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Rice Vision for Bangladesh: 2050 and Beyond

M S Kabir[1], M U Salam[2*], A Chowdhury[1], N M F Rahman[1], K M Iftekharuddaula[1], M S Rahman[1], M H Rashid[1], S S Dipti[1], A Islam[1], M A Latif[1], A K M S Islam[1], M M Hossain[1], B Nessa[1], T H Ansari[1], M A Ali[1] and J K Biswas[1]

ABSTRACT

Combined efforts of farmers, rice scientists, extension personnel and Government of Bangladesh have yielded clean rice growth rate of 0.34 million ton (MT) year^{-1} during 2009-10 to 2013-14 in the country. In 2014-15, the country acquired a rice surplus of about 2 MT. However, maintaining the current surplus of rice in the coming decades is a great challenge. Authentic estimation of future rice requirement and future resource availability would guide to way forward. This paper presents rice vision for Bangladesh leading to 2050 and beyond. In this study, secondary data from different government-owned statistics and research institutes were collected, analyzed and synthesized to develop models and/or model parameters to generate outputs such as future population, rice production and rice requirement. Population of Bangladesh will reach 215.4 million in 2050, when 44.6 MT of clean rice will be required. With the pace of rice-production-increase in the last five years, production can reach 47.2 MT, having a surplus of 2.6 MT in 2050. The study sets 2.6 MT as the target for clean rice surplus every year leading to 2050 and beyond. Several hurdles, such as increasing population, decreasing resources and increasing climate vulnerability, can hinder achieving the target. Three major interventions– accelerating genetic gain, minimizing yield gap and curtailing adoption lag– are proposed to break the barriers to achieve the target. Major challenges to implement the interventions include shrinking net cropped area, decreasing availability of irrigation water and increasing pressure on soil fertility. Smart technology such as, location specific variety, profitable cropping sequences, innovative cultural management, and mechanization coupled with smart dissemination using multiple means would ease production barriers. We recommend a number of measures, such as, guaranteeing a minimum cropped area, accelerating the rate of genetic gain in varietal development and intensifying collaboration among the stakeholders to reduce adoption lag of newly released promising rice varieties, to achieve the rice vision of Bangladesh leading to 2050 and beyond.

Key words: Adoption lag, Bangladesh, cropping intensity, genetic gain, pest and diseases, population, mechanization, rice requirement and rice production

INTRODUCTION

Bangladesh agriculture involves food production for 163.65 million people from merely 8.75 million hectares of agricultural land (Salam *et al*., 2014). More food will be required in future because of increasing population. Decreasing resources (e.g. land, labour, soil health and water), and increasing climate vulnerability (e.g., drought, salinity, flood, heat and cold) appeared as the great challenges to keep the pace of food production in the background of increasing population. Sufficient rice production is the key to ensure food security in Bangladesh. In fact, 'Rice security' is synonymous to 'Food security' in Bangladesh as in many other rice growing countries (Brolley, 2015). Rice security is not just an economic issue but also an important parameter for determining social and political stability (Nath, 2015).

Since independence, there has been a three-fold increase in rice production in Bangladesh, which jumped from nearly 11 MT

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in 1971-72 to about 34.86 MT in 2014-15 (AIS, 2016). This has transformed the country from so called "Bottomless Basket" to a "Full of Food Basket". In recent years, the country has not only earned self-sufficiency in rice production, but also gradually entering into the export regime (BER, 2015). LaFranchi (2015) rightly said, "Bangladesh has emerged as a global model for combating hunger and obtained great success in becoming a country of food surplus from a country lagged with chronic food shortages".

Combined efforts of farmers, rice scientists, extension personnel and Government of Bangladesh have enabled the country with a surplus of about 2 MT of rice in 2014-15. In the last few years (2009-10 to 2013-14), rice production has increased by 0.34 MT per year (BBS, 2014). The challenge, however, is to continue maintaining the current surplus of rice in the coming decades in order to sustain rice security in the country. Before searching the way forward, it is needed to quantify the future rice demand and requirement, and address the resource utilization obligations. Bearing these in mind, this paper aimed to formulate a guideline to ensure sustainable rice production in Bangladesh up to 2050 and beyond.

METHODOLOGY

Definition of terms

Adoption lag. Time difference between releasing a rice variety and it reaches to the adoption peak, expressed as year.

Critical net cropped area. The minimum net cropped area as a function of national averaged clean rice yield to meet the projected rice requirement.

Cropping intensity. Cropping intensity, expressed as percentage, is the ratio of total cropped area and net cropped area in a particular year.

Rice. Rice denotes in this study for "clean rice" (or "milled rice") calculated as paddy rice × 0.65 (Islam *et al.*, 2006).

Net cropped area. Net cropped area is the maximum physical area cultivated in a year.

Smart technology. A technology which is sustainable, meets expectation and has business potential.

Yield gap. Difference between potential farm yield and actual farm yield.

Data collection

Secondary data (both published and unpublished) sourced from different government-owned statistics and research institutes were collected, analyzed and synthesized to develop model parameters and/or models for population prediction, rice production and requirement, rate of production increase of rice, adoption lag of varieties developed by the Bangladesh Rice Research Institute (BRRI), yield gap, cropping intensity, net cropped area, and soil organic matter (SOM) and rice yield relationship.

Population prediction

The model "ProjectPopBD" was developed and used to estimate population of Bangladesh from 1973 to 2100, considering 66.4 million as the base population in the year 1972 (UNPD, 2015). The population of a given year "x" can be calculated from the following equation:

$$Pop\_Yr(x) = Pop\_Yr(x-1) + AddedPop\_Yr(x) \quad \text{Eq. (1)}$$

Here (in Eq. 1), *Pop_Yr(x)* is population (expressed as million) in the year "*x*", *Pop_Yr(x-1)* is population in the immediate past year and *Added Pop_Yr(x)* is the added population for the year "*x*". *Added Pop_Yr(x)* was calculated in two steps: one, by regressing five-year's average of observed population during 1972 to 2015 (Fig. 1). Secondly, multiplying immediate pervious *AddedPop_Yr(x)* by slider multipliers (*MF_to_AddedPop_Yr(x)*). The sliding multipliers were assumed based on future implication on population growth due to changing socio-economic factors of the

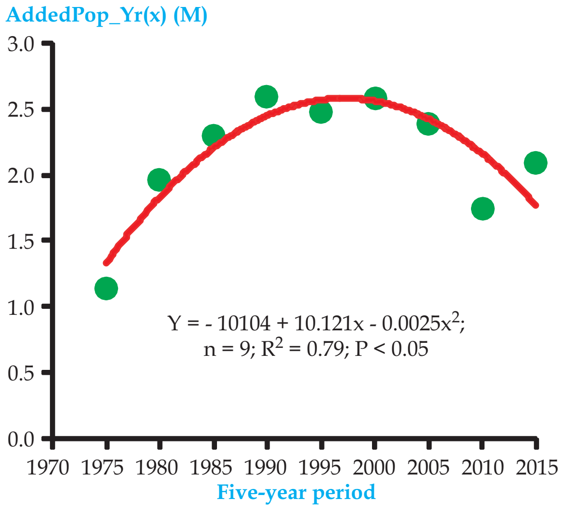

Fig. 1. Estimated statistics of AddedPop_Yr(x) in a five-year interval during 1970 to 2015. This statistics indicates the annual population to be added to the previous year's population in projecting current year's population (Eq. 1).

country, such as better education, employment, women empowerment, rural development, financial capability, changes in social perception, and motivation and awareness. The values of *AddedPop_Yr(x)* used in Eq. 1 to estimate population of Bangladesh from 1972 through to 2100 are shown in Table 1.

Table 1. The value of *AddedPop_Yr(x)* and multiplication factor to *AddedPop_Yr(x)* (*MF_to_AddedPop_Yr(x)*).

Period	*MF_to_AddedPop_Yr(x)*	*AddedPop_Yr(x)* (M*)
1975	-	1.33
1980	-	1.83
1985	-	2.20
1990	-	2.45
1995	-	2.57
2000	-	2.56
2005	-	2.42
2010	-	2.16
2015	-	1.77
2020	0.01	1.76
2025	0.02	1.72
2030	0.03	1.67
2035	0.04	1.60
2040	0.05	1.52
2045	0.06	1.43
2050	0.07	1.33
2055	0.08	1.22
2060	0.17	1.02
2065	0.19	0.82
2070	0.21	0.65
2075	0.23	0.50
2080	0.25	0.38
2085	0.31	0.26
2090	0.33	0.17
2095	0.35	0.11
2100	0.37	0.07

The dashes in column 2 indicate that the values of AddedPop_Yr(x) was estimated during 1972 to 2015 period using the equation shown in Fig. 1. "*" denotes for million.

Requirement and production of clean rice

The model "CleanRiceReq" was developed and used to calculate yearly requirement of clean rice in Bangladesh as a function of population as follows:

$$ReqClnRiceYr(x) = Pop\_Yr(x) \times MF\_ReqCln\ Rice \quad \text{Eq. (2)}$$

Here (in Eq. 2), *ReqClnRiceYr(x)* is the total requirement of clean rice, expressed as million ton (MT), in year "x", *Pop_Yr(x)* is population in year "x" (see Eq. 1), and *MF_ReqClnRice* is a constant.

Requirement of clean rice in Bangladesh has two components, the first one is for human consumption which is most often being confused as total requirement, and the second one is non-consumption uses. Per capita rice consumption in this country has been decreasing day by day. It was 179.9 kg person^{-1} year^{-1} in 1977 (Ahmad and Hasan, 1983), expected to decline to 147.2 kg person^{-1} year^{-1} in 2020, and reach the threshold of 133.2 kg person^{-1} year^{-1} in 2040 (Fig. 2). This threshold is the absolute daily minimum intake of carbohydrate required to meet calorie from rice (Murshid *et al.*, 2008). In addition to human consumption, rice is required as seed and feed. Besides, a significant amount of production gets wastage in the field and/or during processing. The non-human consumption portion of rice adds about 25% of the production (FAO, 2011). We calculated the ratio of total rice requirements and population for the years 1972 to 2014, where the value of the ratio was almost the same (0.21) from 2008 onwards. We assumed this value for the constant *MF_ReqClnRice* (Eq. 2). Clean rice requirement estimated in this

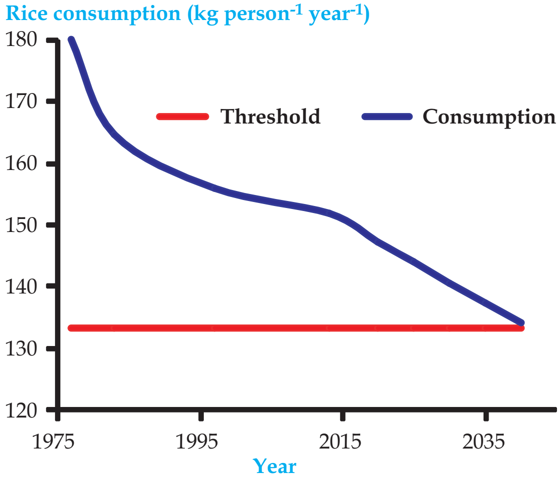

Fig. 2. The trend in declining clean rice consumption in Bangladesh (vertical line). The horizontal line shows the threshold, which is the absolute daily minimum intake of carbohydrate required to meet calorie from rice.

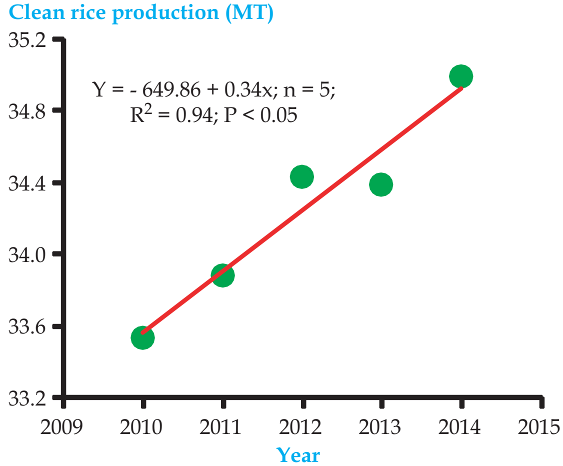

Fig. 3. The regression (solid straight line) between observed production (filled circle) of clean rice and corresponding year of production in Bangladesh.

model was also designated as the "target requirement" of rice in future.

The developed model "CleanRicePdn" calculates annual production of clean rice according to the following regression equation:

$$PdnClnRiceYr(x) = a + b \times Yr(x) \quad \text{Eq. (3)}$$

Here (in Eq. 3), *PdnClnRiceYr(x)* is the total production of clean rice, expressed as million ton (MT), in year "x", and "*a*" and "*b*" are parameters. Rice production data during 2010 to 2014 (BBS, 2015) were used to derive the parameter values (Fig. 3). In this study, production of clean rice estimated by the model is designated as the "target production" of rice for the future.

Clean rice production under resource limitations

In the present study, two factors were considered that could adversely affect future rice production in Bangladesh, (i) gradual decrease in rice land, and (ii) stagnation of national rice yield. These factors were accounted for in the following equation.

$$PdnClnRiceYr(x)\_WS = RiceLandYr(x-1) \times ((100 - RLRR)/100) \times SNRY \quad \text{Eq. (4)}$$

Here (in Eq. 4), *PdnClnRiceYr(x)_WS* is the production of clean rice (MT) under resource limitations in year "x", *RiceLandYr(x-1)* is land under rice (M ha) in the immediate past year, *RLRR* is rice land reduction rate (%) year^{-1}, and *SNRY* is stagnant national rice yield (t ha^{-1}). The *RLRR* is a constant and its value was taken as 0.4% (The daily Prothom Alo, 2015). The *SNRY* is also a constant and the value (3.17 t ha^{-1}) was derived from weighted average of national yield of Aus, T. Aman and Boro during 2009-2013 (BBS, 2015).

Interventions. Three interventions were employed in order to maintain the current momentum of rice production in Bangladesh. These are: (i) accelerating genetic gain, (ii) minimizing yield gap, and (iii) curtailing adoption lag of rice varieties in the field.

(i) ***Accelerating genetic gain.*** Clean rice production, by accounting for accelerating genetic gain, (*PdnClnRiceYr(x)_Interven(1)*, MT) was calculated from the following equation.

$$PdnClnRiceYr(x)\_Interven(1) = RiceLand\ Yr(x) \times (CRYYr(x-1)+RYAC) \quad \text{Eq. (5)}$$

Here (in Eq. 5), *RiceLandYr(x)* is the rice land available for the year "x" (M ha), CRYYr(x-1) is the clean rice yield (t ha^{-1}) in the immediate past year, and *RYAC* is the rate of annual yield increase due to accelerating genetic gain (t ha^{-1} $year^{-1}$). The model was run with the base yield of 3.17 t ha^{-1} (the weighted average yield of Aus, T. Aman and Boro during 2009-2013).

(ii) ***Minimizing yield gap.*** Yield gap, as defined earlier, was calculated as a difference between potential farm yield and actual farm yield. The actual farm yield was calculated as a value of constant *SNRY*, described earlier in Eq. 4. The potential farm yield was calculated from the performance of five prominent BRRI varieties: BRRI dhan26 and BRRI dhan48 (Aus season), BRRI dhan49 (T. Aman season) and BRRI dhan28 and BRRI dhan29 (Boro season) (BRRI, 2015b). The rough rice yield was converted into clean rice yields by multiplying the factor or 0.65 (Islam *et al.*, 2006), and compiled as weighted average. The calculated yield gap is presented in Fig. 4.

Clean rice production, by accounting for minimizing yield gap, (*PdnClnRice Yr(x)_Interven(2)*, MT) was calculated from the following equation.

PdnClnRiceYr(x)_Interven(2) = *RiceLand Yr(x)* × (*CRYYr(x-1)* + *CRYYr(x-1)* × *YGRF*) Eq. (6)

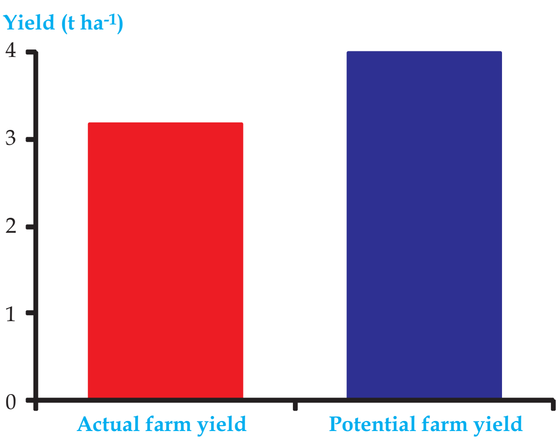

Fig. 4. The actual farm yield and potential farm yield of clean rice in Bangladesh, showing the yield gap of 0.83 t ha^{-1} or 20.7%.

Here (in Eq. 6), *YGRF* is the annual yield gap reduction factor, a parameter of the model. The value of the parameter was calculated as 0.012 by using "solver" function in MS Excel 2010 by imposing a condition that the clean rice surplus in 2050 will remain at least as of the current figure.

(iii) Reducing adoption lag. Data of adoption of four prominent BRRI released varieties - BR11, BR22, BRRI dhan28 and BRRI dhan29 - in three seasons (Aus, T Aman and Boro) were gathered from the Agricultural Economics Division of BRRI. Data were fitted using three parameter Weibull equation (Jansen, 1992; Abernathy, 2006) to develop adoption curves (Fig. 5). The timing of accelerating genetic gain (Intervention 1) scenario was advanced by 5 and 10 years to mimic the reduction in adoption lag.

The outputs of the model run for the above-mentioned three interventions were expressed as deficit or surplus of clean rice requirement compared to "target requirement". The "target requirement" is the amount of clean rice (MT) needed to maintain the expected surplus in 2050.

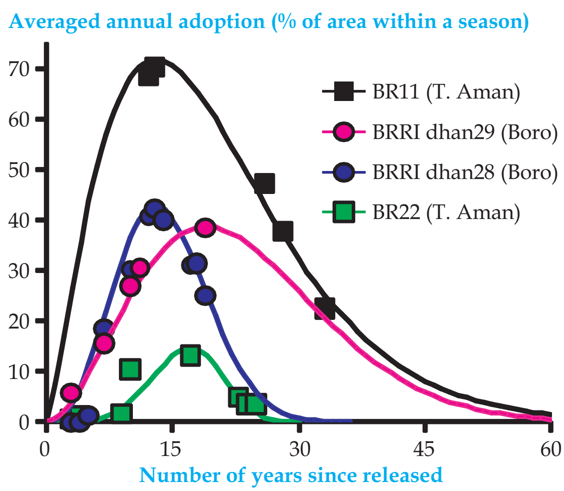

Fig. 5. The adoption curve of four prominent BRRI (Bangladesh Rice Research Institute) released rice varieties in three seasons in Bangladesh. The curves were fitted using three parameter Weibull equation using data from Agricultural Economics Division of BRRI.

Resource utilization obligations

Net cropped area, critical net cropped area and rice area. Relationship between net cropped area and rice area was estimated through regression analysis. For this, 38 years' simulated data (2013 - 2050) were used. These data were generated from present study. Thereafter, a relationship between national average clean rice yield and critical net cropped area was established. The critical net cropped area, as defined earlier, is the minimum net cropped area as a function of national average clean rice yield to meet the predicted rice requirement.

Accumulation of soil organic matter. Accumulation of soil organic matter (SOM) in a Rice-Rice system was predicted from the following equation.

$$SOMYr(x) = SOMYr(x\text{-}1) + SOMIR \quad \text{Eq. (7)}$$

Here (in Eq. 7), *SOMYr(x)* is the SOM (%) in year "x", *SOMYr(x-1)* is the SOM in previous year and *SOMIR* is the annual increase of SOM. The value of *SOMIR* was calculated as 0.009% from 22 years experimental data from BRRI's research station at headquarters, Gazipur.

Prediction of cropping intensity. The ratio of net area sown to the total cropped area or cropping intensity of Bangladesh was calculated based on the net cropped area (NCA), single cropped area (SCA), double cropped area (DCA) and triple cropped area (TCA) of Bangladesh recorded in the Year Book of Agricultural Statistics for different years (1992-2013). The historical data (1972 to 2012) and its trend were used to simulate the long term cropping intensity of Bangladesh. Based on the previous trends, it was considered that SCA would be decreasing gradually for the initiatives of adopting new crops in different stress environment and would reach to 1,789,000 ha in 2037 with the present trend of technological advancement. We further assumed that the SCA would be reduced @ 2% from 2037 on due to adoption of third generation stress tolerant varieties of crops. The model considers the TCA would be increasing @ 44,000 ha year^{-1} up to 2,277,000 ha in 2026 onwards, but a part of that would be shifted to four cropped area through the adoption of super short duration crops. The DCA would be decreasing due to shifting DCA to the TCA. The limit of decreasing SCA and increment of TCA up to a certain limit was calculated consulting the database of Elahi *et al.* (2001) and the dataset of Bangladesh Bureau of Statistics for different years.

RESULTS AND DISCUSSION

Population of Bangladesh: 2050 and beyond

In 2015, population of Bangladesh stood at 160.0 million. Our model predicts the population in 2030 will be 186.0 million, which will reach to 215.4 million in 2050. As shown in Fig. 6, we further predict that the population of this country will become almost static around the year 2071 (about 243 million). In the end of this century, the population of Bangladesh is predicted to reach 249.3 million.

From yearly population data of Bangladesh (Fig. 7), it is evident that the population growth rate was higher in late 70's (UNPD, 2015). Growth rate is decreasing since 1980 (2.85%) and currently (2014) stands as 1.22%. Considering medium fertility as variant, United Nations Population Division (UNPD) has anticipated that there will be an

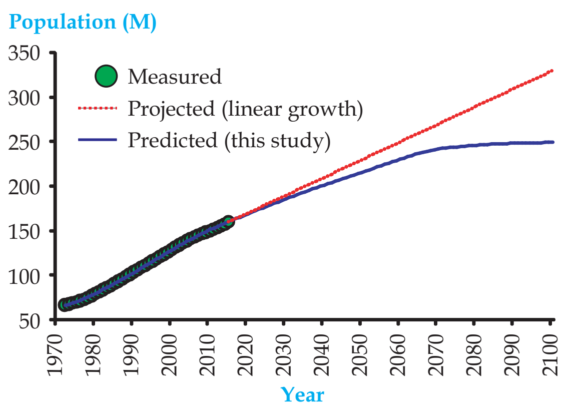

Fig. 6. Measured (solid filled circles from 1972 to 2013) and predicted (solid exponential line) population of Bangladesh leading to 2100. The broken line shows the projected population if the growth continued to be linear.

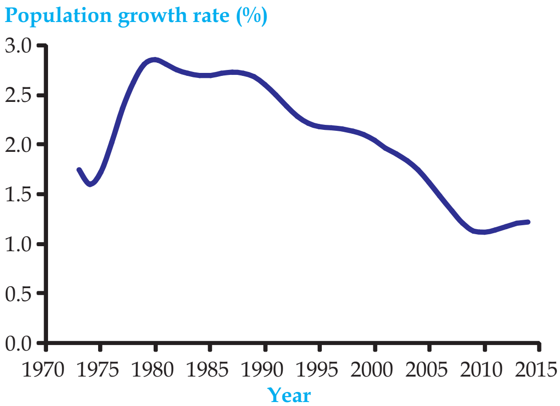

Fig. 7. Population growth rate in Bangladesh during 1972 to 2015 (prepared by authors, data from UNDP (2015)).

added population of more than 56 million by 2050 to share the total available food (Mukherjee *et al.*, 2011).

It may be noted that the Government of Peoples' Republic of Bangladesh has proclaimed "Vision 2021" to drive the country's sustainable development agenda by striking the right balance between equitable national economic progress and human development (MOP, 2015). In predicting the population, incremental effect of various Government interventions were considered. For example, the scope for better education, wider employment facilities, women empowerment, rural development, financial solvency, changes in social perception, and motivation and awareness. It is obvious to expect that increased investment, faster human capital accumulation, enhanced productivity growth and higher outward orientation will lead the country toward becoming middle income and/or developed country within 2050. Government's planning for "Vision 2021" incorporates cent percent net enrolment at primary school, reducing unemployment rate to 15%, reducing maternal mortality to 1.5%, raising the use of birth control methods to 80%, bringing down infant mortality to 15 per thousand live births, ensuring minimum intake of 2,122 kcal person^{-1} day^{-1} and standard food for 85% of the population (MOP, 2015). Although Bangladesh retains one of the highest proportions of teenage marriage in the world (Streatfield and Karar, 2008), it is experiencing a trend of gradual delay in age of marriage for young women. Substantial investments on educational inputs like free schooling for girls up to grade 12, national female secondary school stipend scheme along with improved scope of employment in Ready-made Garment (RMG) sector are being translated into delayed marriage. Continued government interventions in female education and empowerment would bring changes in livelihoods and social perceptions in the coming decades resulting delays in marriage and contribute in decreasing number of child per woman. Rural population growth rate is a big force that elevates the total population. Rapid urbanization has been turning "rural" Bangladesh into "city-like" Bangladesh which has a negative impact on family development. In the coming decades, there will be a provision of social security and allowances for the common people that would guarantee better financial capability. The social perception of the rural population of the country is changing. People in the country no longer believe that older-aged generation will be looked after by the family members, thereby no need to increase family member for this purpose. Better medical facilities, health insurance, living assistance and allowances, and communication and information technology will uplift mass people's living standard and way of thinking. Moreover, awareness of development programs taken by public and private organizations will negatively influence population growth.

Clean rice requirement and production

Bangladesh needs to feed 215.4 million people in 2050. The current consumption of rice is 148 kg person^{-1} year^{-1}, which is decreasing by 0.7 percent each year. This trend is expected to lead the requirement to the threshold level of 133 kg person^{-1} year^{-1} by 2040 (Fig. 2). Furthermore, around 25% of the production is required for non-consumption uses like seed, feed, wastage, and processing (FAO, 2011).

Considering those, our model (Eq. 2) accurately predicted clean rice requirement in Bangladesh during 1972-2013 (R^2 = 0.98; n = 42; P< 0.05, Fig. 8). The partitioning of clean rice requirement between consumption and non-consumption during 1972-2014 is shown in Fig. 9. The figure indicates that during 2014 the total requirement of clean rice was 32.8 MT (24.1 MT for consumption and 8.7 MT for non-consumption). During the same period, the country produced 34.86 MT of clean rice, indicating a surplus of 2.06 MT. We set the rice vision for Bangladesh for 2050 and beyond to maintain, at least, this surplus.

Rice production in Bangladesh has taken significant momentum since 1990-91, especially during two phases, from 1996-97 to 2000-01 and from 2009-10 to 2013-14 (Fig. 10). Significant reasons for this include, Government's support in mechanization and irrigation, controlling fuel and fertilizer price hike, improved loan distribution policy (loan deposit directly to farmers' account operated with 10 Taka only), well organized fertilizer supply, increased quality seed supply by public and private sectors, and technological interventions (e.g. genetic improvements for favorable and unfavorable ecosystems).

With the current rate of production increase by 0.34 MT year^{-1} (averaged during

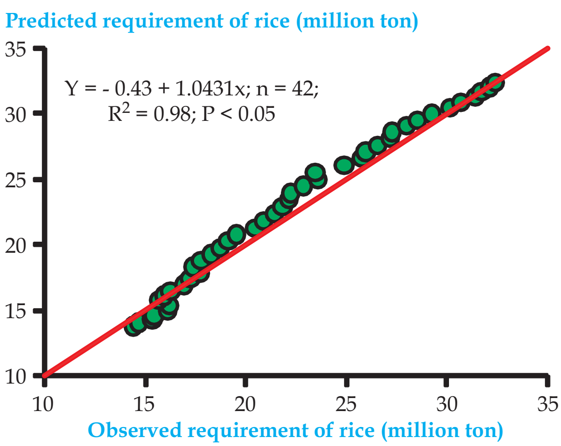

Fig. 8. Regression between observed (filled circles) and predicted requirement of clean rice during 2072 to 2014. The solid line indicates 1:1 line passing through origin.

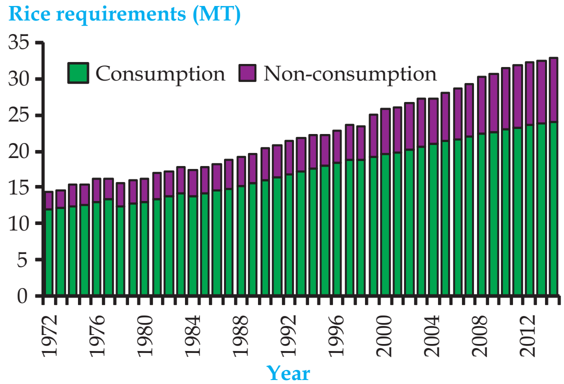

Fig. 9. Partitioning of clean rice requirement in Bangladesh between consumption and non-consumption purposes during 1972-2014.

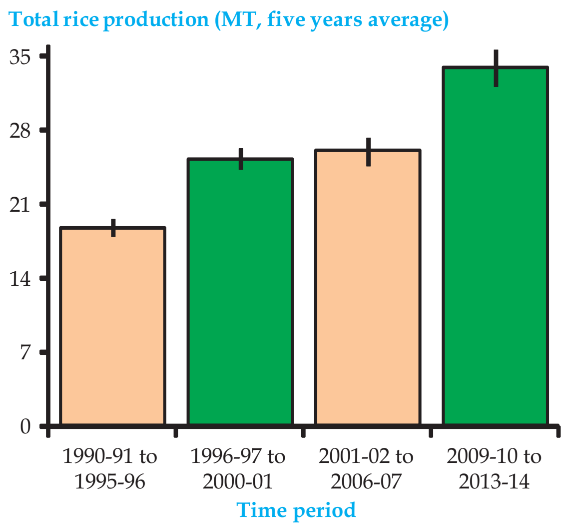

Fig. 10. Phasic development, averaging five-year period, of clean rice production in Bangladesh during 1990-91 to 2013-14. Vertical bars indicate standard errors.

2010-14), rice production in 2050 could reach to 47.2 MT, given the area under rice remains unchanged. Our model predicts, the clean rice requirement for the country in 2050 would be 44.6 MT resulting a surplus of 2.6 MT (Fig. 11).

Portraying future scenario of rice production under resource limitations

There is a hind side of the predicted clean rice production leading to 2050 as depicted above. Statistics indicate that the area under rice has been decreasing at the rate of 0.4% year^{-1} (The

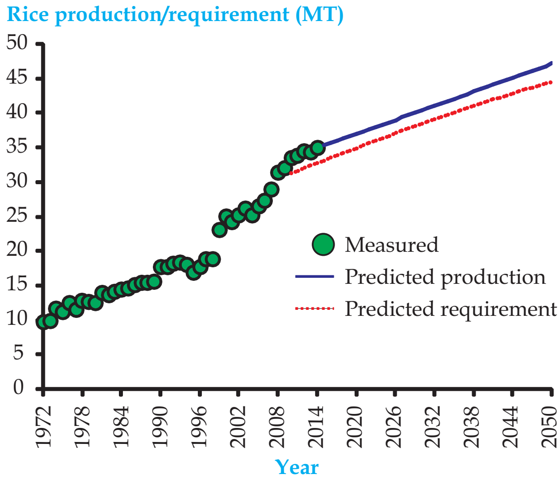

Fig. 11. Measured (filled circles, from 1972 to 2014) and projected requirement and production of clean rice in Bangladesh leading to 2050.

daily Prothom Alo, 2015). If the trend continues and the current national rice yield remains unchanged (average of 3.17 t ha^{-1}), we predict 31.1 MT clean rice production in 2050 from 9.8 M ha rice area (Fig. 12). This translates as a production deficit of 16.1 MT and requirement deficit of 13.5 MT in 2050 to what we calculated in Fig. 11.

Interventions for achieving rice production goal for 2050

The challenge would be to lift the future rice production of Bangladesh from the "red" line to "blue" line in Fig. 12 in order to achieve the goal of maintaining at least 2.6 MT surpluses in 2050. Three major interventions were employed to achieve the goal.

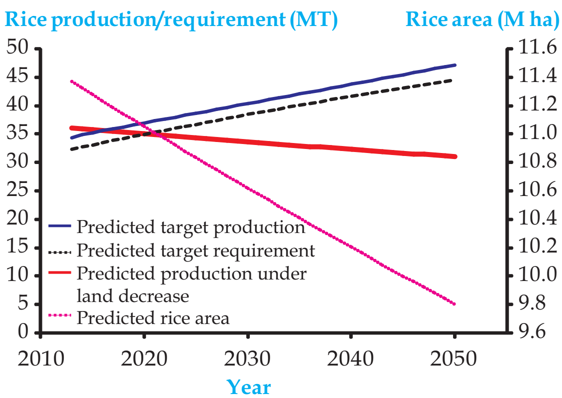

Fig. 12. Predicted decrease in rice area and consequent clean rice production, target production and requirement of clean rice leading to 2050. The target production aims to ensure rice surplus of at least 2.6 MT in the year 2050.

Intervention 1. Results show that by incrementally improving genetic yield potential of rice by 0.044 t ha^{-1} $year^{-1}$, it is possible to secure 2.7 MT of surplus in 2050 (Fig. 13). If this is to happen, the current national average clean rice yield of 3.17 t ha^{-1} will have to be elevated to 4.82 t ha^{-1} in 2050.

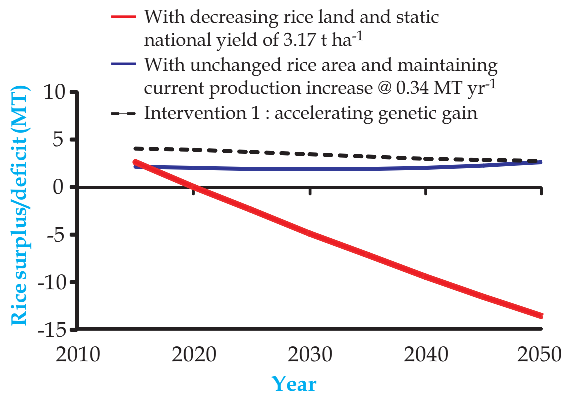

Fig. 13. Achieving clean rice surplus of at least 2.6 MT in year 2050 through the intervention of accelerating genetic gain @ 0.044 t ha^{-1} $year^{-1}$.

Intervention 2. We calculated the yield gap of 0.83 t ha^{-1} (or 20.7%) between actual farm yield and potential farm yield in Bangladesh (Fig. 4). If this yield gap could be reduced @ 1.135% $year^{-1}$, 4.8 MT surplus in 2050 (Fig. 14) can be achieved.

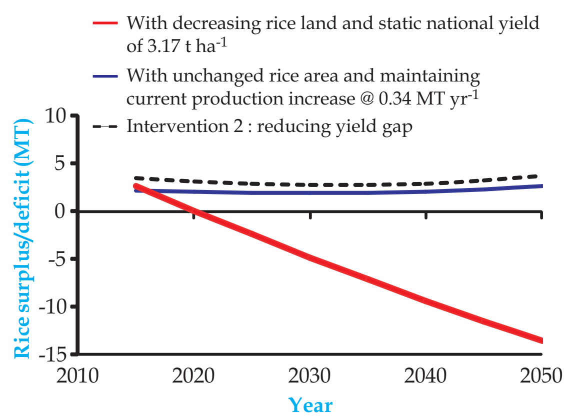

Fig. 14. Achieving clean rice surplus of at least 2.6 MT in year 2050 through the intervention of reducing yield gap @ 1.135% $year^{-1}$.

Intervention 3. The average time to reach the adoption peak of BRRI (Bangladesh Rice Research Institute) released promising varieties has been calculated as 16±3 years (Fig. 5). Results show that curtailing this adoption lag of newly released promising varieties by 5 years and 10 years will result in clean rice surplus of 2.1 MT and 4.3 MT, respectively, in 2050 (Fig. 15).

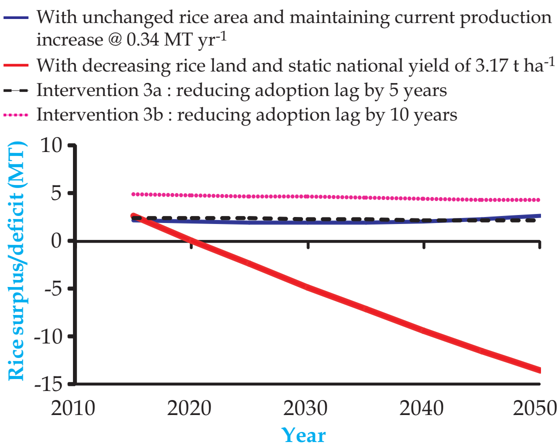

Fig. 15. Achieving clean rice surplus of at least 2.6 MT and 4.6 MT in year 2050 through the intervention of curtailing adoption lag of newly released promising varieties by 5 years and 10 years, respectively.

Resource utilization obligations

For implementing the above mentioned interventions, there would be several obligations to utilize the resources. Land is the key factor for crop production and shrinking cultivable land area is the major threat for the agriculture sector of Bangladesh. The available crop land is under immense pressure of providing food for the big population. Moreover, imbalanced fertilization and increased cropping intensity is hampering soil health. We have pointed out some obligations that would address whether the country's rice land is being affected or not with the decrease of net cropped area, how much land should critically be guaranteed for rice cultivation in the coming decades and how intensively we are allowed to deplete our soil.

Our analysis found a strong positive relationship between net cropped area and rice area in Bangladesh (Fig. 16). This indicates that any change in net cropped area will equally affect rice area, thereby likely to influence the rice production.

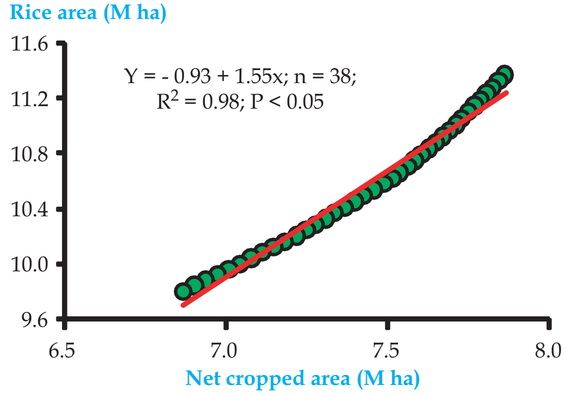

Fig. 16. Regression between net cropped area and rice area during 2013 to 2050. Solid line is the linear regression and filled circles are the estimations.

The minimum net cropped area to meet the rice requirements leading to 2050 will depend on achievable national yield. Fig. 17 shows that provided farmers' yield reach at 4.5, 5.0 and 6.0 t ha^{-1}, respectively, a minimum of 6.98, 6.29 and 5.71 M ha of net cropped area to be guaranteed to meet national rice requirement in 2050.

