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Contents

1 Acknowledgments

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2 Executive summary

In this project, we have adapted the AgMIP (Agricultural Model Intercomparison and Improvement Project) Regional Integrated Assessment (RIA) approach, previously implemented across Sub-Saharan Africa and South Asia, to assess not only adaptation but also mitigation capacity. The AgMIP RIA approach links climate, crop/livestock and socioeconomic data, models, and tools in order to assess the impacts of agricultural mitigation and adaptation interventions under current and future climate conditions. We used this framework to conduct simulation experiments on sustainable rice management options. These included evaluations of conventional continuous flood, alternate wetting and drying and the system of rice intensification under current and future (changed) climate. This approach allowed us to test locally adapted components of management interventions to conditions that are either too resource intensive to undertake in field trials alone (e.g., testing multiple cultivars, inputs, or changes in policies) or involve different future scenarios (e.g., climate change).

We evaluated rice production systems under current and future climate conditions in over 6,000 field sites covering eight major rice production districts in Bangladesh by conducting crop and economic simulations using projections of future regional climate conditions and socio-economic data. We used two sets of data to characterize the rice production systems in the districts of Rangpur, Rajshahi, Faridpur, Gopalganj, Lalmonirhat, Kishoreganj, Dinajpur, and Jashore. This data was used to parameterize the crop and economic simulation models. A farm-level survey data collected by the Bangladesh Rural Advancement Committee (BRAC) and Monash University enabled us to implement the AgMIP RIA whole farm approach in three of the districts. A second set of plot-level data, collected by CIMMYT and the Department of Agriculture Extension was used to estimate yields and economic returns per hectare in the other 5 districts. This enabled the assessment of the potential mitigation and adaptation co-benefits and tradeoffs of different rice management practices in the country.

This study serves as an initial pilot for applying these methods more broadly and systematically to evaluate sustainable farming systems and other mitigation and adaptation options across many countries using AgMIP methodology.

Major messages and results from this project are:

- Climate change reduces farm net returns in most sites and increases greenhouse gas (GHG) emissions.
    - Climate change can result in gainers and losers due to biophysical and socio-economic heterogeneity conditions.
    - This study shows that between 45% to 60% of rice producers are vulnerable to climate change. Even in cases where the net economic impacts (gains minus losses) are positive, the proportion of households vulnerable to climate change is high.
    - In some cases, even when climate change leads to an increase in crop yields and consequent increase in farm net returns, there can be substantial socio-economic and environmental tradeoffs.
- Adoption of Conventional Alternative Wetting and Drying (AWD) or the System of Rice Intensification with AWD (SRI-AWD) under current or future climate shows:
    - Potential adoption rates range between 48% to 67% depending on the system, scenario and type of farm.
    - Strong reductions in GHG emissions of methane and CO2eq.
    - Changes in N2O emissions vary across sites and farm types (small vs large) and how farms manage their crops (e.g., amount of fertilizer use).

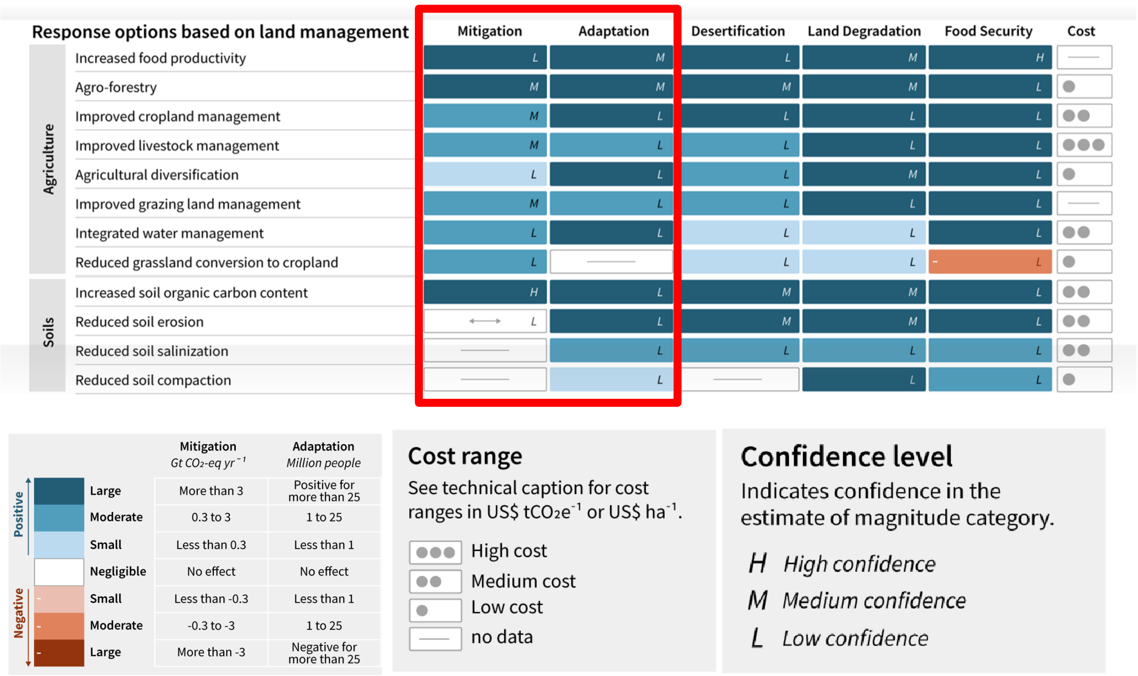
  - Irrigation water use efficiency improves.
- Both Conventional AWD and SRI show potential co-benefits in reducing GHG emissions and increasing income and reducing poverty rates in the region (win-win outcomes).
- SRI shows the largest socio-economic and environmental benefits. However, a more thorough evaluation of socio-economic impacts on farmers and communities, such as gender and food and nutrition security, needs to be incorporated in addition to environmental considerations.
- AWD and SRI are likely to be more resilient to climate change compared to continuous flood systems.
- The DNDC (DeNitrification DeComposition) model is now calibrated and validated to be used to test MAC-B interventions in Bangladesh.
- The estimated potential adoption rates of SRI in this pilot project fall within the range of actual adoption rates identified by Barrett et al., 2022 for farms that received training in SRI management in their study.
- Further research is required to evaluate and comprehend potential barriers or limitations to adoption, such as labor issues, access to water, and control over it.

3 Background

There is increasing interest across research, development, and policy-making communities in identifying agriculture and food system interventions that contribute to food security, climate mitigation and adaptation. The aim is to evaluate the resulting co-benefits, in order to promote and enable their implementation. The IPCC Special Report on Climate Change and Land highlighted the importance of conducting this type of assessment (Figure 3.1) (IPCC, 2019).

Co-benefits span a range of outcomes, from biophysical/chemical (e.g., water conservation or biodiversity) to socio-economic (e.g., resilience to shocks). They can be global (e.g., targeting planetary boundaries), national (contributing to the development of Nationally Determined Contributions (NDCs) and National Adaptation Plans (NAPs) and/or highly regionally dependent, (e.g., relevant to provincial-level policies and goals).

Several interventions for agriculture, such as increasing food productivity, agroforestry, and increased soil organic carbon content, are shown to have mitigation and adaptation co-benefits at the global scale (IPCC 2019). Yet one of the key reasons for the emphasis on mitigation-adaptation co-benefits is that mitigation actions may not be possible to implement unless they deliver direct benefits to farmers. Thus, co-benefits at regional and local scales are particularly important. However, there is limited knowledge at regional and local scales of the potential for co-benefits of agricultural mitigation and adaptation interventions, including their effects on productivity, prospects of adoption, and associated socio-economic impacts, including on gender and nutrition outcomes.



	Response options based on land management	Mitigation	Adaptation	Desertification	Land Degradation	Food Security	Cost
Agriculture	Increased food productivity	L	M	L	M	H	—
	Agro-forestry	M	M	M	M	L	●
	Improved cropland management	M	L	L	L	L	●●
	Improved livestock management	M	L	L	L	L	●●●
	Agricultural diversification	L	L	L	M	L	●
	Improved grazing land management	M	L	L	L	L	—
	Integrated water management	L	L	L	L	L	●●
	Reduced grassland conversion to cropland	L	—	L	L	- L	●
Soils	Increased soil organic carbon content	H	L	M	M	L	●●
	Reduced soil erosion	←→ L	L	M	M	L	●●
	Reduced soil salinization	—	L	L	L	L	●●
	Reduced soil compaction	—	L	—	L	L	●

			Mitigation *Gt CO₂-eq yr⁻¹*	Adaptation *Million people*
Positive		Large	More than 3	Positive for more than 25
		Moderate	0.3 to 3	1 to 25
		Small	Less than 0.3	Less than 1
		Negligible	No effect	No effect
Negative	-	Small	Less than -0.3	Less than 1
	-	Moderate	-0.3 to -3	1 to 25
	-	Large	More than -3	Negative for more than 25

Cost range

See technical caption for cost ranges in US$ tCO2e^{-1} or US$ ha^{-1}.

●●● High cost

●● Medium cost

● Low cost

— no data

Confidence level

Indicates confidence in the estimate of magnitude category.

H High confidence

M Medium confidence

L Low confidence

Fig 3.1. Potential global contribution of response options based on land management to mitigation and adaptation (red rectangle) (IPCC 2019).

One reason for such limited knowledge is that much of the research has focused on empirical studies about individual interventions and the benefits they may provide on their own. This approach requires many studies and many years of research to build the evidence base to compare the interventions and decide which may be the most appropriate to implement. The AgMIP co-benefits modeling approach allows more efficient screening of many potential interventions and their interactions across multiple sites at once, with the result being the identification of a subset that are most promising. Empirical research can then focus on validating this subset of most promising interventions, and supporting the social and institutional mechanisms for their wide scale implementation. Thus, co-benefits modeling can significantly accelerate the innovation pathway, which is vital considering the increasing rate of climate change and increasing calls for more rapid and more ambitious actions across all sectors of the economy (IPCC, 2023).

The AgMIP Mitigation and Adaptation Co-Benefits (MAC-B) approach consists of a set of models, processes, and techniques for understanding and projecting co-benefits (as well as potential trade-offs) to advance agricultural solutions to climate change and sustainable development (Figure 3.2).

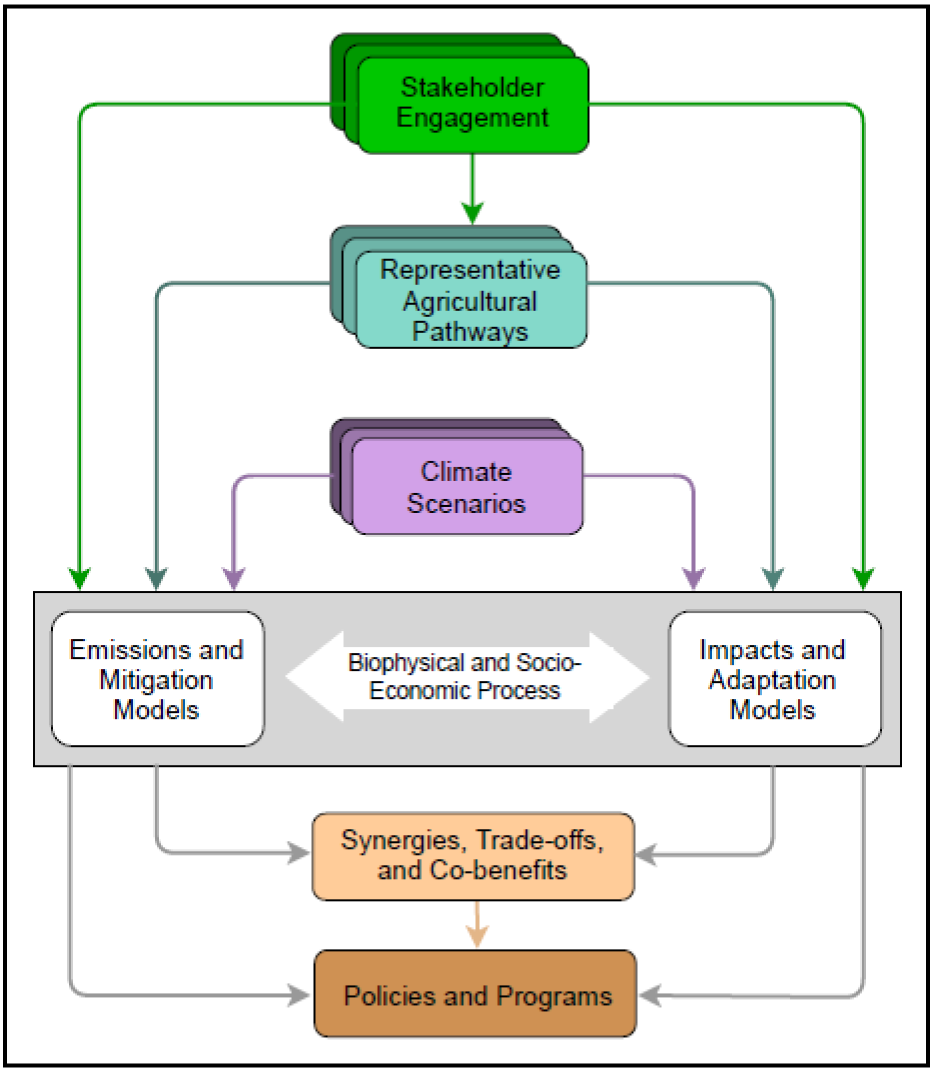


Fig 3.2. Mitigation and Adaptation Co-Benefits (MAC-B) Conceptual Framework.

The MAC-B approach has been developed through the Agricultural Model Intercomparison and Improvement Project (AgMIP) – a global research network focused on modeling agriculture under current and future climate change. Overall, the AgMIP MAC-B approach seeks to answer the following research questions when assessing potential technological innovations or policy interventions:

1) What are the benefits and/or disadvantages for farmers?

2) What are the mitigation benefits?

3) What are the adaptation benefits?

4) What are the mitigation and adaptation trade-offs?

5) What are promising management intervention packages that optimize both farmer benefits and climate mitigation and adaptation?

Criticisms of Integrated Assessment methods have identified the potential for modeling studies to latch on to 'silver bullets' without regard to the on-the-ground contexts for farmers. The AgMIP approach avoids such outcomes by engaging in a robust stakeholder engagement process to guide the modeling work throughout the process. From the AgMIP MAC-B stakeholder-driven simulations we identified a short-list of promising interventions and conducted iterative stakeholder engagement to explore their feasibility.

AgMIP supports policy decision-making through stakeholder engagement that identifies critical drivers of agricultural development pathways consistent with countries' food security and environmental goals. These pathways enable evaluation of how interventions or environmental changes and shocks would impact agricultural systems and farmer livelihoods. AgMIP does this by analyzing the potential trade-offs and synergies among environmental, biophysical, and socio-economic outcomes, including impacts on gender and nutrition.

This project validates the MAC-B methodology through a pilot study of rice production systems in Bangladesh that replicates two ongoing studies in Vietnam and India[1]. Based on the lessons learned from this project, MAC-B is now ready for additional validation and refinement in multiple agricultural systems around the world as a Global Research Alliance Flagship Project.

Given that Bangladesh's food production system is vulnerable to climate change and that rice, one of the major crops in Bangladesh, is a large GHG emissions contributor, the Government of Bangladesh has shown strong focus on food-system climate change research. The recently published National Adaptation Plan of Bangladesh (2023-2050) not only highlights the importance of developing and promoting climate resilient agriculture for food, nutrition and livelihood security, but it also explicitly mentions the need for innovations that can deliver adaptation and mitigation co-benefits through public-private investments and other initiatives like the Mujib climate Prosperity Plan (MoEFCC 2023). Bangladesh is one of the world's most vulnerable countries and has committed 2% of its own domestic GDP to climate finance, established a national cross-sectoral Climate Change Strategy and Action Plan, and emphasized climate response in its 10-year collaboration strategy with ACIAR.

The project's focus on rice systems aligns with Bangladesh's priorities and contributes to climate response in a cropping system of global importance. Nearly 3 billion people rely on rice as a staple crop, and Bangladesh is the fourth-highest rice-producing country in the world (FAO 2019). The importance of rice for food security is such that it may directly feed more people daily than any other crop currently cultivated, providing approximately 20% of dietary energy (CGIAR 2013). This is partly due to the diversity of conditions in which rice may be grown – there are over 40,000 rice varieties, and as a species it can tolerate a wide range of temperature and moisture conditions. As a result, rice serves as the primary staple crop across South, Southeast, and East Asia and is increasingly grown across Africa and Latin America by over 144 million producers. Global demand for rice is expected to increase by 28% in the next three decades (Chen et al. 2020). Thus, rice has a large global footprint, and there exists much opportunity to identify and transfer climate change mitigation and adaptation strategies in rice-based farming systems around the world.

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[1] The Vietnam and India studies are funded by the Carnegie Foundation

4 Objectives

The objectives of the project were to:

1) Integrate stakeholder feedback into the MAC-B assessment process and co-evaluate feasible interventions focused on sustainable rice management and intensification that may generate adaptation and mitigation co-benefits.
2) Evaluate the effects of these interventions in current farming systems using multiple measures of mitigation, adaptation and economic benefits, including measures of greenhouse gas (GHG) emissions, resilience to climate variability, farmer livelihoods, gender, and nutrition (though the latter two were not possible in the end).
3) Evaluate the socio-economic, biophysical and environmental tradeoffs and synergies of the interventions under current and future climate scenarios
4) Support policy development by convening a policy-makers round table to communicate the findings from the project and discuss policy implications for mitigation and adaptation programs.
5) Strengthen capacity in all partners in using and applying AgMIP Regional Integrated Assessment methods

The project adapted the AgMIP Regional Integrated Assessment Protocols (Rosenzweig and Hillel 2015; Rosenzweig et al. 2021) to include data, validation, management, and scenarios for the integration of greenhouse gas emissions/mitigation models and impacts/adaptation models. The outcomes of the modeling framework characterize the synergies, trade-offs, and co-benefits of mitigation and adaptation strategies and aim to contribute to national policy decision-making, such as development of Nationally Determined Contributions (NDCs) to the UNFCCC Paris Agreement and National Adaptation Plans (NAPs).

5 Methodology

In this project, we formed a regional team in Bangladesh that included experts in climate, crops, soils, socio-economics, gender, and stakeholder engagement. With this team, we conducted a pilot MAC-B Regional Integrated Assessment of sustainable rice systems in Bangladesh and evaluated their current and future efficacy to simultaneously boost yields, improve rural livelihoods, adapt to a changing climate, and mitigate GHG emissions.

To do this, we adapted the AgMIP Regional Integrated Assessment (RIA, Rosenzweig et al., 2017) protocols to include mitigation components and replicated the approach of two ongoing studies in India and Vietnam. The resulting RIA methodology was used to estimate the linked Mitigation-Adaptation Co-benefits (MAC-B) of rice systems in Bangladesh. The method retained the multi-disciplinary, climate, crop/livestock, socioeconomic evaluation framework that combines existing data for a population of diverse farming households and crop field trials with state-of-the-art climate, crop, and economic modeling techniques. The data and modeling tools were used in conjunction with scenarios of future climate, policy, and socio-economic conditions.

In the MAC-B pilot study for Bangladesh, we incorporated the DNDC (DeNitrification - DeComposition) process-based biogeochemical model of the land surface and soils. This enabled analysis of current and potential future soil carbon storage, GHG fluxes, and nutrient dynamics alongside crop yield and water productivity under different rice management systems. The model was calibrated and validated using crop management data collected by International Maize and Wheat Improvement Center (CIMMYT) and Bangladesh Rural Advancement Committee (BRAC) in the Rangpur, Rajshahi, Faridpur, Gopalganj, Lalmonirhat, Kishoreganj, Dinajpur, and Jashore districts in Bangladesh (Figure 5.1).

For this study, we tested improved water management through alternate wetting and drying (AWD). The DNDC model is capable of other rice management practices, including testing tillage and crop establishment (directly sown rice), nutrient management, and diversified cropping systems. These are potential components of future studies.

We evaluated the rice production systems under current and future climate conditions and assessed the potential mitigation and adaptation co-benefits of sustainable rice management practices in all districts where primary data were collected and for which model was calibrated. This study served as an initial proof-of-concept for applying these methods more broadly and systematically to evaluate sustainable rice interventions across Bangladesh, as well as other rice-growing regions using AgMIP approaches.

We did not directly consider future socio-economic conditions or policy changes related to agricultural development. We focused our efforts on modeling co-benefits under current socio-economic conditions and under current and future climate. This study, however, can be the foundation to extend the analysis under a broader suite of future socio-economic conditions, i.e., developing and applying AgMIP Representative Agricultural Pathways (RAPs, Valdivia et al., 2021).

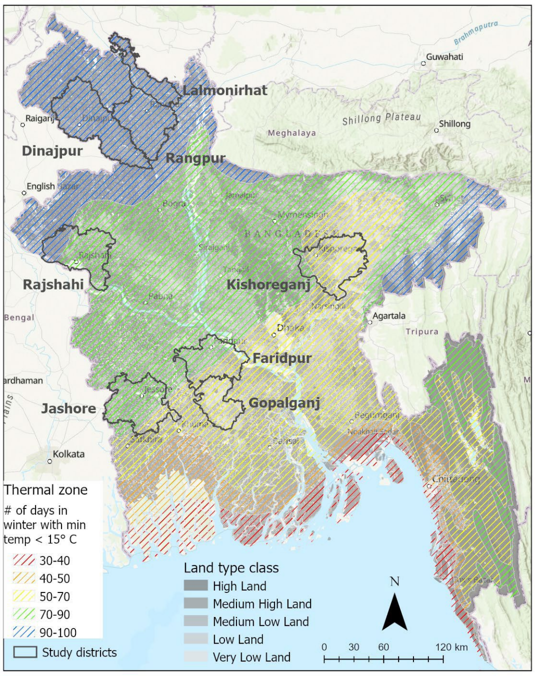

Fig. 5.1. Project study regions.

Core Research Questions

We used the following research questions for a set of management intervention packages (separately and combined) related to conventional continuous flood, alternate wetting and drying and the sustainable rice intensification management practices for current and future climate scenarios. These were generated with stakeholders based on 'on-the-ground' feasibility and acceptability.

1) What are the impacts of adopting the System of Rice Intensification (SRI) or Alternate Wetting and Drying (AWD) in the current climate (i.e., switching from conventional flood to AWD or SRI)?

2) What are the impacts of climate change on conventional continuous flood, SRI and AWD rice management practices?

3) What are the combined mitigation/adaptation co-benefits and trade-offs of SRI and AWD adoption in the future climate?

Models and Output Variables

To answer the core research questions for this pilot study, we implemented the AgMIP’s RIA using the DNDC-ORYZA rice crop model and TOA-MD model (Tradeoff Analysis for Multi-Dimensional Impact Assessment). Climate data for the baseline period of 30 years and future climate scenarios from CMIP6 was used to create daily weather data (e.g., temperature, precipitation and solar radiation) for the crop model. The whole farm approach included characterization of the household and farm-level production activities, plot-based crop simulations which linked to distributions of climate, soils and crop management for a population of farms allowed us to estimate distributions of farm net returns and the parameters for the TOA-MD model. Outcomes from the models that were examined are:

- *GHG emissions*: DNDC-ORYZA Model
    - N_2O, CO_2, and CH_4 flux (kg C/ha, kg N/ha)

- *Crop production:* DNDC-ORYZA model
    - Yield per hectare (kg/ha)
- *Stability of yields*: ORYZA model
    - Coefficient of variation of crop model outputs
- *Tradeoffs and Co-benefits*: TOA-MD model
    - Farm net returns and per-capita income
    - Poverty rates (% of the population below a defined poverty line)
    - Adoption rate (for adaptation analysis)
    - % households vulnerable to climate change (impact of cc analysis)
    - Net economic impact, gains and losses which measures the percentage of farm net returns that may be lost or gained as a result of climate change
    - % change in GHG emissions associated to adoption rates (adaptation analysis) and to vulnerability (climate change analysis).

Data Sources

The key data sources are presented in Table 5.1.

Table 5.1. Data Sources for Bangladesh AgMIP MAC-B study.

