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‘B-M MODEL’ FOR FARMERS’ KNOWLEDGE MANAGEMENT IN INCREASING RICE PRODUCTION

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Abstract: Quantifying knowledge on agriculture can have many benefits to stakeholders. While many knowledge-based systems exist in modern days for farmers’ decision support, specific models are lacking on how knowledge traits can impact on agricultural production systems. This study employed modelling technique, supported by field data, to provide a clear understanding and quantifying how knowledge management in production practices can contribute to rice productivity in the environmentally stressed southwest Bangladesh. This research accounted for ‘Boro’ rice as the target crop and ‘BRRI dhan28’ as the test variety. The ‘B-M Model’ was developed following the principle and procedure from published literature, ‘brainstorming’ and data from field surveys. Three knowledge management traits (KMT) were defined and quantified as the inputs of the model. Those are: self-experience and observation (SEO), extension advisory services (EAS) and accessed information sources (AIS). The yield influencing process (YIP), the intermediate state variable of the model, was deduced by accounting for the two dominant agronomic practices, seedling age for transplanting and triple superphosphate (TSP) application. ‘Knowledge drives farmers’ practice change which in turn influences yield’ was composed as the theoretical framework of the ‘B-M Model’. The model performed strongly against an independently collected field data set. Across the 180 farmers’ data, the average relative rice yield (RRY) predicted by the model (0.705) and observed in the field (0.716) was close (root mean squared deviation (RMSD) = 0.018). The difference between predicted and observed RRY was not statistically different (LSD = 0.03), indicating the model fully captured the field data. A regression of predicted and observed RRY explained 96% variance in observation, further proving the model’s strength in estimating RRY in a wider range of farmers’ rice yield. In a normative analysis, the practicality and usefulness of the model to stakeholders were simulated for the understanding of how much achievable yield could be expected by changing farmers’ knowledge pool (the sum of three KMT) on rice production practices, and at what combination(s) of KMT to be considered at strategic hierarchy to materialize a targeted achievable yield. To the best of the knowledge, a model quantifying rice yield in relation to knowledge management trait does not exist in literature. Upon successful testing under diverse yield scenarios using multiple and sophisticated statistical tools that enhanced the credibility of the model, it is concluded that the model has the potential to be used for identifying quantitative pathways of farmers’ knowledge acquisition for practice change leading to improved productivity of rice in the southwest region of Bangladesh.

Keywords: B-M Model, Knowledge, Trait, Pool

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Introduction

Rice is the staple food of 165 million Bangladeshis. Rice production in the country has increased three-fold since 1971, the time of her independence. The country will, however, need more food to feed the increasing population. A model-estimate, presented by (Kabir *et al*., 2015), showed that the current population (162.2 million) would reach 215.4 million in 2050. This will significantly affect the volume of the requirement of rice. For example, taking 2014 as baseline, the demand for clean rice in 2050 will go up by 27%. The supply of rice production in Bangladesh would on the other hand be severely challenged by a number of constraints. These include decreasing land, scarcity of agricultural labour, deteriorating soil health, scarcity of water, and increasing climate vulnerability with the events of drought, salinity, flood, heat and cold. This will adversely affect the rice production of the country. In order to bring more productivity to contribute to national food security, the government has prioritized the development and improvement of farming systems by growing 'Boro' rice in the southwest region of Bangladesh in winter; this will also reduce pressure from the declining groundwater table in the northern region (CSISA, 2010).

'Boro' rice production in southwest Bangladesh, like any other region, has two dimensions, horizontal and vertical. The horizontal dimension has two wings, cropping area and cropping intensity. The country as a whole has limited scope for a production increase from both the wings of the horizontal dimension. The net cropped area of the country is now standing as 7.81 million ha, which is likely go down to 6.87 million ha in 2050, if the current rate of decrease continues (Kabir *et al*., 2015). This means Bangladesh will be expecting less land for more production. On the other hand, cropping intensity which is currently standing at 194% can reach to a maximum of 221 around 2050 (estimated by Kabir *et al*., 2015). All these glim pictures point out that the required rice production increase will have to be realized vertically through yield increase.

Salam *et al*. (2016, 2017) put forward that the classic equation of yield is 'G' by 'E', where 'G' is the genotype or a variety of a crop, and 'E' is the environment on which the variety is set to express its potential. In recent years, the 'E' component has been segregated to 'E' by 'M', where 'M' is management. This segregation has been necessary because the whole atmosphere of the environment (E) is changed due to management (M); this change could be good or bad. Through good management, a farmer can achieve the increased yield, while the yield could be poor due to poor management. Good management requires a good knowledge of the technology and its use. This explains the existence of the yield gap between the farmers within a geographical location (Evenson *et al*., 1996). Kabir *et al*. (2015) have calculated the yield gap of clean rice in Bangladesh as 0.83 t ha^{-1}, and quantitatively shown how incrementally reducing this gap could immensely contribute to increased future rice production of this country (Alam and Hossain, 1998; Duwayri *et al*., 2000; Mondal, 2011). Salam *et al*. (2016) have stated that management is 'synonymous to agronomic practices'. Therefore, (agronomic) practice change can lead to changes in the yield of 'Boro' rice in southwest Bangladesh.

