SAARC J. Agric., 18(2): 167-180 (2020) *DOI: https://doi.org/10.3329/sja.v18i2.51117*

Research Article

BOOSTING RICE PRODUCTION THROUGH NARROWING OF EXPLOITABLE YIELD GAP

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ABSTRACT

The yield gap discussed in this paper is the difference between the potential farm yield and the actual average farm yield of rice is 1.92 t ha^{-1} in Bangladesh. The yield gap is mainly caused by physical, biophysical, socioeconomic and institutional factors. Different strategies, such as integrated crop management (improve adapted varieties, site specific nutrient management, locally adapted integrated weed management and optimized water management) practices, timely supply of inputs including credit to farmers, research and extension collaboration to transfer the new technologies have been discussed to minimize yield gap. Suggestions have been made to make credit available to resource-poor small farmers to buy necessary inputs, reducing transaction cost, simplifying lending procedures and strengthening monitoring mechanism of the current credit system are, however, essential to enable the farmers to avail the credit facility. Efforts should be made to update farmers' knowledge on the causes of yield gaps in crops and measures to narrow the gaps through training, demonstrations, field visits and monitoring by extension agencies to achieve high yield. Based on present yield gap of rice (1.92 t ha^{-1}) at least Tk. 556 billion could be earned from the additional production annually by narrowing 40 % the yield gap.

Keywords: Rice, Narrow yield gap, Food security

INTRODUCTION

Bangladesh agriculture involves food production for 164.39 million people from merely 8.75 million hectares of agricultural land (Salam et al., 2014). The slogan "Rice is life" is most appropriate for Bangladesh as this crop plays a pivotal role in our national food security and is a means of livelihood for millions of rural households. Decreasing resources and increasing climate vulnerability appeared as the great challenges to keep the pace of food production in the background of

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Received: 03.05.2020 Accepted: 20.06.2020

increasing population. Sufficient rice production is the key to ensure food security in Bangladesh. The yield gap of rice is about 1.92 t ha^{-1} in Bangladesh (BBS, 2012; BINA, 2018; Salam et al., 2014). The term 'yield gap' is used to indicate the difference between the biological and climatic potential yield and the average actual crop yield produced by farmers (Lobell et al., 2009). The yield gaps have at least two components. The first component–yield gap I is the difference between research yield and the potential farmers' yield. This component can't be narrowed or is not exploitable. The second component of yield gaps or gap II is the difference between the potential farmers' yield and the farmers' actual yield (Devkota et al., 2020). The yield gap II is exploitable and can be minimized by deploying research and extension approaches and government interventions, especially institutional issues. Factors affecting crop growth and development are radiation and temperature (yield determining), water and nutrition (yield limiting); the attainable yield is the potential yield limited by these two factors in a given environment (Rabbinge, 1993). An additional factor affecting crop growth is pest and diseases (yield reducing).In addition, productivity is also determined by factors such as cultivar choice and crop management. Narrowing yield gaps not only increases rice yield and production, but also improves the efficiency of land and labour use, reduces production costs and increases sustain ability. Clearly, there is a need to study important yield reducing factors closely in order to determine strategies to help increase and maintain rice productivity on farmers' fields. Sustainable intensification of agricultural systems including the closure of existing yield gap on currently available agricultural land has been pointed as a possible pathway to meet future food demand. Keeping in mind, this review article is to discuss the causes contributing to yield gaps in rice, suggest strategies to minimize the gaps to increase rice yield and finally make recommendations mainly to the government/policy makers to develop guidelines or action plans to address the problem.

METHODOLOGY

The paper is based on review and use of secondary data published in journals, research magazine, scientific reports, books, proceedings and training manual available in the studies conducted by various researchers, institutions and organizations. The review focused primarily on literature search and restricted to articles and report papers published. Published articles were searched and identified from different electronic databases such as library, Web of Science, AGRIS, Research Gate, Science Direct etc. Based on the review objectives and content types, articles and published reports were retrieved from databases mainly focusing on empirical results reported on yield gap of rice. Following a critical review, data and literatures were compiled and discussed on effective ways and recommendations to minimize yield gap of rice in Bangladesh.

RESULTS AND DISCUSSION

Factors causing yield gaps

Non-exploitable factors

Yield gaps in rice are real and the challenge in Bangladesh needs to be addressed in the interest of increased and sustainable crop production (Figure 1).

