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CONTRIBUTION OF GENOTYPE, ENVIRONMENT AND MANAGEMENT COMPONENTS ON RICE YIELD AND STRATEGY FOR YIELD ENHANCEMENT IN FALLOW-T. *AMAN* RICE-FALLOW CROPPING PATTERN

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Abstract

Genotype (G), environment (E) and management (M) form a triangular association in realizing grain yield of T. *Aman* rice. G expresses its yield potential when grown in right E under appropriate M. This study presents additive contribution of these three GEM components to grain yield of the crop. This study was undertaken to develop a GEM-based framework and use it in prioritizing strategic avenues for enhancement of rice in the Fallow-T. *Aman*-Fallow cropping system. Partitioning of grain yield of rice into G, E and M components was done following standard principle using 4491 research data-points from one decade's experiments (2010 to 2019) conducted by the Bangladesh Rice Research Institute. Results showed under the high yield potential varieties, G differences justified 29.5%, E 48.9% and M 21.6% variation in grain yield. The relative contribution of GEM components was not static across the years. As time advanced (from 2010), the contribution of G in explaining grain yield was found gradually reducing, whereas the contribution of E and M increasing. In the interrelationship between the three GEM components, the contribution of G was almost static and M was negative across E. The yield response specific to G, considering the two prominent rice varieties, BR11 and BRRI dhan49 was very narrow (4.60 to 4.68 t ha^{-1}), whereas E and M was much wider (3.53 t ha^{-1} respectively). Two varieties did not equally respond to all management. Furthermore, the grain yield from the same management responded differently to E (both location and year). While E and M are the triggering points for yield improvements in T. *Aman* rice, minimizing yield gap among the E by physical interventions is not a likely option. This study provides three pathways of linking M to yield improvements in T. *Aman* rice management in relation to genotype, location and growing season. Hence, it is concluded that for augmenting grain yield of T. *Aman* rice in the present circumstances, prioritizing M specific to G and E is the practical pathway.

Introduction

Potential yield (Y) of a rice variety is determined by its genetic ability. Improved genotype (G) suitable for target environment (E) is the prime requisite for higher productivity (Alam *et al.*, 2012). However, yield gap could still exist and productivity could become unstable if appropriate management (M) is not synchronized with G in specific environment. Management encompasses practices such as seedling age, planting time, spacing, irrigation, fertilization, pest control and others appropriate. Therefore, in realizing the yield potential of a variety in farmers' field, the contribution of E and M cannot be ignored (Anderson, 2010).

It is generally agreed that both breeding and agronomy have contributed to yield advances although the relative contribution of each have varied according to the crop species, variety and E (Fischer and Wall, 1976; Byerlee, 1994). In rainfed wheat, the yield improvement attributed to crop management was quantified as 47% in USA (Schmidt, 1984), 67% in Victoria, Australia (O'Brien, 1982), 68 to 71% in Western Australia (Perry and D'Antuono, 1989).

To enhance and sustain rice yield performance in a target system, such as Fallow-T. *Aman*-Fallow cropping system (TCS), existing composition of the three 'yield realizing drivers' needs to be estimated, so that the strategic pathways can be prioritized. There have been little studies either Bangladesh or elsewhere on partitioning and quantifying, the contribution of GEM on enhancing rice yield. The contribution of G under farmers existing management practices (FEMP) in the TCS will measure the robustness of the G in the system. Accordingly, the M would need to be designed as the instrument for yield improvement in the TCS.

Keeping the views in mind, this research explored estimation of the existing composition of GEM on rice yield variability and use this information to prioritize strategic avenues for yield enhancement in TCS.

Materials and Methods

This analysis accounted for rice yield variability in T. *Aman* season, as a component of TCS. The principle of partitioning grain yield to the three GEM components followed the works of Salam *et al.* (2017).

Data for the analysis

Altogether 4491 data-points, previously used for meta-analysis in a separate study was used. The data-points comprised of 69 G, 148 E and 38 M. Genotype included 43 high yield potential varieties (HYP) and 26 other variety types (aromatic, market demand and photosensitive varieties were 11, 4 and 11 respectively). Each E was a combination of a location (administrative district) and year of experimentation. Wade *et al.* (1999), Anderson (2010) and MacMillan and Gulden (2020) have also presented a similar definition of E. Each M included a combination of three managements such as i) transplanting time: very early (up to 14 July), early (15-29 July), mid (30 July-13 August), late (14-28 August) and very late (after 28 August); ii) seedling age: younger (≤ 30 days), middle (31-40 days), older (41-50 days) and very older (> 50 days) and iii) hill density (number of hills m^{-2}): standard (≤ 3), high (4-5) and very high (> 5).