Knowledge is interpreted as a "sum of relationships that farmers create in their minds from available information, their experience, their feelings and their ideas" (Ferreira, 2002). Generated information through various sources becomes knowledge when farmers integrate those with what they already know (Dhewa, 2017). Innovative agronomic practices that either stem from the scientific community or farmers' informal engagement through the 'trial and error' method or any other sources, can drive

'Boro' rice yield. The application of acquired 'knowledge' on those innovations can contribute to improve such yield under farmers' circumstances. Velden (2002) argues that limited access of rice farmers to appropriate knowledge is a critical concern to achieve higher production.

Stakeholders can receive many benefits from quantified knowledge on agriculture. Numerous knowledge-based systems exist in modern days for farmers' decision support. However, specific models on how knowledge traits can impact on agricultural production systems are limited. To the best of our knowledge, a model predicting rice yield variability through quantified knowledge attributes does not exist for Bangladesh. Potentially, the model can be used as a decision-making tool to guide various stakeholders to identify which knowledge attribute(s) of farmers and to what level those attributes are needed to reach a maximum rice yield in a locality.

Objectives and Methodology

Objectives

This study aimed to build a framework in order to understand which knowledge attributes and in what quantity of the attributes influence the rice yield to what degree. The research targeted the two specific objectives: (i) To develop a model to predict changes in 'Boro' rice yield based on farmers' knowledge attributes; and (ii) To validate the model with farmers' yield changes in Boro' rice under different knowledge attributes.

Study Area

This study, for the model development and its validation, represented the southwest region of Bangladesh which is a part of the coastal region. It accounts for two administrative districts - Khulna and Satkhira (figure 1). These two districts cover an area of 8,253 km^2, where 4.27 million people live in 1.02 million households (BBS, 2011). The challenges to agricultural productivity in the region include salinity, flooding, cyclonic storm and tidal surge throughout the year (Mondal *et al*., 2006). In both the districts, farmers have been traditionally cultivating 'Boro' rice; however, the yield is low compared to the national average (4.65 t ha^{-1}) which is recorded as 3.35 t ha-1 and 3.75 t ha^{-1}, respectively (BBS, 2016).

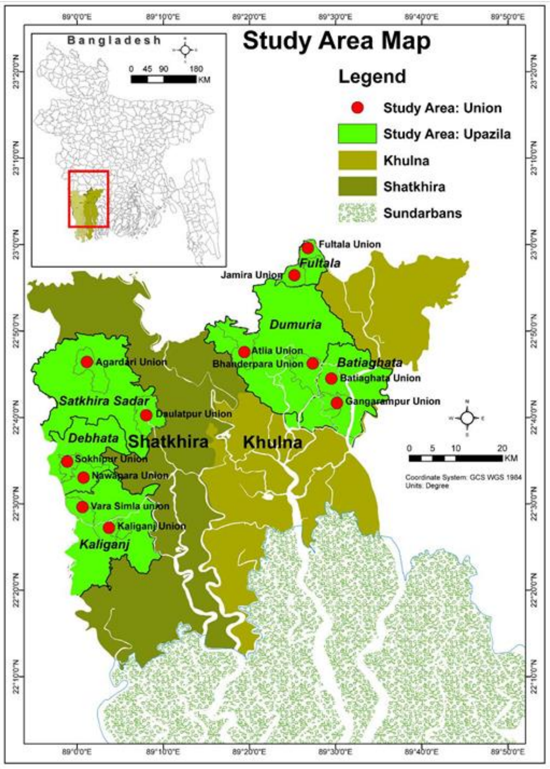

Figure 1. Map of study area showing specific study locations in Khulna and Satkhira districts of southwest Bangladesh.

Data for Model Development and Validation

'Boro' rice was taken as the target crop as it is getting interest in the farmers in the study area in the last two decades (BBS, 2015). The chosen variety was 'BRRI dhan28'. Country-wide, this variety is dominant for 'Boro' rice by area (BBS, 2015). The significant presence of the variety has been reported in the southern region of Bangladesh (16-Hossain *et al*., 2012).

Data for model development were collected from 180 respondents, equally (90 each) from Khulna and Satkhira districts. In each district, three (3) Upazila (sub-district) were purposively selected; in those Upazilas farmers had been widely cultivating 'Boro' rice since the early 2000s. Two (2) unions (the lowest administrative tiers) and one village from each union were randomly selected from each sampled Upazila. Finally, 15 'Boro' rice farmers from each of the villages were randomly selected. The same sample size, but a different set of farmers', was taken for model validation. In both the cases (model development and validation) sampled farmers' demographic and socio-economic status were similar.

Collected data included agronomic practices impacting 'Boro' rice yield: variety, seedling age at transplanting, transplanting method, type and quantity of fertilizer use, insect and disease management practices and yield; and acquisition of knowledge on agronomic practices – source and frequency.

