (g/m^2/d), total dry matter production (g m^{-2}), nitrogen concentration (N %), nitrogen uptake (kg ha^{-1}), number of panicle m^{-2}, number of grains panicle^{-1}, 1000-grain weight (g), grain yield (t ha^{-1}), straw yield (t ha^{-1}), biological yield (t ha^{-1}) and harvest index. Relationship of grain yield to leaf area index (LAI) and total dry matter production, the relationship between grain yield and grain N uptake and grain yield with total N uptake, correlation of grain yield with panicle m^{-2}, grains panicle^{-1}, 1000-grain weight (g), determination of optimum and economic of N doses.

Results of the experiment showed that variety had a significant difference for all the characters, likes plant height (cm), number of tillers hill^{-1}, leaf area index (LAI), crop growth rate (g/m^2/d), total dry matter production (g m^{-2}), nitrogen concentration (N %), nitrogen uptake (kg ha^{-1}), number of panicle m^{-2}, number of grains panicle^{-1}, 1000-grain weight (g), grain yield (t ha^{-1}), straw yield (t ha^{-1}), biological yield (t ha^{-1}) and harvest index. BRRI Dhan48 gave the highest plant height (127.93 cm), number of tillers $hill^{-1}$ (22), and leaf area index (3.07). BRRI dhan48 also gave maximum crop growth rate (14.16 $g/m^2/d$), and total dry matter production (804.95 g m^{-2}). Considering N concentration and uptake, BRRI Dhan82 gave maximum nitrogen concentration (1.22) at 45 DAT, and maximum nitrogen uptake (63.58 kg ha^{-1}) at 60 DAT. However, BRRI dhan48 gave the highest number of panicle m^{-2} (253.80), and the number of grains $panicle^{-1}$ (96.33), and produced the highest grain yield (4.47 t ha^{-1}), nitrogen concentration (N %) of grain (0.93), nitrogen uptake in grain (43.31 kg ha^{-1}) and straw yield (5.47 t ha^{-1}). Whereas, BRRI dhan82 gave the maximum 1000-grain weight (22.41 g). BRRI dhan48 gave maximum biological yield (9.93 t ha^{-1}), and maximum harvest index (0.45) and the maximum nitrogen harvest index (68.15%). Another variety BR26 gave the maximum nitrogen concentration (N %) (0.41) and nitrogen uptake (19.91 kg ha^{-1}) in straw yield.

The experiment showed that nitrogen rates had a significant difference for all the characters, likes plant height, number of tillers $hill^{-1}$, leaf area index (LAI), crop growth rate, total dry matter production, nitrogen concentration (N %), nitrogen uptake in grain and straw, number of panicle m^{-2}, number of grains $panicle^{-1}$, 1000-grain weight, grain yield, and straw yield.

Application of N_{80} (80 kg N ha^{-1}) gave the highest plant height (131.17 cm), the number of tillers $hill^{-1}$ (23), and leaf area index (3.09) at 75 DAT. Nitrogen application (80 kg N ha^{-1}) gave the maximum crop growth rate (14.19 $g/m^2/d$) at 45-60 DAT and total dry matter (838.84 g m^{-2}) at 75 DAT. N_{100} (100 kg ha^{-1}) gave the highest nitrogen concentration (1.73) at 45 DAT, and the maximum nitrogen uptake

(82.34 kg ha^{-1}) at 60 DAT. Application of N_{80} (80 kg ha^{-1}) treatment gave the highest number of panicle m^{-2} (261.56), the number of grains $panicle^{-1}$ (99.89), 1000-grain weight (22.11 g), and grain yield (4.87 t ha^{-1}), straw yield (5.74 t ha^{-1}) and the maximum nitrogen uptake in grain (52.36 kg ha^{-1}). In contrast, N_{100} (100 kg ha^{-1}) gave maximum nitrogen concentration in grain (1.08) and straw (0.43). However, N_{80} (80 kg ha^{-1}) gave maximum nitrogen uptake in straw (23.24 kg ha^{-1}).

The experiment showed that the combination between variety and nitrogen rates was no significant difference for most of the characters. Numerically, BRRI dhan48 × N_{80} (80 kg ha^{-1}) gave the highest plant height (131.75 cm), the number of tillers $hill^{-1}$ (24), and leaf area index (3.09) at 75 DAT. This combination also gave the maximum crop growth rate (15.29 g/m^2/d) at 45-60 DAT and the highest total dry matter (870.20 g m^{-2}) at 75 DAT. Another combination BRRI dhan82 × N_{100} (100 kg ha^{-1}) gave the highest nitrogen concentration (1.74) at 45 DAT. However, the combination BRRI dhan48 × N_{100} (100 kg ha^{-1}) gave the maximum nitrogen uptake (84.39 kg ha^{-1}) at 60 DAT. Among the yield contributing parameters, the highest number of panicles m^{-2} (269.67) and the number of grains $panicle^{-1}$ (106.00) resulted from the combination of BRRI dhan48 × N_{80} (80 kg ha^{-1}), whereas the highest 1000-grain weight (22.85 g) from BRRI dhan82 × N_{80} (80 kg ha^{-1}). The highest grain yield (5.57 t ha^{-1}) and also the maximum nitrogen uptake in grain (61.48 kg ha^{-1}), and nitrogen uptake in grain + straw (84.94 kg ha^{-1}) were obtained from the combination of BRRI dhan48 × N_{80} (80 kg ha^{-1}), while BRRI dhan48 × N_{100} (100 kg ha^{-1}) gave the highest N% in grain + straw (1.52). Although the combination BRRI dhan82 × N_{80} (80 kg ha^{-1}) gave the highest harvest index (0.47), the combination of BRRI dhan48 × N_{80} (80 kg ha^{-1}) gave the maximum nitrogen harvest index (72.37%) that indicates at harvest more N was an uptake in grain then straw.

The experiment showed an inter-relationship between grain yield with leaf area index (LAI) and total dry matter production, grain yield and grain of N uptake and grain yield with total N uptake, correlation of grain yield with panicle m^{-2}, grains $panicle^{-1}$, 1000-grain weight (g). Correlation with grain yield of varieties and yield characters showed a linear and significant positive relationship. Nitrogen uptake in grain, straw also showed a positive and linear relationship irrespective of varieties. The highest grain yield (5.57 t ha^{-1}) obtained when leaf area index (3.09), dry matter production (11.97 t ha^{-1}), panicle m^{-2} (269.67), grains $panicle^{-1}$ (106.00), 1000-grain weight (22.69 g), grain N uptake (61.48 kg ha^{-1}) were found by BRRI dhan48 × N_{80} (80 kg ha^{-1}). The variation of grain yield of BR26, BRRI dhan48, and BRRI dhan82 at different nitrogen rates was determined through a regression equation. Differentiating the quadratic equation of yield response concerning applied different N doses the economic N rate appeared as 97, 93, and 55 kg N ha^{-1} for BR26, BRRI dhan48, and BRRI dhan82, respectively.

Overall results of the experiment showed that the increased rate of nitrogen increased plant height irrespective of varieties and the treatment N_{80} produced higher plant height in all growth stages of *aus* varieties. Rice plant that received no fertilizer were significantly inferior to other treatments.

Tiller number increased with the advancement of time and tiller production rate was highest at 75 DAT. Maximum number of tillers was produced with N_{80} treatment followed by N_{60} and N_{100} treatments.

Application of N fertilizer increased LAI gradually irrespective of varieties and attained its peak at 75 DAT. Among the nitrogen treatments, N_{80} recorded the highest LAI that was significantly superior over all other treatments. Regression analysis between grain yield and LAI was significant and linearly correlated.

The rapid increase of dry matter was observed between 60 and 75 DAT irrespective of varieties. During maturity, the highest dry matter production was produced from N_{80} followed by N_{100} treatment in all the varieties. Regression analysis indicated that the contribution of the dry matter accumulation to the grain yield found a very significant relationship among them.

Crop growth rate (CGR) reached a peak during 45-60 DAT then declined in all nitrogen treatments irrespective of varieties. The treatment N_{80} produced a higher crop growth rate.