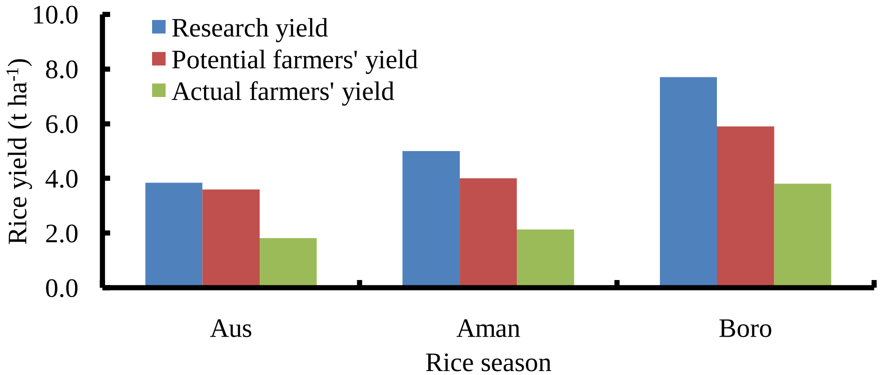

Figure 1. Yield performance of aus, aman and boro rice in different production levels (adapted from BBS, 2012; BINA, 2018; Salam et al., 2014)

No-exploitable factors or yield gap I factors are high solar radiation, long summer days, low night temperature and clear sky for rice production (Figure 2). In Bangladesh most of the times night temperature is high as a result significant respiration is happened in rice plant. If we can develop low respirator rice variety that will be helpful to narrow the yield gap of rice.

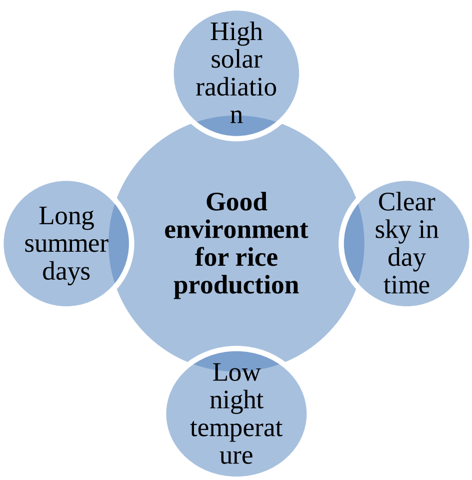

Figure 2. Factors of yield gap

Exploitable factors

Several factors can cause yield gap in rice. In general, factors causing yield gap can be classified in four major groups. These are physical factors, biophysical factors, socioeconomic factors and institutional factors (Figure3). For narrowing yield gap of physical, biophysical, socio-economic and institutional factors are organized in one umbrella as smart agriculture. Socioeconomic and institutional factors are the driving force to improve adapted varieties, site specific nutrient management, locally adapted integrated weed management and optimized water management (Figure 3) as good agricultural practices (GAP) for narrowing yield gap of rice. Yield gap of rice successfully reduce, if we manage physical factors, improve, control, and manage of biophysical factors, create good environment of socioeconomic factors and facilitates institutional factors.