For data collection, interviews were conducted using a semi-structured questionnaire from June to August of 2016, which captured data related to the above-stated key variables for the current time period. This period was designated as 'Period-2'. During the interview, recalled data were also gathered on agronomic practices impacting 'Boro' rice yield. Those recalled data represented the scenarios of

'Boro' rice yield and agronomic practices in the study area a decade ago. This period was designated as 'Period-1'. These two time periods were considered to measure the changes in 'Boro' rice productivity and agronomic practices in the study area.

On farmers' knowledge issue, three pathways of knowledge acquisition, termed as 'knowledge management trait (KMT)' were considered. They are (i) self-experience and observation (SEO), (ii) extension advisory services (EAS) and (iii) accessed information sources (AIS). The SEO accounted for agricultural knowledge gained by the farmers through self-observation of practices within and outside their own households. It also includes their own experiences in farming. The SEO may broadly be synonymous with farmers' 'indigenous knowledge' on their production system (Rogers, 1995). The EAS represented the agricultural knowledge gained from change agents; in this case, agricultural extension service workers, both public and private. The AIS included sources of agricultural information through involving knowledge-sharing-networks, such as farmer groups, fairs, markets, relatives, friends, neighbours, and social networks. AIS also accounted for information from media channels such as newspaper, radio and television, and information, education and communication (IEC) materials from entities (eg. government, private and development organizations). The focus group discussion (FGD) technique (Chambers, 1994) was used to select and define the three KMT.

Development of 'B-M Model'

The model hypothesized that knowledge is the transformer of farm productivity. Accordingly, the statement of the model was drawn as: "Knowledge drives farmers' practice change that in turn, influences yield". The 'B-M Model' was named after its two innovators, Bidyuth K. Mahalder, the development practitioner and Moin Us Salam, a reputed agricultural scientist and modeller. The principle and procedure of the development of the model was followed according to Salam (1992) and Jones *et al*. (2010).

Blueprint of the model

The blueprint of the 'B-M Model', showing the flow of inputs translated into the output, is presented in figure 2. Three KMT – SEO, EAS and AIS - are the inputs of the model. The 'farmers' knowledge pool' (FKP) is the pool of the sum of SEO, EAS and AIS. The FKP directly impacts on 'yield influencing process' (YIP). YIP is the combined effect of all attributes (or agronomic practices) relating yield of a crop. Examples of such attributes are tillage operation, transplanting method, rice seedling age at transplanting, time of transplanting, type and time of weeding operations, fertilizer type and dose, type and time of insect-pest management and harvesting time. In the 'B-M Model', YIP quantifies the relative rice yield (RRY), which is the fraction of achievable yield in the agro-ecological region under consideration, is the output of the model.

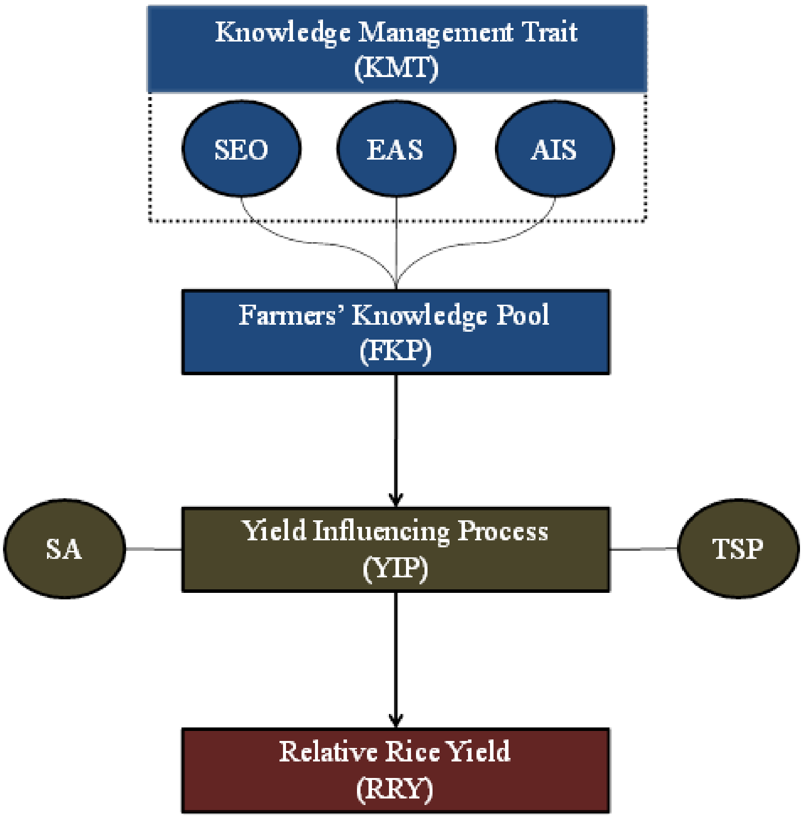

Figure 2. The blueprint of the 'B-M Model' showing the flow of inputs translated into the output. SEO is self-experience and observation, EAS is extension advisory services, AIS is accessed information sources, SA is seedling age and TSP is denoted for triple superphosphate