Nitrogen uptake increased with the advancement of the age of the crop up to the flowering stage (75 DAT) and decreased thereafter. During the time of grain formation grain nitrogen uptake was higher irrespective of N levels compared to straw nitrogen uptake in all the *aus* varieties. The treatment N_{80} obtained the highest N uptake in grain and straw. A relationship between N uptake in grain and grain yield was highly significant and linear. Grain yield of *aus* varieties was significantly and linearly related with total N uptake indicated that higher grain yield would be due to higher N uptake. Interaction effect of variety and nitrogen rates on nitrogen harvest index (NHI) not varied significantly, but the individual effect of variety and nitrogen rates varied significantly.

Interaction effect of *aus* varieties and different N rates did not differ significantly on Yield and yield characters like panicle m^{-2}, grains $panicle^{-1}$, 1000-grain weight, and harvest index, biological yield. But individual effect of varieties and nitrogen rate differed significantly. The N rate N_{80} produced a higher yield in all varieties after that yield decline. The variety BRRI dhan48 produced the highest grain yield. The correlation analysis between grain yields with panicle m^{-2}, grains panicle^{-1}, and 1000-grain weight were statistically significant by different varieties used in the present study.

Based on the above results of the present experiment it was found that the growth and yield response of BRRI *aus* varieties viz. BR26, BRRI dhan48, and BRRI dhan82 to applied different rates of N varied significantly. BRRI dhan48 and BR26 responded to higher N rates, while BRRI dhan82 showed less response to applied higher N doses. BRRI dhan48 showed a yield of 5.57 t ha^{-1} with 80 kg N ha^{-1}. The combination of BRRI dhan48 × nitrogen rate with 80 kg ha^{-1} gave superior growth, development, and yield among all other treatment combinations and it could be suggested to the farmers for the cultivation of *aus* rice. However, the economic N rates calculated from the quadratic regression equations were 97 kg ha^{-1}, 93 kg ha^{-1}, and 55 kg ha^{-1} for BR26, BRRI dhan48, and BRRI dhan82, respectively. Therefore, the N fertilizer requirement of *aus* rice crops should be based on variety, the inherent capacity of soil N supply to improve *aus* rice yield furthermore minimize the excessive use of chemical fertilizer. After all, to reach a specific conclusion and recommendation, more research works on varieties and nitrogen rates for better growth and yield of *aus* rice should be done over different agro-ecological zones of Bangladesh to make a promising practice to the farmers.

REFERENCES

Adhikari, J., Sarkar, A., Uddin, M. R., Sarker, U., Hossen, K. and Rosemila, U. (2018). Effect of nitrogen fertilizer and weed management on the yield of transplant *aman* rice. *Bangladesh J. Agric. Univ.* **16(**1): 12-16.

Ahmed, A., Kabir, M. A., Rashid, M. M., Islam, M. S. and Saha, P. S. (2016). Influence of different fertilizer rates on the growth and yield of transplanted *aman* rice genotypes. *Int. J. Agri. Res.* **9**(1): 47-54.

Ajmal, K. K., Goverdhan, M., Sridevi, S. and Suresh, K. (2020). Growth and dry matter production of semidry rice under varied doses and time of nitrogen application. *Int. J. Chemi. Studi.* **8**(3): 2688-2692.

Alem, R., Hailegebriel, K., Yirgalem, T., Redae, W. and Welegerima, G. (2018). Effects N and P fertilizer application rates on yield and economic performance of upland rice in Tselemti district of N.W Tigray, Ethiopia. *J. Rice Res.* **6**: 191.

Ali, N., Sarkar, M., Sarkar, S. and Paul, S. (2017). Effect of number of seedlings per hill, rate and time of nitrogen application on the growth and yield of late transplant *aman* rice. *Progress. Agric.* **28**(3): 174-183.

Alim, M. A. (2012). Effect of different sources and doses of nitrogen application on the yield formation of *boro* rice. *J. Environ. Sci. Nat. Res.* **5**(1): 273- 282.

Artacho, P., Bonomelli, C. and Meza, F. (2009). Nitrogen application in irrigated rice grown in Mediterranean conditions: Effects on grain yield, dry matter production, nitrogen uptake, and nitrogen use efficiency. *J. Plant Nutr.* **32**: 1574-1593.

Arthanari, P. M., Ramasamy, S. and Amanullah, M. M. (2007). Nutrient uptake as influenced by post panicle initiation nutrient management in rice plant organ. *Res. J. Agric. Biol. Sci.* **3**: 621-624.

Awasthi, U. D. and Bhan, S. (1993). Performance of wheat (*Triticum aestivum*) varieties with different levels of nitrogen in moisture-scarce condition. *Indian J. Agron.* **38**(2): 200-203.

Azam, M. T., Ali, M. H., Karim, M. F., Rahman, A., Jalal, M. J. and Mamun, A. F. M. (2012). Growth and yield of *boro* rice as affected by different urea fertilizer application methods. *Intl. J. Sustain. Agric.* **4**(3): 45-51.

Babiker, F. S. H. (1986). The effect of zinc sulphate levels on rice growth and productivity. *Alexandria J. Agric. Res.* **31**(2): 480-481.

BBS (Bangladesh Bureau of Statistics) (2018). National Accounts Statistics. Government of Bangladesh.

Bhuiyan, M. K. A., Nahar, L., Mahbub, M. M., Shultana, R., Mridha, M. A. J. Rahman, M. A. and Kamruzzaman, M. (2016). Yield response and nitrogen use efficiency of *boro* rice varieties as affected methods of USG and prilled urea application. *Bangladesh J. Agron.* **19**(1): 1-10.

Bhuiyan, M. S. H., Zahan, A., Khatun, H., Iqbal, M., Alam, F. and Manir, M. R. (2014). Yield performance of newly developed test crossed hybrid rice variety. *Intl. J. Agron. Agril. Res.* **5**(4): 48-54.

Bisne, R., Motiramani, N. K. and Sarawgi, A. K. (2006). Identification of high yielding hybrids in rice. *Bangladesh J. Agril. Res.* **31**(1): 171-174.

Bremner, J. M. and Mulvaney, C. S. (1982). Nitrogen-Total. **In**: Methods of soil analysis. Part 2. Chemical and microbiological properties, Page, A.L., Miller, R.H. and Keeney, D.R. (ed.). American Society of Agronomy, Soil Science Society of America, Madison, Wisconsin. pp. 595-624.

BRRI (Bangladesh Rice Research Institute). (2019). Adhunik Dhaner Chash (Cultivation of Modern Rice), Gazipur, Bangladesh. pp. 5-93.

BRRI (Bangladesh Rice Research Institute). (2016). Bangladesh Rice Res. Inst., Joydebpur, Gazipur, Bangladesh. pp. 63-67.

BRRI (Bangladesh Rice Research Institute). (2008). BRRI Annual Internal Review 2007-2008. Soil Science Division. Bangladesh Rice Res. Inst., Gazipur-1701.

BRRI (Bangladesh Rice Research Institute). (2006). Bangladesh Rice Res. Inst. pp. 63-67.

BRRI (Bangladesh Rice Research Institute). (1994). Annual Report July 1994-June 1995. Bangladesh Rice Res. Inst. Joydebpur, Gazipur, Bangladesh. pp. 36-37.

BRRI (Bangladesh Rice Research Institute). (1985). Annual report for 1981. BRRI Pub. No. 71. Joydebpur, Gazipur, Bangladesh. pp. 2-8.

Budhar, M. N. and Palaniappan, S. P. (1996). Effect of integration of fertilizer and green manure nitrogen on yield attributes, nitrogen uptake and yield of lowland rice (*Oryza sativa* L.). *J. Agron. Crop Sci.* **176**: 183-187.

Cassman, K. G., Dobermann, A., Walters, D. T. and Yang, H. (2003). Meeting cereal demand while protecting natural resources and improving environmental quality. *Annu. Rev. Energy. Environ*. **28**: 315-358.

