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Research Paper

Integrating gender and farmer's preferences in a discussion support tool for crop choice

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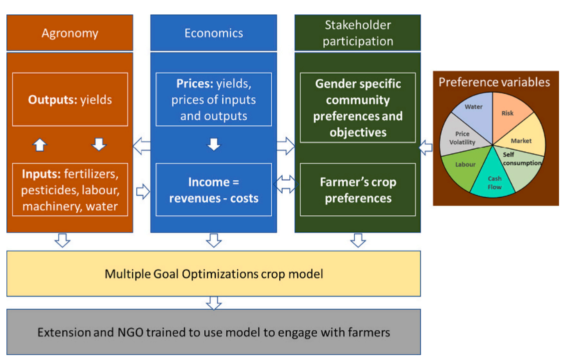
HIGHLIGHTS

- We developed a crop-choice model to support extensionists in engaging with the farming communities more effectively
- Model used to explore consequences of different crop choices on income, gender specific labour, use of inputs and markets
- Gender sensitive co-contribution/participatory model is inclusive allowing participation and application by practitioners
- Inclusive model development facilitated better communication between extension partners and farming communities

GRAPHICAL ABSTRACT



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ABSTRACT

CONTEXT: In northern West Bengal and southern Bangladesh, Rabi crops, sown in winter and harvested in the spring, are an important source of income and nutrition for the target communities. In the study areas, NGOs and extension services have been engaging with farming communities on selecting suitable crops for the upcoming season. This engagement took place in the absence of quantitative tools to discuss trade offs and what-if scenarios to support an informed discussion.

OBJECTIVE: The objective of this study was to design a crop-choice model to support extension agronomists in engaging with the farming communities more effectively using a quantitative analysis tool. In this process, we

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explored how agricultural system models can be inclusive and allow participation and eventual application by NGO and government extension agents, using a process of gender sensitive contribution.
Methods: The crop-choice model includes several constraints related to available resources, including land, labour, capital and technologies to calculate optimal crop areas within the Rabi season. The crop choices are determined considering gender specific community perceptions of risks, labour use, market, price-volatility, self-consumption, water use and cash flow. The model was used to explore the consequences of different crop choices on income, gender specific labour, use of inputs and markets, and to reveal the trade-offs of pursuing different crop choice pathways in the context of agricultural intensification. The initial model was demonstrated to the farmers and the extension agents, and based on their reflections, it was fine-tuned further to make the engagement process more effective. For better communication with the participating farmers, the model related questions and findings were translated in the local language (Bengali).
RESULTS AND CONCLUSIONS: We found that the modelling process can be made more inclusive from the outset by including farmers, NGO and extension agents as co-contributors of the model at each of the modelling steps and incorporating their reflections. Such an inclusive and reflective approach provides easy-to-use interfaces and enables translation of model results in ways that more effectively benefit farming communities. The *process* of engagement with farmers during tool development has been very valuable to farmers and researchers alike and the use of the tool has made the farmers informed about alternative scenarios and led to actual benefits for crop choice decision making. Inclusive farming systems models need to consider the gender dimension and its critical role in farm decision making and how this can be included in models to reflect the diversity of decision process. To maximise relevance of the model for next users and farmers, it was important that these key stakeholders were part of the model development from the beginning, this study has focused on the same throughout.
SIGNIFICANCE: This study demonstrated that appropriate design and development principles enabled bio-economic farming systems models to be used by NGO and government extension agents to engage with farming communities as discussion support tools in farming decisions. Such an approach would make the engagement process more convincing and effective. Besides, it would also provide useful insights to the NGO and extension agents in revising their intervention strategies.

1. Introduction

Farming system models often combine farming activities, management practices, and resource constraints to provide alternative options for decision making (Behrendt et al., 2016; Iglesias et al., 2016; Janssen and van Ittersum, 2007; Kragt et al., 2016; Nidumolu et al., 2007; Nidumolu et al., 2016; Reidsma et al., 2018; Tanure et al., 2013; Villalba et al., 2019). Groot et al. (2012) report that multi-objective optimization linked to bio-economic farm models can play an important role in the design of mixed farming systems and has a strong potential to support the learning and decision-making processes of farmers, farm advisers and scientists. Many models have been developed and applied in case studies, but their impact and application in practice is not so evident (Sterk et al., 2011). There is a substantial gap to be bridged between current models and the capabilities needed to provide information that would be useful to most potential users. This gap implies the need for a way to link users to models (Antle et al., 2017) as well as linking models to the users so as to make them more relevant.

McCown (2002) discusses the challenge of using farming systems models as decision support systems (DSS) developed by 'management scientists to be used by farm managers' such as resistance of family farmers to have their decision processes perceived to be by-passed by DSSs. Sterk et al. (2011) reflect on the contributions of land use models to societal problem solving and suggest four factors for understanding the contribution of modelling to societal change i.e. (i) problem solving stage; (ii) role of models (iii) model types (iv) boundary arrangements. The matching process of these four factors is facilitated by contextualisation and networking. McIntosh et al. (2008) argue that it is important to engage users and other stakeholders in the tool development process to help bridge the gap between design and use. Ditzler et al. (2018) suggest that systems analysis (SA) tool designers should create tools with a broader range of structural and first-order affordances to accommodate users with diverse opinions. Rose et al. (2018) suggest user centred design practices in development of a decision support system in agriculture in four ways – i) to promote user centred design practices, ii) to undertake cross-disciplinary collaboration among researchers, iii) to carry out decision support context assessments, and iv) to understand the dynamics of on-farm decision making by different stakeholders including farmers, input sellers, advisers.

Klerkx et al. (2017) emphasise, in an institutional context, the importance of stakeholder involvement in research processes as essential to enhance the applicability of research. Inclusion of local stakeholders in the research process enables researchers to contextualize the research problem, incorporate local conditions and build trust among stakeholders (Klerkx et al., 2017), thus maximising relevance of the model to users. Kloprogge and Van Der Sluijs (2006) explore how stakeholders' knowledge and perspectives can be better included by selecting the right approach based on objectives, contribution to the overall risk management process, available resources, and boundary work. Berthet et al. (2018) opine that transitions towards a sustainable agricultural future will require systemic approaches to design, where local solutions are also capable of contributing to larger-scale solutions - requiring both an intimate knowledge of the local context, needs and culture while also involving a range of actors and local user communities. Fritz et al. (2019) propose a three-level classification of effects in the context of transdisciplinary research, namely in the 'arena of actor collaboration' (e.g. trust built); the 'arena of involved practitioners' (e.g. networks formed), and the 'arena of the wider practice context' (e.g. raised awareness of sustainability).

Good practice recommendations for model developers to involve users include being clear about the purpose of the tool, working collaboratively with other developers and stakeholders, and building social and scientific credibility (McIntosh et al., 2008). Lisson et al. (2010), point out that participation of smallholder households in system analysis is essential to harness their intimate knowledge of how the system currently functions (including inputs and outputs). Basco-Carrera et al. (2017) make a distinction between participatory modelling and collaborative modelling by using levels of participation and collaboration as conditioning dimensions. In this case we use participatory modelling which can include stakeholder involvement ranging from discussion to consultation to information sharing (Basco-Carrera et al., (2017).

The aim of the work presented here was to explore how farming system models such as those that support crop choice decisions can be made inclusive and allow participation in development and eventual application by NGO and government extension agents using both co-learning and collaborative processes. We combined technical and participatory approaches by inviting NGO and government extension

Table 1
Summary characteristics of case study sites (HHs = households; SHGs = Self-help groups

Broad agro-ecological zones	Socio-ecological settings (village)	General interventions / key development activities
1. Eastern Gangetic alluvial plains, high rainfall, northern West Bengal Primary agricultural intensification opportunity consists in developing tube-well based irrigation to enable dry season cropping. Location: Cooch Behar district	1.1 Caste-based communities; some moderate dry season cropping; predominantly small and marginal farming HHs (Dhaloguri)	• Formation and facilitation of collectives clustered around shared shallow tube wells. • Fostering establishment of new local level institutions and SHGs. • Connecting community to government entitlements and market services. • Developing linkages with different government agencies and programmes
2. Coastal zone, southwest and central south Bangladesh Primary agricultural intensification opportunity consists in storing fresh river water in re-excavated drainage canals or by blocking ingress of brackish water in canals, to enable irrigated dry season cropping of high value crops. Location: Dacope (2.1) and Amtali (2.2) *upazilas* (subdistricts)	2.1 Farming and shrimp growing communities; moderate to strongly affected by salinity; no dry season cropping (Khatail) 2.2 Mixed farming communities; marginally affected by salinity; limited dry season cropping (Sikenderkhali)	• Formation and facilitation of women SHGs and farmer groups comprising marginal HHs. • Formation and facilitation of Water and Silt Management Committees to re-excavate and manage canals for storage and allocation of irrigation water for Rabi cropping (Sikenderkhali); or construction of dykes in canals to block ingress of brackish water (Khatail). • Connecting community to government, market services and private sector.

agents as collaborators of the model development at each of the modelling steps, providing easy to use interfaces and enabling translation of model results in ways that assist farming communities. Our participatory engagement followed the principles of ethical community engagement (Carter et al., 2019).

The context of the development of this inclusive participatory approach was the project undertaken in West Bengal, India and Bangladesh 'Socially Inclusive Agricultural Intensification (SIAGI)' with Australian, Indian and Bangladesh researchers and NGO and government extension agents during 2016–2020 (www.siagi.org). SIAGI's primary aim was to facilitate the inclusion of marginalised individuals and groups, including women and the very poor, in agricultural intensification processes. These groups are typically excluded from development opportunities which can favour farmers with established networks and existing capital. The project partnered with researchers in-country, NGO partner/extension agents, and government institutions to facilitate a range of agricultural activities through community partnership.