Algorithms and parameter estimation

Quantification of knowledge management trait and farmers' knowledge pool

Three KMT were quantified as 'Score Point'. This quantification was done through FGD exercise. For this, farmers, firstly, were asked to make a list of all information sources available to them. The maximum and minimum 'Score Point' for each KMT was determined based on the majority opinion of the FGD participants. The 'Score Point' for three KMT were given an equal weight based on discussion with the participants. Similar scoring of quantifying farmers' knowledge level on agricultural production and practices was also used by Sulaiman (1989), Bonny (1991), Shushma (1993), Jaganathan *et al*. (2012) and Sakib *et al*. (2014). The 'Score Point' for SEO ranged from 10 to 40, and for EAS and AIS from 0 to 30. The minimum 'Score Point' for SEO was not considered as '0' because farmers possessed at least some inherent self-experience attribute on farming practices. Farmers' knowledge pool (FKM) was calculated as: SEO + EAS + AIS, where the value ranged from 10 to 100.

Quantification of yield influencing process

The yield influencing process (YIP) was calculated as: YIP (SA) + YIP (TSP), where, YIP (SA) is the response of seedling age (SA) to achievable relative rice yield (RRY), and YIP (TSP) is the response triple superphosphate (TSP) to achievable relative rice yield (RRY). The values of YIP (SA) and YIP

(TSP) were derived through respective response curves developed using collected data for figure 3 and 4.

In this modelling, other yield influencing factors, such as transplanting time, planting method, application of the dominant plant nutrient (urea) etc., were not considered as changes on those factors were not significant during the two time period. It appears that the framers had gained the knowledge of those improved production practices a long time ago. The variability in YIP (SA) and YIP (TSP) indicates that a significant number of farmers still were not fully aware of the appropriateness of seedling age and level of triple superphosphate for 'BRRI dhan28'.

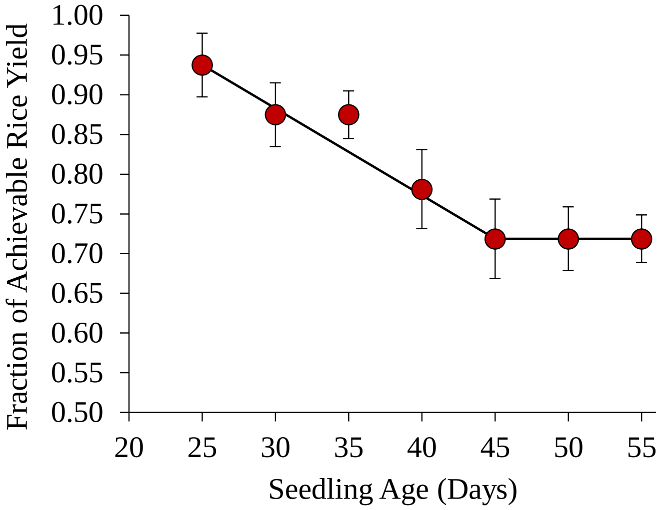

Figure 3. Response of seedling age on 'Boro' rice yield (variety, 'BRRI dhan28') in the designated period-2 in the study area

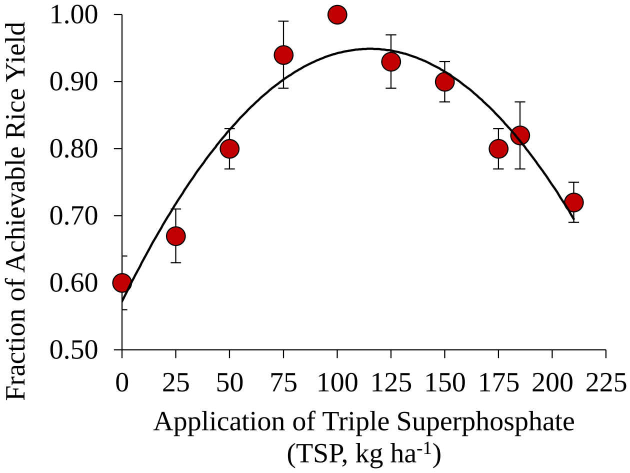

Figure 4. Response of the dose/level of triple superphosphate (TSP) on 'Boro' rice yield (variety, 'BRRI dhan28') in the designated period-2 in the study area

Calculation of achievable relative rice yield

The achievable relative rice yield (RRY) was calculated as: AYISF/HYSF, where AYISF is the yield achieved by individual respondent-farmer, and HYSF is the highest yield recorded in the sampled farmers.

Relationships between farmers' knowledge pool and yield influencing process, and between yield influencing process and relative rice yield

A second order polynomial equation was developed between farmers' knowledge pool (FKP) and yield influencing process (YIP) (figure 5). The equation, Y = 0.805 + 0.0156 X - 0.00007 X2, quantified the relationship, which explained 96% variability in YIP ($R^2 = 0.96$, $P < 0.05$).