Chamely, S., Islam, N., Hoshain, S., Rabbani, M., Kader, M. and Salam, M. (2015). Effect of variety and nitrogen rate on the yield performance of *boro* rice. *Progressive Agric. Sci*. **26**(1): 6-14.

Chaturvedi, I. (2005). Effect of nitrogen fertilizers on growth, yield, and quality of rice (*Oryza sativa*). *J. Cent. Eur. Agric.* **6**(4): 611-618.

Chen, Y., Fan, P., Mo, Z., Kong, L., Tian, H., Duan, M., Li, L., Wu, L., Wang, Z. and Tang, X. (2020a). Deep placement of nitrogen fertilizer affects grain yield, nitrogen recovery efficiency, and root characteristics in direct-seeded rice in south China. *J. Plant Growth Regul.* https://doi.org/10.1007/s00344-020-10107-2

Chen, Z. M., Wang, Q., Ma, J. W., Zou, P. and Jiang, L. N. (2020b). Impact of controlled-release urea on rice yield, nitrogen use efficiency and soil fertility in a single rice cropping system. *Sci. Rep.* **10**: 10432. https://doi.org/10.1038/s41598-020-67110-6 2

Chou, J. T., Wu, Z., Jiang, T. H., Liu, F. and Zhang, Z. J. (2020). Effects of nitrogen reduction at different growth stages on rice population production characteristics and preliminary analysis of nitrogen reduction strategies. *J. Yangzhou Univ.* **65**: 52-58.

Das, L. K. and Panda, S. C. (2004). Effect of varied doses of nitrogen and potassium on crop growth rate of hybrid rice at different growth stages. *Environ. Ecol.* **22**(3): 540-542.

Das, M. L. (2015). Growth and yield of *boro* rice as affected by different methods of urea application. MS. Thesis, Sher-e-Bangla Agricultural University, Dhaka.

Debnath, A., Biswas, P. K., Sardar, M. S. A. and Rahman, A. (2012). Influence of mother and clonal tillers on yield and performance of inbred and hybrid *boro* rice. *Bangladesh J. Agron.* **15**(1): 1-7.

Devaraju, K. M., Gowda, H. and Raju, B. M. (1998). Nitrogen response of karnataka rice hybrid-2. *Intl. Rice Res.* **23**(2): 43.

Diaz, S. H., Castro, R. and Morejon, R. (2000). Morpho-agronomic characterization of varieties of rice. Instituto Nacional de ciencias Agricolas, Gaveta Postall, San Jose, de las, Lajsa, La Habna. **21**(3): 81-86.

Djaman, K., Bado, B. V. and Mel, V. C. (2016). Effect of nitrogen fertilizer on yield and nitrogen use efficiency of four aromatic rice varieties. *Emirates J. Food Agric.* **28**: 126-135.

Djaman, K., Mel, V. C., Ametonou, F. Y., Namaky, R. E. and Diallo, M. D. (2018). Effect of nitrogen fertilizer dose and application timing on yield and nitrogen use efficiency of irrigated hybrid rice under semi-arid conditions. *J. Agric. Sci. Food Res.* **9**: 223.

Dobermann, A. R. (2005). Nitrogen use efficiency-state of the art. **In:** Proceedings of the International Workshop on Enhanced-Efficiency Fertilizers, Frankfurt, Germany. Intl. Fertilizer Industry Association, Paris (CD-ROM).

Fageria, N. K and Santos, A. B. (2014). Lowland rice genotypes evaluation for nitrogen use. *J. Plan. Nutri.* **37** (9): 1410-1423.

Fageria, N. K. (2004). Dry matter yield and nutrient uptake by lowland rice at different growth stages. *J. Plant. Nutri.* **27**(6): 947-958.

Fageria, N. K. (2007). Yield physiology of rice. *J. Plant Nutri.* **30**: 843-879.

Fageria, N. K. (2009). The use of nutrients in crop plants. CRC Press, Boca Raton, FL. pp. 20-50.

Fageria, N. K. and Baligar, V. C. (1999). Yield and yield components of lowland rice as influenced by timing of nitrogen fertilization. *J. Plant Nutri.* **22**: 23-32.

Fageria, N. K. and Baligar, V. C. (2001). Improving nutrient use efficiency of annual crops in Brazilian acid soils for sustainable crop production. *Commun. Soil Sci. Plant Anal.* **32**(7): 1303-1319.

Fageria, N. K. and Wilcox, G. E. (1977). Effect of nitrogen and phosphorus on rice growth. *Lavoura-Arrozeira*. **30**(1): 24-26.

Fan, M., Shen, J., Yuan, L., Jiang, R. and Chen, X. (2012). Improving crop productivity and resource use efficiency to ensure food security and environmental quality in China. *J. Botany Exp. Bot.* **63**: 13-24.7.

FAO (Food and Agriculture Organization). (2018). Rice Market Monitor; Food and Agriculture Organization (FAO) of the United Nations: Rome, Italy.

Garcia, G. A., Dreccer, M. F., Miralles, D. J. and Serrago, R. A. (2015). High night temperatures during grain number determination reduce wheat and barley grain yield: a field study. *Glob. Chang. Biol.* 21: 4153-4164.

Gardner, F. P., Pearce, R. B. and Mistechell, R. L. (1985). Physiology of crop plants. *Iowa State Univ. Press, Powa.* p. 66.

Gewaily, E. E., Ghoneim, A. M. and Osman, M. M. (2018). Effects of nitrogen levels on growth, yield and nitrogen use efficiency of some newly released Egyptian rice genotypes. *Open Agric.* **3**(1): 310-318.

Gill, H. S. and Singh, H. (1985). Effect of mixtalol and agromix in relation to varying levels of N on growth and yield of paddy. *J. Res. PAU*. **22**(4): 617-623.

Haider, I. K. (2018). Appraisal of biofertilizers in rice: To supplement inorganic chemical fertilizer. *Rice Sci.* **25**: 357-362.

Hamidullah, A. T. M., Rahman, M. S., Miah, M. N. M. and Miah, M. A. K. (2006). Growth and yield performance of BINA Dhan5 in *boro* season as affected by nitrogen rate. *Bangladesh J. Nucl. Agric.* **22**: 93-98.

Haque, M. A. and Haque, M. M. (2016). Growth, yield and nitrogen use efficiency of new rice variety under variable nitrogen rates. *American J. Plant Sci.* **7**: 612-622.

Haque, M. A., Razzaque, A. H. M., Haque, A. N. A. and Ullah, M. A. (2015b). Effect of plant spacing and nitrogen on yield of transplant *aman* rice var. BRRI Dhan52. *J. Biosci. Agric. Res*. **4**(2): 52-59.

Haque, M. M., Pramanik, H. R., Biswas, J. K., Iftekharuddaula, K. M. and Hasanuzzaman, M. (2015b). Comparative performance of hybrid and elite inbred rice varieties with respect to their source-Sink relationship. *World J. Sci*. 11. https://doi.org/10.1155/2015/326802

Hasan, M. S., Khan, A. R., Islam, M. and Haque, M. M (2017). Growth and productivity of short duration *aman* rice genotype. *Bangladesh J. Agron.* **20**(2): 27-36.

Hasegawa, T., Koroda, Y. and Eligman, N. G. (1994). Response to spikelet number of plant nitrogen concentration and dry weight in paddy. *Agro. J*. **86**: 673-676.

Hassan, M. S., Khair, A., Haque, M. M., Azad, A. K. and Hamid, A. (2009). Genotypic variation in traditional rice varieties for chlorophyll content, SPAD value and nitrogen use efficiency. *Bangladesh J. Agric. Res.* **34**(3): 505-515.

Hirooka, Y., Homma, K., Maki, M., Sekiguchi, K., Shiraiwa, T. and Yoshida, K. (2017). Evaluation of dynamics of leaf area index of rice in farmers' fields in Vientiane province, Lao PDR. *J. Agric. Meteor*. **73**(1): 16-21.