Soil organic matter is a key to maintain soil health. BRRI (Bangladesh Rice Research

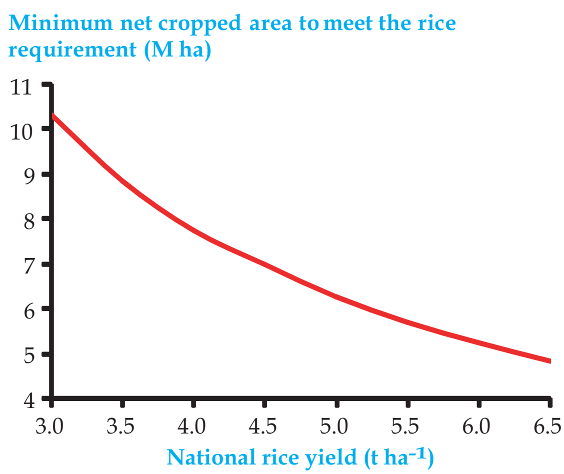

Fig. 17. Relationship between achievable national clean rice yield and the minimum net cropped area to meet the clean rice requirement in 2050.

Institute) research data shows about 2.4% of soil organic matter is critical to achieve annual rice yield of above 10 t ha^{-1} (Fig. 18). Research findings further indicate that in the Rice-Rice cropping systems, soil organic matter content does not deteriorate, rather it increases. It has been estimated that maintaining 20 cm rice straw cut height can eventually elevate soil organic matter content to threshold level of 2.4% (Fig. 19) and add 30-40 kg ha^{-1} muriate of potash (MOP) fertilizer in the soil (BRRI, 2015a).

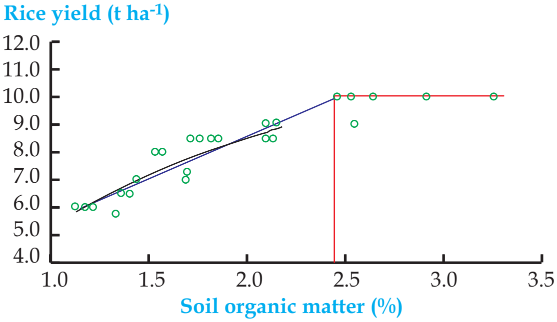

Fig. 18. Critical soil organic matter (SOM) content to maintain high rough rice yield (>10 t ha^{-1}). Data from various agro-ecological zones of Bangladesh. Reconstructed from published figure presented in the Annual Research Review 2009-10, Soil Science Division, Bangladesh Rice Research Institute (BRRI). Blue line shows increase of yield with increasing SOM, and the horizontal red line shows static yield when the SOM reaches ~2.4% (vertical read line).

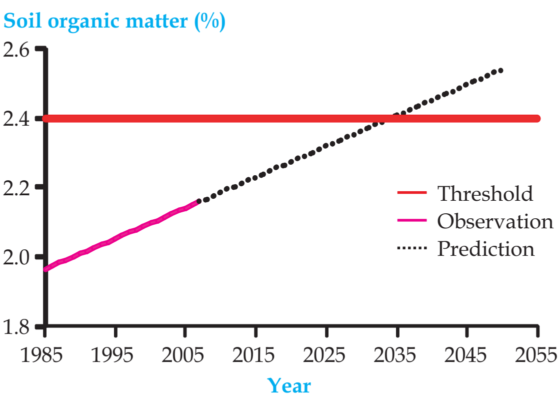

Fig. 19. Observed and predicted soil organic matter content in the Rice-Rice cropping systems through maintaining 20 cm rice straw cut height. The threshold indicates the level to be ensured to achieve annual rough rice yield of above 10 t ha^{-1}.

Long-term BRRI research indicates that rice productivity can be increased any time by re-fertilization of zero-fertilized rice land. Figure 20 shows re-fertilization of zero-fertilized rice land after 14 years restored productivity as of fertilized land. Therefore, proper management of soil for getting the highest yield is an urgent need.

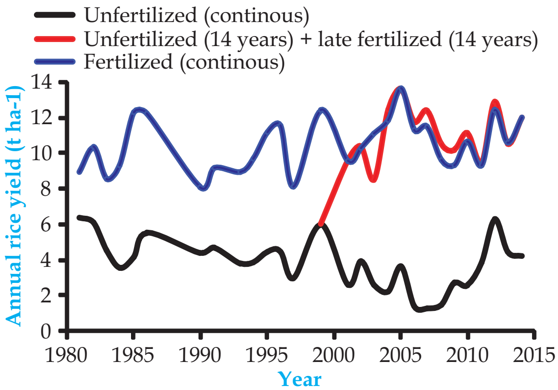

Fig. 20. The long-term experimental results at Bangladesh Rice Research Institute (BRRI) research station headquarters at Gazipur, Bangladesh. Re-fertilization of zero fertilized rice land after 14 years restored productivity as of continued fertilized land.

It would be difficult to feed the growing population by practicing only organic agriculture in rice production. Use of balanced fertilizers (urea, triple superphosphate (TSP), muriate of potash (MOP), Zinc (Zn) and Sulfur (S)) is a necessary mean of exploring the yield potential of rice varieties. Balanced fertilization has no serious harmful effect on soil health for further crop production rather the production will decline under organic practice alone. However, application of rotten poultry litre @ 2 t ha^{-1} (on a dry-weight basis) can supply full amount of TSP and S for rice and save 50% of urea and MOP (BRRI, 2015a). Use of Urea Super Granule (USG) is another mean of urea management which is considered as resource saving and trigger the yield.

There will be limited scope of increase in cropping intensity, which stands as 193% in 2015 (BBS, 2015). Our model predicts the cropping intensity of Bangladesh cannot be exceeded beyond 221% leading to 2050 (Fig. 21).

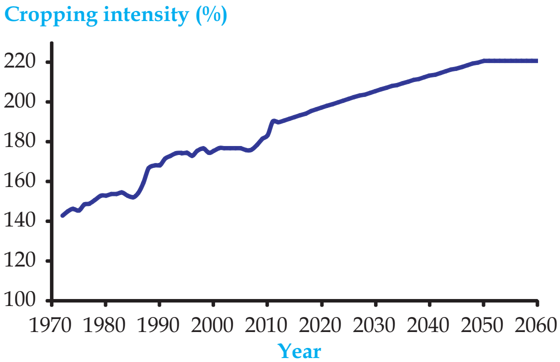

Fig. 21. Predicted cropping intensity of Bangladesh leading to 2050 and beyond.

Declining ground water table is a common scenario across the agricultural regions of Bangladesh, where Boro rice is greatly affected. Obligations, in this regards, include, shifting of ~15% "water shortage Boro area" to rainfed culture (i.e., Aus rice), adoption of dry-direct seeded aerobic culture, scoping partial irrigation for T. Aus during crop establishment and supplementary irrigation for T. Aman, finding and adopting short duration high yielding T. Aman rice varieties (*Rabi* (winter) crop in preceding season), and efficient utilization of water in rice cultivation.

Profitability is an essential driver to sustain rice production of Bangladesh. As a common nature, rice production can get reduced in the following year if the profitability of current year is not ensured. For this, farmers need to get right price for their products. Steps are required to formulate efficient rice marketing system involving all stakeholders so that farmers can receive profitable farm-gate price.

Options to maintain the momentum: smart technology

Improved variety. A number of smart rice varieties have been released by BRRI (Bangladesh Rice Research Institute) for different environments and seasons (Table 2). For example, in T. Aman season under favorable ecosystem, BRRI dhan62 has 100 days growth duration with 5.0 t ha^{-1} yield potential, BRRI dhan72 is zinc enriched (22.8 ppm) variety with 125-130 days growth duration and 5.5 t ha^{-1} yield potential, BRRI dahn49 is one-week earlier than BR11with Nizersail-type grain with 5.5 t ha^{-1} yield potential, BRRI dhan70 is a long slender aromatic variety with 130 days growth duration and 5.0 t ha^{-1} yield potential. For the same season, BRRI dhan66, BRRI dhan70, BRRI dhan71 and BRRI dhan72 could be replaceable to "Swarna" as these varieties possess similar yield potential with 10-25 days earlier growth duration than "Swarna" cultivars. During T. Aman, BRRI dhan56, BRRI dhan66 and BRRI dhan71 have drought tolerance, BRRI dhan52 has submergence tolerance, BRRI dhan41, BRRI dhan54 and BRRI dhan73 have salinity tolerance, BR22, BR23 and BRRI dhan46 are suitable for late planting under post-flood situation, BR23 and BRRI dhan30 can tolerate moderate water stagnation, and BRRI dhan44 can tolerate moderate tidal submergence.

In Boro season, BRRI dhan58 is 7-10 days earlier than widely adopted BRRI dhan29 with similar yield potential and grain quality, whereas, BRRI dhan60 has ~1.0 t ha^{-1} yield advantage with extra-long slender grain and 3-4 days longer growth duration than another mega-variety BRRI dhan28. BRRI dhan50 and BRRI dhan63 are the export potential premium quality high yielding (6.0-7.0 t ha^{-1}). BRRI dhan74 is a zinc enriched (24.2 ppm) variety, yielding ability of 7.1–8.3 t ha^{-1}, 147 days duration, 28% amylose content, moderately tolerant to blast disease; besides, BRRI dhan67 which has slender grains is better tolerant to salinity compared to BRRI dhan47.

BRRI dhan48, BRRI dhan65 (also as B. Aus) and NERICA Mutant are short duration high yielding varieties with adaptation capability under T. Aus ecosystem.

Disease management. Rice diseases always have a significant impact on rice productivity. In Bangladesh, a total of 32 rice diseases have been identified. Historically, severe epidemics led to serious food shortages

Table 2. List of smart rice varieties released by the Bangladesh Rice Research Institute (BRRI) for different environments and seasons.

Category	Conventional variety	Smart variety
T. Aman: Favourable environment		
Short duration	BRRI dhan33	BRRI dhan62
	BRRI dhan39	BRRI dhan72
		BRRI hybrid dhan4
Medium/long duration	BR11	BRRI dhan49
Aromatic high yielding	BRRI dhan38	BRRI dhan70
Possible replacement of "Swarna" in rainfed lowland	Swarna	BRRI dhan66
		BRRI dhan70
		BRRI dhan71
		BRRI dhan72
T. Aman: Unfavourable environment		
Drought	-	BRRI dhan56
		BRRI dhan66
		BRRI dhan71
Submergence	-	BRRI dhan52
Salinity	-	BRRI dhan41
		BRRI dhan54
		BRRI dhan73
Late planting (post flood)	-	BR22
		BR23
		BRRI dhan46
Water stagnation (moderate tolerance)	-	BR23
		BRRI dhan30
Tidal submergence (moderate tolerance)	-	BRRI dhan44
Boro: Favourable environment		
Short duration	BRRI dhan28	BRRI dhan60
		BRRI dhan63
Long duration	BRRI dhan29	BRRI dhan60
		BRRI dhan63
Premium quality	-	BRRI dhan50
		BRRI dhan63
High zinc	-	BRRI dhan74
Hybrid	-	BRRI hybrid dhan3
Boro: Saline environment		
Salt tolerant	BRRI dhan47	BRRI dhan67
T. Aus: Favourable environment		
Standard duration	Parija	BRRI dhan48
	Jamaibabu	BRRI dhan65 (also as B. Aus)
	BR26	NERICA Mutant

due to diseases. The Bengal famine in 1942 was, in part, attributed to brown spot of rice disease (Padmanabhan, 1973). Bacterial leaf blight and neck blast are chronic diseases both in T. Aman and Boro season in Bangladesh while severity of sheath blight has been higher in T. Aman season. Bacterial leaf streak has become an emerging disease in both T. Aman and Boro season. Tungro and Root knot diseases are serious threat especially to Aus rice cultivation in Bangladesh. Regarding host resistance, it is unfortunate that resistance capacity of a particular disease resistant variety deteriorates or totally breaks down because of emerging a new race of the pathogen in few years. Understanding both pathogen population structure as well as host pathogen resistance is the prerequisite in designing of effective strategy for deployment of resistance. Durable resistant varieties can help to minimize the resistance breakdown problem. Gene pyramiding is one of the ways to develop durable resistant variety (Ashkani *et al.*, 2015). New races of pathogen population of the diseases like blast and bacterial blight could be evolved causing threat to rice disease management. For example, recently BRRI dhan28 is being affected seriously with leaf or neck blast although it had been considered as moderately resistant to blast since its release (BRRI 2015a). Identification of physiological races of bacterial blight and blast diseases are in progress (Khan *et al.*, 2009; Khan *et al.*, *2014*) for the development of durable resistant varieties. However, the control of blast and sheath blight diseases can be done following integrated disease management strategies (BBRI, 2015b). Recently developed TSR (Tray Seedling Raising) is highly effective protocol in raising healthy seedling against seedling blight disease (Ansari *et al.*, 2016). TSR protocol will eliminate the adoption barrier of mechanical transplanter in Boro season. Another smart technology "Ankuri" can ensure healthy seed germination saving around 20% seed resource during cold environment (Ansari and Ahmed, 2015).

Rice false smut is a typical example of changing status of a disease in Bangladesh. This disease is now emerging, which is hindering adoption of a promising T. Aman rice variety, BRRI dhan49. Intensive research is underway to formulate prescription for the management of the disease. The yield loss model has been developed (Nessa *et al.*, 2015a), and spatial distribution leading to an important aspect of the epidemiology of the disease under natural condition have been studied (Nessa *et al.*, 2015b). While proper chemical control option has not been worked out yet, the disease likely to be managed through adopting a transplanting time so that the T. Aman rice does not flower on and after mid-October (Fig. 22). Late planting is also vulnerable to production of sclerotia (the resting stage of the pathogen), the inoculum source for next year's disease infection.

Disease management systems, across the world, have relied primarily on new resistant

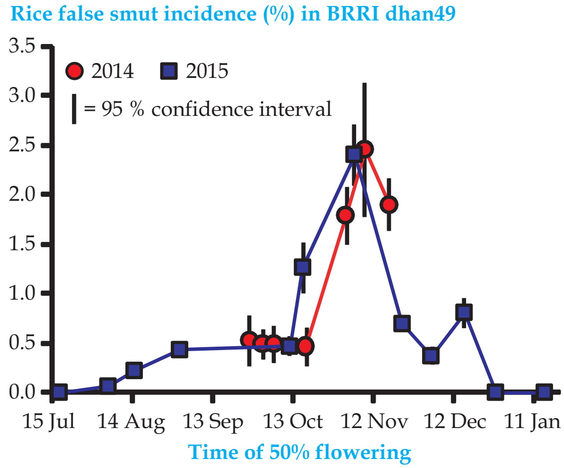

Fig. 22. Incidence of rice false smut disease on BRRI dhan49 as affected by the flowering time of the crop (Nessa *et al.*, 2015c).

varieties based on single gene, cultural management practices and on application of fungicides. A true measure of a successful disease research and management program is required to sustain modern agriculture with the needed intensity to meet food demand. In addition, monitoring and preparedness for preventive measures like gene pyramiding, durable resistant varieties and disease forecasting, sustainable integrated disease management and seed health management technologies should be taken into account.

Insect pests management. In the years leading to 2050, rice planthoppers (RPH, such as brown plant hoppers (BPH), whitebacked planthoppers (WBPH) and small brown Planthopper (SBPH)) as migratory pests, Leaf folder (LF), Gall-midge (GM), Mealy bug and Rice rats (for short duration varieties like BRRI dhan62) can become major damaging pests. Invading new pests like SBPH and Rice black beetle could evolve causing threat. Furthermore, some insects might change their biotype (e.g., BPH and GM) Therefore, preventive measures by strengthening surveillance and field monitoring system for pests (such as, using Light Trap and Yellow Sticky Trap) and environment friendly pest management options like perching, eco-engineering with pest and natural enemies, and establishment of Owl Watching Tower for rat control should be taken into account.

Human nutrition. Sustainable food security is not only depends on sustainable food production but also include the intake of food calories and nutrition. Commercial exploitation and efficient rice processing of nutrient enriched rice could be an attractive. Premium quality rice and zinc and iron enriched rice could be the planned target.

Parboiling reduces glycemic index (GI) value by 16 to 30% compared to the non-parboiled (Larsen *et al*., 2000). Reducing the degree of milling from 10 to 6 or 4% increase mean zinc content to 27 and 47%, respectively (Dipti, 2013). Rice itself does not cause common lifestyle diseases (e.g. Alzheimer's disease, cancer, chronic liver disease/ cirrhosis, diabetes and heart disease).

Rice is a source of nutrition. Changes in food habit as well as rice based nutrient enriched food processing should be taken into consideration to achieve or accelerate the projected threshold rice intake at 133.2 kg person^{-1} year^{-1} by 2050 or even before.

Mechanization. The agricultural labor force has followed decreasing trend (48.3% in 2002-03 and 45.1% in 2013) whereas increased in non-agricultural sector (51.7% in 2002-03 and 54.9% in 2013) due to shifting from low productivity to high productivity sector (BBS, 2015). Transplanting, weeding, harvesting, threshing and cleaning are the most labor intensive operations in rice cultivation. Mechanical transplanting reduces 61% labor and 18% cost, weeder reduces 74% labor and 72% cost, and mechanical harvesting saves 96% labor and 72% cost compared to traditional method (Islam *et al*., 2016). In order to make agriculture attractive and sustainable to future generation, cent percent mechanization is essential for enhancing productivity. Such mechanization will allow timely and faster operation with less drudgery. It will minimize labor shortage, reduce postharvest loss by 2-3%, and increase head rice recovery by 2-3% (Islam, 2004).

Land reform (changing size and shape) and creation of farm road for accessibility of farm machinery are very important aspects to operate machines at full capacity. Government assistance is needed for purchasing high cost machinery especially transplanter and combine harvester. Much awareness programs need to be strengthened for successful farm mechanization. Service provider oriented mechanization could be an effective way for getting faster benefit. Land preparation by power tiller is such an example in this country being practiced in the last decades. Public-private partnership approach is another way to manufacture quality machine, develop skilled operator and mechanic and promote farm mechanization. Policy makers can consider this 'service provider mechanization system' and Government should come forward to equip the service provider with subsidized rice transplanter, reaper, and combine harvester. Commercial utilization of these agricultural machineries will definitely help for food security and sustainability in this country.

Ensuring quality seed supply. Considering a conservative estimates of seed multiplication rate (1:80), minimum of 80 kg "Foundation Seed" can be produced from one kg "Breeder Seed". From this 80 kg "Foundation Seed" and a minimum of 6400 kg "Certified Seed" can be produced. BRRI annually produces around 100 ton "Breeder Seed", from which 6.5 lakh ton "Certified Seed" can be produced. This amount is about double of the national quality seed demand.

However, 35% of the quality seed is now being supplied by the government. The rest of the seed sources are the farmers' saved rice seed produced for their own food, NGO's seed, private traders or local market. Those are not good quality seeds as a whole. Therefore, quality seed production and distribution system should be ensured so that quality seed become available and farmers can use good quality seed in rice production. This will ultimately minimize yield gap and significantly increase productivity.

Options to maintain the momentum: smart dissemination

A number of avenues are available or to be available to smartly disseminate smart technologies. These include, use of televisions, such as Bangladesh Television or BTV (*Mati O Manush*, *Banglar Krishi*, and *Krishi Songbad*), Channel i (*Hridoye Mati O Manush*, *Manusher Dak*, and *Krishi Songbad*), Bangla Vision (*Shaymol Bangla*), and Boishakhi Television (*Krishi O Jibon*), GTV (*Shobuj Bangla*); and radios, e.g. Bangladesh Betar (*Desh Amar Mati Amar*, *Krishi Shomachar*, *Shonali Foshol*, *Shobuj Prantor*, and *Shoshho Shaymol*). Other facilities could be the Agricultural Call Centre (cell number: 16123), BRRI Web Portal (www.brri.gov.bd), and Bangladesh Rice Knowledge Bank (BRKB) and its mobile apps (www.knowledgebank-brri.org). Technologies could also be smartly disseminated through "Fact Sheets" and BRRI Newsletter. Social networks, such as, *Krishi Bhabna* and *Krishi Kotha*, could also be used for smartly dissemination of technologies. Application of GIS techniques is a good way of presenting a rice variety adoption domain as shown in Fig. 23.

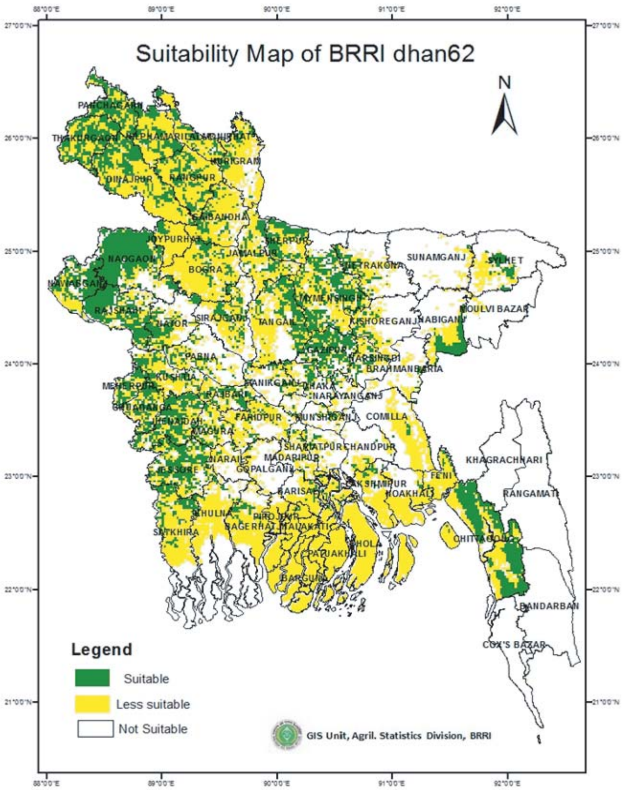

Fig. 23. Land suitability map for BRRI dhan62.

CONCLUSIONS AND RECOMMENDATIONS

Clean rice surplus in Bangladesh is targeted as at least 2.6 MT in 2050 based on requirement-production scenario. This target could be achieved through three major interventions - accelerating genetic gain, minimizing yield gap and curtailing adoption lag. Several obligations have been identified to implement the interventions taking into account of limited net cropped area, limited cropping intensity, scarcity of water for irrigation and other purposes, immense pressure on soil fertility and productivity. Smart technology and smart dissemination can help overcoming production barriers.

Following recommendations are made from this study.

- Net cropped area to be guaranteed minimum of 6.29 M ha in 2050, given the expected national clean rice yield of 5.0 t ha^{-1}.
- Agricultural policy planning to be formulated by reminding that cropping intensity cannot be increased beyond 221%.
- The rate of genetic gain in varietal development of BRRI's breeding program should be accelerated.
- Intense collaboration among the stakeholders is required to reduce adoption lag of newly released promising rice varieties.
- Variety and/or environment specific crop management systems should be formulated to reduce yield gap in farmers' field.
- Multiplication of BRRI produced 100 t "Breeder Seed" would be needed annually to ensure quality seed supply to adequately meet national demand.
- Monitoring and forecasting of diseases, insects and pests infestation should be

regulated to ensure proper management of the biotic hazards.

- At least 20 cm straw cut height to be ensured to maintain soil organic matter content to threshold level of 2.4%.
- Hundred percent mechanization should be targeted in all stages of crop production.
- Conversion of engelberg huller to rubber rolls huller to increase head rice recovery.
- Encourage "pressure parboiling" to reduce glycemic index (GI) value of rice.
- Degree of milling should be reduced to increase inherent zinc content and other nutrition.
- Effort to be made on shifting of around 15% "water shortage Boro area" to rainfed culture, and accommodate dry-direct-seeded aerobic rice.
- Development of water-use-efficient varieties should be strengthened.
- Proper plan to be formulated for rainwater harvest and increased utilization of surface water (rubber dam, sluice gate, flash gate and dugwell).
- Scoping should be initiated for construction of desalinization plant(s), and re-excavation of canals and rivers.
- Arrangements to be made for skill development of farmers, extension workers and scientists through appropriate training.
- Rice price and farmers' profitability to be ensured.
- Efficient rice marketing system should be developed.

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Probability of Low Temperature Stress at Different Growth Stages of Boro Rice

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ABSTRACT

The most sensitive stages of Boro rice against the low temperature are agronomic panicle initiation (API), reduction division (RD) and flowering/anthesis. The critical low temperature is growth stage specific. The time and intensity of the critical low temperature during Boro season has a direct impact on the growth and yield of a crop. Therefore, it is necessary to understand the probability of the critical low temperature with respect to the growth stages to have a good planning for safe harvest. Long term weekly low temperature data have been used to estimate the probability of falling low temperature on those stages and the return period was computed. The growth durations of 1- and 30- November seeded Boro rice crop from 45-day-old seedling of BRRI dhan28 (short duration) and BRRI dhan29 (long duration) are considered to observe the probability. A Boro crop encountering critical low temperature is appeared to suffer from cool injury. The extent of cool injury depends on the nature and duration of low temperature and diurnal change of low (night) and high (day) temperature. The critical low temperature for a rice crop at API, RD and anthesis are 18, 19 and 22°C, respectively. Boro rice is grown between November and May. The low temperature occurs from October to early March. There is, therefore, the probability of low temperature occurrence from the crop establishment to the flowering stage is a great concern. The probability of experiencing stage-wise critical temperature approaches to 100% for early established and short duration crop. However, the late established and long duration crop has the probability little less than the early and short duration crop. In a study it has been observed that short duration BRRI dhan28 having 64.6% sterility to yield 2.5 t ha^{-1} and BRRI dhan29, 40.8% sterility to yield 6.5 t ha^{-1}. The percentages of corresponding sterility for late established crops were 35.9 and 32.8%. Irrespective of growth duration, the yield is affected a little of the late established crop. Despite low temperature along with the reproductive phase, the late established crop is quite safe due to the parallel high (day) temperature (31-35°C). The high maximum temperature appears to play an important role through the alleviating effect of low temperature. But for early-established particularly short duration variety could not escape the low temperature at some of its sensitive growth stages as the high temperature appears to stay a several degree low (27-29°C) at that time. The low level of high temperature is appeared to drag down the low temperature to aggravate the growth and development of a crop. Therefore, not only the variation of high temperature of the day but also the variation of critical low temperature might have some role in alleviating effect of cool-injury. The periodic return of critical low temperature (10-15°C) during the reproductive stage may occur every year or every alternate year depending on the time across the cropping season and the region as well. Therefore, the critical low temperature, the high temperature during the low temperature period, periodic return of the critical low temperature with respect to growing region and concerned factors should be a consideration for planning a Boro crop.

INTRODUCTION

Extreme temperatures either low or high are destructive to plant growth and development. The critically low and high temperatures, normally below 20°C and above 30°C vary from one growth stage to another. These critical temperatures vary with the genotype, duration of critical temperature, diurnal changes and physiological status of the plant,

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Yoshida (1981). The probability of experiencing critical temperature for a particular rice crop also varies with the crop growing season, crop establishment schedule and agronomic practices also. In Bangladesh, sterility due to critical low temperature in Boro rice (irrigated rice generally grown from November to May) is getting importance in the recent years. Boro rice might suffer from extreme temperature particularly low temperature at the reproductive stage of the crop. Even low temperature at the crop establishment and tiller development stage (vegetative phase) of the crop might affect the growth and development of the crop. The most sensitive stages against the stresses are API (24 days before heading), RD (12-14 days before heading) and anthesis (0 days before heading), Hoshikawa (1975); Yoshida (1981).

The cool-injury symptom differs from a growth stage to another. Poor panicle exsertion, delayed heading, spikelet degeneration at the reproductive stage might yield complete sterility. Low temperature at the transplanting affects root growth and poor leaf development leading to poor crop establishment. The low temperature at the early growth stages affects natural nutrient uptake and metabolic activities leading to poor vegetative growth reflected as yellowing leaves, stunt growth and reduced tiller number, Nishiyama (1995). Bangladesh Rice Research Institute recommends seeding of short and long duration crop on 15 November-30 November and 5 November-25 November, respectively. But farmers in some of the intensive Boro areas (haor area) might not follow the prescribed schedule due to early recession of flood water as they have to utilize residual flood water for the seedling raising and initial crop establishment practice. Generally a short duration BRRI variety is recommended in a *haor* area to avoid the flash flood during late April to Early May. Early seeding of a short duration variety on seed bed (late October to early November) might experience low temperature at any growth stage. Even a long duration, direct seeded crop may succumb to cool injury at its reproductive stage, Biswas *et al.* (2008). The time and intensity of low temperature during Boro season have direct impact on the growth and yield of a crop. This study examines the probabilities of critical low temperature and its effect on different growth stages and their pattern of periodic return with respect to few regions of intensive Boro area.

MATERIALS AND METHODS

Weekly average of daily minimum temperature data of 33 (1975-2007) years for Gazipur (favourable), 57 (1950-2006) years for Dinajpur (Boro-intensive northern cold belt) and Mymensingh (includes Boro intensive Kishoreganj *haor* area) are used in this study (Data source: BRRI and Bangladesh Meteorological department: BMD). For the simplicity only three regions were considered. Pearson Type I distribution was applied to graduate probability distribution of weekly minimum temperature of each district. The probability density function (pdf) of Pearson Type I distribution is given by

$$f(x) = \frac{1}{(b - a)^{m_1 + m_2 + 1} B(m_1 + 1, m_2 + 1)} (x - a)^{m_1} (b - x)^{m_2},$$
$$a \le X \le b;\ m_1, m_2 > 0$$

where, x is the value of minimum temperature; B is the Beta function; a, b, m_1 and m_2 are estimated from the above function using minimum temperature value.

A computer programme written in SAS language (MH, 2007) was used to estimate the expected weekly low temperature at different probability (5-95%) levels. The probability curves were fitted using Excel 2000. The return period or recurrence interval (T) was computed by

$$T = \frac{1}{F},$$ where F is the cumulative probability.

Two crop establishment schedules were used, one at 1 November (early established) and another at 30 November (late established).

Forty-five-day-old seedlings were considered for the study. The growth stages of the BRRI dhan28 (short duration) and BRRI dhan29 (long duration) were estimated as per Gomosta *et al.* (2001). The crop establishment of both long and short duration variety was considered at the same time. The critical low temperatures with respect to growth stages were used as per Yoshida (1981).

RESULTS AND DISCUSSION

Results

Early established (1 November seeded) crop. The active root and tiller development of 1 November seeded 45-day-old seedling take place in between late December to late January (Fig 1).

The most sensitive API, RD and flowering/anthesis are appeared to occur on 5 February, 13 February and 26 February respectively for short duration BRRI dhan28. For long duration BRRI dhan29, these dates are 1 March, 8 March and 22 March. As the short and long duration crops are considered to establish at the same time, they have to experience more or less similar low temperature at the crop establishment. The probability of falling critical low temperature at the crop establishment at Gazipur, Dinajpur and Mymensingh are 74, 100 and 80%, respectively (Table 1 and Fig. 3).

The probability of the onset of low critical temperature is varied from panicle initiation stage and onward. For API, BRRI dhan28 has the probability of 100% for all the regions considered here but for BRRI dhan29 the probabilities vary from 88% at Dinajpur to 100% at Gazipur and Mymensingh. Irrespective of growth duration and region, the RD and anthesis stage have 100% probability. The ripening stage of BRRI dhan29 has less probability of critical low temperature than that of BRRI dhan28. The probabilities at the ripening stage for BRRI

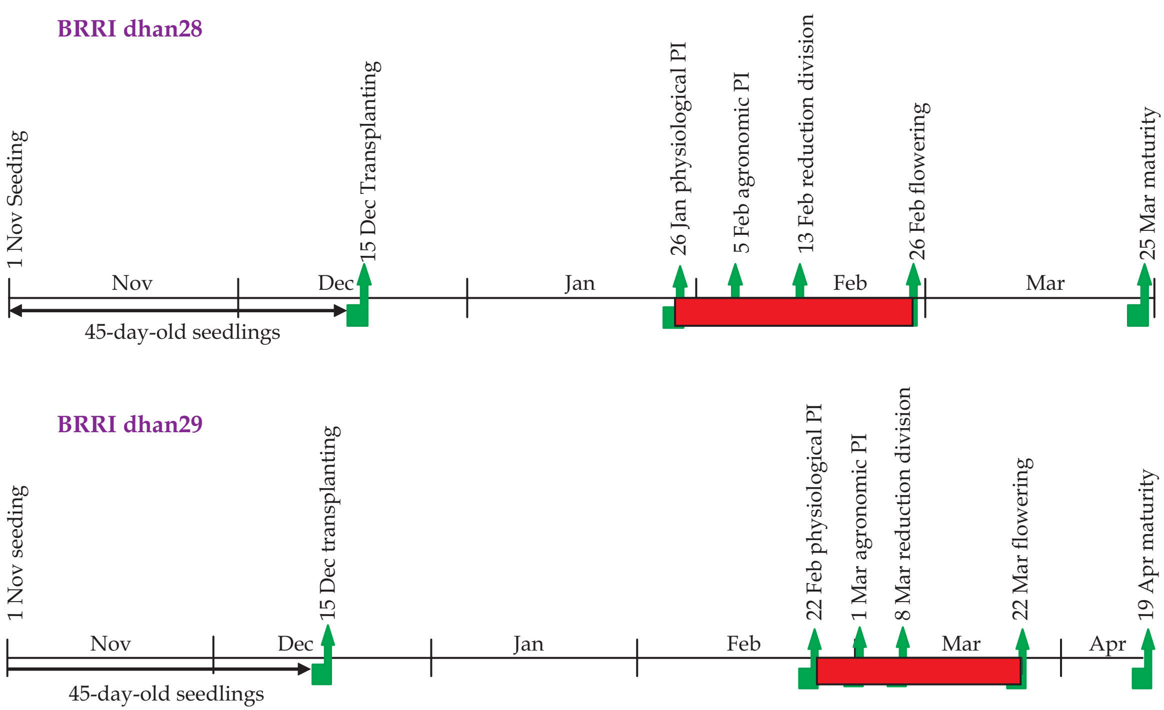

Fig. 1. Life cycle of BRRI dhan28, when seeded on 1 November (Growth duration 145 days) and BRRI dhan29, when seeded on 1 November (Growth duration 170 days).

Table 1. Probability of falling growth stage-wise critical minimum temperature for 1 November seeding.

Growth stage	Critical low temp (°C)	Probability of falling growth stages at critical temp.					
		Gazipur		Mymensingh		Dinajpur	
		BRRI dhan28	BRRI dhan29	BRRI dhan28	BRRI dhan29	BRRI dhan28	BRRI dhan29
Germination	10	0	0	0	0	0	0
Seedling establishment (transplanting)	13	74	74	80	80	100	100
Physiological PI	15	100	67	100	70	100	87
Agronomic PI	18	100	100	100	100	100	88
Reduction division	19	100	100	100	100	100	100
Flowering/Anthesis	22	100	100	100	100	100	100
Ripening	18	44	15	60	14	81	17

dhan29 at Gazipur, Dinajpur and Mymensingh are 15, 17 and 14%, respectively whereas these values for BRRI dhan28 are 44, 81 and 60%, respectively.

Late established (30 November seeded) crop. The active root and tiller development of these crops occur during late January to late February (Fig. 2).

The subsequent growth stages, API, RD and flowering/anthesis for short duration variety are appeared to occur on 6, 15 and 30 March, respectively. The corresponding dates for long duration variety are 17 March, 25 March and 9 April. Irrespective of regions and growth durations the probability of critical low temperature during crop establishment is 100% (Table 2 and Fig. 3).

Dinajpur has 100% probability of critical low temperature at the API stage for both BRRI dhan28 and BRRI dhan29. The probabilities for BRRI dhan29 are comparatively less, which are 52 and 74% for

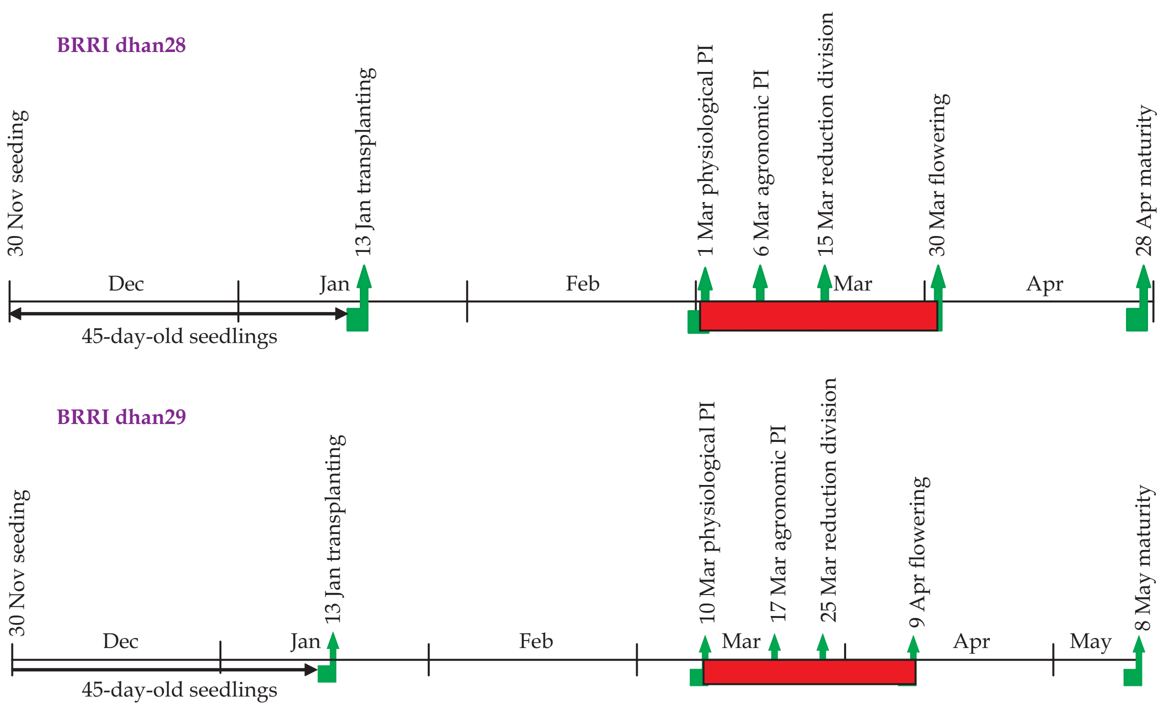

Fig. 2. Life cycle of BRRI dhan28, when seeded on 30 November (Growth duration 150 days) and BRRI dhan29, when seeded on 30 November (Growth duration 160 days).

Table 2. Probability of falling growth stage-wise critical minimum temperature for 30 November seeding.