This paper explored, within the larger objective of the SIAGI project, (i) what processes need to be conceptualised and actioned for the model to be used in a decision process? (ii) what data collection and modelling interface will help with the integration?, and (iii) what level of interactions between the 'modellers', farmers and the 'NGO extension agents (in-country project partners)' would be required?.

2. Study area

The work presented here was conducted in case study villages at two of the three SIAGI study sites:

i. Eastern Gangetic Plains - northern West Bengal: Dhaloguri village in Coochbehar district.

ii. Coastal Zone, southwest Bangladesh: – Khatail village in Dacope upazila and Sikenderkhali village, in Amtali upazila. A brief description of the case study villages is given in Table 1.

Agricultural intensification in the region is promoted to improve both livelihoods and food security. In the monsoon Kharif season, paddy rice is the default crop in the region. Rabi (post monsoon dry season) cropping is being promoted in the study areas – largely facilitated by the growing availability of modern shorter-season Monsoon rice varieties, which increase the chances of Rabi crop success by earlier sowing and subsequent avoidance of late-season heat and salinity problems (Mainuddin et al., 2019). In Dhaloguri, ground water is used to irrigate the crops while in Sikenderkhali and Khatail, freshwater in the canal has encouraged the farmers to participate in diversified irrigated agriculture in Rabi season. However, in both cases access to water as well as access to labour in the rabi season are considered as constraints. Rabi season crops are predominantly vegetables grown both for markets and for self-consumption. For Rabi season, farmers listed the following crops that they will either grow or are interested to cultivate. In northern West Bengal villages, cabbage, cauliflower, chili, potato, tomato, brinjal (eggplant), spinach, and coriander were listed. While in south-west Bangladesh villages, green chili, sunflower, sweet_pumpkin, bottle gourd, chinese okra, okra, bitter gourd, snake gourd, eggplant, tomato, radish, winter spinach, bean, cucumber, potato, cabbage, beetroot, watermelon, and onion were listed.

3. Methods

Rabi crops are an important source of income and nutrition for the target communities in the SIAGI case study regions. In the study areas, NGOs and extension services have been engaging with farming communities on selecting suitable crops for the upcoming season. This engagement took place in the absence of quantitative tools to discuss trade offs and what-if scenarios to support an informed discussion; a systematic trade -off analysis of crop choice is an under-researched area in the SIAGI study sites. It did however have a very strong community engagement approach, which sets the scene for learning and collaboration to develop a set of solutions. In the context of this project, the participatory modelling described here sought to change 'outcomes' (eg changes in knowledge). (Belcher et al., 2019). Change in impacts was a longer-term goal. NGOs in this study took the role of intermediaries. This included facilitating the flow of knowledge between communities and researchers (and vice versa) and assisting with translation of concepts and customs unfamiliar to participating parties. Such an approach also helped in communicating with the farming community and capturing and required data.

Combining the crop choice model with community preference weights connects this work to the larger ethical community engagement approach underpinning the SIAGI project. An ethical community engagement (ECE) approach recognises that the preferences, values and aspirations of poor and marginalised farmers, including women, are typically excluded from development decisions and extension support (Carter et al., 2019). An ECE approach aims to facilitate the inclusion of individuals and groups in a participatory process of collaboration and decision-making. A participatory modelling approach as described in this section, supports the inclusion and use of community-derived data and provides equal weight to preferences of female and male farmers. This approach relates to the question on the processes need to be conceptualised and actioned in the model to be used in the decision process.

3.1. Interactive crop-choice model

The proposed crop choice model is a multi-objective optimization model that maximizes a weighted objective function. By changing the weights of the different objectives based on preferences of different type of farmers we can determine more preferable cropping patterns. The

Table 2
Explanation of parameters,variables and model equations.

Parameter	Description	units
w_i	Importance weight of objective function i	–
$sc_{c,s,i}$	Performance of crop *c* on soil type *s* on objective function i	score/ha
F_i^{max}	The ideal value of objective function *i*	score
F_i^{min}	The pessimistic value of objective function *i*	score
al_s	Available land in soil type *s*	ha
$xup_{c,s}$	Upper bound for the area of crop *c*	ha
$xlo_{c,s}$	Lower bound for the area of crop *c*	ha
$Lb_{c,s,g}$	Labour requirements per ha of crop *c* on soil *s* by gender *g*	days/ha
alb_g	Available labour by gender *g*	days
$cw_{c,s}$	Canal water requirement by crop *c* on soil *s*	m^3/ha
Acw	Available canal water	m^3
Variables		
$X_{c,s}$	The optimal area allocated to crop *c* at soil type *s*	ha
F_i	Farm level performance for objective *i*	score
W	Weighted sum of objectives (objective function value)	–

$$max\left\{W=\sum_i\frac{w_i\times F_i}{F_i^{max}-F_i^{min}}\right\}$$

$$F_i=\sum_{c,s}sc_{c,s,i}\times X_{c,s}\qquad\forall i\qquad(1)$$

$$\sum_c X_{c,s}\le al_s\qquad\forall s\qquad(2)$$

$$X_{c,\ s}\le xup_{cs}\qquad\forall c,\ s\qquad(3)$$

$$X_{c,\ s}\ge xlo_{cs}\qquad\forall c,\ s\qquad(4)$$

$$\sum_{c,s}lb_{c,s,g}\times X_{c,s}\le alb_g\qquad\forall g\qquad(5)$$

$$\sum_{c,s}cw_{c,s}\times X_{c,s}\le acw\qquad(6)$$

$$X_{c,\ s}\ge 0\qquad\forall c,\ s\qquad(7)$$

*i - Index for the set of objectives (*i.e. *criteria to be optimized); c - Index for the set of crops; s - Index for the set of soil types; g - Index for the genders.*

farmers' objectives are included as linear functions of optimal crop areas in different soil types and the per ha contribution of each crop grown in a certain soil type to each of the objectives. To ensure that we calculate cropping patterns feasible from a technical point of view we have included a set of resource constraints. The resource constraints ensure that calculated cropping patterns do not exceed available land, labour and water at the farm level. Moreover, to accommodate crop choice preferences and crop rotation considerations (agronomic constraints) of the stakeholders we provide the opportunity to set a minimum and a maximum level of certain crops in different soil types. The explanation of parameters and variables used in the model are provided in Table 2. The mathematical formulation of the interactive crop choice model is presented below:

Objective function (1) is a weighted sum of the different objectives normalized (made unit less) by dividing with the ideal minus the pessimistic value (Kalvelagen, 2002) of each objective function. Eqs. (2) are the farmer's objectives specified as functions of the decision variables. Constraints (3) restricts the optimal cultivated area to the available land in each soil type. Constraints (4, 5) set an upper and a lower bound to the area of each crop in each soil type. The soil types have an influence on crop yields and as such have been included the soil type in the area constraint. Constraints (6) ensures that the labour requirements of the optimal cropping pattern, from each gender, do not exceed the available labour. Constraint (7) restricts the water requirements of the optimal cropping pattern to the available canal water. Finally, constraint (8) are the non-negativity constraints.

3.2. Data and setup of calculations

Exploring the second question raised in the introduction on data collection and modelling interface to help with the integration, the model framework, data requirements and model interface have been developed and elaborated in this section. Seven objective functions were defined that relate to labour (preference based on labour hours required), market (ease of access to market), risk to production, home consumption, cash flow, water (requirements by crop choice) and price volatility. The scores for the objectives ($sc_{c,s,i}$) were determined by the participants using a scale of 1–5.

The model framework is given in Fig. 2. The model selects an optimal set of crops and area (agricultural activities) to be planted based on a set of available resource constraints. The main decision variables are the optimal area allocated to the available crops. This modelling approach uses a set of objectives to drive the model through the 'Performance assessment and scoring' process. The model optimizes according to the preference scores and weights. The objectives could be maximising profit based on preferences and weights, for example while producing enough for family home-consumption arrived at through the 'Interactive Weight Elicitation' process.

3.2.1. Scoring activities and weight elicitation process

As part of the data survey among the participating farmers, men and women farmers were asked to score Rabi crops on seven variables, based on their preference. Labour (preference based on the labour time required and difficulty), risk of production (factors such as incidence of pest and disease, climate risk to production have been considered), access to market (based on how easy or difficult to reach the produce to the market), self-consumption, water (water use by crop), cash-flow (one off cash payment for the produce such as potato or regular cash flow from crops such as chili) and price volatility. They have scored on a Likert scale of 1–5. Women and men farmers scored these variables in separate focus group discussion meetings organized by the collaborating NGOs and a single value was used for female famers and another single value from the male farmers. A weight factor on profit and the seven variables is included where the farmers can score between 0 and 1 (total across all the 8 variables including profit should add up to 1). These weights along with the scores will influence the objective function to reflect the preferences of crops gender-wise and the weight they place on these versus profit. For example, they may score on labour higher for a crop (i.e. it is less labour intensive) but when they must weigh between labour and profit, they may preferentially score profit higher.

A key innovation in this modelling work is including gender-differentiated community perceptions to influence crop choice. Women contribute significantly to the agricultural activities in the regions of our study and their perceptions and preferences in crop choice sometimes differ from the male members of the family. Therefore, it was important to capture these differing preferences and explore the commonalities and differences in crop choices as a result for an informed discussion. This has been achieved by seeking female and male farmers to score separately on their preferences for each crop (on a scale of 1–5) on seven different variables as described earlier. To account for the importance of the different objectives we used importance weights (w_i). Female and male farmers were asked to allocate points (all added up to a total of 10) to each of 7 variables (labour, risk, access to market, self-consumption, water, cash-flow and profit). Based on these allocations we calculated the importance weight, which was a value between 0 and 1 and all weights sum to 1.