Hossain, M. E., Ahmed, S., Islam, M. T., Riaj, M. M. R., Haque, K. A. and Hassan, S. M. Z. (2018). Optimization of nitrogen rate for three aromatic rice varieties in Patuakhali region. *Intl. J. Natur. Soci. Sci.* **5**(4): 65-70.

Hossain, M. M., Srikant, Kulkarni, Hegde. Y. R. and Angadi, V. V. (2002). Effect of nitrogen levels on the incidence of blast and yield levels of rice under upland conditions of Karnataka. *Plant Patho. Newsl.* **20**: 17-19.

Hussain, J., Siddique, M. A., Mia, M. M., Hasan, G. N., Seajuti, A. S., Mallik, M. R. and Zaman, E. (2016). Effect of different doses of nitrogen fertilizer on T. *aman* rice. *Intl J. Busin. Soci. Sci. Res.* **4**(4): 328-332.

Islam, M. S. M., Gaihre, Y. K., Shah, .A. L., Singh, U., Sarkar, M. I. U., Satter, M. A., Sanabria, J. and Biswas, J. C. (2016). Rice yields and nitrogen use efficiency with different fertilizers and water management under intensive lowland rice cropping systems in Bangladesh. *Nutr. Cycl. Agroecosyst*. **106**: 143-156.

Islam, M., Akhter, M., Huda, A., Hashem, M. and Asad, M. (2018). Forms and placement of nitrogen fertilizers influence nitrogen use efficiency and yield of BRRI Dhan49 under continuous flooded condition. *J. Environ. Sci. Nat. Res.* **11**(1-2): 53-58.

Islam, S. M. M., Khatun, A., Rahman, F., Hossain, A. T. M. S., Naher, U. A. and Saleque, M.A. (2015). Rice response to nitrogen in tidal flooded non-saline soil. *Bangladesh J. Rice*. **19**(2): 65-70.

Jahan, A., Islam, A., Sarkar, M. I. U., Iqbal, M., Ahmed, M. N. and Islam, M. R. (2020). Nitrogen response of two high yielding rice varieties as influenced by nitrogen levels and growing seasons. *Geol. Ecol. Land.* DOI: 10.1080/24749508.2020.1742509

Jahan, N., Islam, M. R., Siddique, A. B., Islam, M. R., Hassan, M. M., Shamsuzzaman, S. M. and Samsuri, A. W. (2014). Effects of integrated use of prilled urea, urea super granule and poultry manure on yield of transplant *aus* rice and field water quality. *Life Sci. J.* **11**: 101-108.

Jannat, T. (2013). Performance of some selected hybrid rice varieties in *aus* season. MS. Thesis, Sher-e-Bangla Agricultural University, Dhaka.

Jisan, M. T., Paul, S. K. and Salim, M. (2014). Yield performance of some transplant *aman* rice varieties as influenced by different levels of nitrogen. *Bangladesh J. Agril. Univ.* **12**(2): 321-324.

Kandil, A. A., El-Kalla, S. E., Badawi, A. T. and El-Shayb, O. M. (2010). Effect of hill spacing, nitrogen levels and harvest date on rice productivity and grain quality. *Crop Environ.* **1**(1): 22-26.

Karim, M. R. (2011). Effect of nitrogen on growth, productivity and seed quality of long grain rice. MS. Thesis, BSMRAU.

Karim, M., Kashem, M. A., Huda, A., Aziz, M. A. and Goswami, B. K. (2019). Effect of different doses of urea on the yield of *boro* rice varieties in hoar areas of Bangladesh. *Asian J. Plant Res.* **3**(2): 1-9.

Karmakar, B., Mamun, M., Rahman, M., Islam, M., Islam, M., Mukul, M., Shamsunnaher, Zahan, A., Barua, R., Biswash, M., Parveen, S., Akter, S., Shaikh,

N. and Ahmed, B. (2019). Adaptation of promising rice genotypes for broadcast *aus* season. *Bangladesh J. Rice*. **23**(2): 35-48.

Kausar, K., Akbar, M., Rasul, E. and Ahmad, A. N. (1993). Physiological responses of nitrogen, phosphorus and potassium on growth and yield of wheat. *Pakistan J. Agric. Res.* **14**: 2-3.

Khalifa, A. A. B. A. (2009). Physiological evaluation of some hybrid rice varieties under different sowing dates. *Australian J. Crop Sci.* **3**(3): 178-183.

Khatun, S., Mondal, M. M. A., Khalil, M. I., Roknuzzaman, M. and Mollah, M. M. I. (2020). Growth and yield performance of six *aman* rice varieties of Bangladesh. *Asian J. Agric. Res.* **12**(2): 1-7.

Kim, C. K., Kee, S. Y., Lim, M. S. and Cho, C. I. (1987). Effect of nitrogen split application on the rice growth and yield production under machine transplanting in rice (*Oryza sativa* L.). *Korean J. Crop Sci.* **32**(1): 48-54.

Kirrilov, Y. A. I. and Pavlov, V. D. (1989). Effect of fertilizer on yield and protein contents in wheat grain. *Agrochimiya*. **1**: 49-51.

Koutroubas, S. D. and Ntanos, D. A. (2003). Genotypic differences for grain yield and nitrogen utilization in *Indica* and *Japonica* rice under Mediterranean conditions. *Field Crops Res*. **83**: 251-260.

Kulagod, S. D., Hegde, M., Nayak, G. V. and Vastrad, A. S. (2011). Influence of fertilizer on the incidence of insect pests in paddy. *Karnataka J. Agric. Sci.* **24**(2): 241-243.

Kumar, S., Kour, S., Gupta, M. Kachroo, D. and Singh, H. (2017). Influence of rice varieties and fertility levels on performance of rice and soil nutrient status under aerobic conditions. *J. Appli. Natur. Sci.* **9**(2): 1164 -1169.

Li, H., Huang, Q., Chen, C., Liu, G., Wu, Z., Luo, Q., Zhu, Q. and Li, Q. (2020). Effects of density and nitrogen fertilizer rate on yield, appearance and processing quality of high quality rice guiyu8. *Southwest China J. Agric. Sci.* **33**: 718-724.

Li, R., Li, M., Ashraf, U., Liu, S. and Zhang, J. (2019b). Exploring the relationships between yield and yield-related traits for rice varieties released in China from 1978 to 2017. *Front. Plant Sci.* **10**: 543.

Li, X., Liu, Z. Z. and Ji, W. W. (2019a). Effects of nitrogen application on osmotic regulators in leaves of different plant types of rice. *Jiangsu Agric. Sci.* **47**: 117-121.

Liu, G. L., Wu, Z. S., Luo, Q. C., Li, H., Zhu, Q. N., Li, Q. W. and Chen, C. H. (2020). Analysis of nitrogen fertilizer efficiency of six high quality conventional rice varieties under different nitrogen application levels. *Acta Agric. Southwest*. **33**: 1716-1721.

Liu, X., Wang, H., Zhou, J., Hu, F., Zhu, D., Chen, Z. and Liu, Y. (2016). Effect of N fertilization pattern on rice yield, N use efficiency and fertilizer-N fate in the Yangtze River Basin, China. *PLoS One.* **11**(11). e0166002.

Lv, X. H., Fu, L. D., Song, Y. T. and Chen, W. F. (2017). Effects of nitrogen application on nitrogen metabolism and related physiological characteristics of leaves of rice of different plant types. *Jiangsu Agric. Sci.* **45**: 62-65.

Mae, T., Inaba, A., Kaneta, Y., Masaki, S., Sasaki, M., Aizawa, M., Okawa, S., Hasegawa, S. and Makino, A. (2006). A large-grain rice cultivar, Akita 63, exhibits high yields with high physiological N-use efficiency. *Field Crops Res.* **97**(2-3): 227-237.

Mahato, M., Gautam, B., Kunwar, R. and Joshi, D. (2019). Effect of different date of sowing and nitrogen level on production of direct seeded rice. *American J. Food Sci. Nutri.* **6**(1): 1-5.