Data Type	**Primary Sources**	**Secondary Sources**
Climate information	Bangladesh Meteorological Department	AgMERRA, AgMIP archives; CMIP6 and NASA NEX GDDP archive of climate model outputs

Economic data	1. Survey Data 2014-2015, 2015-2016 (boro season) collected by Bangladesh Rural Advancement Committee (BRAC) and Monash University, Melbourne, Australia.[2] Plot and farm-level data 2. Crop cut survey data 2019-20, 2020-2021 in boro season, collected by CIMMYT and the Department Agriculture Extension. Plot-level management and economic data.	Bangladesh Bureau of Statistics (BBS) (2020). Yearbook of Agricultural Statistics-2019. Statistics and Informatics Division (SID), Ministry of Planning, Government of the People's Republic of Bangladesh. Bangladesh Bureau of Statistics (BBS) (2013). District Statistics-2011, Gopalganj, Kishoreganj, and Lalmonirhat. Statistics and Informatics Division (SID), Ministry of Planning, Government of the People's Republic of Bangladesh. Bangladesh Bureau of Statistics (BBS) & World Food Programme (WFP) (2020). Poverty MAPS of Bangladesh 2016. Statistics and Informatics Division (SID), Ministry of Planning, Government of the People's Republic of Bangladesh & WFP.
Crop management data	1. Survey Data 2014-2015, 2015-2016 (boro season) collected by Bangladesh Rural Advancement Committee (BRAC) and Monash University, Melbourne, Australia. Plot and farm-level data 2. Crop cut survey data 2019-20, 2020-2021 in boro season, collected by CIMMYT and the Department Agriculture Extension. Plot-level management and economic data.	Bangladesh Rice Research Institute
Soil information	Based on geocoordinates of cropping fields in CIMMYT and BRAC/Monash datasets, soil information was extracted from SoilGrid (v2) (https://soilgrids.org/)	Bias correction using the data provided by Dr. Umme Aminu Naher through comparison with regional soil profiles

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[2] Farm household data were collected by BRAC and Monash University, Melbourne, Australia in the boro season of 2014-2015 and 2015-2016 under the study "Technology Adoption and Food Security in Rural Bangladesh". Barrett et al., 2022

Climate Data and Scenarios

Daily climate data for key variables, including maximum and minimum temperatures, precipitation, and solar radiation, are required for crop and soil model simulations. To account for climate and yield variation over time, we performed all simulations for 30 continuous years. However, continuous station data that best represented the geographic distribution of the study sites was sparse. Therefore, we leveraged the spatially explicit 0.25˚ latitude x longitude AgMERRA climate dataset (Ruane et al 2015), a version of the NASA MERRA reanalysis product that contains the key daily climate variables required for crop-soil model simulation and has been bias-corrected following the Methods of Ruane et al 2015 and additionally with Bangladesh Meteorological Department station data in the specific districts where MAC-B methods are being applied (see below). More generally, AgMERRA has been widely used for crop model applications.

Before running the crop model simulations with AgMERRA climate data, we evaluated and removed monthly biases using an observational product for one co-located (i.e., within the Red River Delta) station. Specifically, we obtained maximum and minimum temperatures and precipitation, ranging from 1980-2010 for the six Bangladesh sites from the Bangladesh Meteorological Department (BMD). BMD is a government organization under the administrative control of the Ministry of Defence, Government of the People's Republic of Bangladesh. The main responsibility of BMD is to monitor and collect all types of meteorological data (Khatun et al., 2016).

Future climate scenarios were then constructed using outputs from the Sixth Coupled Model Intercomparison Project (CMIP6) (Eryng et al 2016) and the procedures detailed in Ruane et al. (2017) and Ruane and McDermid (2017). The monthly mean anomalies and changes to daily variation in the relevant climate variables from two global climate models (GCMs) were obtained from the NASA NEX GDDP (Thrasher et al. 2022, Thrasher et al. 2021) dataset of downscaled climate model projections using the outputs of CMIP6 (Eryng et al., 2016). The GCMs designated "P" (KACE-1-0-G, NIMS-KMA climate model) and "R" (MIROC6 climate model) were selected from a set of 24 GCMs (Figure 5.2). For the present study, this sample of climate models represents a fairly broad range of possible future climate conditions that are still within the envelope of projections for updated climate projections and allows us to bracket sensitivities and uncertainties in the crop and biophysical responses.

Anomalies between the future climate projections for SSP2-4.5 (medium mitigation ambition climate scenario) for 30-years centered on 2050, and historical simulated climate (1980-2010) were then applied to the baseline, bias-corrected AgMERRA datasets at each site. We also utilize the forced atmospheric CO2 concentrations for both the middle-year of the 30-year historical and future climate simulations for the respective crop-soil model simulations,

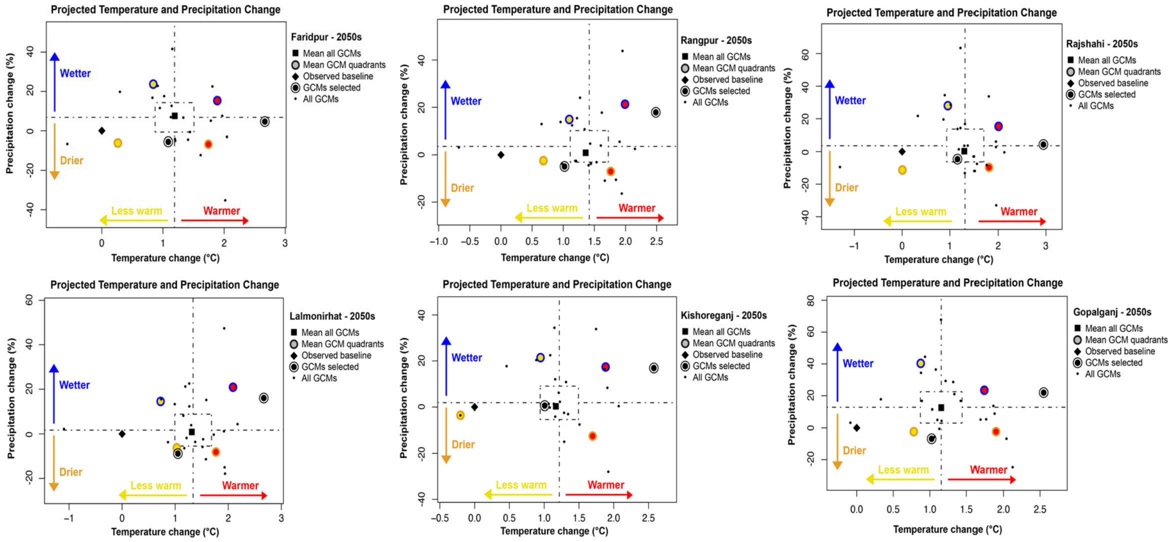

Fig. 5.2. Scatterplot distribution of mean Boro season temperature and precipitation anomalies for 24 downscaled global climate model (GCM) projections representing SSP2-4.5, centered on 2050. The “median” is identified by dashed lines, defined by +/- one standard deviation of change on each axis. The black square represents the mean anomaly across all GCMs. The colored circles with contrasting borders represent the mean of each “quadrant”, which delineate warmer/less warm and drier/wetter anomalies, relative to the distribution of climate model anomalies. The black diamond represents baseline (current) climate conditions, situated at “0” temperature and precipitation change. The black circles with black borders represent the site-specific anomalies of the selected models, “P” (KACE-1-0-G) and “R” (MIROC6).

Crop and Greenhouse Gas Modeling

The DNDC-ORYZA model was used to simulate crop growth, grain yield, soil carbon change, and greenhouse gas emissions. DNDC-ORYZA is an improved version of the geochemical model DNDC through integration with the ecophysiological rice crop model ORYZA (Li et al., 2018). The inclusion of rice physiological processes enables the analysis of genotype, environment, and management (GxExM) interactions in rice-growing systems.

To conduct modeling studies with DNDC-ORYZA, the essential inputs are weather, soil, crop, and land management. Daily data for precipitation, maximum and minimum temperature, and solar radiation is required. Additional information about daily relative humidity and wind speed could improve the accuracy of DNDC-ORYZA. The basic cropping and land management inputs are planting and harvest dates, fertilizer and irrigation application, and observed grain yield. The observed grain yields after the data quality screening were used to calibrate and validate the model predictability on rice production.

Data Sources

The climate modeling group provided the historical and projected weather data, consisting of daily radiation, maximum and minimum air temperature, precipitation, relative humidity, and weed speed. These were provided for 30 years for the current period and 30 years for the future (centered around 2050)..

Soil texture, organic carbon and nitrogen, and soil pH data corresponding to the field from where crop management and economic data were collected were extracted from the SoilGrid (v2) (https://soilgrids.org/) using the geocoordinates in the datasets. The soil organic carbon and nitrogen were corrected based on soil profile information provided by Dr. Umme Aminu Naher.

Cropping and land management information was extracted from the CIMMYT and BRAC/Monash datasets, including the geo coordinates and administrative location, rice cultivar, sowing, transplanting, and harvest dates, fertilizer type and amount, general water management description, and grain yield. The cost of cultivation data available in the dataset were used in the economic model study.

Model calibration

A data quality check was conducted on the CIMMYT dataset for selecting high-quality data for the model calibration to characterize crop parameters of two cultivars (BRRIdhan28 and BRRIdhan29). The CIMMYT dataset included survey data from 8981 farmers' fields. After the quality check, the data points with incomplete information for crop modeling were eliminated, with a total of 4427 data points remaining for the modeling studies. Among these 4427 data points, observations where the survey reported grain yields that did not correspond to the fertilizer management data were further eliminated to compose the subset of data for model calibration. Finally, the data from 1458 sites were used to calibrate and validate DNDC-ORYZA for two cultivars: BRRIdhan28 and BRRIdhan29. This dataset was split into calibration and validation subsets (about two-thirds vs. one-third of data points were used for calibration and validation of model, respectively). The calibration sub-dataset for BRRIdhan28 and BRRIdhan29 included 813 and 160 sites respectively, while 404 and 81 sites were used for validation.

Figure 5.3 illustrates the plot analysis results of model calibration and validation. The regression correlations between model predicted and survey grain yield were lowered down in the validation. Without considering the intercept as an original bias (i.e., forced the linear regression pass through the original point, implying the predicted yield equal to zero when survey yield was zero), the model presented a great prediction power with that regression slope and correction were higher than 0.9. The root mean square errors normalized by the mean of the survey yields were around 15% in the calibration phase (Table 5.2). The errors were slightly larger in the validation phase probably because of higher variation in survey data from farmers' fields unlike experimental results. Nevertheless, DNDC-ORYZA can predict grain yield for the two rice cultivars analyzed in this study with acceptable confidence.

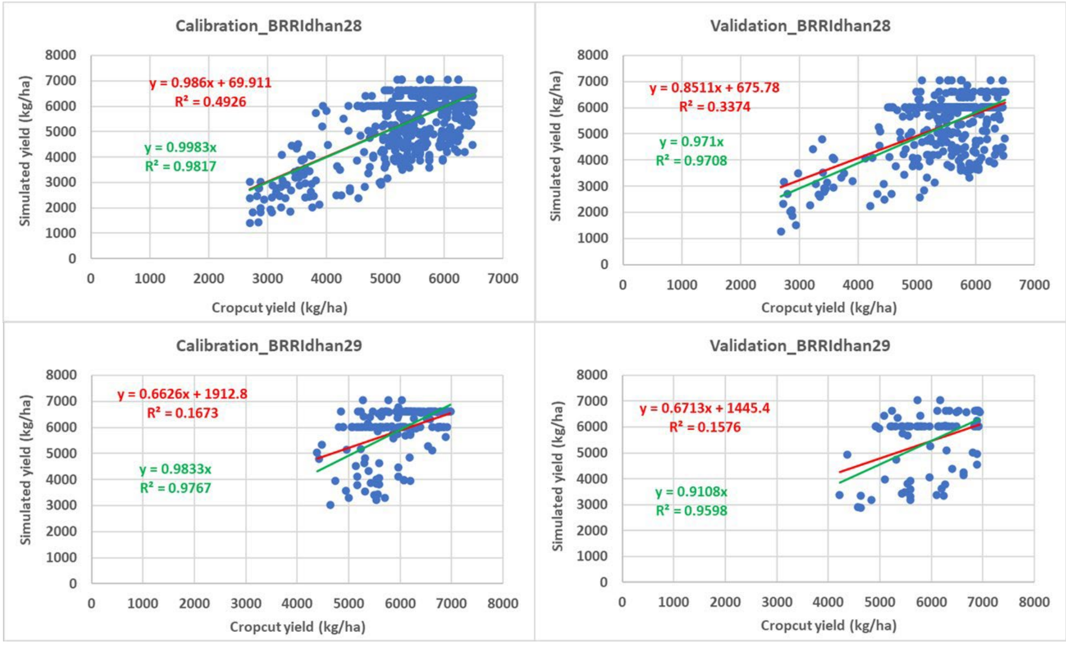

Fig. 5.3. Model-predicted grain yield compared to survey data under calibration and validation sub-datasets for cultivars BRRIdhan28 and BRRIdhan29. The regression lines and equation in red and green, represent the analysis with- and without intercept, respectively.

Table 5.2. Statistical analysis of model calibration and validation simulations of grain yield compared to surveyed grain yields. $RMSE_n$ is the root mean square error (RMSE) normalized by the means of survey values.

Cultivar	**Sub-dataset**	**Mean ± sd (kg/ha)**		**Regression**		**RMSE (kg/ha)**	**$RMSE_n$ (%)**
		Survey	**Simulation**	**Slope**	**R^2**		
BRRIdhan28	Calibration	5545 ± 764	5537 ± 1072	0.998	0.982	764	13.8
	Validation	5524 ± 784	5377 ± 1149	0.971	0.971	953	17.3
BRRIdhan29	Calibration	5903 ± 598	5867 ± 918	0.983	0.977	907	15.4
	Validation	5951 ± 715	5483 ± 1179	0.911	0.960	1238	20.8

Scenario design and simulation

To address the study targets, two major types of simulations were designed. First, the simulations were designed to quantify the effects of climate change and water management in conventional rice production systems. Second, the simulations were designed to compare the system of rice intensification (SRI) and conventional rice production systems under different climate and water management conditions.

The first group included the 3970 data points from the CIMMYT dataset and 2631 sites from the BRAC/Monash dataset. For each site, six simulations were implemented for two water management practices and three climate datasets (one for the current climate and two for future climate change projections). The two water management practices were continuous flooding in the entire cropping season (Baseline) and alternative wet (5 days) and dry (7 days) cycles in the period from transplanting to crop maturity (AWD). The three climate input datasets were historical weather (Current) and scenarios from two global climate models (GCMs) (Future) (Table 5.3). Each simulation was conducted for 30 continuous cropping seasons in 30 years. Therefore, the full set of 30-year weather data were provided from the climate team accordingly.

The second group included 432 sites from the BRAC/Monash dataset. Two sub-groups of simulations were designed to address the conventional and SRI cropping systems. The conventional system comprised current management practices followed by the farmers as reported in the survey whereas SRI practice included transplanting younger seedling, addition of organic fertilizer, AWD approach of water management and improved weed/disease/pest management.

Table 5.3. Simulation design for the two simulation study groups.

Group	Cropping type	Sites		Water management		Climate data		
		CIMMYT	BRAC/ Monash	Baseline	AWD	Current	GRXF	GPXF
1	Conventional	3907	2631	✓	✓	✓	✓	✓

2	SRI		432	✓	✓	✓	✓	✓
	Conventional			✓	✓	✓	✓	✓

Analysis of simulation outputs

Two types of simulation outputs, annual and seasonal, were aggregated for each site and each year. The annual outputs reported the variables at the end of each fiscal year, while the seasonal outputs were reported at the end of each cropping season. The study used seasonal outputs in the statistical analysis to address the research questions. The ratios described below were aggregated at both national (covering the 8 districts) and district levels; the latter were used to characterize the geographical distribution of the computed ratios across the study sites and regions.

The target variables included in the statistical analysis were:

- Grain yield (Yield, Mg/ha)
- Soil organic carbon content at the top 20 cm soil layer (SOC20) (Mg C/ha)
- CO_2, N_2O, and CH_4 emissions (CO2, N2O, and CH4) (Mg/ha, kg/ha, and kg/ha)
- CO_2 equivalent global warming potential (CO2eq) (Mg/ha)
- Irrigation water consumption (Irrigation) (mm)
- Nitrogen fertilizer applied (Fert_N) (kg N/ha)
- Irrigation water use efficiency (WUE_Irri) (kg yield/mm water)
- Nitrogen fertilizer use efficiency (NUE) (kg yield/kg N)
- Greenhouse gas (GHG) emission efficiency of irrigation water (Irri_Emit) (kg CO2eq/mm water)
- GHG emission efficiency of nitrogen fertilizer (Fern_Emit) (kg CO2eq/kg N)
- GHG emission efficiency of grain yield (Yield_Emit) (kg CO2eq/kg yield)

Note: CO2eq, WUE_Irri, NUE, Irri_Emit, Fern_Emit, and Yield_Emit were secondary variables, which were calculated from the first variables of Yield, CO2, N2O, CH4, Irrigation, and Fert_N in equations 5.1 to 5.6:

$$CO2eq = CO2 + 23.0 \times CH4 + 298 \times N2O \quad (5.1)$$

$$WUE\_Irri = Yield/Irrigation \quad (5.2)$$

$$NUE = Yield/Fert\_N \quad (5.3)$$

$$Irri\_Emit = CO2eq/Irrigation \quad (5.4)$$

$$Nfer\_Emit = CO2eq/Fert\_N \quad (5.5)$$

$$Yield\_Emit = CO2eq/Yield \quad (5.6)$$

AWD Simulations. For the first group of simulations, the ratios of all target variables were calculated from AWD to Baseline and Future Climate to Current Climate to determine the effects of AWD application and climate change. The climate change adaptation effects of AWD were quantified by the ratios of all target variables in comparisons between AWD under Future Climate with Baseline under the Current Climate, and Baseline under the Future Climate with the Baseline under the Current Climate.

With the target variables Yield, SOC20, WUE_Irri, and NUE, the ratios larger than 1.0 represent benefits but imply trade-offs in regard to the target variables CO2, N2O, CH4, CO2eq, Irrigation, Irri_Emit, Fert_N, Fern_Emit, and Yield_Emit.

SRI Simulations. For the second group, the ratios of all target variables were calculated from the values in the SRI simulations to conventional cropping systems under different water management and climate categories.

Economic Modeling: Tradeoffs and Co-Benefits

In this project we used the Tradeoff Analysis model for Multi-Dimensional Impact Assessment (TOA-MD, Antle and Valdivia, 2022) to implement the economic and tradeoff analysis of the MAC-B approach. The TOA-MD model is a parsimonious, generic model for analysis of technology adoption and impact assessment, and ecosystem services analysis. The tradeoff analysis integrates data from climate-crops and livestock and pathways to assess the sustainability of development pathways, technologies (e.g. adaptation and mitigation strategies) and policies and the impacts of climate change by evaluating the inter-relationships (both tradeoffs and synergies) among economic indicators (farm income, poverty rates), environmental indicators (e.g. GHG emissions), and social indicators (food security and gender).

The TOA-MD simulates impacts that are statistically associated with adoption, using the standard statistical framework for econometric policy evaluation in which economic “agents” (i.e., farms) self-select into “treatment”, in other words, they choose to adopt or not adopt. The model can be used to estimate the so-called “treatment effects” or the impacts associated with technology adoption. The impacts of climate change estimated by the TOA-MD model are the “treatment effects” of climate change. The TOA-MD model can be used to show how the distributions of outcomes are affected by climate and by adaptations farmers may undertake in response to climate change.

The TOA-MD represents the whole farm production system (i.e., includes crops, livestock and aquaculture sub-system, and the farm household characteristics). The TOA-MD is a model of a farm population, not a model of an individual or “representative” farm. Accordingly, the fundamental parameters of the model are population statistics – means, variances and correlations of the economic variables in the models and the associated outcome variables of interest. With suitable bio-physical and economic data, these statistical parameters can be estimated for current systems. Using the methods described in the AgMIP Regional Integrated Assessment Handbook (www.agmip.org), we can estimate how the TOA-MD model parameters would change in response to climate change or technological adaptations (e.g., changes in crop management). These changes in model parameters are the basis for the climate impact, vulnerability and adaptation analysis used in this pilot study (Figure 5.4).

With suitable data, we can use the TOA-MD model to assess how GHG emissions may change due to adoption of alternative rice management practices or due to the impacts of climate change.

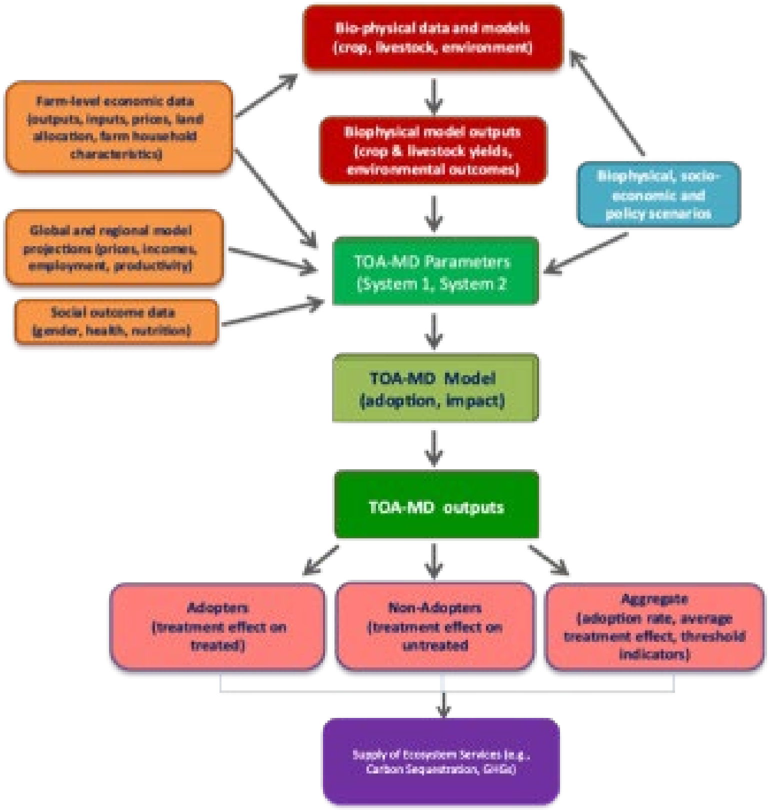

Fig. 5.4. Tradeoff Analysis Model: Landscape-scale technology adoption, environmental impacts, and ecosystem services (Antle and Valdivia, 2022)

Characterizing rice-based systems in Bangladesh: BRAC/Monash whole-farm survey data

While data for crop modeling (i.e., crop management, inputs, etc) was available for all the sites targeted in this pilot project, adequate and necessary data to characterize whole-farm production activities was only available from the BRAC/Monash survey data. The BRAC/Monash data was collected as part of a study that looked at the impacts of training farmers on the implementation of the System of Rice Intensification during 2014-2016. The survey design is an RCT that collected baseline data which included farmers using conventional management (continuous flood system and alternate wetting and drying). Mid-term and endline data were collected after selected farmers participated in one or two training events on SRI. The survey data included farmers that were not ‘treated’ (control), and farmers that received training (treated). This created an ideal set of data that allowed us to estimate counterfactuals for the same farmers (e.g., farmers that initially used a base management system, like continuous flood, and then ‘adopted’ an alternative system, such as AWD or SRI). Given the limited time for this pilot, we only used data from three districts in Bangladesh: Lalmonirhat (North region), Gopalganj (South region), and Kishoreganj (Eastern region). Description of farm characteristics are summarized in Table 5.4.

Table 5.4. Farm characteristics of households BRAC/Monash survey data.

		Aggregate (average three districts)			Gopalganj			Kishoreganj			Lalmonirhat		
SYSTEM	**Variable**	**N**	**Mean**	**STD**	**N**	**Mean**	**STD**	**N**	**Mean**	**STD**	**N**	**Mean**	**STD**
Continous flood	**HH size**	447	5.39	1.79	219	5.45	1.87	29	4.9	1.72	199	5.39	1.7
	Farm size (Hectare)	491	0.85	0.68	249	0.8	0.54	34	0.58	0.53	208	0.96	0.81
	Area rice (Hectare)	491	0.37	0.26	249	0.46	0.28	34	0.37	0.34	208	0.28	0.16
	Area Wheat-Maize-Pulse (Hectare)	295	0.3	0.23	148	0.24	0.18	2	0.12	0.03	145	0.36	0.26
	Area other crops (Hectare)	179	0.24	0.2	130	0.26	0.21	2	0.1	0.03	47	0.18	0.14
	Land owned (Cropland)	491	0.78	0.64	249	0.73	0.53	34	0.51	0.51	208	0.88	0.75
	Yield (Kg/hectare)	491	5766.71	1524.15	249	5859.16	1692.93	34	4546.95	1348.38	208	5855.42	1230
AWD	**HH size**	1,855	5.41	2.01	337	5.39	1.95	1,154	5.47	2.13	364	5.24	1.65
	Farm size	2,116	0.74	0.71	383	0.84	1.06	1,317	0.68	0.52	416	0.86	0.8
	Area rice	2,116	0.35	0.24	383	0.42	0.33	1,317	0.36	0.22	416	0.26	0.19
	Area Wheat-Maize-Pulse (Hectare)	582	0.27	0.21	258	0.26	0.23	60	0.16	0.11	264	0.31	0.2
	Area other crops	447	0.2	0.24	245	0.26	0.29	81	0.1	0.08	121	0.16	0.13
	Land owned (Cropland)	2,116	0.66	0.67	383	0.76	1.02	1,317	0.59	0.48	416	0.78	0.75
	Yield (per hectare)	2,116	5013.97	1399.98	383	5494.82	1498.48	1,317	4687.02	1321.25	416	5606.38	1217.2
SRI	**HH size**	412	5.28	1.79	147	5.44	1.84	188	5.16	1.8	77	5.29	1.68
	Farm size	432	0.76	0.73	154	0.93	0.82	196	0.56	0.51	82	0.89	0.86
	Area rice	432	0.37	0.26	154	0.47	0.32	196	0.34	0.21	82	0.26	0.16
	Area Wheat-Maize-Pulse (Hectare)	164	0.31	0.29	109	0.29	0.29	9	0.19	0.12	46	0.38	0.3
	Area other crops	144	0.26	0.36	101	0.31	0.41	21	0.1	0.05	22	0.14	0.12
	Land owned (Cropland)	432	0.69	0.71	154	0.87	0.81	196	0.5	0.49	82	0.81	0.82
	Yield (Kg/hectare)	496	6279.57	1601.03	173	7352.44	1450.88	211	5777.23	1098.84	112	5568.77	1761.03

Table 5.5. Summary statistics for conventional continuous flood rice management system. CIMMYT/DAE survey data.