3.2.2. Data and model parameterization

Data on different crop and vegetables (cost of cultivation, yields), ground water use and related yields (for Rabi), input use (fertilisers, pesticides) was collected from the farmers This data was collected on a data framework that was based on the objectives and questions that have been developed via an iterative process with key stakeholders. Data was collected from farmers in surveys conducted during March and April 2017 for Dhaloguri and August to October 2017 for the Khatail and Sikenderkhali and with the ACIAR funded collocated projects. The data collection was carried out through focus group discussions (FGDs) with both male and female farmers. Participants were mainly from the SIAGI project participating farmers. The FGDs were thought to be an appropriate way to capture gender specific perspectives along with other socio-economic dynamics. Importantly, the same set of farmers participated in the FGDs to examine the changes/consistencies in responses

Table 3
Gender-wise participanting farmers in FGDs and survey.

	Male farmers	Female farmers	Total
Dhaloguri	11	13	24
Khatail	9	9	18
Sikenderkhali	8	8	16

post model development and for validation.

Data (technical coefficients) requirements of the model include:

(i) Land area (good and medium soils)
(ii) Crop yields
(iii) Ground water use by crop (Rabi crops)
(iv) Cost of ground water (northern West Bengal only)
(v) Crop prices
(vi) Land preparation cost
(vii) Fertiliser use and cost
(viii) Pesticide use and cost
(ix) Seeding rate and cost
(x) Labour available, labour use by crop/vegetable and cost
(xi) Machine use and cost

All the above parameters are for crops/vegetables that have been included in the model.

3.3. Participatory process and model run

This section provides the methods applied in relation to the third question posed in the introduction on the level of interactions between the modellers, farmers and NGO/extension agents. The development of the model and interface were conducted together with project partners and farmers. The interest and participation from the in-country project partners in the tool developed from the conceptual stage to data collection to model development and demonstration to the farmers is illustrated in Fig. 3.

NGO partners were acting as "intermediaries" for knowledge transfer. The discussion was in local language Bengali, the NGO team translated the outputs of the model to the farmers. The outputs were simple in terms of crop name, area to planted and costs and revenue. It is not the intention of the model that it will be used by farmers themselves. 'Village' was taken as a unit to demonstrate the model (as a whole farm). The model could be applied to a 5-acre plot as well. This was explained to the participant farmers. While farmers said they were comfortable with the scale at which we use the model as a demonstration, there are challenges of modelling at different scales (village to plot) in terms of labour resources, capital and technologies, and these should be considered in discussing a whole farm model (in this case at a village scale) with medium and small-scale farmers who cultivate 5 acres or less. However, there were active discussions between the female and male farmers during the workshops based on the preferences, perceptions and the model outputs. The insights gathered in the process contributed to development of the model and its subsequent fine-tuning.

Initially, in 2016 the approach presented in this paper was discussed with the project partners and they in turn worked with the participating farmers (in SIAGI project) to define the objectives of the model and the questions that the model may be able to provide answers for. Thereafter, two sets of farmer engagements were carried out. One set was with researchers and farmers with participation from NGO partner/extension agents. This was done in April 2018 in Sikenderkhali (14 male and 6 female farmers participated) and Khatail (7 male and 5 female farmers participated) in Bangladesh. Participating farmers were selected on a voluntary basis from the SIAGI intervention villages. The selected farmers also participated while basic data on input use, crops yield, water availability were collected from the villages. The second set of interactions was conducted by the NGOs without the involvement of the researchers. This was carried out after the training of the NGO and academic in-country partners. In November 2018, NGO partner/extension agents engaged with farmers in Sikenderkhali (8 male and 8 female farmers participated) and Khatail (9 male and 9 female farmers participated) in Bangladesh. In Dhaloguri village, two rounds of focus group discussions (FGDs) were conducted with participation of men and women farming groups in April 2017 and October 2017. In both the FGDs, the same 11 men and 13 women participated.

Through the whole engagement process with the farmers as part of this work, following is the breakdown of participants gender and location-wise (Table 3).

The participating farmers are a subset of the farmers who participated in activities of the SIAGI project and had been oriented to the project objectives and their role in the project. They were selected by the NGO partner/extension agents based in their interest to engage with the research and interest to grow crops in Rabi season. A healthy gender ratio was achieved as can be seen in terms of the farmer participation numbers mentioned. The workshops were conducted in the usual places where farmers gather for their meetings and group activities in the village. Before every meeting, farmers were provided the details of the project activity, the objectives, and their and the researchers' roles in the project. Their verbal consent for participation was taken before the workshop. The participating farmers included landless and marginal farmers with less than five acres land holding.

Reflecting back on the question 2 on what data collection and modelling interface will help with the integration, the model user interface was deliberately designed with ease of use as an objective and contains key features to allow practitioner participation at various stages. The tool contains a commonly used spreadsheet for data collection and storage and the same spreadsheet is available for data outputs. General Algebraic Modelling System (GAMS) was selected, and the programming was carried out within the restrictions of the demo version.

The objective was to use the model in an interactive way and a model run is about 30 s in duration so as not to lose the interest of the farmers when used as a discussion tool. Since the modelling tool is to be used as a discussion tool with the farmers, the model outputs have been developed to be displayed in Bengali considering that the Bengali used for the terms used in the model are slightly different in West Bengal (Indian case study) and in Bangladesh.

In November 2017, we engaged with the farmers in Dhaloguri and ran the model scenarios with them. In scenario 1, the model was run with profit maximisation as the only objective without any preferences from male and female farmers. Three scenarios were defined for the demonstration of the model viz., Scenario 1 where profit maximisation was the only objective. In Scenario 2, female farmers placed weights on profit 0.1, on labour 0.9 while male farmers placed their weights on profit 0.2 and market 0.8. In scenario 3, the male and female farmers placed the same weights of 0.8 and 0.2 on cash flow and profit respectively.

Like in Dhaloguri, we ran the scenarios with the participating farmers in Khatail in March 2018. In Scenario 1, profit maximisation was the only objective with no weights on preferences. In scenario 2, female farmers placed their weights in profit 0.20, risk 0.60 and water 0.20 while male farmers placed their weights on profit 0.40, risk 0.20 and market 0.40. For Sikenderkhali, in Scenario 1, profit maximisation was the objective with no weights on preferences. In case of Scenario 2, female farmers placed their weights in profit 0.20, risk 0.40 and self-consumption while male farmers placed their weights on profit 0.60 and market 0.40.

Once the model interface had been developed with this background, the capacity building workshops for the project partners worked out to be a smooth handover of the model, software and knowhow. Since the project collaborators have been partners in this effort from the beginning, they were familiar with the model framework, and data (as this was collected by them) and they were able to relate to the working of

Table 4
Results of model application in three different scenarios for Dhaloguri with crops by soil type and crop area in hectares.

	Scenario 1		Scenario 2		Scenario 3	
Crops	male	female	male	Female	male	female
Cabbage	25	25	101	–	–	–
Potato	336	336	–	–	–	–
Tomato	3	3	277	–	358	–
Coriander	5	5	10	10	10	10
Eggplant	–	–	–	255	–	–
Spinach	–	–	–	101	–	–
Chili	–	–	–	–	–	358
Total	369	369	388	366	368	368

Scenario 1: Profit maximisation only; no weights; **Scenario 2:** Crop choice with weights placed on Female Profit 0.1, Labour 0.9; male Profit 0.2, Market 0.8; **Scenario 3:** Crop choice with weights placed on Cash flow for both male and female farmers weighted 0.8 and profit 0.2.

Table 5
Scenarios for Khatail village with crop areas for different soil types and crops area in hectares.

		Scenario 1		Scenario 2	
Soil	Crops	male	female	male	female
High	Sweet_pumpkin	10	10	10	10
Medium	Sweet_pumpkin	10	10	–	10
High	Bottle_gourd	–	–	–	30
Medium	Bottle_gourd	23	23	23	30
High	Potato	23	23	33	–
High	Watermelon	7	7	7	–
Medium	Watermelon	7	7	7	–
Total		**80**	**80**	**80**	**80**

Scenario 1: Profit maximisation only no weights on preferences; **Scenario 2:** Crop choice with weights placed on preferred variables Female Profit 0.20, Risk 0.60 and Water 0.20; Male Profit 0.40, Risk 0.20 and Market 0.40.

this model easily.

3.4. Survey on the model development process and application

The workshops organized for designing, validating and fine-tuning the model involved different stakeholders including the farmers, local agricultural entrepreneurs and local agriculture department officials as participants. The topics discussed in these workshops included existing farming practices (in the context of the agro-climatic and physical settings), objectives, driving forces in making crop choice decisions, linkages with governmental support schemes, perceptions about farming outcomes. In particular, the gender dimension was given special emphasis during these discussions to understand the differences in their objectives, farming behaviour, constraints, and perceptions about the opportunities. Based on these discussions, the model was designed, and stakeholders' reflections were captured during the demonstration. This helped in fine-tuning the model further. Especially, farmers' realization of the importance of costs and book-keeping related aspects was an important reflection during the workshops. It was also reflected that such data driven and interactive engagement tools are more convincing vis-à-vis what is commonly practiced. Nevertheless, in principle, the application of this model is restricted to facilitate informed crop choice decisions by the farmers, not to guide them toward any particular direction.

3.4.1. Survey on the utility and value of crop choice modelling tool on crop decisions with farmers in the case study villages

In Dhaloguri village, two rounds of focus group discussions (FGDs) were conducted with participation of the men and women farming groups in April 2017 and October 2017. In both the FGDs, the same 11 male and 13 female farmers participated. This helped in examining the changes/consistencies in responses by the participating farmers.

As part of the engagement process in March 2018, we administered a short survey to capture feedback from farmers ($n = 32$; female = 15; male = 17) before and after the model presentation and discussion. The survey format is given below. The form was translated into Bengali and was written on a board, the farmers were later assisted with filling out the questionnaire.

Questions posed **before** the model presentation and discussion

1. What are the top 3 factors influencing your crop choice decisions?
2. On a scale of 1–10 how do you rate your current knowledge of factors influencing rabi crop choice?