Malik, T. H., Lal, S. B., Wani, N. R., Amin, D. and Wani, R. A. (2014). Effect of different levels of nitrogen on growth and yield attributes of different varieties of basmati rice (*Oryza Sativa* L.). *Int. J. Sci. Technol. Res.* **3**(3): 444-448.

Mandal, N. N., Chaudhry, P. P. and Sinha, D. (1992). Nitrogen, phosphorus and potash uptake of wheat (var. Sonalika). *Environ. Ecol.* **10**: 297.

Mannan, M., Bhuiya, M., Hossain, H. and Akhand, M. (2010). Optimization of nitrogen rate for aromatic Basmati rice (*Oriza sativa* L.). *Bangladesh J. Agric. Res.* **35**(1): 157-165.

Manzoor, Z., Ali, L., Akhtar, S., Ijaz, M., Akhter, M., Bhati, M. K., Rizwan, M. and Hussain, W. (2015). Effect of different nitrogen levels on yield and yield components of fine grain advance rice line. *Pakistan J. Sci.* **67**(3): 235-238.

Masni, Z. and Wasli, M. E. (2019). Yield performance and nutrient uptake of red rice variety (MRM 16) at different NPK fertilizer rates. *Intl. J. Agron*. **2**: 1-6.

Masum, S. M., Ali, M. H. and Ullah, J. (2008). Growth and yield of two T. *aman* rice varieties as affected by seedling number per hill and urea supper granules. *J. Agric. Educ. Technol.* **11**(1&2): 51-58.

Meena, S. L., Surendra, S., Shivay, Y. S. and Singh, S. (2003). Response of hybrid rice (*Oryza sativa*) to nitrogen and potassium application in sandy clay loam soils. *Indian J. Agric. Sci.* **73**(1): 8-11.

Metwally, T. F., Gewail, E. E. and Naeem, S. S. (2011). Nitrogen response curve and nitrogen use efficiency of Egyptian hybrid rice. *J. Agric. Res. Kafer El-Sheikh Univ.* **37**: 73-84.

Moro, B. M., Nuhu, I. R., Ato, E. and Naathanial, B. (2015). Effect of nitrogen rates on the growth and yield of three rice (*Oryza sativa* L.) varieties in rain-fed lowland in the forest agro-ecological zone of Ghana. *Intl. J. Agric. Sci.* **5**(7): 878-885.

Murshida, S., Uddin, M. R., Anwar, M. P. Sarker, U. K., Islam, M. M. and Haque, M. M. I. (2017). Effect of variety and water management on the growth and yield of *boro* rice. *Progress. Agric.* **28**(1): 26-35.

Nasim, M., Shahidullah, S. M., Saha, A., Muttaleb, M. A., Aditya, T. L., Ali, M. A. and Kabir, M. S. (2017). Distribution of crops and cropping patterns in Bangladesh. *Bangladesh J. Rice Res.* **21**(2): 1-55.

Ndebeh, A. K., Asumanah, P., Ndebeh, J., Ndaloma, P. G., Lahai, S. J. B., Kolleh, D, M. and Ahiakpa, J. K. (2018). Agronomic performance of four upland rice genotypes under rainfed condition. *Afr. J. Food Agric. Nutr. Dev.* **18**(2): 13304-13316.

Nori, H., Abdul Halim, R. and Ramlan, M. F. (2018). Effects of nitrogen fertilization management practice on the yield and straw nutritional quality of commercial rice varieties. *Malaysian J. Mathema. Sci.* **2**(2): 61-71.

Paikaray, R. L., Mahapatra, B. S. L. and Sharma, G. L. (2001). Integrated nitrogen management in rice (*Oryza sativa*), wheat (*Tricum aestivum*) cropping system. *Indian J. Agron.* **46**(4): 592-600.

Pan, J. F., Liu, Y. Z., Zhong, X. H., Lampayan, R. M., Singleton, G. R., Huang, N. R., Liang, K. M., Peng, B. L. and Tian, K. (2017). Grain yield, water productivity and nitrogen use efficiency of rice under different water management and fertilizer-N inputs in South China. *Agric. Water Manag.* **184**: 191-200.

Parashivamurthy, S., Prashad, R., Lakshmi, J. and Rama-chandra, C. (2012). Influence of varieties and fertilizer levels on growth, seed yield and quality of rice under aerobic conditions. *Mysore J. Agric. Sci*. **46**(3): 602-609.

Paul, S. K., Islam, S. M. M., Sarkar, M. A. R., Alam, A. and Zaman, F. (2014). Physiological parameters of transplant *aman* rice (cv. BRRI dhan49) as influenced by weeding regime and integrated nutrient management. *J. Agrofor. Environ.* **8**(2): 121-125.

Paul, S. K., Rahman, K. S. and Sarkar, M. A. R. (2013). Physiological attributes of transplant *aman* rice (cv. BRRI dhan52) as affected by tiller seedlings and urea super granules. *Progress. Agric.* **24**(1 & 2): 17-27.

Paul, S. K., Roy, B., Hasan, A. K. and Sarkar, M. A. R. (2017). Yield and yield components of short duration transplant *aus* rice (cv. Parija) as influenced by plant spacing and nitrogen level. *Fundam. Appli. Agric.* **2**(2): 233-236.

Peng, S., Cassman, K. G., Virmani, S. S., Sheehy, J. and Khush, G. S. (1999). Yield potential trends of tropical rice since the release of IR8 and the challenge of increasing rice yield potential. *Crop Sci*. **39**: 1552-1559.

Peng, S., Huang, J., Sheehy, J. E., Laza, R. C. and Visperas, R. M. (2004). Rice yields decline with higher night temperature from global warming. *Proc. Natl. Acad. Sci. USA*. **101**: 9971-9975.

Perez, C. M., Juliano, B. O., Liboon, S. P., Alcantara, J. M. and Cassman, K. G. (1996). Effects of late nitrogen fertilizer application on head rice yield, protein content, and grain quality of rice. *Cereal Chemist.* **73**: 556-560.

Qiao, J., Yang, L., Yan, T., Xue, F. and Zhao, D. (2012). Nitrogen fertilizer reduction in rice production for two consecutive years in the Taihu Lake area. *Agric. Ecosyst. Environ.* **146**(1): 103-112.

Qurashi, T. A., Salam, M. A., Jannat, M. and Rabbani, M. G. (2013). Evaluation of urea super granule as a source of nitrogen in transplant *aman* rice. *Progress. Agric.* **24**(1 & 2): 29-37.

Rahman, M. H., Ali, M. H., Ali, M. M. and Khatun, M. M. (2007). Effect of different level of nitrogen on growth and yield of transplant *aman* rice CVBRRI dhan32. *Intl. J. Sustain. Crop Prod.* **2**(1): 28-34.

Rajesh, K., Thatikunta, R., Naik, D. S. and Arunakumari, J. (2017). Effect of different nitrogen levels on morpho-physiological and yield parameters in rice (*Oryza sativa* L.). *Intl. J. Curr. Microbiol. App. Sci*. **6**(8): 2227-2240.

Rajput, M. K. K., Ansari, A. H., Mehdi, S. and Hussain, A. M. (1988). Effect of N and P fertilizers alone and in combination with OM on the growth and yield of Toria. *Sarhad J. Agri. Res.* **4**: 3-6.

Ray, S., Sarkar, M. A. R., Paul, S. K., Islam, A. K. M. M. and Yeasmin, S. (2015). Variation of growth, yield and protein content of transplant *aman* rice by three agronomic practices. *J. Agric. Bio. Sci.* **1**(4): 167-176.

Rea, R. S., Islam, M. R., Rahman, M. M. and Mix, K. (2019). Study of nitrogen use efficiency and yield of rice influenced by deep placement of nitrogen fertilizers. *SAARC J. Agric*. **17**(1): 93-103.

Rupp, D. and Hubner, H. (1995). Influence of nitrogen fertilization on the mineral content of apple leaves. *Erwerbs-Obstbau*. **37**: 29-31.

Rusdiansyah, R. and Saleh, M. (2017). Response of two local rice cultivars to different doses of nitrogen fertilizer in two paddy fields. *Agrivita*. **39**(2): 137-144.