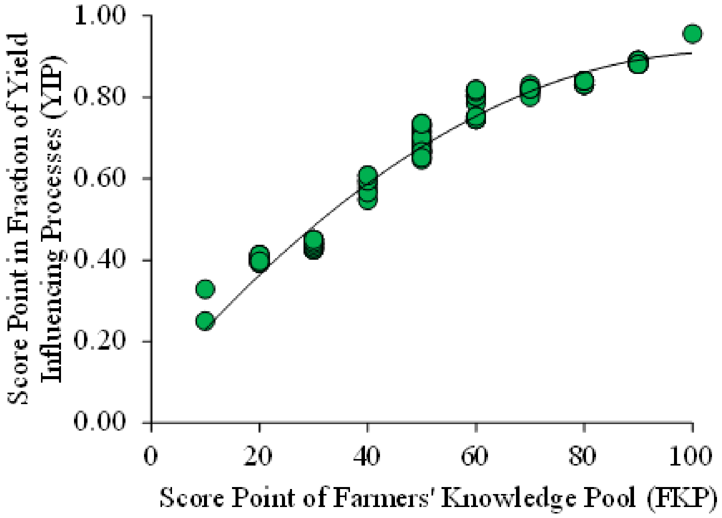

Figure 5. Association between farmers' knowledge pool (FKP) and yield influencing process (YIP) in relation to 'Boro' rice yield (variety, 'BRRI dhan28') cultivated in the designated Period-2 in the study area

The relationship between the yield influencing process (YIP) and relative rice yield (RRY) was determined through a second-order polynomial equation (figure 6). The equation, Y = 0.2691 - 0.02145 X + 1.152 X2, quantified the relationship, which explained 96% variability in RRY ($R^2 = 0.99$, $P < 0.05$).

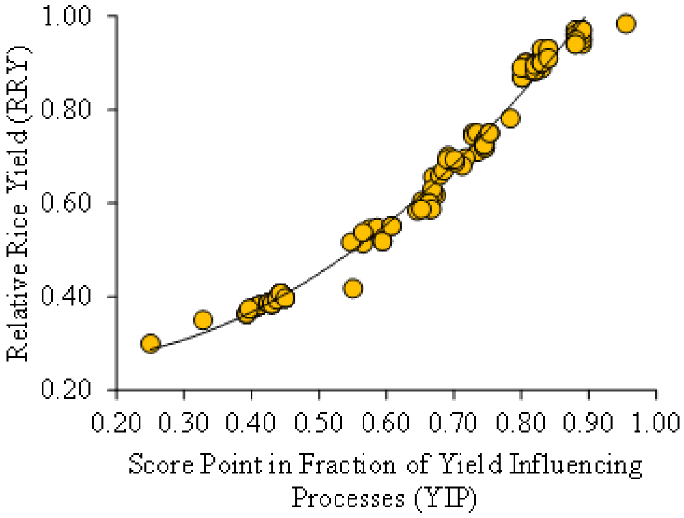

Figure 6. Association between yield influencing process (YIP) and relative rice yield (RRY) in relation to 'Boro' rice yield (variety, 'BRRI dhan28') cultivated in the designated period-2 in the study area

Model Validation and Potential Application

Model validation

Performance of the 'B-M Model' was analyzed statistically using three approaches: (i) correlation-regression approach (Kobayashi and Salam, 2000; Gauch *et al*., 2003) (ii) paired mean testing approach (predicted value versus observed value) (Mead *et al*., 2002) and (iii) a deviation approach (predicted value minus observed value) (Kobayashi and Salam, 2000).

For the correlation-regression approach (predicted value versus observed value), two regression statistics were used: (i) the coefficient of determination (R2) for the 1:1 (y = x) line and (ii) the slope (m) of the regression line which was forced through the origin (Asseng *et al*., 2000). The standard error of the slope, the level of significance (P) to test whether the slope was different from 1 and the number of points (n) included in the regression analysis were also used. For paired mean testing approach, the standard error of the difference (SED) between two means was calculated. The least significance difference (LSD) was calculated using the SED and t-value at 5% level of significance and the means of the model's prediction and observation were compared. For the deviation approach, two deviation statistics were used. The first deviation statistic was the root mean squared deviation (RMSD), which is the average product of deviations for each 'data-point pair' in two datasets (Kobayashi and Salam, 2000). The second one was the mean squared deviation (MSD). MSD has three components; squared bias (SB), squared difference between predicted and observed standard deviations (SD) and lack of positive correlation weighted by the standard deviations of predicted and observed values (LCS). MSD measures the total deviation between predicted and observed values. The lower the value of MSD, the closer the predicted value is to the observed value. SB indicates the agreement between the predicted and observed means, whereas SDSD and LCS together show how closely the model predicts variability around the mean. The two sources of this variability are the magnitude of fluctuations among the n observations and pattern of the fluctuations across n observations; SDSD and LCS quantify the ability of the model to describe the magnitude and pattern of fluctuation, respectively.

Potential application of the model

Determination of achievable yield could be expected by changing farmers' knowledge pool on rice production practices

The 'B-M Model' was run for the range of FKP - 10 (lower bound) to 100 (upper bound) 'Score Point' with step 1. The achievable relative rice yield (output of the model as percentage) was regressed over the 'Score Point' of FKP (input of the model) using the 'data analysis tool pack' of MS-Excel application software.