Questions posed **after** the model presentation and discussion

1. On a scale of 1–10 how do you rate your current knowledge of factors influencing rabi crop choice?
2. What are your first impressions following the model presentation and discussion (key words)?
3. Do you see this tool as something useful for discussion support?
   a. If Yes, how
   b. If No, why and what would make this tool more relevant for you?

Farmers provided the response in Bengali and responses were translated from Bengali to English. The results are discussed in Section 4 below. The objective of this short survey was to capture quick reflections on the use of the tool, at a very basic level we wanted to know if they thought this was a useful way to think about crop choices. We did not want to over analyze the data as the sample is small and the responses were immediately after the workshop and not clear if the understanding was sustained for a longer time. However, we wanted to get some initial understanding if the model presentation and working was relevant. This feedback was critical before proceeding to invest further time and resources in the modelling exercise.

3.4.2. Survey on the utility and value of the model on development practice with NGO and research partners

NGO partners were acting as "intermediaries" for knowledge transfer. We wanted to obtain feedback on how well they understood the workings of the model before they went out and engaged with the farmers. The total NGO partners were nine for Bangladesh and the West Bengal case study together.

As part of our own learning and evaluation process, we also surveyed academic and NGO project partners after their training and interactions with the farming community where they interacted using the model. Written responses were received which were later analyzed thematically.

Q1 On a scale of 1–10 how do you rate your understanding of the crop choice modelling tool (both ease of use and how helpful it is)?

Why did you score high or low?

Q2 Does the modelling tool support your engagement process and advisory work with the farming community?

- If so, in what way?
- If the tool helps you in your work, how would you know?

Q3 Can you give examples of how your engagement using the tool with farmers has influenced their cropping decisions?

- If farmers have changed practices, how would you know it was because of the engagement with the model?

Q4 What do you like most about the model? What do you think needs to be improved?

Table 6
Scenarios for Sikenderkhali village with crops by soil type and crop area in hectares.

		Scenario 1		Scenario 2	
Soil	Crops	male	female	male	female
High	Sweet potato	75	75	75	75
Medium	Sweet Potato	75	75		75
High	Sweet Pumpkin	95	95	170	145
Medium	Sweet Pumpkin	95	95	95	145
High	Bottle Gourd	50	50	50	
Medium	Bottle Gourd	50	50	50	
Total		440	440	440	440

Scenario 1: Profit maximisation only no weights on preferences; **Scenario 2:** Crop choice with weights placed on preferred variables Female Profit 0.20, Risk 0.40 and Self-consumption 0.40; Male Profit 0.60 and Market 0.40.

Fig. 1. Location of case study villages.

4. Results

4.1. Scenarios developed as part of the engagement with the participating farming communities in the case study locations

4.1.1. Dhaloguri – Scenario-based engagement with participating farmers

In November 2017, we engaged with the farmers in Dhaloguri and ran the model scenarios with them. In scenario 1, the model was run with profit maximisation as the only objective without any preferences from male and female farmers (Table 4). The sample scenarios developed in discussions with the farmers during the interactions as part of the model demonstration.

In scenario 3, 0.8 weight was placed on cashflow and 0.2 on profit. While the weights placed by both male and female farmers were the same the resultant crop choice is different because the preference scores were different. While the resultant profits varied between male and female farmers the response from the farmers in the discussion was that these scenarios reflected their choices based on their priorities.

4.1.2. Khatail – Scenario-based engagement with participating farmers

Like in Dhaloguri, we ran the scenarios with the participating farmers in Khatail in March 2018. The model results are presented in Table 5. Since the scenario 1 was just on profit maximisation without preferences or weights being included the crop choice is the same for both male and female farmers. Farmers in the meeting agreed that sweet pumpkin, bottle gourd, potato and watermelon would be their choice if they went just for profit as a criterion in their decision making.

In the case of scenario 2 the model run was a mix of profit, risk and water (optimising water) with different weights placed by male and female famers. While the crop choices of sweet pumpkin and bottle gourd are common for male and female farmers, focusing on markets and profit in the case of male farmers resulted in model allocating 33 ha to potato and 7 ha to watermelon. In case of female farmers' preferences and weights, the model allocated 60 ha for bottle gourd and 20 ha for sweet pumpkin.

We ran the scenarios with the participating farmers in Sikenderkhali in March 2018. The model results are presented in Table 6. Since the scenario 1 was just on profit maximisation without preferences or weights being included the crop choice is the same for both male and female farmers. Farmers in the meeting agreed that sweet potato and bottle gourd be their choice if they went just for profit as a criterion in their decision making. In scenario 2, the model run was a mix of profit, risk and self-consumption and market with different weights placed by male and female famers. While the crop choices of sweet potato and sweet pumpkin are common for male and female farmers, focusing on markets and profit in the case of male farmers resulted in model allocating 100 ha to bottle gourd. In case of female farmers' preferences and weights, the model allocated 150 ha for sweet potato and 290 ha for sweet pumpkin.

4.2. Survey responses on the utility of crop choice modelling activity and scenario building exercise with users

4.2.1. Feedback from farmers in Sikenderkhali and Khatail

On the question about what the top three factors were in influencing their crop choice decisions, farmers listed (i) crops preferred for home consumption (ii) crops that fetch a better market price (iii) crops that help in improved nutrition. On the first impressions of the modelling tool after it was presented in the workshop, the key statement was the exercise with the tool in the workshop helped them improve their understanding of the complexity of incorporating a number of variables (input costs, labour, finances, markets) in making their crop choices for the upcoming season. According to farmers, the model 's capacity to combine large amounts of data and generate optimal choices based on preferences in about 30 s (processing time for the model), was attractive as a discussion tool. In Khatail for example, once the results were displayed through projector onto the screen, they participants seemed surprised looking at the crop choice as the demo results were in line with their own preferences of crop choice. In both villages, male and female farmer preferences are different where men were focused on the markets and profit maximisation while female farmers preference was on reduced labour and self-consumption. Since the model is able to capture the preferences and crop choices options reflect the different priorities of the male and female famers, both genders were able relate to the model crop choice outputs. However, this study has not explored who has final say in case of crop choice decision, Rahman et al. (2020) show that it depends on household and community context and consultation with female members of the family depends on their education, time allocation to farming and extent of engagement with NGOs.

Asked about their before and after (the workshop) experience with crop choice decisions, Sikenderkhali female farmers reported an improved understanding of the crop choice approach with a median score from 6 to 8.5 (Fig. 4a following participation in the workshop). Similarly, male farmers in Sikenderkhali reported an improved understanding from a median score of less than 6 pre-workshop to 8 post-

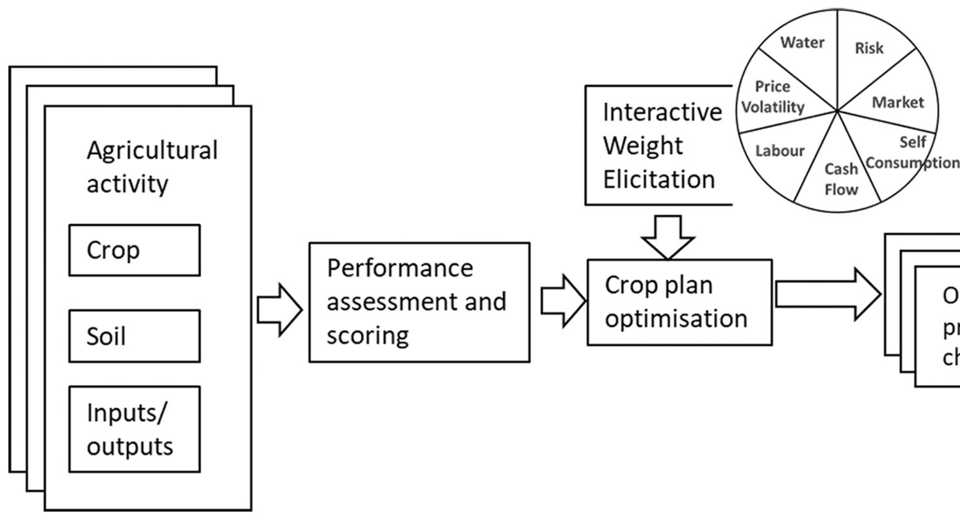

Fig. 2. Model schematic.