Saha, B., Panda, P., Patra, P. S., Panda, R., Kundu, A., Roy, A. K. S. and Mahato, N. (2017). Effect of different levels of nitrogen on growth and yield of rice (*Oryza sativa* L.) cultivars under Terai-agro climatic situation. *Intl. J. Curr. Microbiol. Appl. Sci.* **6**(7): 2408-2418.

Sahu, K. C., Kariali, E. and Mohapatra, P. K. (2004). Tiller dominance in rice is dependent on assimilate concentration of the panicle. *Indian J. Plant Physiol*. **9**: 402-406.

Salem, A. K. M. (2006). Effect of nitrogen levels, plant spacing and time of farmyard manure application on the productivity of rice. *J. Appl. Sci. Res.* **2**(11): 980-987.

Sapkota, T. B., Singh, L. K., Yadav, A. K., Khatri-Chhetri, A., Jat, H. S., Sharma, P. C., Jat, M. L. and Stirling, C. M. (2020). Identifying optimum rates of fertilizer nitrogen application to maximize economic return and minimize nitrous oxide emission from rice-wheat systems in the Indo-Gangetic Plains of India. *Archiv. Agron. Soil Sci.* **66**(14): 2039-2054.

Sarkar, S. C., Akter, M., Islam, M .R. and Haque, M. M. (2016). Performance of five selected hybrid rice varieties in *aman* season. *J. Plant Sci.* **4**(2): 72-79.

Sarkar, S. K., Sarkar, M. A. R., Islam, N. and Paul, S. K. (2014). Yield and quality of aromatic fine rice as affected by variety and nutrient management. *Bangladesh J. Agril. Univ*. **12**(2): 279-284.

Sarker, U. K., Uddin, M. R., Sarkar, M. A. R., Salam, M. A. and Hasan, A. K. (2017). Physiological parameters and yield differ in rice (*Oryza sativa* L.) cultivars with variable water management systems. *Archiv. Agric. Environ. Sci.* **2**(4): 247-256.

Shanmugam, A. (1983). Studies on azolla as a partial substitute for nitrogen in lowland rice. M.Sc. (Ag.) Thesis, Tamil Nadu Agricultural University, Coimbatore (T.N.).

Sharma, A. R. and Mittra, B. N. (1990). Effect of N and P on rice and their residual effect on succeeding wheat/gram crop. *Indian J. Agron.* **34**: 40-44.

Shiratsuchi, H., Yamagishi, T. and Ishii, R. (2006). Leaf nitrogen distribution to maximize the canopy photosynthesis in rice. *Field Crops Res*. **95**: 291-304.

Siddaram, K., Murali, B. N., Manjunatha, Y. M., Ramesha, M. K., Basavaraja and Policepatil, A. S. (2010). Effect of nitrogen levels through organic sources on growth, dry matter production and nutrient uptake of irrigated aerobic rice (*Oryza sativa* L.). *Intl. J. Agric. Sci.* **6**(2): 426-429.

Sinclair, T. R. and Sheehy, J. E. (1999). Erect leaves and photosynthesis in rice. *Sci.* **283**(5407): 1455.

Singh, Y., Chaudhary, D. C., Singh, S. P., Bhardwaj, A. K. and Singh, D. (1996). Sustainability of rice (*Oryza sativa*), wheat (*Triticum aestivum*) sequential cropping through introduction of legume crops and green manure crops in the system. *Indian J. Agron.* **41**(4): 510-514.

Songyikhangsuthor, K., Sybounheuang, S. and Samson, B. K. (2014). Response of rice landraces and promising cultivars to nitrogen fertilizer on sloping uplands. *Intl. J. Agric. Sci. Res.* **3**(9): 181-186.

Sowmyalatha, B. S., Ramachandra, C., Shivakumar, N. and Manjunatha, K. B. (2012). Effect of methods of cultivation and fertility levels on growth and yield of rice hybrids. *Mysore J. Agric. Sci.* **46**(1): 171-173.

Sultana, S., Hashem, M. A., Haque, T. S., Baki, M. Z. I. and Haque, M. M. (2015). Optimization of nitrogen dose for yield maximization of BRRIdhan49. *American J. Biol. Life Sci.* **3**(3): 58-64.

Sumon, M. J. I., Roy, T. S., Haque, M. N., Ahmed, S. and Mondal, K. (2018). Growth, yield and proximate composition of aromatic rice as influenced by inorganic and organic fertilizer management. *Not. Sci. Biol.* **10**(2): 211-219.

Talashilker, S. C. and Vimol, O. P. (1986). Studies on increasing the use efficiency of N and P fertilizers in combination with city solid waste. *Indian J. Soc. Soil Sci.* **34**(4): 780-784.

Tanaka, A. (1983). Physiological aspects of productivity. **In:** Potential productivity of field crops under different environments. Intl. Rice Res. Inst. Los Banos, Philippines. pp. 61-99.

Tang, Q. Y., Zou, Y. B., Mi, X. C., Wang, H. and Zhou, M. L. (2003). Grain yield formation and N fertilizer efficiency of super hybrid rice under different N applications. *Hybrid Rice*. **18**(1): 44-48.

Tang, X. R., Pan, S. G., Duan, M. Y., Tian, H., Zhong, K. Y. and Xiao, L. Z. (2014). Technical rules of fragrant rice cultivation. *Guangdong Agric. Sci.* **41**: 5-7.

Tayefe, M., Gerayzade, A., Amiri, E. and Zade, A. N. (2014). Effect of nitrogen on rice yield, yield components and quality parameters. *African J. Biotech.* **13**(1): 91-105.

Thakur, K. S. and Singh, C. N. (1987). Effect of organic wastes and N levels on transplanted rice. *Indian J. Agron.* **32**(2): 161-164.

Tunio, G. S., Agustin, M. B., Nihal-ud-din-Mari and Babar, M. A. (2002). Growth and yield of scented rice varieties under different nitrogen levels. *Sarhad J. Agric.* **18**(3): 303-305.

USDA (United States Department of Agriculture). (2020). USDA, World Agricultural Outlook Board, World Agricultural Supply and Demand Estimates.

Wilhelm, W. W. (1998). Dry matter partitioning and leaf area of winter wheat grown in a long term fallow tillage comparisons in U.S. Central Great Plans. *Soil Tillage Res.* **49**: 49-56.

Xie, W. X., Wang, G. H. and Zhang, Q. C. (2007). Potential production simulation and optimal nutrient management of two hybrid rice varieties in Jinhua, Zhejiang Province. *Zhejiang J. Univ. Sci. B.* **8**(7): 486-492.

Yesuf, E. and Balcha, A. (2014). Effect of nitrogen application on grain yield and nitrogen efficiency of rice (*Oryza sativa* L.). *Asian J. Crop Sci.* **6**(3): 273-280.

Ying, J., Peng, S., He, O., Yang, H., Yang, C., Visperas, R. M. and Cassman, K. G. (1998). Comparison of high-yield rice in tropical and subtropical environments: II. Nitrogen accumulation and utilization efficiency *Field Crops Res.* **57**(1): 85-93.

Yoseftabar, S. (2013). Effect nitrogen management on panicle structure and yield in rice (*Oryza sativa* L.). *Intl. J. Agric. Crop Sci.* **5**(11): 1224-1227.

Yoshida, S. (1981). Physiological analysis of rice yield. **In**: Fundamentals of Rice Crop Science. IRRI, Los Banos, Philippines. pp. 1-41, 269.

Yoshida, S. (1984). Rice Science and Technology. Translated by Li, B., Zhejiang Science and Technology Press, Hangzhou.

Yoshida, S., Cock, J. H. and Parao, F. T. (1972). Physiological aspects of high yield. *Intl. Rice Res. Inst. Rice breeding*, pp. 455-469.

Yu, Q. G., Ma, J. W., Zou, P., Lin, H., Sun, W. C., Yin, J. Z. and Fu, J. R. (2015). Effects of combined application of organic and inorganic fertilizers plus nitrification inhibitor DMPP on nitrogen runoff loss in vegetable soils. *Environ. Sci. Pollut. Res. Int.* **22**: 472-481.