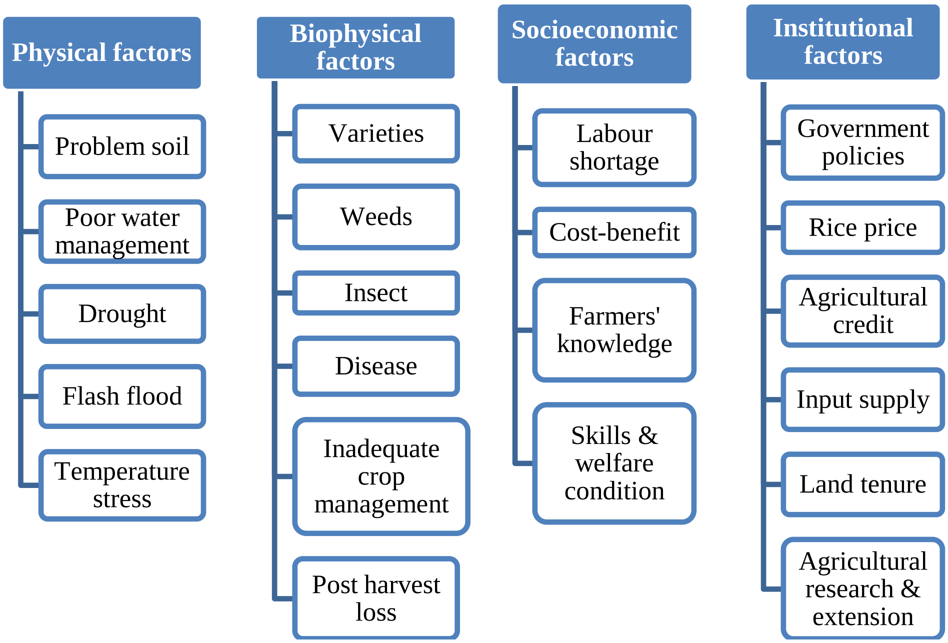

Figure 3. Factors causing yield gaps II of rice

Yield gaps of rice by different factors

Varietal effect

Kabir et al. (2015) reported that BRRI has developed some drought (T. Aman, BRRI dhan56, BRRI dhan66 and BRRI dhan71), submerged (BRRI dhan52) and salinity (BRRI dhan41, BRRI dhan 54 and BRRI dhan73) tolerant rice which can help to narrowing yield gap of rice. Kabir et al. (2015) conducted field experiment to study the effect of variety on rice yield. BRRI dhan26 and BRRI dhan48 (Aus season), BRRI dhan49 (T. Aman season) and BRRI dhan28 and BRRI dhan29 (Boro season) were used for this study. The yield gap of rice is 0.83 t ha^{-1} or 20.7%. In Boro season, BRRI dhan60 has 1.0 t ha^{-1} yield advantage with extra-long slender grain than another mega-variety BRRI dhan28 (Kabir et al., 2015). NERICA cultivars have good adaptation with short cycles, weed competitiveness and resistance to important diseases under a range of yield reducing factors (Balasubramanian et al., 2007; Seck et al., 2012). Brar and Virk (2010) reported that some cultivars had developed which can tolerant temperature or water stress without compromise of productive capacities. Singh and Feroze (2017) reported that Ranjit cultivar was performed the highest yield gap (1.95 t ha^{-1}), which was accounted to be 51.99 per cent of potential yield and followed by Lahi cultivar (1.80 t ha^{-1}), Pasyrbhuh cultivar (1.40 t ha^{-1}), Hybrid cultivar (1.12 t ha^{-1}) and Assam (0.37 t ha^{-1}). The yield and yield gap varied from cultivars to cultivars, Ajeet and Namdeo (2005) also found similar results with respect to variation in the grain yield of hybrid rice and IR 36 variety of rice.

Fertilizer effect

Alam (2006) conducted field experiments by BRRI in Faridpur and Gazipur districts in Bangladesh to evaluate the yield gap in boro rice. Under research and farmer's fields, the yields of boro rice were 4.47 and 3.67 tha^{-1} at farmers' field and the potential yields with better management were 5.90 and 4.73 tha^{-1} at BRRI station of Faridpur and Gazipur, respectively. The yield gaps were 1.43 and 1.06 tha^{-1} at Faridpur and Gazipur, respectively. Based on these results, it indicates that crop suitability in respect of region/location is an important factor for narrowing yield gap of rice. Roy (1997) reported yield gaps of 44.44 and 60 % in aus and aman, respectively. Saito et al. (2017) conducted field experiments in different locations in Africa to study the effect of nitrogen on yield gap of rice. The yield gap was 0.9, 1.2 and 1.7 tha^{-1} in irrigated lowland, rainfed lowland and rainfed upland rice production systems, respectively. Rainfed upland rice has the largest yield gap due to N limitation followed by rainfed lowland rice. In fact, both irrigated lowland and rainfed lowland rice, the yield gap is larger in East and Southern African countries than in West and Central African countries, as the N application rate is lower in East and Southern African countries. The yield gap due to poor N use efficiency is 1.1, 1.9 and 2.7 t ha^{-1} in irrigated lowland, rainfed lowland and rainfed upland rice production systems, respectively. Again, the largest yield gap is found in rainfed upland rice, where drought may have occurred and soil fertility might be poor. Fertilizer application in proper amount, at proper time and at proper place helps to reduce weeds as the main crop will gain all the nutrients (Dubey, 2014). Herbicide with one hand weeding and BRRI weeder treated plot with 160:46:53 kg NPK ha^{-1} increased 89.38 % and 81.51 % higher yield than 120:26:33 kg NPK ha^{-1} with no weeding plot (Sultana et al., 2016). From these results it may be concluded that optimum fertilizer with weed control increase yield of rice. Islam et al. (2018)