Growth stage	Critical low temp (°C)	Probability of falling growth stages at critical temp.					
		Gazipur		Mymensingh		Dinajpur	
		BRRI dhan28	BRRI dhan29	BRRI dhan28	BRRI dhan29	BRRI dhan28	BRRI dhan29
Germination	10	0	0	0	0	0	0
Seedling establishment (transplanting)	13	100	100	100	100	100	100
Physiological PI	15	52	31	62	38	100	86
Agronomic PI	18	100	52	100	74	100	100
Reduction division	19	67	60	100	78	100	100
Flowering/Anthesis	22	100	74	100	87	100	100
Ripening	18	18	0	14	0	26	15

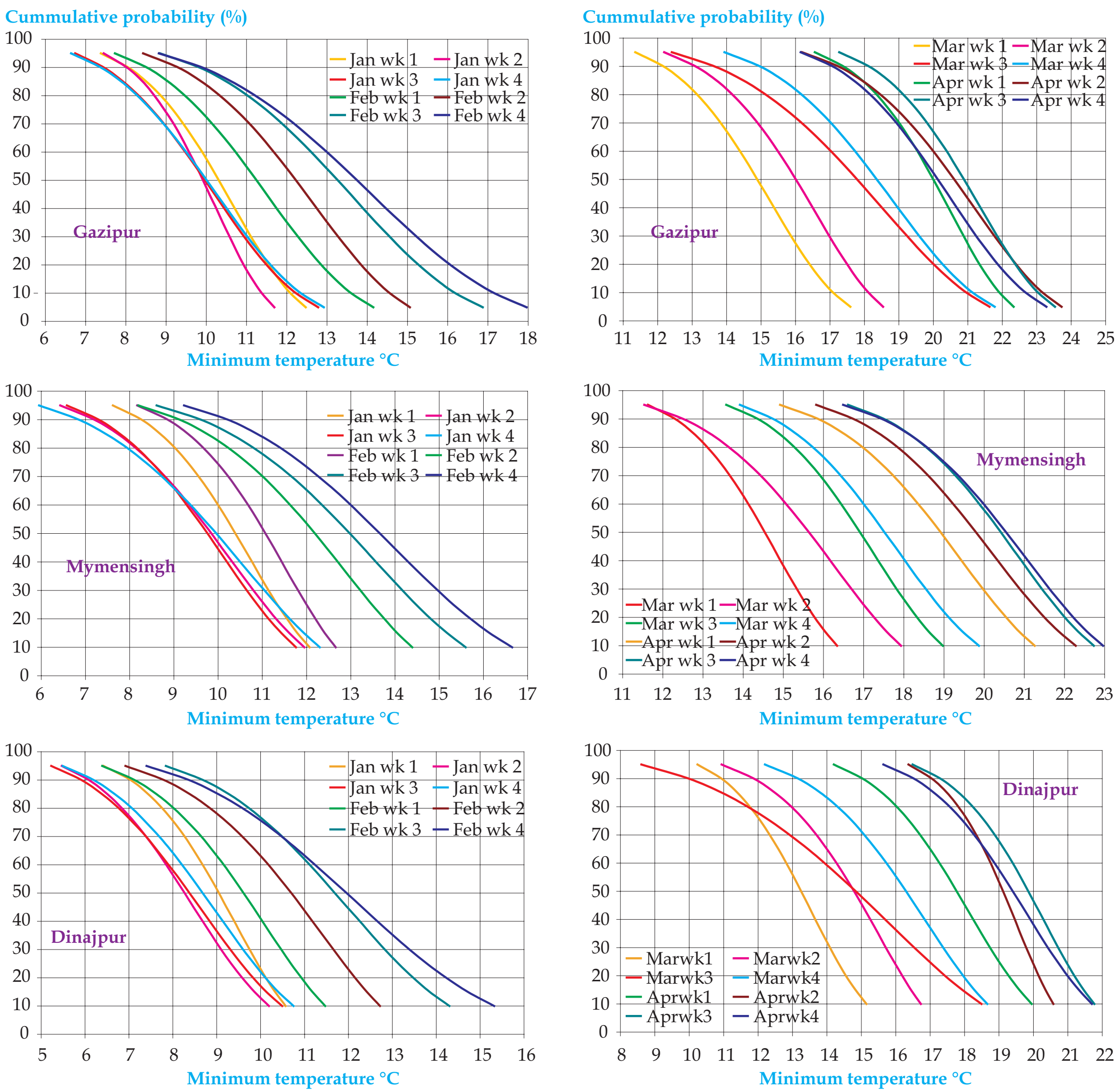

Fig. 3. Probability of minimum temperature occurred from January to April at Gazipur, Mymensingh and Dinajpur.

Gazipur and Mymensingh, respectively. At RD and flowering/anthesis, the onset of probability pattern is more or less the same as that of API stage.

DISCUSSIONS

From the above result it is obvious that irrespective of growth duration, the 1 November established crop has more probability of getting cool-shock. However, 30-November established crop has also some probabilities of experiencing critical low temperature too. This probability is remarkable for a short duration crop. That means, in Boro season a crop has some probabilities of encountering critical low temperature at any of the sensitive stages of the crop. Anyway, the cool-injury problem does not occur always. It depends on the duration of critical low temperature and diurnal change. When a rice plant is subjected to low temperature for three days, it is more sensitive at the booting (6-days prior to heading/flowering) than at heading as indicated by the higher percentage of sterility. When the low temperatures are continued for 6-9 days, heading is equally or more sensitive than booting, Yoshida (1981). A rice plant subjected to temperature below 20°C at about RD (pre-booting stage) usually induced high spikelet sterility, Satake (1969; 1976). Temperature as low as 12°C would not induce sterility if they last for two days but would induce about 100% if they last for six days.

Generally, low temperature mediated sterility is attributed to night temperature and high to the day (high temperature). The high temperature during cool period has the ability to alleviate the effects of low night temperature, Yoshida (1981). There is the probability of low critical temperature (<15°C) during 1st week of March at the API of short duration Boro crop. A relatively early established long duration crop might experience the similar fate. When a crop is established early (1 November), API, RD stages of a short duration crop have to suffer from critical low temperature of 10-14°C during early to mid February (Table 3).

The level of high temperature during the same period was 27-29°C. In contrast, long duration crop established on 1 November has to experience the critical low temperature of 15-16°C for the same growth stages. But the high temperature for the same period is 32°C. There is a 4-5°C variation of critical low temperature and high temperature for the growth stages here. So not only the variation of high temperature but also the variation of critical low temperature might have some role in the alleviating effect of cool-injury. Similar results were observed by Gomosta *et al.* (2001). They observed that short duration BRRI dhan28 have 64.6% sterility to yield 2.5 t ha^{-1} and BRRI dhan29 have 40.8% sterility to yield 6.5 t ha^{-1} when seeded on early November. The above mentioned late established short and long duration varieties have 35.9 and 32.8% sterility and 6.8 and 7.5 t ha^{-1}, grain yield respectively (Table 4).

The early established short duration variety, in this case encounter low temperature stress during the reproductive phase resulted more sterility and poor yield as well. In contrast, the early established long duration variety experienced low temperature stress at vegetative phase prolonging the growth duration and attained enough scope to avoid low temperature stress at the reproductive phase. Irrespective of variety, the late established crop had enough opportunity to compensate the low temperature through the alleviating effect of high temperature during the reproductive phase resulting comparatively low sterility and higher yield.

For *haor* area, short duration variety is advocated to cultivate to avoid flash flood provided the establishment must not be too early. Even the early crop could be advocated provided the crop should have long growth duration. However, the early established long duration crop has elongated vegetative phase. Early transplanting dates ensure safety from flood damage but the opportunity for

Table 3. Distribution of weekly temperature in Dinajpur, Mymensingh and Gazipur at 80% probability.

Weeks	Temperature (°C)					
	Gazipur		Mymensingh		Dinajpur	
	Min.	Max.	Min.	Max.	Min.	Max.
Nov Wk 1	17.99	31.49	20.81	32.40	19.04	32.04
Nov Wk 2	16.28	30.45	19.24	31.96	17.44	31.29
Nov Wk 3	14.79	29.56	17.86	31.28	16.24	30.68
Nov Wk 4	13.41	28.93	16.46	30.69	14.06	29.98
Dec Wk 1	12.22	27.66	15.21	30.28	13.27	29.11
Dec Wk 2	11.37	27.18	14.29	29.18	12.82	28.31
Dec Wk 3	10.27	26.24	12.01	28.43	9.98	27.57
Dec Wk 4	9.57	26.21	11.78	28.52	9.98	27.37
Jan Wk 1	8.87	24.79	11.56	27.54	10.12	27.29
Jan Wk 2	8.71	24.77	11.31	27.30	9.58	26.61
Jan Wk 3	8.32	25.77	11.14	27.33	9.83	27.96
Jan Wk 4	8.29	26.54	11.62	28.23	10.11	27.9
Feb Wk 1	9.47	27.35	12.2	28.99	10.93	28.41
Feb Wk 2	10.34	28.09	13.76	30.35	12.15	30.23
Feb Wk 3	11.03	29.51	14.81	31.95	13.48	31.03
Feb Wk 4	11.22	29.69	15.71	32.13	14.23	32.23
Mar Wk 1	13.15	30.98	15.78	33.60	14.55	32.97
Mar Wk 2	14.17	32.20	17.26	34.71	16.19	34.68
Mar Wk 3	15.14	33.13	18.33	35.72	17.43	35.54
Mar Wk 4	16.18	33.85	19.12	36.23	17.96	37.21
Apr Wk 1	18.36	33.97	20.55	36.86	19.28	38.17
Apr Wk 2	18.47	33.95	21.5	37.06	20.15	38.37
Apr Wk 3	19.13	33.66	22.01	37.18	21.19	38.84
Apr Wk 4	18.17	33.92	22.22	36.91	20.99	37.73

Table 4. Effect of seeding time on sterility, grains m^{-2} and grain yield (Gomosta *et al.*, 2001).

Seeding date	Sterility (%)		Grains m^{-2}		Grain yield (t ha^{-1})	
	BRRI dhan28	BRRI dhan29	BRRI dhan28	BRRI dhan29	BRRI dhan28	BRRI dhan29
1 November	64.6	40.8	16456	20536	2.5	6.5
30 November	35.9	32.8	22602	25282	6.8	7.5

manipulating seedling age is limited because of low temperature, Salam *et al.* (1994). The late established crop is good for avoidance of low temperature at the reproductive phase but probability to encounter flashflood is very high, Biswas *et al.* (2008). Even the crop might encounter high temperature stress at the flowering/anthesis. The high temperature during last April to May goes beyond 35°C, a critical level of high temperature injury. If the anthesis and the critical temperature coincide anyway, a severe sterility might occur.

Another important consideration is the return period of the critical low temperature. It is observed that the temperature <15°C occurs in every year during 3rd and 4th week of February at Gazipur, Mymensingh and Dinajpur but 15-20°C temperature occurs once in every five and three years in Gazipur, 10 and five years in Mymensingh during 3rd and 4th weeks of February, respectively (Table 5).

The similar pattern of temperature is observed in Dinajpur only at the 4th week of February. In Gazipur and Mymensingh, 10-15°C and 15-20°C temperature occurs in every alternate year in the 1st and 2nd weeks of March. The similar frequency occurs in Dinajpur but in the 2nd and 3rd weeks of March. In Dinajpur, 10-15°C occurs in every year but 15-20°C occurs once in every 20 years in the 1st week of March. In the 3rd and 4th weeks of March, 15-20°C occurs in every year in both Gazipur and Mymensingh but 10-15°C occurs once in every five and seven years in

Table 5. Return period of occurring cold temperature.

Week	Gazipur				Mymensingh				Dinajpur			
	<10	10-15	15-20	20-25	<10	10-15	15-20	20-25	<10	10-15	15-20	20-25
Dec Wk 1		1.25	5.00			1.33	6.67		10.00	1.25		
Dec Wk 2	10.00	1.18	20.00			1.11			10.00	1.25		
Dec Wk 3	5.00	1.25					2.50	2.00	1.25	10.00		
Dec Wk 4	3.33	1.43			4.0	1.54			1.25	10.00		
Jan Wk 1	2.22	1.82			2.9	1.82			1.33	6.67		
Jan Wk 2	1.82	2.22			2.0	2.50			1.18	20.00		
Jan Wk 3	1.82	2.22			1.8	2.86			1.25	10.00		
Jan Wk 4	2.00	2.00			2.0	2.50			1.33	6.67		
Feb Wk 1	3.33	1.43			4.0	1.54			1.82	2.86		
Feb Wk 2	5.00	1.25			6.7	1.33			2.86	1.82		
Feb Wk 3	10.00	1.43	5.00		10.0	1.43	10.00		5.00	1.43		
Feb Wk 4	10.00	1.67	3.33		20.0	1.54	5.00		5.00	1.54	20.00	
Mar Wk 1		1.82	2.22			1.67	3.33			1.18	20.00	
Mar Wk 2		2.86	1.54			2.86	1.82			2.00	2.50	
Mar Wk 3		5.00	1.67	5.00		6.67	1.33			2.50	2.50	
Mar Wk 4		6.67	1.54	5.00		10.00	1.25			4.00	1.54	
Apr Wk 1			1.82	2.22		20.00	1.54	5.00		20.00	1.18	
Apr Wk 2			2.22	1.82			2.00	2.50			1.33	6.67
Apr Wk 3			2.86	1.54			2.50	2.00			2.00	2.50
Apr Wk 4			2.00	2.00			2.50	2.00			1.67	3.33

Gazipur and seven and 10 years in Mymensingh, respectively. During 4th week of March 15-20°C occurs in every year but 10-15°C occurs once in every four years in Dinajpur. Therefore, periodic return of critical temperature with respect to growing region should be a consideration for planning a Boro crop.

CONCLUSIONS

The probability of low temperature occurrence from the crop establishment to the flowering stage is a great concern. The probability of experiencing stage-wise critical temperature approaches to 100% for early established and short duration crop. However, the late established and long duration crop has the probability little less than the early and short duration crop. Irrespective of growth duration, the yield is affected a little of the late established crop. Despite low temperature along with the reproductive phase, the late established crop is quite safe due to the parallel high (day) temperature (31-35°C). The high temperature appears to play an important role through the alleviating effect of low temperature. But early-established particularly short duration variety could not escape the low temperature at some of its important growth stages as the high temperature appears to stay a several degree low (27-29°C) at that time. The low level of high temperature is appeared to drag down the low temperature to aggravate the growth and development of a crop. Therefore, not only the variation of high temperature of the day but also the variation of critical low temperature might have some role in the alleviating effect of cool-injury. Therefore, the critical low temperature, the high temperature during the low temperature period, periodic return of the critical low temperature with respect to growing region and concerned factors should be a consideration for planning a Boro crop. However, the influence of high temperature with respect to the low temperature deserves further study.

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Rice False Smut Disease at Different Flowering Times

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ABSTRACT

Rice false smut (RFSm) has lately been recognized as an emerging disease worldwide. Its alarming prevalence in Bangladesh in the transplant Aman rice in the last three years has been widely reported. However, there is no effective control measure against the disease in this country. We hypothesized that manipulation of flowering time in Aman rice may avoid RFSm incidence. A two-year study (2014 and 2015) during T. Aman season using the widely regarded RFSm-prone variety, BRRI dhan49, across a range of flowering regime from mid-July to mid-January, demonstrated lower disease incidence in earlier (till mid-October) and later (after mid-November) part. The highest incidence of the disease was recorded when the crop flowered on 9 and 5 November in 2014 and 2015, respectively. The disease was recorded on ratoons. The peak of the infection recorded on ratoons when flowered on 7 November. To the best of our knowledge, worldwide, this is the first record of the disease on ratoons. Rainfall did not influence the disease. The relationship between the disease incidence and relative humidity and sunshine hours were significant. Avoiding flowering time during mid-October to mid-November through planting time adjustment appeared as an effective practice to escape rice false smut disease incidence in Aman season.
Key words: Disease incidence, false smut, flowering time, maximum temperature, minimum temperature, rain-days, ratoon, relative humidity, rice, sunshine hours, transplanting time, *Ustilaginoidea virens*, *Villosiclava virens*

INTRODUCTION

The status of rice false smut (RFSm) as an emerging fungal disease (anamorph: *Ustilaginoidea virens* (Cooke) Takah.; teleomorph *Villosiclava virens* (Nakata) E. Tanaka and C. Tanaka) of rice (*Oryza sativa* L.) has been recognized worldwide (Atia, 2004; Brooks *et al*., 2009; Ashizawa *et al*., 2010; Li *et al*., 2013; Singh *et al*., 2014; Nessa *et al*., 2015a). The disease is a serious concern to the farmers of Bangladesh during T. Aman season (rainfed rice), due to its epidemic outbreak especially on a popular variety `BRRI dhan49`. RFSm is an inflorescence disease. The symptom of the disease only appears after rice crops flower. On the other hand, recent findings indicate that the infection is likely to onset one to three weeks earlier to appearance of smut balls (Li *et al*., 2013; Jia *et al*., 2014). While few studies were conducted relating weather and spore release (Sreeramulu *et al*., 1966), the potential association of weather variables during infection stage to incidence of RFSm has not been well documented.

The management of the disease is not well recognized as its salient epidemiological features under field conditions are still unknown (Nessa *et al*., 2015b, Tanaka, 2015). As Jecmen (2014) points out, "Understanding how to manage RFSm (rice false smut) has been difficult because the literature is

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fragmented, unclear or at times, even contradictory. Many questions relevant to the integrated management of RFSm using cultural practices, fungicide applications and deployed resistance remain unaddressed". Among the cultural management options, a number of studies have attempted to control RFSm through manipulation of transplanting time in China (Liang *et al*., 2014, Egypt (Atia, 2004), India (Dodan and Singh, 1994), Nigeria (Ahonsi *et al*., 2000) and in the USA (Brooks *et al*, 2009). However, a similar study has not yet been conducted in Bangladesh.

Although the disease infects main crop (primary planting), recent observation shows, for the first time in the world, that it also affects ratoons (regenerated tillers from harvested main crop) (Nessa *et al*., 2015b). However, further studies are required to re-establish the findings and to investigate whether the pattern of the disease incidence in ratoons is similar to that in the main crop.

With the above background, the present study was undertaken to investigate whether false smut epidemic on susceptible rice variety can be escaped with changing flowering times of the crop by varying the transplanting time. The study also aimed to identify major weather parameters influencing the disease.

MATERIALS AND METHODS

Experimental site study period

The experiments were conducted in the research farm of the Bangladesh Rice Research Institute (23°59 N, 90°24 E), Gazipur, Bangladesh during T. Aman season of 2014 and 2015. This farm has built up an intensive rice-ecosystem over the last 40 years while growing rice in as many as three seasons annually in about 88 fields spread over 35 hectare area. It is situated at about 35 m above the mean sea level and has a subtropical climate strongly influenced by the south-western monsoon (Nessa *et al*., 2015a).

Experimental design and treatments

Effect of the varying flowering times on natural incidence of RFSm was investigated in repeated experiments laid out following a randomised complete block (RCB) design with 10 replications in 2014 and three replications in 2015. To generate wide range of flowering time, seven different transplanting times (15 June, 30 June, 15 July, 30 July, 14 August, 29 August and 13 September) of BRRI dhan49 (a highly susceptible variety) served as treatments in 2014 trial. However, 12 different transplanting times (19 May, 4 June, 19 June, 4 July, 20 July, 4 August, 19 August, 5 September, 19 September, 5 October, 19 October an 5 November) of the same variety were used in the 2015 trial. The individual plot was 2.5 m × 2.5 m in 2014, and 30.5 m × 2.5 m in 2015.

Transplanting and crop management

Thirty-day-old seedlings were hand transplanted at two or three seedlings per hill, maintaining a spacing of 20 cm × 20 cm. The crops were fertilized with recommended doses of nitrogen (N) (200 kg ha^{-1} as urea), phosphorus (P) (63 kg ha^{-1} as triple super phosphate), potassium (K) (84 kg ha^{-1} as muriate of potash) and sulphur (S) (56 kg ha^{-1} as gypsum) (BRRI, 2013). Nitrogen was top dressed in three equal splits: 20, 35 and 50 days after transplanting (DAT), whereas P, K, and S were applied once, during final land preparation. The crops received moisture predominantly through monsoonal rains, but supplemented by irrigation water to maintain a water level of 2 to 3 cm. Management of the crops included manual weed control twice, at 30 and 45 DAT. No insecticide, fungicide or other chemical were used for pest and disease control. No artificial inoculation was conducted to modify natural disease pressure.

Ratooning

For ratooning, the hills in the main crops were harvested at maturity by manually cutting the tillers at 40-60 cm height. No additional crop management practice was applied for ratoons.

In the 2014 trial, ratoons voluntarily generated in two plots transplanted on 15 June, and nine plots transplanted on 15 July. However, in 2015 trial, ratoons generated in all the plots transplanted on 19 May and 19 June.

Trial assessment

Dates of 50% flowering were recorded for each transplanting time on main crops and ratoons. In addition, the progression of newly formed smut balls on ratoons was recorded by at three days interval during 15 August 2015 to 15 January 2016. The trials were assessed for disease incidence by counting smut ball(s) bearing panicles (diseased panicles) and total panicles in each plot at the late ripening stage. The same was done for ratoons.

Data presentation and analysis

The disease incidence (DI) on main crops and ratoons was calculated using the following equation

DI = [(Number of diseased panicles)/(total number of panicles)] × 100 Eq. (1)

All the DI values were summarized against 50% flowering time of main crops and the ratoons. The DI data were analyzed and compared at the 95% confidence interval (CI) using an in-built formula in MS Excel 2010 (Nessa *et al*. 2015b).

Data on five weather parameters, maximum temperature (°C), minimum temperature (°C), relative humidity (%), sunshine hours and rain-days (number), were summarized for 5-days prior to 15 days (Jia *et al*., 2014) of each record of 50% flowering to find any association of weather to the level of disease incidence. The daily weather data for 2014 and 2015 gathered from the Physiology Division of BRRI were used for this purpose.

In order to relate DI with weather parameters, the range of DI in both years was categorized into three sections of flowering window: "early" (5 August to 12 October), "mid" (17 October to 23 November) and "late" (4 December to 28 December). The association of five weather parameters to DI in the three defined periods of flowering window was measured through correlation. The significant weather parameters from correlation study were subjected to regression analysis relating DI.

RESULTS

In 2015, the rice false smut (RFSm) disease initiated (DI (%) = 0.07±0.01, is 95% confidence interval) when the crop flowered on 5 August (Fig. 1). The level of the disease remained low (DI 0.47%) in the crops flowering before mid-October. The RFSm reached the peak (DI (%) = 2.40±0.30) on 5 November and ceased on 28 December flowering crops. The data on initiation and cessation time of the disease was not available for 2014 season. However, like 2015, the disease level was low (DI 0.47 to 0.49%) in the crops flowering till mid-October. The RFSm reached the peak (DI (%) = 2.45±0.67) on the crop flowered on 9 November.

When measured the disease progression in relation to time of 50% flowering of ratoons, it was observed that the first appearance of

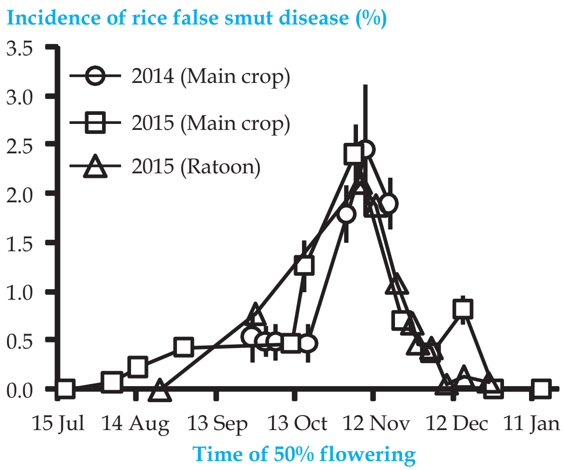

Fig. 1. Incidence of rice false smut disease across the flowering window rice during T. Aman seasons of 2014 and 2015. "Jul", "Aug", "Sep", "Oct", "Nov", "Dec" and "Jan" denotes for July, August, September, October, November, December and January, respectively. Vertical bars indicate 95% confidence intervals.

RFSm appeared on ratoons that flowered on 28 September (Fig. 1). The peak of the disease incidence (2.11%) occurred on ratoons that flowered on 7 November. The disease incidence was very low on the ratoons that flowered after 10 December.

Table 1 presents the disease status and weather parameters influencing the disease infection. The table shows that the disease in the "mid-flowering-window" was significantly higher (1.47±0.54, is 95% confidence interval) than "early-flowering-window" (0.39±0.13) or "late-flowering-window" (0.19±0.37). Corresponding weather parameters during the probable infection of the disease did not show significant correlation between the disease incidence and maximum temperature or minimum temperature, or rain-days. The relationship between the disease incidence and relative humidity or sunshine hours were significant (Table 1).

Figure 2 presents further analysis of the two significant weather parameters - sunshine hours and relative humidity - and disease incidence across the whole range of flowering window of BRRI dhan49 during 2015 T. Aman season. The figure shows a positive significant response (expressed in regression) of the disease incidence (DI) to the sunshine hours (*$P< 0.05$, $R^2 = 0.46$*). As indicated earlier, the relationship between relative humidity and DI was also significant but negative. The relationship between sunshine hour and relative humidity, on the other hand, had been strongly negative ($P< 0.05$, $R^2 = 0.75$).

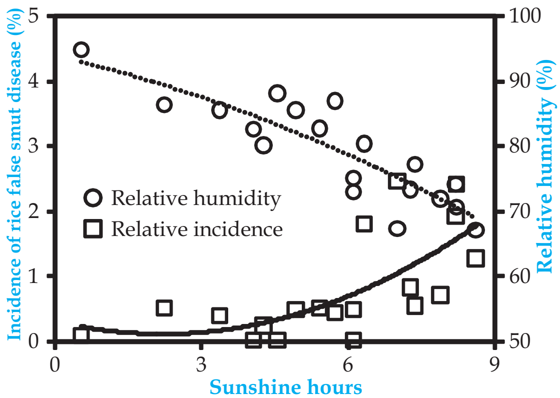

Fig. 2. Regression between sunshine hours and disease incidence (Y = 0.3001 - 0.179X + 0.0408X2, R2 = 0.46, n = 18), and between sunshine hours and relative humidity (Y = 93.792 - 1.7356X - 0.1351X2, R2 = 0.75, n = 18) across the whole range of flowering window of BRRI dhan49 during 2015 T. Aman season.

DISCUSSION

In this study, the incidence of rice false smut (RFSm) disease was estimated across a range of flowering regimes of a T. Aman rice variety in 2014 and 2015 by setting the transplanting time accordingly. With this, the start and cessation of the timing of the disease on T. Aman rice have been recognized, which have not been reported so far in Bangladesh. Our results show early flowering crops (thereby planted early) had significantly lower disease incidence compared to later flowering crops. In his early work in Japan, Ikegami (1960) observed that RFSm disease on 20 May sown crop was almost 2-fold compared to the crop sown on 1 May. In India, similar findings have

Table 1. The incidence of rice false smut disease (DI, %) in BRRI dhan49 and weather variables in three sections of flowering window during T. Aman seasons of 2014 and 2015. Also shown, the correlations between five weather variables and the DIs. The ± indicates 95% confidence interval, "*ns*" denotes for not significant and "*" for significant at *P* < 0.05.

Disease status, or	Flowering window			Correlation coefficient (r)
Weather parameters	Early	Mid	Late	(*n* = 18)
Disease incidence (%)	0.39±0.13	1.47±0.54	0.19±0.37	-
Maximum temperature (°C)	32.2±1.1	32.0±1.2	28.3±1.5	$+ 0.38^{ns}$
Minimum temperature (°C)	24.4±0.8	20.2±2.6	15.2±3.2	$- 0.09^{ns}$
Relative humidity (%)	84.0±3.9	72.0±3.4	83.9±2.9	$- 0.62^{*}$
Sunshine hours	4.6±1.4	7.6±0.6	3.7±0.7	$+ 0.62^{*}$
Rain-days (number)	2.3±1.0	0.1±0.3	0.0±0.0	$- 0.40^{ns}$

been reported in the 1980s and 1990s (Narinder and Singh, 1984; Singh and Kang, 1987; Dodan and Singh, 1994). Thus, manipulation of planting time could be a way to control this disease (Parsons *et al*., 2001; Ahonsi and Adeoti, 2002; Brooks *et al*., 2011). It is suggested that escaping false smut epidemic by planting the early maturating group of cultivars (Zhou *et al*., 2010) as late maturing varieties show higher rates of infection (Liang *et al*., 2014).

Our findings also suggest that the disease incidence declines after reaching at the peak during 2 to 9 November. The timing of this peak was consistent from 2015 observations in main crops and ratoons, 2014 crops, and observations in another variety (BR11) from different experiments (S Islam, MS Islam and M Ahmed, BRRI, 2015, unpublished data). The level of the disease towards the tail-end of flowering regime was very similar to early-part of flowering window. Most of the literature hardly mentioned the disease at the tail-end of flowering window. In an early work, Raw (1964) noted that mid- duration crop had the highest incidence than short or long duration crop. Raw's finding is a subjective agreement to our findings.

While there is no disagreement that "early" planting can be a mean of avoiding the major incidence of RFSm disease, the term "early" itself may be confusing to many aspects. For example, how early this "early" should be? Besides, farmers use varieties of different growth durations. In that case, the timing of "early" planting of a long duration variety will vary with the timing of "early" planting of a medium or short duration variety. To avoid these confusions, we have worked out that the chance of the high disease incidence may be avoided if the crop does not flower during mid-October to mid-November.

Many reports associate high cloud cover (Ho, 1979; Ahonsi, 1995), frequent rainfall (Ho, 1979; Ahonsi, 1995; Cartwright *et al*., 2002; Fan *et al.,* 2014) and high relative humidity (Raw, 1964; Ahonsi, 1995; Biswas, 2001) to high disease incidence. However, we did not find any positive relationship between rainfall and disease incidence. For example, in our studies, rainfall did not influence the disease; analysis rather showed negative correlation between rain-days and DI; under rainless conditions, the DI varied between 0 to 2.5%. It may be noted that the 2.5% was the highest disease recorded during the two experiment years. A number of findings agree with our results. Raw (1964) observed that actual precipitation has less effect on the incidence of the disease. Dodan and Singh (1996) reported that low rainfall favoring the disease. In spore-trap experiments, it has been reported that the continuous and heavy rain can significantly decrease or even completely disappear RFSm spore-load (Sreeramulu and Vittal, 1966). With no rain at all, Devi and Singh (2007) found the highest RFSm spore concentration on air. In our studies, rainfall did not influence relative humidity (RH) or sunshine hours (SSH). Under rainless conditions, the RH varied between 67.0 to 85.4%, whereas SSH varied between 3.4 to 8.6 hours.

In this study, SSH and RH influenced the disease, SSH positively and RH negatively. The association between SSH and RH was very strong. The question may arise, which is the prime factor for the disease? Is it the SSH or the RH or the both? The RH may not be the sole answer, as high disease occurred at lower RH and low disease occurred at higher RH. It is likely that higher SSH in association with relatively lower RH (possible threshold: 70-80%) encouraged good crop growth as well as RFSm disease development.

CONCLUSION

This study finds that the major incidence of rice false smut disease during T. Aman can be avoided by planting rice varieties in such a way that the crops do not flower during mid-October to mid-November. However, this information may be variety and site specific and, therefore, required to be validated using other rice varieties across the agro-ecological regions of Bangladesh. Furthermore, both qualitative and quantitative relationships between two weather variables (relative humidity and sunshine hours) and disease incidence need to be established through further studies.

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Increasing Crop Diversity and Productivity of Rice (*Oryza Sativa* L.)-Wheat (*Triticum aestivum* L.) Cropping System through Bed Planting

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ABSTRACT

Adoption of new crop establishment methods, changing management practices and inclusion of new crops in the rice-wheat cropping system are very important for maintaining and increasing system productivity. Experiments were conducted at the Bangladesh Rice Research Institute, Gazipur and farmers' fields in Chuadanga during 2002-03 to evaluate the performances of rice, wheat and mungbean in bed planting and to evaluate the system productivity of Rice-Wheat-Mungbean cropping pattern. Wheat-Mungbean-Direct seeded rice (DSR), Wheat-Mungbean-Transplant rice (TPR), Wheat-Fallow-DSR and Wheat-Fallow-TPR cropping system under bed planting and conventional methods were evaluated. Grain yields of wheat, mungbean, rice and rice equivalent yield (REY) under bed planting were significantly higher (25.41, 40.91, 13.00 and 21.12%, respectively) than the conventional method. The Wheat-Mungbean-Rice cropping pattern produced significantly greater REY (38.25%) than Wheat-Fallow-Rice cropping pattern. Total variable cost was lower (17.33%) in bed planting than conventional method. Gross return, gross margin and benefit-cost ratio of Wheat-Mungbean-Rice cropping system in bed planting were higher (14.43, 40.99 and 38.52%, respectively) than the conventional method.

Key words: Bed planting, rice-wheat cropping system

INTRODUCTION

Rice and wheat are grown in sequence on the same land in the same year over 26 million ha of South and East Asia to meet the food demand of rapidly expanding human population (Timsina and Connor, 2001). South Asian countries, Bangladesh, India, Nepal and Pakistan with a geographical area of 401.72 million ha, hold nearly half of the world population of 3.1 billion (Timsina and Connor, 2001). Nearly 60% of the farming households live on less than 30% of global agricultural lands (Gupta *et al*., 2003a) and approximately 240 million people in South Asia consume rice and/or wheat produced in rice-wheat system (Benites, 2001). Moreover, the annual productivity of the rice-wheat system in the Indo-Gangetic Plain is lower (5-7 t ha^{-1}) compared with currently attainable (8-10 t ha^{-1}) and site potential (12-19 t ha^{-1}) yields (Aggarwal *et al*., 2000).

The continuous cultivation of two crops or more per year including rice and wheat has provided food and livelihoods for millions of rural and urban poor in South Asia. Now a crisis looms as the population is growing at more than 2% (nearly 24 millions additional mouth to feed) each year and agricultural land area dwindles and yield increase are leveling off (Hobbs, 2003). Increasing food production of this area in the next 20 years to match population growth is challenging. It is made even more difficult because, land area devoted to agriculture will be stagnated or declined and better quality land and water resources is expected to be diverted to other sector of the national economy. In order to grow more food

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from marginal and good quality lands, the quality of natural resource base must be improved and sustained. Efficiency of natural resources like, seed, water, fuel and labour require to be improved. Development of resource conservation technologies is essential since they provide one of the few ways to achieve the above goals.

To meet up the increasing food demand, the productivity of the rice-wheat cropping system must be increased and continued. There should be several options for increasing productivity and reducing cost of production and to conserve natural resources. Development or adoption of new crop establishment methods, changing management practices and inclusion of new crops in the system may be some ways of increasing productivity and resource conservation. Bed planting in rice-wheat cropping systems may be a technique for improving resource use efficiency and increasing the yield (Connor *et al*., 2003). In this system, the land is prepared conventionally (full tillage) and raised bed and furrows are prepared manually or using a raised bed planter. Crops are planted in rows on top of the raised beds and irrigation water is applied in the furrows between the beds. Water flows horizontally from the furrows into the beds. This system is often considered for growing high value crops that are more sensitive to temporary waterlogging stress. Growing wheat on raised beds though introduced in the Indo-Gangetic Plain, the practice of rice, the major water-using crop in the rice-wheat cropping system, on raised bed introduced very recently (Connor *et al*., 2003). An additional advantage of bed planting becomes apparent when beds are permanent, that is, when they are maintained over the medium term and not broken down and reformed for every crop (Hobbs and Gupta, 2003a). All the crops of the system, except the first crop, grown in zero tillage, which cut down the costs of land preparation and bed making, and only repairing cost for bed is needed.

Crop diversification may also be an important contributor to environmental sustainability and economic viability of rice-wheat areas. Bed planting system greatly facilitates and provides the opportunity for increasing crop diversification and higher productivity for crops traditionally grown on flat surfaces, especially in the wet season, because of less water logging. Crop diversification of the rice-wheat system ameliorates the family incomes, minimizes peak labour demands, facilitates easier weed and nitrogen management, and often results in better yield (Gupta *et al*., 2003b).

Inclusion of grain legumes in the dry-wet transition period of rice-wheat cropping system as a third crop may be another option of increasing cropping intensity, crop diversity and productivity of the system. Although the non-rice season across the rice-wheat area is low rainfall, heavy pre-monsoonal rain can have disastrous effects on the third crop, such as maize or mungbean grown after wheat or before rice, both during establishment and grain filling because of water logging (Timsina and Connor, 2001; Quayyam *et al*., 2002). Due to lack of proper crop establishment techniques and temporary water logging at reproductive stage, inclusion of a grain legume like mungbean in rice-wheat cropping system very often faces problems. Bed planting may be a solution of this problem because raised beds not only facilitate irrigation but also drainage, and therein lies their potential to increase the yield of crops other than rice in the system. Therefore, the study was undertaken to evaluate the performances of rice, wheat and mungbean in bed planting for increasing crop diversity through inclusion of mungbean in rice-wheat cropping systems and to evaluate the total system productivity of rice-wheat-mungbean cropping systems under bed planting.

MATERIALS AND METHODS

The experiment was conducted at the Bangladesh Rice Research Institute (BRRI) experimental farm, Gazipur and at farmers' fields in Chuadanga in Rabi season 2002-03 (November to March, wheat), *Kharif-I* season 2003 (March to June, mungbean) and *Kharif-II* season 2003 (June to November, rice). In both the locations, the experiment was repeated simultaneously in two separate fields. The soil of the experimental plots in BRRI farm was clay loam whereas in farmers' fields it was silty loam. Four cropping patterns namely Wheat-Mungbean-Direct seeded rice (DSR), Wheat-Mungbean-Transplant rice (TPR), Wheat-Fallow-DSR and Wheat-Fallow-TPR under two planting methods, bed (raised bed) and conventional (flat) planting were evaluated. The experiment was laid out in a randomized complete block (RCB) design with three replications.

For wheat, 70 cm wide raised beds (40 cm top and 30 cm furrow) were made manually following the conventional land preparation and height of beds was 15 cm. Beds prepared for wheat were used for mungbean and rice. The beds prepared for wheat kept intact and mungbean, DSR and TPR on bed were grown as zero tillage condition. Normal tillage practices were followed in conventional method for all the crops. Weed population and dry biomass of weed were recorded at the time of weeding from a sample area of 0.25 m^2 for all the crops. Grain yields and yield components of all the crops were collected at maturity. The productivities of different cropping systems were compared in terms of rice equivalent yield (REY). Cost of land preparation, bed preparation, labour wage, inputs and irrigation and price of the products and byproducts were recorded. Simple economic analysis such as total variable cost (TVC), gross return, gross margin and benefit-cost ratio (BCR) were done for different planting methods.