Estimation of partitioning grain yield variability between the three GEM components

The contribution of GEM components was estimated using the following equations:

$$\text{G (\% contribution)} = \frac{\text{G. var.}}{\text{Total var.}} \times 100$$

$$\text{E (\% contribution)} = \frac{\text{E. var.}}{\text{Total var.}} \times 100$$

$$\text{M (\% contribution)} = \frac{\text{M. var.}}{\text{Total var.}} \times 100$$

Where, G. var. = Genetic variance, E. var. = Environmental variance and M. var. = Management variance for respective number of data-points; Total var. = Total variance is the sum of G. var., E. var. and M. var. Variance was calculated using 'VAR' function of MS-Excel (2016).

Overall relative contribution of the three GEM components was estimated for 69 G, 148 E and 38 M using 4491 data-points; and for HYP varieties, 43 G, 145 E and 36 M using 3870 data-points.

Estimation of annual changes, periodic sensitivity and interrelations in HYPs of the three GEM components

Using the data of HYPs, the periodic sensitivity of the three GEM components was estimated for 10 years (2010 to 2019). For this, G. var., E. var. and M. var. were estimated for individual years of experimentation. The sample size for each set (GEM component × Year) was as follows (Table 1).

Table 1. The sample size for each set (GEM component × Year)

Year of experimentation	GEM component		
	G	E	M
2010	23	9	15
2011	23	16	16
2012	24	19	20
2013	21	27	24
2014	15	10	14
2015	29	24	23
2016	33	12	24
2017	32	8	17
2018	37	14	14
2019	36	6	20

For individual years, relative contribution of GEM components was estimated following the equations. The linear trend of the periodic sensitivity of the three GEM components was calculated with the above data through estimated intercept and slope of linear regression equation for respective G, E and M. The level of probability of the liner trends across the 10 years was calculated for each trend. The interrelationships between the three GEM components were estimated using the above data (year-by-year contribution of GEM components). For this, data on contribution of G and M were regressed separately over E. The level of probability was calculated for each regression line. All the calculation were performed in MS-Excel using respective functions.

Development of GEM-based framework for enhancing yield of T. *Aman* rice

For enhancing the yield of T. *Aman* rice in the TCS, the assumption was consideration of the HYP genotypes to be the ideal first option. Accordingly, the state of performance of two varieties, BR11 and BRRI dhan49 were considered. Rice var. BR11, released in 1980, is one of the most visible mega-varieties of T. *Aman* rice that Bangladesh ever produced. To replace the variety with a newer one, BRRI dhan49 was released in 2008.

Six locations (Cumilla, Gazipur, Kushtia, Rajshahi, Rangpur and Satkhira) of three years' data for rice var. BR11 and/or BRRI dhan49 were considered for this analysis. The available data provided 39 combinations of E, and 24 combinations of M within the Es. Including 2 G, total available data-points were 273, out of probable 1872 data-points (2 G × 39 E × 24 M). It may be noted that all the matrices (2 G × 39 E × 24 M) were not available according to selection criteria. The 39 Es were- E1: 2010 Cumilla, E2: 2010 Rajshahi, E3: 2011 Cumilla, E4: 2011 Gazipur, E5: 2011 Kushtia, E6: 2011 Rajshahi, E7: 2012 Cumilla, E8: 2012 Gazipur, E9: 2012 Kushtia, E10: 2012 Rajshahi, E11: 2012 Rangpur, E12: 2012 Satkhira, E13: 2013 Gazipur, E14: 2013 Kushtia, E15: 2013 Rajshahi, E16: 2014 Gazipur, E17: 2014 Kushtia, E18: 2014 Satkhira, E19: 2015 Cumilla, E20: 2015 Gazipur, E21: 2015 Rajshahi, E22: 2015 Rangpur, E23: 2015 Satkhira, E24: 2016 Cumilla, E25: 2016 Gazipur, E26: 2016 Kushtia, E27: 2016 Satkhira, E28: 2017 Cumilla, E29: 2017 Gazipur, E30: 2017 Kushtia, E31: 2017 Rajshahi, E32: 2017 Satkhira, E33: 2018 Cumilla, E34: 2018 Kushtia, E35: 2018 Rajshahi, E36: 2018 Rangpur, E37: 2018 Satkhira, E38: 2019 Gazipur and E39: 2019 Satkhira.