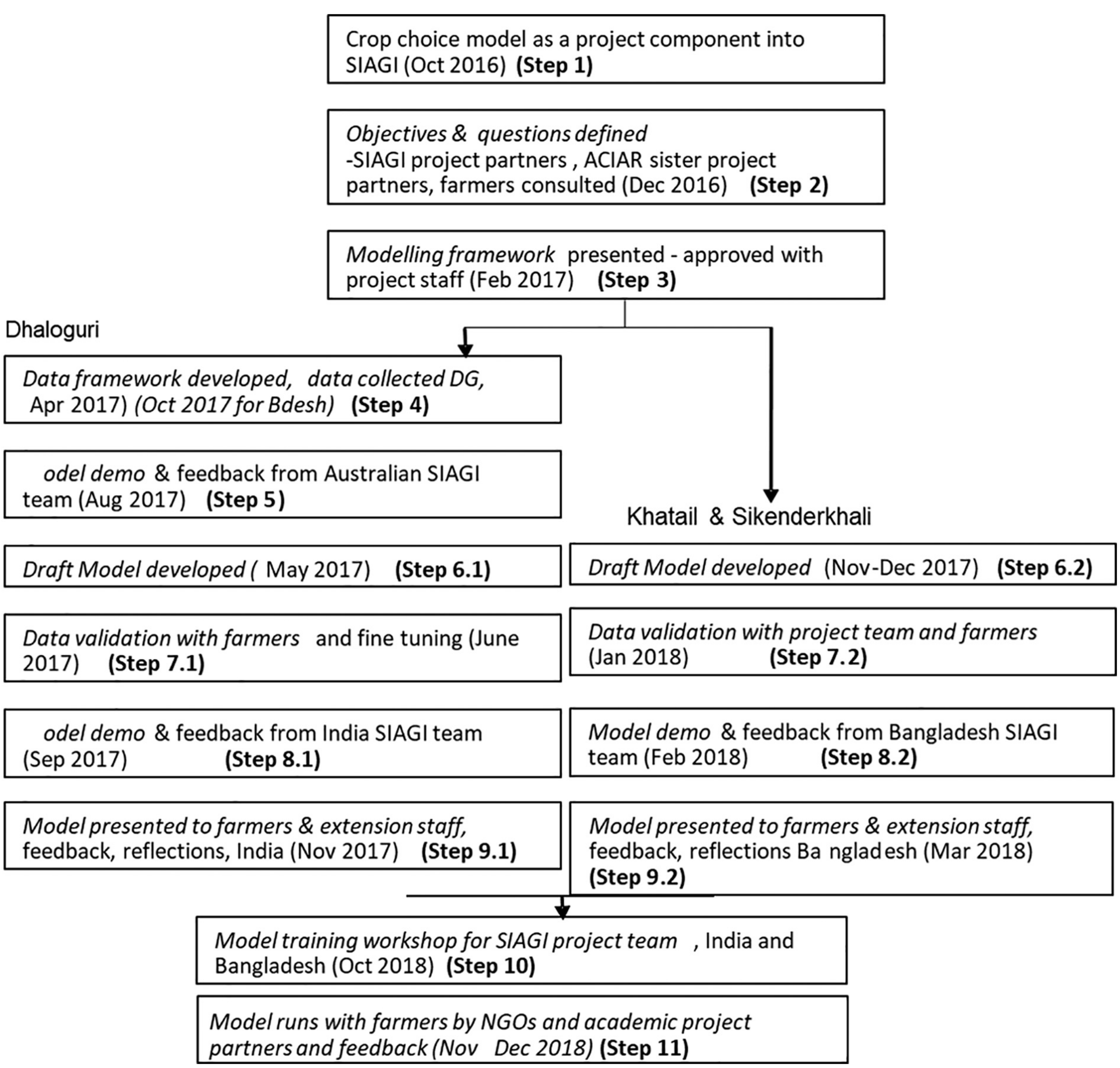

Fig. 3. Participatory model development steps and timeline.

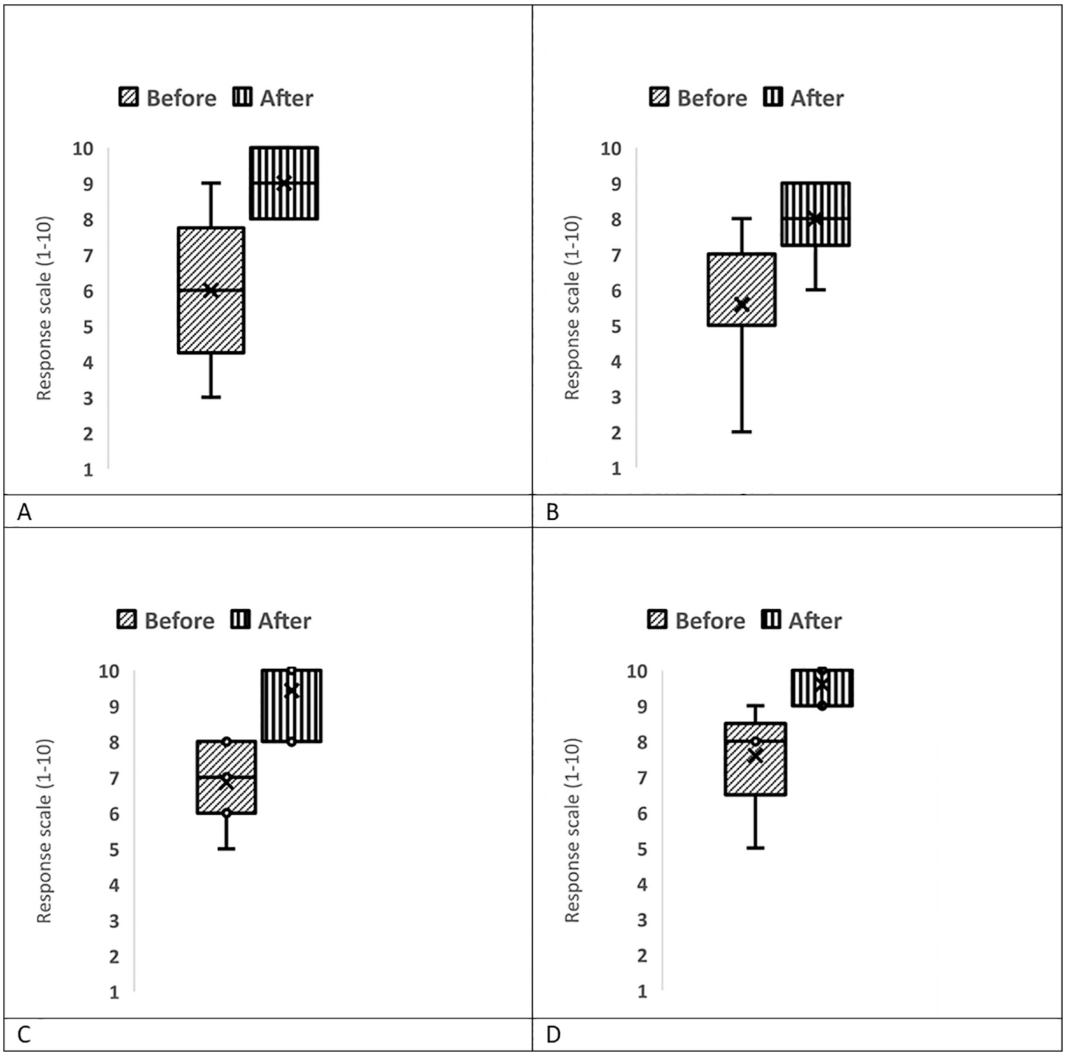

Fig. 4. a: Sikenderkhali – Female farmers' response about awareness of crop choice before and after the workshop $N = 8$. b Sikenderkhali - Male farmers' response about awareness of crop choice before and after the workshop $N = 12$. c Khatail – Female farmers' response about awareness of crop choice before and after the workshop $N = 7$. d Khatail - Male farmers' response about awareness of crop choice before and after the workshop $N = 5$.

workshop (Fig. 4b).

In the case of Khatail, female farmers reported an increased understanding of crop choice decisions between pre- and post-workshop from a median score of 7 to 9 (Fig. 4c). In the case of Khatail male farmers, there is a marginal median score change between pre- and post-workshop. However, the distribution of scores is far tighter in their post-workshop response (Fig. 4d).

On the question if the farmers see this tool as something useful for discussion support, almost all farmers concurred that this tool would help them in their discussions on crop choice, help them explore new cropping options, and has improved their knowledge of crop choices. They also expressed the view that they would need further engagement with the tool overtime to become more familiar with it. The NGO partner/extension agents have been engaging with the farmers, as part of their outreach activities, after they have been trained in the use of the model.

4.2.2. *Dhaloguri*

In Dhaloguri, an important result of the initial engagement with the farmers was more than just discussing scenarios. Participating farmers said that before we presented this tool and discussion, they had had many visits from different project teams, who interacted with them to collect data and information. Farmers were uncertain why data was being collected and often wondered *"if it was waste of their time"*. After the tool was presented and the discussions held, their impression was that their data was being used to develop tools as discussion support (as demonstrated to them in this meeting). They said they realised the importance of data/information/views they provided. There was a genuine feeling of recognition and importance to their data, views and feedback which is an important outcome of the engagement and consistent with the ethical community engagement espoused by SIAGI. They also pointed out that when their data, views and reflections are recognised, they feel included in the research and development process. Hence, they will always be ready to participate in such studies and provide necessary inputs.

4.2.3. *Feedback from NGO partner/extension agents*

The practitioners (NGO and research partners) have been contributors in the design and development of the model. They collected the survey data and helped with FGDs when the model was initially demonstrated to the farmers. Following this they went through a day long training on the model logic, data used in the model and running the model. They then demonstrated their understanding of the model in a mock FGD with the researchers taking the role of farmers and asking questions and seeking clarifications. The presentation and discussions were in Bengali mimicking how they would interact with the farmers.

Following the day long workshop, they responded to the survey questions.

Related to question 1 on how NGO partner/extension agents rate their understanding of the crop choice modelling tool, participants rated their understanding on scale of 1–10 in the range 5–8.5. Six out the 9 of respondents scored between 7 and 8.5 (1 × 8.5; 2 × 8; 3 × 7; 1 × 6; 2 × 5). For respondents, understanding meant either confidence and convenience in using the tool (and explaining it to others) or tool utility (e.g. tool enabled engagement with farmers) or understanding 'the workings of the tool' (the programming that underpinned it). What stood out here was understanding depended on who used it and why (i.e. organizational interest in using the tool). However, it was clear from the responses that the participatory aspect of refining the tool (i.e. bringing our partners along as we developed and refined it), and requiring them to explain it to others, was a key factor in facilitating understanding. With the NGO being the intermediator and using local language, the demonstration was effective and this was reflected in responses of the participants.

On the question whether the modelling tool supported their engagement process and advisory work with the farming community (Q2), all respondents confirmed this positively. In terms of the tool's capacity to support work with farming communities, all the respondents confirmed that the tool supported engagement processes and to some extent cropping decisions. Engagement here has multiple meanings, can be across disciplines (between project members), and across a range of stakeholders (other than NGOs, famers). Observed benefits of the tool to support engagement with farmers as reported by the respondents included:

- connection and trust-building between project members and communities;
- motivation building for farmers (for making decisions around farming generally);
- as a general aid in crop decision making;
- day-to-day record keeping and documentation for decision-making;
- as a tool for approaching local stakeholders for access to local schemes and value chain actors;
- evidence of tool being used in crop decision making and

Benefits of tool to support other aspects of research for development

- common platform for sharing knowledge among multiple actors.