Crop management practices

The wheat variety Kanchan was used in both the locations. The seed rates were 120 kg ha^{-1} and 90 kg ha^{-1} for conventional and bed planting, respectively. Seeds were treated with Viatvax-200 at the rate of three gram kg^{-1} seed. For beds, seeds were sown on 26 and 17 November in Gazipur and Chuadanga, respectively, in two rows bed^{-1} and for conventional method, row-to-row distance was 20 cm. In the row, seeds were sown continuously and covered properly with soil. Phosphorus (P), potassium (K), sulphur (S) and zinc (Zn) were applied at the rates of 36, 25, 20 and 4 kg ha^{-1}, respectively. The N rates were 100 kg ha^{-1} and 80 kg ha^{-1} for conventional and bed planting, respectively. Twenty-five percent seed and 20% N were reduced in bed planting based on previous results (Gupta *et al*., 2000; Hossain *et al*., 2001). Two-thirds N and whole P, K, S and Zn fertilizers were applied at the time of final land preparation. The remaining one-third N was topdressed at 19 days after sowing at crown root initiation stage (three leaf stage) followed by irrigation. For the treatments with bed planting, N was topdressed on the top of beds only. Seeds were sown in rows in both bed and conventional methods. Other crop management practices were followed as per recommendation (Sufian, 2001). Wheat was harvested on 22 and 15 March in Gazipur and Chuadanga, respectively.

Mungbean variety BARI Mung-5 was used in both the locations. Seed rate was 50 kg ha^{-1} for both the conventional and bed planting. Seeds were sown in two rows at 20 cm apart, on the top of beds keeping 10 cm at each edge in bed and for conventional method, row-to-row distance was 35 cm. Seeding dates of mungbean were 23 March and 16 March in Gazipur and Chuadanga, respectively. Nitrogen, P and K were applied at the rate of 18, 16 and 15 kg ha^{-1}, respectively. For the treatments with conventional tillage, all the fertilizers were applied at the time of final land preparation and for bed planting it was applied on bed top before sowing. Other recommended crop management practices were followed. Irregular maturity was observed in both the locations. Mature pods were picked up manually thrice from each plot during 26 May-15 June and 18 May-10 June at Gazipur and Chuadanga, respectively.

Aman rice varieties BRRI dhan30 and BRRI dhan39 were used in Gazipur while BR11 and BRRI dhan30 were used in Chuadanga. In the *Kharif-II* season a pre-sowing herbicide, Glycel (41% Glyphosate) was applied at the rate of 3.7 liter per hectare on fallow plots only as huge number of weeds grew on fallow lands. It was applied 15 days before sowing and transplanting of direct seeded and transplanted rice, respectively, in all the fields. For DSR, seed rates were 60 and 45 kg ha^{-1} for conventional and bed planting, respectively. Pre-germinated seeds were sown in rows in both the methods with same spacing as in wheat. In Gazipur, seeds were sown on 1 July and that of on 28 June in Chuadanga. For TPR, 27- and 28-day-old seedlings were transplanted on 20 and 18 July in Gazipur and Chuadanga, respectively. Two to three seedlings $hill^{-1}$ were used maintaining the spacing of 20 cm × 20 cm. For the beds, seedlings were transplanted in two rows at 20 cm apart on the top of beds keeping 10 cm at each edge. Irrigation water was applied between the furrows of bed one day before transplanting to make the soil soft.

Phosphorus, K, S and Zn were applied at the rates of 20, 35, 10 and 4 kg ha^{-1}, respectively. The N rates were 100 and 80 kg ha^{-1} for conventional and bed planting, respectively. In the conventional treatment, the whole of P, K, S and Zn were applied at final land preparation while in bed planting, fertilizers were applied on the top of the beds before sowing and transplanting. For DSR, N was applied in four equal splits. One-forth of N fertilizer was applied as basal and the remaining splits were topdressed at 20, 40 and 60 days after sowing (DAS) for BRRI dhan39 and at 20, 45 and 70 DAS for other three varieties (BRRI, 2000). For TPR, urea was topdressed in three equal splits at 15, 30 and 45 days after transplanting (DAT) for BRRI dhan39 and at 15, 35 and 55 DAT for other varieties. For the treatments with bed planting, N fertilizer was topdressed on the top of beds (BRRI, 2000). Other recommended crop management practices were followed. In Gazipur, rice was harvested on 1-13 November and in Chuadanga it was harvested on 7-8 November.

RESULTS AND DISCUSSION

Agronomic productivity

Grain yields of wheat, mungbean and rice were significantly affected by planting method both at on-farm and on-station. The grain yields of all the crops in the system under raised bed planting were significantly higher than that of conventional (flat) planting (Table 1). These higher yields in raised beds might be attributed to the higher number of grains $panicle^{-1}$ and more 1000-grain weight of wheat, higher number of pods plant $^{-1}$ of mungbean and higher number of grains $panicle^{-1}$ of rice since the differences of other components were insignificant (Table 3). The total REY was also higher in bed planting than the conventional

Table 1. Grain yield of wheat, mungbean and rice and total rice equivalent yield (REY) under bed planting and conventional planting methods.

Planting method	Grain yield			REY* ($t\ ha^{-1}$)
	Rabi	Kharif-I	Kharif-II	
	Wheat ($t\ ha^{-1}$)	Mungbean ($kg\ ha^{-1}$)	Rice ($t\ ha^{-1}$)	
Experimental farm, BRRI, Gazipur (1)				
Raised bed	3.15 a	678.17 a	5.28 a	10.42 a
Flat	2.80 b	481.83 b	4.79 b	9.11 b
CV (%)	5.59	9.18	5.09	2.97
Experimental farm, BRRI, Gazipur (2)				
Raised bed	2.88 a	780.00 a	4.38 a	9.39 a
Flat	2.27 b	550.83 b	4.16 b	7.98 b
CV (%)	8.26	1.89	4.03	3.18
On-farm, Chuadanga (1)				
Raised bed	3.79 a	850.83 a	5.18 a	11.42 a
Flat	3.13 b	628.17 b	4.71 b	9.72 b
CV (%)	5.36	3.62	4.39	2.89
On-farm, Chuadanga (2)				
Raised bed	3.43 a	805.83 a	5.15 a	10.88 a
Flat	2.74 b	626.67 b	4.57 b	9.12 b
CV (%)	8.10	3.72	4.58	3.73

Figures in a column followed by different letters differ significantly at the 5% level by DMRT. *REY was calculated based on the local market price of rice, wheat and mungbean @ Tk 7.50, 9 and 30, respectively.

method. The higher grain yield of each crop of the system in raised bed resulted significantly higher REY than flat in every locations. Yield increase in wheat, mungbean and rice by bed planting was also reported by Hobbs and Gupta (2003b), Sayre (2003), Hossain *et al.* (2004), Talukder *et al.* (2004), Meisner *et al.* (2005) and Mollah *et al.* (2008).

Yield of wheat and mungbean did not differ under different rice-wheat based cropping patterns (Table 2). There were also no significant differences in yield components of both wheat and mungbean while the rice grain yield was affected by different cropping patterns in both the locations. In Gazipur, both TPR and DSR of BRRI dhan30 in Wheat-Mungbean-Rice cropping pattern and TPR in Wheat-Fallow-Rice cropping pattern produced statistically similar grain yields, which were significantly higher than DSR in Wheat-Fallow-Rice cropping pattern (Table 2). The lower grain yield of DSR in Wheat-Fallow-Rice cropping pattern was due to high weed infestation. The weed infestation was very low in DSR in Wheat-Mungbean-Rice cropping pattern as compared to Wheat-Fallow-Rice cropping pattern, which indicated that inclusion of mungbean in rice-wheat cropping system possibly would be an effective measure of weed control in DSR (Table 4). Grain yield of BRRI dhan39 followed the same trend though the yield differences were insignificant.

In Chuadanga, the grain yield of both the rice varieties, BR11 and BRRI dhan30, significantly differed under different rice-wheat cropping systems. The TPR under both Wheat-Mungbean-Rice and Wheat-Fallow-Rice cropping patterns provided significantly better grain yield than DSR under respective cropping pattern (Table 2). The performance

Table 2. Grain yield of wheat, mungbean and rice, and total REY of different rice-wheat cropping systems.

Cropping pattern			Grain yield*			
Rabi	Kharif-I	Kharif-II	Wheat (t ha^{-1})	Mungbean (kg ha^{-1})	Rice (t ha^{-1})	REY (t ha^{-1})
			Experimental farm, BRRI, Gazipur (1)			
Wheat	Mungbean	TPR	2.89	589.17	5.11 a	10.94 a
Wheat	Mungbean	DSR	2.99	570.83	5.27 a	11.14 a
Wheat	Fallow	TPR	3.03	-	5.17 a	8.80 b
Wheat	Fallow	DSR	3.00	-	4.59 b	8.19 c
CV (%)			5.59	9.18	5.09	2.97
			Experimental farm, BRRI, Gazipur (2)			
Wheat	Mungbean	TPR	2.55	671.67	4.37	10.11 a
Wheat	Mungbean	DSR	2.63	659.17	4.36	10.16 a
Wheat	Fallow	TPR	2.51	-	4.17	7.17 b
Wheat	Fallow	DSR	2.61	-	4.18	7.31 b
CV (%)			8.26	1.89	4.03	3.18
			On-farm, Chuadanga (1)			
Wheat	Mungbean	TPR	3.39	730.33	5.35 a	12.33 a
Wheat	Mungbean	DSR	3.54	748.67	4.88 b	12.12 a
Wheat	Fallow	TPR	3.42	-	5.31 a	9.41 b
Wheat	Fallow	DSR	3.50	-	4.23 c	8.43 c
CV (%)			5.36	3.62	4.39	2.89
			On-farm, Chuadanga (2)			
Wheat	Mungbean	TPR	3.06	717.50	5.32 a	11.85 a
Wheat	Mungbean	DSR	3.15	715.00	4.82 b	11.46 a
Wheat	Fallow	TPR	3.10	-	5.17 a	8.90 b
Wheat	Fallow	DSR	3.04	-	4.14 c	7.79 c
CV (%)			8.10	3.72	4.58	3.73

Figures in a column followed by different letters differ significantly at the 5% level by DMRT. *BRRI dhan30 in experimental farm, BRRI, Gazipur (1) and on-farm, Chuadanga (2), BRRI dhan39 in experimental farm, BRRI, Gazipur (2) and B11 in on-farm, Chuadanga (2).

Table 3. Yield components of wheat, mungbean and rice under bed planting and conventional planting methods.

Planting method	Wheat Panicles (no. m^{-2})	Wheat Grains panicle^{-1} (no.)	Wheat 1000-grain wt (g)	Mungbean Plants (no. m^{-2})	Mungbean Pods plant^{-1} (no.)	Mungbean Grains pod^{-1} (no.)	Mungbean 1000-grain wt (g)	Rice Panicles (no. m^{-2})	Rice Grains panicle^{-1} (no.)	Rice 1000-grain wt (g)
Experimental farm, BRRI, Gazipur (1)										
Bed	309	34.9 a	41.9 a	45.7	10.3 a	7.4	33.8	249	118 a	23.6
Flat	296	27.0 b	37.9 b	44.5	8.3 b	7.2	32.8	250	102 b	23.4
CV (%)	6.24	3.46	1.41	8.53	10.04	5.08	2.62	2.63	1.22	6.30
Experimental farm, BRRI, Gazipur (2)										
Bed	297	34.3 a	42.0 a	43.0	10.5 a	7.4	32.9	217	93 a	25.2
Flat	292	27.2 b	37.9 b	43.7	8.2 b	7.3	32.9	217	82 b	25.0
CV (%)	7.60	3.48	1.38	13.05	8.80	3.74	3.04	3.40	1.87	4.13
On-farm, Chuadanga (1)										
Bed	309	34.9 a	41.0 a	38.0	12.9 a	7.6	32.9	246	115 a	24.2
Flat	303	27.2 b	37.0 b	35.8	10.4 b	7.4	32.a	240	101 b	23.9
CV (%)	6.51	4.61	2.09	12.45	11.23	6.16	3.67	4.54	1.87	4.18
On-farm, Chuadanga (2)										
Bed	312	34.8 a	40.9 a	35.7	14.3 a	7.7	32.6	247	117 a	23.6
Flat	304	26.8 b	36.9 b	34.0	10.4 b	7.3	32.7	239	98 b	23.5
CV (%)	7.04	4.08	1.43	10.79	10.77	4.70	3.42	5.74	2.04	4.35

Figures in a column followed by different letters differ significantly at the 5% level by DMRT.

Table 4. Weed vegetation in wheat, mungbean and rice in different rice-wheat cropping pattern.

Cropping pattern Rabi	Kharif -I	Kharif-II	Wheat Population (no. m^{-2})	Wheat Dry biomass (kg ha^{-1})	MB Population (no. m^{-2})	MB Dry biomass (kg ha^{-1})	Rice Population (no. m^{-2})	Rice Dry biomass (kg ha^{-1})
Experimental farm, BRRI, Gazipur (1)								
Wheat	MB	TPR	129	111.0	82 b	73.5 b	155 c	140.0 c
Wheat	MB	DSR	119	100.9	85 b	76.0 b	166 c	149.5 c
Wheat	Fallow	TPR	132	113.8	471 a	981.4 a	256 b	210.0 b
Wheat	Fallow	DSR	134	114.6	465 a	977.8 a	278 a	230.4 a
CV (%)	19.91	15.32	8.77	2.55	5.65	4.79		
Experimental farm, BRRI, Gazipur (2)								
Wheat	MB	TPR	132	119.5	86 b	78.0 b	154 c	134.0 c
Wheat	MB	DSR	134	117.2	84 b	75.8 b	166 c	148.4 c
Wheat	Fallow	TPR	120	110.8	471 a	950.5 a	254 b	217.8 b
Wheat	Fallow	DSR	134	118.1	486 a	963.1 a	284 a	241.8 a
CV (%)	13.97	11.39	6.46	4.11	6.87	6.63		
On-farm, Chuadanga (1)								
Wheat	MB	TPR	134	114.7	91 b	80.4 b	149 d	130.3 d
Wheat	MB	DSR	132	118.8	93 b	80.5 b	185 c	157.2 c
Wheat	Fallow	TPR	140	123.6	514 a	984.7 a	255 b	223.1 b
Wheat	Fallow	DSR	136	120.4	513 a	974.7 a	329 a	290.2 a
CV (%)	12.02	10.00	6.29	2.91	7.13	5.97		
On-farm, Chuadanga (2)								
Wheat	MB	TPR	154	128.3	90 b	83.8 b	158 d	143.5 d
Wheat	MB	DSR	157	134.4	95 b	85.8 b	191 c	174.1 c
Wheat	Fallow	TPR	152	124.0	502 a	981.8 a	252 b	228.1 b
Wheat	Fallow	DSR	162	128.2	494 a	983.9 a	344 a	321.3 a
CV (%)	10.89	7.62	6.45	6.34	6.78	6.11		

Figures in a column followed by different letters differ significantly at the 5% level by DMRT.

of DSR in Wheat-Mungbean-Rice cropping pattern was also better than in Wheat-Fallow-Rice cropping pattern. The poor yield of DSR in Wheat-Fallow-Rice cropping pattern in Chuadanga was also the result of high weed infestation since the field was remained fallow after wheat.

Inclusion of mungbean in the cropping pattern greatly increased the total REY of the system. The Wheat-Mungbean-Rice cropping pattern where rice was grown either as DSR or as TPR resulted significantly higher total REY than Wheat-Fallow-Rice cropping pattern (Table 2). The differences of rice yield in different cropping patterns also contributed differently to the REY. The lowest REY was computed in Wheat-Fallow-DSR cropping pattern in all the fields except the pattern with BRRI dhan39 in Gazipur, which was similar to Wheat-Fallow-TPR cropping pattern. The interaction effect of planting method and cropping on grain yields of wheat, mungbean and rice was insignificant.

Economic productivity

Tables 5 and 6 present the costs of production in details. Bed planting reduced TVC of different cropping patterns as compared to the same pattern under conventional method in each location. It was the combined costs of all the crops in the pattern. Moreover, the total costs of the cropping patterns with three crops were more than the cropping patterns with two crops under both bed and conventional methods in both the locations as the cost of mungbean cultivation was added in the TVC. Furthermore, the TVC was higher in the patterns with TPR than similar pattern with DSR, because the production cost of TPR was higher than DSR.

The gross returns followed the same trends as mentioned for REY. However, Wheat-Mungbean-Rice cropping pattern, where rice was grown either DSR or TPR, under bed planting resulted the highest gross return (Tk 98,680 ha^{-1} with TPR and Tk 99,470 ha^{-1} with DSR at Gazipur and Tk 112,810 ha^{-1} with TPR and Tk 111,370 ha^{-1} with DSR at Chuadanga), which was followed by same pattern under conventional method in both the locations (Table 7). The lowest gross return was earned by Wheat-Fallow-DSR cropping pattern under conventional method, which followed the Wheat-Fallow-TPR pattern.

Bed planting resulted higher gross margin than the conventional method of similar pattern at each location (Table 7). In on-station trial, the highest gross margin was found by bed planting of Wheat-Mungbean-DSR cropping pattern (Tk 64,760 ha^{-1}) followed by Wheat-Mungbean-TPR pattern (Tk 62,670 ha^{-1}). However, in on-farm trial, the highest was recorded in bed planting of Wheat-Mungbean-TPR cropping pattern (Tk 78,050 ha^{-1}) followed by Wheat-Mungbean-DSR cropping pattern (Tk 77,890 ha^{-1}) under bed planting. This was because of lower yield of DSR than TPR. The gross margins of Wheat-Mungbean-DSR and Wheat-Mungbean-TPR cropping patterns were very similar in each location. The lowest gross margin was recorded by Wheat-Fallow-DSR cropping pattern under conventional method, which followed the Wheat-Fallow-TPR pattern. The cropping patterns with two crops under bed planting and with three crops under conventional gave similar gross margin in both the locations, which indicated that by using bed planting method the gross margin could be increased to a great extent (Table 7). This result might be supported by the results of Chandra and Gupta (2004) and Singh and Beecher (2005).

The BCR computed for different cropping patterns under different planting methods showed similar trends as gross margins in both the locations (Table 7). Bed planting increased BCR, because of higher gross return and lower TVC than those of conventional method in every location. The three crops pattern (Wheat-Mungbean-DSR/TPR) under bed planting resulted the highest BCR while the two crops pattern (Wheat-Fallow-DSR/TPR) under conventional method recorded the lowest BCR at each location.

Table 5. Variable cost for wheat, mungbean (MB) direct seeded rice (DSR) and transplant (TPR) Aman rice in different rice-wheat cropping systems under bed and conventional planting, Gazipur.

Activity/resource	Variable cost (Tk ha^{-1})							
	Raised bed				Conventional (flat)			
	Wheat	MB	DSR	TPR	Wheat	MB	DSR	TPR
Seed	1,350	1,200	653	331	1,800	1,200	870	580
Land preparation	2,100	-	-	-	2,100	1,050	2,100	2,100
Bed preparation	2,100	-	-	-	-	-	-	-
Seedling	-	-	-	857	-	-	-	1,500
Sowing/transplanting	1,000	1,000	1,000	1,800	1,750	1,000	1,750	2,625
Fertilizer: Urea	1,056	240	1,056	1,056	1,320	240	1,320	1,320
TSP	2,160	960	1,200	1,200	2,160	960	1,200	1,200
MP	500	300	700	700	500	300	700	700
Gypsum	480		240	240	480	-	240	240
$ZnSO_4$	400		400	400	400	-	400	400
Herbicide (Pre-sowing)*	-	-	1,850	1,850	-	-	1,850	1,850
Weeding	1,050	1,050	1,680 (1,470)	1,575 (1,260)	1,575	1,050	2,170 (1,680)	1,960 (1,575)
Insecticide	-	-	1,290	1,290	-	-	1,290	1,290
Irrigation	1,015	190	214	525	1,800	293	1,106	1,374
Harvesting	1,400	2,625	1,680	1,540	1,725	2,625	1,960	1,890
Threshing	1,050	525	1,050	1,050	1,050	525	1,050	1,050
Total	15,661	8,095	13,013 (10,953)	14,414 (12,249)	16,660	9,250	18,006 (15,666)	20,079 (17,844)

Figures in the parenthesis and without parenthesis for weeding and total variable cost of DSR and TPR are for the pattern Wheat-MB-DSR/TPR and Wheat-Fallow-DSR/TPR, respectively. Price of seed: wheat=15 Tk kg^{-1}; rice=14.50 Tk kg^{-1} and mungbean=40 Tk kg^{-1}. Labour: Gazipur=8.75 Tk man-hour^{-1}, Chuadanga=7.50 Tk man-hour^{-1}. *Pre-sowing herbicide was applied only in fallow plots before 15 days of rice seeding.

Table 6. Variable cost for wheat, mungbean (MB) direct seeded rice (DSR) and transplant (TPR) Aman rice in different rice-wheat cropping systems under bed and conventional planting, Chuadanga.

Activity/resource	Variable cost (Tk ha^{-1})							
	Raised bed				Conventional (flat)			
	Wheat	MB	DSR	TPR	Wheat	MB	DSR	TPR
Seed	1,350	1,200	653	331	1,800	1,200	870	580
Land preparation	2,100	-	-	-	2,100	1,050	2,100	2,100
Bed preparation	1,800	-	-	-	-	-	-	-
Seedling	-	-	-	857				1,500
Sowing/transplanting	840	840	840	1,560	1,440	840	1,500	2,250
Fertilizer: Urea	1,056	240	1,056	1,056	1,320	240	1,320	1,320
TSP	2,160	960	1,200	1,200	2,160	960	1,200	1,200
MP	500	300	700	700	500	300	700	700
Gypsum	480	-	240	240	480	-	240	240
$ZnSO_4$	400	-	400	400	400	-	400	400
Herbicide (Pre-sowing)*	-	-	1,850	1,850	-	-	1,850	1,850
Weeding	1,080	1,200	1,550 (1,350)	1,320 (1,140)	1,500	1,350	2,220 (1,980)	1,750 (1,500)
Insecticide	-	-	1,530	1530	-	-	1,530	1,530
Irrigation	1,024	170	194	517	1,800	287	912	1,211
Harvesting	1,260	2,250	1,440	1,350	1,500	2,250	1,620	1,500
Threshing	1,350	450	900	900	1,350	450	900	900
Total	15,370	7,610	12,553 (10,503)	13,811 (11,781)	16,350	8,927	17,362 (15,272)	19,031 (16,931)

Figures in the parenthesis and without parenthesis for weeding and total variable cost of DSR and TPR are for the pattern Wheat-MB-DSR/TPR and Wheat-Fallow-DSR/TPR, respectively. Fertilizer: Urea=6 Tk kg^{-1}, TSP=12 Tk kg^{-1}, MP=10 Tk kg^{-1}, Gypsum=4 Tk kg^{-1} and $ZnSO_4$=40 Tk kg^{-1}. Herbicide: Glysel: 500 Tk L^{-1}. Insecticide: Furadan 5G=105 Tk kg^{-1} and Malathion=240 Tk L^{-1}. **Pre-sowing herbicide was applied only in fallow plots before 15 days of rice seeding.

Table 7. Economic productivity of different rice-wheat cropping systems under bed and conventional planting.

Tillage option	Cropping pattern	Total variable cost (000' Tk ha^{-1})	Gross return (000' Tk ha^{-1})	Gross margin (000' Tk ha^{-1})	BCR
		Experimental farm, BRRI, Gazipur			
Raised bed	Wheat-MB-TPR	36.01	98.68	62.67	2.74
	Wheat-MB-DSR	34.71	99.47	64.76	2.87
	Wheat-F-TPR	30.01	73.43	43.42	2.45
	Wheat-F-DSR	28.67	73.80	45.13	2.57
Conventional	Wheat-MB-TPR	43.75	86.10	42.35	1.97
	Wheat-MB-DSR	41.58	88.21	46.63	2.12
	Wheat-F-TPR	36.77	67.45	30.68	1.83
	Wheat-F-DSR	34.67	64.71	30.04	1.87
		On-farm, Chuadanga			
Raised bed	Wheat-MB-TPR	34.76	112.81	78.05	3.25
	Wheat-MB-DSR	33.48	111.37	77.89	3.33
	Wheat-F-TPR	29.18	86.22	57.04	2.95
	Wheat-F-DSR	27.92	77.92	50.00	2.79
Conventional	Wheat-MB-TPR	42.21	98.81	56.60	2.34
	Wheat-MB-DSR	40.55	95.95	55.40	2.37
	Wheat-F-TPR	35.38	74.92	39.54	2.12
	Wheat-F-DSR	33.71	66.23	32.52	1.96

The local market price: rice=7.5 Tk kg^{-1}, wheat=9 Tk kg^{-1}, mungbean=30 Tk kg^{-1}, wheat straw=1 Tk kg^{-1}, rice straw=1 Tk kg^{-1} and mungbean straw=1 Tk kg^{-1}.

CONCLUSIONS

The total agro-economic productivity and crop diversity of rice-wheat cropping system could be increased to a great extent over conventional method by adopting bed planting and inclusion of a grain legume like mungbean in the system, which made the system more profitable.

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Growth of Wheat (*Triticum aestivum* L.) under Raised Bed Planting Method in Rice-Wheat Cropping System

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ABSTRACT

An experiment was conducted at the Bangladesh Rice Research Institute, Gazipur during Rabi season 2001-02 and 2002-03 (November to March) to evaluate the effect of raised bed planting method on different crop growth parameters, which influence the wheat productivity. Total tiller production, leaf area index (LAI), dry mater production (DMP), crop growth rate (CGR) and agronomic productivity of wheat under bed planting on 70, 80 and 90 cm wide beds with two and three plant rows bed^{-1} and conventional method were investigated. The number of tillers m^{-2} in 70 cm beds with both two and three rows were statistically identical to conventional method. Wheat plants grown on narrow beds (70 cm) produced similar LAI to that grown in conventional method but plants in wider beds (80 and 90 cm) had less LAI than that in conventional method. Similarly, DMP and CGR in 70 cm beds were either comparable or higher than conventional method. Grain yield of 70 cm beds were higher than conventional method. Wheat in 70 cm beds increased number of panicles m^{-2}, number of grains panicle^{-1} and 1000-grain weight of wheat.

Key words: Bed planting, rice-wheat and wheat growth

INTRODUCTION

Bed planting in rice-wheat cropping system is an alternative tillage and crop establishment method for improving resource use efficiency and increasing the yield frontier (Hobbs *et al*., 2001). In this system, the land is prepared conventionally and raised bed and furrows are prepared manually or using a raised bed planting machine. Crops are planted in rows on top of the raised beds and irrigation water is applied in the furrows between the beds. Water moves horizontally from the furrows into the beds. This system is often considered for growing high value crops that are more sensitive to temporary water-logging stress. Growing wheat on raised beds though introduced in the Indo-Gangetic Plain few years ago, the practice of rice, the major water-using crop in the rice-wheat cropping system, on narrow raised bed introduced very recently (Connor *et al*., 2003b). In rice-wheat cropping system, new raised beds are prepared for wheat and after harvesting of wheat, rice is grown in Aman season (*Kharif-II*) following a required repairing of the beds. An additional advantage of bed planting becomes apparent when beds are permanent, that is, when they are maintained over the medium term and not broken down and reformed for every crop (Hobbs and Gupta, 2003a, Sayre, 2003). In the permanent bed, all the crops of the system, except the first crop in the first year, grown in zero tillage, which cut down the costs of land preparation and bed making, and only repairing cost for bed is needed.

The continuous cultivation of rice and wheat - two crops or more per year - has provided food and livelihoods for millions of rural and urban poor in South Asia. Now a

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crisis looms as the population is growing at more than 2% (nearly 24 millions additional mouth to feed) each year and agricultural land area dwindles and yield increase are levelling off (Hobbs, 2003). Increasing food production of this area in the next 20 years to match population growth is challenging. It is made even more difficult because, land area devoted to agriculture will be stagnated or declined and better quality land and water resources is expected to be diverted to other sector of the national economy. In order to grow more food from marginal and good quality lands, the quality of natural resource base must be improved and sustained. Efficiency of natural resources like, seed, water, fuel and labour needs to be improved and that could be achieved by development of resource conservation technologies like bed planting technology (Hobbs *et al*., 2001).

Research activities in India and Pakistan showed many advantages of bed planting in rice-wheat systems. The bed planting in rice-wheat systems saved 50% seed and 30-40% water, increased yield, reduced lodging, facilitated mechanical weeding, offered opportunity for a last irrigation at grain filling stage of wheat, avoided temporary water logging problem, allowed surface basal and top dress fertilizer placement, reduced N loses and promoted rain water conservation (Moreno *et al*., 1993, Gupta *et al*., 2000; Connor *et al*., 2003a). The soil on the surface of the bed is drier, which is not favourable for weed growth (Malik *et al*., 1998). Lodging problem is also less on raised bed (Meisner *et al*., 1992). Additional light enters the canopy and strengthens the straw and soil around the base of the plant. Adoption of bed planting has increased dramatically in the last decade in the high yielding irrigated wheat growing area of northwestern Mexico. It has increased from 6% in 1981 to 75% in 1994 due to improved and efficient management of irrigation water; improved fertilizer use efficiency; better weed management; lower seed rate and better plant stands; better drainage and less lodging of wheat (Hobbs and Gupta, 2003a). The research activities on bed planting of wheat so far done and/or reported are mainly on the productivity and resource conservation. Therefore, this study was undertaken to evaluate the effect of bed planting on different crop growth parameters, which influence the agronomic productivity of wheat.

MATERIALS AND METHODS

The study was carried out at the Bangladesh Rice Research Institute (BRRI), Gazipur during Rabi season 2001-02 and 2002-03 (November to March). The soil of the experimental plot was clay loam with pH 6.78. Bed planting in 70, 80 and 90 cm (center- to-center of furrows) wide bed with two and three plant rows bed^{-1} along with flat (conventional) planting were tested. The experiment was laid out in a randomized complete block design with four replications. The unit plot size was 24 m^2. Wheat variety Kanchan was used and seed rate was 120 kg^{-1}. Raised beds and furrows were made manually by spade following the conventional land preparation in the first year. According to the treatments 70, 80 and 90 cm wide beds were made. The height of beds was 15 cm. In the second year, no new beds were made. The beds of the previous year where wheat followed by direct seeded Aman rice were grown kept as permanent bed. It was repaired before seeding of next year's wheat.

Nitrogen, P, K, S and Zn were applied at the rates of 100, 36, 25, 20 and 4 kg ha^{-1}, respectively. In the first year, two-thirds N and whole P, K, S and Zn fertilizers were applied at final land preparation. The remaining one-third N was topdressed at 20 days after sowing (DAS) at crown root initiation (CRI) i.e. three leaf stage. This was followed by irrigation. For the treatments with bed planting, N was applied on the top of beds only. In the second year, the basal doses of fertilizer were applied at final land preparation in the plots with conventional tillage treatment but in the plots with bed planting treatments, the basal doses were applied before sowing on the top of the beds. Seeds were sown in rows in both bed and conventional methods. For beds, seeds were sown in two and three rows according to the treatments. For conventional method, row-to-row distance was 20 cm. In the row, seeds were sown continuously and covered with soil properly. The dates of sowing were 29 and 20 November in the first and second year, respectively. Other recommended crop management practices were followed.

Tiller number, leaf area index (LAI), dry matter production (DMP) and crop growth rate (CGR) were recorded at 10 day intervals starting from 20 DAS. Three sample areas, one square meter each, were marked by bamboo stick in each plot to count total tiller production and panicle number. To measure LAI, from each plot, plant sample of 0.25 m^{-2} were collected from outside the harvest area excluding border plant rows. Whole sample plants were uprooted. Six representative tillers from each sample were removed as sample tillers. Green leaves of sample tillers were removed. The leaf area of sample tillers was measured by using an automatic leaf area meter. Other green leaves from the each sample were removed from the tillers. Then leaves from the sample tillers and leaves from the other tillers of the samples were dried and weighed separately. The LAI was computed by using the method given by Yoshida *et al.* (1976) as follow:

$$\text{Leaf area of the sample} = \frac{\text{Total leaf area of the sample tillers } (cm^2) \text{ x dry wt of all leaves}}{\text{Dry wt of leaves from sample tillers (g)}}$$

where, dry wt of all leaves = dry wt of sample leaves + dry wt of remaining leaves

$$\text{LAI} = \frac{\text{Leaf area of the sample } (cm^2)}{\text{Area of land covered by the sample } (cm^2)}$$

Dry matter production and CGR were measured from the same samples collected for LAI. The plant samples were dried in an oven at 80°C until to reach a constant dry weight. Total dry matter was expressed in g m^{-2} and crop growth rate in g day^{-1} m^{-2}. Wheat was harvested on 28 and 21 March in the first and second year, respectively. Grain yield and yield components data were collected at maturity.

RESULTS AND DISCUSSION

Tiller production

In the first year, where wheat was sown on new beds, at beginning (20 DAS), the number of tillers m^{-2} in conventional method was significantly higher than all bed planting treatments and with the progressing of the days from seeding, the differences became reduced and finally no difference was observed between conventional method and bed planting with 70 cm beds (Table 1). At 30 DAS the tiller production in conventional method was comparable to 70 cm beds with three plant rows. However, at 40 DAS it was statistically identical to 70 cm beds with both two and three rows. At 50 DAS the number of tillers m^{-2} was higher in 70 cm beds with both two and three rows than conventional method. From 60 to 120 DAS (maturity) the number of tillers m^{-2} in bed with both two and three rows was statistically similar to conventional method. The number of tillers m^{-2} was decreased with the increase in bed width with the same plant rows per bed, and three rows per bed produced slightly higher number of tillers m^{-2} than two rows per bed in the same bed width.

In second year, where wheat was sown in permanent beds, the planting method did not affect the number of tillers m^{-2} significantly at the beginning (20 DAS) and with the advancement of days, the differences were significant. At 30 DAS, the highest number of tillers m^{-2} was recorded in 70 cm beds with three plant rows. At 40 and 50 DAS, the tiller production in conventional method and 70 cm beds with both two and three rows were statistically identical. From 60 to 120 DAS, the 70 cm beds with three rows produced significantly the highest number of tillers m^{-2}.

Table 1. Tiller production of wheat under different planting methods at different days after seeding (DAS).

Planting method	Tillers (no. m^{-2}) at DAS										
	20	30	40	50	60	70	80	90	100	110	120
					2001-02						
70 cm bed + 2 rows	148 cd	243 b	358 a	363 a	347 a	336 a	329 a	319 a	313 a	311 a	309 a
70 cm bed + 3 rows	159 b	246 ab	350 a	354 ab	341 a	338 a	336 a	327 a	321 a	319 a	318 a
80 cm bed + 2 rows	149 cd	224 c	310 b	314 c	286 b	276 b	272 b	251 b	240 c	237 c	235 c
80 cm bed + 3 rows	152 bcd	214 d	285 c	289 d	273 c	266 bc	262 bc	255 b	252 b	249 d	248 b
90 cm bed + 2 rows	144 d	200 e	270 d	273 e	257 d	249 d	244 d	232 c	226 d	224 d	223 d
90 cm bed + 3 rows	155 bc	208 d	275 cd	279 de	263 cd	259 cd	256 c	245 b	240 c	237 c	235 c
Conventional	175 a	252 a	349 a	352 b	339 a	334 a	331 a	324 a	321 a	318 a	315 a
					2002-03						
70 cm bed + 2 rows	154 a	259 b	354 ab	359 ab	346 b	332 b	322 b	317 b	312 b	311 b	310 b
70 cm bed + 3 rows	160 a	279 a	360 a	375 a	362 a	354 a	346 a	339 a	329 a	328 a	325 a
80 cm bed + 2 rows	153 a	239 c	300 de	318 d	297 d	288 d	280 d	272 d	265 d	263 d	260 d
80 cm bed + 3 rows	155 a	245 bc	318 cd	338 c	316 c	308 c	301 c	293 c	286 c	285 c	282 c
90 cm bed + 2 rows	153 a	207 d	287 e	296 e	268 f	252 e	253 e	248 e	244 e	243 e	241 e
90 cm bed + 3 rows	153 a	215 d	335 bc	352 bc	282 e	264 e	254 e	248 e	245 e	243 e	242 e
Conventional	160 a	250 bc	342 ab	360 ab	325 c	311 c	300 c	295 c	286 c	280 c	274 c

Figures in a column followed by different letters differ significantly at the 5% level by DMRT.

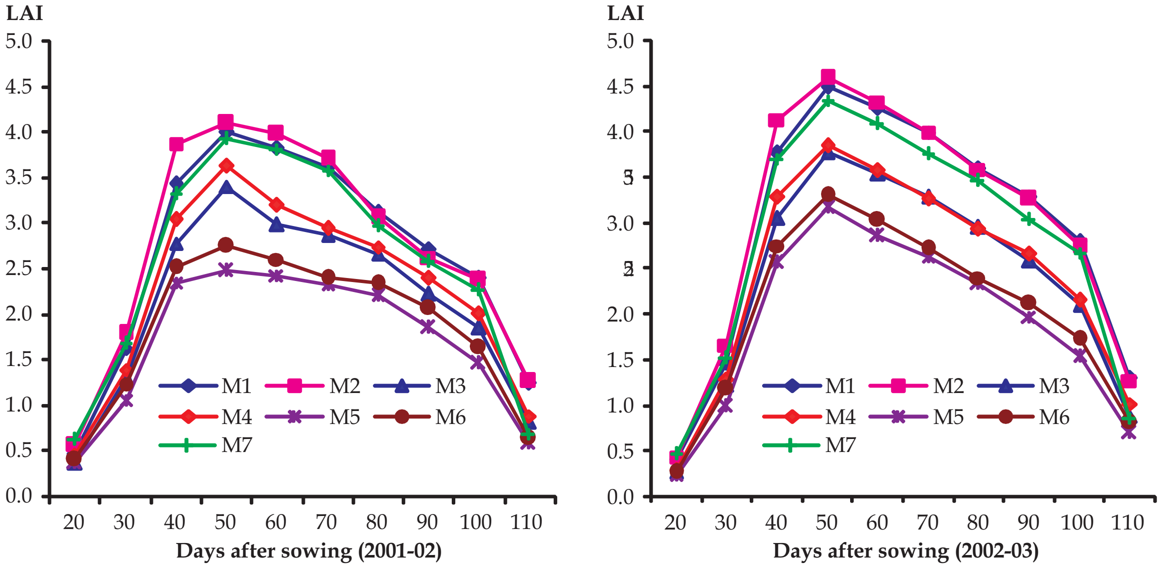
This was the lowest in 90 cm beds with two rows. These tiller productions obviously matched up with the number of panicles m^{-2}, and which might be contributed to the grain yield of corresponding method. The results also indicated that the bed planting with narrow beds were able to compensate the number of tillers m^{-2} for blank spaces between beds while the wider one did not. In every treatment the number of tillers m^{-2} increased very rapidly in early stages and reached to the highest at 50 DAS and then started declining due to death of some tillers and at later stages it became more or less stable, which indicated that the maximum tillering of wheat might be occurred in between 40 and 60 DAS.