		Dinajpur		Faridpur		Jessore		Rajshahi		Rangpur	
Variable	**N**	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**
Average Yield (kg/hectare)	1797	5792.75	1166.70	6149.32	811.79	6142.08	771.92	5732.51	1105.58	5340.85	1239.45
Average Production cost (USD/hectare)	1797	213.30	47.41	197.60	65.47	215.86	54.00	228.96	63.73	203.85	74.54
Revenue (USD/per hectare)	1797	22.65	5.10	23.83	3.96	23.76	3.51	22.22	4.79	20.30	5.11
Net Return (USD/hectare)	1797	1711.45	402.63	1827.01	336.83	1802.52	271.87	1659.23	383.19	1520.29	403.56

Characterizing rice-based systems in Bangladesh: CIMMYT/DAE plot-level data

The survey data from CIMMYT and the Department of Agriculture Extension was collected between 2019-2021 covering the districts of Jessore, Faridpur, Rangpur, Rajshahi and Dinajpur. The data collected focused on plot-level management and production. Whileit was not possible to implement the whole-farm approach of the MAC-B protocols, we could interpret this data as representative of small farms (e.g. farms with small farm-size) that produced only rice on a 1 hectare farm size. Other household characteristics were missing, thus, available data and other secondary data from the Bangladesh Bureau of Statistics was used to estimate distributions of yields and per-hectare production cost and returns. Summary statistics are described in Table 5.5.

Simulated crop yields and environmental data

We used outputs from DNDC-ART crop simulations to estimate relative yield changes for the different scenarios described below. In addition, we used simulated GHG emissions (SOC20, CO2, CH4, N2O, CO2eq, Irrigation, and WUE) to estimate how adoption of alternative rice management practices or climate change, may lead to mitigation-adaptation co-benefits or create socio-economic and environmental tradeoffs (Figure 5.4).

Simulation experiments

i. Rice management systems:

In this pilot study we focused on three management systems based on the available data to characterize and quantify crop management, including input use, yields, cost of production, prices and other household characteristics:

- Conventional continuous flood (**Conv.CF**)
- Conventional with Alternate Wetting and Drying (**Conv.AWD**)
- System of Rice Intensification combined with AWD (**SRI.AWD**)[3]

ii. Climate Projections:

As described in the climate section above, we designed the simulation experiments under three possible climate scenarios:

- Current climate (G**0X**F)
- KACE-1-0-G, NIMS-KMA (G**PX**F: Hot- variable precipitation)
- MIROC6 (G**RX**F: less warm, lower precipitation)

iii. Strata

Given the inherent biophysical and socio-economic heterogeneity in the population of farms, we stratified the data as follows:

- *BRAC/Monash data:*

This data included 3 regions: Gopalganj (Gopa), Kishoreganj (Kish) and Lalmonirhat (Lalm). We further stratified the data by type of farms: *small rice producers* who produce rice in less

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[3] For easier description, the System of Rice Intensification combined with AWD will be simply called “SRI”

than 0.5Ha, and *large rice producers* who produce rice in areas larger than 0.5Ha. As a result we have 6 strata:

Stratum 1: Gopa , <0.5Ha rice
Stratum 2: Kish, <0.5Ha rice
Stratum 3: Lalm, <0.5Ha rice
Stratum 4: Gopa , >0.5Ha rice
Stratum 5: Kish, >0.5Ha rice
Stratum 6: Lalm, >0.5Ha rice

- *CIMMYT data:*

The plot-level data was stratified by district:

Stratum 1: Dinajpur
Stratum 2: Faridpur
Stratum 3: Jessore
Stratum 4: Rajshahi
Stratum 5: Rangpur

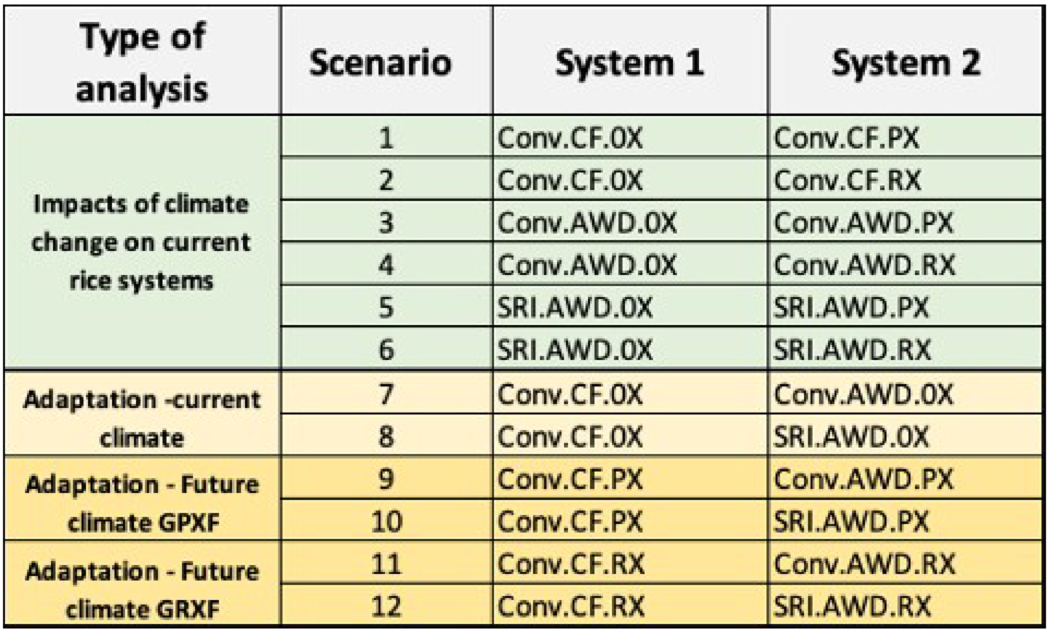
iv. Scenarios

Two types of analysis were implemented in this pilot project:

1. Assessing the impacts of climate change on current rice systems. This analysis evaluates the impacts of the two climate change scenarios (G**PX**F and G**RX**F) on the continuous flood, AWD and SRI systems and include scenarios 1-6 in Table 5.6 where System 1 is a rice system under current climate, and System 2 is the same system under future climate.

2. Adaptation analysis (e.g, adoption of an alternative system). This analysis assesses the potential adoption of AWD or SRI (i.e., switching from conventional flood to AWD or SRI) under current and future climate conditions which are scenarios 7-12 described in Table 5.6. In these scenarios, System 1 is the conventional continuous flood system under current or future climate, and System 2 are the AWD and SRI systems under current or future climate conditions.

Table 5.6. Simulation experiments: Scenarios



Type of analysis	Scenario	System 1	System 2
Impacts of climate change on current rice systems	1	Conv.CF.0X	Conv.CF.PX
	2	Conv.CF.0X	Conv.CF.RX
	3	Conv.AWD.0X	Conv.AWD.PX
	4	Conv.AWD.0X	Conv.AWD.RX
	5	SRI.AWD.0X	SRI.AWD.PX
	6	SRI.AWD.0X	SRI.AWD.RX
Adaptation -current climate	7	Conv.CF.0X	Conv.AWD.0X
	8	Conv.CF.0X	SRI.AWD.0X
Adaptation - Future climate GPXF	9	Conv.CF.PX	Conv.AWD.PX
	10	Conv.CF.PX	SRI.AWD.PX
Adaptation - Future climate GRXF	11	Conv.CF.RX	Conv.AWD.RX
	12	Conv.CF.RX	SRI.AWD.RX

Note: For the CIMMYT data, we focused only on the conventional continuous flood and AWD systems.

Iterative Stakeholder Engagement Process

Stakeholder engagement was a major activity throughout the project. Before the MAC-B Stakeholder Kick-off Webinar held on January 27, 2022, we prepared a participants list including all potential stakeholders from the public, private sectors, donors, development partners, etc. So that an improved understanding of the MAC-B integrated assessment modeling system and possible MAC-B interventions that enable engaging appropriate stakeholders, with whom additional interventions are identified and tested in current and future conditions. Hence, these stakeholders understand the MAC-B framework and advocate for its use in national planning documents such as the National Adaptation Plan (NAP), Nationally Determined Contributions (NDC), etc. Bangladesh researchers are encouraged to learn how to improve/test MAC-B interventions. Stakeholders and regional researchers will then be more likely to adopt the MAC-B framework and create practices to achieve development impacts. Eventually, MAC-B will achieve regional capacity for its practical use.

Through in-house exercise, potential stakeholder organizations were listed, which included the Bangladesh Meteorological Department (BMD), Bangladesh Agricultural Research Council (BARC), Bangladesh Agricultural Research Institute (BARI), Bangladesh Rice Research Institute (BRRI), Bangladesh Livestock Research Institute (BLRI), Krishi Gobeshona Foundation (KGF), Jahangir Nagar University, London School of Economics, University of Eastern Finland, etc. Based on the Stakeholders' nature of services provided, they were categorized into groups like Weather, Climate and Environment; Crops and Livestock; Extension; Social Aspects; Donors, and Other Researchers (Table 5.7).

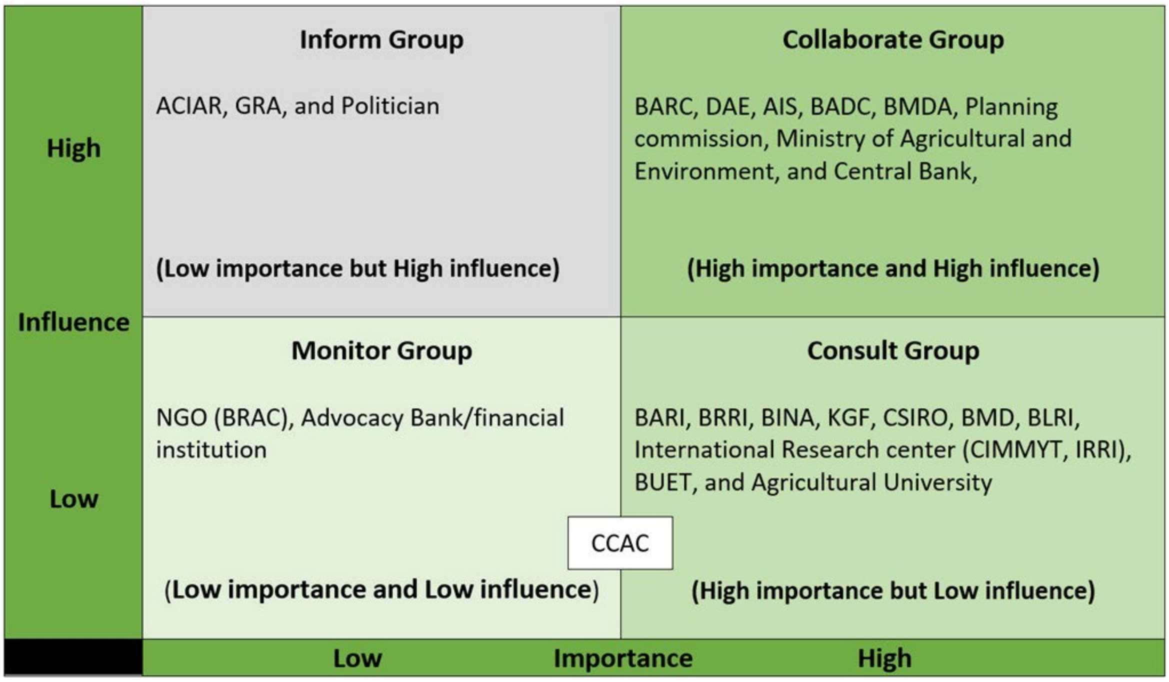
Table 5.7. MAC-B Stakeholder Representatives Organizations

Weather, Climate and Environment	**Crops and Livestock**	**Donors**
Bangladesh Meteorological Department (BMD) Climate and Clean Air Coalition Department of Environment	Bangladesh Agricultural Research Council (BARC) Bangladesh Agricultural Research Institute (BARI) Bangladesh Rice Research Institute (BRRI) Bangladesh Livestock Research Institute (BLRI) Krishi Gobeshona Foundation (KGF)	Australian Centre for International Agricultural Research (ACIAR) Global Research Alliance on Agricultural Greenhouse Gases (GRA)
Extension	**Social Aspects**	**Other Researchers**
Department of Agricultural Extension (DAE)	Jahangir Nagar University (JU) London School of Economics (LSE) University of Eastern Finland (UEF)	International Rice Research Institute (IRRI), Commonwealth Scientific and Industrial Research Organization (CSIRO), Australian Government, Bangladesh University of Engineering & Technology (BUET) New Zealand Ag GHG Research Centre Bangabandhu Sheikh Mujibur Rahman Agricultural University Institute of Water Modelling (IWM) Center for Environmental and Geographic Services (CEGIS) International Centre for Climate Change and Development (ICCCAD) Independent University, Bangladesh (IUB)

Following the methodology suggested by Grimble and Wellard (1997), the stakeholders were grouped according to their importance and influence on research. We started the process by conducting an Importance-Influence Grid Activity through consultation with the MAC-B Bangladesh team to identify groups of stakeholders based on their importance and influence regarding mitigation and adaptation interventions. We organized the stakeholders into the stakeholder analysis matrix as Informing, Collaborating, Consulting, and Monitoring groups.

Then we conducted several participatory mapping exercises with different stakeholder groups. After explaining the stakeholders mapping exercise, we showed the analysis matrix that was prepared earlier and asked the participants to give feedback, add/remove stakeholder organizations, and change their grouping and level of influence and importance. From this and other exploratory discussions, we revised the stakeholder analysis matrix and listed the stakeholders to invite for engagement throughout the project's lifetime. The finalized stakeholder analysis matrix is presented in Table 5.8.

Table 5.8. Stakeholder Analysis Matrix



High	**Inform Group** ACIAR, GRA, and Politician **(Low importance but High influence)**	**Collaborate Group** BARC, DAE, AIS, BADC, BMDA, Planning commission, Ministry of Agricultural and Environment, and Central Bank, **(High importance and High influence)**
Influence **Low**	**Monitor Group** NGO (BRAC), Advocacy Bank/financial institution CCAC (**Low importance and Low influence**)	**Consult Group** BARI, BRRI, BINA, KGF, CSIRO, BMD, BLRI, International Research center (CIMMYT, IRRI), BUET, and Agricultural University **(High importance but Low influence)**
	Low	**Importance** **High**

[Reference: Grimble and Wellard, 1997]

Collaborate group (High importance and High influence):

- Bangladesh Agricultural Research Council (BARC): BARC is the apex body in charge of the National Agricultural Research System
- Department of Agricultural Extension Bangladesh (DAE)
- Agriculture Information Service (AIS)
- Planning commission,
- Ministry of agriculture, ministry of environment (line ministries)
- Bangladesh Central Bank
- Bangladesh Agricultural Development Corporation (BADC) is a Government agency that manages the agricultural input supplies i.e., agricultural seeds, fertilizers, etc., in Bangladesh.
- The Barind Multipurpose Development Authority (BMDA): Government agency that works in the northwestern region of the country for irrigation. They have already introduced a pre-paid card system for volumetric pricing of irrigation water.

Consult group (High importance but low influence):

- Bangladesh Agricultural Research Institute (BARI)
- Bangladesh Rice Research Institute (BRRI)
- Krishi Gobeshona Foundation (KGF): KGF is a government-sponsored non-profit grants-making organization for sustainable support to agricultural research and development
- Bangladesh Meteorological Department (BMD)
- Centre for Environmental and Geographic Information Services (CEGIS)
- Bangladesh Institute of Nuclear Agriculture (BINA): BINA is one of the Government agencies responsible for crop improvement through induced mutation, biotechnology, soil management and biofertilizer, etc. BINA has developed rice varieties, especially short-duration and salt-tolerant rice varieties, and has also developed different climate-smart technologies for rice cultivation.
- Agricultural universities (Bangladesh Agricultural University, Sher-e-Bangla Agricultural University, etc.)
- Bangladesh University of Engineering and Technology (BUET)
- CSIRO Research for Development Alliance
- International research centers (CIMMYT, IRRI)
- Bangladesh Livestock Research Institute (BLRI): BLRI can be involved in an integrated rice-based mixed farming system and BLRI also conducting some research on the mitigation of GHG gas from animal diets (especially from dry rice folder and green grass)

Inform Group (High influence but low importance):

- Australian Government's special agricultural research (ACIAR)
- Global Research Alliance (GRA),
- Politicians

Monitor Group (Low importance and low influence):

- NGOs (e.g., BRAC)
- Advocacy groups
- Bank/financial institutions (they are relevant, but they don’t play any role in decision-making)

Mixed Group (Monitor & Consult):

- Climate and Clean Air Coalition (CCAC) falls in the middle of the Monitor and consult group.

6 Achievements against activities and outputs/ milestones

Objective 1: Directly integrate stakeholder feedback into the MAC-B assessment process

no.	**activity**	**outputs/ milestones**	**completion date**	**comments**
1.1	Hold scoping webinar with relevant researchers and stakeholders from the region, as well as from the AgMIP, GRA, and ACIAR networks	Webinar Recording Identified key stakeholders in Bangladesh	January 27, 2022	See Recording: AgMIP MAC-B: Kick-off Stakeholder Webinar - YouTube
1.2	Establish linkages to gender and nutrition outcomes, among others	We developed a framework for consideration of the different vulnerability contexts and benefit structures related to gender	April 2023	The data used in this pilot project lacked adequate specificity to incorporate this component in the analysis. This is an area for future expansion for MAC-B as the methods and approaches are capable of including gender, nutrition and other social outcomes
1.3	Hold mid-term Stakeholder Workshop	Workshop Report	September 15, 2022	See Appendix 11.1 and the AgMIP website
1.4.	Visit to rice farms in Bangladesh	Input and feedback from farmers about different rice management systems, constraints and opportunities	September, 2022	Field trip as part of the trip of R. Valdivia to attend the stakeholder workshop in September 2022.

Objective 2: Evaluate the efficacy rice management interventions to current farming systems

no.	activity	outputs/ milestones	completion date	comments
2.1	Finalized MAC-B protocols	- Building from AgMIP's Regional integrated Assessment approach that links process-based biophysical and socioeconomic models, we extended the framework to explicitly evaluate co-benefits and tradeoffs from combined mitigation and adaptation - We discussed interventions with stakeholders to be tested in future research beyond the management options used in this pilot project. The framework is adaptable to stakeholder feedback and input. - We identified areas for further research to enhance understanding of interactions of climate, soils and management with GHG emissions, model improvement and calibration.	April 2023	Protocols and results have been presented at different venues, meetings and conferences.
2.2	Assessment of MAC-Bs for sustainable rice interventions in the current farming system and under current climate	We evaluated the efficacy of interventions as they are or could be deployed now	April 2023	This included climate, crop and economics data and models.

Objective 3: Evaluate the effects of the interventions on the multiple measures of benefit but under future climate scenarios

no.	activity	outputs/ milestones	completion date	comments
3.1	Assessment of MAC-Bs for sustainable rice interventions under climate change	- We evaluated the impacts of climate change on three different rice management systems using two climate change projections - We assessed the potential impacts of switching from conventional continuous flood to AWD and SRI systems We analyzed the potential tradeoffs and pathways to win-win outcomes between socio-economic and environmental outcomes)	April 2023	We evaluated results aggregated across districts and scenarios, but also produced disaggregated results that show heterogeneity with respect to socio-economic conditions, bio-physical and environmental. We estimated the proportion of households that are vulnerable to climate change, change in farm net returns, poverty rates, gains and losses, and GHG emissions We estimated potential adoption rates, changes in mean farm returns and the associated changes in GHG emissions

Objective 4: Support policy development by convening a policy-makers round table

no.	activity	outputs/ milestones	completion date	comments
4.1	Hold final stakeholder workshop/policy makers round table	Round Table Report	April 5, 2023	See Appendix 11.2 and the AgMIP website

Objective 5: Strengthen capacity of all partners in using and applying AgMIP RIA methods

no.	activity	outputs/ milestones	completion date	comments
5.1	AgMIP Bangladesh regional team	Team formed with members from BARI, BRRI, BMD, MoPA, and CIMMYT Bangladesh	September 2021	Regional team included transdisciplinary scientists with special consideration on gender balance and involving young/junior researchers.
5.2	Team trained in AgMIP methodology through learning-by-doing and webinars	AgMIP modeling methodology now ready to be tested in additional regions in Bangladesh by local researchers	March 2023	Webinars and weekly all-team check-in calls were organized to check progress and discuss methodology, results etc. Virtual meetings by discipline and across disciplines were also organized throughout the project.

5.3.	Local economist in Bangladesh completed Basic training on the TOA-MD model	Economist capable of preparing data and creating parameters for the TOA-MD model, setting up the model for different case studies	March 2023	Economist worked under supervision of Dr. Roberto Valdivia

7 Key results and discussion

Effects of AWD and Climate Change on Conventional Rice Cropping System

The first set of simulations examined the effects of alternate wetting and drying (AWD) and climate change on the current rice production systems in the study regions.

Spatial and temporal variations

The modeling study included 6601 field sites covering 8 major rice production districts of Bangladesh. The simulated grain yield across the sites and regions varied from less than 1 Mg/ha to over 8 Mg/ha. However, the inter-season variations of grain yields were generally less than 1 Mg/ha without considering the impacts of weed, diseases, and pests among seasons (Figure 7.1). Greenhouse gas emissions were extremely high in some sites. About 90% of these sites had CO2eq emissions varying between 2.5 and 8.5 Mg/ha and CH4 emissions of 24 to 108 kg/ha; emissions per unit yield ranged from 0.6 to 2.6 kg CO2eq/kg yield.