The 24 Ms were- M1: very early younger standard, M2: very early younger high, M3: very early middle high, M4: early younger standard, M5: early younger high, M6: early younger very high, M7: early middle standard, M8: early middle high, M9: early middle very high, M10: mid younger standard, M11: mid younger high, M12: mid younger very high, M13: mid middle standard, M14: mid middle high, M15: mid older standard, M16: late younger standard, M17: late younger high, M18: late younger very high, M19: late middle standard, M20: late middle high, M21: late older standard, M22: very late younger standard, M23: very late younger high, M24: very late older high.

The distribution of grain yield was presented in four steps: (i) across all 273 data-points (ii) 2 G, (iii) 39 Es and 24 Ms. Further, mapping of grain yield in the matrix of G (2 varieties) × E (39 environments) × M (24 management combinations) was done in MS-Excel. The grain yield difference between BR11 and BRRI dhan49 was calculated under 24 scenarios of M by subtracting the yields between the two varieties. The grain yield variation in the two varieties was measured as standard deviation for the 6 locations and 10 years of experimentation within each of 24 management combinations.

Results and Discussion

Partitioning grain yield variability between genotype, environment and management

The partitioning of grain yield variability between GEM components has been presented in the light of meta-data which accounted for diverse genotype, environment (both location and year) and chosen management. Farmers' survey data were not used as it accounted for only one specific location and year. Experimental data purposively included varieties having wide range of yield potential; therefore, this data is biased to genotype component of GEM and thus not included in this analysis.

Genotype, environment and management across all varieties

Figure 1 shows that, G explained the highest of 50.7% of the total variation in grain yield; whereas the proportion of E was 31.6% and that of M was lower (17.7%).

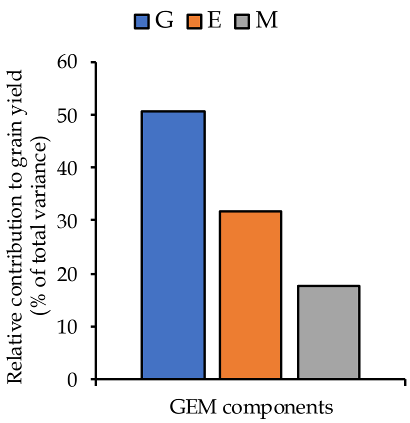

Fig.1. Relative contribution of the GEM components (genotype, environment and management) in explaining grain yield variation of T. *Aman* rice. The data included all variety category.

A recent G × E-interaction study (Akter *et al.*, 2019), shows the attribution of G and E to grain yield of rice as 54.86 and 36.31%, respectively. The findings of the present study are not unexpected, because the experiments were conducted under the scenarios of wide range of genotypes, over 69 local and high yielding types, having varied yield potential. The wider the genetic potential exists, the larger would be the relative share of G in the GEM components in achieving yield. Conversely, smaller yield variations between genotypes could reduce contribution of G to grain yield as evident from the G × E-interaction study of Wade *et al.* (1999) and Bashir *et al.* (2016). The scenario of larger contribution of G to GEM is comparable to an under-developed region where farmers have been predominantly using low yielding local varieties and development program initiated with demonstrating the potential of high yielding varieties.

Genotype, environment and management across high yield potential varieties

Under the variety category of HYP compared to whole data, the relative contribution of G to grain yield variation greatly reduced and that of E highly increased (Fig. 2). Genotypic differences justified 29.5%, whereas the proportion of E in explaining variation of yield performance was 48.9%. The contribution of M was lower (21.6%) than the other two GEM components.

Using hybrid rice varieties in the G × E interaction study, Bashir *et al.* (2016) estimated sole contribution of G and E as 1.03 and 93.8%, respectively, to grain yield. In the similar type of interaction study with rainfed lowland rice varieties, Wade *et al.* (1999) estimated the sole contribution of G and E as 5 and 63%, respectively, to grain yield. It thus appears that the yield enhancement strategy for modern-day agriculture such as for T. *Aman* rice in the cropping system would need due consideration of E and M components of GEM.

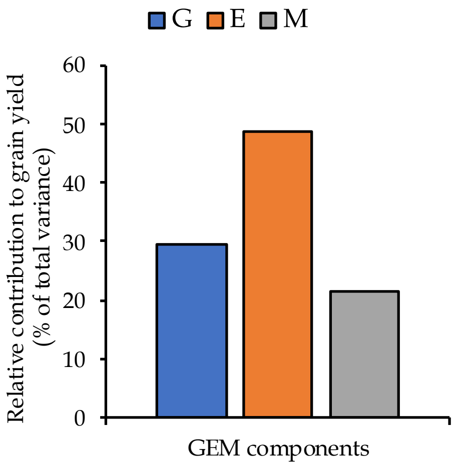

Fig. 2. Relative contribution of the three GEM components (genotype, environment and management) in explaining grain yield variation of T. *Aman* rice. The data included only high yield potential category.