conducted field experiment to investigate the integrated effect of prilled urea and urea super granules with poultry manure on yield of BRRI dhan49. Urea super granule in combination with poultry manure (56 kg USG + 3.0 t ha^{-1} poultry manure treated plot increased 17 % higher yield than 165 $kgha^{-1}$ prilled urea. Urea super granule ×100 % urea treatment produced the highest grain yield (13%) ofrice over prilled urea ×100 % urea treatment (Hossain and Sarker, 2020). Casanova et al. (1999) reported that an average yield gap of 1000 $kgha^{-1}$ was not identified by fertilizer and probably due to other factors such as management practices. Poultry manure (PM) @ 3.0 tha^{-1} + integrated plant nutrient system (IPNS) based inorganic fertilizers for potato ($N_{80}P_0K_{30}S_0Zn_0Mg_4B_1$) and maize ($N_{136}P_0K_{40}S_2Zn_{1.8}Mg_2B_1$) crops and soil test based (STB) dose for T. Aman crop ($N_{65}P_3K_{27}S_8$) have been recommended for Potato-Maize-T. Aman cropping patternin Rangpur of Bangladesh. They also reported for maize and potato crops, fertilizer dose needs to be updated after every three years of successive crop cultivation under Potato-Maize-T. Aman cropping pattern (Saha et al., 2016).

Weed effect

A weed is defined as, any plant that is a hazard, nuisance or causes injury to man, his animals or his desired crops. Rahman and Masood (2019) stated in weedy plots produced above 5.0 tha^{-1} dry matter of weed that reduced the crop dry matter to only 0.8-0.9 tha^{-1} and contributed to about 77-85 % yield loss. Weeds cause 39-41 % yield reduction in dry direct seeded rice compared to weed-free condition (Chauhan and Opena, 2012). The results revealed that seeding at 5 cm depth and pre-emergence application of Panida followed by one hand weeding at 20 days after sowing (DAS) plus application of Panida better than four hand weeding for the best weed control to produce the highest rice yield (Rahman and Masood, 2019). The use of herbicide along with different manual weed control measures could be help to reduce weeding cost and amount of herbicide use towards reducing the adverse effect on environment (Charudattan, 2005). Farooq et al. (2009) reported that in absence of proper weed control, rice yields are reduced by 35-100 % in direct seeded rice cultivation. Kankal (2015) discussed that weed control and integrated nutrient management increased plant height (74.04 cm), numbers of tillers/0.25 m^2 (37.43) and dry matter accumulation (61.02 g) in rice over the un-weeded control. Uncontrolled weed growth loosed from 40 to 100% rice yield in upland condition. To obtain a good yield, a weed-free period of 40 to 60d from sowing is needed (Chadha et al., 1969). De Datta (1981) also reported that weed must be controlled within 20-40 days after transplanting (DAT) to avoid reduction in grain yield. Weeds are estimated to cause more than US$40 billion in annual global losses through degraded agricultural and silvicultural productivity, reduced access to land and water, impaired aesthetics and disruption of human activities and well-being. In Bangladesh, economic losses causes of weed have not measured but negative effect is large. Weed control played a key role in improving the yield of rice because of

18% increase of panicle m^{-2} due to weed control over its lower level. Many researchers working on weed management in direct seeded rice opined that herbicide may be considered to be a viable alternative to hand weeding (Khaliq et al., 2012). For direct seeded rice, it is important to keep field weed free for first 30 days. Therefore, use of pre-emergence or early post-emergence herbicides is effective and economical at initial stages. The pre-emergence or early post-emergence herbicide either prevents weed seeds germination or inhibits the growth of seedlings (Mishra and Dash, 2013). BRRI (2006) reported that rice yield losses due to weeds were estimated at 70-80 % in aus rice (early summer), 30-40 % in transplanted Aman rice (late summer) and 22-36 % in boro rice (winter rice). Kumar et al. (2008) reported that in the absence of weed control, rice yield get reduced by 35-100 % in direct-seeded.