Leaf area index (LAI)

In the first year, at 20 DAS, the highest LAI was recorded in the conventional method. At 30 DAS the highest LAI was found in 70 cm beds with three plant rows followed by 70 cm beds with two rows and conventional method (Fig. 1). This trend was continued up to 90 DAS and at the later stages (100-110 DAS), 70 cm beds with both two and three rows gave similar LAI, which were higher than the conventional method and rest of the bed planting treatments. Among the bed planting treatments, the 70 cm beds irrespective of plant row resulted in the highest LAI and with the increase in width of beds, the LAI was decreased throughout the growing period. Three plant rows per bed produced higher LAI than two plant rows per bed under same width bed width, which might be due to higher number of tillers m^{-2}. In the second year, the results showed very similar pattern to that of first year.

At the early stage of crop growth, the LAI increased rapidly and reached the maximum at 50 DAS for all the treatments. From 60 DAS, it started decreasing, which was continued up to the maturity. The narrow beds (70 cm) were able to produce LAI as much as conventional method or even higher than conventional method at mid to later stage of crop growth while the wider beds (80 and 90 cm) failed to do so. At maturity stage (110 DAS), the crop was greener in bed planting, especially in narrow beds, than conventional method resulting higher LAI, while it was sharply decreased in conventional method.

Simple linear regression analysis of LAI at different growth stages with grain yield of wheat showed that the relationship was significant in both the years (Fig. 2). However, the value of coefficient of determination at CRI



M1 = 70 cm bed + 2 rows, M2 = 70 cm bed + 3 rows, M3 = 80 cm bed + 2 rows, M4 = 80 cm bed + 3 rows, M5 = 90 cm bed + 2 rows, M6 = 90 cm bed + 3 rows, M7 = conventional

Fig. 1. Leaf area index of wheat under different methods of planting at different days after sowing.

stage (20 DAS) was low (R^2 = 0.23–0.44). The significant linear relationship of the LAI at heading (50 DAS), grain filling (80 DAS) and ripening (110 DAS) stages with grain yield (R^2 = 0.59–0.88) indicated that the grain yield was increased with increasing LAI. Therefore, the higher LAI in bed planting with 70 cm bed at the later stages of crop growth might be a reason for higher grain yield.

Dry matter production (DMP)

Planting method significantly affected the DMP (shoot) of wheat at different DAS in both the years. In first year, at preliminary stage (20 DAS), the conventional and 70 cm beds with three rows produced similar dry matter yield, which was significantly higher than the rest of the treatments (Table 2). At 30 DAS 70 cm beds with both two and three rows, 80 cm beds with three rows and conventional method produced alike dry matter yield. This trend was continued up to 60 DAS. During 70 to 90 DAS, 70 cm beds with both two and three rows and conventional method recorded statistically similar DMP. From 100 to 120 DAS, 70 cm beds with both two and three rows produced significantly higher dry matter yield than conventional method. Higher DMP of wheat under raised bed planting than conventional method was also reported by Khaleque *et al*. (2008). The similar pattern of DMP was observed in second year, in permanent beds.

Figure 3 illustrated simple linear regression analysis of DMP at CRI (20 DAS), heading (50 DAS), grain filling (80 DAS) and ripening (110 DAS) stages with grain yield of wheat. The relationship was significant in both the years. The linear relationship indicated that the grain yield was increased with increasing DMP. Therefore, the higher DMP in bed planting with 70 cm bed, especially at heading, grain filling and ripening stages might be a reason for higher grain yield (R^2 = 0.54–0.75).

Crop growth rate (CGR)

In the first year, the bed planting in 70 cm bed with both two and three rows always resulted in higher CGR than conventional and other bed planting treatments (Fig. 4). The wider beds (80 and 90 cm) gave lower

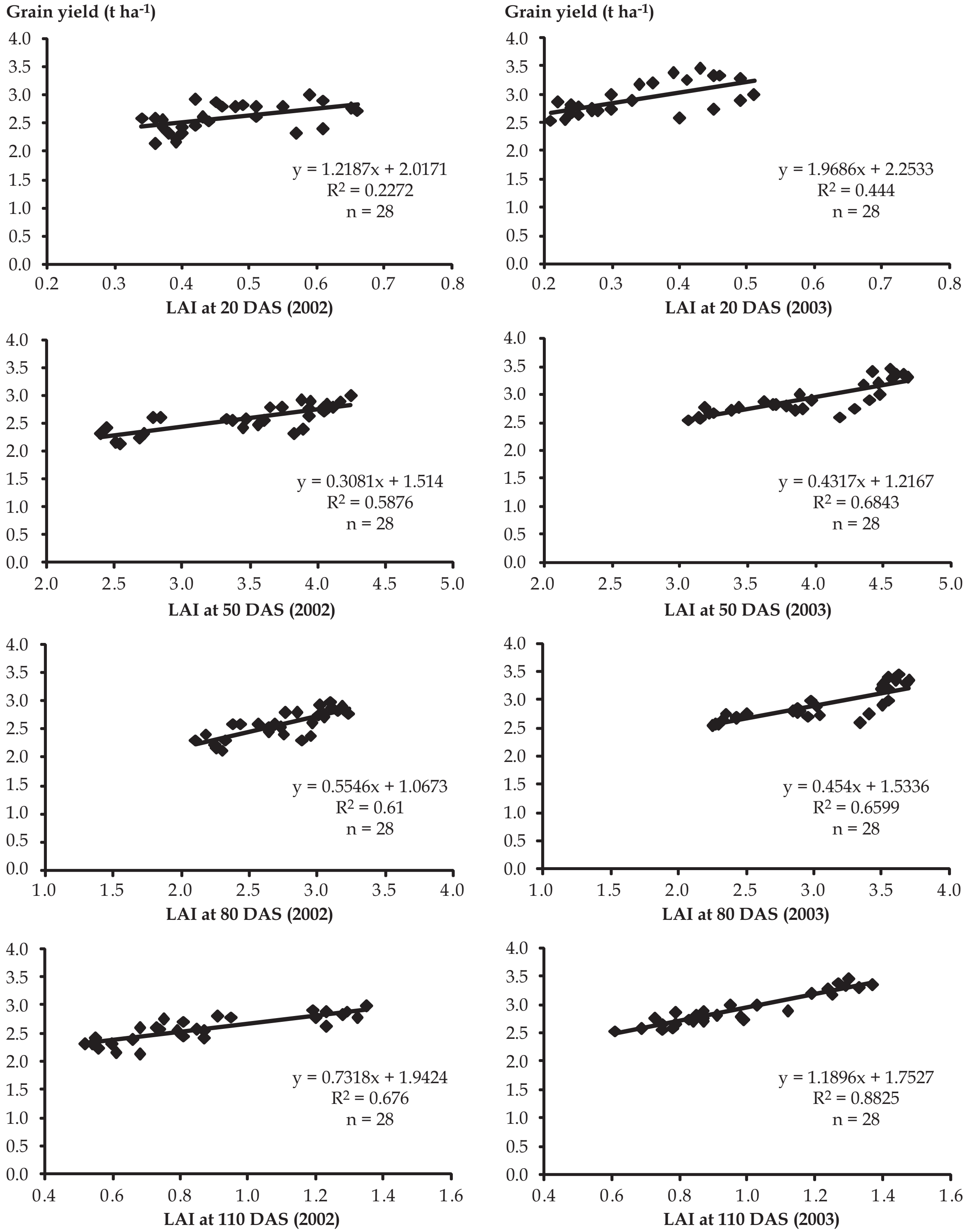


Fig. 2. The relationship between LAI at different stages of crop growth and grain yield of wheat.

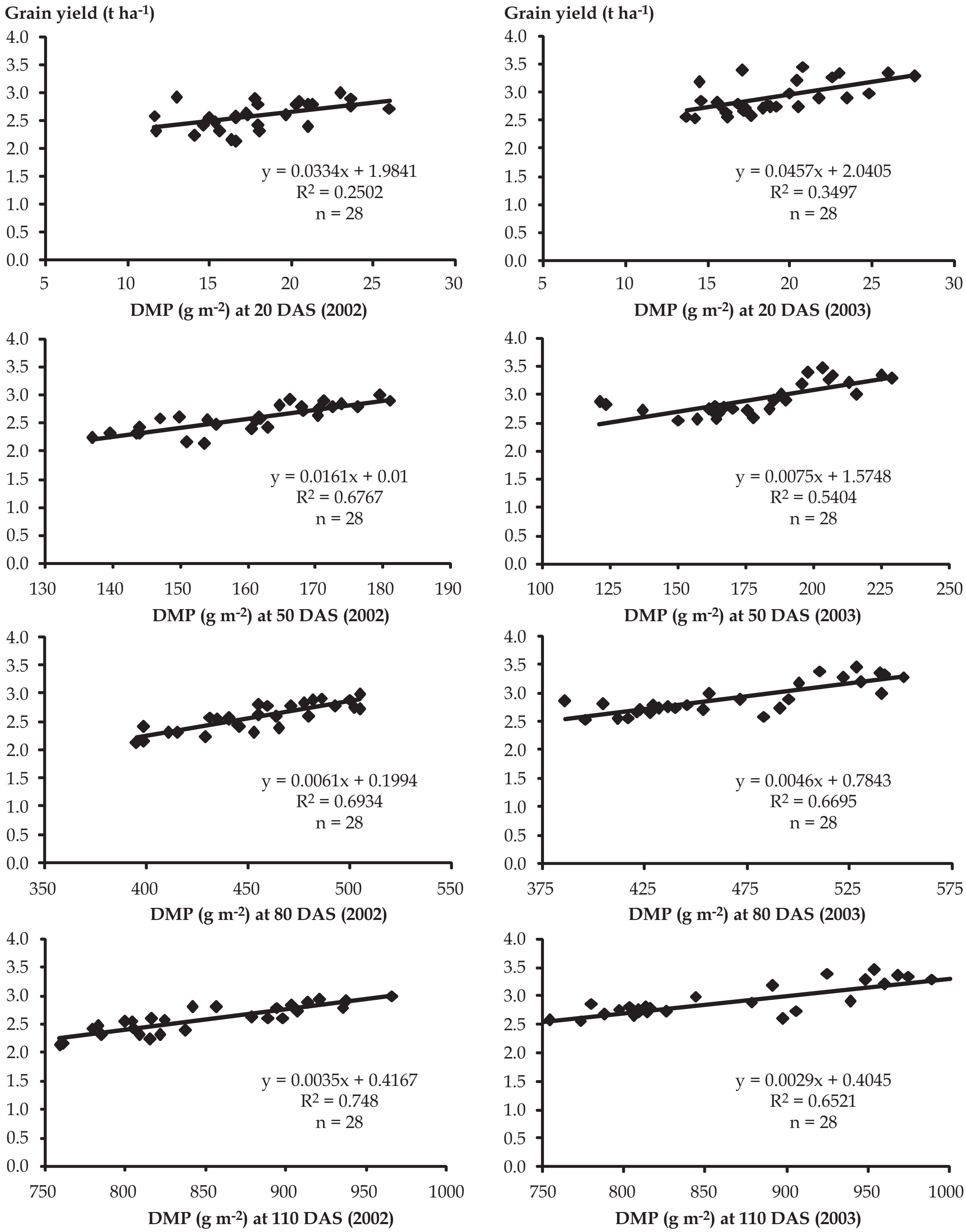
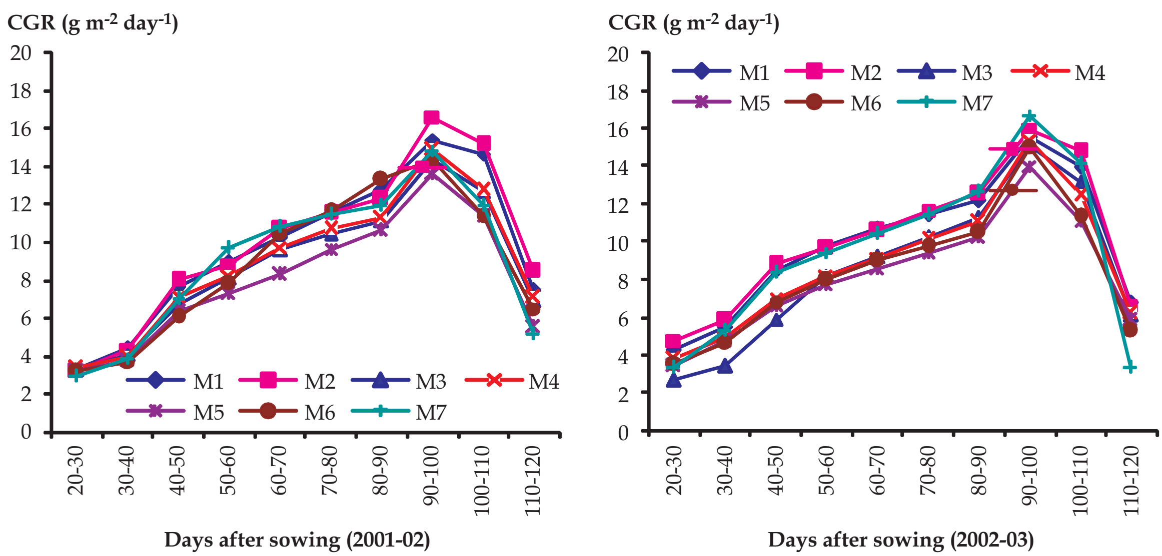


Fig. 3. The relationship between DMP at different stages of crop growth and grain yield of wheat.

Table 2. Dry matter production (DMP) of wheat under different planting methods at different days after seeding (DAS).

Planting method	DMP (g m^{-2}) at different DAS										
	20	30	40	50	60	70	80	90	100	110	120
					2001-02						
70 cm bed + 2 rows	18b	51abc	95ab	171ab	261ab	363ab	479a	607a	761ab	908a	977b
70 cm bed + 3 rows	21a	53a	97a	177a	265a	372a	488a	611a	778a	929a	1014a
80 cm bed + 2 rows	15d	49cd	89bcd	157bc	238bcd	334c	438b	550d	699d	812d	867ef
80 cm bed + 3 rows	18bc	51ab	91abc	162abc	245abc	342bc	450b	563cd	707d	820cd	885de
90 cm bed + 2 rows	15d	47d	85d	148c	221d	304d	401c	507e	644e	771e	846f
90 cm bed + 3 rows	17c	49bcd	86cd	147c	226cd	331c	447b	580bc	724cd	853bc	923c
Conventional	22a	52ab	91a-d	161abc	258ab	366ab	481a	600ab	749bc	868b	920cd
					2002-03						
70 cm bed + 2 rows	19cd	62b	116b	201b	299ab	405ab	520ab	641ab	796a	935a	1002a
70 cm bed + 3 rows	24a	72a	130a	218a	314a	420a	536a	661a	821a	968a	1034a
80 cm bed + 2 rows	17de	43e	77e	136e	218e	309e	411d	523d	674c	805c	866d
80 cm bed + 3 rows	19bc	57bc	107c	176c	258c	349c	450c	560c	714b	838b	900c
90 cm bed + 2 rows	15e	49d	96d	162d	238d	324de	417d	520d	659c	770d	828e
90 cm bed + 3 rows	18cde	53cd	99cd	167cd	246cd	336cd	433cd	538cd	687bc	801cd	853de
Conventional	22ab	55c	107c	191b	285b	388b	502b	628b	795a	936a	969b

Figures in a column followed by different letters differ significantly at the 5% level by DMRT.



M1 = 70 cm bed + 2 rows, M2 = 70 cm bed + 3 rows, M3 = 80 cm bed + 2 rows, M4 = 80 cm bed + 3 rows, M5 = 90 cm bed + 2 rows, M6 = 90 cm bed + 3 rows, M7 = conventional

Fig. 4. Crop growth rate of wheat under different methods of planting at different days after sowing.

CGR than conventional method except at very early and very later stages of crop growth, where conventional method gave the lowest. In the second year, during 20-30 DAS, the highest CGR was recorded in 70 cm beds with three rows, which was followed by the same bed width with two rows. However, CGR of these two treatments during 30-40 DAS were comparable. During 40-50 to 100-110 DAS, CGR in 70 cm beds with both two and three rows and conventional method were comparable. However, at the final stage (110-120 DAS) all the bed planting treatments resulted in higher CGR than conventional method. From the two years results it was revealed that the CGR in narrow beds (70 cm) was either comparable or higher than conventional method and in wider beds (80 and 90 cm), it was lower in most of the cases. The CGR of different treatments correspond the grain yield of the respective treatments.

Agronomic productivity

The highest grain yield was recorded in 70 cm wide beds with two plant-rows bed^{-1}, which was statistically equal with the grain yield of 70 cm wide beds with three plant-rows bed^{-1} and higher than conventional method and 80 and 90 cm wide beds with both two and three plant rows (Table 3). Similar results by bed planting in wheat was also reported by Dhillon *et al.* (2000), Gupta *et al.* (2000), Connor *et al.* (2003b), Sayre (2003), Hossain *et al.* (2004), and Meisner *et al.* (2005). Grain yield was higher in narrow bed (70 cm) and with the increase in bed width, yield was decreased. There was no significant yield difference between three and two plant-rows bed^{-1}. The highest yield in the bed planting with 70 cm beds were attributed to higher number of panicles m^{-2}, grains panicle^{-1} and 1000-grain weight (Table 3). In spite of similar number of panicles m^{-2} in conventional and 70 cm bed, the grain yield of conventional method was lower due to lower number of grains panicle^{-1} and lower grain weight.

CONCLUSIONS

In raised bed planting with narrow beds (70 cm), different crop growth parameters such as total tiller production, LAI, DMP and CGR were similar or higher than conventional method at different growth stages of wheat. Agronomic productivity of wheat could be increased by bed planting with 70 cm bed in rice-wheat cropping system.

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Table 3. Grain yield and yield components of wheat under different methods of planting.

Planting method	Yield and yield components							
	2001-02				2002-03			
	Grain yield (t ha^{-1})	Panicle m^{-2} (no.)	Grain panicle^{-1} (no.)	1000-grain wt (g)	Grain yield (t ha^{-1})	Panicle m^{-2} (no.)	Grain panicle^{-1} (no.)	1000-grain wt (g)
70 cm bed + 2 rows	2.85 a	306 a	34.3 a	42..3 a	3.34 a	310 a	36.3 a	42.3 a
70 cm bed + 3 rows	2.82 a	312 a	32.0 b	41.7 a	3.28 a	325 a	33.8 b	41.9 a
80 cm bed + 2 rows	2.54 bc	231 c	34.2 a	41.3 a	2.78 bc	260 c	35.9 a	41.5 a
80 cm bed + 3 rows	2.65 b	244 b	31.1 c	41.4 a	2.87 b	282 b	32.9 c	41.5 a
90 cm bed + 2 rows	2.26 d	219 c	34.2 a	41.9 a	2.64 c	241 d	36.0 a	42.1 a
90 cm bed + 3 rows	2.43 c	231 c	31.3 bc	41.5 a	2.67 bc	242 d	33.0 c	41.7 a
Conventional	2.35 dc	305 a	27.3 d	39.2 b	2.81 bc	274 bc	28.3 d	39.6 b

Figures in a column followed by different letters differ significantly at the 5% level by DMRT.

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Phosphorus Fractionations in Ganges Tidal Floodplain Soil of Bangladesh

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ABSTRACT

The present investigation aimed to evaluate different fractions of P of Ganges tidal floodplain soils of Bangladesh in terms of plant availability in the selected soil. The samples were analyzed for solution P, labile pool, alkali-extracted inorganic pool, organic pool, acidic pool and residual P. The soil solution P in the tested soils ranged from 0.03 to 0.11 mg L^{-1}. The concentration of 0.5M $NaHCO_3$ extracted P had a range of 8-34 mg kg^{-1}. Dilute NaOH extracted inorganic P had a range of 25-59 mg kg^{-1}. NaOH extracted organic P ranged from 334 to 542 mg kg^{-1} and acid extracted P represented from 140 to 443 mg kg^{-1}, respectively. Residual P of the tested soils showed a concentration of 104-262 mg kg^{-1}. On average of the 12 soils, the relative concentration of solution P was 0.01%, $NaHCO_3$ P was 3.2%, NaOH-Pi was 6.8%, NaOH-Po was 44.6%, acid pool was 27.3% and residual fraction was 18.1%. Different P pools showed strong correlation either with sand, silt, clay, electrical conductivity, pH(H_2O), ΔpH, organic carbon or extractable Fe content. The tested Ganges tidal floodplain soils demonstrated wide variation in the relative proportion of different P pools.

Key words: Tidal floodplain, solution P, inorganic P, organic P, acid P, labile P, stable P, residual P

INTRODUCTION

Ganges tidal floodplain soils spread widely in Bangladesh and India. The Ganges tidal floodplain soils below 24°30" north latitude covering about 7,115 square miles, which is about 85 percent of the total area of the three coastal districts (greater Khulna, Barisal and Patuakhali) of Bangladesh. Regular tidal inundation throughout the April-October in each year makes the coastal zone different from that of the inland. Single rice, rice-lathyrus and rice-rice are the dominant cropping systems in the zone. The soils in the tidal flooded ecosystems receive no or little P fertilizer application for long time, because the rice showed little response to applied P fertilizer even during the period of green revolution. The tidal flooded soils received little attention for its soil fertility evaluation (Saleque *et al.*, 2004), particularly for P. Because of great diversity in tidal deposits and cropping history, tidal flooded soils may have wider variation in soil P availability and fractions of P. Hedley *et al.* (1982) proposed a modified P fraction scheme, which sequentially extracts most available P first and progressively less available P with each subsequent extraction. The P pools of Hedley's method are resin-P, NaOH-Pi (NaOH extracted inorganic P), NaOH-Po (NaOH extracted organic P), acid-P and residual P. Saleque and Kirk (1995) applied Hedley's method of P fraction for lowland rice soil and found it successful by recovering about 98% of the applied P. Sui *et al.* (1999) modified Hedley's method of P fraction by avoiding resin strip. The fractions of P in this method are: water soluble P, labile P (extracted by $NaHCO_3$), NaOH-Pi, NaOH-Po, acid-P and

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residual P. Saleque *et al*. (2004) applied Sui's method for P fractionation scheme of a rice soil from a long-term experiment in rice-rice cropping system. Phosphorus fractionation studies in Bangladesh are not much reported, however, Shil (2002) observed P fraction in soils Sreepur, Gazipur and Satkhira and Islam *et al*. (2010) studied P fraction in Acid Piedmont soils in north-east of Bangladesh.

Phosphorus fractionation of tidal flooded soils and the distribution of different P pools in soils need to be understood for designing P fertility management. Therefore, the present research work was carried out to determine the distribution of soil P fractions in selected rice growing Ganges tidal floodplain soils.

MATERIALS AND METHODS

Twelve surface (0-15 cm) soil samples used for the fractionation study were collected from cultivated rice fields in January to March 2008 after T. Aman harvest. The selected soil sampling sites were of different upazilas (Dumki, Kalapara, Amtali, Wuzirpur, Gouranadi, Borhanuddin, Lalmohan) of Patuakhali, Borguna, Barisal and Bhola districts. According to USDA soil taxonomy, these have been classified as Typic Edoaquept, Typic Haplaquept, Aeric Haplaquept, Thapto-Histic Haplaquept, Aquic Eutrochrept and Histosols. For the convenience of discussion, the 12 soils are referred to as soil 1 through soil 12 (Table 1). The collected soil samples were air-dried and ground to pass a 2-mm sieve and then mixed to form a composite sample.

Soils were analyzed in Soil Science laboratory and Central laboratory of Patuakhali Science and Technology University during January 2008 to April 2008. The sand, silt and clay content of soils were determined using the hydrometer method (Black *et al*., 1965). Soil pH_{H2O} was measured in a 1:2.5 soil water ratio, using glass electrode pH meter method (Jackson, 1958), and the pH_{KCl} was also measured by using a 1.0 M KCl in a similar manner as in pH_{H2O} determination. Organic carbon of soil was determined by Walkley and Black wet digestion method as outlined by Nelson and Sommers (1982). Mehlich-3 (M3) extractable P was determined by using the Mehlich-3 extraction method (Mehlich, 1984). Available Fe was determined by sodium dithionate-citrate system buffered with sodium bicarbonate (Mehra and Jackson, 1960). Table 1 presents the physical and chemical characteristics of the tested initial soils.

Phosphorus fractionation

The experiment was conducted in a complete randomized block design with three replications. One g air-dried soil was taken in 50 ml centrifuge tube for P fractionation study. One run of the analysis was considered as one replication.

Fractionation of inorganic P was performed on each soil following Saleque *et al*. (2004) method modified from P fractionation scheme of Sui *et al*. (1999).

The following soil P fractions were measured in sequence:

i) Solution P, by shaking 1 g soil in 30 ml of 0.05M $CaCl_2$ for 16 hours, centrifuging, filtering and measuring P in the filtrate.

ii) ii) $NaHCO_3$-P, by shaking the residue from (i) in 30 ml 0.5M $NaHCO_3$ for 16 hours, centrifuging, filtering and measuring P in the filtrate.

iii) iii) NaOH-Pi, by shaking the residue from (ii) in 30 ml 0.1M NaOH for 16 hours, centrifuging, filtering and measuring P in the filtrate after acidifying with 5 ml concentrate HCl.

iv) NaOH-Po, by digesting 5 ml of the filtrate from (iii) in 6 ml of concentrate H_2SO_4 for 1 hour, cooling, adding 5 ml of H_2O_2 and reheating until the residue becomes white, determining P in the digest and subtracting the NaOH-Pi from it.

iv) v) Acid-P, by shaking the residue from (iii) in 30 ml 1:1 mixture of 1M HCl/1M H_2SO_4, centrifuging, filtering and measuring P in the filtrate.

Table 1. Some selected properties of the studied soils.

Soil no.	Sand (%)	Silt (%)	Clay (%)	EC (dS/m)	pH (H_2O)	pH (KCl)	ΔpH	CEC (meq/ 100 g soil)	OC (%)	Avail. P (ppm)	Avail Fe (g/g soil)
Soil 1 (Barisal clay, pH 6.2)	3.30	28.16	68.54	1.45	6.20	4.58	-1.62	16.5	2.28	4.1	158.95
Soil 2 (Jhalokathi clay, pH 5.9)	3.33	38.17	58.50	2.50	5.90	4.71	-1.19	14.0	2.69	5.2	118.75
Soil 3 (Bhola silty clay)	4.26	54.27	41.47	6.15	5.80	4.94	-0.86	12.4	2.45	10.7	131.96
Soil 4 (Nilkamal silty clay loam)	4.32	70.95	24.73	7.60	7.00	7.75	0.75	9.4	0.71	22.6	16.33
Soil 5 (Ramgati silty clay loam)	8.48	54.67	36.85	1.16	7.36	6.25	-1.11	12.1	1.40	5.3	98.44
Soil 6 (Katra silt loam)	8.00	68.72	23.28	1.23	7.49	5.97	-1.52	10.0	1.43	16.5	79.21
Soil 7 (Barisal clay, pH 6.0)	7.13	40.02	52.85	1.26	5.99	3.76	-2.23	13.4	0.74	4.3	253.10
Soil 8 (Jhalokathi clay, pH 5.7)	7.81	37.27	54.92	1.23	5.70	7.04	1.34	15.5	2.49	6.1	248.43
Soil 9 (Harta silty clay loam)	16.87	55.67	27.46	2.11	6.30	5.27	-1.03	15.6	5.14	8.5	157.73
Soil 10 (Satla silty clay)	19.50	48.32	32.18	4.18	5.90	4.82	-1.08	15.4	10.86	6.0	494.74
11. Sara silty clay	10.81	45.29	43.90	0.98	6.10	4.68	-1.42	14.9	2.07	8.3	258.76
12. Barisal clay (pH 6.6)	3.02	41.47	55.51	1.05	6.60	5.38	-1.22	16.3	2.91	19.9	185.42

iv) Residual-P, by fluxing the soil residue from (v) in 6 ml of a 5:2 mixture of concentrated HNO_3 and $HClO_4$ and determining P from the digest.

All P was determined colorimetrically (Murphy and Riley, 1962) after neutralization when necessary with dilute HCl and NaOH and the neutral pH indicated by the slight yellowish colour of the solution in the presence of p-nitrophenol indicator. Absorbance of P was determined at a wavelength 712 nm by spectrophotometer. All measurements of P were done in duplicate and the data were analyzed by Excel software.

RESULTS AND DISCUSSION

Soil solution phosphorus

Soil solution P in the tested soils ranged from 0.03 mg L^{-1} to 0.11 mg L^{-1} (Table 2). Nilkamal silty clay loam had the highest solution P followed by Bhola silty clay (0.10 mg L^{-1}), Katra silt loam (0.07 mg L^{-1}). Ramgati silty clay loam, Jhalakhathi clay of pH 5.7, Harta silty clay loam and Sara silty clay had the lowest solution P (0.03 mg L^{-1}). Islam *et al*. (2010) observed 0.2 to 0.6 mg kg^{-1} solution from different Piedmont soils of Bangladesh. Vig *et al*. (2000) also found 0.01M $CaCl_2$ extractable P ranged from 0.05 mg P kg^{-1} to 0.37 mg P kg^{-1} in Habibowal sandy loam soil. Critical level of solution P associated with near maximum rice yield (flooded pots) is 0.02 mg L^{-1} (Hue and Fox, 2010). The tested soils had solution P above the critical level (0.02 mg PL^{-1}).

$NaHCO_3$-P

The range of $NaHCO_3$-P varied from 8 to 34 mg kg^{-1} (Table 2). The highest $NaHCO_3$-P was found in Barisal clay of pH 6.6. Katra silt loam had the second highest (26 mg kg^{-1}) $NaHCO_3$-P followed by 20 mg kg^{-1} in Nilkamal silty clay loam, 19 mg kg^{-1} in Sara silty clay, 17 mg kg^{-1} in Bhola silty clay, 15 mg kg^{-1} in Jhalokathai clay of pH 5.9 and the lowest (8 mg kg^{-1}) in Barisal clay of pH 6.0. The labile P is strongly related to P uptake by plants (Fixen and Grove, 1990) and it quantitatively measures organic P associated with rapid inorganic P mineralization (Bowman and Cole, 1978). The $NaHCO_3$-P pool is readily available to plants (Bowman and Cole, 1978). Islam *et al*. (2010) reported 5-50 mg kg^{-1} $NaHCO_3$-P in acid Piedmont soils of Bangladesh.

NaOH-Pi

The NaOH Pi ranged from 25 to 59 mg kg^{-1} (Table 2). Sara silty clay soil had the highest (59 mg kg^{-1}) NaOH Pi followed by 58 mg kg^{-1} of NaOH Pi was found in Satla silty. Barisal clay (pH 6.2) had NaOH-Pi of 52 mg kg^{-1} compared to 44 mg kg^{-1} in Barisal clay (pH 6.6), 43 mg kg^{-1} in Bhola silty clay and 37 mg kg^{-1} in Barisal clay (pH 6.0), 33 mg kg^{-1} in Jhalokathi clay (pH 5.7) and, 31 mg kg^{-1} in

Table 2. Soil P fractions and total P in some Ganges tidal floodplain soils.

Soil	Solution P ($mg\ L^{-1}$)	$NaHCO_3$-P ($mg\ kg^{-1}$)	NaOH-Pi ($mg\ kg^{-1}$)	NaOH-Po ($mg\ kg^{-1}$)	Acid P ($mg\ kg^{-1}$)	Residual P ($mg\ kg^{-1}$)
Barisal clay (pH 6.2)	0.05	14	52	443	174	114
Jhalokathi clay (pH 5.9)	0.05	15	31	431	141	128
Bhola silty clay	0.10	17	43	541	299	149
Nilkamal silty clay loam	0.11	20	29	498	365	142
Ramgati silty clay loam	0.03	13	25	490	286	153
Katra silt loam	0.07	26	31	425	443	152
Barisal clay (pH 6.0)	0.05	8	37	419	177	121
Jhalokathi clay (pH 5.7)	0.03	9	33	345	161	104
Harta silty clay loam	0.03	12	38	334	230	227
Satla silty clay	0.04	9	58	355	184	232
Sara silty clay	0.03	19	59	339	207	237
Barisal clay (pH 6.6)	0.05	34	44	354	298	262
Minimum	0.03	8	25	334	141	104
Maximum	0.11	34	59	541	443	262
Mean	0.05	16	40	415	247	168
CV(%)	51	47	28	17	37	33

Jhalokathi clay (pH 5.9 (soil no. 2). Ramgati silty clay soil had the lowest NaOH-Pi. Islam *et al.* (2010) reported 12-108 mg kg $^{-1}$ of NaOH Pi in thirteen acid Piedmont soils of Bangladesh. Hoque *et al.* (2011) reported 22 to 35 mg kg^{-1} of NaOH Pi in tidal floodplain soils of Bangladesh. The fraction of NaOH extracted inorganic P is associated with amorphous and crystalline Al and Fe phosphate. This fraction of P is less related to plant uptake than $NaHCO_3$-P and contribute about only 10% of the total P depletion by rice plants (Saleque *et al.*, 2004).

NaOH-Po

The concentration of NaOH Po ranged from 334 mg kg^{-1} to 541mg kg^{-1} (Table 2). Bhola silty clay had the highest NaOH-Po and the lowest was in Harta silty clay loam. Hydroxide extractable Po is generally considered as stable form of organic P involved in long-term transformation in soil and it could be an important source for soil microorganisms, especially when labile P ($NaHCO_3$-Pi) is low (Tiessen *et al.*, 1984). Labile organic P is mineralized rapidly and NaOH Po replenishes P in the labile inorganic P pools in response to P uptake by plants (Sharply, 1985). Organic P pool theoretically should be correlated to the soil organic matter, but our results contradicted to the hypothesis.

Acid phosphorus

Acid-P fraction varied from 141 mg kg^{-1} to 443 mg kg^{-1} among the tested soils (Table 2). The highest (443 mg kg^{-1}) acid-P was observed in Katra silt loam and the lowest (141 mg kg^{-1}) was in Jhalakhathi clay of pH 5.9. The acid-P fraction is associated with insoluble Ca-P compounds such as hydroxyapatite (Williams *et al*., 1980); so it would unlikely contribute to the eutrophication of water sources. The acid-P fraction is being considered less labile fractions and hence sparingly available for plant uptake (Syers *et al*., 2008). However, it would be mobilized to labile fraction when the later is depleted. Saleque and Kirk (1995) reported that the acid-P contributed about 25% of the total uptake by rice under green house conditions. They also reported that exerting proton exudation under lowland situation, rice plant can uptake P from acid-P fraction.

Residual phosphorus

The concentration of residual P ranged from 104 mg kg^{-1} to 262 mg kg^{-1}. The highest concentration of residual of 262 mg kg^{-1} P was found in Barisal clay of pH 6.6 followed by 237 mg kg^{-1} in Sara silty clay and 232 mg kg^{-1} in Satla silty clay, respectively. Harta silty clay loam had residual P of 227 mg kg^{-1}. Nilkamal silty clay loam, Bhola silty clay, Katra silt loam and Ramgati silty clay loam had residual P in the range of 142-153 mg kg^{-1}. Jhalakathi clay (pH 5.7), Jhalakathi clay (pH 5.9), Barisal clay (pH 6.0), Barisal clay (pH 6.2) had residual P in the range of 104-128 mg kg^{-1}. Residual P fraction is likely in the stable humus fraction and very insoluble forms (Islam *et al.,* 2010). The variation in residual P pool among the soils is attributed to parent materials and long-term genesis of the soil (Iyamuremye *et al*., 1996a). Ball-Coelho *et al*. (1993) reported that depletion of the residual P fraction occurred with time.

Relative concentration (%) of P fraction in different soils

The relative concentration of a soil is the proportion of that fraction in the total amount of P. On average in the tested soils, solution P fraction constituted about 0.01%, $NaHCO_3$-P fraction contributed about 1.8%, NaOH-Pi fraction comprised 4.3%, NaOH-Po fraction represents 46.7%, acid P 28.2% and the rest was by residual P (Table 3). The variations in relative contribution of different P fractions to the total soil P were enormous except solution P. Of the total P in soil, the solution P constituted about 0.02% in Nilkamal silty clay loam (soil no. 4) and about 0.01% in rest of the soils.

The contribution of $NaHCO_3$-P fraction to the total soil P was 2.3-3.4% for most of the tested soils. The $NaHCO_3$-P fraction of Nilkamal silty clay loam, Katra silt loam and Barisal clay contributed about 3.4-4.7% of the total P. The relative contribution of the NaOH-Pi fraction to the total soil P varied from 4.7% in Ramgati silty clay loam to 9.6% in Sara silty clay. The NaOH-Po fraction constituted about 33.9% of total P in Barisal clay (pH 6.6) to 53.3% in Jhalokathi clay (pH5.9). The relative concentration of the acid P was slightly lower than NaOH-Po pool of soil P. The relative concentration of acid P in most of the soils varied from 20-30%. Acid P in Nilkamal silty clay loam soil constituted about 34% of the total P compared to 40.1% in Katra silt loam. The residual P comprised about 12.8-15.8% of the total P in most of the tested soils. Four, out of 12 soils, showed about 25.0-27.0% contribution of the residual P to the total P. Hoque *et al*. (2011) reported that organic and residual P fraction in the Ganges tidal floodplain soil might have been dwindled over decades of rice production without proper P management. They also reported that the labile and non-labile fractions of the soil P was exhausted due to long-term crop production, the resistant P pools would not be a source, which support to mobilize P for long time.

Correlation of different P fractions with soil properties

Table 4 presents the relationship between the soil characteristics and different fractions of

Table 3. Relative concentration (%) of P fraction in different Ganges tidal floodplain soils.