Annual changes in the relative contribution of genotype, environment and management components across high yield potential varieties

The relative contribution of GEM components as revealed in the Fig. 1 was not static across the years (Fig. 3). For example, G explained 47.96% yield variation, followed by E of 31.5% and M of 19.6% in 2010. In 2019, the explained yield variation attributed to the three GEM components was very similar (G = 30.6%, E = 33.4% and M = 36.0%). On the contrary in 2017, M explained the absolute major proportion of yield variation (71.4%), have small contribution of G (12.0%) and E (16.36%). In 2018, the contribution of E justified the major yield variation (63.0%), where G contributed to 23.7% and M to 13.3%.

As time advanced (from 2010), the relative contribution of G in explaining grain yield was found gradually reducing, whereas the contribution of E and M increasing (Fig. 4). Quantitatively, the rate of reduction in G component to grain yield variation was 2.11% year^{-1}

(P = 0.05), and increase in E and M components was 1.14 (P = 0.25) and 0.96% (P = 0.33) year^{-1}, respectively.

This can be explained in two angels. Firstly, genetic yield potential of T. *Aman* rice varieties may not be increasing, and/or may have become narrowed between evolving varieties. This has reflected in T. *Aman* rice varieties released by the Bangladesh Rice Research Institute (BRRI). The yield potential of the BRRI released T. *Aman* rice varieties has not exceeded since BR11 (6.0 t ha^{-1}) was released in 1980 except for BRRI dhan87 (6.5 t ha^{-1}) which was released in 2018 (BRRI, 2020b). Secondly, grain yield variation due to E and/or M has increased. Analyses of BRRI shows that the 'stability index' of T. *Aman* rice varieties, accounting for various locations and seasons, has not been constant, rather fluctuating during 2001 to 2020 (BRRI, 2021). This study has provided an indication that the contribution of E in GEM components has been increasing numerically at an estimated rate of 1.14% year^{-1} (P = 0.25). This reveals that the yield performance of T. *Aman* rice across the Es is widening. The pattern of contribution of M in the GEM components has been observed similar to E, but in a lower scale (increasing at an estimated rate of 0.97% year^{-1}, P = 0.33). This reveals that all Ms are not resulting in similar yield performance of T. *Aman* rice across Gs and Es. As observed by Khatun *et al.* (2002), the relative effect of seedling age did not similarly respond to rice yield between two Es (considering 'season' as environment); it was more pronounced in *Boro* than T. *Aman* season with the variety BR3. In Nepal, Shah and Yadav (2001) did not observe the highest yield in varieties with same transplanting time, seedling age and season (year of experimentation). In their findings, all varieties yielded better in 1999-2000 than 1998-1999, but in one variety received the highest yield by transplanting 25-day-old seedlings on 7 August, whereas the highest yields in four varieties achieved by transplanting 50-day-old seedlings on 14 July.

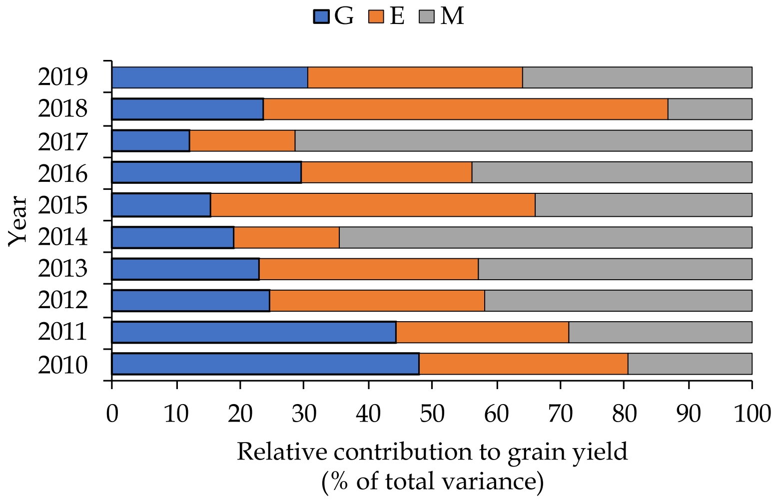

Fig. 3. Relative contribution of the three GEM components-genotype, environment and management - in explaining grain yield variation of T. *Aman* rice. The data included only high yield potential category across 10 years (2010–2019).