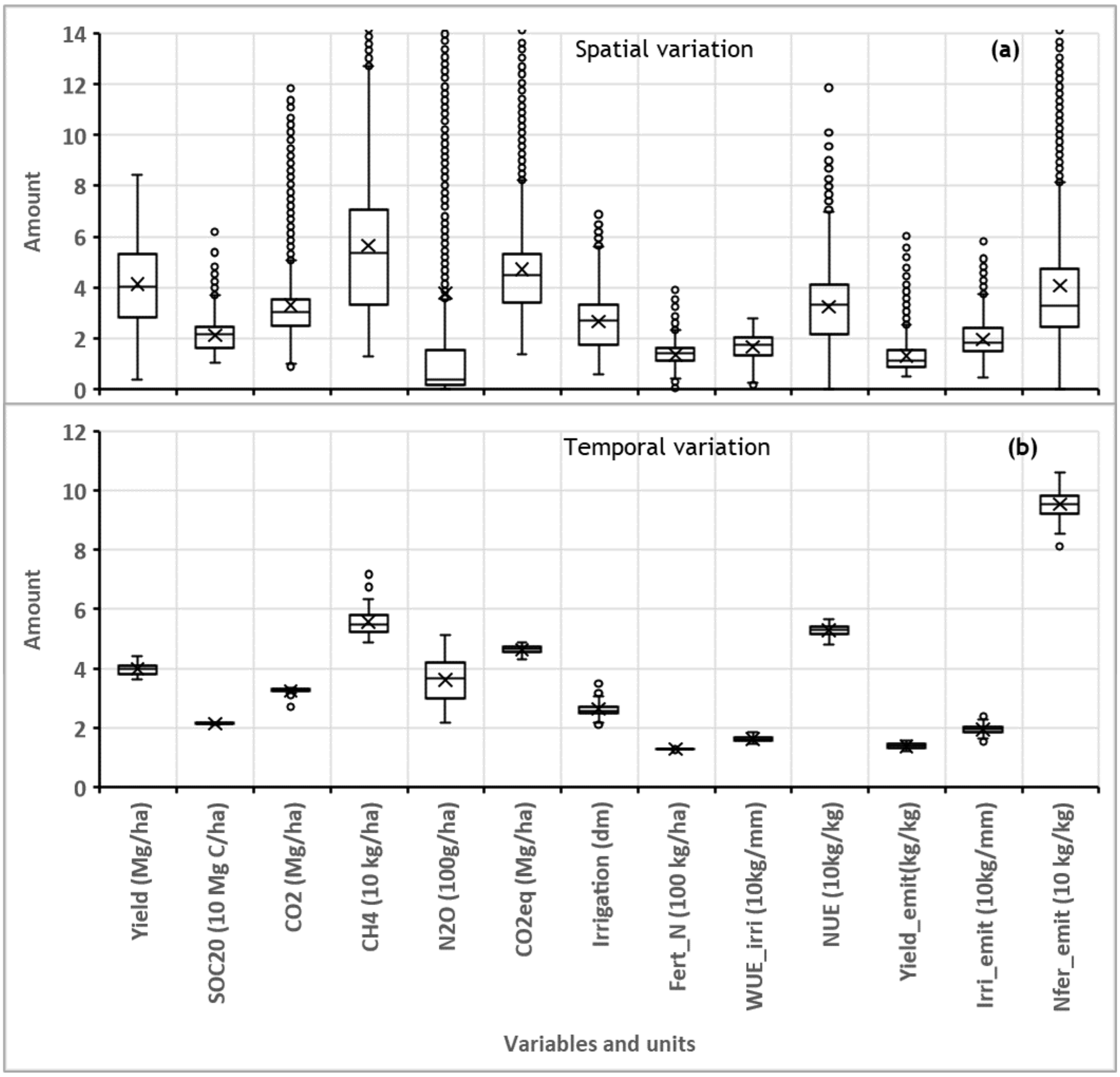
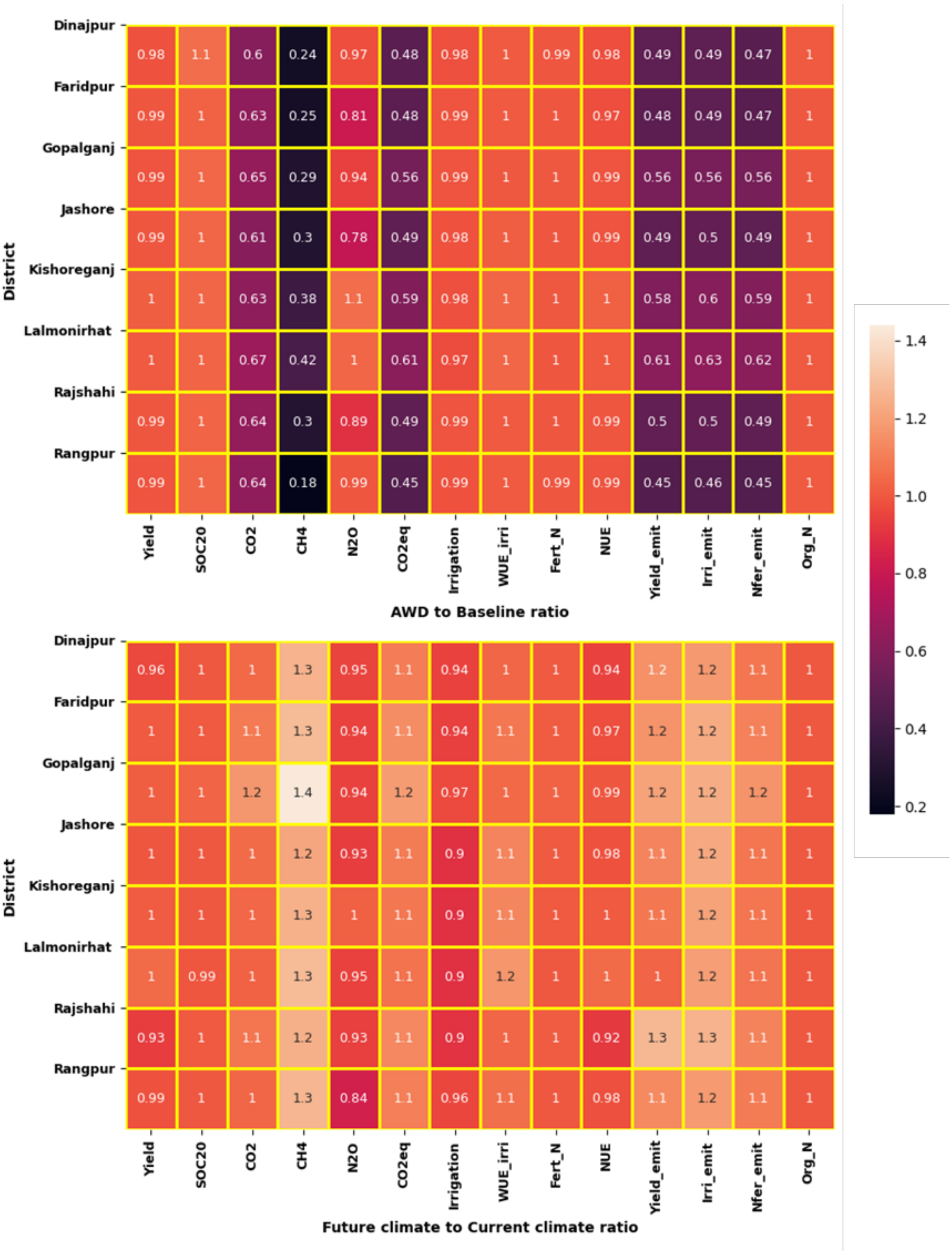


Fig. 7.1. The spatial (a) and temporal (b) variation of target variables across AgMIP MAC-B study sites in Bangladesh predicted by the DNDC-ORYZA crop model.

Effects of Alternate Wetting and Drying

At the district level, the application of alternate wetting and drying did not have significant effects on rice yields, but showed large reductions in GHG emissions. There is a ~50% decrease in the emissions normalized by yield, irrigation water applied, and nitrogen fertilizer application (Fig. 7.2a). Under AWD management, N2O emissions slightly increase as the soil environment becomes congenial for nitrification and denitrification. But in this study N2O emissions vary greatly possibly due to the drying period being either too short or too long. Denitrification involves conversion of nitrogen through multiple steps such as NO3 to NO2, to NO, to N2O, and finally to N2. We applied the uniform dry and wet cycle across all sites without considering the site-specific biophysical conditions, which might have resulted in a short drying period in some cases and a long drying period in others. If the drying period was too short, the denitrification may not happen, or even if happen but not enough to generate N2O because AWD improved the oxidation condition significantly. If the drying period was long which implied the anaerobic was too strong, the denitrification process had been completed to generate N2 instead of N2O.



District	Yield	SOC20	CO2	CH4	N2O	CO2eq	Irrigation	WUE_irri	Fert_N	NUE	Yield_emit	Irri_emit	Nfer_emit	Org_N
Dinajpur	0.98	1.1	0.6	0.24	0.97	0.48	0.98	1	0.99	0.98	0.49	0.49	0.47	1
Faridpur	0.99	1	0.63	0.25	0.81	0.48	0.99	1	1	0.97	0.48	0.49	0.47	1
Gopalganj	0.99	1	0.65	0.29	0.94	0.56	0.99	1	1	0.99	0.56	0.56	0.56	1
Jashore	0.99	1	0.61	0.3	0.78	0.49	0.98	1	1	0.99	0.49	0.5	0.49	1
Kishoreganj	1	1	0.63	0.38	1.1	0.59	0.98	1	1	1	0.58	0.6	0.59	1
Lalmonirhat	1	1	0.67	0.42	1	0.61	0.97	1	1	1	0.61	0.63	0.62	1
Rajshahi	0.99	1	0.64	0.3	0.89	0.49	0.99	1	1	0.99	0.5	0.5	0.49	1
Rangpur	0.99	1	0.64	0.18	0.99	0.45	0.99	1	0.99	0.99	0.45	0.46	0.45	1

AWD to Baseline ratio

District	Yield	SOC20	CO2	CH4	N2O	CO2eq	Irrigation	WUE_irri	Fert_N	NUE	Yield_emit	Irri_emit	Nfer_emit	Org_N
Dinajpur	0.96	1	1	1.3	0.95	1.1	0.94	1	1	0.94	1.2	1.2	1.1	1
Faridpur	1	1	1.1	1.3	0.94	1.1	0.94	1.1	1	0.97	1.2	1.2	1.1	1
Gopalganj	1	1	1.2	1.4	0.94	1.2	0.97	1	1	0.99	1.2	1.2	1.2	1
Jashore	1	1	1	1.2	0.93	1.1	0.9	1.1	1	0.98	1.1	1.2	1.1	1
Kishoreganj	1	1	1	1.3	1	1.1	0.9	1.1	1	1	1.1	1.2	1.1	1
Lalmonirhat	1	0.99	1	1.3	0.95	1.1	0.9	1.2	1	1	1	1.2	1.1	1
Rajshahi	0.93	1	1.1	1.2	0.93	1.1	0.9	1	1	0.92	1.3	1.3	1.1	1
Rangpur	0.99	1	1	1.3	0.84	1.1	0.96	1.1	1	0.98	1.1	1.2	1.1	1

Future climate to Current climate ratio

Fig. 7.2. The effects of AWD (a) and climate change (b) on yield, soil organic carbon, resource consumption, and GHG emissions on current rice-growing system.

At the national scale, about 57% of sites had less than 5% of yield decrease under AWD management, and 40% of the sites had less than 5% of yield increases (Figure 7.3). GHG emissions decreased by more than 10% at all sites. AWD also decreased irrigation water by around 5% at 97% of sites because the AWD schedule of wet (5 days) and dry (7 days) periods were fixed in the growth season at all sites. The dry period may be too long (which may be the cause of lower N2O emissions) resulting in the development of deep cracks, which leads to more irrigation water consumption to return the fields to the wet period.

At the district scale, more than 50% of sites had less than 5% yield penalty in the Rangpur, Dinajpur, Rajshahi, Jashore, Faridpur, and Gopalganj districts, but more than 50% of sites in Lalmonirhat and Kishoreganj showed yield increases by about 5%.

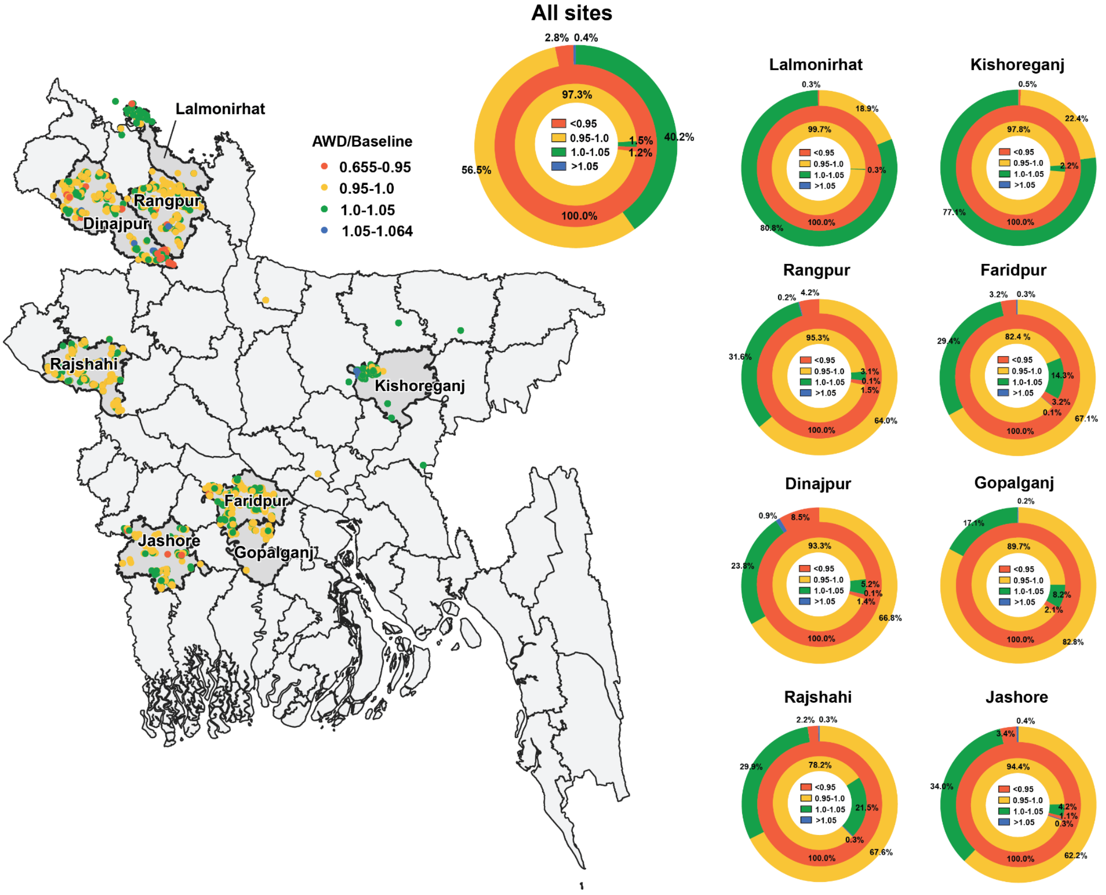


Fig. 7.3. The rice yield ratios and the distributions of yield, CO2eq, and irrigation water consumption of alternate wetting and drying (AWD) compared with continuous flood water management (Baseline) at national and district levels. The donut graphs present the probabilities of increase or decrease for grain yield (outside cycles), irrigation water consumption (inner cycles), and the CO2eq emissions (middle cycles).

Effects of climate change

Climate change is projected to decrease grain yields by 1 to 7% in the Rangpur, Dinajpur, and Rajshahi districts, but the yields in other districts did not change significantly (Fig. 7.2). Climate change would increase CO2 and CH4 emissions by up to 40% but decrease N2O emissions by up to 7% resulting in a 10-20% increase in global warming potential in terms of CO2eq. Moreover, the yield, irrigation water, and nitrogen fertilizer emission indicators also increased in all districts. Climate change accelerates the carbon decomposition for higher CO2 and CH4 emissions, or results in higher root biomass as substrate of more carbon decomposition to generate more CO2 and CH4. The large biomass accumulation consumed more soil mineral nitrogen, and lowered down the substrate for denitrification, resulting in low N2O emissions.

At the national scale taking into account all sites, climate change would cause a yield decrease of more than 5% in 26% of the sites and a less than 5% yield decrease in 26% of the sites (Figure 7.4). In contrast, 18% of the sites would experience more than 5% yield increase. However, more than 85% sites would experience more than 5% increase in total

GHG emissions due to increased CO2 and CH4 emissions under the climate change scenario.

At the district scale, yield decreases occurred in about 50% of sites in 7 of the 8 districts, except for in Lalmonirhat. Also, the CO2eq increased by more than 5% at more than 70% of sites in all districts.

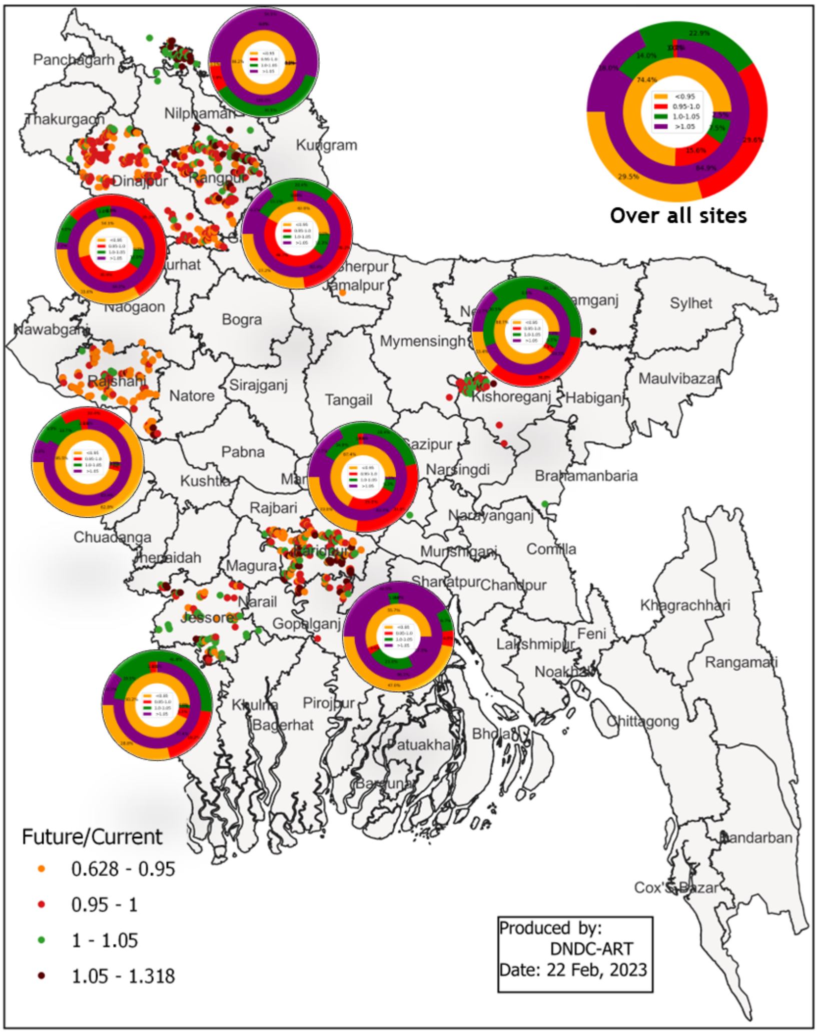
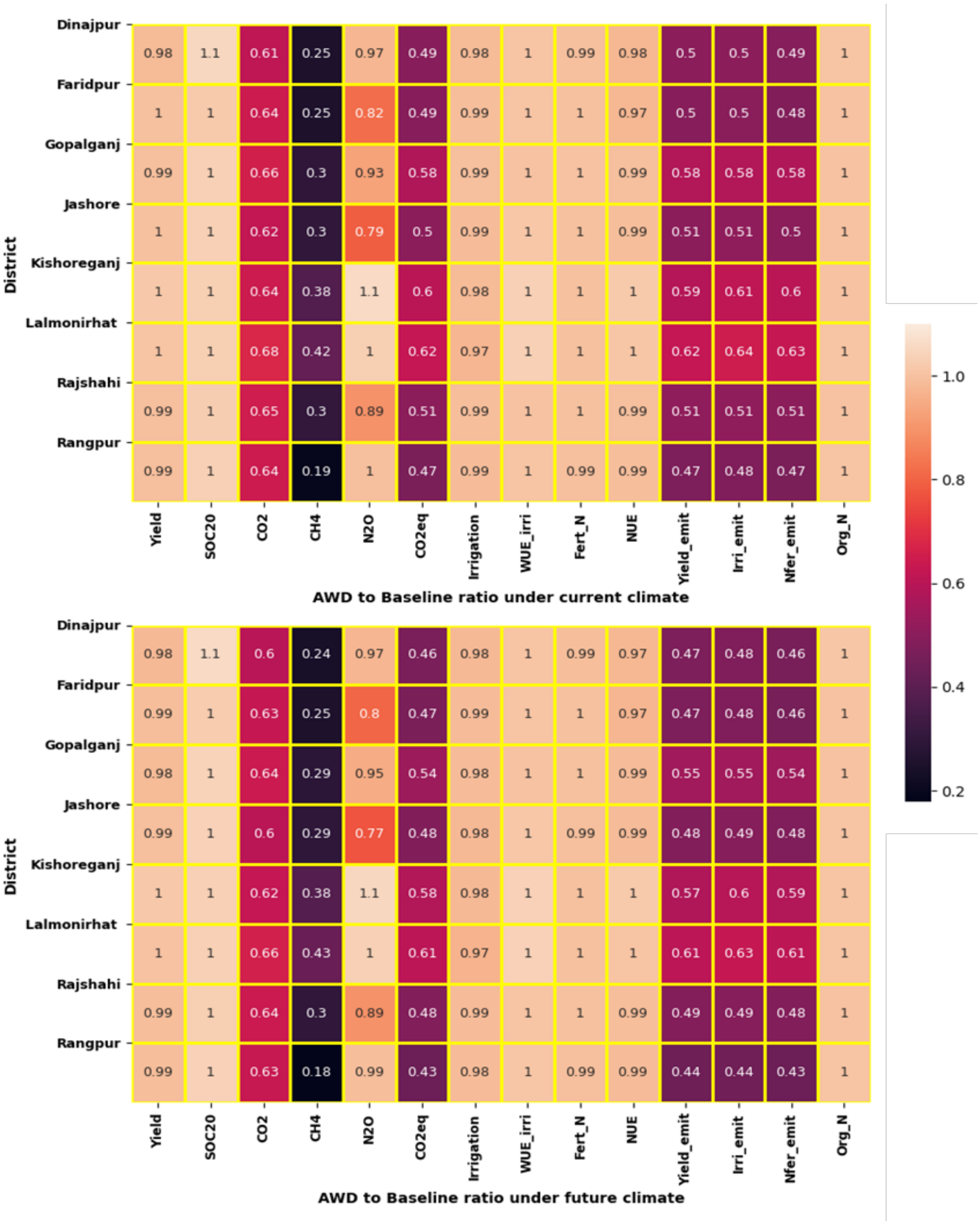


Fig. 7.4. Yield ratios and distributions of yield, CO2eq, and irrigation water consumption in comparison between current and future climate at national and district levels. The donut graphs present the probabilities of increase or decrease for grain yield (outside cycles), irrigation water consumption (inner cycles), and the CO2eq emissions (middle cycles).

Use of Alternate Wetting and Drying for Climate Change Mitigation and Adaptation

With the application of AWD, the yields did not change or experienced only a very minor penalty (up to 2%) under current and future climate conditions (Figure 7.5). Greenhouse gas emissions decreased overall in all districts, particularly in CH4 emissions (58 to 82%). Total GHG emissions (CO2e) per unit of grain yield, irrigation water, and nitrogen were lower under AWD compared to conventional practice. However, the application of AWD did not affect the N rate or NUE. This result confirmed the need for site-specific AWD to achieve significant co-benefits on yield increases, irrigation water saving, and GHG reductions. Currently, the fixed dry periods (7 days) for all sites may be too long for some sites in which deep cracks may be formed as bypasses for the water, resulting in the need for more irrigation water for resealing the cracks.



AWD to Baseline ratio under current climate

District	Yield	SOC20	CO2	CH4	N2O	CO2eq	Irrigation	WUE_irri	Fert_N	NUE	Yield_emit	Irri_emit	Nfer_emit	Org_N
Dinajpur	0.98	1.1	0.61	0.25	0.97	0.49	0.98	1	0.99	0.98	0.5	0.5	0.49	1
Faridpur	1	1	0.64	0.25	0.82	0.49	0.99	1	1	0.97	0.5	0.5	0.48	1
Gopalganj	0.99	1	0.66	0.3	0.93	0.58	0.99	1	1	0.99	0.58	0.58	0.58	1
Jashore	1	1	0.62	0.3	0.79	0.5	0.99	1	1	0.99	0.51	0.51	0.5	1
Kishoreganj	1	1	0.64	0.38	1.1	0.6	0.98	1	1	1	0.59	0.61	0.6	1
Lalmonirhat	1	1	0.68	0.42	1	0.62	0.97	1	1	1	0.62	0.64	0.63	1
Rajshahi	0.99	1	0.65	0.3	0.89	0.51	0.99	1	1	0.99	0.51	0.51	0.51	1
Rangpur	0.99	1	0.64	0.19	1	0.47	0.99	1	0.99	0.99	0.47	0.48	0.47	1

AWD to Baseline ratio under future climate

District	Yield	SOC20	CO2	CH4	N2O	CO2eq	Irrigation	WUE_irri	Fert_N	NUE	Yield_emit	Irri_emit	Nfer_emit	Org_N
Dinajpur	0.98	1.1	0.6	0.24	0.97	0.46	0.98	1	0.99	0.97	0.47	0.48	0.46	1
Faridpur	0.99	1	0.63	0.25	0.8	0.47	0.99	1	1	0.97	0.47	0.48	0.46	1
Gopalganj	0.98	1	0.64	0.29	0.95	0.54	0.98	1	1	0.99	0.55	0.55	0.54	1
Jashore	0.99	1	0.6	0.29	0.77	0.48	0.98	1	0.99	0.99	0.48	0.49	0.48	1
Kishoreganj	1	1	0.62	0.38	1.1	0.58	0.98	1	1	1	0.57	0.6	0.59	1
Lalmonirhat	1	1	0.66	0.43	1	0.61	0.97	1	1	1	0.61	0.63	0.61	1
Rajshahi	0.99	1	0.64	0.3	0.89	0.48	0.99	1	1	0.99	0.49	0.49	0.48	1
Rangpur	0.99	1	0.63	0.18	0.99	0.43	0.98	1	0.99	0.99	0.44	0.44	0.43	1

Fig. 7.5. The adaptation effects quantified by the ratios in comparison AWD and Baseline under future and current climate.

Effects of SRI

In the SRI system, organic fertilizer application was more than 200% of those applied in the conventional system. The higher yields of SRI were similar regardless of the differences in climate conditions, water management, or even the combined climate and water management conditions. However, the increases in GHG emissions were affected by water management and climate conditions. However, the increases in CO2 and CH4 emissions were slightly lower under future climate conditions for SRI (Figure 7.6).