The combination(s) of knowledge management trait to materialize a targeted achievable yield

A target of 80% achievable yield was set at three levels of SEOs – 10, 20 and 30. The combination(s) of the two KMT, EAS and AIS to reach a targeted achievable yield was investigated. For each level of SEO, the model was run in a combination of 6 (six) levels of EAS and AIS (both in the range of 5 to 30 at 5 steps). Altogether, there were 108 combinations (3 [SEO] × 6 [EAS] × 6 [AIS]).

Results and Discussion

Performance of the 'B-M Model'

When validated the model's output using data from the field, the performance of the 'B-M Model' was strong against the observed datasets (Fig. 7). Across the 180 farmers' data, the average RRY predicted by the model (0.705) and observation (0.716) was close (RMSD = 0.018). The difference between predicted and observed RRY was not statistically different (LSD = 0.03), indicating the model fully captured the validation data. A regression of predicted and observed RRY in all the data points (n = 180) explained 96% variance (R2 = 0.96) in observation, further proving the model's strength in estimating RRY in a wider range of farmers; rice yields (figure 7). Addition statistical analysis with the slope of the regression in 1:1 line showed no significant difference ($P > 0.05$) between predicted and observed values (slope = 0.95, standard error of the slope = 0.01, n = 180).

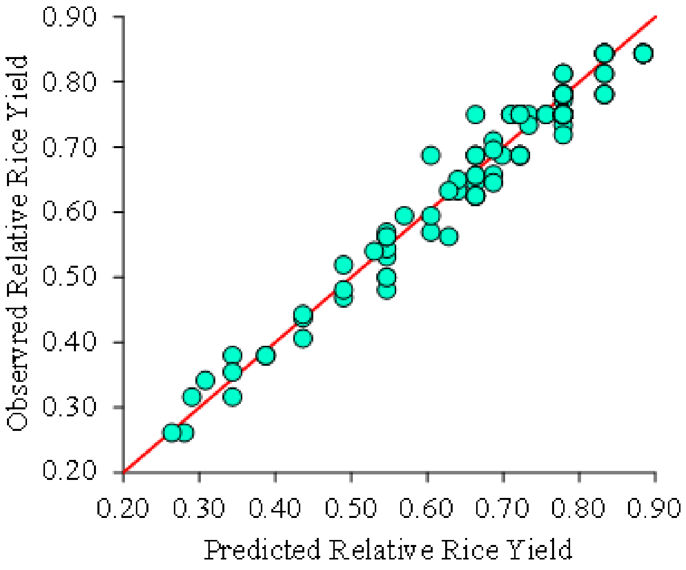

Figure 7. Comparison of predicted and observed achievable relative rice yield (RRY) in the study area. The 1:1 line shows no significant difference (P > 0.05) between predicted and observed values (R2 = 0.96)

An additional analysis between the model's prediction and field observation using three deviation statistics shows a small squared bias (SB) of 0.0001 (i.e., agreement in the predicted and observed means), squared difference between predicted and observed standard deviation (SDSD) of 0 (zero) (i.e., the magnitude of fluctuation in the observed data-points) and lack of positive correlation weighted by the standard deviation of predicted and observed values (LCS) of 0.0006 (i.e., the pattern of fluctuation in the observed data-points).

The 'B-M Model' was constructed through two algorithms only, and it used three knowledge management trait (KMT) as inputs. The model is of empirical nature, but it showed robustness because (i) the algorithms were developed using a large number of data and the output achievable relative rice yield (RRY) was tested using diverse yield data (2,064 to 6,669 kg ha^{-1}) and in large quantities (180 farmers). During the steps of model development and validation, strict principle was applied of not using the data from the same farmers for both the purposes (Spedding, 1975). In this study, paired mean test, correlation-regression approach and deviation-based approach were applied to perform rigorous statistical analysis to successfully prove the 'usefulness' of the model (Baker and Curry, 1976).

Potential Application of the Model – A Normative Analysis

As cited by Salam (1992), Charlton and Street (1975) highlight that objective of systems modelling exercises should be their practicality and usefulness to stakeholders. This sub-section reflects this view through normative analysis.

Normative analysis, a way of finding potential application of the model, was employed to answer two questions: (i) how much achievable yield could be expected by changing farmers' knowledge pool on rice production practices? (ii) at what combination(s) of knowledge management trait be considered at strategical hierarchy to materialize a targeted achievable yield in an agro-ecosystem?

To answer the first question, the model was set to run for the range of farmers' knowledge pool (FKP) - 10 to 100 scale with step 1 (one). It may be reiterated that this range is the lower and upper bound of the FKP (figure 8).