Soil	Solution P (%)	$NaHCO_3$-P (%)	NaOH-Pi (%)	NaOH-Po (%)	Acid P (%)	Residual P (%)
Barisal clay (pH 6.2)	0.01	2.7	9.5	52.3	22.1	13.4
Jhalokathi clay (pH 5.9)	0.01	3.2	7.5	53.3	20.3	15.8
Bhola silty clay	0.01	3.2	6.3	48.9	28.0	13.5
Nilkamal silty clay loam	0.02	3.8	4.8	44.6	34.0	12.8
Ramgati silty clay loam	0.01	2.3	4.7	48.2	29.7	15.2
Katra silt loam	0.01	4.0	4.8	37.6	40.1	13.6
Barisal clay (pH 6.0)	0.01	2.3	7.4	51.6	23.6	15.0
Jhalokathi clay (pH 5.7)	0.01	3.0	7.2	49.1	25.8	14.9
Harta silty clay loam	0.01	2.4	6.3	37.6	28.2	25.6
Satla silty clay	0.01	2.8	6.1	41.0	23.1	27.0
Sara silty clay	0.01	3.4	9.6	36.8	23.9	26.3
Barisal clay (pH 6.6)	0.01	4.7	7.7	33.9	28.8	25.0
Minimum	0.01	2.3	4.7	33.9	20.3	12.8
Maximum	0.02	4.7	9.6	53.3	40.1	27.0
Mean	0.01	3.2	6.8	44.6	27.3	18.2
CV (%)	27	23	24	15	20	32

Table 4. Correlation of different P fractions with soil properties.

Soil property	Solution P	$NaHCO_3$-P	NaOH-Pi	NaOH-Po	Acid P	Residual P
Sand	-0.22	-0.42	-0.18	-0.42	-0.07	0.66**
Silt	0.55*	0.27	-0.82**	-0.41	0.84**	-0.12
Clay	-0.40	-0.08	0.77**	0.51	-0.71**	-0.14
EC	0.71**	0.15	-0.42	0.13	0.18	-0.22
pH (H_2O)	-0.58*	-0.19	0.73**	-0.07	-0.72**	0.58*
pH (KCl)	0.33	0.30	-0.59*	-0.31	0.82**	-0.28
ΔpH	0.71**	0.30	-0.17	-0.04	0.16	-0.10
Org. C	-0.25	-0.17	-0.03	-0.28	-0.32	0.66**
Fe	-0.43	-0.26	0.32	-0.14	-0.54*	0.62*

*Significant at the 5% level, **Significant at the 1% level.

soil P. Significant relationship was observed between the soil characteristics and different P fractions of soils. Solution P was positively correlated (r = 0.55, P < 0.05) with silt and (r = 0.71, P < 0.01) with pH but negatively correlated with EC, (r = -0.58, P < 0.05) and with pH (H_2O) and (r = 0.71, P < 0.01). $NaHCO_3$-P showed poor relationship with the soil properties. NaOH-Pi showed significantly positive relationship with clay (r = 0.77, P < 0.01) and pH (H_2O) (r = 0.73, P < 0.01) negatively correlated with silt (r = -0.82, P < 0.01) and with pH (KCl) (r = -0.59, P < 0.05). Positive and significant relationship of acid P was observed with silt (r = 0.84, P < 0.01) and $pH_{(HCl)}$ (r = 0.82, P < 0.01) but negative correlation was found (r = -0.71, P < 0.01) with clay, (-0.72, P < 0.01) with pH(H_2O), (-0.54, P < 0.05) with Fe and (r = -0.54, P < .05) with Cu. Residual P had also a positive and significant correlation (r = 0.66, P < 0.01) with sand, (r = 0.58, P < 0.05) with pH (H_2O), (r = 0.66, P < 0.01) with organic carbon, (r = 0.62, P < 0.05) and with Fe, (r = 0.64, P < 0.05).

Link between P fractions in soil

Solution P was poorly linked with the other fractions of P (Table 5). $NaHCO_3$-P was negatively correlated (r = -0.54, P < 0.05) with NaOH Po. There was significant negative (r = -0.71, P < 0.01) correlation between NaOH Pi and acid P. Similarly, significant negative relationship (r = -0.71, P < 0.05) was observed between NaOH-Po and residual P.

CONCLUSIONS

Soil P is distributed in solution, $NaHCO_3$-P, NaOH-Pi, NaOH-Po, acid and residual P fractions. On average of the 12 soils, the relative concentration of native soil P was 0.01% in solution P, 3.2% in $NaHCO_3$ P, 6.8% in NaOH-Pi, 44.6% in NaOH-Po, 27.3% in acid pool and 18.2% in residual fraction. However, there was large variation in the distribution of different P fractions of tidal floodplain soils of Bangladesh. This information would be helpful for recommendation of phosphorus in the respective areas.

Table 5. Correlation coefficient values of the relationship between P fractions of the experimental soils.

	Solution P	$NaHCO_3$-P	NaOH-Pi	NaOH-Po	Acid P	Residual P
Solution P	1	0.28	-0.38	0.00	0.38	-0.29
$NaHCO_3$-P		1	-0.03	-0.54*	0.47	0.08
NaOH-Pi			1	0.09	-0.71**	0.28
NaOH-Po				1	-0.46	-0.71**
Acid P					1	-0.27
Residual P						1

*Significant at the 5% level, **Significant at the 1% level.

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Rice Response to Nitrogen in Tidal Flooded Non-saline Soil

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ABSTRACT

Cultivation of modern varieties (MV) of rice in the coastal non-saline soils of the Asian countries is increasing. Nitrogen (N) deficiency is one of the most nutritional disorders for lowland rice production in Bangladesh. N management recommendation for MV rice in the coastal non-saline soils deserves special attention. A field experiment was conducted for consecutive two years aimed to determine the effect of different nitrogen levels on the yield and nitrogen nutrition of MV rice in coastal non-saline soils of Bangladesh. The field experiment involved five nitrogen levels- 50, 100, 150, 200 and 250 kg ha^{-1} including one N-control in randomized complete block design. The application of 150 kg N ha^{-1} gave the highest yield of 6.76 t ha^{-1} in 2009 and 6.49 t ha^{1} in 2010, respectively. Total nitrogen uptake at 150 kg N ha^{-1} showed 112 and 116 kg ha^{-1} in 2009 and 2010, respectively. Results averaged over two years showed agronomic use efficiency and physiological use efficiency of 22 and 47 kg kg^{-1} with the application of 150 kg N ha^{-1}. The apparent recovery efficiency of applied nitrogen (150 kg N ha^{-1}) had 44 and 50% in 2009 and 2010, respectively.

Key words: Rice yield, tidal flooded soil, nitrogen use efficiency, nitrogen rate

INTRODUCTION

Coastal and offshore soils occupies about 2.85 million ha in Bangladesh and about 0.73 million ha of the coastal cultivable land has salinity of more than 4.0 dS/m (Saleque *et al*., 2010). The coastal non-saline soils are suitable for growing modern rice in winter season. Nitrogen is the most limiting nutrient for rice in tropical Asian soils and almost every farmer has to apply the costly N fertilizer to get a desirable yield of rice (Fageria *et al*., 2007). The nitrogen fertilizer requirement in a particular area would not be the same for all type of soils, although their yields would be similar in well-fertilized fields. Modern rice varieties need chemical N fertilizer application to achieve higher yield. Tropical rice-growing soils have a capacity to supply about 40-60 kg N from its inherent reserve of organic matter and from the biological fixation during rice growth, which is sufficient to produce rice yield of 2-3 t ha^{-1} (Saleque e*t al*., 2004). A modern rice variety may yield up to 8 t ha^{-1} in the coastal non-saline soils, but it must be supplied with the proper dose of N fertilizer (BRRI, 2008).

However, limited researches has been done so far in Bangladesh to recommend optimum N dose for modern rice in coastal soils of Bangladesh. There are several information on the optimum N rate of rice production in different countries. Manzoor *et al*. (2006) reported the most favourable nitrogen rate of 175 kg ha^{-1} over three years in clay loam soils of Pakistan. Peng *et al*. (2006) reported the optimum nitrogen rates of 150-250 kg ha^{-1} in soils of China. Kumar *et al*. (2010) reported most advantageous nitrogen rate of 122 kg ha^{-1} for Gangetic soil of India. Fageria and Baligar (2001) reported the optimum nitrogen rates of 78-120 kg ha^{-1} in three consecutive years in Inceptisols of Brazil. Saha *et al*. (2012) reported that 30-60 kg N ha^{-1}

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is sufficient to obtain rice yield (5.0 t ha^{-1}) of some promising lines of T. Aman season in Bangladesh. The nitrogen use efficiency and recovery efficiency of N fertilizer in rice production are rather low. Only 30-40% of applied N is used by the crop, however, due to losses through volatilization, denitrification, leaching and run off (De Datta and Buresh, 1989). Increase in fertilizer nutrient input, especially N fertilizer, has contributed significantly to the improvement of the crop yields in the world (Cassman *et al*., 2003).

Most of the farmers in Bangladesh use N fertilizer for rice production and the dose of N are being increased year after year to sustain the crop yield. Because of using more fertilizer with benefit in yield, the efficiency and recovery of N fertilizer are threatened further. Over application of N fertilizer may actually decrease grain yield by increasing susceptibility to lodging (Pham *et al*., 2004) and damage from pests and diseases (Cu *et al*., 1996). Judicious use of N fertilizer in rice requires synchronizing N fertilizer applications with plant needs. The application of nitrogen fertilizer either in access or less than optimum rate affects both yield and quality of rice to remarkable extent, hence, proper management of crop nutrition is of immense importance. An increase in nitrogen supply increased dry matter and straw yield and N, P and K uptake (Hussain *et al*., 1989; Mahabari *et al*., 1996; Nawaz, 1999; Meena *et al*., 2003).

Salinity level in many coastal soils of the Asian countries (Bangladesh, India, Myanmar, Thailand and Vietnam) is not necessarily high enough to prevent modern rice cultivation. Non-saline coastal lands represent an excellent niche for modern rice production, however, received scant attention in nutrient management option, particularly nitrogen management. Because of tidal sedimentation in every year, coastal non-saline soils possess a good inherent fertility level and nourish the local rice varieties for centuries without any yield reduction. With continuous increasing demand of rice production, MV rice varieties need to be grown in non-saline coastal soils. Our recent studies showed that the tidal flooded coastal soil had no response of rice to applied phosphorus or potassium, but omission of nitrogen greatly limits its yield (BRRI, 2007). However, limited literatures focused on the nitrogen management for coastal non-saline soils. Therefore, the present investigation aimed to compare the yield and nitrogen nutrition of MV rice in tidal non-saline soils under varying levels of nitrogen application.

MATERIALS AND METHODS

The experiment was conducted at the experimental farm of the Bangladesh Rice Research Institute Regional Station, Barisal, Bangladesh in Boro season during 2009 and 2010 located at 22°43 N latitude and 90°27 E longitude. The average annual rainfall is 200 mm with more than 80% of it occurring from mid June to the end of September. Mean temperature is the lowest (15°C) in January and the highest (30°C) in May.

The soil of the experimental field is clay loam in texture. Initial properties of the surface soil (0-15 cm depth) were as follows: pH 6.08, organic carbon 1.2%, available phosphorus (P) 8.7 mg kg^{-1} (0.5 M $NaCO_3$ extracted) and exchangeable potassium (K) 0.26 meq/100 g soil (Neutral 1.0 N NH_4OAc extracted). Treatments consisted of six nitrogen rates : 0, 50, 100, 150, 200 and 250 kg ha^{-1} were applied as urea. A flat dose of P, K and S @ 15-50-10 kg ha^{-1} was applied as soil test basis (STB), respectively. The experiment was laid out in randomized complete block design (RCBD) with three replications. Urea was applied in three equal splits i.e. one-third N at basal, one-third N at active tillering stage and one-third N at 5 to7 days before panicle initiation stage of BRRI dhan29. Phosphorous, K and S fertilizers were applied at final land preparation. The unit plot size was 6 m × 3 m. Fifty-four-day-old seedlings using 2-3 seedlings $hill^{-1}$ were transplanted at 20 cm ×

20 cm spacing. All intercultural operations were done as and when required. At maturity, the crop was harvested at 5 m^2 areas at the centre of each plot for straw and grain yield. The grain yield was adjusted to 14% moisture content and straw yield as oven dry basis (Yoshida *et al.*, 1976). Nitrogen content from plant samples (grain and straw) was determined by micro Kjeldahl method (Yoshida *et al.*, 1976). Means for the treatment effect and coefficient of variance were analyzed using CropStat7.2 software (IRRI, 2007).

RESULTS AND DISCUSSIONS

Grain and straw yield

Nitrogen control plot showed grain yield of 3.41 t ha^{-1} in 2009 and 3.22 t ha^{-1} in 2010. Receiving 50 kg N ha^{-1}, the grain yield increased to 5.19 t ha^{-1} in 2009 and 4.44 t ha^{-1} in 2010 (Table 1). Rice grain yield increased progressively with the increase of nitrogen rate and reached to a maximum (6.76 t ha^{-1} in 2009 and 6.49 t ha^{-1} in 2010) with 150 kg N ha^{-1}. Literatures suggested higher paddy yield at higher nitrogen rates (Marazi *et al.*, 1993; Daniel and Wahab, 1994; Bali *et al.*, 1995; Nawaz, 1999; and Meena *et al.*, 2003). Fageria *et al.* (2011) also reported the highest grain yield by nitrogen application of 150 kg ha^{-1} and 250 kg ha^{-1}, respectively. Another study revealed that maximum average grain yield of 20 lowland rice genotypes was obtained at 150 to 200 kg N ha^{-1} (Singh *et al.*, 1998). Similarly, Dobermann *et al.* (2000) obtained maximum average grain yield in the dry season at IRRI, Philippines with 120 to 150 kg N ha^{-1}. Singh *et al.* (2007) observed 120 kg N ha^{-1} as an optimum dose for a yield level of 7.45 and 6.80 t ha^{-1} in two consecutive years for direct wet season rice in Indo-Gangetic plain of Ludhiana, India.

Nitrogen application at the rate of 200 and 250 kg ha^{-1} declined rice yield compared to that of 150 kg N ha^{-1}. Rice grain yield showed quadratic response with the rates of nitrogen application in both 2009 and 2010 (Figure 1). Response equation ($Y = 3.31 + 0.044\ N - 0.00015\ N^2$, $R^2 = 0.94$ in 2009 and $Y = 3.13 + 0.032N - 0.00008N^2$, $R^2 = 0.99$ in 2010) explained the quadratic relationship between applied N and grain yield. Differentiating the quadratic equation of yield response with respect to applied N doses, the economic optimum dose appeared as 145 kg ha^{-1} in 2009 and 200 kg ha^{-1} in 2010, respectively.

Data points in Figure 1 showed insignificant yield difference between 150 kg N ha^{-1} and 200 kg N ha^{-1} both in 2009 and 2010. But the quadratic equation significantly explained the relationship between applied N and grain yield (R^2=0.94 in 2009 and 0.99 in 2010). The predicted optimum N dose appeared to be an overestimation in 2010.

The experimental field soil had a potential nitrogen supplying capacity of 94 kg ha^{-1} and capable of supporting 8.50 t ha^{-1} yield of MV rice according to QUEFTS model (Janssen *et al.*, 1990). The calculated dose of N appeared for the estimated yield level was 152 kg ha^{-1}, which agrees the predicted optimum dose of N from the response trial. The observed yields in both the years were about 2 t ha^{-1} lower than the predicted achievable yield. The lower yield might be attributed to the aged seedlings in 2009 and insect (stem borer) infestation in both the years. The application of N increased straw yield significantly in both the years, except the N_{50} treatment in 2009 (Table 1). The

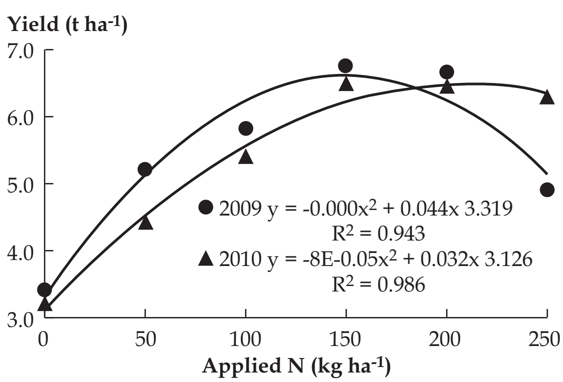

Fig. 1. Quadratic relationship between applied nitrogen and grain yield of rice in 2009 and 2010 under tidal flooded ecosystem.

Table 1. Effect of N fertilizer rates on grain and straw yields of BRRI dhan29 in BRRI RS farm, Barisal, Boro 2009-10.

N rate (kg ha^{-1})	Panicle m^{-2}		Grain yield (t ha^{-1})		Straw yield (t ha^{-1})	
	2009	2010	2009	2010	2009	2010
N_0	183	141	3.41	3.22	3.20	2.33
N_{50}	238	194	5.19	4.44	4.07	3.20
N_{100}	304	196	5.82	5.40	6.78	4.25
N_{150}	332	236	6.76	6.49	6.64	5.18
N_{200}	368	227	6.66	6.48	6.57	5.04
N_{250}	404	271	4.91	6.31	7.57	4.97
$LSD_{0.05}$	34	13	0.70	0.46	2.31	0.39

variation of straw yield between N control and N_{50} treatment was insignificant in 2009. Other N treatments showed insignificant straw yield in 2009. In 2010, straw yield increased with the increase of N rate up to 150 kg N ha^{-1} then decreased insignificantly. These might be associated with higher nitrogen fertilizer application and tiller or panicle production.

Nitrogen nutrition and uptake

The N concentration in grain varied significantly among the treatments (Table 2). The grain N concentration in N-control plot observed 0.87%, which increased to 1.06% in 2009 and 1.03% in 2010 receiving 50 kg N ha^{-1}. The grain N concentration increased progressively with the increase of N rates. The highest seed N concentration was obtained from 200 kg N ha^{-1} in 2009 (1.18%) and 250 kg N ha^{-1} in 2010 (1.42%). The straw N concentration varied from 0.50 to 0.60% in 2009 and from 0.52 to 0.78% in 2010; however, the values were statistically similar (Table 2).

Table 2. Concentration of N in grain and straw of BRRI dhan29 in BRRI RS farm, Barisal, Boro 2009-10.

N rate (kg ha^{-1})	Grain N (%)		Straw N (%)	
	2009	2010	2009	2010
N_0	0.87	0.87	0.53	0.52
N_{50}	1.06	1.03	0.61	0.53
N_{100}	1.11	1.27	0.50	0.58
N_{150}	1.12	1.30	0.56	0.62
N_{200}	1.18	1.36	0.57	0.67
N_{250}	1.13	1.42	0.55	0.78
$LSD_{0.05}$	0.06	0.20	ns	ns

Grain N uptake in the N control plots had 29.71 and 28.20 kg ha^{-1} in 2009 and 2010, respectively (Table 3). The application of N increased grain N uptake significantly in both the years. Increasing the N rates increased grain N uptake progressively and reached maximum to 78.62 kg ha^{-1} in 2009 and 89.87 kg ha^{-1} in 2010. Straw N uptake varied from 16.95 to 40.87 kg ha^{-1} in 2009 and from 12.35 to 38.74 kg ha^{-1} in 2010, respectively. In both the years, the N-control plots had the lowest N uptake and the plots that received the highest dose of N gave the highest N uptake in rice straw. Total N uptake varied from 46.66 to 115.69 kg ha^{-1} in 2009 and from 40.55 to 128.61 kg ha^{-1} in 2010. The predicted N supplying capacity of 94 kg ha^{-1} from the QUEFTS model corroborated the magnitude of N uptake (46.66 kg ha^{-1} in 2009 and 40.55 kg ha^{-1} in 2010) in the N-control plots assuming about 50% of N recovery of the soil N by lowland rice. The requirement of rice for N fertilizer can, however, vary greatly from location to location, season to season, and year to year because of high variability among fields, seasons, and years in N-supplying capacity of soil (Cassman *et al*., 1996; Dobermann *et al*., 2003). The predicted N supplying capacity from the QUEFTS model supported the extent of N uptake 50% and 43% in the N-control plots.

Nitrogen use efficiency

Agronomic use efficiency (AUE) of N varied from 6.0 to 35.7 kg kg^{-1} in 2009 and from 12.36 to 24.40 kg kg^{-1} in 2010 (Table 4). The AUE

Table 3. Nitrogen uptake in BRRI dhan29 as influenced by different nitrogen fertilizer rates in BRRI RS farm, Barisal, Boro 2009-10.

N rate (kg ha^{-1})	Grain N uptake (kg ha^{-1})		Straw N uptake (kg ha^{-1})		Total N uptake (kg ha^{-1})	
	2009	2010	2009	2010	2009	2010
N_0	29.71	28.20	16.95	12.35	46.66	40.55
N_{50}	55.11	46.24	24.79	17.02	79.90	63.26
N_{100}	64.26	69.11	35.46	24.91	99.73	94.02
N_{150}	75.75	84.03	36.40	32.12	112.15	116.15
N_{200}	78.62	88.41	37.07	33.77	115.69	122.18
N_{250}	55.42	89.87	40.87	38.74	96.29	128.61
$LSD_{0.05}$	7.58	13.27	15.00	4.97	20.11	15.43

Table 4. Agronomic use efficiency, physiological efficiency, internal efficiency and recovery of N by BRRI dhan29 in BRRI RS farm, Barisal, Boro 2009-10.

N rate ($kg\ ha^{-1}$)	Agronomic efficiency ($kg\ kg^{-1}$)		Physiological efficiency ($kg\ kg^{-1}$)		Reciprocal internal use efficiency ($kg\ kg^{-1}$)		Apparent recovery efficiency (%)	
	2009	2010	2009	2010	2009	2010	2009	2010
N_0	-	-	-	-	13.67	12.59	-	-
N_{50}	35.7	24.40	53.7	53.72	15.37	14.24	66.5	45.42
N_{100}	24.1	21.80	45.4	40.77	17.12	17.41	53.1	53.47
N_{150}	22.3	21.80	51.1	43.25	16.59	17.90	43.7	50.40
N_{200}	16.2	16.30	47.1	39.94	17.37	18.85	34.5	40.81
N_{250}	6.0	12.36	30.2	38.60	19.60	20.38	19.9	35.22

was the highest at 50 kg N ha^{-1} and then decreased progressively with the increase of N rates in both the years. The 150 kg N ha^{-1}, which was the desired level of N application for tidal soils, had AUE of 22.3 and 21.8 kg kg^{-1} in 2009 and 2010, respectively. Fageria and Baligar (2001) reported that AUE was 23 kg grain produced per kg of N applied across N rates. Yoshida. (1981) reported agronomic efficiency in lowland rice in the tropics in the range of 15 to 25 kg grain produced per kg of applied N. Physiological N use efficiency (PUE) varied from 30.2 to 53.7 kg kg^{-1} in 2009 and 38.6 to 53.7 kg kg^{-1} in 2010. As a rule, physiological N use efficiency decreased with the increasing N rates.

Reciprocal of internal N use efficiency (kg N required to produce 1 t of grain) varied from 13.67 to 19.60 kg t^{-1} in 2009 and from 12.59 to 20.38 kg t^{-1} in 2010 (Table 4). Reciprocal of internal N use efficiency (RIUE) showed the lowest in N-control and the highest with the highest rate of N. The RIUE at 150 kg N ha^{-1} had 16.59 and 17.90 kg t^{-1} in 2009 and 2010, respectively. Buresh *et al*. (2010) reported mean RIUE of 16.4 kg t^{-1} with full fertilization and 12.8 kg t^{-1} in-N plots.

Apparent recovery efficiency of N varied from 19.9 to 66.5% in 2009 and 35.22 to 53.47% in 2010 (Table 4). The apparent recovery efficiency (ARE) was higher at 50 kg N ha^{-1} compared to the other higher doses of N and the highest N dose showed the lowest N recovery. The 150 kg N ha^{-1} treatment showed 43.7 and 50.40% N recovery in 2009 and 2010, respectively. For lowland rice in the tropics ARE is 30-50% of applied N depending on season, yield level, the rate and timing of N application (Yoshida, 1981; De Datta, 1986). Fageria and Baligar (2001) also reported that ARE was 39% across N rates in flooded rice cultivar Metica 1.

CONCLUSIONS

Nitrogen management is essential to reduce N losses, improve N use efficiency and obtain higher rice yield. The optimum N dose for tidal soils in Boro season might be 150 kg ha^{-1} for rice. The application of 150 kg N ha^{-1} showed AUE, PUE and RIUE for N as 22.3 and 21.8 kg kg^{-1}, 51.1 and 43.25 kg kg^{-1}, 16.59 and 17.90 kg kg^{-1} in 2009 and 2010, respectively. However, the economic optimum rate of N for BRRI dhan29 appeared as about 173 kg N ha^{-1} averaged over two years. Thus, sufficient N application is one of the strategies to boost straw yield and consequently grain yield in tidal flooded non-saline soil.

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Field Performance Evaluation of Push Type Prilled Urea Applicator in Rice Cultivation

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ABSTRACT

BRRI prilled urea applicator was designed and developed to facilitate deep placement of regular urea. Experiments were conducted to evaluate the performance of BRRI prilled urea applicator in the farmers' fields at Gosaidanga in Shailkupa upazila under Jhenaidah district and at Rashidpur in Mithapukur upazila under Rangpur district during Boro 2015 season. Three treatments: hand broadcasting of urea (recommended dose) (HB), BRRI prilled urea applicator (70% of the recommended dose) (PUA) and BRRI USG applicator (70% of the recommended dose) (USGA) were compared in the experiments. The experiment was laid out in randomized complete block design (RCBD) and replicated in four farmers' plots in each location using BRRI dhan28 as test crop in both the locations. Prior to field experiment, prilled urea applicator was calibrated and urea dispensed was set to 14 gm in one revolution of drive wheel for Boro season. The field capacity of the PUA and USGA was almost similar (0.09-0.10 ha hr^{-1}) in both the locations. Field efficiency of PUA and USGA had 64-65 and 68-69 percent, respectively. PUA and USGA saved 29-32 percent urea fertilizer compared to HB whereas labour requirement of HB (3.74-4.04 man-hr ha^{-1}) in three splits showed similar to single application of urea by PUA (3.68-4.00 man-hr ha^{-1}) and USGA (3.78-3.97 man-hr ha^{-1}). Urea application cost in HB, PUA and USGA was Tk 4,624, 3,216-3,424 and 3,305-3,483 per hectare in both the locations. Prilled urea application method reduced the production cost. Urea application methods showed insignificant effect on grain yield. BRRI prilled urea safely dispensed urea fertilizer in subsurface, increased the efficacy of urea fertilizer and saved urea fertilizer without sacrificing grain yield. BRRI prilled urea applicator could be a viable technology in rice cultivation. Extensive dissemination works should be undertaken in different agro-ecological zones for wide spread adoption of the applicator.

Key words: Field capacity, fertilizer saving, labour requirement, benefit-cost ratio

INTRODUCTION

Nitrogen is one of the essential plant nutrients, which can augment the production of rice to a great extent. Prilled urea is an important source of nitrogen and application of urea-N plays a vital role in vegetative growth, development and yield of rice. A substantial amount of the urea-N is lost through different mechanisms including ammonia volatilization, denitrification and leaching losses, causing environmental pollution problems (Choudhury and Kennedy, 2005). The importance of the role of nitrogenous fertilizer in increasing rice yields has been widely recognized. Most of the farmers of Bangladesh apply fine urea in the rice field by broadcasting method. The efficiency of urea-N is very low, often only 30-40% and, in some cases, even lower (Choudhury and Khanif, 2004). Yearly requirement of urea in Bangladesh is 2.9 million tons (MT) of which 80% (2.3 MT) is used for rice alone. When it is applied in at a desired depth, its application efficiency is increased to 60 percent. If all the urea could be applied in at a desired depth, then 1.15 MT urea could be saved. In that case only 0.05 MT urea needs to be imported

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(BADC, 2011). If urea is applied in at a desired depth, a huge amount of urea production could be reduced, which in turn would save a lot of natural gas. The saved natural gas could be used to generate electricity (Bowen *et al.*, 2005). The fine urea reduces the effectiveness of fertilizer and may lose up to 70%. The losses occur in following ways: i) some of the fertilizers convert into gaseous form and mix with air, ii) some of them are dissolved with rain or irrigation water and runoff to surrounding canal and river from the applied field, and iii) even some of those go beyond the root zone of the rice plants (NAP, 2009). In the present (prilled or fine type of urea) method of application, only 40% of the applied urea is used by the plant and the remaining 60% is lost by air, water or leaching under the ground (Iqbal, 2009). Statistics indicated that about 80% of urea of total production is used for rice production. However, only 15 to 35% of the total applied nitrogen used by the rice plant (Prasad and Datta, 1979) and literature showed that two out of three bags of urea go unused in wetland rice production (Amit, 2011). Nitrogen loss caused due to ammonia volatilization, de-nitrification, runoff, seepage and leaching (Bhuiyan *et al.,* 1998). Therefore, there is a great need to improve nitrogen use efficiency for rice production. Due to excessive loss of nitrogen, farmer in Bangladesh have not been able to make more efficient use of fertilizer to their rice yield. In our country, there are two types of urea i) prilled or fine type and ii) super granular type or urea super granule (USG) on the basis of size of the particles. Super granular type can be classified again as i) general granular (1.8 g) for Aman and Aus rice ii) mega granular (2.7 g) for Boro rice. The weight of a USG varied from 1.6-2.8g. Inserting or placing the fertilizer below the soil surface by means of any tool or implement at desired depth to supply plant nutrient to crop before or in the standing crop is called deep placement of urea. Deep placement or subsurface placement of fertilizer also ensures better distribution in the root zone and prevent any loss by surface drain-off. Much effort has been made to improve fertilizer use efficiencies in low land rice production. Deep placement of urea fertilizer into the anaerobic soil zone is an effective method to reduce volatilization loss. However, urea in the form of USG has been proved to be superior to regular urea in all aspects. It is applied in the rice field only for one time after three to four days of plantation and it contributes for the whole growing period of rice. Instead of normal doses of 247 kg of granular urea, only 160 kg of USG is required (35% less) per hectare and it increases rice yield up to 500 kg (20%) per hectare (Iqbal, 2009). Thus using USG, the requirement of urea of the country could be reduced to 15.47 lac ton from 24.51 lac ton during 2006-07. Bangladesh Rice Research Institute (BRRI) had designed and developed a push type USG applicator during 2008 (Hossen *et al.,* 2013). This applicator applies USG at 6 to 7 cm depth below the soil surface in the middle of four bunches of rice seedlings. When USG is applied by hand, 28 hours are required per hectare, whereas only 10 hours are required by the applicator. The USG applicator reduced the human drudgery. International Fertilizer Development Corporation (IFDC) has been trying to popularize the USG technology in different countries since long time. The USG technology could not be popularized at the desired level due to lack of a good applicator. From the above discussion, it is clear that USG has great impact for increasing the nitrogen use efficiency, yield of rice and its application method is also an important factor contributing to total cost of production. During operation of the USG applicator, there is a possibility to make bridge while rotating metering device due to oval shape of USG. Two USGs may drop at a time due to under size of the briquette. Besides, the USG machine would not perform satisfactory when the hopper is fully loaded. Moreover, proper size of USG was not available in the market and some percentage of urea is lost during the formation of USG. Cost of installing the USG briquetting machine was also high. To overcome these problems, in 2013, the scientists of Farm Machinery and Postharvest Technology Division of BRRI had developed the applicator to deep place prilled urea in between two rows plant in one time (Rahman *et al.,* 2014). This machine needs to be thoroughly investigated in various agro-ecological zones. Therefore, the present study was undertaken with the objectives to estimate the savings of urea fertilizer and to compare the cost of applying prilled urea by applicator over USG applicator and hand broadcasting.

MATERIALS AND METHODS

This experiment was conducted in the farmers' field at Gosaidanga in Shailkupa upazila under Jhenaidah district and at Rashidpur in Mithapukur upazila under Rangpur district. The experiment was carried out in randomized complete block design (RCBD) and replicated in four farmers' plots (Gomez and Gomez, 1984). Twelve plots within one kilometer radius were selected to conduct this study. The treatments were T_1 = Hand broadcasting of urea (recommended dose) (HB); T_2 = BRRI prilled urea applicator (70% of the recommended dose) (PUA) and T_3 = BRRI USG applicator (70% of the recommended dose) (USGA). BRRI dhan28 was grown in all the experimental plots. Seedbed preparation often involves secondary tillage by using spade and puddling was done after inundating the field. Sprouted seeds were broadcast in the field. Drainage canals were constructed for proper water removal. Puddled soil was levelled and raised to 5-10 cm height. Organic manure (decompose) and a small amount of inorganic fertilizer was applied as basal dressing to increase seed vigour and allows easier uprooting for transplanting. The field was prepared using common tillage practice, which is first plowing (primary tillage) once, followed puddling (secondary tillage) twice and levelling using two-wheel tractor under the flooding conditions. After first rotatilling, the field was flooded with water and kept as such for seven days and then second rotatilling was done on 8th day and the field was levelled by a plank. During final land preparation, all cares were taken for uniform levelling of the land. A fertilizer dose per hectare of 136 kg P, 111 kg K, 111 kg S and 11.25 kg Zn as triple super phosphate, muriate of potash, gypsum and zinc sulfate, respectively was applied at final land preparation. Irrigation water was applied uniformly time to time as when required in all the transplanted plots for proper growth and development of crops. Maximum irrigation was needed at the panicle initiation stage. The nursery bed was made wet by application of water one day before uprooting the seedlings. The seedlings were uprooted on 29^{th} January 2015 without causing much mechanical injury to the roots and they were immediately transferred to the main field. Forty-five-day (for Rangpur site) and fifty-six-day (for Jhenaidah site)-old seedlings were uprooted carefully from the nursery field and transplanted in each of the well puddle unit plots on two different days. The date of transplanting was 29^{th} January 2015 in Rangpur site and 10^{th} February 2015 in Jhenaidah site. Row to row spacing of 20 cm was maintained but plant to plant spacing was varied. The plant to plant spacing depends largely on the skill of the labour.

Calibration of PUA

BRRI prilled applicator was designed by considering the line to line spacing of 20 cm. Laboratory trial was done by using large granule prilled urea. Drive wheels was rotated by pouring large granule in hopper. After one revolution of drive wheel, amount of urea dispensed in both the hoppers was almost 14 gm, which satisfied the amount of urea displacement during Boro season. Fertilizer rate was varied in Aus and Aman seasons due to change in fertilizer requirement in rice crop.

Before field operation, applicator was calibrated and urea dispensed was set to 14 gm in one revolution of drive wheel for Boro season.

Urea application

Generally, hand broadcasting of prilled urea was applied in three equal splits i.e. one-third at 20 DAT, one-third at active tillering stage and one-third at 5-7 days before panicle initiation stage. The prilled urea and USG were applied by applicator at 70% of the recommended dose in one time at 2-3 days after transplanting (Photo 1a, b).

The amount of human labour involved in each operation was investigated through field measurements. As pre-planting weedicide was not applied so the weed infestation was severe and weed was controlled by hand weeding. Hand weeding was done at 30 DAT to keep the experimental plot weed free. In addition, hand weeding was done again at 58 DAT. During the Boro season, some pest infestation was severe. However, the pests were controlled by a single application of Virtako and Nativo at the vegetative growth stage. Table 1 presents the comparative inputs of three urea application methods. Fertilizer rate was different and all other inputs were similar in three methods. Grain yield was recorded from pre-selected 10 m^2 land area and adjusted moisture content of 14% moisture level. For computing above ground biomass and yield contributing characters, four hills were collected from the outside of the selected area. The dry weight of straw was determined after oven-drying at 70°C to constant weight. Panicle number of each hill was counted to determine the panicle number m^{-2}. Plant samples were separated into straw and panicles. Panicles were hand-threshed and the filled spikelets were separated from unfilled spikelets. Above ground total biomass was the total dry matter of straw, rachis and filled and unfilled spikelets. Spikelets per panicle, grain-filling percentage and harvest index were calculated. Border areas of all sides of the plot were excluded to avoid border competition effects. In order to estimate the production cost, the data on working speed, total time and labour involvement and materials inputs to complete the operation were recorded. Land value and interest on investment was considered to calculate the total production cost. The purchase price of the BRRI prilled urea applicator was considered as Tk 5,000 per unit. Price of the produce was collected from the local markets to compute total production cost, gross return, gross margin and benefit-cost ratio. Statistical analysis was done by using software Statistix 9.0. Least significant difference was used to compare the means.

a. BRRI prilled urea applicator

b. BRRI USG applicator

Photo 1. Fertilizer application methods.

Table 1. Comparative input in three practices at Rangpur and Jhenaidah site.

Parameter	HB	PUA	USGA
		Rangpur site	
Variety	BRRI dhan28	BRRI dhan28	BRRI dhan28
Seeding date	14 Dec 2014	14 Dec 2014	14 Dec 2014
Transplanting date	29 Jan 2015	29 Jan 2015	29 Jan 2015
Seedling age	45 days	45 days	45 days
Spacing	20 × 20 cm	20 × 20 cm	20 × 20 cm
Basal fertilizer	TSP@136 kg ha^{-1} MOP@111 kg ha^{-1} Gypsum@111 kg ha^{-1} Zn@7.5 kg ha-1	TSP@136 kg ha^{-1} MOP@111 kg ha^{-1} Gypsum@111 kg ha^{-1} Zn@7.5 kg ha-1	TSP@136 kg ha^{-1} MOP@111 kg ha^{-1} Gypsum@111 kg ha^{-1} Zn@7.5 kg ha-1
Weedicide	Superclean@0.75 kg ha^{-1}	Superclean@0.75 kg ha^{-1}	Superclean@0.75 kg ha^{-1}
Application time	23 Feb 2015	1 Feb 2015	1 Feb 2015
Weeding	One time	One time	One time
Top dressing	Urea 272 kg ha^{-1}	Urea 188 kg ha^{-1}	Urea 186 kg ha^{-1}
1st top dress	Urea 90 kg ha^{-1}	-	-
2nd top dress	Urea 90 kg ha^{-1}	-	-
3rd top dress	Urea 92 kg ha^{-1}	-	-
Insecticide	Virtako one time @ 75 g ha^{-1}	Virtako one time @75 g ha^{-1}	Virtako one time @75 g ha^{-1}
Fungicide	Nativo one time @ 300 g ha^{-1} Trooper one time @ 2.25 kg ha^{-1}	Trooper one time @ 2.25 kg ha^{-1} Nativo one time @ 300 g ha^{-1}	Nativo one time @ 300 g ha^{-1} Trooper one time @ 2.25 kg ha^{-1}
Maturity date	2 May 2015	3 May 2015	2 May 2015
		Jhenaidah site	
Variety	BRRI dhan28	BRRI dhan28	BRRI dhan28
Seeding date	15 Dec 2014	15 Dec 2014	15 Dec 2014
Transplanting date	10 Feb 2015	10 Feb 2015	10 Feb 15
Seedling age	56	56	56
Spacing	20 × 20 cm	20 × 20 cm	20 × 20 cm
Basal fertilizer	TSP@90 kg ha^{-1} MOP@112 kg ha^{-1} Gypsum@90 kg ha^{-1} Zn@7.5 kg ha-1	TSP@90 kg ha^{-1} MOP@112 kg ha^{-1} Gypsum@90 kg ha^{-1} Zn@7.5 kg ha-1	TSP@90 kg ha^{-1} MOP@112 kg ha^{-1} Gypsum@90 kg ha^{-1} Zn@7.5 kg ha-1
Weedicide	Rifit+Logran@185 g ha^{-1}+ 10 g ha^{-1}	Rifit+Logran@185 g ha^{1}+ 10 g ha^{-1}	Rifit+Logran@185 g ha^{-1}+ 10 g ha^{-1}
Application date	7 Mar 2015	13 Feb 2015	13 Feb 2015
Weeding	2 times	One time	One time
Top dressing	Urea 272 kg ha^{-1}	Urea 187 kg ha^{-1}	Urea 186 kg ha^{-1}
1st top dress	Urea 90 kg ha^{-1}	-	-
2nd top dress	Urea 90 $kgha^{-1}$	-	-
3rd top dress	Urea 92 kg ha^{-1}	-	-
Insecticide	Virtako one time @ 75 g ha^{-1}	Virtako one time @ 75 g ha^{-1}	Virtako one time @ 75 g ha^{-1}
Fungicide	Nativo one time @ 300 g ha^{-1}	Nativo one time @ 300 g ha^{-1}	Nativo one time @ 300 g ha^{-1}
Maturity date	13 May 2015	15 May 2015	14 May 2015

RESULT AND DISCUSSION

Field capacity

Field capacity is an important factor for any kind of machine operation. Figure 1 shows that field capacity of PUA and USGA applicator was similar (0.09-0.10 ha hr^{-1}) in both the locations. Field efficiency of PUA and USGA obtained 64-65 and 68-69 percent, respectively.