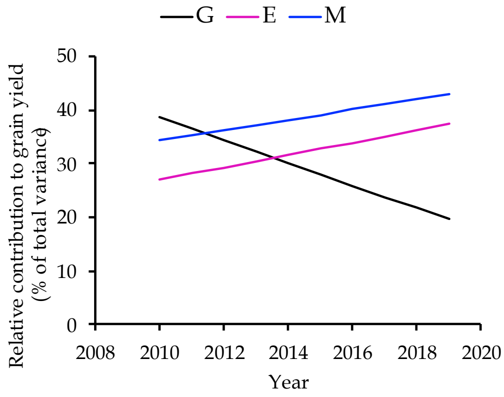

Fig. 4. The trend in the relative contribution of the three GEM components-genotype, environment and management, in explaining grain yield variation of T. *Aman* rice during 10 years. The data included only high yield potential category across 10 years (2010–2019).

Interrelationship between genotype, environment and management components across HYP varieties

Interrelationship between the three GEM components, presented in Fig. 5, shows that across the range of the contribution of E (16.2 to 63.0%), the contribution of G was almost static ($r = -0.05$, $P = 0.45$). On the other hand, the relative contribution of E and M was significantly negative ($r = -0.76$, $P = 0.01$). Results further reveal that the relative contribution of G and M in explaining the grain yield was significantly negative as well ($r = -0.61$, $P = 0.03$).

As observed in national statistics, comparing three districts (Khulna, Rajshahi and Rangpur), it reveals that the yield variation (expressed as standard deviation) between them was narrow (0.01 t ha^{-1}) during 1995-1996 to 1999-2000 period. In the next 5-year period, it widened to 0.12 t ha^{-1} and went further (0.15 t ha^{-1}) in the following 5-year period (compiled using BBS, 2018).

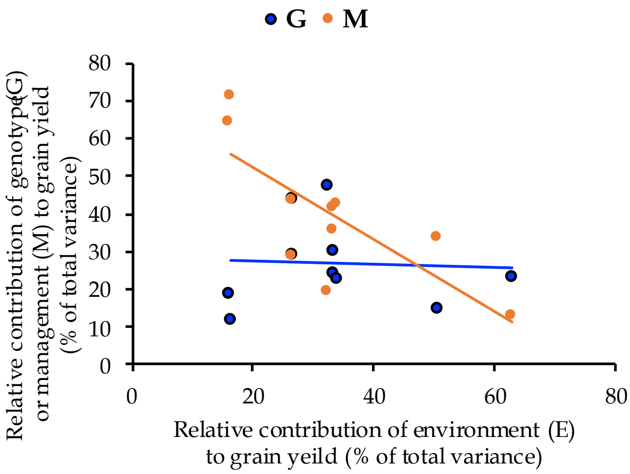

Fig. 5. The interrelationships between the three GEM components with respect to relative contribution in explaining grain yield variation of T. *Aman* rice.

Genotype, environment and management components for two selected high yield potential T. *Aman* rice varieties – Yield spread

For enhancing the yield of T. *Aman* rice, theoretically, consideration of the HYP Gs to be the ideal first option. This study undertook further analysis to layout reality-based pathways for enhancing grain yield of T. *Aman* rice. For this investigation, the performance levels of the varieties BR11 and BRRI dhan49 were taken into account. Results presented in Fig. 6 indicates yield achieved with the two varieties in 273 scenarios (data-points, G × E × M) in the range of 1.00 to 6.90 t ha^{-1}. However, the yield response specific to G was very narrow (4.60 to 4.68 t ha^{-1}) (Fig. 6). The yield response specific to E was much wider than G, in the range of 3.53 to 5.74 t ha^{-1} (Fig. 6), and to M was also wider, in the range of 2.87 to 6.58 t ha^{-1} (Fig. 6).

The analysis indicates that G contributed moderately to grain yield variation (29.5%, Fig. 2); in addition, the contribution of G had been steadily decreasing in the last decade, 2010–2019 (Fig. 4). Reality could be different in rightly attributing G as the driving yield-enhancing component of GEM. Findings clearly reveal that E and M components of GEM are the two reality-based pathways of increasing grain yield of T. *Aman* rice at the current situation in Bangladesh.