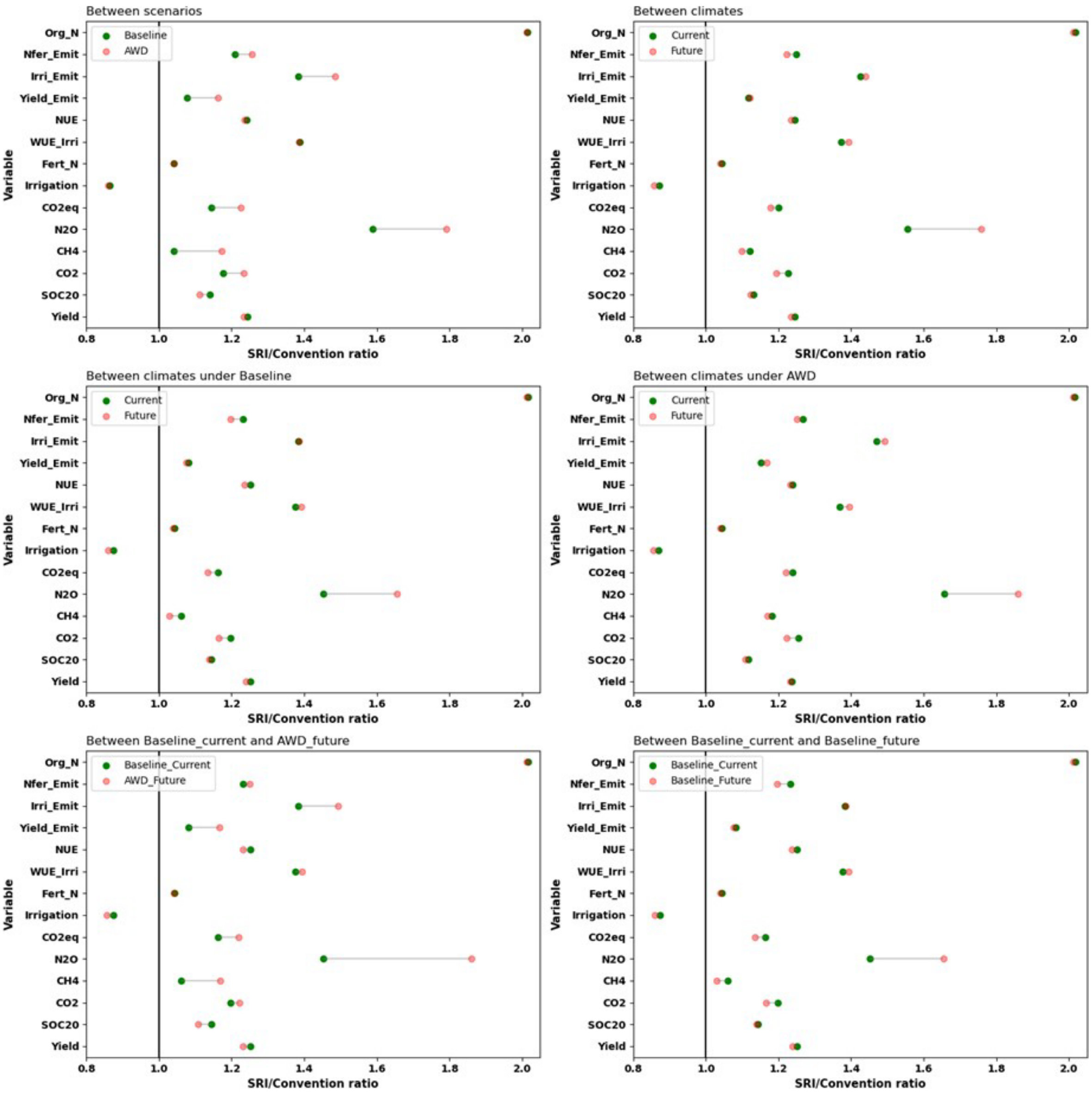
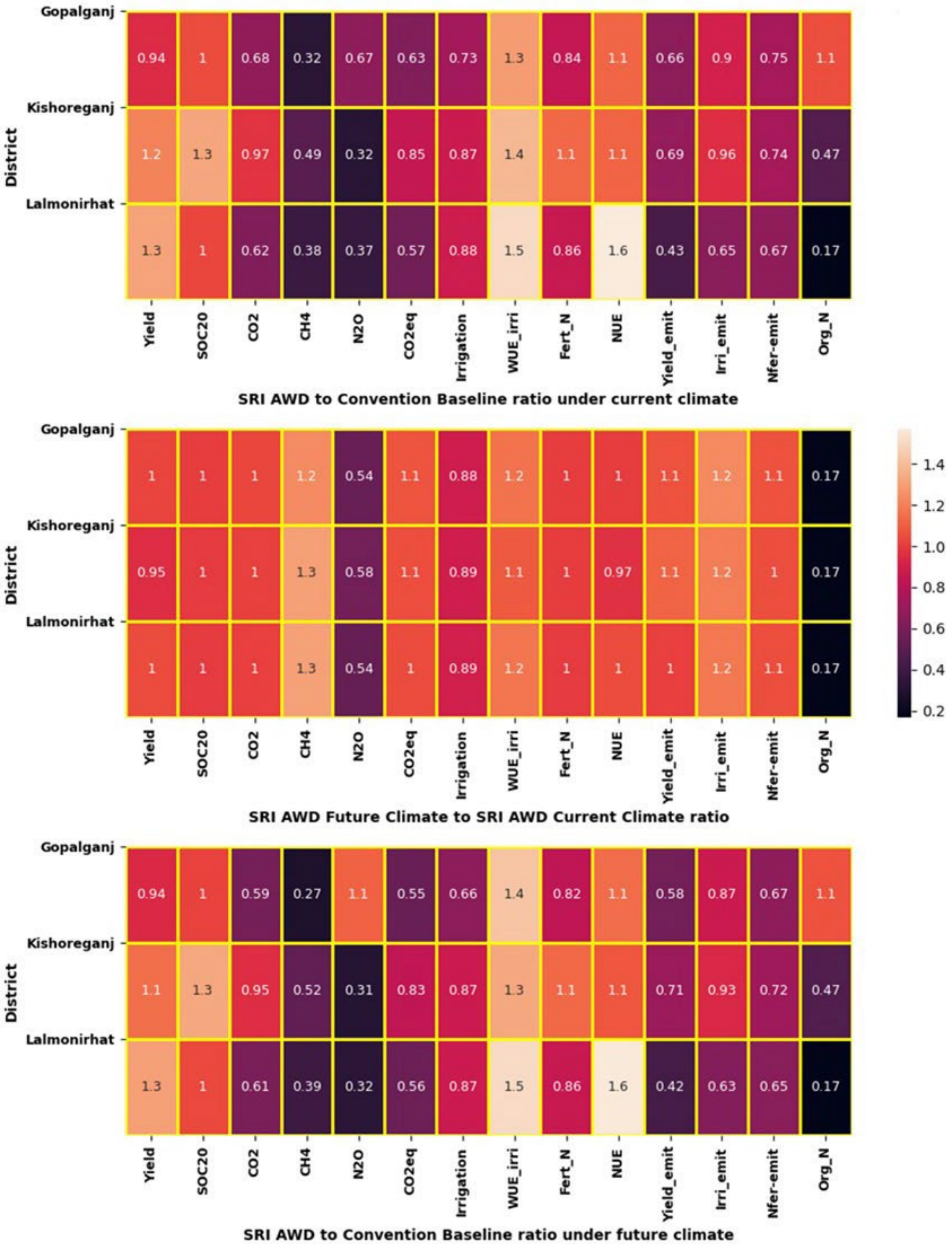


Fig. 7.6. The ratios of all target variables between those in the Sustainable Rice Intensification (SRI) cropping system and those in the conventional cropping system.

SRI combined with Alternate Wetting and Drying (AWD) would be one approach to adapt to climate change (Figure 7.7). The yields might increase by up to 40%. The yield increases were likely misleading in the Gopalganj district because a large amount of chemical nitrogen fertilizer was replaced by organic fertilizer characterized as 6.6 times higher in Org_N. Again, the amount of organic nitrogen application in the SRI AWD system increased N_2O emissions by 34% under the current climate, and 120% under the future climate. The adaptation of SRI+AWD decreased CO_2 and CH4 emissions significantly in all districts, resulting in decreases of 15 to 45% in total CO2eq emissions. Moreover, the mitigation measures greatly decreased the emission intensity per unit of grain yield, irrigation water, and nitrogen fertilizer. However, the mitigation benefits were smaller under future climate than those under current climate.



SRI AWD to Convention Baseline ratio under current climate

SRI AWD Future Climate to SRI AWD Current Climate ratio

SRI AWD to Convention Baseline ratio under future climate

Fig. 7.7. The mitigation and adaptation effects of SRI with different water management practices under future climate change. Note: To control the display scale of ratio numbers in the heatmaps, the ratio numbers for N_2O emissions (N2O) and the percentages of organic nitrogen to total nitrogen fertilizer application (Org_N) in the heatmaps are 1/2 and 1/6 of actual numbers.

The significant yield increases are attributed to the greater organic fertilizer application, which could also lead to greater soil carbon sequestration indicated by increased soil carbon contents in the top 20 cm of soil. The very large amount of organic fertilizer application (up to 10 Mg dry mass/ha) pushed the farming practice more to be like organic farming, and only be practical in small plots. The type of SRI practice would be constrained by the source of organic fertilizer for an extension on a regional scale.

Farm net returns under current conditions

Using the BRAC/Monash farm-level data, the contribution of the different crops grown on the farm-to-farm net returns were estimated. The data showed a large diversity of crops being grown in the region, for this analysis we grouped them in three major groups: rice, wheat, maize and pulses (WMP) and other crops[4]. The data suggests that rice is a major contributor to farm net returns for farmers growing conventional continuous flood (CF) and AWD systems, in particular for larger farms. For farmers growing SRI, while still rice plays a major role in the system, is not the main contributor to farm net returns, except for farmers in Gopalganj. This is explained by the fact that the area under SRI in these farms is smaller compared to the CF and AWD cases (Figure 7.8).

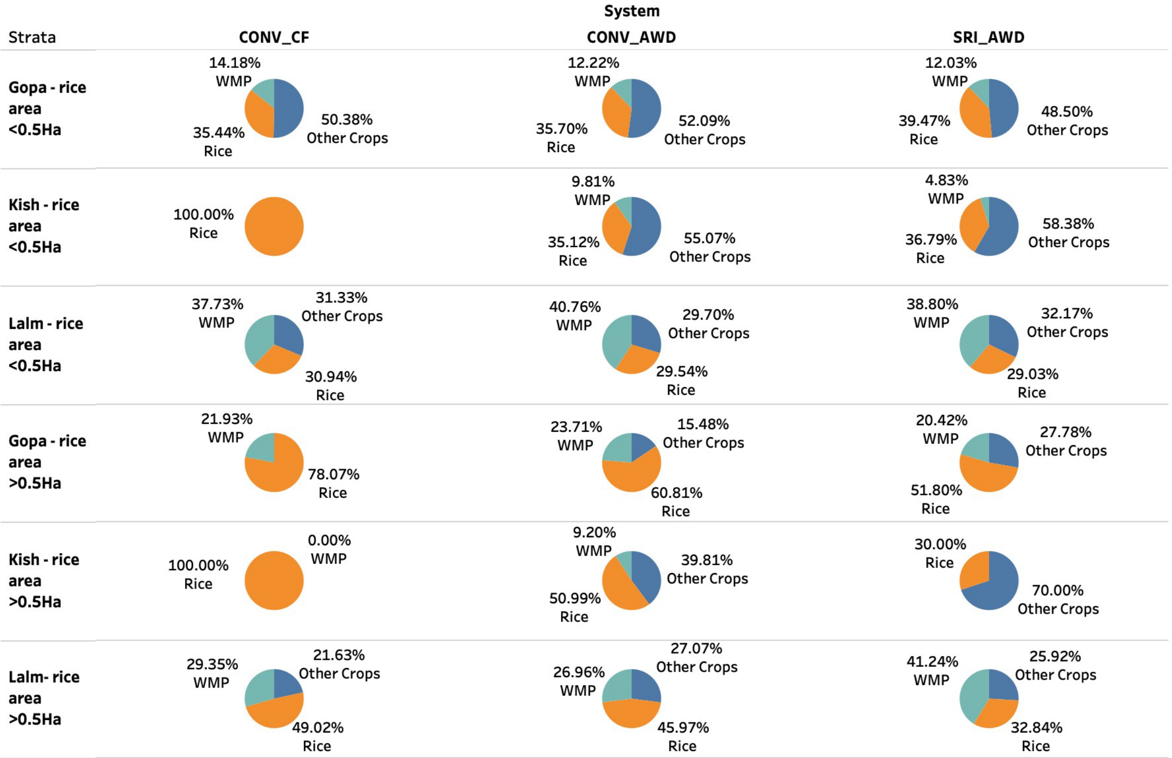


Fig. 7.8. Contribution crop enterprises to farm net returns (%) by district and farm type. Crop enterprises grouped in i. rice; ii. wheat, maize and pulses (WMP); and iii. other crops

Impacts of climate change on CF, AWD and SRI

Figure 7.9 summarizes the aggregate results of the impacts of climate change on CF, AWD, and SRI management systems under two climate projections: GPXF (hot and variable precipitation) and GRXF (less warm and lower precipitation) which correspond to the simulation experiments 1-6 described in table yy.

Vulnerability. The results show that under the GPXF scenario, 50% to 58% of households are vulnerable to climate change, while for AWD and SRI, the range is between 49% and 52%. The GRXF scenario appears to decrease vulnerability for the three management

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[4] Other crops included: jute, oil seed, potato, onion, tobacco, spice, vegetables, grass, banana, potol, dhuniya, peanut, black cumin, betel leaf, chili, flower, and turmeric.

systems. For AWD and SRI cases vulnerability is less than 50%, while the range for CF is between 45% and 55%.

Mean farm net returns (MFNR). Under the GPXF scenario, farmers using the CF system are likely to experience a decrease in MFNR up to 7% from climate change. For AWD, most farmers could benefit, although the increase in MNFR is small. SRI farmers may also experience a small reduction in MFNR. The GRXF scenario appears to benefit rice farmers, in particular those under AWD and SRI. However, results show a higher variability in the CF farms, and this can be explained by the socio-economic and bio-physical heterogeneity that characterizes farms in the region such as soil conditions, water access, crop management, input use, etc.

Poverty rate. In most cases, scenario GPXF resulted in an increase in poverty rates in the region, except for some AWD farms. The increase in poverty is larger for CF farms. The GRXF scenario contributed to decreasing poverty rates among farms that grow rice under AWD and SRI. As for the case of CF farms, there are instances where poverty rates decrease, but consistent with the mean net farm returns results, the variability is higher.

In summary, the results show that both AWD and SRI can enhance the resilience of rice systems to climate change as they can offset some of the negative impacts of climate change or provide benefits under moderate climate scenarios with less extreme changes in temperature and precipitation variability. The higher variability in the distribution of outcomes related to CF systems could be due to the fact that the survey data shows that crop management under CF can vary significantly among farmers and regions and the number of observations (farms using CF) is larger than the AWD and SRI, whereas AWD and SRI have relatively more ‘prescribed’ management recommendations, resulting in less variability due to management. It is also important to note that, although AWD and SRI show lower vulnerability in comparison to CF, a significant proportion of the population remains vulnerable to climate change.

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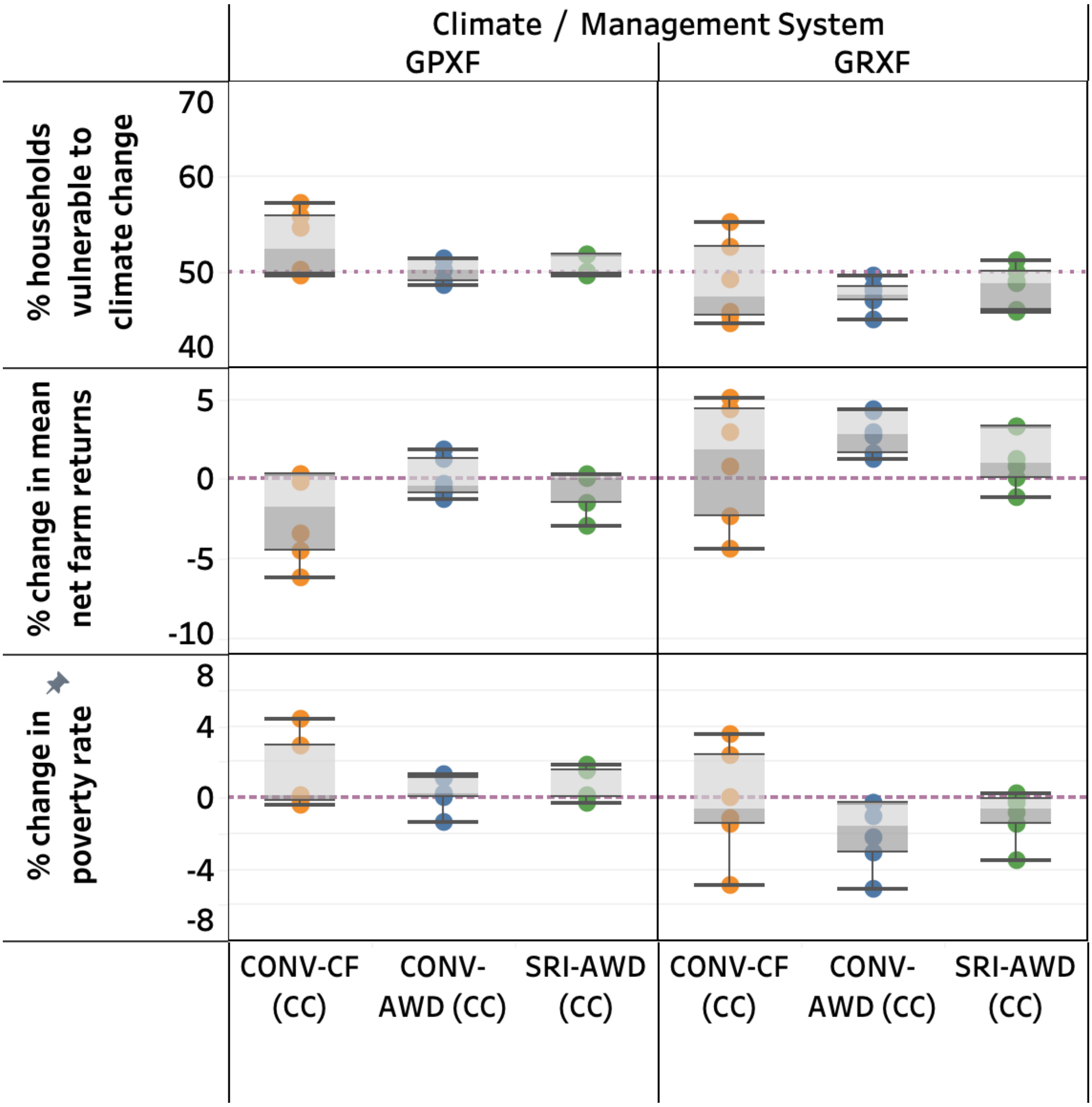


Fig. 7.9. Distributional impacts of CC on rice systems in Bangladesh (3 districts)

Adaptation/adoption analysis

Figure 7.10 summarizes the results of the adoption analysis that include the adaptation scenarios 7-12 described in table xxx. This analysis estimates the potential adoption rates and the associated consequences of this adoption if farmers were to switch from conventional CF to SRI combined with AWD. The analysis was done under current and the two future climates.

Adoption rates. The results show that about 50% of farms using conventional CF would switch to AWD under current or future climates. Adoption rates for the case of farmers switching from conventional CF to SRI is much higher. Under current climate, adoption rates range from 50% to 66%, while under climate change the range is between 53% to 65%.

Mean farm net returns (MFNR). The results show switching to AWD and SRI benefits farmers. MFNR in the population increases between 14% and 27% when farmers switch from conventional CF to AWD under current climate. Similar range is obtained under the GPXF climate scenario but the increase in MNFRs under the GRXF scenario is only between 7% and 10%. The benefits are larger when farmers switch to SRI, MFNR in the population increases between 16% and 66% under current climate. Under future climate conditions, MFNR increases between 24% and 44%.

Poverty rate. Poverty rates decrease in all cases due to the increase in MFNR. Switching to conventional CF can reduce poverty rates up to 22% under current or future climate. The results show that in the case of switching from conventional CF to SRI, poverty rates decrease up to 25% under current climate and up to 30% under future climate.

The analysis shows that both AWD and SRI are suitable crop management options to be used as climate adaptation strategies. In other words, farmers would benefit if they were to adopt AWD or SRI, under current or changed climate. Figure 7.10 shows that in some cases the distribution of outcomes is larger than others, this due to the heterogeneity across regions as shown on the disaggregated figures included in the Appendix.

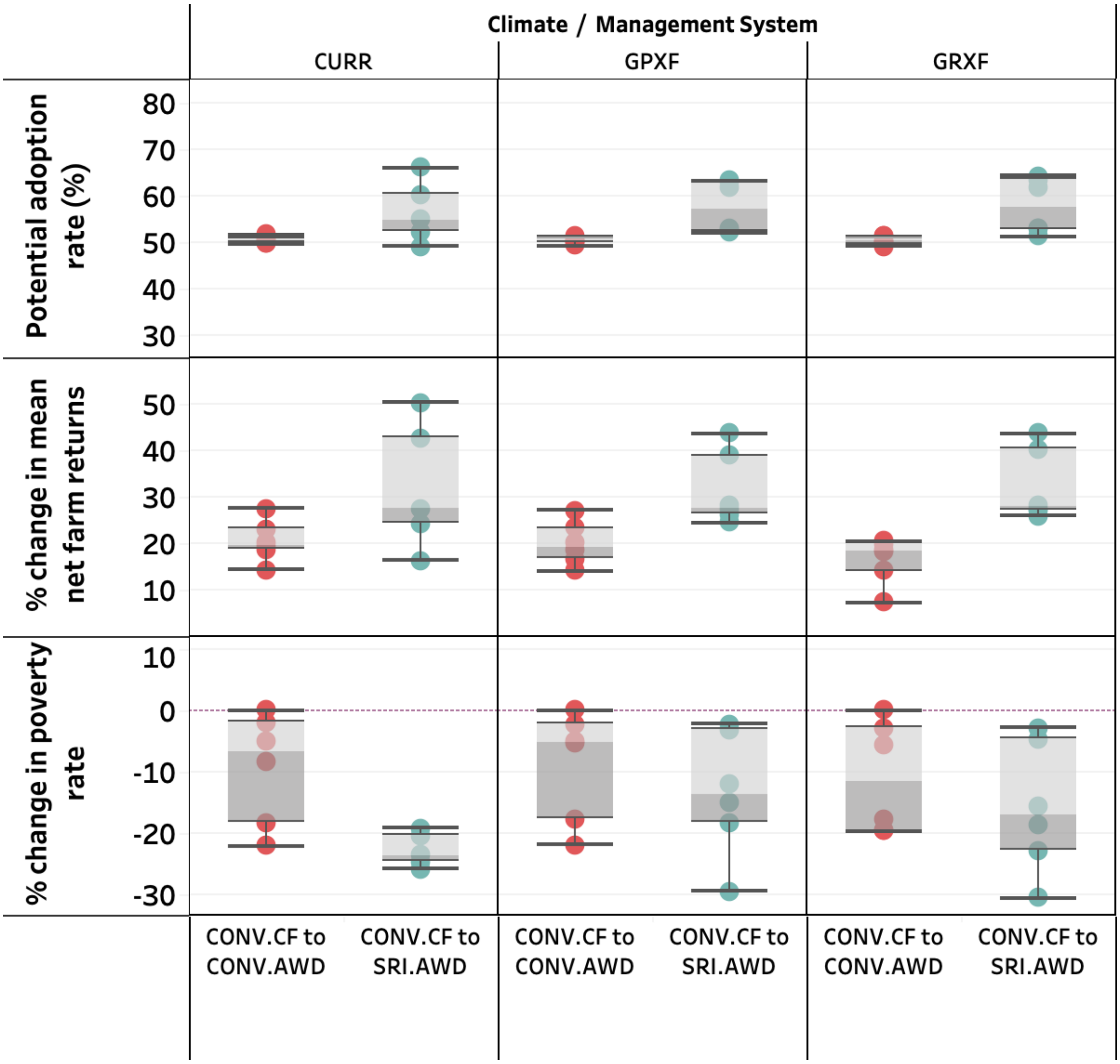


Fig. 7.10. Distributional impacts of adoption of AWD and SRI in Bangladesh (3 districts)

Mitigation-Adaptation Co-Benefits: Assessing tradeoffs in rice- based systems

As described above, the TOA-MD model estimates the impacts of climate change on farm net returns and environmental outcomes on a population of farms. The results indicate that there are farms that can be negatively impacted by climate change, but there are also farms that can benefit from it. This creates sub-populations of gainers and losers and each of these producing different outcomes. GHGs emissions might be different for farms where crop yields are negatively impacted by climate change than those where crop yields benefit from climate change. Likewise, in the adoption analysis, the model estimates a potential adoption rate and the impacts on outcomes associated with adoption. This means that farm net returns, GHG emissions and other outcomes might be different between adopters and non-adopters. This approach enables the identification of tradeoffs and synergies between socio-economic and environmental outcomes.

Figure 7.11 shows the population-aggregated (strata level) results for all impact and adoption scenarios. The figures focus on the tradeoffs between mean net farm income and four key GHG emissions: methane (CH4), nitrous oxide (N2), irrigation water use efficiency (WUE_irr), and CO_2 equivalent global warming potential (Co2eq). The climate change impact analysis shows that farm net returns increase or decrease depending on the climate scenario, management system and location. These results correspond to the points in orange, green and blue in each panel and range between -10% to 5% on the Y-axis (% change in mean net returns).