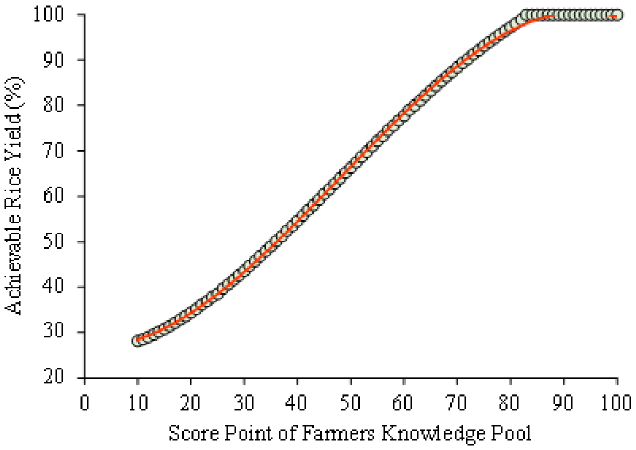

Figure 8. Relationship between of farmers' knowledge pool (FKP) and achievable relative rice yield (RRY expressed as percentage) based on 'B-M Model' run

The figure shows that achievable rice yield is related to the FKP following a third-order polynomial equation (Y = 27.11 – 0.1217 X + 0.0279 X2 – 0.0002 X3 ($R^2 = 0.99$, n = 100, $P < 0.05$). The achievable rice yield does not increase beyond the FKP Score Point of 84. It is evident from the model's prediction that interventions on farmers' knowledge gain in practice change could have a great impact on the productivity of 'Boro' rice in the study area.

So, what channels may be employed for this knowledge gain, especially in a shorter period of time? Of the three pathways (KMT) the model considered, self-experience and observation (SEO) is relatively longer-term effect; therefore, this modelling exercise designed to explore the combination(s) of the rest two KMT, extension advisory services (EAS) and accessed information sources (AIS) to reach a targeted achievable yield. In this exercise of experimentation with the model, a target of 80% achievable yield was set at three levels of SEOs – 10, 20 and 30. For each level of SEO, the model was run in a combination of six levels of EAS and AIS (both in the range of 5 to 30 at 5 steps). Results in figure 9 shows at the SEO level of 10, the set target could be achieved only through 3 combinations of EAS and AIS – 30/25, 25/30 and 30/30 (EAS/AIS). When the SEO level raises to 20 (figure 10), the set target could be achieved through 10 combinations of EAS and AIS – 30/15, 25/20, 30/20, 20/25, 25/25, 30/25, 15/30, 20/30, 25/30 and 30/30 (EAS/AIS). On the other hand, with SEO level of 30 (figure 11), as many as 21 combinations of EAS and AIS are potentially open to reach the target – 30/5, 25/10, 30/10, 20/15, 25/15, 30/15, 15/20, 20/20, 25/20, 30/20, 10/25, 15/25, 20/25, 30/25, 5/30, 10/30, 15/30, 20/30, 25/30, and 30/30 (EAS/AIS).

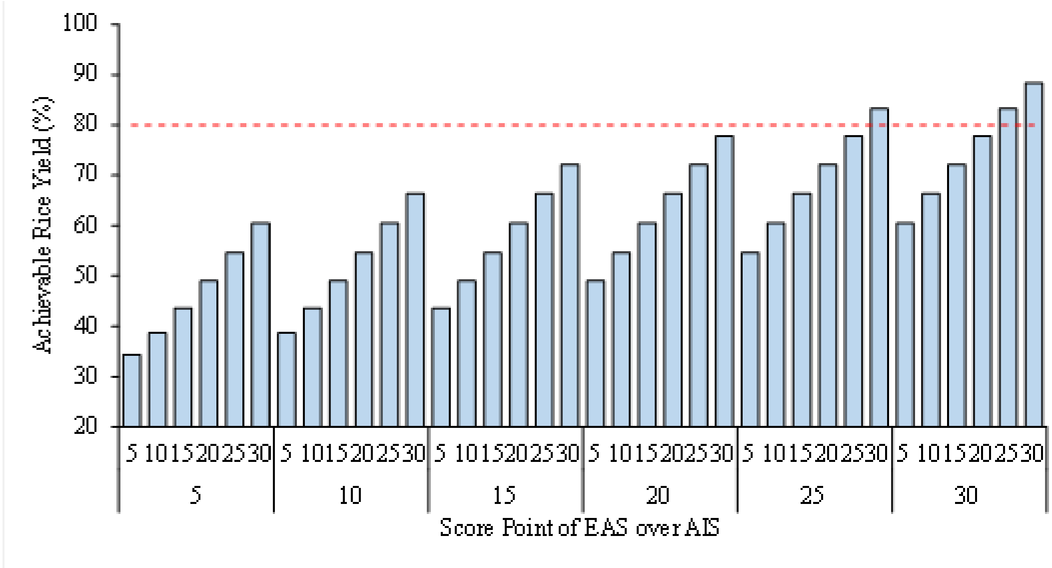

Figure 9. Achievable rice yield in the study area in combination of extension advisory services (EAS) and accessed information sources (AIS) on a defined self-experience and observation (SEO) score point of 10 at a target of 80% achievable yield