Irrigation effect

Sattar (2000) reported that food shortage can mitigate by single rice crop like T. Aman by increasing the present level of modern variety adoption from 51 to 55 percent, providing supplemental irrigation, using balanced fertilizers and adopting better plant production measures. Under rain fed conditions, potential yield is also affected by water availability, and refers to water-limited yield (Fischer, 2015).Some researchers reported that large yield gap variation was observed in water availability within small distances in rain fed rice fields (Homma et al., 2003; Boling et al., 2010; Worou et al., 2013). Large yield gap exist in irrigated rice systems in Madagascar for instance, a gap of 2.1 tha^{-1} (a difference between 6.1 and 4.0 tha^{-1}) was determined in irrigated rice (Tran, 2004).

Others effect

The yield gap between experiment stations and the farmers' fields varies from 1.02 to 2.53 tha^{-1} in Boro with an average of 1.63 tha^{-1}, 1.56 to 3.39 tha^{-1} with an average of 2.32 tha^{-1} in Aman and from 1.24 to 2.62 tha^{-1} in Aus with an average of 1.69 tha^{-1} (Sattar, 2000). Optimum plant population in the field provides competition to weeds and inhibits their growth by occupying space or taking available nutrients (Meena et al., 2010). Yield gaps caused by biological, socio-economic, and institutional constraints can be effectively addressed through an integrated crop management (ICM) practices. Transfer of the practices through extension agents could effectively minimize yield gaps at farmers' level. Timely planting, irrigation, weeding, plant protection, and timely harvesting could account for more than 20 % yield increase (Siddiq, 2000). However, input/output prices and employment opportunities influence farmers' decision on the level of inputs to be applied. Irrigation, cover crop, intercropping, crop rotation, tillage, sowing and fertilizer application timing etc. May be considered as one of the best and oldest method to control weed (Kumar et al., 2014). Yield gaps between experiments and farmers' fields are governed by field-specific biophysical factors such as weather conditions, nutrient deficiencies and diseases (Lobell et al., 2009; van Ittersum et al., 2013). Yield gap studies to identify areas with the greatest potential for enhanced rice production need to be complemented by data and analyses of socio-economic factors such as distance to markets, road conditions and land-tenure issues and the existing area for rice cultivation in Bangladesh, where expansion for rice cultivation will be needed for achieving self-sufficiency (You et al., 2011; van Oort et al., 2015).

Opportunities to narrowing yield gap of rice

Good agricultural practices

Research-extension linkage, training of extension personnel on the new technology, their knowledge and education level about the technology, demonstration of the technology, field visits and monitoring, etc. by extension personnel strengthen to implement the site-specific nutrient management, improved varieties, integrated weed management and water management factors as good agricultural practices to the farmers'(Figure 4).

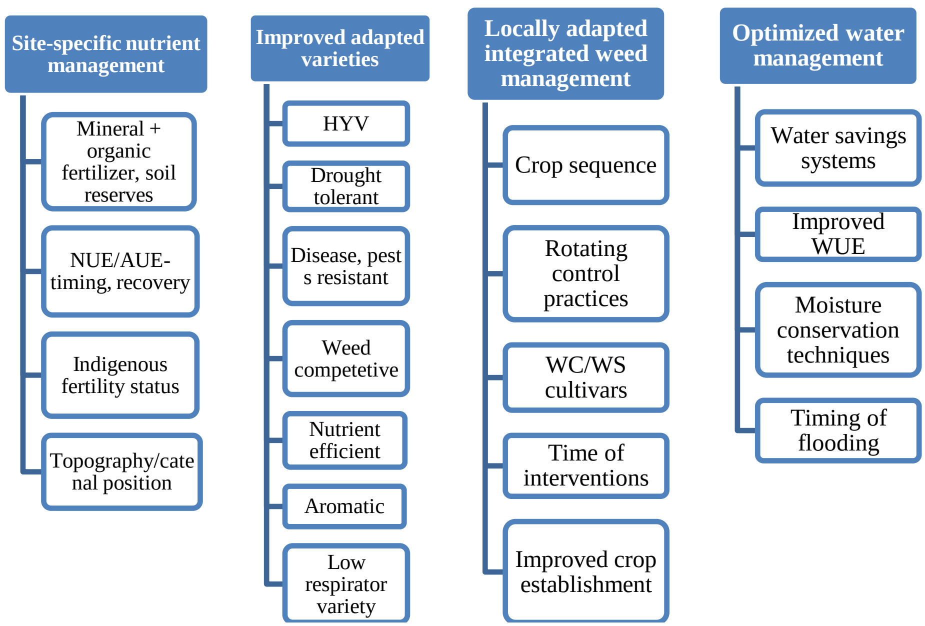

Figure 4. Factors affecting the narrowing the yield gap of rice

Driving force for good agricultural practices

Quality inputs play an important role in the productivity of crops and minimizing yield gaps. Farmers need adequate amounts of quality inputs at the right time to obtain high yields. It is also important that the fertilizer inputs are integrated with organic fertilizers for balanced use of nutrients. Resource-poor small but productive farmers representing more than 80 % of farm population are usually unable to purchase required quantities of the inputs for application for better yield in