Fertilizer savings

Traditionally, farmers used 272 kg ha^{-1} of urea in the field in three equal splits. Figure 2 shows that 29-32 percent urea fertilizer can be saved by using PUA and USGA.

Plant spacing

In USGA plot, it is mandatory to maintain exact plant to plant spacing and line to line distance to facilitate the operation of applicator as USG needs to be placed adjacent

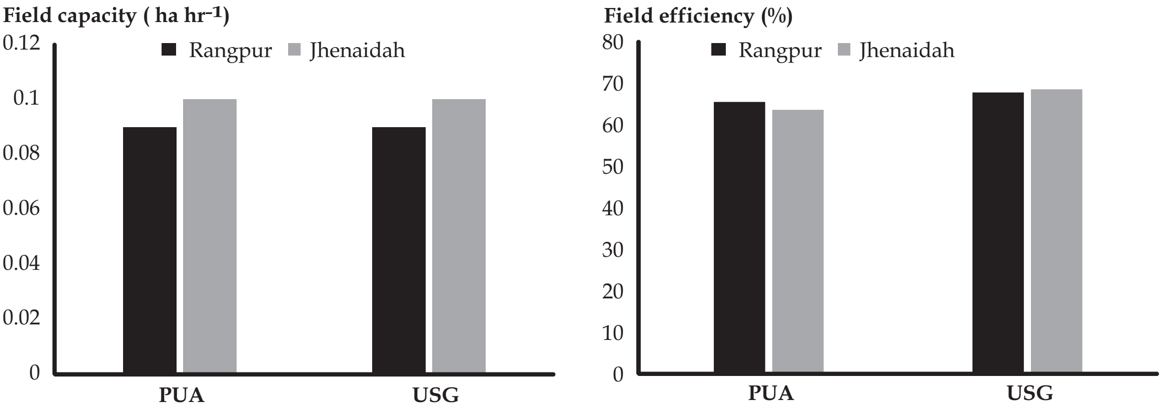

Fig. 1. Field capacity and efficiency of PUA and USGA.

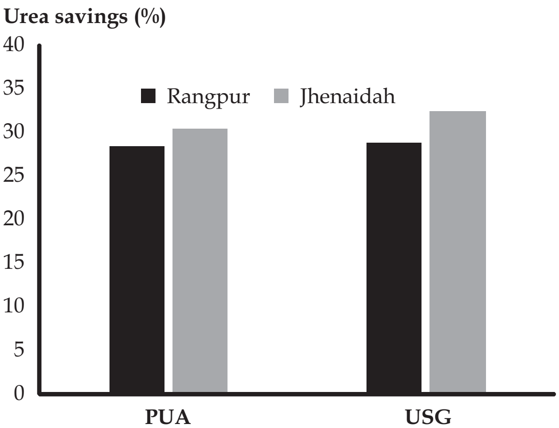

Fig. 2. Fertilizer savings by PUA and USGA.

to four consecutive hills for better fertilizer efficacy. Whereas, in PUA plot, it is mandatory to maintain line to line distance of the plants only as prilled urea dispensed adjacent to two lines. Farmers were advised to maintain exact spacing as 20 × 20 cm in PUA and USGA plots. Actually, plant to plant spacing depends largely on the skill of the labour. In Rangpur site, plant spacing obtained 24.62 × 23.30, 24.83 × 22.67 and 23.74 × 21.73 cm in HB, PUA and USGA plots, respectively. In Jhenaidah site, plant spacing of 17.97 × 22.18, 18.07 × 22.14 and 18.57 × 21.74 cm in HB, PUA and USGA plots, respectively. Results on plant spacing were not consistent (Fig. 3). It was observed that more than 80% of the plant did not maintain the spacing uniformly, which affected the operation of the applicator. Only 20% plant maintained the uniform spacing.

Plant population per hill

Figure 4 shows the effect of management practices at different days after transplanting. Plant population observed similar in both practices. Plant population increased progressively overtime attaining the highest at 40 DAT. Plant population followed rapid growth from 20 to 40 DAT in three practices.

Plant height

Figure 5 shows the effect of urea fertilizer application at different days after transplanting. Plant height observed similar in three practices. Plant height increased progressively over time. Plant height followed rapid growth from 20 to 60 DAT in three practices.

Tillering pattern

Figure 6 shows the effect of management practices on tillering in both the locations. Tillering pattern behaved similar pattern throughout the production period. Irrespective of the management practices, tillering pattern followed increasing trend. In three practices, the tiller production sharply increased from 20 DAT.

Grain yield

Table 2 presents grain yield and yield contributing character, which was statistically

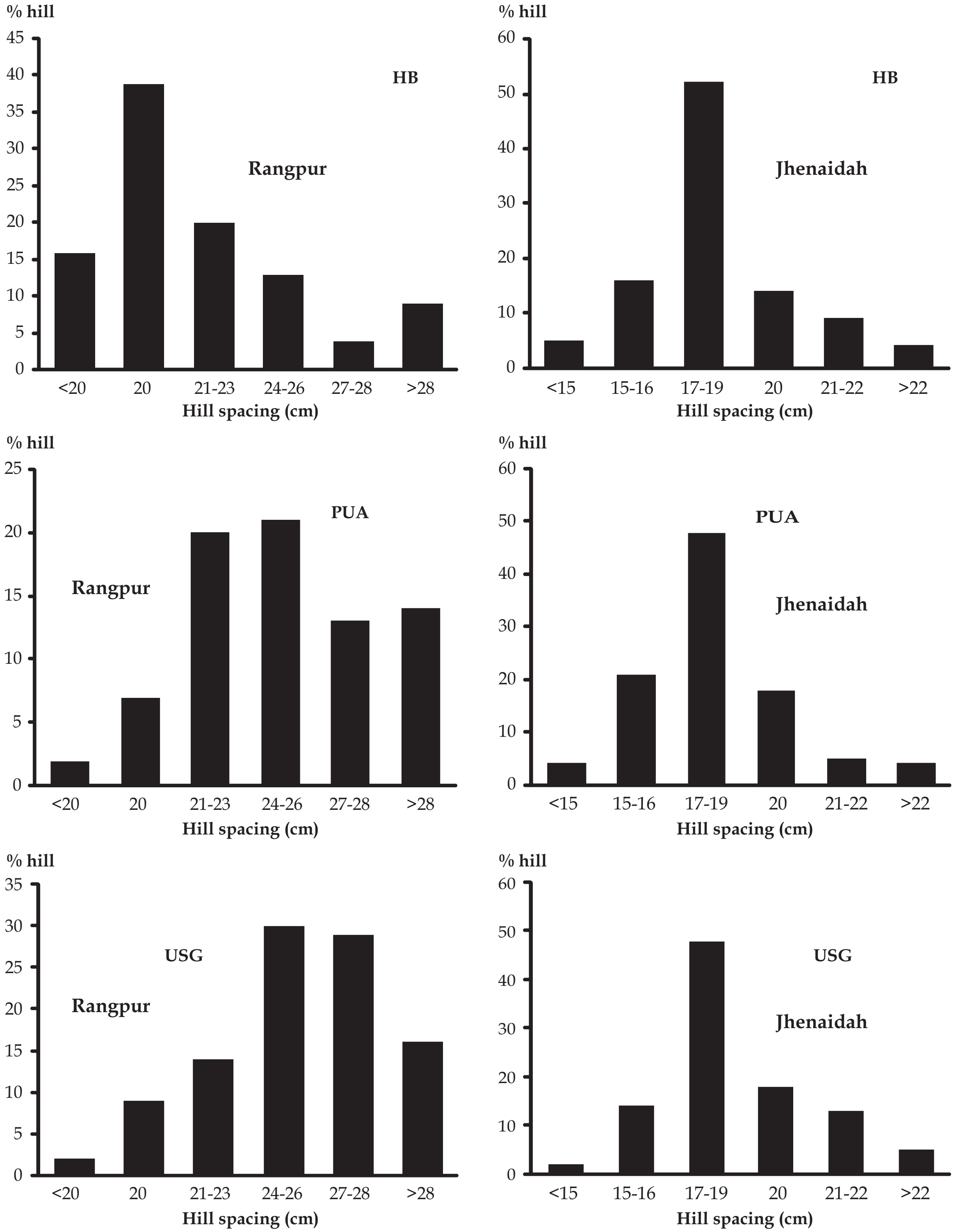

Fig. 3. Distribution of seedling spacing.

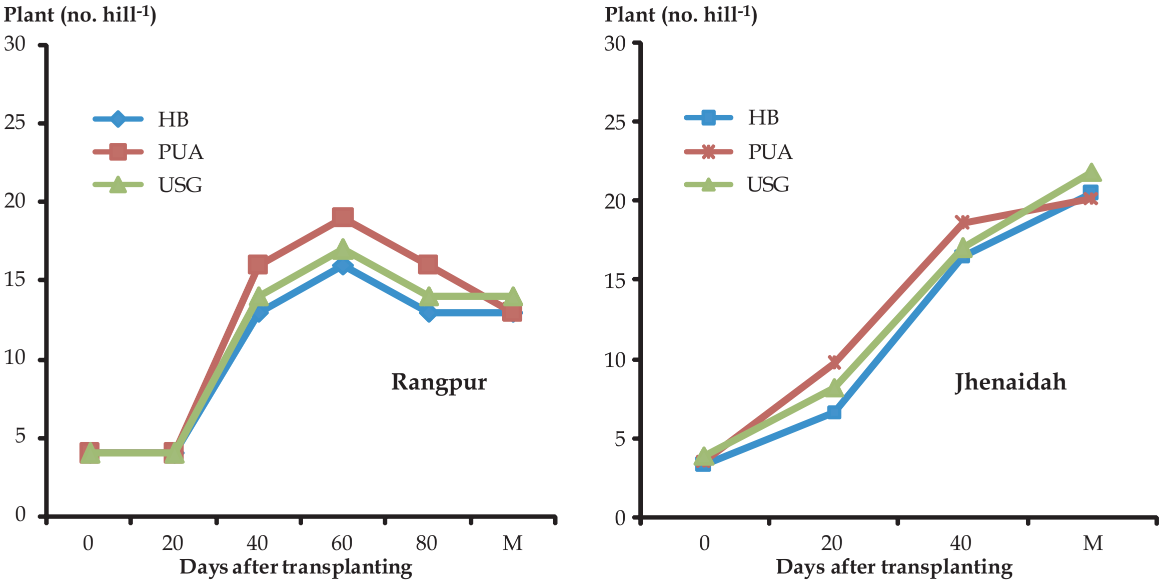

Fig. 4. Hill density of urea application plot.

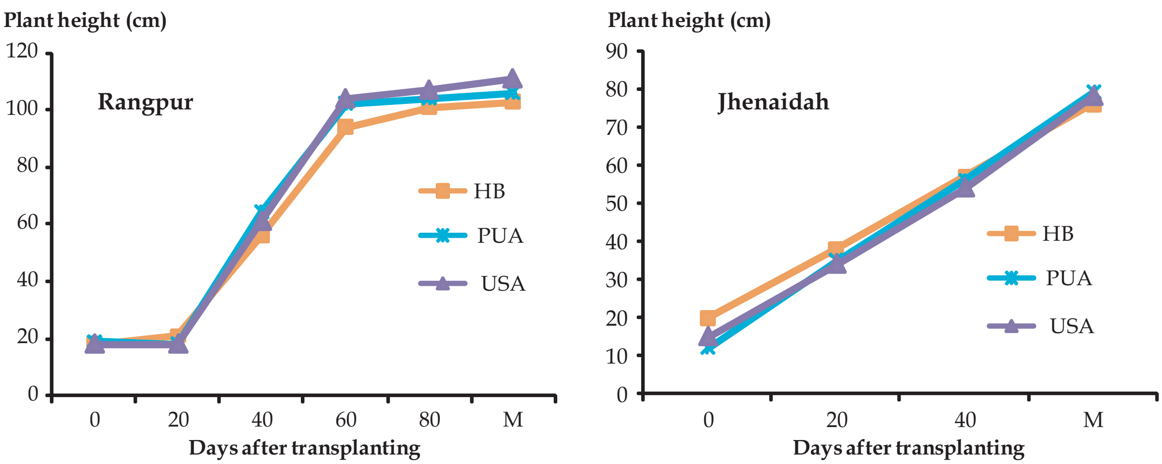

Fig. 5. Plant height in both sites.

analyzed. Irrespective of location, urea application method showed insignificant effect on grain yield. Urea application method showed insignificant effect on panicle intensity, panicle length and 1000-grain mass. Grain yield of all the treatment is lower in Jhenaidah than Rangpur site due to crop damaged by hail storm. Hail storm occurred after maximum tillering stage (on 6 Apr 2015, after 60 days of transplanting) and some crops revived within panicle initiation stage.

Labour requirement in crop production

Table 3 shows the overall labour requirement for the urea application system in two districts. The total labour requirement for rice cultivation observed the highest in Jhenaidah than Rangpur region. It was due to severe weed infestation occurred in Jhenaidah as well as higher labour required removing weeds from the land. Total labour requirement of HB (3.74-4.04 man-hr ha^{-1}) in three splits showed similar to single application of urea by PUA

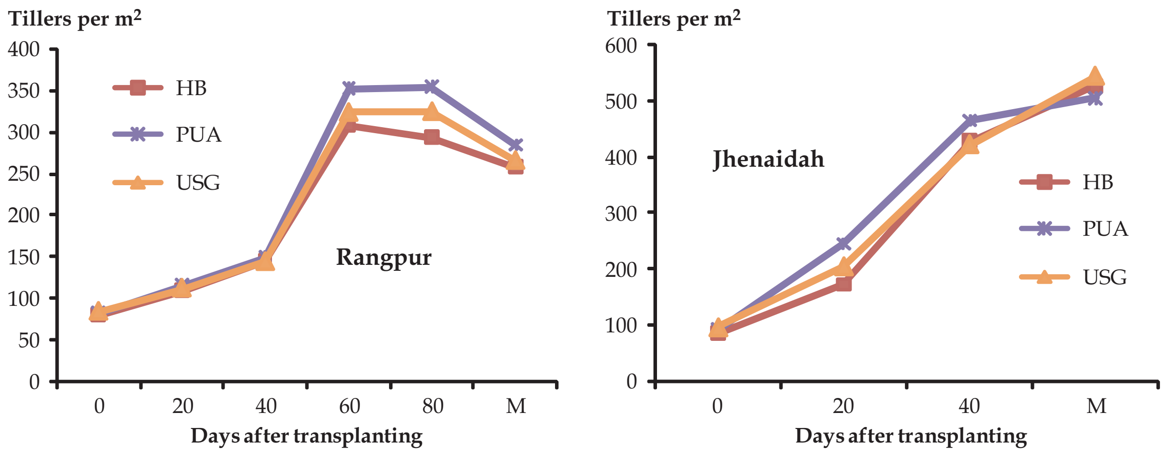

Fig. 6. Plant population in both sites.

Table 2. Yield and yield contribution character.

Location	Treatment	Grain yield (t ha^{-1})	Panicle (no. m^{-2})	Panicle length (cm)	Grain (no. m^{-2})	Sterility (%)	1000-grain mass
Rangpur	HB	5.11	209.5	20.38	21517	28.87	23.12
	PUA	5.19	220.25	21.42	18875	32.44	22.28
	USGA	5.12	240.15	21.23	24601	31.41	21.36
Jhenaidah	HB	4.22	383.50	18.58	31894	22.12	23.47
	PUA	4.48	345.00	18.75	21863	30.24	23.05
	USGA	4.70	365.00	18.41	30146	33.75	23.55
CV, %	5.34	13.08	5.33	19.63	15.25	5.03	
$LSD_{0.05}$	L	0.22	33.47	0.92	4238.6	NS	1.00
	T	NS	NS	NS	5191.2	4.84	NS
	L×T	NS	NS	NS	NS	NS	NS

Table 3. Labour requirement (man-hr ha^{-1}) in urea application method in two locations.

Activity	Rangpur			Jhenaidah		
	HB	PUA	USG	HB	PUA	USG
Seedbed preparation	1.97	1.98	2.01	1.59	1.56	1.59
Seeding	0.38	0.38	0.3	0.35	0.34	0.37
Irrigation	24.01	23.97	23.94	24	24.01	24.01
Seedling uprooting	28.96	28.97	29.02	19.98	19.67	20.01
Subtotal	55.32(8.21%)	55.3(8.21%)	55.29(8.17%)	45.92(6.39%)	45.58(6.37%)	45.98(6.40%)
Land preparation						
Tillage	10.3(1.53%)	10.15(1.51%)	10.6(1.57%)	9.03(1.26%)	8.97(1.25%)	9.02(1.26%)
Levelling	5.6(0.83%)	5.62(0.83%)	5.78(0.85%)	2.01(0.28%)	2(0.28%)	2.03(0.28%)
Transplanting	147.96(21.96%)	148(21.98%)	150.52(22.24%)	150(20.89%)	149.99(20.96%)	150.01(20.89%)
Weeding	99.99(14.84%)	99.98(14.85%)	99.98(14.77%)	170.11(23.69%)	170(23.76%)	169.96(23.67%)
Insecticide spray	10.00(1.48%)	9.99(1.48%)	10.03(1.48%)	5.01(0.70%)	5.07(0.71%)	4.99(0.70%)
Fertilizer application	3.74(0.56%)	3.68(0.55%)	3.78(0.56%)	4.04(0.56%)	4.00(0.56%)	3.97(0.55%)
Harvesting	130.01(19.30%)	130.02(19.31%)	130.02(19.21%)	150(20.89%)	149.99(20.96%)	150.01(20.89%)
Carrying	45.02(6.68%)	45.00(6.68%)	45.04(6.66%)	42.00(5.85%)	39.87(5.57%)	41.98(5.85%)
Threshing	109.99(16.33%)	110.01(16.34%)	109.94(16.25%)	79.97(11.14%)	79.97(11.18%)	80.06(11.15%)
Winnowing	51.99(7.72%)	51.97(7.72%)	51.96(7.68%)	55.98(7.80%)	56.03(7.83%)	56.00(7.80%)
Total	673.66	673.4	676.73	718.11	715.47	717.98

(3.68-4.00 man-hr ha^{-1}) and USGA (3.78-3.97 man-hr ha^{-1}). It can be concluded that PUA and USGA did not reduced the labour requirement in urea fertilizer application.

Economic analysis

Table 4 shows that the item wise costs of crop establishment and total production costs. The data demonstrated that the land preparation, transplanting weeding, harvesting, carrying, threshing and winnowing costs were nearly same for three urea application methods on both the sites. Irrigation cost was the lowest in Jhenaidah site due to use of canal water of GK project at cheapest price. Therefore, irrigation cost greatly influenced the production cost. Fertilizer costs varied depending upon the urea application method. PUA and USGA dispensed 29-32% less prilled urea than HB. PUA and USGA reduced the production cost in both the locations.

Effect of urea application methods on total cost, gross return and net return

Table 5 shows the total production cost including all the costs. The gross return was

Table 4. Production costs of urea application methods in Rangpur and Jhenaidah.

Activity	HB, Tk ha^{-1}	PUA, Tk ha^{-1}	USGA, Tk ha^{-1}
		Rangpur	
Seedling raising	4,063	4,063	4,063
Land preparation	6,775	6,775	6,775
Transplanting	7,456	7,456	7,456
Machine rental charge	-	40	40
Urea	4,624	3,424	3,483
Basal fertilizer	4,259	4,259	4,259
Urea application	184	184	184
Insecticide application	4,620	4,620	4,620
Weeding	5,000	5,000	5,000
Irrigation	6,500	6,500	6,500
Harvesting	6,500	6,500	6,500
Carrying	2,250	2,250	2,250
Threshing	5,500	5,500	5,500
Winnowing	2,600	2,600	2,600
Subtotal	60,331	59,171	59,230
Land value	20,000	20,000	20,000
Interest on investment	2,008	1,979	1,981
Subtotal	22,008	21,997	21,981
Total production cost	82,339	81,150	81,211
		Jhenaidah	
Seedling raising	3,530	3,530	3,530
Land preparation	7,800	7,800	7,800
Transplanting	7,500	7,500	7,500
Machine rental charge	-	40	40
Urea	4,624	3,216	3,305
Basal fertilizer	4,260	4,260	4,260
Urea application	200	200	200
Insecticide application	2,920	2,920	2,920
Weeding	8,500	8,500	8,500
Irrigation	1,500	1,500	1,500
Harvesting	7,500	7,500	7,500
Carrying	2,080	2,080	2,080
Threshing	3,167	3,167	3,167
Winnowing	1,937	1,937	1,937
Subtotal	55,518	54,150	54,239
Land value	20,000	20,000	20,000
Interest on investment	1,888	1,856	1,856
Subtotal	21,888	21,856	21,856
Total production cost	77,406	76,006	76,095

Table 5. Effect of urea application methods on gross return, net return and benefit cost ratio (BCR) at Rangpur and Jenaidha.

Treatment	Total production cost, Tk ha^{-1} A	Grain yield, Tk ha^{-1} B	Straw yield, Tk ha^{-1} C	Gross return, Tk ha^{-1} D=B+C	Net return, Tk ha^{-1} E	Benefit cost ratio (BCR) F
			Rangpur			
HB	82,339	83,038	11,490	94,528	12,189	1.15
PUA	81,150	84,338	11,700	96,038	14,888	1.18
USG	81,211	83,200	11,520	94,720	13,509	1.17
			Jhenaidah			
HB	77,406	73,850	11,490	85,340	7,934	1.10
PUA	76,004	78,400	11,700	90,100	14,096	1.19
USG	76,095	82,250	11520	93,,770	17,675	1.23

calculated based on the then market price of paddy and straw. The BCR were almost same in all the urea application methods in Rangpur site whereas higher in USG plot in Jhenaidah site.

CONCLUSIONS

It can be concluded that among the nitrogen management options, PUA and USGA saved 29-32% of prilled urea without sacrificing grain yield whereas labour requirement of HB in three splits was similar to single application of urea by PUA and USGA.

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Genotype × Environment Interaction and Yield Stability Analysis in Hybrid Rice (*Oryza sativa* L.) By AMMI Biplot

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ABSTRACT

Assessing the adaptability and stability of promising rice genotypes is one of the important steps for accurate evaluation. This study determined the genotype × environment interaction (GEI) and stability performance of 12 promising rice genotypes in four environments during 2009 Aman season. The experiment used randomized complete block design with three replications. Yield stability and adaptability of yield performance were analyzed by combined analysis and additive main effects and multiplicative interaction (AMMI) model. The environment, genotype main effects, and the GEI were all highly significant ($P<0.001$). The study indicated that the tested genotypes, such as BRRHA G1 (5.47 tha^{-1}), G2 (5.68 tha^{-1}), G3 (6.29 tha^{-1}) and G4 (5.27 tha^{-1}) had higher average yields, which indicated these genotypes adapted to favourable environments (E1 and E3). Whereas the environment, E3 could be regarded as a more stable site for high yielding hybrid rice improvement than the other locations. Based on AMMI biplot analysis, genotypes BRRI1A/BRRI827R (G1), IR58025A/BRRI10R (G2), BRRI 10A/BRRI 10R (G3) and BRRI hybrid dhan1 (G4) have higher average mean yields with high main (additive) effects and positive IPCA1 score, among them BRRI 10A/BRRI10R (G3) being the overall best. Locations E1 and E3 could be regarded as a good selection site for rice hybrid improvement due to stable yields.

Key words: G × E interaction, stability, AMMI analysis, hybrid rice

INTRODUCTION

Hybrid rice is a modern technology which gives 15-30% yield advantage over inbreeds rice. It is obviously proved that hybrids show better performance under adverse conditions like drought and saline conditions. If we can develop high yielding stable hybrid rice adopted on diverse environments, we can find most diverse stable heterotic hybrid combinations to increase food production for increasing world population. But grain yield depends on genotype, environment and management practices and their interaction with each other (Messina *et al.*, 2009). Under the same management conditions, variation in grain yield is principally explained by the effects of genotype and environment (Dingkuhn *et al.*, 2006). So information of genotype × environment interaction leads to successful evaluation of stable genotype, which could be used for general cultivation.

The level of performance of any character is a result of the genotype (G) of the cultivar, the environment in which it is grown (E), and the interaction between G and E (GEI). Interaction between these two explanatory variables gives insight for identifying genotype suitable for specific environments. The environmental effect is typically a large contributor to total variation (Blanche *et al.*, 2009). Moreover, G × E interactions greatly affect the phenotype of a variety, so the stability analysis is required to characterize the

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performance of varieties in different environments, to help plant breeders in selecting desirable varieties. Sreedhar *et al.* (2011), evaluated 60 hybrid rice cultivars for yield and its component stability across three different agro-climatic zones, and also found that stability in single plant yield was due to plasticity and stability in yield components. Mosavi (2013) observed significant yield differences among rice genotypes, environment and genotype by environment interaction.

Various statistical procedures have been proposed to find out the stability of new cultivars. One of the most frequently used stability measures is based on a regression model (Yates and Cochran 1938). The additive main effects and multiplicative interaction (AMMI) model has found more use recently since it incorporates both the classical additive main effects model for G x E interaction and the multiplicative components into an integrated least square analysis and thus becomes more effective in selection of stable genotypes (Crossa *et al.,* 1991; McLaren and Chaudhary, 1994; Ariyo, 1998; De Cauwer and Ortiz, 1998; Haji and Hunt, 1999; Ariyo and Ayo-Vaughan, 2000; Taye *et al.*, 2000; Yan and Hunt, 2001). The effectiveness of AMMI procedure has been clearly demonstrated by various authors using multilocation data in soybean (Zobel *et al.*, 1998), maize (Crossa *et al.,* 1990), Wheat (Crossa *et al.,* 1991; Haji and Hunt,1999; Yan and Hunt, 2001; Tarakanvos and Ruzgas, 2006), Pear millet (Shinde *et al.,* 2002), Okra (Ariyo and Ayo-Vaughan 2000), Field pea (Taye *et al.,* 2000) and Rice (Zavel-Garcia *et al.,* 1992; Das *et al.,* 2009; Sewagegne Tariku *et al.,* 2013; Nassir, A L. 2013; Islam *et al.,* 2014). The present experiment was aimed to identify high yielding stable promising hybrids and to determining the variations about locations by AMMI model.

MATERIALS AND METHODS

Experimental design and plant materials

The experiments were conducted at four districts (environments) namely Gazipur (E1), Jamalpur (E2), Bhanga (E3) and Rajshahi (E4) representing four different agro-ecological zones (AEZ) of Bangladesh during T. Aman season 2009. Twelve genotypes consisting of three advanced lines (BRRI1A/BRRI827R (G1), IR58025A/BRRI10R (G2) and BRRI 10A/BRRI10R (G3), six released hybrids (BRRI hybrid dhan1 (G4), Tea (G5), Mayna (G6), Richer (G7), Heera-2 (G8) and Heeta 99-5 (G9) and three inbreed check varieties (BRRI dhan31 (G10), BRRI dhan33 (G11) and BRRI dhan39 (G12)) were used. The experiments were carried using the randomized complete block design (RCBD), with three replications. Twenty-one-day-old seedlings were transplanted in 20 square meter plot using single seedling per hill at a spacing of 20 cm × 15 cm. Fertilizers were applied at 150:100:70:60:10 kg ha^{-1} of urea, TSP, MP, gypsum and $ZnSO_4$ respectively. Standard agronomic practices were followed and plant protection measures were taken as required following the recommendation of *Adhunik dhaner chash*, BRRI (2009). Two border rows were maintained to minimize the border effects. The grain yield (t ha^{-1}) data were collected at 14% moisture level. Data were collected followed by standard method as described by Yoshida *et al*. (1976).

Statistical analysis

The combined analysis of variance was proceeded to look at G × E and stability of the genotypes across all environments. The AMMI model, which combines standard analysis of variance with PC analysis (Zobel *et al.,* 1988), was used to investigate of G × E interaction. In AMMI model the contribution of each genotype and each environment to the GEI is assessed by use of the biplot graph display in which yield means are plotted against the scores of the IPCA1 (Zobel *et al.*,1988). The AMMI model is: $Y_{ge} = \mu + \alpha_g + \beta_e + \sum_{n=1}^{N} \lambda n \gamma_{gn} \delta_{en} + \rho_{ge}$

where, Y_{ge} = yield of the genotype (g) in the environment (e); μ = grand mean; α_g= genotype mean deviation; β_e = environment mean deviation; N = No. of IPCAs (Interaction Principal Component Axis) retained in the model; λn = singular value for IPCA axis **n**; γ_{gn}= genotype eigenvector values for IPCA axis **n**; δ_{en} = environment eigenvector values for IPCA axis **n** and ρ_{ge}= the residuals.

Biplot analysis

Biplot analysis is the most powerful interpretive tool of AMMI models. Biplots are graphs where aspects of both genotypes and environments are plotted on the same axis so the inter-relationships can be visualised. There are two basic AMMI biplots, the AMMI1 biplot where the main effects (genotype mean and environments) are plotted against each other and the AMMI2 biplot where scores for IPCA 1 and IPCA 2 are plotted.

RESULTS AND DISCUSSION

Combined analysis of variance

Table 1 presents the combined analysis of variance. Genotype (G), environment (E) and genotype × environment interaction (GEI) were highly significant (P<0.001) for grain yield. The factors explained showed that rice grain yield was affected by genotype (48.61%), environment (19.98%) and their interaction (20.65%). In general, a wide genetic diversity for maximum traits existed in the rice materials used in this study and this may be due to their diverse origins. The effects of G and E as shown in their highly significant mean square (MS) for maximum traits reflected genotypic differences towards adaptation to different environments. Thus the highly significant G × E effects suggest that the genotypes may be selected for adaptation to specific environments. This is in harmony with the findings of Aina *et al*. (2009) and Xu Fei-fei *et al.* (2014) in G × E interaction effects of cassava genotypes. The significant genotype × environment interaction effects demonstrated that genotypes responded differently to the variation in environmental conditions of locations. This is indicative of the necessity of testing rice varieties at multiple locations. This also attests to the difficulties encountered by breeders in selecting new varieties for release.The large sum of squares for genotypes indicated that the genotypes were diverse, with large differences among genotypic means causing most of the variation in grain yield, which is harmony with the findings of Misra *et al.* (2009) and Fentie *et al.* (2013) in rice production.

AMMI analysis of variance

The AMMI analysis of variance for hybrid rice grain yield (t ha^{-1}) of 12 genotypes tested in four environments showed that 19.98% of the total sum of squares was attributed to environmental effects, only 48.61% to genotypic effects and 20.65% to genotype × environment interaction effects (Table 2). The genotypes sum of squares was about approximately 2.5 times larger than that for environments and genotype × environment interaction, which determined substantial differences in genotypes. The presence of GEI was clearly demonstrated by the AMMI model, when the interaction was portioned among the first three interaction principal component axis (IPCA), as they were significant P< 0.001 in a postdictive

Table 1. Combined analysis of variance of grain yield for 12 rice genotypes evaluated at four environments.

Source	df	SS	MS	Explained SS (%)
Genotype (G)	11	66.529	6.048***	48.61
Environment (E)	3	27.359	9.119***	19.98
G x E interaction(GEI)	33	28.262	0.856***	20.65
Error	96	14.721	0.153	
Total	143	136.871	0.957	

***indicates significance at P<0.001 probability level; df=degree of freedom; SS=Sum of squares; MS=Mean of squares.

Table 2. Additive main effects and multiplicative interaction (AMMI) analysis of variance for grain yield (tha^{-1}) of 12 rice genotypes across four environments.

Source	df	SS	MS	Explained SS (%)
Genotype (G)	11	22.176	2.016***	48.61
Environment (E)	3	9.119	3.039***	19.98
G × E interaction(GEI)	33	9.421	0.285***	20.65
IPCA1	13	5.628	0.433***	12.34
IPCA2	11	2.605	0.237***	5.71
IPCA3	9	1.187	0.132**	2.60
Error	96	4.906	0.051	
Total	143	45.623	0.319	

** and *** indicate significances at the P<0.01 and P<0.001 respectively.

assessment. These imply that the interaction of the 12 rice genotypes with four environments was predicted by the first three components of genotypes and environments, which is in agreement with the recommendation of Sivapalan *et al.* (2000).

Stability analysis by AMMI model

The mean grain yield value of 12 rice genotypes averaged over four environments presented in Table 3, which showed that the genotypes G3 and G12 had the highest (6.29 tha^{-1}) and the lowest (3.84 tha^{-1}) productivity, respectively. Different genotypes showed inconsistent performance across all the environments. The genotype G3 (6.29) was the top performers, while G1 (5.47 tha^{-1}), G2 (5.68 tha^{-1}) and G4 (5.27 tha^{-1}) were moderate and G5 (4.62 tha^{-1}) to G12 (3.84 tha^{-1}) were the poorest yielders. Among environments, the mean grain yield ranged from 5.28 to 4.33 tha^{-1} and average grain yield over environments and genotypes was 4.81 tha^{-1}. On the other hand, the genotypes G1, G2, G3 and G4 had higher average yields with positive index values, which indicated these genotypes adapted to favourable environments, while genotypes G5 to G12 adapted in poor environments. On the basis of environmental index value in terms of negative and positive, E2 and E4 were poor and E1 and E3 were rich environment.

Table 3. Stability analysis for grain yield (t ha^{-1}) of 12 rice genotypes in four environments.

Genotype/Environment	Gazipur (E1)	Jamalpur (E2)	Bhanga (E3)	Rajshahi (E4)	Genotype mean	Index	IPCA1	IPCA2
BRRI 1A/ BRRI 827R (G1)	5.60	5.50	6.10	4.70	5.47	0.66	0.21	-0.41
IR58025A/BRRI10R(G2)	6.65	5.42	6.08	4.57	5.68	0.87	0.60	0.16
BRRI10A/BRRI10R(G3)	7.76	5.66	6.87	4.87	6.29	1.31	0.89	.37
BRRI hybrid dhan4(G4)	6.16	4.77	5.70	4.43	5.27	0.46	0.40	0.21
Tea (G5)	4.48	4.03	5.83	4.13	4.62	-0.19	-0.06	-0.65
Mayna (G6)	4.45	4.49	5.45	3.93	4.58	-0.23	0.07	-0.62
Richer (G7)	5.09	3.94	4.58	4.43	4.51	-0.30	-0.16	0.37
Heera-2 (G8)	4.53	4.03	5.12	4.07	4.44	-0.37	-0.07	-0.29
Heera-995(G9)	4.67	3.97	4.29	4.33	4.32	-0.50	-0.26	0.26
BRRI dhan31 (G10)	4.75	3.89	4.52	4.80	4.49	-0.32	-0.48	0.29
BRRI dhan33(G11)	4.40	3.67	4.36	4.47	4.23	-0.59	-0.45	0.17
BRRI dhan39 (G12)	3.99	2.54	4.42	4.40	3.84	-0.97	-0.69	0.16
Environment mean	5.21	4.33	5.28	4.43	GM=4.81			
Index	0.40	-0.49	0.47	-0.38				
IPCA1	0.75	0.32	0.22	-1.29				
IPCA2	0.88	-0.37	-0.79	0.28				
SE	0.08	0.04	0.27	0.23				
CV (%)	5.31	4.41	9.82	10.86				
5% LSD	0.47	0.32	0.88	0.81				

AMMI 1 biplot display

The AMMI 1 biplot gave a model fit 90.7% (Fig. 1). Among the hybrids, (G1), (G2), (G3) and (G4) were generally exhibited high yield with high main (additive) effects showing positive IPCA1 score, but the hybrid (G3) being the overall best. Hence, the hybrid (G3) was identified as specially adapted to the environments E1 and E3 and these two environments were considered as the wide range suitable environments for this genotype. Genotype G6 showed positive IPCA1 score while genotypes G5 and G8 showed negative IPCA1 score with below average yield and IPCA1 score near zero. Other genotypes showed below average yield and negative IPCA1 score. On the other hand, the environments E1 had large positive IPCA1 score with high mean value while E3 showed small positive IPCA1 score near zero with high mean value. Environment, E2 had relatively small positive IPCA1 scores and E4 had large negative IPCA1 scores. In the AMMI 1 biplot, the genotypes that group together (i.e G1, G2, G3 and G4) have similar adaptation while environments, which group together influences the genotypes in the same way

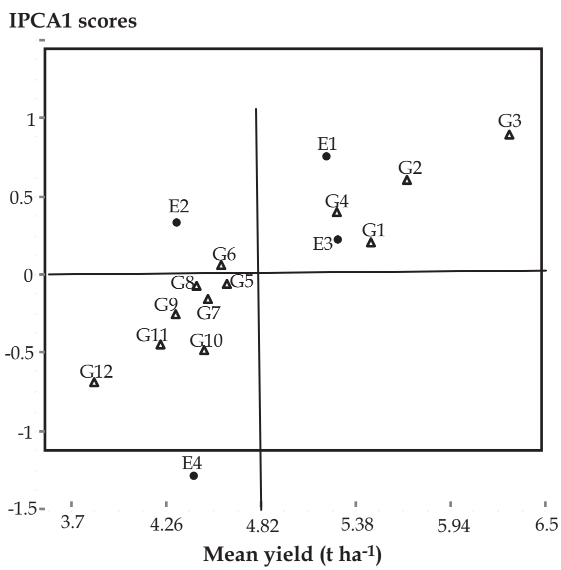

Fig. 1. AMMI 1 biplot for grain yield (t ha^{-1}) of 12 rice genotypes (G) and four environments (E) using genotypic and environmental IPCA scores.