One India case study NGO (Ind_NGO#7) partner commented, *"In formal social science research, scholars usually collect information from the farmers and in return, they give some abstract ideas on how they going to use this information. But in the case of bio-economic modelling farmers experiencing the benefits of research which helps researcher to communicate with the community. Using this tool both farmers, NGOs and researchers are sharing a common platform to develop the traditional farming practices though more optimal decision making"*. IND_NGO#X is an identifier for respondent #X from the Indian case study, Ban_NGO#Y is an identifier for respondent #Y from Bangladesh case studies. A key finding here was that the approach and model had observed benefits for crop and farming decision-making as well as an aid in the process of that decision-making. To the question (Q3) of how their engagement using the tool with farmers had influenced their cropping decisions, respondents reported that the:

- Tool has demonstrated it can produce knowledge that aligns with farmers' experience; aligns to some extent with farmer's current knowledge – providing legitimacy.
- Tool also contains knowledge that is new to farmers, extending their own knowledge
- Tool promotes record-keeping and documentation
- There is evidence of tool influencing farmer behaviour by altering farming practice

Evidence of changed practice:

- Some observed changes include better account keeping practices among farmers

A key point here might be that it's not the tool itself that is the indicator of impact but what happens around it. So, it provides legitimacy (to existing farmer knowledge), and accountability and record-keeping more broadly in farming practice. One NGO partner in Dhaloguri (Ind_NGO#6) commented *"The use of the tool has influenced the farmers to think about a lot more parameters before deciding on a crop. Earlier they used to decide crops mainly as per their established tradition. Also, they realized the importance of keeping records of their accounts"*.

Likewise, another NGO partner in Bangladesh commented (Bng_NGO#2) *"We applied various social tools including the bioeconomic modelling tool to encourage the farmers to choose and practice crops at the field level since they had lack of experience on High Value Crops during Rabi season. Thus, it is very hard to make a decision that farmers' motivation on crops' choice has been changed only for the bioeconomic modelling tool practice, but obviously, bioeconomic modelling tool has an influence among the farmers. At the field level, we practiced crop planning by the farmers. Before preparation of the farmers' crop plan, we identified the suitable and profitable crops using bioeconomic modelling tool with PRA tools"*. The same NGO partner in Bangladesh pointed out *"All farmers have not been influenced, but some farmers in both villages demanded input supports based on the tool demonstration and crop planning. This year, some farmers have also planted bottle gourd, sweet gourd, sweet potato and chili in Sikenderkhali village) and sweet pumpkin and watermelon in Khatail village"*.

In relation to the question (Q4) on what they valued most about the model, the responses included that the tool is generally user-friendly, generally supports community inclusion in farming discussions through some of its features and has scientific merit which generates trust and legitimacy and helps to assist different stakeholders come together to discuss farming more broadly. On the question of what NGO partner/extension agents thought the model needed to be improved, respondents stated that aspects of the model did not adequately capture the complexity of farming for poor farm households (e.g. alternative situations or other livelihood activities – beyond cropping decisions, changing weather patterns and environmental conditions). *"Choosing crops depends on many other factors including the farmers' motivation, their poverty, very small size of agriculture plot (for small and marginal farmers), dependency on weather, quality water, soil salinity level and agriculture support from the government and others" one of the NGO partners (Bng_NGO#2) in Bangladesh pointed out.*

We could frame the impact around three key areas. (i) its value in the process of community inclusion in farming decision-making and it's potential to bring diverse actors together in the development process (ii) its value in knowledge brokering (between science and community and vice versa but also across disciplinary boundaries). Importantly, it seems to have had a knowledge validation effect in that it provides some legitimacy to farmers' existing knowledge and (iii) the model and the outputs it generates has a role in engagement, inclusion and knowledge production more generally.

NGO partners were acting as "intermediaries" for knowledge transfer. We wanted to get feedback on how well they understood the workings of the model before they went out and engaged with the farmers. NGO partners reported the feedback from the farmers (qualitative info) and summarized that the tool has been useful to discuss crop choices, that they understand that various components of cost of cultivation need to be included in their profit/loss discussion (as farmers only focused on the revenue but not as much attention to the costs). Detailed responses to the survey are provided in Appendix 1.

5. Discussion

One of the objectives of this work was to explore if systems models can be developed that allow user engagement to explore options for crop choice in an attempt to bridge gap between modelling tools and their use, a need that was highlighted by Antle et al. (2017) and consistent with McIntosh et al. (2008) arguing the importance of bridging the gap between design and use by engaging users and other stakeholders. Relating to the first question raised in the Introduction 'what processes need to be conceptualised and actioned for the model to be used in a decision process?', it reinforced the fact that for models to be useful discussion tools, they need to incorporate the preferences of the participating farmers so they become realistic to the situation on the ground. The other key learning is that a gender-sensitive approach helped to unpack the variation across gender and is especially critical where female members of the farming community take significant responsibilities in farming activities. Including extension agents/NGO partners as intermediaries and potential facilitators of the model from the conceptual stage to model delivery is critical for continued use of these tools post-project life. For farmers, the learnings are that understanding the cost of cultivation is equally important as the focus on revenue, and that models such as this help explicitly to lay out the costs of cultivation. The male and female farmer preferences were explicitly expressed, resulting in different crop choices and facilitating a structured discussion among themselves on the reasons for the preferences and the pros and cons of these choices. The outcomes of this approach are consistent with Groot et al. (2012) suggestion that the utility of bioeconomic modelling tools' role in design of mixed farming system has a strong potential to support learning by farmers, NGO/extension agents and scientists.

A key innovation of the model has been the inclusion of gender in its design so male and female farmers could participate equally in crop choice discussions. This approach followed the goal of SIAGI in facilitating the inclusion of often excluded individuals and groups in agricultural development decisions and processes. Historically, gender inequality remains a deeply entrenched institutional barrier to economic empowerment in development settings (Hansda, 2018). Using the scoring and weight elicitation process, the model facilitated both male and female farmers to input their preferences of crop choice allowing model outputs to be consistent with their individual preferences across the seven variables viz., water, risk, markets, self-consumption, cash flow, labour and price volatility.

Gender specific preferences helped with highlighting differences in perspectives between male and female farmers. While these discussions are a regular feature in farming families, the scenario development activity enabled a more explicit expression of the choices. For example, in the case of Dhaloguri, in a scenario where minimising labour was important for female farmers the model's crop choice was coriander, eggplant and spinach while profit and markets were important for male farmers the crop choice was cabbage and tomato. In the case of Khatail, in the scenario where risk and optimising water were important for female farmers, the model choice was on sweet pumpkin and bottle gourd while for male farmers the crop choice was bottle gourd, potato and watermelon. Male and female farmers priorities and preferences on which crop to grow differ for a number of reasons including labour, regular cash flow (e.g. chilies) versus one-off income (e.g. potatoes). The ability of the model to differentiate the crop choices to reflect the preferences and priorities of the male and female farmers is a key contribution of this approach. The engagement with male and female farmers on capturing the preferences and including in the model that eventually reflected in the crop choices provided a basis for objective discussions.

The model scenarios presented are a sample from potentially hundreds of scenarios that can be generated with the model. These scenarios are those that participating farmers indicated during the workshops we held with them in the case study villages. The objective of the workshops was to expose users to the model and 'validate' the model results using their preferences of crop choice. Feedback received from farmers made it clear that the choices made via the model interaction corresponded to their preferences. This helped to build confidence of the participating farming community to generate of scenarios to explore options in collaboration with NGO extension partners and researchers. These scenarios are useful in discussions among farming communities and the eventual decision on which crop to plant in the upcoming season is entirely up to them based on the model generated options and various variables that are not included in the model such for example access to credit, expertise in growing a certain crop, access to timely inputs, family circumstances among many others.

This tool may also be useful in assessing new or emerging agronomic practices (with which farmers are currently unfamiliar) from a socio-economic perspective. Such assessments would necessarily differ from the examples described here, as farmers would be unable to provide sensible estimates of crop yields, risk, and water use for these technologies directly from their experiences. Well-tested cropping systems models (like APSIM) could provide estimates of such variables as inputs to the model. There are numerous examples of linking models of different scale and focus to deliver pragmatic outcomes in such situations (Brennan et al., 2008; Kabir et al., 2017; Mainuddin et al., 2020). The outcomes we anticipate among farming communities are improved understanding on the various factors influencing crop choices, how male and female farmers consider (and differ) in their choices when choosing what crops to grow and potentially, a useful discussion tool for NGO extension partners to engage with farming communities more effectively along with their PRA tools.

In relation to the second question raised in the Introduction 'what data collection and modelling interface will help with the integration?', the model interface was deliberately designed with ease-of-use as an objective consistent with Rose et al. (2018) suggestion of a user centred design practices. Since the modelling tool is intended to be used as a discussion tool with farmers, the model outputs have been developed to be displayed in local language - Bengali. Once the model interface had been developed, the capacity building workshops with project partners helped users to understand the software and its functions. NGO partner/extension agents were able to use the modelling tool with the expectation that these tools add to their portfolio of approaches for engaging with farming communities and provides an example of a tool that can cross the 'technology barrier'.

Feedback on the utility of the model from farmers (Section 4.2.1) has clearly indicated improved understanding of the various components which requires consideration before making crop choice decisions. As can be seen in Fig. 4 there is a wider distribution of scores pre-workshop and the distribution of the scores did improve after the workshop which indicates that participation in the workshop improved understanding of crop choice approaches post-workshop. Participating farmers, NGOs and academic partners commented that an important asset of the modelling was that it provided them a better appreciation of the various inputs that were applied in growing different crops in the region, and costs and revenues as a result of their crop choices. While making this statement, we refer back to the methods section on the survey and reiterate the point that these feedback data were from a small sample of farmers and that it was provided immediately after the workshop.