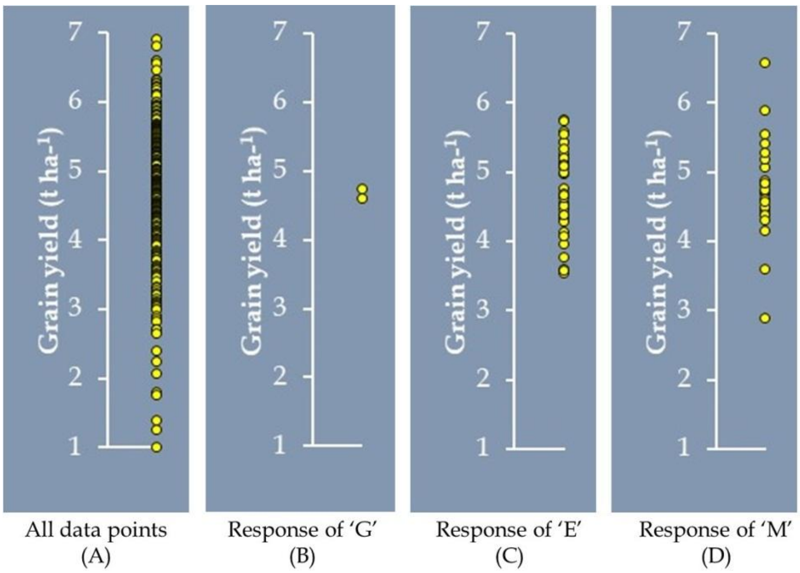

Fig. 6. Yield spread of two T. *Aman* rice varieties across the dataset and the three GEM components.

Genotype, environment and management components for two selected high yield potential T. *Aman* rice varieties – Yield mapping

Various combinations of E and M largely resulted in similar yield gradient as shown in Fig. 7. For example, EM combinations E3M4, E10M18 and E36M24 produced the highest yield gradient (4th quarter (>=75%) in the yield range of Fig. 7) for G, whereas EM combinations E12M2, E27M2 and E37M19 found the second highest yield gradient (3rd quarter (>=50% to <75%) in the yield range of Fig. 7) for G. On the other hand, EM combinations E5M11, E7M13 and E25M10 showed the second lowest yield gradient (2nd quarter (>=25% to <50%) in the yield range of Fig. 7) for G. The same results indicate that, for example, E3, E10 and E36 produced the highest yield gradient, whereas E12, E27 and E37 had the second highest yield gradient. Furthermore, E5, E7 and E25 showed the second lowest yield gradient. With respect to M, for example, M4, M18 and M24 produced the highest yield gradient, whereas M2 and M19 had the second highest yield gradient. The second lowest yield gradient was achieved M10, M11 and M13.

This study undertook detailed analysis on GEM considering two high yield potential T. *Aman* varieties BR11 and BRRI dhan49. BR11 is one of the extensively adopted varieties that BRRI ever released. BRRI dhan49 has shorter growth duration by 7 days compared to BR11; though slightly low yielder than BR11 (potentially, by 0.5 t ha^{-1}), it has finer quality grains (Nizershail type) (BRRI, 2020a), and thus considered to be a good potential for wider adoption (BRRI, 2020). The varieties (designated as G) provided a narrow difference in averaged grain yield (BR11 = 4.72 t ha^{-1}; BRRI dhan49 = 4.60 t ha^{-1}) across 39 Es (designated as E-combination of location and growing season) and 24 M combinations (designated as M), whereas the differences attributed to E (3.53-5.74 t ha^{-1}, SD = 0.63 t ha^{-1}) and M (2.87-6.58 t ha^{-1}; SD = 0.73 t ha^{-1}) were much wider. As also revealed in the findings that while E explained wide range of grain yield variation (16.2 to 63.0%), the influence of G remained the same (Fig. 5). Results re-emphasis that for yield improvements in T. *Aman* rice, the scope of engaging G is limited, whereas E and M is wider.