Panel ***a*** in figure 7.11 shows the tradeoffs between mean farm net returns and methane emissions. The impacts of climate change increase methane emissions between 12% to 54% (X-axis, % change in CH4). The hot scenario (GPXF) has the most negative consequences in both environmental and economic outcomes, as most of the results fall on the lose-lose space (lower-right quadrant on panel a). The adoption analysis shows that switching from conventional CF to AWD or SRI significantly increases farm net returns and reduces CH4 emissions in all cases, moving all of the results to the win-win space (upper-left quadrant on panel a).

Panel ***b*** focuses on mean net farm returns and N2O. In this case, the impacts of climate change and adaptation on N2O is highly variable due to the interactions of climate, soil, and management as discussed in the crop modeling results. The response of N2O to the different management systems and climate change require further research as discussed in the conclusions section. This approach allows to identify the population of farms and associated scenarios that fall within the win-win space and those that are in the win-lose space (top-right quadrant on panel b). This can be the basis to understand how the interaction of climate, management and biophysical conditions contribute to the results, while at the same time identify limitations and strengths of the crop model to capture these interactions.

Panel ***c*** shows the effects of climate change and adaptation on irrigation water use efficiency (WUE) and the tradeoffs with mean net farm returns. WUE improves with climate change for most cases, including those where farm net returns decrease. The adoption analysis shows that switching from conventional CF to AWD leads to a small improvement in WUE relative to the increase in WUE when farms switch from conventional CF to SRI, which moves all the cases to a win-win space between mean net farm returns and mean irrigation water use efficiency.

Panel **d** shows that climate change contributes to increasing total global warming (CO2eq) in all scenarios up to 25%. The adoption analysis show that switching to AWD or SRI can contribute to decreasing CO2eq up to 30% while increasing mean farm net returns between 7% to 27% in the AWD case, and between 16% to 50% in the case of SRI.

The aggregated results described in Figure 11 suggest that tradeoffs between socio-economic and environmental outcomes are important to understand the complex interactions of the different management systems, climate change and adaptation. This analysis can inform decision making about the pathways to win-win outcomes, areas for further research and investment.

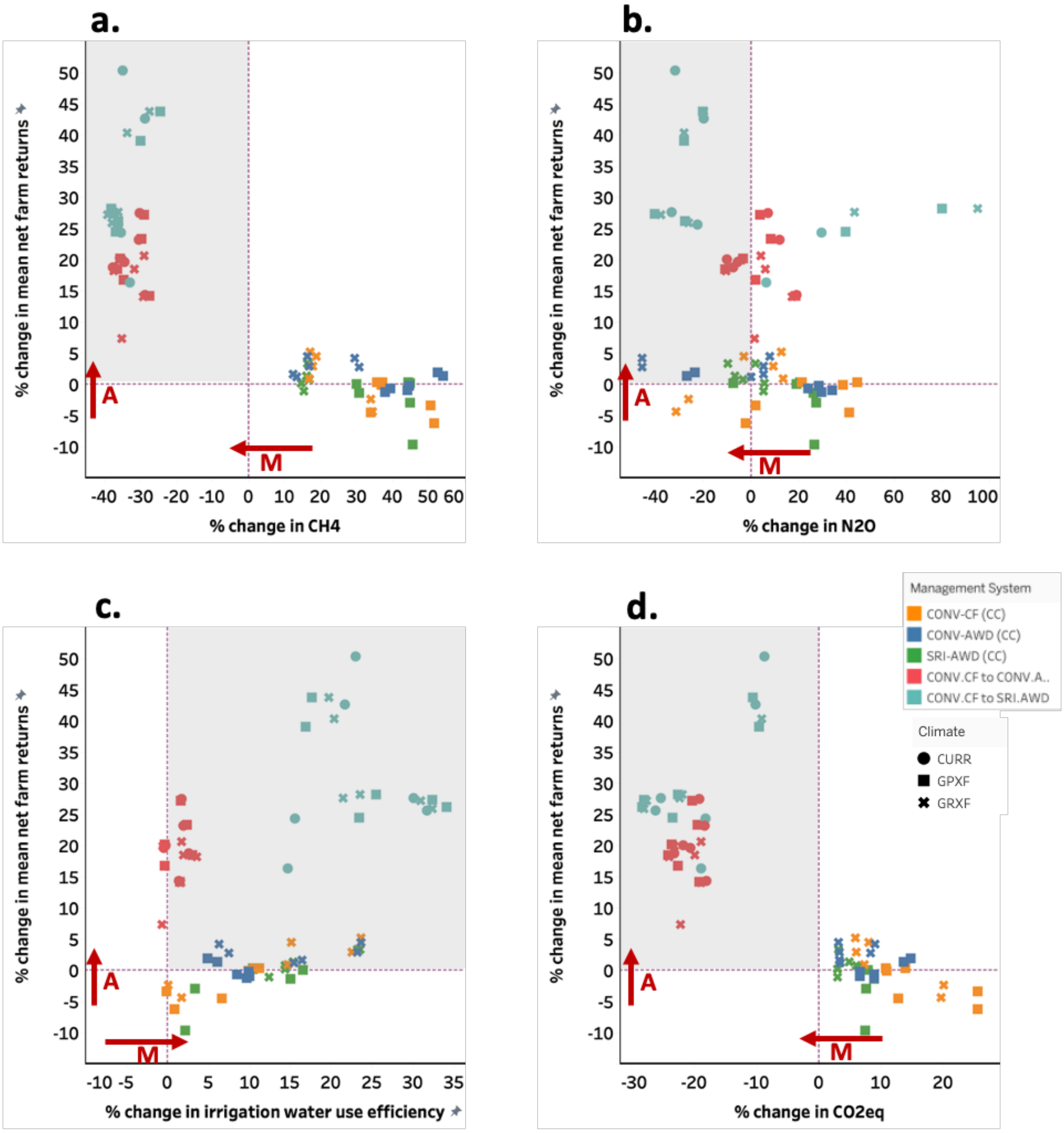


Fig. 7.11. Mitigation and adaptation tradeoffs and co-benefits for rice management systems in Bangladesh. 1. climate change impacts: conventional continuous flood (*Conv.CF(CC)*), conventional AWD (*Conv.AWD(CC)*) and System of Rice Intensification with AWD (*SRI.AWD(CC)*). 2. Impacts of adaptation: Switching from *Conv.CF to AWD* and switching from *Conv.CF to SRI.AWD.* Panel a.: mean net farm returns and methane (CH4); Panel b. Mean farm net returns and N2O; Panel c. change in mean net returns and water use efficiency; and Panel 4. mean farm net returns and CO2eq. Arrow with an A indicates direction of Adaptation. Arrow with an M, indicates direction of mitigation. Shaded areas indicate WIN-WIN space.

Analysis using the CIMMYT-DAE data

As described in the methods section, the CIMMYT_DAE data is plot-based and adjusted to represent management, yields and outputs on a per hectare unit. While the data does not have other farm production activities and household characteristics, it is not possible to conduct a full whole-farm assessment as in the previous case (e.g., poverty rates can't be estimated). However, the data can be interpreted as being representative for farms that grow only rice with a farm size of 1 hectare. This enables the estimation of the impacts of climate change on "mean net farm returns" (in this case rice being the only production/economic activity), the impacts of switching from conventional CF to AWD, and the associated environmental impacts.

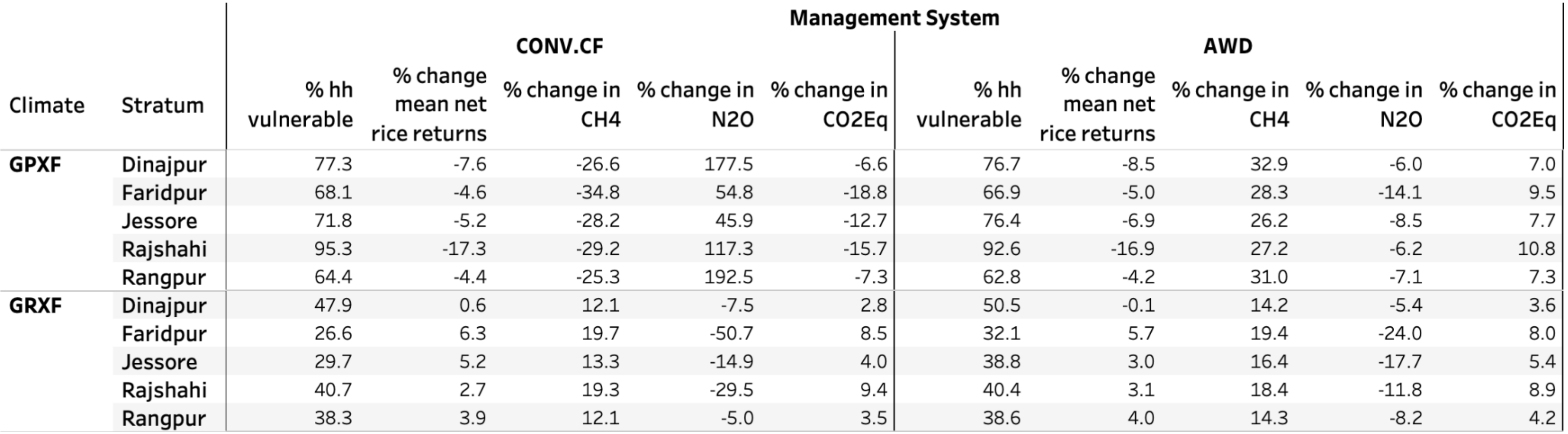
Table 7.1 summarizes the climate change impacts on conventional CF and AWD management systems. The hotter climate model (CPXF) impacts reduce mean farm net returns in both continuous flood and AWD, however the GHG response varies among the two management systems. Methane emissions and CO2eq decrease for conventional CF systems under the CPXF scenario and increase for AWD systems. In the CRXF climate scenarios, there is a slight increase in farm net returns, but CH4 and CO2eq also increase.

The table shows a large variation across the different strata (districts) and scenarios. Further research is needed to disentangle the components that contribute to this large heterogeneity (e.g., climate, soils, management, etc.)

The adoption analysis described in Table 7.2 shows the results of farms switching from CF to AWD. The results show that adoption rates are relatively low, between 18% to 50%. This adoption results in a slight increase in mean net farm returns across sites and scenarios and a reduction in CH4 and CO2eq emissions in most cases.

While this analysis is limited by the lack of data to fully characterize the production system, it provides interesting insights on the relationships between farm income and GHG emissions. N2O remains as one of the most uncertain GHG emission results that require further research and analysis.

Table 7.1. Climate change impacts on rice conventional continuous flood and AWD management systems in 5 districts in Bangladesh



		Management System									
		CONV.CF					**AWD**				
Climate	**Stratum**	**% hh vulnerable**	**% change mean net rice returns**	**% change in CH4**	**% change in N2O**	**% change in CO2Eq**	**% hh vulnerable**	**% change mean net rice returns**	**% change in CH4**	**% change in N2O**	**% change in CO2Eq**
GPXF	**Dinajpur**	77.3	-7.6	-26.6	177.5	-6.6	76.7	-8.5	32.9	-6.0	7.0
	Faridpur	68.1	-4.6	-34.8	54.8	-18.8	66.9	-5.0	28.3	-14.1	9.5
	Jessore	71.8	-5.2	-28.2	45.9	-12.7	76.4	-6.9	26.2	-8.5	7.7
	Rajshahi	95.3	-17.3	-29.2	117.3	-15.7	92.6	-16.9	27.2	-6.2	10.8
	Rangpur	64.4	-4.4	-25.3	192.5	-7.3	62.8	-4.2	31.0	-7.1	7.3
GRXF	**Dinajpur**	47.9	0.6	12.1	-7.5	2.8	50.5	-0.1	14.2	-5.4	3.6
	Faridpur	26.6	6.3	19.7	-50.7	8.5	32.1	5.7	19.4	-24.0	8.0
	Jessore	29.7	5.2	13.3	-14.9	4.0	38.8	3.0	16.4	-17.7	5.4
	Rajshahi	40.7	2.7	19.3	-29.5	9.4	40.4	3.1	18.4	-11.8	8.9
	Rangpur	38.3	3.9	12.1	-5.0	3.5	38.6	4.0	14.3	-8.2	4.2

Table 7.2. Impacts of adoption of AWD in rice systems in Bangladesh

		Management System CONV to AWD				
Climate	Stratum	Adoption rate (%)	% change mean net rice returns	% change in CH4	% change in N2O	% change in CO2Eq
CURR	Rangpur	41.47	6.33	-7.71	74.55	-0.49
	Rajshahi	35.47	4.49	-8.21	43.02	-3.52
	Jessore	30.49	2.79	-5.83	14.50	-1.84
	Faridpur	18.23	1.58	-5.25	11.14	-3.15
	Dinajpur	49.98	7.82	-10.82	79.48	-0.88
GRXF	Rangpur	42.01	6.82	-7.40	74.36	-0.88
	Rajshahi	37.15	5.18	-9.21	71.09	-4.21
	Jessore	27.96	2.75	-4.18	15.52	-0.61
	Faridpur	19.28	1.82	-6.18	32.97	-3.55
	Dinajpur	48.54	7.82	-10.10	84.33	-1.38
GYXF	Rangpur	42.12	6.75	2.17	71.37	2.18
	Rajshahi	37.82	5.58	-2.18	45.94	-0.74
	Jessore	28.73	2.86	0.53	15.40	1.35
	Faridpur	20.79	2.12	-3.27	12.24	-2.41
	Dinajpur	48.06	7.27	1.59	71.74	2.34

Effects on Gender and Nutrition

The MAC-B pilot study in Bangladesh developed a framework for consideration of the different vulnerability contexts and benefit structures for men and women (Figure 7.12). This is because different groups have differing capacity to influence farm household decision-making and differing opportunities to participate in farm activities. Interventions that result in equal access and benefits will impact livelihoods overall. The data used in this pilot project lacked adequate data to incorporate this component in the analysis. Future research should identify data that include key social variables such as age, education, land ownership, household headship, gender roles, gendered decision making, migration, ethnicity and language, and intra-household consumption patterns.

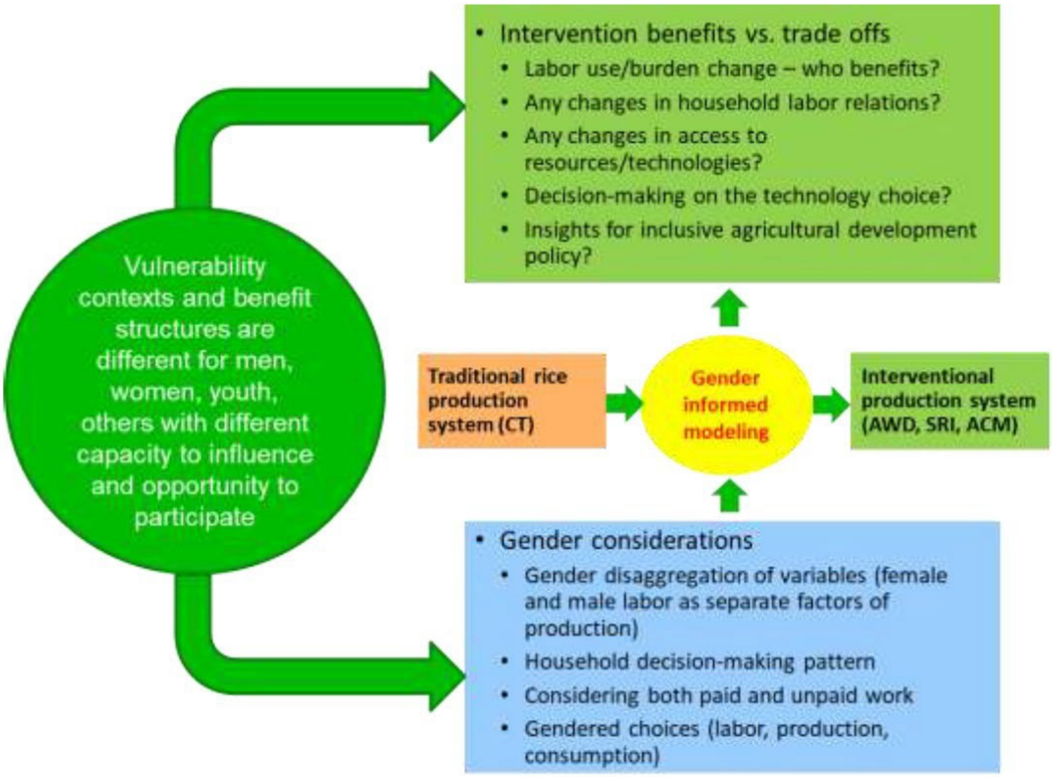


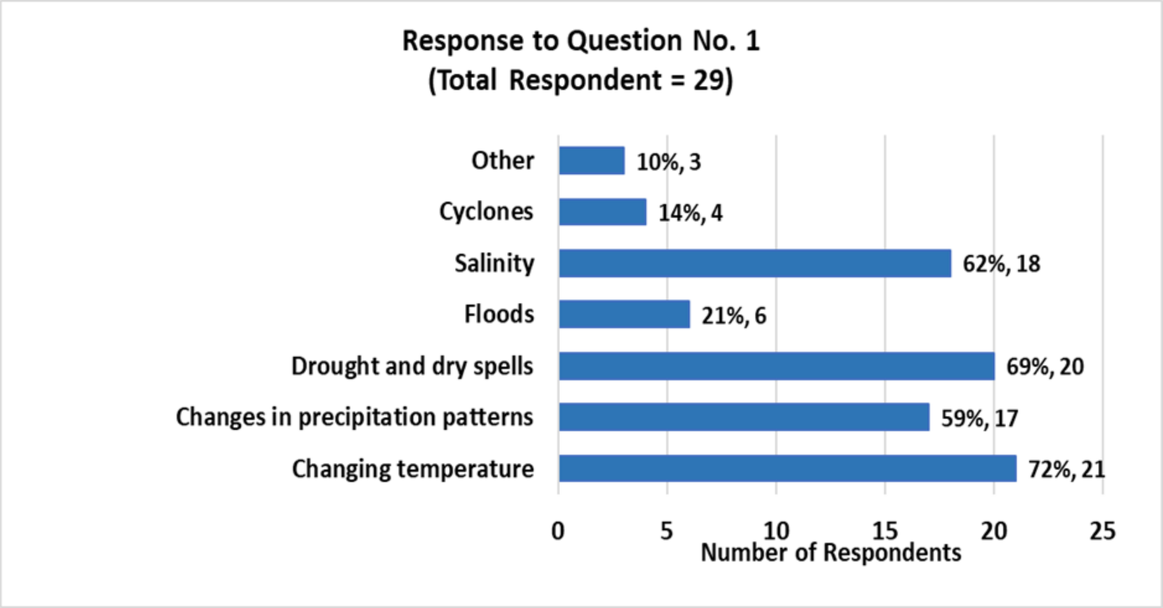
Fig. 7.12. Gender vulnerability framework

MAC-B Stakeholder Survey Results

The AgMIP MAC-B Stakeholder Roundtable was held on April 05, 2023, at the Bangladesh Rice Research Institute (BRRI) (see Appendix 11.2). Forty-six experts and scientists from different organizations in Bangladesh and abroad joined the meeting, of which 30 participated in person and 16 virtually. While the participants were sharing ideas, a survey link was shared via email and on the screen QR code with several questions on MAC-B about its potential, challenges, and recommendations, and requested them to provide their valuable responses. In this initial pilot project on MAC-B, our goal was to evaluate promising options (as well as discover data gaps and model improvement needs) for changing agricultural practices in ways that deliver both mitigation and adaptation benefits in Bangladesh. Based on the results of this pilot assessment, we will endeavor to expand the analysis to cover additional research areas, including those highlighted during the roundtable. Responses to the questions will help us address those concerns in future larger-scale assessments. Most Bangladeshi participants who attended in person and some who attended online completed the survey. In all, there were 29 respondents. The response is presented in graphical form depicting the number of respondents who selected the options and the percentage of respondents who chose the option.

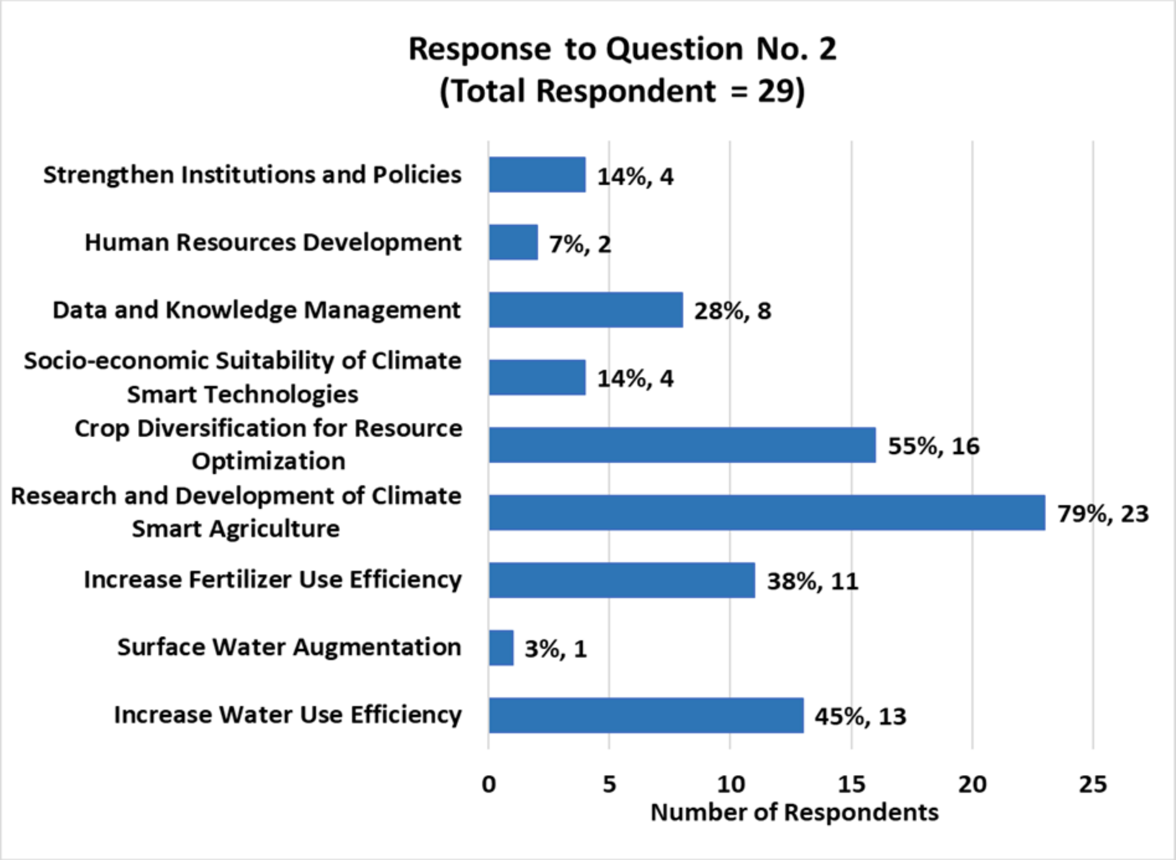
Question 1: What climate change vulnerabilities (related to agriculture) are you focusing on in your role in relation to national climate change mitigation and/or adaptation planning processes in Bangladesh?

In response to Question No. 1, the top three climate change vulnerabilities in agriculture identified were Changing temperature (72%), Drought and dry spells (69%) and Salinity (62%).



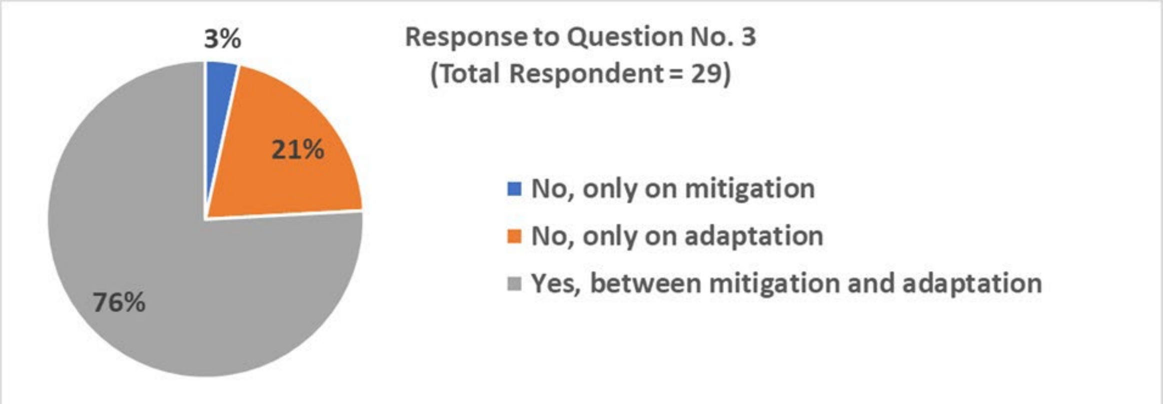
Question 2: What climate change mitigation and/or adaptation strategies/interventions are you focusing on in your role?

The first top three selected options were Research and Development of Climate Smart Agriculture (79%), Crop Diversification for Resource Optimization (55%), and Increase Water Use Efficiency (45%).