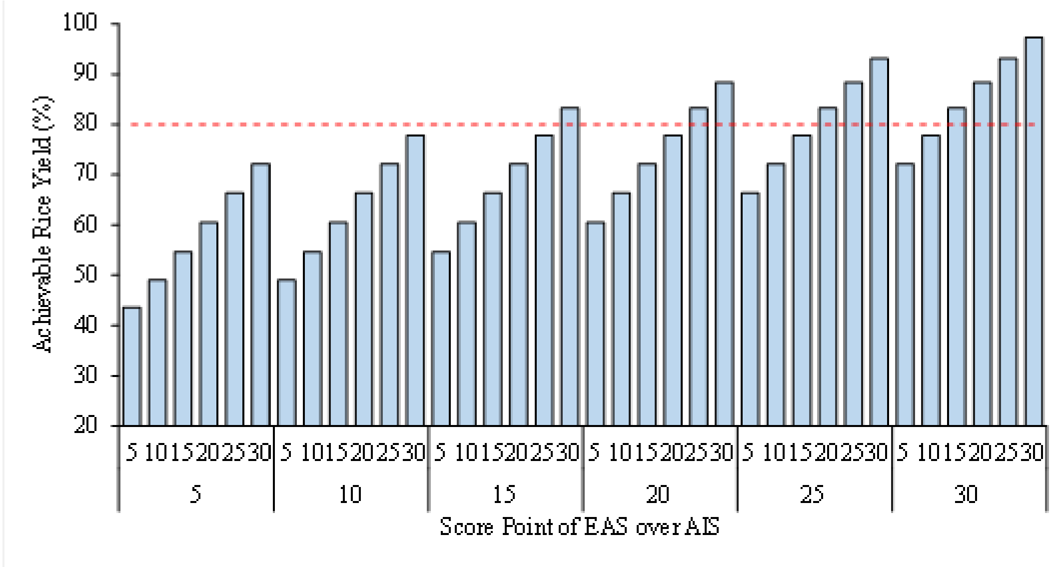

Figure 10. Achievable rice yield in the study area in combination of extension advisory services (EAS) and accessed information sources (AIS) on a defined self-experience and observation (SEO) score point of 20 at a target of 80% achievable yield

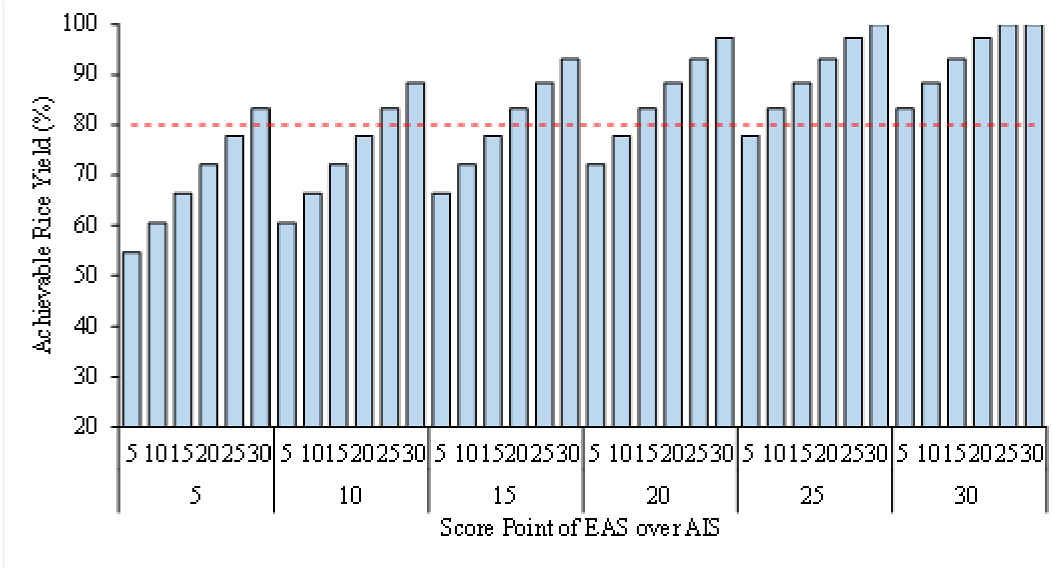

Figure 11. Achievable rice yield in the study area in combination of extension advisory services (EAS) and accessed information sources (AIS) on a defined self-experience and observation (SEO) score point of 30 at a target of 80% achievable yield

Conclusion and Way Forward

The ‘B-M Model” is simple because it was constructed through two algorithms only, and it uses three knowledge management trait (KMT) as inputs; those inputs come from the ‘Scoring Point’ of the KMT in a designated range. In spite of this simplicity and empirical nature of the model, it showed robustness. To best of the knowledge, a model quantifying rice yield in relation to farmers’ knowledge management trait does not exist in literature. Successful testing under diverse yield scenarios using multiple and sophisticated statistical tools enhanced the credibility of the model to be used on farmers’ knowledge acquisition for practice change leading to improved productivity of rice in the southwest region of Bangladesh.

This study formulated the recommendations on policy implication and future research. Two specific recommendations are drawn at the policy level: (i) formally presenting the model to development agencies highlighting its merits on strategic decision-making towards pin-pointing the probable knowledge channels for farmers’ practice change leading to increased rice productivity; and (ii) demonstrating the model as a decision guide to the farmers to help them understand how knowledge gain can link to increased rice yield. The undertaking of future research is suggested on three aspects: (i) extensive testing of the model in diverse environments to gain confidence in the model’s credibility and applicability; (ii) applying the model for other production systems and accordingly adjusting and/or calibrating it for extendibility of the model; and (iii) test and validate the model by including more explanatory variables in the model.

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