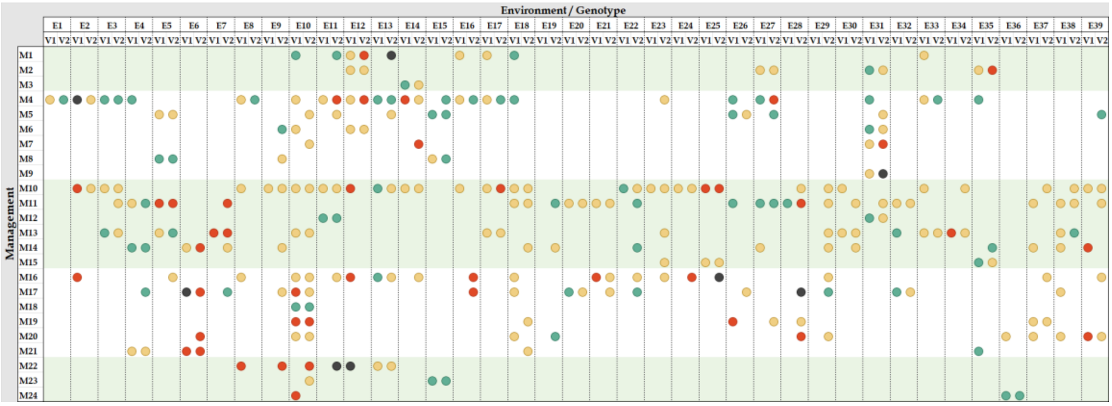

Fig. 7. Mapping of T. *Aman* yield gradient of two varieties (G, BR11 (V1) and BRRI dhan49 (V2)) across 39 environments (E, E1-E39) and 24 managements (M, M1-M24). The notations of 39 environments and 24 management combinations have been referred in materials and methods section. Green, yellow, red and black solid circles indicate, respectively, the highest yield gradient (4th quarter, >=75% in the yield range), the second highest yield gradient (3rd quarter, >=50% to <75% in the yield range), the second lowest yield gradient (2nd quarter, >=25% to <50% in the yield range) and lowest yield gradient (1st quarter, <25% in the yield range).

Grain yield difference between two selected T. *Aman* rice varieties under different management combinations

Two varieties did not equally respond to all management combinations (Fig. 8). For example, BR11 better performed than BRRI dhan49 under M9, M3, M12, M23, M1, M8, M2, M5, M21, M20 and M4. On the other hand, BRRI dhan49 showed better yield response than BR11 under M24, M19, M22 and M6. The managements M7, M10, M11, M13, M14, M15, M16, M17 and M18 were almost equally responsive to both the varieties.

This study provides three pathways of linking M to yield improvements in T. *Aman* rice. Here, M in relation to G. This study clearly shows that the same M did not produce similar grain yield between Gs. The same is also evident from other studies. For example, Roy *et al.* (2003) reported that not all the seven rice varieties responded to respective highest yield to any of the seven transplanting dates undertaken in that study. An experiment with seven T. *Aman* varieties under three transplanting dates (TD), observed that statistically highest yield was achieved in three TD by three varieties, in TD_2 and TD_3 by one variety, only in TD_2 by two varieties, and only in TD_1 by one variety. Therefore, actions to be find out variety-specific management.

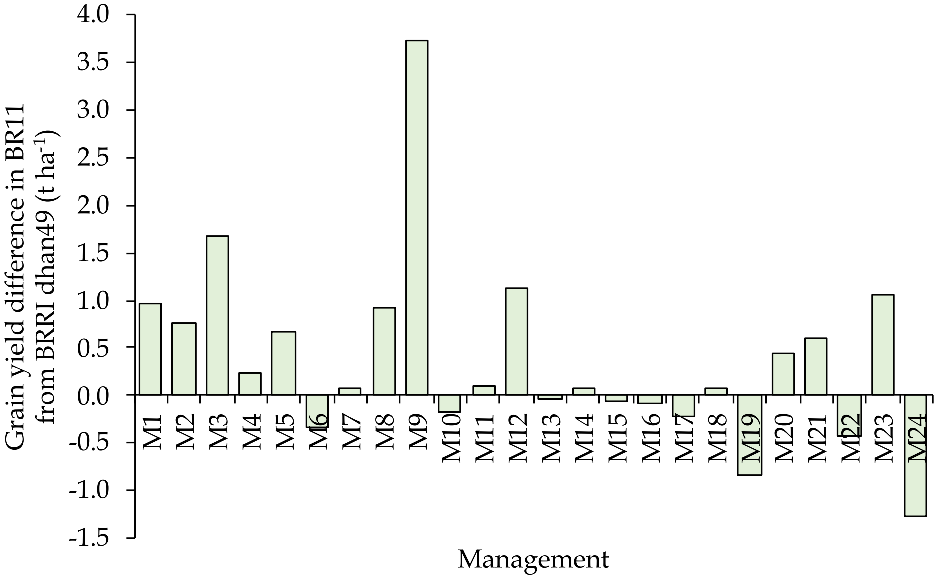

Fig. 8. Grain yield difference in BR11 from BRRI dhan49 under 24 management combinations. 'M' denotes for management combination accounting for transplanting time, seedling age and hill density. The notations of 24 management combinations (M1-M24) have been referred in materials and methods section.