Bangladesh. Therefore, these farmers need to be supported by adequate and timely supply of credit to narrow yield gaps. But the current credit system in Bangladesh remains far below the needs of small farmers. They have very limited access to institutional credit mainly because of collateral requirement. Therefore, appropriate measures must be taken to reduce transaction costs, simplify lending procedures, revise eligibility criteria and strengthen monitoring and supervision mechanism of the credit system. The action may also be taken for the expansion of rural bank branches under public sector. The support of research and extension is necessary for narrowing yield gap. The researcher should understand farmers' constraints to high productivity and accordingly develop integrated technological package (appropriate variety, timely planting, fertilizer, irrigation, and pest management) for farmers for specific locations to bridge up the gaps. The extension service should at the same time ensure that the farmers apply correctly and systematically the recommended technological packages in fields through effective training, demonstrations, field visits, monitoring, etc. The judicious application of inputs from seeding to heading in terms of quantity and timing will significantly contribute to reducing yield gaps and thereby increasing productivity of crops. As mentioned earlier, socio-economic and institutional/policy constraints can cause yield gap significantly. It is thus necessary that the government address the issues seriously and come forward with solutions to the problems to increase productivity by minimizing the yield gaps. Hanson et al. (1982) recommended that the government find solutions to socio-economic and political questions for narrowing the agronomic gap between farmers' fields and the research stations. By GAP, we can increase rice yield of 21.75×10^5, 43.69×10^5, 65.51×10^5 and 87.36×10^5 tones by reducing 10, 20, 30 & 40 per cent from the existing yield gap of Bangladesh, respectively (Figure 5). The yield gap of rice is about 1.92 tha^{-1} and at least Tk. 556 billion could be earned from the additional production annually by narrowing 40 % the yield gap.

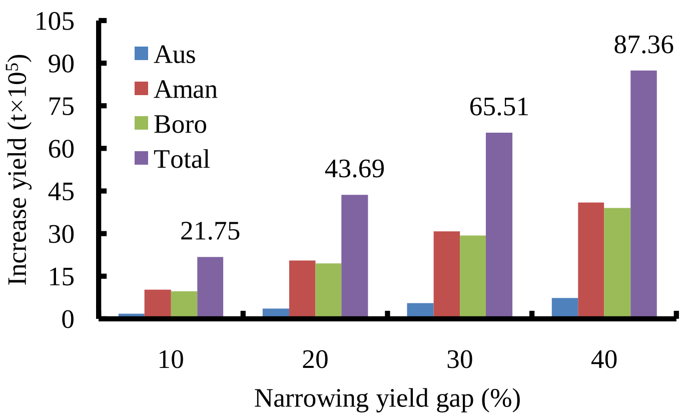

Figure 5. Influence of narrowing yield gap (%) on increase rice yield

Yield gap of rice is high in Asian countries because agricultural research system is not well equipped in terms of infrastructure and human resources to develop up to genetic yield potential achievable high yielding varieties in normal practice, sustainable production technology i.e. irrigation practice, land and weed management, pest and disease control system for an effective bridging of rice yield gap. Now-a-day, Asian countries are facing unexpected circumstances due to climate change in agricultural sectors. So, efforts should concentrate to develop well equipped laboratory facility with effective human resource to cope this problem.

CONCLUSIONS

Socio-economic circumstances of farmers remain a major challenge because rice farmers in Bangladesh are often resource constrained and do not have the organizational skills and know-how required for timely and proper implementation of improved technologies. It is also essential to promote collaboration among research, extension and private sector to develop appropriate technologies with a view to narrowing yield gaps. Socioeconomic and institutional factors are the driving force to improve adapted varieties, site specific nutrient management, locally adapted integrated weed management and optimized water management for good agricultural practices (GAP) to narrowing yield gap of rice.

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