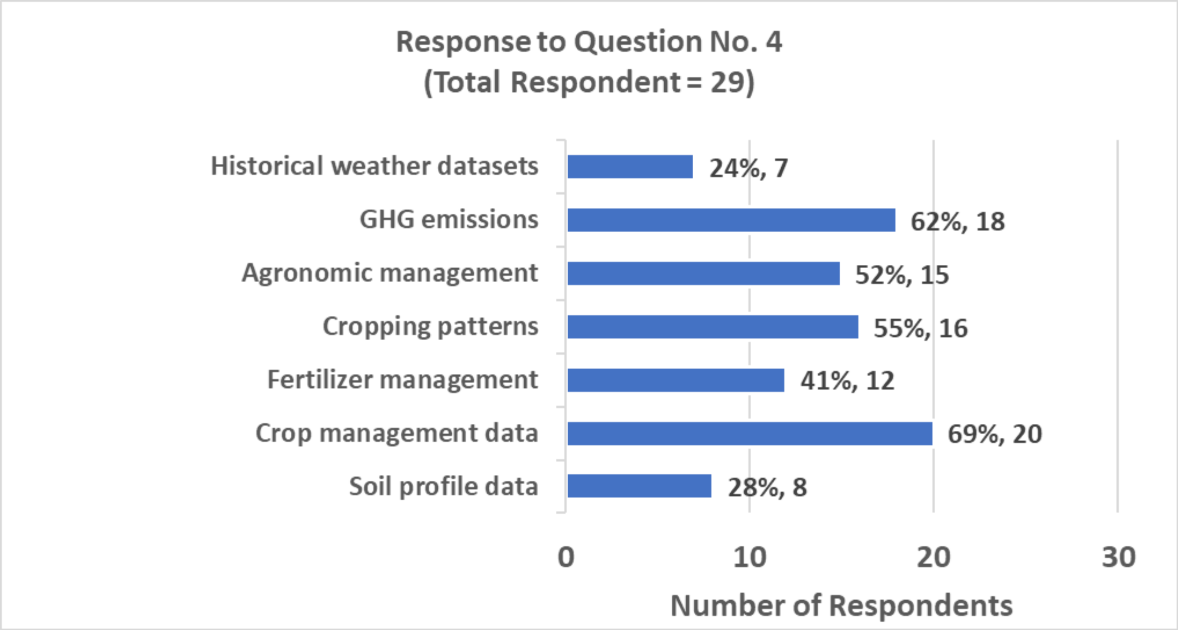
Question 3: Are you focusing on co-benefits between mitigation and adaptation strategies?

The large majority of participants (76%) indicated they are focusing on both mitigation and adaptation.



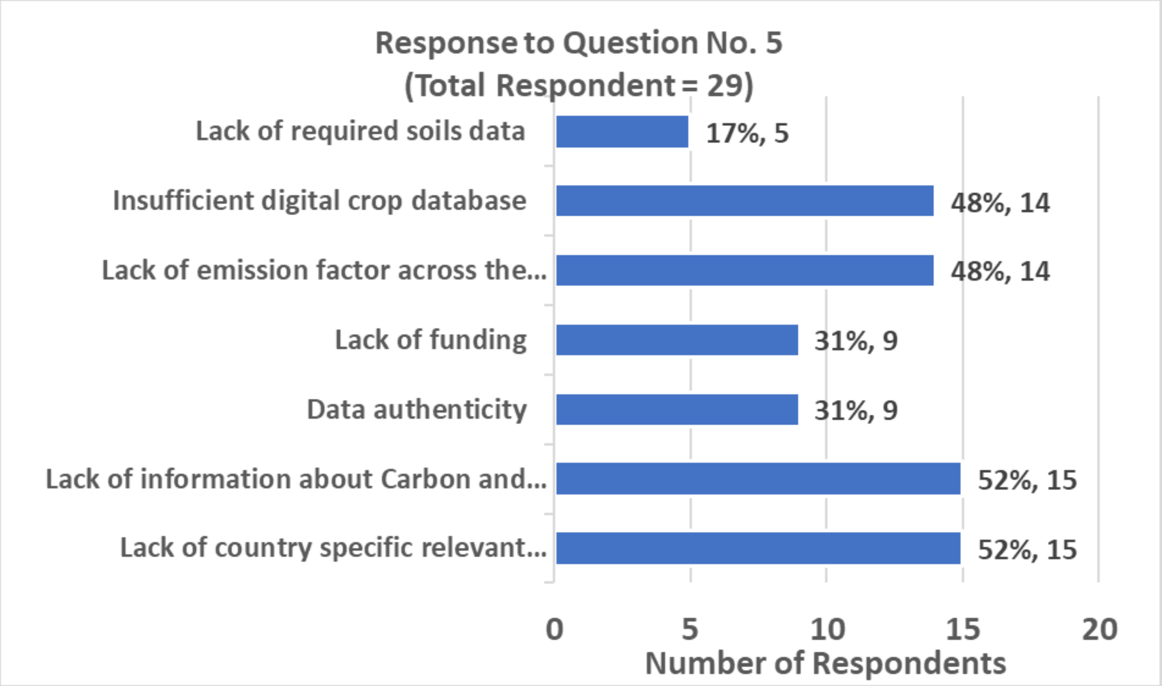
Question 4: What information is most relevant to you in your role in relation to national climate change mitigation and/or adaptation planning processes for agriculture in Bangladesh?

The top responses were crop management data (69%), GHG emissions (62%), cropping patterns (55%), and agronomic management (52%).



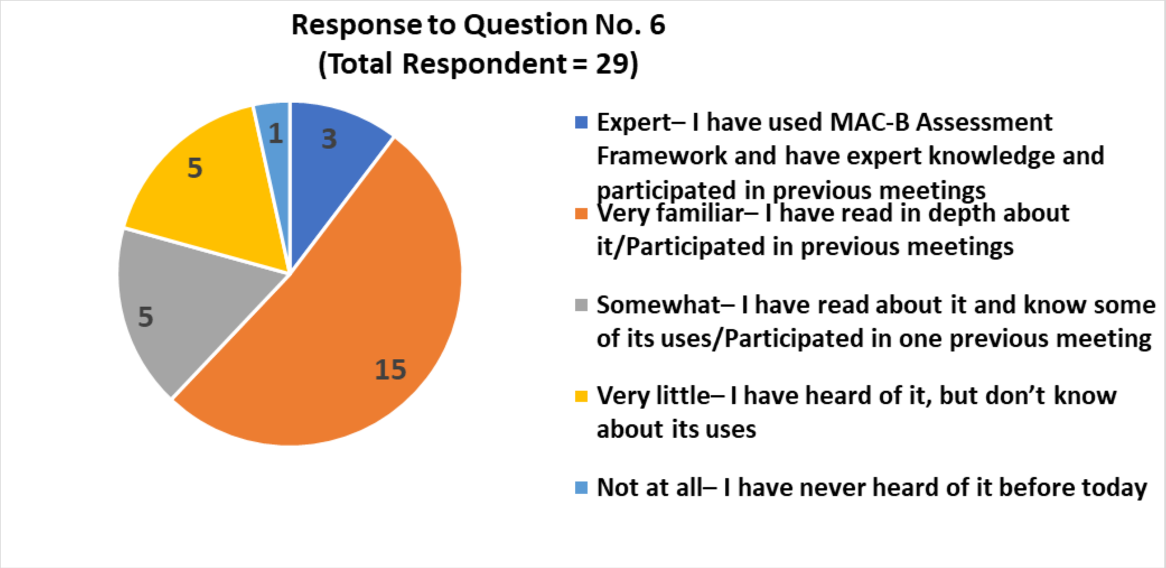
Question 5: What information or evidence have you wanted to have in your role in relation to national climate change mitigation and/or adaptation planning that you were not able to find or that you were not satisfied with?”

The majority of respondents selected lack of country-specific relevant climate scenarios or lack of information about Carbon and Nitrogen footprint (52%) followed by insufficient digital crop database or lack of emission factor across the country (48%) and data authenticity or lack of funding (31%).



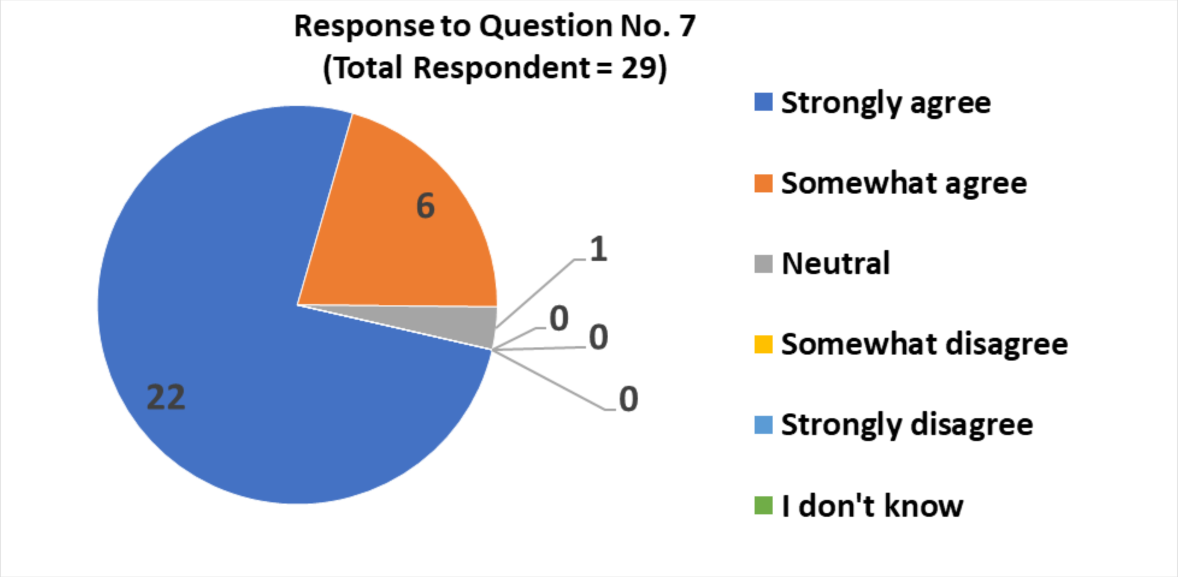
Question 6: How familiar are you with the Mitigation and Adaptation Co-Benefits (MAC-B) Assessment Framework approach?

A majority of the respondents (15) indicated they were already very familiar, as they had participated in the previous MAC-B Webinar and Stakeholder Workshop.



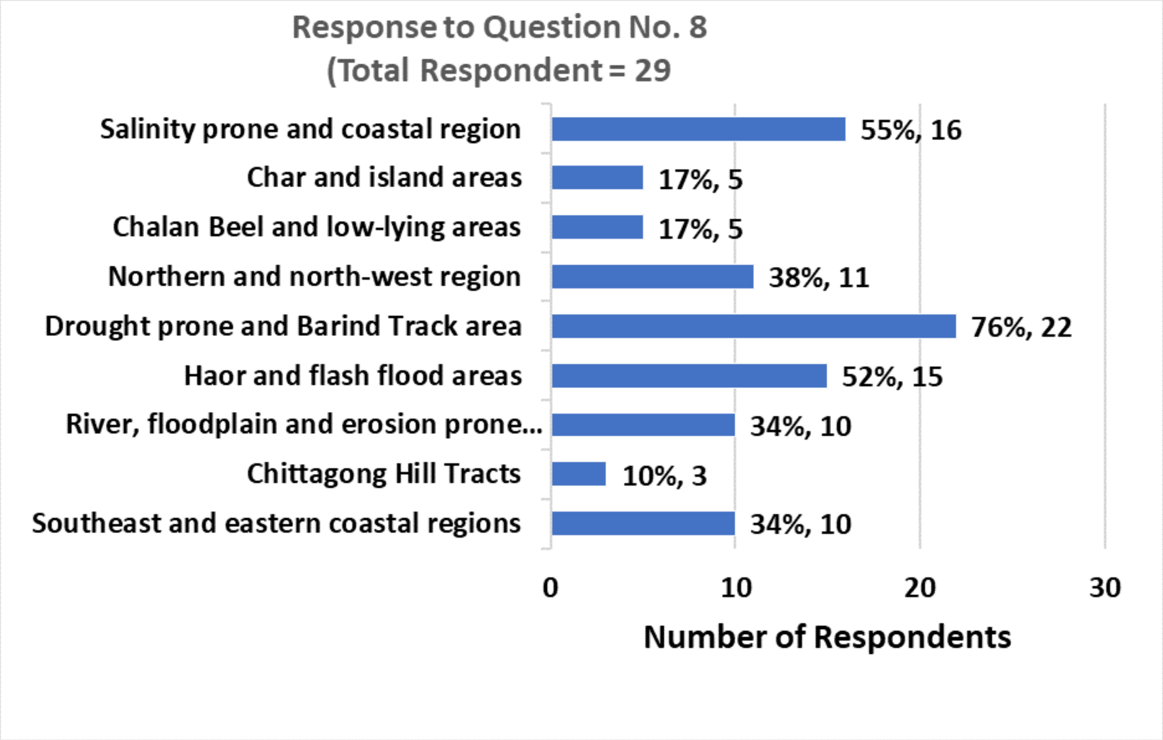
Question 7: In your opinion, is a national MAC-B project/program needed?

A large majority strongly agreed that MAC-B should be a national program.



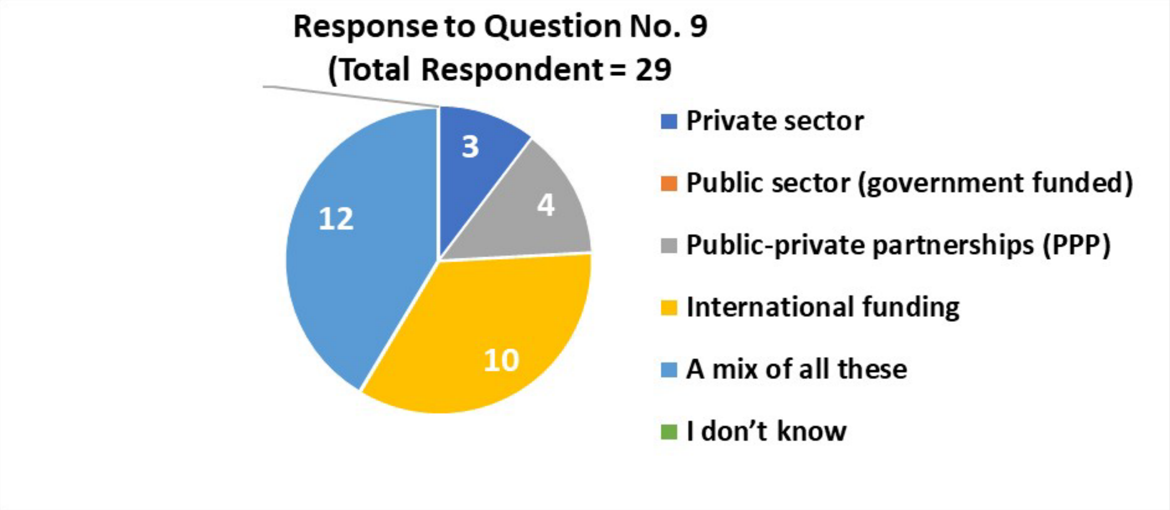
Question 8: In your opinion, in which areas of Bangladesh should data be collected for scaling MAC-B Assessment Framework?

The majority (76%) selected drought prone areas, including Barind Track, followed by 55% salinity prone and coastal regions and 38% northern and north-west regions of the country.



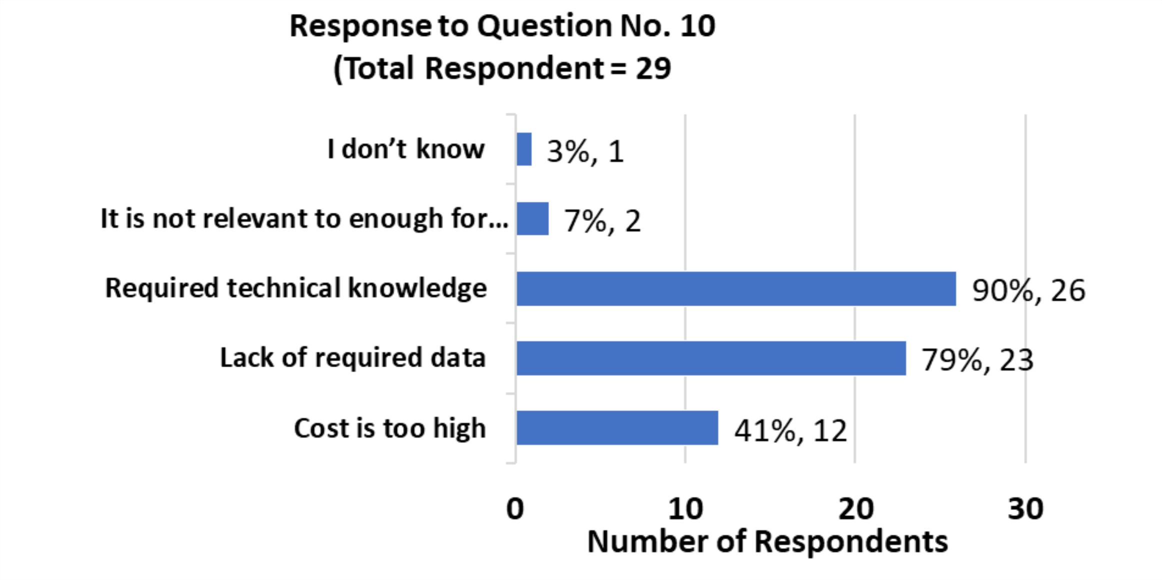
Question 9: What is the best way to finance a national project like MAC-B in Bangladesh?

In response to this question, out of 29 respondents, 12 of them think a mix of all funding sources will be the best way to finance a project like MAC-B in Bangladesh, while 10 persons believe international funding and 4 of them think the project can be funded by public-private partnerships (PPP).



Question 10: In your opinion, what are the major barriers to using the AgMIP MAC-B approach in Bangladesh?

In reply to this question, 90% selected lack of required technical knowledge, followed by lack of necessary data (79%) and 41% think the cost is too high for implementing such a project.



Additional comments and suggestions

Respondents also provided the following comments and suggestions:

1. There is a need for experimental data on GHG emissions and GHG absorption from crop cultivation.
2. The MAC-B methodology should be piloted in all climate-stressed areas identified in Bangladesh's National Adaptation Plan (NAP)
3. Additional capacity building is required to ensure MAC-B be included in institutional practices
4. Ensure the farmers' perspective is always included

5. The MAC-B methodology should include all ecosystems in Bangladesh so policy-makers can devise a complete mitigation and adaptation strategy.
6. Expand MAC-B to include complex crop diversity and diverse socio-economic factors in Bangladesh.

The responses and suggestions received will help in selecting and identifying appropriate locations, climate smart technologies, climate scenarios, data collection needs, and other key variables for future MAC-B projects.

8 Impacts

8.1 Scientific impacts – now and in 5 years

The Bangladesh AgMIP MAC-B project represents one of the earliest developments of addressing mitigation and adaptation in a key greenhouse gas emitting agricultural system. The AgMIP MAC-B project has developed a modeling framework and rigorous, interdisciplinary protocols to conduct advanced regional assessments. This approach aligns with the latest argument presented in the Bangladesh National Adaptation Plan (NAP) emphasizing the importance of raising awareness and building capacities to invest in the development of innovative approaches and tools that can assist in supporting climate change adaptation which is part of the Goal 6 of the NAPs strategic framework: "*Ensure transformative capacity-building and innovation for climate change adaptation*".

The goal for this pilot MAC-B project in Bangladesh is for other countries, especially those in the Global Research Alliance on Agricultural Greenhouse Gases (GRA), to adopt the MAC-B protocols in their own agricultural development context. The scaling-up of the AgMIP MAC-B approach will encompass other major greenhouse gas emitting systems, including methane from livestock-grasslands systems and nitrous oxide from both organic and inorganic sources.

If additional MAC-B assessments are conducted in Bangladesh, evidence-based results from these studies can inform the Bangladesh NAPs and NDCs, policy planning and priority setting for investment, research and development.

8.2 Capacity impacts – now and in 5 years

The MAC-B project has trialed a modeling approach for quickly and efficiently determining the likely best options for changing agricultural practices in ways that deliver both mitigation and adaptation benefits. The project has identified key management strategies that combine adaptation and mitigation benefits that contribute to Bangladeshi stakeholders' understanding of systems for testing in their climate change and development programs. The transdisciplinary team (climate, crop modeling, economists, soil experts and others) that were part of this pilot project have enhanced their capacity to implement the Regional Integrated Assessment approach, make use of tools and understand the kinds of data needed for this type of analysis.

The intended long-term outcome is to accelerate the process of identifying the most promising options, and thus progress to trialing and scaling more quickly than has generally been done to date. We are in discussion with Bangladeshi stakeholders about expanding the pilot to include other regions and agricultural systems.

8.3 Community impacts – now and in 5 years

8.3.1 Socio-economic impacts

If the combined mitigation/adaptation management systems evaluated by this study are adopted, farmers can enhance their livelihoods, leading to a reduction in poverty rates across various districts of Bangladesh.

If the AgMIP MAC-B management systems that were tested are adopted, rice-growing communities in Bangladesh will have greater opportunities to address climate change challenges, all while helping reduce greenhouse gas emissions. The pilot study can be extended to include food and nutrition security, gender and other social outcomes. In addition, it can serve as the basis to create or enhance monitoring and evaluation processes to better track the adoption of MAC-B practices and its impact over time.

Furthermore, the project partners can also utilize the MAC-B approach to evaluate other cropping systems, such as wheat, and perform similar assessments.

8.3.2 Environmental impacts

If the management systems tested in this MAC-B project and that produce mitigation-adaptation co-benefits under current and future climate are adopted, greenhouse gas emissions of CO2 and CH4 would decrease, although application of organic nitrogen fertilizer also leads to a variable response on N2O emissions. However, decreased CO2 and CH4 emissions under SRI-AWD outweigh the increase in N2O emissions resulting in a net reduction of GHG emissions in terms of CO2 equivalent. SRI-AWD also reduces emissions intensity per unit of crop yield, irrigation water, and nitrogen fertilizer and therefore could be an important strategy to meet both food security and environmental objectives. Further research will help to better understand the complex interactions, in particular about N2O.

Our results show that these benefits may be smaller under future climate conditions compared to the current climate indicating that further assessment, adaptation and improvement may be required to maximize synergies and minimize trade-offs of food security and environmental objectives.

8.4 Communication and dissemination activities

Date	Event	Description
Nov 9, 2021	COP26	Cynthia Rosenzweig participated virtually during the COP26 Global Research Alliance in Glasgow, Scotland. She provided an introduction of the Bangladesh MAC-B trial project.
Jan 27, 2022	MAC-B Scoping Webinar	The MAC-B project team held a scoping webinar with relevant researchers and stakeholders from the region, as well as from the AgMIP, GRA, and ACIAR networks.
March 21, 2022	Sustainable Development Seminar, Columbia SIPA, New York	Sonali McDermid presented: “Crops and Drops: Agriculture-Water- Climate Interactions”
April 15, 2022	Division of Ocean and Climate Physics Seminar, Columbia University Lamont-Doherty Earth Observatory	Sonali McDermid presented: “Crops and Drops: Agriculture-Water- Climate Interactions”
May 9, 2022	Sustainability Seminar Series, Montclair State	Sonali McDermid presented: “Crops and Drops: Agriculture-Water- Climate Interactions”

	University	
Sep 15, 2022	MAC-B Stakeholder Workshop, Bangladesh	The MAC-B project team held a mid-term Stakeholder Workshop in Dhaka, Bangladesh and online to share progress on the trial project and get feedback from stakeholders.
Nov 29, 2022	ADBI Annual Conference	Cynthia Rosenzweig and Sonali McDermid gave invited virtual presentations focusing on AgMIP's projects in South Asia and highlighting the work of the MAC-B Bangladesh team
Feb 15, 2023	Seminar at Union College Env Sciences	Sonali McDermid presented: "Co-benefits and trade-offs of mitigation and adaptation: a rice case study earth and environment"
Feb 27, 2023	Webinar: CARICOM-GCF Readiness Project, Inter-American Institute for Cooperation on Agriculture (IICA)	Roberto Valdivia presented: "Assessing Mitigation-Adaptation Tradeoffs and Co-Benefits"
Apr 5, 2023	MAC-B Stakeholder Roundtable workshop, Bangladesh & virtual	The MAC-B project team held a stakeholder roundtable workshop in Dhaka, Bangladesh. Results from the pilot project were presented to stakeholders, and the research community in Bangladesh.
Apr 23-26, 2023	GRA Council Meeting, Spain	Roberto Valdivia and Erik Mencos attended the GRA Council meeting in Madrid, Spain. MAC-B is now a Flagship project of the GRA and they provided an overview of results from the project.
May 2, 2023	Seminar at Boston University	Sonali McDermid presented: "Co-benefits and trade-offs of mitigation and adaptation: a rice case study earth and environment"
Jun 27-29, 2023	AgMIP9 Global Workshop, New York, NY	Apurbo Chaki was an invited panelist speaker and presented key results from the MAC-B trial. Sonali McDermid also gave an invited presentation on "Co-benefits and tradeoffs of agricultural mitigation and adaptation in rice based cropping systems". Cynthia Rosenzweig, Roberto Valdivia and Erik Mencos were in attendance and hosted various sessions on topics related to mitigation and adaptation co-benefits.
Sep 25-29, 2023	Tsukuba Conference 2023 - The Future of Rice contributing to decarbonization, Japan	Roberto Valdivia has been invited as speaker to present current advances in modeling rice farming systems and GHG emissions based on the results from the MAC-B pilot project in Bangladesh

9 Conclusions and recommendations

9.1 Conclusions

The 'Mitigation and Adaptation Co-Benefits Modelling Trial in Bangladesh' project found that:

- Climate change reduces farm net returns in most sites and increases greenhouse gas (GHG) emissions.
    - Climate change can result in gainers and losers due to biophysical and socio-economic heterogeneity conditions.
    - This study shows that between 45% to 60% of rice producers are vulnerable to climate change. Even in cases where the net economic impacts (gains minus losses) are positive, the proportion of households vulnerable to climate change is high.
    - In some cases, even when climate change leads to an increase in crop yields and consequent increase in farm net returns, there can be substantial socio-economic and environmental tradeoffs.
- Adoption of Conventional Alternative Wetting and Drying (AWD) or the System of Rice Intensification with AWD (SRI-AWD) under current or future climate shows:
    - Potential adoption rates range between 48% to 67% depending on the system, scenario and type of farm.
    - Strong reductions in GHG emissions of methane and CO2eq.
    - Changes in N2O emissions vary across sites and farm types (small vs large) and how farms manage their crops (e.g. amount of fertilizer use).
    - Irrigation water use efficiency improves.
- Both Conventional AWD and SRI show potential co-benefits in reducing GHG emissions and increasing income and reducing poverty rates in the region (win-win outcomes).
- SRI shows the largest socio-economic and environmental benefits. However, a more thorough evaluation of socio-economic impacts on farmers and communities, such as gender, food and nutrition security, needs to be incorporated in addition to environmental considerations.
- AWD and SRI are likely to be more resilient to climate change compared to continuous flood systems.
- The DNDC model is now calibrated and validated to be used to test MAC-B interventions in Bangladesh.
- The estimated potential adoption rates of SRI in this pilot project fall within the range of actual adoption rates identified by Barrett et al., 2022 for farms that received training in SRI management in their study.
- Further research is required to evaluate and comprehend potential barriers or limitations to adoption, such as labor issues, access to water, and control over it.