(Kempton R A, 1984). Genotypes and environments on the same parallel line, relative or ordinate have similar yields and a genotype or environment on the right side of the midpoint of this axis has higher yields than those of left hand side. Although, the genotypes G1, G2, and G4 were considered as the favourable environments for E1 and E3. Similar outcomes have reported by Das *et al.* (2010) and Kulsum *et al.* (2013). The genotype G6 showed positive IPCA1 score and genotypes G5 and G8 were showed negative IPCA1 score with below average yield and IPCA1 score near zero indicating that these varieties were stable and less influenced by the environments (Yau S K, 1995). Other genotypes showed below average yield and negative IPCA1 score. On the other hand, the environments E1 have large positive IPCA1 score with high mean value and E3 showed small positive IPCA1 score near zero with high mean value and hence had small interaction effects indicating that all the genotypes performed well in these locations. The environment, E4 has large negative IPCA1 scores, which interact positively with genotypes having negative IPCA1 scores and negatively with the genotypes that having positive IPCA1 scores. Environment, E2 has relatively small positive IPCA1 scores, suggesting that it had little interaction with genotypes. Similar findings and interpretation have been made by Adugna *et al.* (2007); Anandan *et al.* (2010) and Islam *et al.* (2014). Finally, the AMMI 1 biplot statistical model has been used to diagnose the G × E interaction pattern of grain yield of hybrid rice. The hybrids (G1), (G2), (G3) and (G4) were hardly affected by the G × E interaction and thus will perform well across a wide range of environments. Locations, such as E1 and E3 could be regarded as a good selection site for rice hybrid improvement due to stable yields.

AMMI 2 biplot display

In Figure 2, the environments fell into three sections. Among the environments E2 and E3

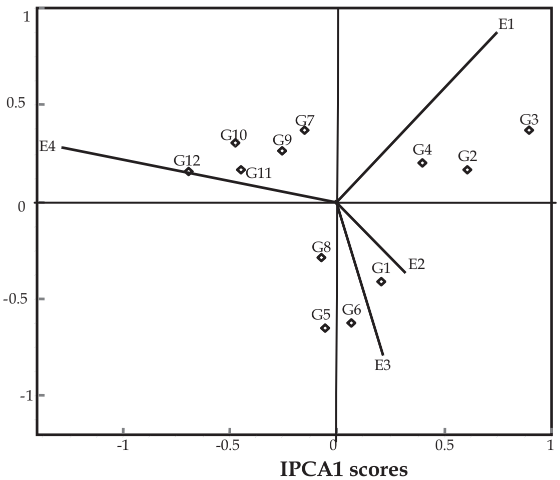

Fig. 2. AMMI 2 biplot for grain yield (t ha^{-1}) showing the interaction of IPCA2 against IPCA1 scores of 12 rice genotypes (G) in four environments (E).

had short spokes and they do not exert strong interactive forces but the environments E4 and E1 had long spokes and hence represent the most discriminating environments. In AMMI 2 biplot, the genotypes, G3 and G12 were more responsive since they are more distant from the origin where - as the best genotype is G3 with respect to the best enhancing environment E1. On the other hand, the genotypes G1, G5, G6, G7, G8 and G9 were close to the origin and hence were less sensitive to environmental interactive forces. Similar result was reported by Anandan *et al*. (2009); Crossa, (1990) and Kempton R A, (1984).

CONCLUSIONS

AMMI statistical model could be a great tool to select the most suitable and stable high yielding hybrids for specific as well as for diverse environments. As a result, almost all of the evaluated genotypes were affected by the genotype × environment interaction effects, so that no genotype had superior performance in all environments. Thus the highly significant G × E effects suggest that genotypes may be selected for adaptation to specific environments. In the present study, the mean grain yield value of genotypes averaged over environments indicated that G3 had the highest (6.29 tha^{-1}) and G12 the lowest yield (3.84 tha^{-1}), respectively. It is noted that the variety G3 showed higher grain yield than all other varieties over all the environments. The genotypes (G1), (G2), (G3) and (G4) were hardly affected by the G × E interaction and thus would perform well across a wide range of environments. Most of the genotypes showed environment specificity. The biplots also indicated the stability levels of the cultivars and the environment. AMMI biplots are necessary in describing the test sites and the genotype performance across tests sites. In this study, the AMMI biplot model classified the testing environments into three sections. Accordingly, four of the tested genotypes (G1, G2, G3 and G4) were found to be the best for environments E1 and E3 and five genotypes (G7, G9, G10, G11 and G12) were most adapted to environment E4, while the other two genotypes (G5 and G8) were not found best to any of the testing environments.

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Effect of Magic Growth on Rice Yield

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ABSTRACT

Investigation during T. Aus 2012 through Boro 2013-14 at BRRI farm, Gazipur evaluated the effect of magic growth (MG) solution on rice. The experiment compared variable doses of N with or without MG along with N control in a randomized complete block design with three replications. Basal application of N with its top dress was also compared with only top dress of N (no basal). All the plots (except control) received a blanket application of phosphorus, potassium, sulfur and zinc. The application of MG spraying produced no yield advantage on rice grain yield in Aus, Aman and Boro seasons. Basal application of N with top dress produced higher yield over N top dressing only in Boro season at lower rate of N.

Key words: Liquid fertilizer, N spray, N top dress, Basal N, rice

INTRODUCTION

Judicious application of fertilizer is one of the most effective means for maximizing rice yield. Modern rice plants uptake more nutrients to produce more yields. Nitrogen is one of major essential plant nutrients and plays a key input role for increasing crop yield. (De Datta and Buresh, 1989). Urea is the most frequently used N fertilizer, which can be applied in different ways. In Bangladesh crystal urea is applied mostly as top dressing. Urea can also be supplied to plants as foliar sprays. Major nutrients, such as N, P, K and S are needed by the rice plants in large quantities (Anonymous, 2010). So, supplying them adequately as spray may cause foliar burn. Because of this problem, major nutrients are applied as granular fertilizers. Application of urea super granule (USG) @ 75 kg ha^{-1} produced 22.03% more yield than granular urea application at two and three equal splits. Foliar spray of urea produced the lowest yield (Hasanuzzaman *et al.*, 2009). Aerial spray of nutrients is preferred in many cases than the soil application (Jamal *et al.*, 2006).

Recently foliar application of nutrients has become an important practice in the production of crops while application of fertilizers to the soil remains as the basic method of feeding the major crop plants. Some of the companies/individuals claim that liquid fertilizer is better than granular ones. Magic growth, a liquid fertilizer has been proposed by a company that it can supplement nitrogenous fertilizer. We hypothesize that magic growth may affect rice growth and development based on its application rates and methods along with N fertilizer at variable rates. So, series of experiments were conducted at BRRI farm, Gazipur during T. Aus, T. Aman and Boro seasons.

MATERIALS AND METHODS

Series of experiments were conducted at BRRI farm, Gazipur. In all seasons, unit plot size was 4- × 5-m and surrounded by 30-cm bund and 50-cm drain. Rice was transplanted at 20- × 20-cm spacing and grown on submerged soil

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(5-10 cm water depth). The experiments were laid out in a randomized complete block (RCB) design with three replications.

T. Aus 2012

The treatment combinations were: 56 kg N ha^{-1} + spraying magic growth (MG) five times (T_1), 56 kg N ha^{-1} (T_2), 75 kg N ha^{-1} (T_3), 75 kg N ha^{-1} + spraying MG twice (T_4), 38 kg N ha^{-1} (T_5) and no fertilizer (T_6). A basal dose of PKSZn @10-37-7-1 kg ha^{-1} was used. Twenty-seven-day-old seedlings of BRRI dhan43 was transplanted on 14 June 2012. Seedlings used in T_1 where sprayed with MG liquid fertilizer at 12, 22 days after sowing (DAS) and one day before transplanting. The concentration of MG liquid fertilizer was 2ml L^{-1} water for an area of 3- × 1.5-m seed bed. Nitrogen was applied on 10 and 25 DAT at 34 and 17 kg N ha^{-1}, respectively. Spray of MG at 96 ml $48L^{-1}$ water + 600g urea/33 dec was done in the afternoon at 25 and 40 DAT. Similar amount of MG was sprayed in the main field in T_4. In other treatments, N was applied at basal, 25 and 39 DAT in equal splits. At maturity, the crop was harvested from 5 m^2 area at the centre of each plot and grain yield was adjusted to 14% moisture content and straw yield was recorded from 16 hills.

T. Aman 2012

The treatment combinations were: 51 kg N ha^{-1} + 4 kg N ha^{-1} from urea spraying with MG five times (T_1), 56 kg N ha^{-1} (T_2), 75 kg N ha^{-1} (T_3), 75 kg N ha^{-1} + spraying MG twice (T_4), 38 kg N ha^{-1} (T_5) and no fertilizer (T_6). A basal dose of PKSZn @10-37-7-1 kg ha^{-1} was used. Forty-eight-day-old seedlings of BR22 were transplanted on 11 September 2012. In T_1, MG was sprayed as in T. Aus. Similar amount of MG alone was sprayed in the main field in T_4. In T_1, N was applied in two splits: 1st top-dress at 15 DAT (34 kg N ha^{-1}) and 2nd top-dress at 27 DAT (17 kg N ha^{-1}). In other treatments N was applied in three equal splits (at basal, 25 DAT and 43 DAT). Data were recorded as like as T. Aus.

Boro 2012-13

Field 1. The treatment combinations were: no fertilizer (T_1), 50 kg N ha^{-1} (T_2), 50 kg N ha^{-1} + 6 kg N ha^{-1} from urea spraying with MG seven times (T_3), 100 kg N ha^{-1} as three top dresses (T_4), 100 kg N ha^{-1} + 6 kg N ha^{-1} from urea spraying with MG seven times (T_5), 50 kg N ha^{-1} (T_6), 75 kg N ha^{-1} (T_7), 100 kg N ha^{-1} (T_8), 125 kg N ha^{-1} (T_9) and 150 kg N ha^{-1} (T_{10}). A basal dose of PKSZn @ 20-60-10-2.2 kg ha^{-1} was used. Fifty-three-day-old seedlings of BRRI dhan29 were transplanted on 22 January 2013. However, seedlings used in T_3 and T_5 where MG liquid fertilizer was sprayed four times at 17, 27, 38 DAS and one day before transplanting. Concentration of MG for seed bed was similar to T. Aus. In T_2 and T_3, N was applied at 15 DAT (33 kg N ha^{-1}) and 29 DAT (17 kg N ha^{-1}). First spray of MG applied at 96 ml MG $48L^{-1}$ water + 600g urea/33 dec in the afternoon on 29 DAT, 2nd spray at 96 ml MG $48L^{-1}$ water + 600g urea/33 dec + 300g MoP/33 dec on 44 DAT and 3rd spray at 96 ml MG $48L^{-1}$ water + 600g urea/33 dec + 300g MoP/33 dec on 58 DAT in T_3. Similar amount of MG was sprayed in the main field in T_5. In T_4 and T_5, N was applied at 15, 29 and 44 DAT in equal splits. In other treatments N was applied at basal, 25 and 43 DAT equally. Data were recorded as like as T. Aus.

Field 2. The treatment combinations were: no fertilizer (T_1), 50 kg N ha^{-1} (T_2), 50 kg N ha^{-1} + 6 kg N ha^{-1} from urea spraying with MG three times (T_3), 100 kg N ha^{-1} as three top dresses (T_4), 100 kg N ha^{-1} + 6 kg N ha^{-1} from urea spraying with MG three times (T_5), 50 kg N ha^{-1} (T_6), 75 kg N ha^{-1} (T_7), 100 kg N ha^{-1} (T_8), 125 kg N ha^{-1} (T_9) and 150 kg N ha^{-1} (T_{10}). A basal dose of PKSZn @ 20-60-10-2.2 kg ha^{-1} was used. Sixty-four-day-old seedlings of BRRI dhan29 were transplanted on 4 February 2013. There was no spray at seed bed. Amount and time of MG spray in the main field for T_3 and T_5 were similar to Field 1. In T_2 and T_3, N was applied at 14 DAT (33 kg N ha^{-1}) and 29 DAT (17 kg N ha^{-1}). In T_4 and T_5, N was applied at 14, 29 and 44 DAT equally. In other treatments, N was applied at basal, 26 and 48 DAT equally. Data were recorded as in T. Aus.

Boro 2013-14

Table 1 shows the treatment combinations. In T_4, T_5 and T_6, N was applied on soil in two splits. In T_4 and T_5, 20% at 7 DAT and 30% at 27 DAT while in T_6 25% at 7 DAT and 35% at 27 DAT. In T_4 and T_6, 10% N of STB but in T_5, 15% N of STB were sprayed three times with MG. In T_2 and T_{10} only MG (no N) was sprayed. In other treatments, N was applied at 7, 27 and 47 DAT equally. A basal dose of PKSZn @ 17-60-20-4 kg ha^{-1} was used. The test rice variety was BRRI dhan28. Roots of the seedlings were dipped in a solution containing KCl and MG according to supplier's recommendation. Data were recorded as in T. Aus.

Table 1. Treatment imposed during Boro 2013-14.

$T_1 = N_0$
$T_2 = N_0$ (only MG)
$T_3 = N_{60}$ % of STB (70 kg N ha^{-1})
$T_4 = N_{50}$ % of STB + 10% with MG (58 kg+ 12 kg N ha^{-1})
$T_5 = N_{50}$ % of STB + 15% with MG (58 kg+ 17 kg N ha^{-1})
$T_6 = N_{60}$ % of STB + 10% with MG (70 kg+ 12 kg N ha^{-1})
$T_7 = N_{70}$ % of STB (82 kg N ha^{-1})
$T_8 = N_{85}$ % of STB (99 kg N ha^{-1})
$T_9 = N_{100}$ % of STB (116 kg N ha^{-1})
$T_{10} = N_{100}$ % of STB + MG)

RESULT AND DISCUSSION

T. Aus 2012

Nitrogen fertilizer application significantly increased straw and grain yield (t ha^{-1}) compared to without fertilizer (Table 2).

Table 2. Influence of magic growth fertilizer on yield of BRRI dhan43, T. Aus 2012, BRRI farm, Gazipur.

Treatment	Straw yield (t ha^{-1})	Grain yield (t ha^{-1})
$T_1 = N_{56} + MG_5$	2.59ab	3.05a
$T_2 = N_{56}$ (without MG)	2.54ab	2.92a
$T_3 = N_{75}$ (AEZ base dose)	2.83a	3.01a
$T_4 = N_{75} + MG_2$	2.75a	3.12a
$T_5 = N_{38}$ (50% of T_3)	2.29b	2.53b
T_6 = Control (no fertilizer)	1.66c	1.91c
Level of significance	**	**
CV (%)	9.5	6.0

Blank dose: PKSZn @ 10-37-7-1 kg ha^{-1}.

Statistically similar grain yield was obtained with and without MG sprays at similar levels of N. It means that spraying of MG in rice did not show any yield advantage over similar rate of conventional N fertilizer application. These results are supported by the findings of Aziz and Miah (2008) who revealed that STB fertilizer dose gave significantly higher rice yield than flora (liquid fertilizer) treated (3ml L^{-1} water) plot. There was no significant yield difference between STB dose and STB + flora treatments. Nutrient content in MG indicated 0.67% total N along with considerable concentration of P, K and S (Table 3) and the amount of N added to rice crop through spraying of MG was very negligible and thus had no effect on rice yield. The N content did not vary even after modification of determination process (Table 4).

Table 3. Nutrient content of magic growth liquid fertilizer.

Parameter	Sample supplied for T. Aus		Sample supplied for Boro	
	Fresh aliquot	Digested aliquot	Fresh aliquot	Digested aliquot
pH	1.17	-	0.98	-
Total N (%)	0.67	5.23	0.35	7.07
Total P (%)	2.18	-	3.18	-
Total K (%)	9.6	-	7.5	-
Total S (%)	0.65	-	0.33	-
Total Fe (%)	0.02	-	0.01	-
Total Cu (%)	0.03	-	0.03	-
Total Zn (%)	0.02	-	0.02	-
Total Mn (%)	0.004	-	0.01	-

Table 4. Percent N content of magic growth liquid fertilizer.

Magic growth	Aliquot without digestion		Aliquot digestion without shaking
	Without shaking	Shaking Shaking	
Sample supplied for T. Aus	1.12	1.44	3.73
Sample supplied for Boro	1.85	1.89	5.13

Note. Table 3 shows the N contents of fresh and digested aliquot. Percent N in fresh aliquot was less than digested aliquot. Obtained N from fresh aliquot was quite perfect to uptake by plant in field condition, because this amount is the available form, but N from digested aliquot is not suitable for plant because most of the N is in unavailable form.

T. Aman 2012

Nitrogen fertilizer application significantly increased plant height, tiller numbers, straw and grain yields than control (Table 5). Nitrogen @ 56 kg ha^{-1} in three splits produced yield 3.52 t ha^{-1}, which was significantly higher than $T_1 = N_{51}$ + 4 kg N ha^{-1} from urea spraying with MG five times. It indicated that soil application of urea-N (56 kg ha^{-1}) was superior to 51 kg N ha^{-1} soil application (2 × top dress) plus 4 kg N ha^{-1} as urea solution spray with MG. The yield obtained with this dose was also statistically at per with N 75 kg ha^{-1} with and without MG spraying treatment. In late transplanting situation, 56 kg N ha^{-1} was considered as optimum dose for satisfactory grain yield. However, rice yield at 75 kg N ha^{-1} with and without MG was statistically similar. It means MG spray also did not bring any yield advantage over without MG spray and also indicated that soil application of N fertilizer was better than foliar application of MG. This result represents the findings of Alam *et al.* (2010) who revealed that application of 1% urea solution alone (46 kg N ha^{-1}) is not enough to produce good yield, while with 94 kg urea soil application (112.24 kg N ha^{-1}) the performance was better but still the yield were lower than that obtained with soil application alone. On the other hand, 3% urea alone also showed poor performance compared to soil application of urea and even with 2% urea solution.

Boro 2012-13

Field 1. There was no significant effect of MG on rice yield (Table 6). Regardless of N application method, grain yield increment was observed up to 125 kg N ha^{-1} (Fig. 1). The highest grain yield (5.05 t ha^{-1}) was obtained at 125 kg N ha^{-1} applied with basal and two top dresses (T_9), which was statistically similar to 100 kg N ha^{-1} with basal and two top dresses (T_8), 100 kg N with MGS_7 (T_5) and 150 kg ha^{-1} N (basal and two top dresses) (T_{10}). So, the best performance was observed when 100 kg N ha^{-1} was used as basal and two top dresses. Yogendra *et al.* (2013) also found better performance with basal N fertilizer application than without basal. Application of 50 kg ha^{-1} N following basal and two top dresses (T_6) produced similar grain yield with 50 kg N + MG_7 (T_3) followed by without basal N (T_2) but T_6 was superior to T_3. There was significant difference on grain yield between T_3 (N_{50+6*} with MG_7 and

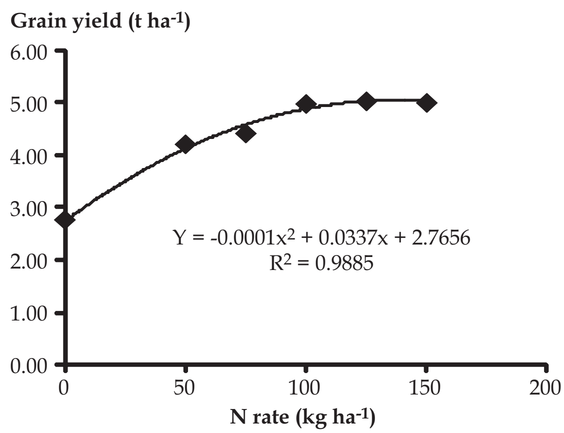

Fig. 1. Influence of N rate on yield of BRRI dhan29, Boro 2012-13, BRRI farm, Gazipur.

Table 5. Influence of magic growth liquid fertilizer on yield and yield components of BR22, T. Aman 2012, BRRI farm, Gazipur.

Treatment	Plant height (cm)	Tiller no./m^{-2}	Straw yield (t ha^{-1})	Grain yield (t ha^{-1})
$T_1 = N_{51+4*}$ with MG_5	82a	278a	2.88bc	3.28b
$T_2 = N_{56}$ (without MG)	84a	263ab	3.30ab	3.52a
$T_3 = N_{75}$ (AEZ base dose)	82a	270a	3.23abc	3.64a
$T_4 = N_{75} + MG_2$	84a	275a	3.50a	3.59a
$T_5 = N_{38}$	80a	243bc	2.84c	3.31b
T_6 = Control (no fertilizer)	67b	232c	2.16d	2.00c
Level of significance	**	**	**	**
CV (%)	6	4.6	8.7	3.5

*4 kg N calculated from urea solution spray with MG liquid fertilizer.

Table 6. Influence of magic growth fertilizer on yield of BRRI dhan29, Boro 2012-13, BRRI farm, Gazipur.

Treatment	Plant ht (cm)	Tiller no. m^{-2}	Straw yield (t ha^{-1})	Grain yield (t ha^{-1})
T_1 = Control (no fertilizer)	80e	164d	1.90d	2.76f
$T_2 = N_{50}$ (without MG and without basal)	85cd	221bc	3.00c	3.67e
$T_3 = N_{50+6*}$ (with MG_7 and without basal)	86bcd	205cd	2.84cd	3.87de
$T_4 = N_{100}$ (without MG and without basal)	89abcd	234bc	3.35bc	4.47bc
$T_5 = N_{100+6*}$ (with MG_7 and without basal)	90ab	257b	4.46a	4.93ab
$T_6 = N_{50}$ (Basal and two top dresses)	86bcd	191cd	2.59cd	4.22cd
$T_7 = N_{75}$ (Basal and two top dresses)	84d	205cd	2.85cd	4.43c
$T_8 = N_{100}$ (Basal and two top dresses)	93a	234bc	4.03ab	5.00a
$T_9 = N_{125}$ (Basal and two top dress)	91ab	264b	4.05ab	5.05a
$T_{10} = N_{150}$ (Basal and two top dresses)	90abc	346a	4.26ab	5.02a
Level of significance	**	**	**	**
CV (%)	2.4	7.9	11.8	4.4

*N with MG.

without basal) and T_4 (N_{100} without basal and without MG). So, these findings do not support our hypothesis. Our findings are also supported by Karim *et al.* (2015) who reported maximum grain yield through soil fertilization compared to liquid fertilizer spray.

Field 2. Nitrogen fertilizer application significantly increased tiller number, straw and grain yields than without fertilizer addition (Table 7). The highest grain yield of 6.15 t ha^{-1} was obtained with T_8 (N_{100} with basal and two top dresses), which was statistically similar to T_5 (N_{100+6*} with MGS_3 and without basal), T_7 (N_{75}: Basal and two top dresses) and T_9 (N_{125}: Basal and two top dresses). Statistically similar grain yield was obtained from T_2 (N_{50} without MG and without basal) and T_3 (N_{50+6*} with MG_3). Similar trend was found with T_4 (N_{100} without MG) and T_5 (N_{100+6*} with MG_3). There was a significant difference on grain yield between T_3 (N_{50+6*} with MG_3 and without basal) and T_8 (N_{100} with basal and two top dresses). In spite of same N dose in the T_2 and T_6, significantly higher grain yield was obtained from T_6 (N_{50}: Basal and two top dresses). Similar trend was observed with T_4 (N_{100} without basal and three top dresses) and T_8 (N_{100} with basal and top dresses). It might be due to the variation in fertilizer application time and method. Regardless the method of N application, the highest grain yield increment was observed up to 100 kg N ha^{-1} (Fig. 2). The highest number of tiller (316) was obtained in T_{10}, which was statistically similar to T_4, T_5 and T_9. The highest straw yield of 5.87 t ha^{-1} was obtained in T_{10}, which was statistically similar to T_5 and T_9. There was no significant difference on straw yield among T_2, T_3, T_4, T_6,

Table 7. Influence of magic growth fertilizer on yield of BRRI dhan29, Boro 2012-13, BRRI farm, Gazipur.

Treatment	Tiller no. m^{-2}	Straw yield (t ha^{-1})	Grain yield (t ha^{-1})
T_1 = Control (no fertilizer)	173e	2.72d	3.95e
$T_2 = N_{50}$ (without MG and without basal)	237d	4.36bc	5.02d
$T_3 = N_{50+6*}$ (with MG_3 and without basal)	254bcd	4.39bc	5.36cd
$T_4 = N_{100}$ (without MG and without basal)	273abcd	4.64abc	5.56bc
$T_5 = N_{100+6*}$ (with MG_3 and without basal)	292abc	5.16ab	5.95ab
$T_6 = N_{50}$ (Basal and two top dresses)	249cd	3.66cd	5.61bc
$T_7 = N_{75}$ (Basal and two top dresses)	268bcd	3.72cd	5.86abc
$T_8 = N_{100}$ (Basal and two top dresses)	267bcd	4.30bc	6.15a
$T_9 = N_{125}$ (Basal and two top dresses)	295ab	5.19ab	5.74abc
$T_{10} = N_{150}$ (Basal and two top dresses)	316a	5.87a	5.61bc
Level of significance	**	**	**
CV (%)	6.3	11.4	3.8

*N with MGS.

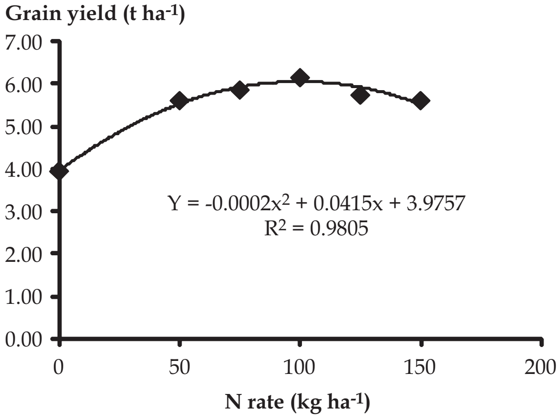

Fig. 2. Influence of N rate on grain yield of BRRI dhan29, Boro 2012-13, BRRI farm, Gazipur.

T_7 and T_8. Similar finding was achieved by Alam *et al.* (2010) who reported that soil application of N fertilizer was the best for obtaining higher grain yield. Yogendra *et al.* (2013) also found that basal N fertilizer application performed better than without basal.

Boro 2013-14

Nitrogen fertilizer application significantly increased tiller m^{-2} and straw yield of BRRI dhan28 (Table 8). But grain yield of BRRI dhan28 was not significantly increased with application of N irrespective of method (soil application or spray with MG). However, the N_0 treatment gave the lowest grain yield, which insignificantly increased with N application. The highest grain yield was obtained with T_6 where 60% N was applied in soil and 10% sprayed with MG. In comparison to T_7 where 70% N was applied as BRRI method (without MG and spray), the yield increment with T_6 (507 kg ha^{-1}) was not significant. On the other hand, if we compare T_1 with T_2 and T_9 with T_{10} MG spray slightly decreased the grain yield of BRRI dhan28 though the differences were not significant. It means MG spray did not bring any yield advantage over without MG spray and soil application of N fertilizer was better than foliar application of liquid fertilizer. Similar finding was also reported by Alam *et al.* (2010) who found that soil application of N fertilizer was the best treatment for obtaining higher grain yield.

CONCLUSIONS

Similar grain yield was obtained with and without magic growth liquid fertilizer spray at similar levels of N in T. Aus season. Also, there was no added benefit of magic growth spray on grain yield during T. Aman and Boro seasons. Proposition of producer about 44% saving of N due to magic growth spraying did not match with the present results. However, the study showed a significant effect of N fertilizer application method for rice cultivation. Basal application of N with top dresses produced higher grain yield over N top dress only.

Table 8. Influence of magic growth fertilizer on growth and yield of BRRI dhan28, Boro 2013-14, BRRI farm, Gazipur.

Treatment	Tiller m^{-2}	Grain yield (t ha^{-1})	Straw yield (t ha^{-1})
$T_1 = N_0$	307cd	5.38	3.84c
$T_2 = N_{0\ (only\ MG)}$	286d	5.28	4.01bc
$T_3 = N_{60\ \%\ of\ STB\ (70\ kg\ N\ ha^{-1})}$	371ab	5.78	5.35a
$T_4 = N_{50\ \%\ of\ STB\ +\ 10\%\ with\ MG\ (58\ kg\ +\ 12\ kg\ N\ ha^{-1})}$	337bcd	6.12	4.77abc
$T_5 = N_{50\ \%\ of\ STB\ +\ 15\%\ with\ MG\ (58\ kg\ +\ 17\ kg\ N\ ha^{-1})}$	327bcd	6.10	4.83abc
$T_6 = N_{60\ \%\ of\ STB\ +\ 10\%\ with\ MG\ (70\ kg\ +\ 12\ kg\ N\ ha^{-1})}$	346bc	6.23	4.74abc
$T_7 = N_{70\ \%\ of\ STB\ (82\ kg\ N\ ha^{-1})}$	352bc	5.72	4.88abc
$T_8 = N_{85\ \%\ of\ STB\ (99\ kg\ N\ ha^{-1})}$	349bc	5.94	4.94abc
$T_9 = N_{100\ \%\ of\ STB\ (116\ kg\ N\ ha^{-1})}$	412a	5.91	5.82a
$T_{10} = N_{100\ \%\ of\ STB\ +\ only\ MG}$	364ab	5.79	5.80a
Level of significance	**	NS	**
CV (%)	9.5	10.0	14.3

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Isolation of Arsenic Oxidizing-reducing Bacteria and Reclamation of As (III) in *invitro* Condition

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ABSTRACT

The study aimed to isolate arsenic (As) oxidizing-reducing bacteria from As contaminated soil and water and to determine their ability to remove As from broth culture. Soil and water samples were collected from As contaminated area of BRRI farm, Bhanga, Faridpur. Arsenic oxidizing and reducing bacteria were isolated from the As contaminated soil (13 mg kg^{-1}) and water (410 µg/L) using spread plate count method in minimal salt (MS) medium after seven days of incubation. The oxidation activity of the bacteria as well as reclamation of As [III] was determined from $NaAsO_2$ supplemented broth using atomic absorption spectrophotometer (AAS). The As-oxidizing bacteria population was present only in one soil sample, while in all water samples both oxidizing and reducing bacteria were present. A total of 36 As oxidizing-reducing bacteria were isolated. As-oxidizing bacteria removed 71-99% of applied As [III] in broth culture. Two out of 10 As-oxidizing bacterial strains appeared more efficient than others to remove As [III] under broth culture conditions.

Key words: Arsenic oxidizing-reducing bacteria; isolation; reclamation

INTRODUCTION

Arsenic is a metalloid of global concern due to its toxic and carcinogenic effects. It is widely distributed in the environment due to natural geochemical process and anthropogenic activities (Cullen *et al*., 1989). Arsenic occurs in nature in four oxidation states (+5, +3, +2, +1 and -3). The most common oxidation states of As in the nature are pentavalent arsenate As [V] and trivalent arsenite As [III] and the latter one is more toxic for plant than As [V] (Echrlich, 1996).

In Bangladesh various levels of arsenic contamination were reported in 59 out of 64 districts. Seventy-five million people are at risk and 24 million are potentially exposed to As contamination (MacDonald, 2001 and Malellan, 2002). Thus the removal of As from contaminated environment is necessary for human welfare. The currently available conventional techniques such as precipitation, chemical oxidation and reduction, ion exchange, filtration, reverse osmosis etc for removing heavy metals are found often inappropriate or expensive because of vast polluted area (Chaala *et al*., 2005). Therefore, generation of technologies using microorganisms received tremendous attention in the field of bioremediation of heavy metals (Clausen, 2000).

Like many organic contaminants, As cannot be destroyed. It can be immobilized or transformed into less toxic forms. Arsenic bioremediation has already been achieved with As resistant bacteria (Katsoyiannis *et al*., 2002). A diverse group of heterotrophs are related to As transformation in nature. Arsenic speciation in nature is related to oxidations or reduction by microbes (Oremland *et al*., 2003). Microbial redox carried out either for detoxification or for energy generation to support cellular growth. In oxidation, microbes convert arsenite As [III] to arsenate As [V] state, which is less toxic to environment. The As [III] oxidation enhances

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growth of heterotrophic arsenite-oxidizing bacteria and provide sole energy source for chemoautotrophic As-oxidizing bacteria. Moreover, arsenate resistant microbes reduce arsenate [V] to arsenite As [III] (Oremland *et al*., 2003). Arsenic can be reduced to volatile compounds arsine (AsH_3) and methyl-arsines. However, the present study aimed to isolate potential As oxidation-reduction bacteria and to determine its capability for detoxification.

Sample collection. Arsenic contaminated soil and water samples were collected from Bhanga area of Faridpur district, Bangladesh. Soil samples were preserved in plastic containers and refrigerated until further analysis. Soil used was classified as inceptisol and initial chemical properties were: pH 7.3 (in 1:2.5 water), organic carbon 1.7%, total N 0.17%, available P 9 mg kg^{-1}, exchangeable K 0.56 cmol kg^{-1}, available S 29 mg kg^{-1}, and available Zn 0.9 mg kg^{-1}. The soil contained 13 mg As per kg.

Isolation of As oxidizing-reducing bacteria. The isolation was done within seven days after sample collection. One gram of soil samples were taken into 95 ml sterile distilled water and a series of 10 fold dilutions were made up to 10^{-8}. Exactly 0.1 ml of dilution was spread on each media plate. The As oxidizing-reducing bacterial populations were determined using spread plate count method in minimal salt (MS) medium. Composition of the medium was NaCl (1.17 g L^{-1}), KCl (0.30 g L^{-1}), NH_4Cl (0.15 g L^{-1}), $MgCl_2$ $6H_2O$ (0.41 g L^{-1}), $CaCl_2$ (0.11 g L^{-1}), KH_2PO_4 (0.20 g L^{-1}), Na_2SO_4 (0.07 g L^{-1}) and $NaHCO_3$ (2.00 g L^{-1}), pH 8.0. The MS medium was supplemented separately with 7 ppm of sodium arsenite ($NaAsO_2$) for isolation of As-oxidizing and 7 ppm of sodium arsenate (Na_2HAsO_4) for As-reduction bacteria. After three days of incubation population were counted.

Determination of As transforming ability of the isolated bacteria. Verification of the transforming ability of the isolate was carried out by using of $AgNO_3$ method. MS media containing 5mM Na-lactate as carbon source and 5mM Na-arsenate as the electron acceptor were used to determine the ability of isolates to reduce As [V]. Bacteria were grown under anaerobic conditions and after seven days of incubation at 28°C, the agar plates were immersed with 0.1 M $AgNO_3$ solution. Reaction of $AgNO_3$ with As [V] or As [III] resulted a coloured precipitate (Simeonova *et al*., 2004). A brownish precipitate indicates the presence of Ag_3AsO_4 (silver arsenate) in the medium while, a yellow precipitate reveals the presence of $AgAsO_3$ (silver arsenite).

Arsenic removal ability of bacterial isolates. The oxidation activity of the bacteria as well as reclamation of As [III] was determined from $NaAsO_2$ supplemented broth. Exactly, 7000 ppb of $NaAsO_2$ was added to 50 ml of minimal salt broth. After seven days of incubation As [III] was determined using atomic absorption spectrophotometer (AAS) with flow-injection hydride generation system (Model: A Analyst 100 Atomic Absorption Spectrometer, Perkin Elmer).

As oxidizing-reducing bacterial population. Initial soil and water As at Bhanga was 13.3 mg kg^{-1} and 160 µg L^{-1}, respectively. The As-oxidizing bacterial population was found only in one soil sample, while in all water samples both bacterial species were present (Table 1). The population of As-reducing bacteria was higher compared to As-oxidizing bacteria. A total of thirty-six As oxidizing-reducing bacteria were isolated and both types can tolerate seven ppm of As. Results of different studies also supported the abundance of As oxidizing-reducing bacteria in the contaminated soil and water (Liao *et al*., 2011 and Huang *et al*., 2012).

Table 1. Population of As oxidizing-reducing bacteria supplemented with seven ppm arsenic.

Treatment	Bacterial population	
	As-oxidizer	As-reduction
Soil 1	0	0
Soil 2	2×10^3	0
Soil 3	0	0
D1(water)	8×10^5	12×10^6
A3 (water)	2.6×10^2	2.5×10^4
A4 (water)	8.5×10^2	1.1×10^3
B34 (water)	1.1×10^4	4.3×10^3

Strain verification and reclamation of As [III] *invitro* condition. The verification of the transforming ability was carried out by using $AgNO_3$ method. The MS agar plates with brownish precipitate revealed the presence of arsenate and activity of arsenite-oxidizing bacteria, while the presence of bright yellow precipitation was the activity of As-reducing bacteria.

The As oxidizing bacteria were able to use As [III] for its metabolic activity and consequently decreased about 71-99% of As [III] in the broth supplemented with 7000 ppb of $NaAsO_2$ after seven days of incubation. Among the tested 10 oxidizers, strain 1 and 2 were found most efficient to use As [III] followed by strain 8 (Table 2). It was found that *Pseudomonas putida* strain OS-5 completely oxidized 1 mM of As [III] to [V] within 35 hour (Chang *et al*., 2007).

A total of 36 As oxidation-reduction bacteria were isolated from Bhanga soil and water samples that can tolerate seven ppm As, either in $NaAsO_2$ or in Na_2HAsO_4. Under invitro condition As-oxidizers were able to reduce 71-99% of As [III] in the broth supplemented with 7000 ppb of $NaAsO_2$ after seven days of incubation. The potential isolated bacterial strains can be used as biofertilizer for removal of As from contaminated soil and water resources.

Table 2. Reclamation of As (III) using As-oxidizing bacteria after seven days of incubation period.

As oxidizing bacterial strain	As [III] remaining (ppb)	% reclamation of As [III]
As strain 1	23.23	99.67
As strain 2	15.74	99.78
As strain 3	1301	81.41
As strain 4	1974	71.80
As strain 5	1642	76.54
As strain 6	1902	72.83
As strain 7	1733	75.24
As strain 8	387	94.47
As strain 9	1569	77.59
As strain 10	1616	76.91

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