Zhang, G. L., Zhao, R., Liu, Y. T., Yao, F. W. and Tang, W. B. (2019). Effect of different amount of nitrogen on the yield and the quality of high quality rice and its nitrogen utilization efficiency. *J. Hunan Agric. Univ.* (*Nat. Sci.)* **45**: 231-236.

Zhang, H., Xue, Y., Wang, Z., Yang, J. and Zhang, J. (2009). Alternate wetting and moderate soil drying improves root and shoot growth in rice. *Crop Sci.* **49**: 2246-2260.

Zhang, J., Tong, T., Potcho, P.M., Huang, S., Ma, L. and Tang, X. (2020). Nitrogen effects on yield, quality and physiological characteristics of giant rice. *J. Agron*. **10**(11): 1816.

Zhang, Y., Tang, Q., Peng, S., Xing, D., Qin, J., Laza, R. C. and Punzalan, B. R. (2012). Water use efficiency and physiological response of rice cultivars under alternate wetting and drying conditions. *World J. Sci.* **10**(4): 287907.

Zohra, F. T., Ali, M., Salimand, R. and Kader, M. A. (2013). Effect of urea super granules on the performance of transplant *aman* rice. *J. Agrofor. Environ.* **7**(1): 49-52.

APPENDICES

Appendix I. Map showing the experimental site under study

Appendix II. Average monthly rainfall, air temperature, solar radiation and relative humidity during the experimental period between April to September 2019 at the BRRI area, Dhaka

Month	Monthly average air temperature (^{0}C)			Average rainfall (mm)	Average relative humidity (%)	Average daily sunshine (hrs.)	Average daily Cloudy (hrs.)	Average daily Solar radiation (cal cm^{-2})
	Maximum	Minimum	Average					
March	33.90	21.12	27.51	81.80	68.50	7.70	4.1	407.63
April	35.73	24.22	29.97	9.60	72.70	8.28	4.22	445.65
May	35.00	24.99	30.00	100.80	79.60	5.92	7.32	378.84
June	34.82	27.56	31.19	29.80	82.10	6.13	7.47	387.37
July	33.16	27.03	30.10	122.60	82.20	4.63	8.86	336.65
August	34.45	27.68	31.06	23.60	79.31	7.84	5.06	440.24
September	31.86	25.31	28.58	116.60	87.30	1.91	10.29	218.97

Source: Bangladesh Rice Research Institute (Plant Physiology division), Gazipur, Dhaka-1207

Appendix III. Physiochemical properties of the initial soil

Characteristics	**Value**
Textural class	Clay loam
pH	6.45
Organic matter (%)	1.54
Total N (%)	0.14
Available P (ppm)	24.65
Exchangeable K (me/100 g soil)	0.18
Available S (ppm)	19.55

Appendix IV. Analysis of variance of the data on plant height (cm) of BR26, BRRI dhan48, and BRRI dhan82 as affected by nitrogen rates during *aus* 2019 at BRRI, Gazipur

Source of variation	DF	Means square values at different days after transplanting					
		Plant height (cm) at					
		15 DAT	30 DAT	45 DAT	60 DAT	75 DAT	Maturity
Replication	2	0.94^{ns}	9.08^{ns}	1.11^{ns}	2.29^{ns}	1.06^{ns}	2.74^{ns}
Variety (V)	2	0.99^{ns}	1.14^{**}	81.95^{**}	11.38^{**}	2.92^{ns}	17.25^{*}
Nitrogen rate (N)	4	46.31^{**}	67.93^{ns}	68.91^{**}	150.23^{**}	107.13^{**}	52.07^{**}
Interaction (V×N)	8	0.41^{ns}	1.59^{**}	1.72^{*}	0.37^{ns}	0.70^{ns}	4.20^{ns}
Error	28	0.42	1.56	0.77	2.22	1.64	3.82

*Significant at 5% level

**Significant at 1% level

ns not significant

Appendix V. Analysis of variance of the data on tiller pattern (Tiller hill^{-1}) of BR26, BRRI dhan48, and BRRI dhan82 as affected by nitrogen rates during *aus* 2019 at BRRI, Gazipur

Source of variation	DF	Means square values at different days after transplanting					
		Number of tiller hill^{-1} at					
		15 DAT	30 DAT	45 DAT	60 DAT	75 DAT	Maturity
Replication	2	0.77^{ns}	0.36^{ns}	3.07^{**}	3.73^{*}	3.27^{**}	5.27^{**}
Variety (V)	2	1.35^{ns}	2.37^{**}	1.34^{ns}	1.21^{ns}	2.87^{**}	0.67^{ns}
Nitrogen rate (N)	4	11.22^{**}	22.19^{**}	$19.57*^{*}$	16.57^{**}	14.64^{**}	11.36^{**}
Interaction (V×N)	8	0.27^{ns}	0.83^{ns}	0.48^{ns}	0.41^{ns}	0.39^{ns}	0.46^{ns}
Error	28	0.46	0.40	0.66	0.86	0.59	0.27

*Significant at 5% level

**Significant at 1% level

ns not significant

Appendix VI. Analysis of variance of the data on leaf area index of BR26, BRRI dhan48, and BRRI dhan82 as affected by nitrogen rates during *aus* 2019 at BRRI, Gazipur

Source of variation	DF	Means square values at different days after transplanting					
		Leaf area index at					
		15 DAT	30 DAT	45 DAT	60 DAT	75 DAT	Maturity
Replication	2	0.17^{*}	0.24^{**}	0.47^{**}	0.21^{ns}	0.74^{ns}	0.15^{ns}
Variety (V)	2	0.21^{**}	0.38^{ns}	0.62^{**}	0.23^{**}	0.16^{ns}	0.14^{ns}
Nitrogen rate (N)	4	0.24^{**}	0.15^{**}	0.27^{**}	0.17^{**}	0.19^{**}	0.10^{ns}
Interaction (V×N)	8	0.29^{ns}	0.60^{ns}	0.56^{ns}	0.25^{ns}	0.18^{ns}	0.14^{ns}
Error	28	0.46	0.37	0.40	0.48	0.24	0.14

*Significant at 5% level

**Significant at 1% level

ns not significant

Appendix VII. Analysis of variance of the data on total dry matter production (g m^{-2}) of BR26, BRRI dhan48, and BRRI dhan82 as affected by nitrogen rates during *aus* 2019 at BRRI, Gazipur

Source of variation	DF	Means square values at different days after transplanting					
		Total dry matter production (g m^{-2}) at					
		15 DAT	30 DAT	45 DAT	60 DAT	75 DAT	Maturity
Replication	2	49.16^{**}	422.49^{**}	32.07^{ns}	179.36^{ns}	452.48^{ns}	857.22^{*}
Variety (V)	2	88.09^{**}	1180.69^{**}	175.20^{*}	3241.15^{*}	4191.20^{**}	4158.16^{**}
Nitrogen rate (N)	4	778.91^{**}	2602.74^{**}	3748.06^{**}	15669.3^{**}	15372.7^{**}	56399.9^{**}
Interaction (V×N)	8	2.73^{ns}	148.83^{*}	48.17^{ns}	1021.77^{ns}	577.11^{ns}	169.99^{ns}
Error	28	6.08	67.06	48.28	867.59	537.04	233.56

*Significant at 5% level

**Significant at 1% level

ns not significant

Appendix VIII. Analysis of variance of the data on crop growth rate ($g/m^{2/}d$) of BR26, BRRI dhan48, and BRRI dhan82 as affected by nitrogen rates during *aus* 2019 at BRRI, Gazipur

Source of variation	DF	Means square values at different days after transplanting			
		CGR ($g/m^{2/}d$) at			
		15-30 DAT	30-45 DAT	45-60 DAT	60-75 DAT
Replication	2	0.89^{**}	0.99^{ns}	0.33^{ns}	0.48^{ns}
Variety (V)	2	2.98^{**}	2.15^{**}	12.69^{*}	4.79^{ns}
Nitrogen rate (N)	4	2.39^{**}	0.67^{ns}	18.83^{**}	0.96^{ns}
Interaction (V×N)	8	0.63^{**}	0.49^{ns}	4.14^{ns}	2.83^{ns}
Error	28	0.18	0.33	3.36	2.45