Grain yield variability across locations and years within each management combination

The grain yield from the same M responded differently to both location and year (Fig. 9). This variation, measured as standard deviation (SD), was not similar across the 24 Ms. For example, with respect to location, there was higher SD of 2.20 (t ha^{-1}) with M24, 1.36 (t ha^{-1}) with M12, 1.33 (t ha^{-1}) with M1 and 1.00 (t ha^{-1}) with M8; whereas lower SD of 0.44 (t ha^{-1}) with M17, 0.43 (t ha^{-1}) with M14 and 0.26 (t ha^{-1}) with M6. For example, with respect to year, there was higher SD of 2.20 (t ha^{-1}) with M24, 1.17 (t ha^{-1}) with M22, 1.12 (t ha^{-1}) with M12 and 1.10 (t ha^{-1}) with M2; whereas lower SD of 0.43 (t ha^{-1}) with M10, 0.35 (t ha^{-1}) with M5 and 0.15 (t ha^{-1}) with M18.

Here M in relation to location, this study further indicates that one M does not produce the same grain yield in different locations. Other studies agree with the present observation. For example, using the same level of nitrogen, phosphorus and potassium fertilizer, Mamun *et al.* (2017) observed a yield variation in six locations within Madaripur district with BRRI dhan29 in the range of 4.84-7.08 t ha^{-1}, within Faridpur district with BRRI dhan28 in the range of 6.23-7.15 t ha^{-1} and within Gopalganj district with BRRI dhan28 in the range of 6.63-7.31 t ha^{-1}. Therefore, actions to be find out location-specific M (location-induced management). Thirdly, M in relation to growing season. This study further reveals instability in grain yield due to year-to-year seasonal variability. For example, Hossain *et al.* (2020) recorded significant yield variation (4.22-4.72 t ha^{-1}) in T. *Aman* rice var. BRRI dhan33 between the four years of experimentation (2010, 2011, 2012 and 2013). In a similar type of experiment, Deb *et al.* (2012) observed yield variation between 4.81 and 7.20 t ha^{-1} in lowland rice during 2006, 2007, 2008 and 2009 using the same seedling age (14-day old) and var. Shiuli. Therefore, management options could be worked out towards stabilizing varietal grain yield between growing seasons.

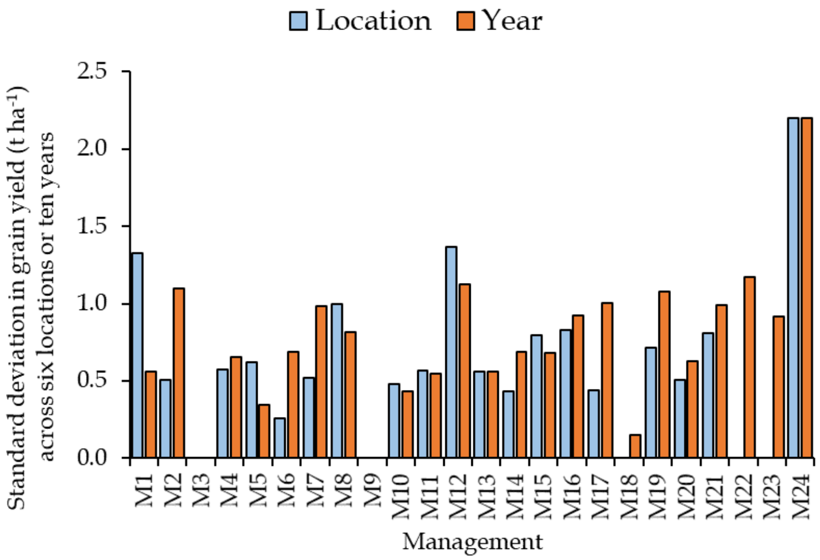

Fig. 9. Grain yield difference, measured as standard deviation, across six locations, and 10 years under 24 management combinations. 'M' denotes for management combination accounting for transplanting window, seedling age and hill density. The notations of 24 management combinations (M1-M24) have been referred in materials and methods section.

Conclusion

By analyzing the grain yield attribution during the decade of 2010-2019, particularly on the performance of prominent variety, BR11 and BRRI dhan49, it indicates that for yield improvements in T. *Aman* rice, the scope of engaging G is limited, whereas E and M is wider. However, physical interventions for improving E as such is not a likely option. It is then concluded that under the present scenarios of variety options and environmental diversities, crop management synchronized with G and E would be the practical pathway of enhancing grain yield of T. *Aman* rice.

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