In relation to the third research question on the level of interactions between the 'modellers', farmers and the 'NGO extension agents (in-country project partners)' that would be required, it is evident from the study that a collaborative learning process between key stakeholders i.e., researchers, extension staff, NGOs and participating farmers is critical. The method adopted in this work is consistent with the approaches summarized in Fig. 3 outlining the step-wise approach that we took to conceptualise the model development with modellers, extension staff and participating farmers and is consistent with the approach suggested by McIntosh et al. (2008). As Klerkx et al. (2017) and Kloprogge and Van Der Sluijs (2006) suggest, this study highlights the importance of inclusion of local stakeholders in the research process to contextualize research problem and incorporate local condition and build trust among stakeholders. In the context of Fritz et al. (2019) proposed approach of transdisciplinary research, this study covered the three key areas – 'arena of actor collaboration' – where researchers, NGO/extension agents, academic partners and farmers collaborated in the development of the model; 'arena of involved practitioners' – where networks have been developed and/or strengthened between the stakeholders as part of the model development process outlined in Fig. 3; 'arena of wider practice context' where the awareness among the stakeholders (NGO/extension partners and farmers) was raised on the various dimensions of crop choice decisions.

As researchers, we observed that during the discussions that male farmers were more concerned over market, profit, and the underlying risks, while female farmers were more focussed on self-consumption of the produce by their family members, labour requirement, and regular flow of returns. Decision-making practices in the households is a collective process with participation of both men and women members where women could freely express their opinions over any crop choice and men listened to their concerns carefully before taking a final call. Nevertheless, the final decisions are often driven by the objectives of farming, which in turn depend on whether the household head is male or female. Male and female farmers came together and worked in a group in this activity where extension officials and practitioners involved themselves in a supportive manner. This created a space for dialogue and mutual consideration among men and women farmers as well as among all the stakeholders. The extension services officials reflected that this engagement tool will make their future interventions more informative and hence convincing to the farmers.

The feedback received from academic and NGO partner/extension agents in the region on the utility of the model is critical in assessing the utility and value of the model beyond the life of the project. The feedback from respondents indicates that they have a good understanding of the model concept and how it works where 7 out 9 respondents assessed themselves at 6.5–8.5 on a range of 1–10 for understanding. From self-reported NGO partner/extension agents' experiences of using the modelling tool with farming communities, it was highlighted that the tool assisted them to build trust with the communities that they were interacting with because farmers could see that the data they provided had been collected and used in a way that supported their decisions. A key observation from respondents was that with the tool, multiple aspects of crop choice decision making were made explicit both for the extension workers and the farmers. Enhanced record keeping of costs incurred in farming activities was an important outcome of this process. Earlier to the model discussions, farmers in these villages only focused on the revenue from selling the crops but not the costs of producing them. Feedback from NGO partner/extension agents revealed that farming communities valued engaging with this modelling tool as they saw that it brought new knowledge and extended their own knowledge on combining a number of variables in crop choice decision making.

6. Conclusions

This study demonstrated that appropriate design and development principles enabled 'complex' systems models to be used by NGO partner/extension agents to engage with farming communities as discussion support tools in farming decisions. The value of modelling tool to bring together researchers, extension agents and farmers in farming decision-making helps in the development process brining in legitimacy and building trust (Cash et al., 2003; Sterk et al., 2011). In addition to inclusion of development actors, participatory model development allows for the brokering of diverse knowledge types (between science and community and across multiple disciplinary boundaries (Adelle, 2015). Importantly, the co-development process has had a knowledge validation effect in that it provides some legitimacy to farmers' existing knowledge, which helps to build confidence in farming decisions. Using the reflective learning process, we highlight that the modelling is not an end in itself but should support a co-learning process among researchers and the farming community (Norström et al., 2020). Farming systems models need to consider the gender dimension and its critical role in farm decision making and how this can be included in models to reflect the diversity of decision process. While the modelling tool may support informed discussion in making cropping choices, the outcomes of improved financial and food security will be a diffused pathway. Attribution of these outcomes from the tool application needs to be carefully calibrated while emphasising that this tool is not a prescriptive tool but rather a discussion tool.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix 1

Sample responses to the questions in relation to their understanding of the bioeconomic modelling tool and its application in their communities (IND_NGO#1 is identifier for respondent #1 from Indian case study, Ban_NGO#2 is identifier for respondent #2 from Bangladesh case studies)

Question	Response
What is your understanding of the bioeconomic modelling tool?	"I am fully confident to run this model and can discuss with the community according to their language and culture. I made some PRA tools based on the bio-economic modelling tool for choosing suitable crops and easy understanding of the field staff and the community" (Ban_NGO#2). "Very logical structure of the model - Combines multiple objectives with diverse but complex factors in logical fashion; Involvement during the process of designing of the model, data collection, demonstration, etc. helped in better understanding of the model. Presentations and discussions in several team meetings also benefitted in this regard. The tool is very user friendly – could be experimented quite easily". (Ind_NGO#5)

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(*continued*)

Question	Response
	"The bio-economic modelling is a good discussion tool to engage the farmers. It provides opportunities to learning, sharing and reflecting from each-other in the project location".(Ind_NGO#8)
How does the modelling tool support your engagement process and advisory work with the farming community?	"I had the opportunity to work with the scientists who developed the model and got training to apply the model at field level, I feel comfortable to engage with the community as we could demonstrate the model in front of them thereby provoke joint discussion." (Ban_NGO#1)
	"To motivate the farmers in a different way to choose the crops not only using social process/PRA tools but also using technology with various factors of agricultural inputs, risks and opportunities. When both the social process and computer technology are used, farmers may find a better motivation". (Ban_NGO#2)
	"Given production and market related risks, making informed crop choice is very important to mitigate the same, particularly by the small and marginal farmers. While the farmers make cropping decisions on their own, systematic information processing and dissemination now make the engagement process ethical (as it does not only gather information, but also disseminates and takes reflections into consideration)". (Ind_NGO#5)
	"In formal social science research, scholars usually collect information from the farmers and in return, they give some abstract ideas on how they going to use this information. But in the case of Bio-economic Modelling farmers experiencing the benefits of research which helps researcher to communicate with the community. Using this tool both farmers, NGOs and researchers are sharing a common platform to develop the traditional farming practices though more optimal decision making". (Ind_NGO#7)
If the tool helps you in your work, how would you know?	"It helps me to connect with the farming community in a better way, it also helps to enhance trust between researcher and farming community as they got familiarly- how we work with data." (Ban_NGO#1)
	"The benefits of the tool could be realized during subsequent engagement with the community. It was reflected by the farmers that they are now more systematic and confident in making cropping decisions" (Ind_NGO#5)
	"My understanding of crop choice decision making, and related parameters has broadened with the use of bioeconomic modelling tool". (Ind_NGO#6)
	"Individual farmers and their groups are maintaining the record keeping and resolution books and farmers are now confidently sharing the crops and irrigation data". (Ind_NGO#8)
Can you give examples of how your engagement using the tool with farmers has influenced their cropping decisions?	"I see the farmer happy faces during demonstration. It implies that they accept the demonstration. However, they consult themselves about the tools and match with their own experience then apply". (Ban_NGO#1)
	"All farmers have not been influenced, but some farmers in both villages demanded input support based on the tool demonstration and crop planning. This, year, some farmers have also planted bottle gourd, sweet gourd, sweet potato and chili in Sikenderkhali village and sweet pumpkin and watermelon in Khatail village". (Ban_NGO#2)
	"I would like to mention about a program which had a deep impact on the farmers of Sikenderkhali. On 12th November, a demonstration program on tool was held. Most of the active male and female farmers attended the program. During this demonstration farmers set weight factors according to their choice and generated several vegetable choices. According to the scenario generated from the tool, suggested crops were bottle guard, sweet potato, potato, okra, green pepper, pumpkin. Three farmers of the village were totally surprised and agreed with the result since they benefited from the bottle guard and okra in that season. Since the tool also suggested the same vegetables, the coincidence created a great impact on the farmer's mind. After that, several calls from farmer side come up to further discuss using the tool. Now a days, bottle guard and pumpkin are now popular vegetables in Sikenderkhali as high value crops." (Ban_NGO#3)
If farmers have changed practices, how would you know it was because of the engagement with the model?	"It is very difficult to disaggregate the effects of bioeconomic model in changing practices. I do believe, if the tool is used regularly (each season) by the local partner then it would be easy to distinguish the exact effects of bioeconomic model" (Ban_NGO#1)
	"We applied various social tools including the bioeconomic modelling tool to encourage the farmers to choose and practice crops at the field level since they had lack of experience on High Value Crops during Rabi season. Thus, it is very hard to make a decision that farmers' motivation on crops' choice has been changed only for the bioeconomic modelling tool practice, but obviously, bioeconomic modelling tool has an influence among the farmers. At the field level, we practiced crop planning by the farmers. Before preparation of the farmers' crop plan, we identified the suitable and profitable crops using bioeconomic modelling tool with PRA tools". (Ban_NGO#2)
	"The farmers revealed that the tool has changed their farming practices in gathering and analyzing various information (instead of relying only on the age-old practices). It is also noticed that now they record necessary information and maintain accounts (in respect of costs and earnings) regularly. Such practices were not noticed before engagement with the farmers using this tool". (Ind_NGO#5)
What do you like most about the model? What do you think needs to be improved?	"The best thing of the model is that we could demonstrate the model in front of the farming community which is unusual case for other models. Both literate and illiterate farmers could take part in the discussion. Model itself is ok it has enough flexibility, but we need to demonstrate more in the field". (Ban_NGO#1)
	"Farmers do not operate the bioeconomic modelling tool, but they can understand that the computer software is giving the results based on the data they have provided. Moreover, they can change the options/score of data. Another beauty of this model is that the result is generated in Bangla (some farmers can read and understand Bangla)". (Ban_NGO#2)
	"The model deals with a lot of parameters at a time which is good but while disseminating the outcome it may confuse the farmers thinking. So, in the outcome part if focus can be given only one or two major parameters that will help farmers' thinking process". (Ind_NGO#6)
	"With this model optimal utilization of resources and management can be possible for marginal framers. In rural areas, some problems can be solved through better communication among farmers. In scenario analysis, part farmers are passing information to build a better opportunity for themselves". (Ind_NGO#7)
	"We need to think about how to use it under facilitation of farming communities themselves at everywhere by reducing dependency on technology (computer / programing). It can be challenging issue for scaling-out". (Ind_NGO#8)

References

Adelle, C., 2015. Contexualising the tool development process through a knowledge brokering approach: the case of climate change adaptation and agriculture. Environ. Sci. Pol. 51, 316–324.