*Significant at 5% level

**Significant at 1% level

ns not significant

Appendix IX. Analysis of variance of the data on nitrogen concentration (N %) of BR26, BRRI dhan48, and BRRI dhan82 as affected by nitrogen rates during *aus* 2019 at BRRI, Gazipur

Source of variation	DF	Means square values at different days after transplanting					
		N % at					
		15 DAT	30 DAT	45 DAT	60 DAT	75 DAT	Maturity
Replication	2	0.35^{ns}	0.70^{ns}	0.73^{ns}	0.57^{ns}	0.76^{ns}	0.68^{ns}
Variety (V)	2	0.17^{*}	0.64^{*}	0.14^{ns}	0.24^{*}	0.74^{ns}	0.55^{ns}
Nitrogen rate (N)	4	0.11^{**}	1.53^{**}	2.19^{**}	0.87^{**}	0.64^{**}	0.57^{**}
Interaction (V×N)	8	0.22^{ns}	0.91^{ns}	0.61ns	0.46^{ns}	0.45^{ns}	0.19^{ns}
Error	28	0.49	0.17	0.13	0.56	0.47	0.39

*Significant at 5% level

**Significant at 1% level

ns not significant

Appendix X. Analysis of variance of the data on nitrogen (N) uptake (kg ha^{-1}) of BR26, BRRI dhan48, and BRRI dhan82 as affected by nitrogen rates during *aus* 2019 at BRRI, Gazipur

Source of variation	DF	Means square values at different days after transplanting					
		N Uptake (kg ha^{-1}) at					
		15 DAT	30 DAT	45 DAT	60 DAT	75 DAT	Maturity
Replication	2	0.68ns	5.89^{ns}	16.50^{ns}	7.06^{ns}	1.17^{ns}	12.96^{ns}
Variety (V)	2	3.01**	68.15**	41.39^{ns}	205.86**	54.48^{ns}	1.25^{ns}
Nitrogen rate (N)	4	15.77**	978.98**	4774.58**	4269.53**	4731.74**	3703.54**
Interaction (V×N)	8	0.23^{ns}	5.54^{ns}	13.31^{ns}	26.03^{ns}	20.90^{ns}	4.08^{ns}
Error	28	0.37	9.07	22.35	23.51	31.94	20.28

*Significant at 5% level

**Significant at 1% level

ns not significant

Appendix XI. Analysis of variance of the data on yield and yield components of BR26, BRRI dhan48, and BRRI dhan82 as affected by nitrogen rates during *aus* 2019 at BRRI, Gazipur

Source of variation	DF	Means square values at different days after transplanting						
		Grains panicle^{-1}	Panicle m^{-2}	1000-grain weight (g)	Grain yield (t ha^{-1})	Straw yield (t ha^{-1})	Biological yield (t ha^{-1})	Harvest index
Replication	2	44.82^{ns}	149.96^{ns}	0.37^{ns}	0.19^{ns}	0.31^{ns}	0.97^{ns}	0.15^{ns}
Variety (V)	2	534.69**	2154.42**	15.89**	2.29**	1.94*	8.36**	0.67^{ns}
Nitrogen rate (N)	4	769.74**	1415.97**	1.51*	5.56**	4.43**	19.85**	0.23**
Interaction (V×N)	8	97.25^{ns}	532.12^{ns}	0.19^{ns}	0.58^{ns}	0.64^{ns}	2.39^{ns}	0.11^{ns}
Error	28	107.87	401.122	0.54	0.43	0.48	1.77	0.23

*Significant at 5% level

**Significant at 1% level

ns not significant

Appendix XII. Analysis of variance of the data on yield components of nitrogen concentration (N %) and nitrogen (N) uptake of BR26, BRRI dhan48, and BRRI dhan82 as affected by nitrogen rates during *aus* 2019 at BRRI, Gazipur

Source of variation	DF	Means square values at different days after transplanting						
		N% of grain yield (t ha^{-1})	N % of straw yield (t ha^{-1})	N % of Biological yield (t ha^{-1})	N uptake of grain yield (t ha^{-1})	N uptake of straw yield (t ha^{-1})	N uptake of biological yield (t ha^{-1})	Nitrogen harvest index (%)
Replication	2	0.69^{ns}	0.27*	0.17^{ns}	9.29^{ns}	9.33^{ns}	35.59^{ns}	17.34^{ns}
Variety (A)	2	0.48**	0.28**	0.13^{ns}	519.41**	50.56**	574.22**	253.31**
Nitrogen rate (B)	4	0.55**	0.41**	0.88**	2159.72**	263.81**	3903.49**	156.94**
Interaction (A×B)	8	0.54^{ns}	0.13^{ns}	0.89^{ns}	44.01^{ns}	5.65ns	61.86^{ns}	3.91^{ns}
Error	28	0.60	0.85	0.59	47.12	10.54	90.42	9.95

*Significant at 5% level

**Significant at 1% level

ns not significant

Plate 1. Field view after seedbed

Plate 2. Field view at 15 DAT after seedbed

Plate 3. Field view at 15 DAT after transplanting

Plate 4. Time to apply pesticide on rice field

Plate 5. Field view beautiful with normal green color plants

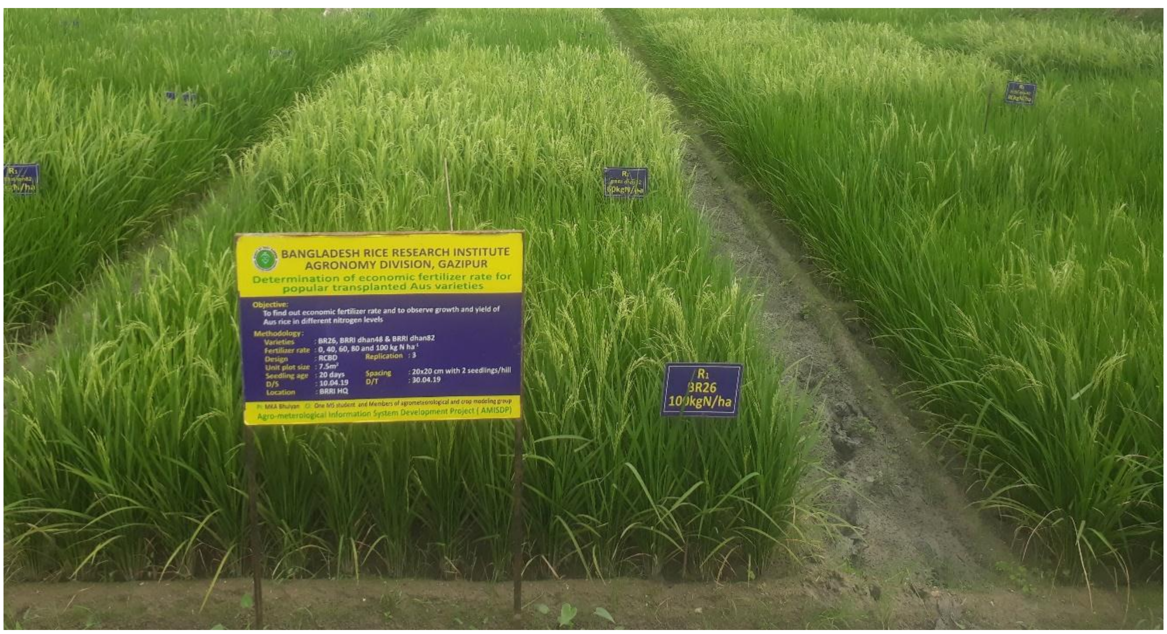

Plate 6. Field view at milking stage

Plate 7. Field view at ripening stage

Plate 8. Field view of BR26 at harveting stage

Plate 9. Field view of BRRI dhan48 and BRRI dhan82 at harveting stage