Antle, J.M., Jones, J.W., Rosenzweig, C.E., 2017. Next generation agricultural system data, models and knowledge products: introduction. Agric. Syst. 155, 186–190.

Basco-Carrera, L., Warren, A., van Beek, E., Jonoski, A., Giardino, A., 2017. Collaborative modelling or participatory modelling? A framework for water resources management. Environ. Model. Softw. 91, 95–110.

Behrendt, K., Cacho, O., Scott, J.M., Jones, R., 2016. Using seasonal stochastic dynamic programming to identify optimal management decisions that achieve maximum economic sustainable yields from grasslands under climate risk. Agric. Syst. 145, 13–23.

Belcher, B.M., Claus, R., Davel, R., Ramirez, L.F., 2019. Linking transdisciplinary research characteristics and quality to effectiveness: a comparative analysis of five research-for-development projects. Environ. Sci. Pol. 101, 192–203.

Berthet, E.T., Hickey, G.M., Klerkx, L., 2018. Opening design and innovation processes in agriculture: insights from design and management sciences and future directions. Agric. Syst. 165, 111–115.

Brennan, L.E., Lisson, S.N., Poulton, P.L., Carberry, P.S., Bristow, K.L., Khan, S., 2008. A farm-scale, bio-economic model for assessing investments in recycled water for irrigation. Aust. J. Agric. Res. 59.

Carter, L., Williams, L., Cosijn, M., 2019. The Principles and Practices of Ethical Community Engagement Resources to Support Engaging for Impact. https://siagi.files.wordpress.com/2019/10/2019-09-siagi_rdi_ece-prinicples-and-practices_final.pdf.

Cash, D.W., Clark, W.C., Alcock, F., Dickson, N.M., Eckley, N., Guston, D.H., Jager, J., Mitchell, R.B., 2003. Knowledge systems for sustainable development. Proc. Natl. Acad. Sci. U. S. A. 100, 8086–8091.

Ditzler, L., Klerkx, L., Chan-Dentoni, J., Posthumus, H., Krupnik, T.J., Ridaura, S.L., Groot, J.C., 2018. Affordances of agricultural systems analysis tools: a review and framework to enhance tool design and implementation. Agric. Syst. 164, 20–30.

Fritz, L., Schilling, T., Binder, C.R., 2019. Participation-effect pathways in transdisciplinary sustainability research: an empirical analysis of researchers' and practitioners' perceptions using a systems approach. Environ. Sci. Pol. 102, 65–77.

Groot, J.C.J., Oomen, G.J.M., Rossing, W.A.H., 2012. Multi-objective optimization and design of farming systems. Agric. Syst. 110, 63–77.

Hansda, R., 2018. Small-scale farming and gender-friendly agricultural technologies: the interplay between gender, labour, caste, policy and practice. Gend. Technol. Dev. 21, 189–205.

Iglesias, E., Báez, K., Diaz-Ambrona, C.H., 2016. Assessing drought risk in Mediterranean Dehesa grazing lands. Agric. Syst. 149, 65–74.

Janssen, S., van Ittersum, M.K., 2007. Assessing farm innovations and responses to policies: A review of bio-economic farm models. Agric. Syst. 94, 622–636.

Kabir, J., Cramb, R., Gaydon, D.S., Roth, C.H., 2017. Bio-economic evaluation of cropping systems for saline coastal Bangladesh: II. Economic viability in historical and future environments. Agric. Syst. 155, 103–115.

Kalvelagen, E., 2002. Solving Multi-Objective Models with GAMS.

Klerkx, L., Seuneke, P., de Wolf, P., Rossing, W.A.H., 2017. Replication and translation of co-innovation: the influence of institutional context in large international participatory research projects. Land Use Policy 61, 276–292.

Kloprogge, P., Van Der Sluijs, J.P., 2006. The inclusion of stakeholder knowledge and perspectives in integrated assessment of climate change. Clim. Chang. 75 (3), 359–389.

Kragt, M.E., Pannell, D.J., McVittie, A., Stott, A.W., Vosough Ahmadi, B., Wilson, P., 2016. Improving interdisciplinary collaboration in bio-economic modelling for agricultural systems. Agric. Syst. 143, 217–224.

Lisson, S., MacLeod, N., McDonald, C., Corfield, J., Pengelly, B., Wirajaswadi, L., Rahman, R., Bahar, S., Padjung, R., Razak, N., Puspadi, K., Dahlanuddin, Sutaryono, Y., Saenong, S., Panjaitan, T., Hadiawati, L., Ash, A., Brennan, L., 2010. A participatory, farming systems approach to improving Bali cattle production in the smallholder crop–livestock systems of Eastern Indonesia. Agric. Syst. 103, 486–497.

Mainuddin, M., Bell, R.W., Gaydon, D.S., Kirby, J.M., Barrett-Lennard, E.G., Glover, M., Razzaque, M.A., Maji, B., Ali, M.A., Bramachari, K., Maniruzzaman, M., 2019. An overview of the Ganges coastal zone: climate, hydrology, land use and vulnerability. J. Indian Soc. Coast. Agricult. Res. 37 (2), 1–11.

Mainuddin, M., Maniruzzaman, M., Gaydon, D.S., Sarkar, S., Rahman, M.A., Sarangi, S. K., Sarker, K.K., Kirby, J.M., 2020. A water and salt balance model for the polders and islands in the Ganges delta. J. Hydrol. 587.

McCown, R.L., 2002. Changing systems for supporting farmers' decisions: problems, paradigms, and prospects. Agric. Syst. 74, 179–220.

McIntosh, B.S., Giupponi, C., Voinov, A.A., Smith, C., Matthews, K.B., Monticino, M., Kolkman, M.J., Crossman, N., van Ittersum, M., Haase, D., Haase, A., Mysiak, J., Groot, J.C.J., Sieber, S., Verweij, P., Quinn, N., Waeger, P., Gaber, N., Hepting, D., Scholten, H., Sulis, A., van Delden, H., Gaddis, E., Assaf, H., 2008. Chapter three bridging the gaps between design and use: Developing tools to support environmental management and policy. In: Jakeman, A.J., Voinov, A.A., Rizzoli, A. E., Chen, S.H. (Eds.), Developments in Integrated Environmental Assessment, Vol. 3. Elsevier, pp. 33–48.

Nidumolu, U., van Keulen, H., Lubbers, M., Mapfumo, A., 2007. Combining interactive multiple goal linear programming with an inter-stakeholder communication matrix to generate land use options. Environ. Model. Softw. 22, 73–83.

Nidumolu, U.B., Lubbers, M., Kanellopoulos, A., van Ittersum, M.K., Kadiyala, D.M., Sreenivas, G., 2016. Engaging farmers on climate risk through targeted integration of bio-economic modelling and seasonal climate forecasts. Agric. Syst. 149, 175–184.

Norström, A.V., Cvitanovic, C., Löf, M.F., West, S., Wyborn, C., Balvanera, P., Bednarek, A.T., Bennett, E.M., Biggs, R., de Bremond, A., Campbell, B.M., Canadell, J.G., Carpenter, S.R., Folke, C., Fulton, E.A., Gaffney, O., Gelcich, S., Jouffray, J.-B., Leach, M., Le Tissier, M., Martín-López, B., Louder, E., Loutre, M.-F., Meadow, A.M., Nagendra, H., Payne, D., Peterson, G.D., Reyers, B., Scholes, R., Speranza, C.I., Spierenburg, M., Stafford-Smith, M., Tengö, M., van der Hel, S., van Putten, I., Österblom, H., 2020. Principles for knowledge co-production in sustainability research. Nat. Sustain. 3, 182–190.

Rahman, M.W., Jahan, H., Palash, M.S., Mainuddin, M., Shok, J., 2020. An empirical investigation of men's views of women's contribution to farming in Northwest Bangladesh. Sustainability 12, 3521. https://doi.org/10.3390/su12093521.

Reidsma, P., Janssen, S., Jansen, J., van Ittersum, M.K., 2018. On the development and use of farm models for policy impact assessment in the European Union – A review. Agric. Syst. 159, 111–125.

Rose, D.C., Parker, C., Fodey, J.O.E., Park, C., Sutherland, W.J., Dicks, L.V., 2018. Involving stakeholders in agricultural decision support systems: improving user-centred design. Int. J. Agricult. Manag. 6 (3–4), 80–89.

Sterk, B., van Ittersum, M.K., Leeuwis, C., 2011. How, when, and for what reasons does land use modelling contribute to societal problem solving? Environ. Model. Softw. 26, 310–316.

Tanure, S., Nabinger, C., Becker, J.L., 2013. Bioeconomic model of decision support system for farm management. Part I: systemic conceptual modeling. Agric. Syst. 115, 104–116.

Villalba, D., Díez-Unquera, B., Carrascal, A., Bernués, A., Ruiz, R., 2019. Multi-objective simulation and optimisation of dairy sheep farms: exploring trade-offs between economic and environmental outcomes. Agric. Syst. 173, 107–118.