9.2 Recommendations

As a result of the 'Mitigation and Adaptation Co-Benefits Modelling Trial in Bangladesh' project, there is now a strong AgMIP team in the region able to implement the regional integrated MAC-B methodology.

Responses and suggestions received through the iterative stakeholder engagement process will help in selecting appropriate locations, climate smart technologies, climate scenarios, and required data collection, for any future MAC-B projects.

Based on stakeholder engagement, project team discussions, and the results of the pilot study, the following suggestions and recommendations are proposed for future MAC-B assessments:

1. Complete assessment in additional regions, in particular areas identified as climate-stressed in Bangladesh's National Adaptation Plan (NAP). This includes assessments of other crop systems (e.g., wheat) that are important in Bangladesh.
2. Analyze other rice farming practices in Bangladesh besides alternate wetting and drying (AWD) and the system of rice intensification (SRI)
3. The Bangladesh Rice Research Institute (BRRI) is interested in testing other technological innovations and rice management systems they are developing for the Bangladesh context.
4. Expand MAC-B methodology to encompass complex crop diversity and varied socio-economic factors in Bangladesh
5. Better integrate farmers' perspective into modeling methodology
6. Perform data collection for key variables:
    a. Gender and equity factors play an important factor in rice systems. Adequate data to analyze these factors is currently lacking.
    b. Experimental data on crop management and GHG emissions are needed to continue model improvement.
    c. Whole-farm socio-economic data is needed to understand how interventions, policies and shocks such as climate change may impact farmers' livelihoods and how the potential bio-physical, environmental and socio-economic tradeoffs can be transformed to synergies (win-win outcomes).
7. Further research is needed to understand barriers to adoption in rice systems. Labor constraints, access to and management of water, and extension and training on alternative management practices among other factors, seem to be some of the drivers that influence adoption.
8. Future research should include more in depth analysis of the bio-physical and environmental interactions that drive crop yield and GHG emissions. In particular, how climate, soils, and crop management interact to produce N2O emissions.
9. Future research should also include socio-economic and agricultural development pathways to characterize different, plausible future conditions under which Bangladesh rice systems can operate.
10. A multi-model approach (e.g., multiple crop models) would help to understand some of the uncertainties and provide more accurate information to decision-makers.
11. Engage with national-level stakeholders to support decisions related to Bangladesh NAPs and NDCs.
12. Training on AgMIP methods and specific models (e.g., DNDC, TOA-MD) is needed to increase the network of collaborators in AgMIP-Bangladesh to enable undertaking of larger assessments in the country.
13. Strengthen partnerships with local stakeholders, including government agencies, NGOs, and farmer cooperatives.

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Agricultural Pathways: A Multi-Scale Co-Designing Process to Support Transformation and Resilience of Agricultural Farming Systems. In: Handbook of Climate Change and Agroecosystems: Climate Change and Farming System Planning in Africa and South Asia: AgMIP Stakeholder-driven Research (In 2 Parts) (Vol. 5). World Scientific Publishing. [Rosenzweig, C., C.Z. Mutter and E. Mencos Contreras (eds.)]. June 2021. *C, D, FA, M, S, Su, G, W1,W2, DEI*

Climate scenarios used were from the NEX-GDDP-CMIP6 dataset, prepared by the Climate Analytics Group and NASA Ames Research Center using the NASA Earth Exchange and distributed by the NASA Center for Climate Simulation (NCCS).

10.2 List of publications produced by project

AgMIP. 2022. Proceedings of the MAC-B Stakeholder Workshop. The Grandmark, Dhaka, Bangladesh. Online.

AgMIP. 2023. Proceedings of the MAC-B Stakeholder Roundtable. BRRI, Gazipur, Bangladesh. Online.

Rosenzweig, C. et al. 2023. Integrated Climate Change Assessments on Selected Farming Systems in India, Pakistan, Bangladesh, and Vietnam: Insights from the Agricultural Model Intercomparison and Improvement Project. Fostering Resilient Global Supply Chains Amid Risk and Uncertainty. Asian Development Bank Institute. *Accepted.*

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11 Appendixes

11.1 Appendix 1: MAC-B Mid-term Stakeholder Workshop

ACIAR

AgMIP The Agricultural Model Intercomparison and Improvement Project

Mitigation and Adaptation Co-Benefits (MAC-B)
Modelling Trial in Bangladesh Project

Proceedings of the MAC-B Stakeholder Workshop

September 15, 2022
Golden Tulip: The Grandmark, Dhaka, Bangladesh

CIMMYT Columbia University Oregon State University NYU DNDC-ART NASA

Mitigation and Adaptation Co-Benefits Modelling Trial in Bangladesh Project

MAC-B Stakeholder Workshop Agenda

Golden Tulip: The Grandmark Dhaka, House 84, Rd No. 7, Block H, Banani,
Dhaka 1213

September 15, 2022

09:00-16:45, Bangladesh local time

09:00–09:30	Registration	
09:30–09:45	Welcome and introductions	Dr. Timothy Krupnik (CIMMYT) and Mr. Erik Mencos (Columbia University, virtually)
Opening Remarks		
09:45–09:55	Dr. Veronica Doerr, Research Program Manager, Climate Change, ACIAR (virtually)	
09:55–10:05	Dr. Md. Shahjahan Kabir, Director General, Bangladesh Rice Research Institute (BRRI)	
10:05–10:15	Dr. Mian Sayeed Hassan, Member-Director, Natural Resources Division, Bangladesh Agricultural Research Council (BARC)	
10:15–10:35	Climate Change Challenges in Agriculture: Overview of the AgMIP and MAC-B Project	Dr. Cynthia Rosenzweig (NASA/Columbia University, virtually) and Dr. Timothy Krupnik (CIMMYT)
10:35–11:00	Group photo Coffee/tea break	All participants
Presentations of Preliminary Findings of Research on Mitigation and Adaptation Co-Benefits		
11:00–11:20	Climate Team	Dr. Sonali McDermid (NYU) and Md. Bazlur Rashid (BMD)
11:20–11:40	Crop, GHG and Soils Team	Dr. Tao Li (DNDC), Dr. Tek Bahadur Sapkota (CIMMYT), Dr. Umme Aminun Naher (BRRI) and Dr. Apurbo Kumar Chaki (BARI)
11:40–12:00	Economics Team	Dr. Roberto Valdivia (OSU) and Dr. Md. Rajibul Alam (Ministry of Public Administration)

12:00–12:20	Stakeholder engagement and social aspects	Sk. Ghulam Hussain (CIMMYT-BD) and Dr. Hom Gartaula (CIMMYT-India)
12:20–12:50	Questions and discussion	All participants
12:50–13:00	Remarks by the session chair	Dr. Debasish Sarker, Director-General, Bangladesh Agricultural Research Institute (BARI)
13:00–14:00	Lunch and prayer break	
Panel Discussion: Mitigation and Adaptation Co-Benefits		
14:00–14:50	Dr. Md. Abdur Rashid Sarker, Professor, Department of Economics, University of Rajshahi	
	Dr. S.M. Mofijul Islam, Senior Scientific Officer, Soil Science Division, Bangladesh Rice Research Institute, Joydebpur, Gazipur.	
	Dr. Sohela Akhter, Director (TCRC), Bangladesh Agricultural Research Institute (BARI)	
	Mr. Malik Fida A. Khan, Executive Director, Centre for Environmental and Geographic Information Services (CEGIS)	
14:50–15:00	Dr. Mohammed Asaduzzaman, Professorial Fellow, Bangladesh Institute of Development Studies (BIDS)	Moderator
Breakout Sessions on the MAC-B Focus Areas		
15:00–15:50	Biophysical Impacts (Crop, GHG, Soils)	Group facilitators: Dr. Umme Aminun Naher (BRRI) and Dr. Tek Sapkota (CIMMYT)
	Economic Impacts	Group facilitators: Dr. Roberto Valdivia (OSU) and Dr. Md. Rajibul Alam (MoPA)
	Gender and Social Aspects	Group facilitators: Sk. Ghulam Hussain (CIMMYT-BD) and Dr. Hom Gartaula (CIMMYT)
15:50–16:20	Plenary Presentation per Focus Areas	Group rapporteurs
16:20–16:30	Synthesis, reflections and next steps	Dr. Timothy Krupnik (CIMMYT)
Wrap-Up and Closing		
16:30–16:45	Professor Dr. Ainun Nishat, Professor Emeritus at BRAC University, Bangladesh	

Proceedings of the MAC-B Stakeholder Workshop

The 'Mitigation and Adaptation Co-Benefits (MAC-B) Modelling Trial in Bangladesh' project is supported by the Australian Centre for International Agricultural Research (ACIAR) and led by Columbia University in partnership with the International Maize and Wheat Improvement Center (CIMMYT), Bangladesh Rice Research Institute (BRRI), Bangladesh Agricultural Research Institute (BARI), Oregon State University, New York University, and DNDC-ART. As a part of the project activities, the MAC-B Stakeholder Workshop was organized at the Golden Tulip: The Grandmark Dhaka, Bangladesh, on September 15, 2022, from 9:00 am until 4:45 pm (Bangladesh local time). Of the total of 54 experts and scientists who participated, 31 attended in person from various organizations in Bangladesh and 23 joined the workshop virtually from Australia, India, Japan, United States of America and Bangladesh. In this hybrid event, preliminary findings were presented by the research team to engage stakeholders in generating key relevant and feasible interventions for simulation by the MAC-B modelers. The one-day workshop was designed in such a way that the stakeholders could become involved in structured discussion on the barriers and bridges to cross-scale linkages and participate in break-out groups to foster interactions between stakeholders and scientists.

Welcome and Introductions (09:30–09:45)

Dr. Timothy Krupnik (International Maize and Wheat Improvement Center, CIMMYT and CGIA) and **Mr. Erik Mencos** (Columbia University, virtually) welcomed everyone to the MAC-B stakeholder workshop, both those joining in person and online. Dr. Krupnik explained how the MAC-B project (which stands for 'mitigation and adaptation co-benefits') is working to increase rice production in Bangladesh in the face of the climate crisis. He also explained that it is a pilot project, aimed at determining what can be done with large and unique data sets that might not otherwise be used for modelling.

After his words of welcome, Dr. Krupnik requested Dr. Veronica Doerr (ACIAR, virtually), Dr. Mohammad Khalequzzaman (Director of Research, BRRI), Dr. Mian Sayeed Hassan (Natural

In-person Speakers at the Opening Session of the the MAC-B Stakeholder Workshop

Resource and Management Division, BARC), Dr. Cynthia Rosenzweig (NASA/Columbia University, virtually) and Dr. Roberto Valdivia (OSU) to give their opening remarks.

Opening remarks (9:45–11:00)

Dr. Veronica Doerr (Research Program Manager, Climate Change, ACIAR, virtually) stated that having worked in the field of climate change for quite some time, one must be simultaneously both optimistic and pessimistic. She said, “We saw incredible heatwaves all around South Asia this year and the devastating floods in Pakistan right now. All these climate change effects are making me think about what we are doing. We have spent decades doing quality research, yet sometimes we are not able to implement mitigation and adaptation solutions on the ground. We have made progress and there are some successes, but sometimes it is frustrating that results are not quick enough. There are many reasons behind it, which social scientists can explain, but as researchers, I think there are two key things that can really change this situation and accelerate implementation that is completely in our control. One of those is interactions between the people who research mitigation and the people who research adaptation. They often don’t talk to each other and collaborate, and we desperately need that, particularly in agriculture. As agriculture has the potential to be a dual-solution space for climate change, it is essential to reach across whatever technical divides might be there so that we work on dual solutions that address both adaptation and mitigation in agriculture. This is very much in our control.

Another thing that we can do is be conscious about our research work to get to implementation as fast as we can. So here in Australia, we have invested in some land sector mitigation actions (about 400 individual field research experiments) through internal investments for some time But we cannot afford that time anymore. We can’t try everything. The MAC-B research model is designed to address the collaboration of the two areas - adaptation and mitigation - and to be used as the vehicle of this collaboration between adaptation scientists and mitigation scientists. It’s also a tool to bring the best of the field research together through modelling. This way we don’t have to do 400 different studies but rather identify the most promising experiments that can bring us the quickest solutions. Through MAC-B, we as researchers can participate in accelerating those actions and the process of learning about the action. I am frustrated, but I am also inspired by working with the MAC-B project – I feel like that’s how I feel all the time working in climate change. I hope you feel the same way too.”

In response to Dr. Veronica Doerr, Dr. Timothy Krupnik said, “I think in the year 2022, climate change has come very much to the doorstep of everyone on the planet; it is no longer a problem of the Global South. We have also seen that countries who are large emitters of the Global North are facing it too. Examples are Europe struggling with the extreme temperatures this summer, the disastrous flooding in Pakistan, and the droughts running through Africa. What I am encouraged by is the intention of forcing change into action. Let’s hope it is not too late.”

Next, **Dr. Mohammad Khalequzzaman (Director of Research, BRRI)** started by mentioning that the MAC-B project is very valuable and that the time is ripe for such an activity. He stated, “I would like to discuss here some of the climate change scenarios in Bangladesh and their impact on rice production. Based on 1985 to 2000, the occurrence of variation of temperature is increasing day by day. Rice production can be hampered due to maximum and minimum temperatures, especially in the *aus* season, in the northwest and southwest of Bangladesh. Observed data show that if the minimum temperature decreases by one degree, *boro* rice production will be reduced by 3.4 tons per hectare.

Overall rainfall in Bangladesh is not changing over time, but uneven distribution and intensity is increasing. As a result, runoff is increasing, causing a lower amount of groundwater recharge. Day by day, increasing runoff is causing groundwater declines. During the flood of 1998, we saw how it decreased agricultural production in the country by 45%. Bangladesh has suffered around 20 droughts within the last 50 years. It caused the northwest of Bangladesh to lead to shortcomings in rice production of 3.5 million tons in 1990. If the sea rises by one-meter, normal flood waves can increase from 7.4 to 9.1 meters. Cyclones cause considerable damage to rice production – Cyclone Sidr in 2007 caused damage in 70% of the coastal region.

However, let's consider the success of the rice varieties in Bangladesh. We have developed 108 modern varieties, of which 28 are stress tolerant. Eleven are salinity tolerant, three submergence tolerant, three drought tolerant, four cold tolerant, two tidal submergence tolerant, one deep water tolerant, and one salinity and submergence tolerant. Apart from these, nine premium quality rice, seven zinc-enhanced rice, and more than three low glycemic index rice [varieties] for diabetic patients have been developed. BRRI-released varieties have covered more than 80% of the cultivation area, and their contribution to national rice production is 91%.

We have found that alternate wetting and drying (AWD) methods. have saved 4-5 irrigations compared to the farmers practising cultivation in continuous standing water. AWD saves about 25%-35% on fuel costs and 40% of water from shallow tubewells to deep tubewells. It also increases rice production by 0.5 tons per hectare; it reduces methane gas emissions from the environment caused by the rice fields and it reduces arsenic.

Most importantly, this is an environmentally friendly modern technology and procedure. However, there needs to be more knowledge among farmers regarding adaptation of the AWD land-based irrigation system. However, unreliable water and electricity supplies discourage farmers from adopting this technology, [and there are] few benefit-sharing practices among the farmers, the pump owners, and the water users.

In response to Dr. Mohammad Khalequzzaman, Dr. Tim Krupnik mentioned that the project has an interesting mix of key partners, with cross-ministerial partnerships and scientists contributing from different organizations.

In his speech, **Dr. Mian Syeed Hassan** (Member-Director, Natural Resources Management Division, BARC) said, “In Bangladesh, two-thirds of the rural population is directly involved in agriculture and more than 80% of households in rural areas rely on agriculture. Bangladesh is one of the countries most vulnerable to climate change - according to some studies, it is the seventh most vulnerable country in the world.

According to the Bangladesh Meteorological Department, in July this year, the average rainfall was only 211 mm, 57.6% less than the average July rainfall over the last 30 years - the lowest since 1981 (it was, on average, 496 mm for the past 30 years). The maximum average temperature was 33.7 degrees Celsius this year, which was a 2.6-degree rise from the average of 31.1 degrees Celsius in the past 30 years. Crop management has been the key tactic regarding rice production in Bangladesh.

Farmers have been growing over 50 varieties of rice in more than 300 patterns, and cropping intensities have reached about 200%. Bangladesh has been increasing production by intensifying rice-based cropping systems, emphasizing resource efficiency and climate adaptation benefits. According to the FAO Food Outlook 2022, Bangladesh produced 37.8 million tons of rice in 2021. Over the past four decades, Bangladesh had a population growth rate of 1.3% and a rice production growth rate of 2.8%.

Globally, Bangladesh stands third in rice and vegetable production, second in jute production, sixth in potato, and eighth in mango and guava production.. We have many more options to harvest, adapt, mitigate and get co-benefits from agricultural sectors. We have developed climate-smart crop varieties, fertilizers, water management practices, mechanization of cropping and harvesting, and resource-conserving crop establishment practices.

Bangladesh has developed its National Adaptation Plan 2022, the Second Perspective Plan 2041, the Bangladesh Delta Plan 2100, and the National Agriculture Policy 2018. Other policies are also aligned towards the same goal: better production, better nutrition, a better environment, and a better life. Then we can measure the co-benefits of mitigation and adaptation in terms of health, biodiversity and environmental conservation, economy, and productivity of farmers' livelihoods. To implement long-term policy, we must enhance initiatives for simultaneous research and development. Bangladesh's government has committed to a greenhouse gas reduction of 21.85% by 2030. Bangladesh also aims to become an upper-middle-income country over the next decade. With careful planning and policy development, climate mitigation and adaptation interventions can have many positive impacts providing co-benefits to society."

Finally, **Dr. Mian Sayeed** mentioned that according to recent research findings, there are three key challenges to the implementation of adaptation and mitigation co-benefits in Bangladesh. These include:

- Lack of capacity
- Lack of local political support
- Lack of technical development

According to Dr. Syed, the main missing link is finding the right stakeholders to represent the communities suffering from the effects of climate change.

In response to Dr. Mian Syeed, Dr. Timothy Krupnik said, "I want to focus on how you said climate change affects the vulnerable. Climate change affects farmers in different ways, particularly the most vulnerable. And in many ways the most vulnerable members within farming households. It is also important to reflect on these multiple vulnerabilities in modelling efforts, which are often seen to be separate from such work."

Dr. Krupnik introduced Dr. Cynthia Rosenzweig of NASA and Columbia University and remarked that "We are extremely proud to have Dr. Rosenzweig involved in this project as she is the 2022 World Food Prize laureate for recognizing efforts in the field of climate change adaptation and mitigation modelling.

Dr. Cynthia Rosenzweig (NASA/Columbia University, virtually) provided an overview of AgMIP and the MAC-B project AgMIP's main mission is to bring science-based agricultural decision-making models and assessments of climate change to achieve local to global food security. It is a global network comprising more than a thousand agriculture, climate, and food researchers. The intention is to provide science- based assessments for national mitigation and adaptation plans. AgMIP has over 50 initiatives, all working for present and future of food security. With a goal to make a more sustainable, productive, and resilient future. I am excited to work with the MAC- B project in Bangladesh. The diagram presented here shows the regional integrated assessment methodology AgMIP has used in many regions of Africa and South Asia. We are implementing similar actions in the MAC-B project in Bangladesh. As you can see, it always links back to engaging stakeholders. The project analyses alternate wetting and drying (AWD), which is often considered part of the System of Rice Intensification (SRI).

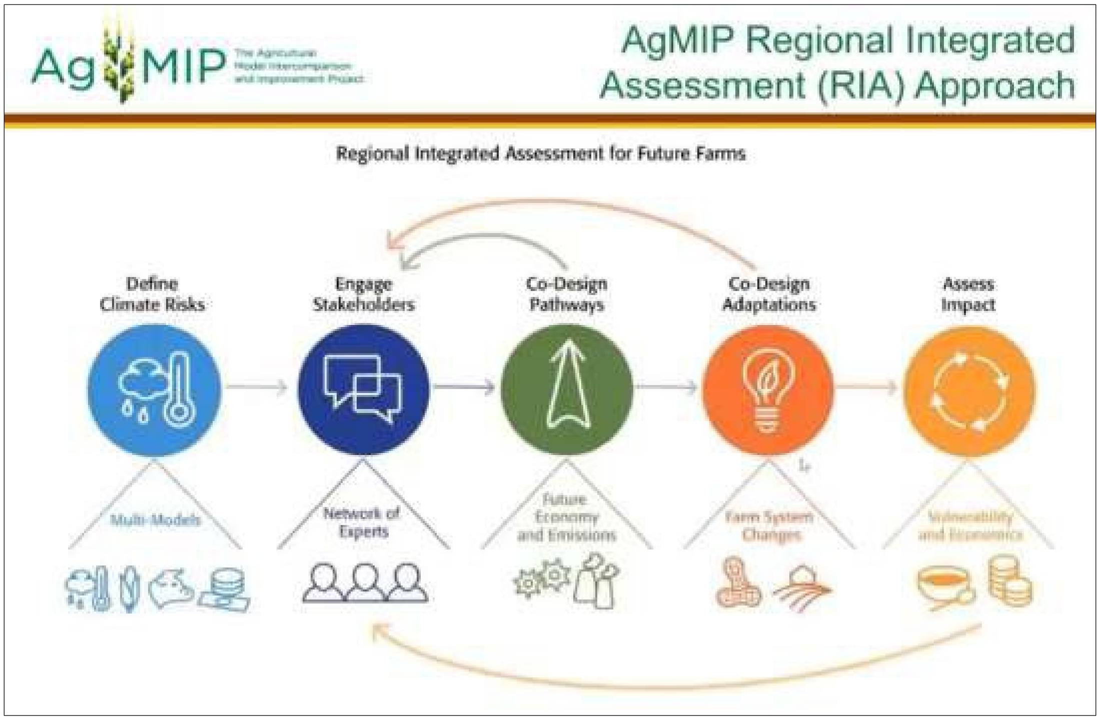


Figure 1. AgMIP Regional Integrated Assessment methodology

Dr. Rosenzweig presented Climate Change Projections in South Asia from the Intergovernmental Panel on Climate Change (IPCC).

Climate Change Projections in South Asia

- Heatwaves and humid heat stress will be more intense and frequent during the 21st century (medium confidence)
- Both annual and summer monsoon precipitation will increase during the 21st century, with enhanced interannual variability (medium confidence)

IPCC AR6, 2021

And she explained the mission of the MAC-B project:

MAC-B Project Mission

- The MAC-B project will trial a modeling approach for quickly and efficiently determining the likely best options for changing agricultural practices in ways that deliver both mitigation and adaptation benefits.
- The intended long-term outcome is to be able to accelerate the process of identifying the most promising options, and thus progress to trialing and scaling more quickly than has generally been done to date.

Dr. Rosenzweig showed that the MAC-B project framework links stakeholder engagement, emissions and mitigation models, and impacts and adaptation models for evidence-based decision-making related to policies and programs.

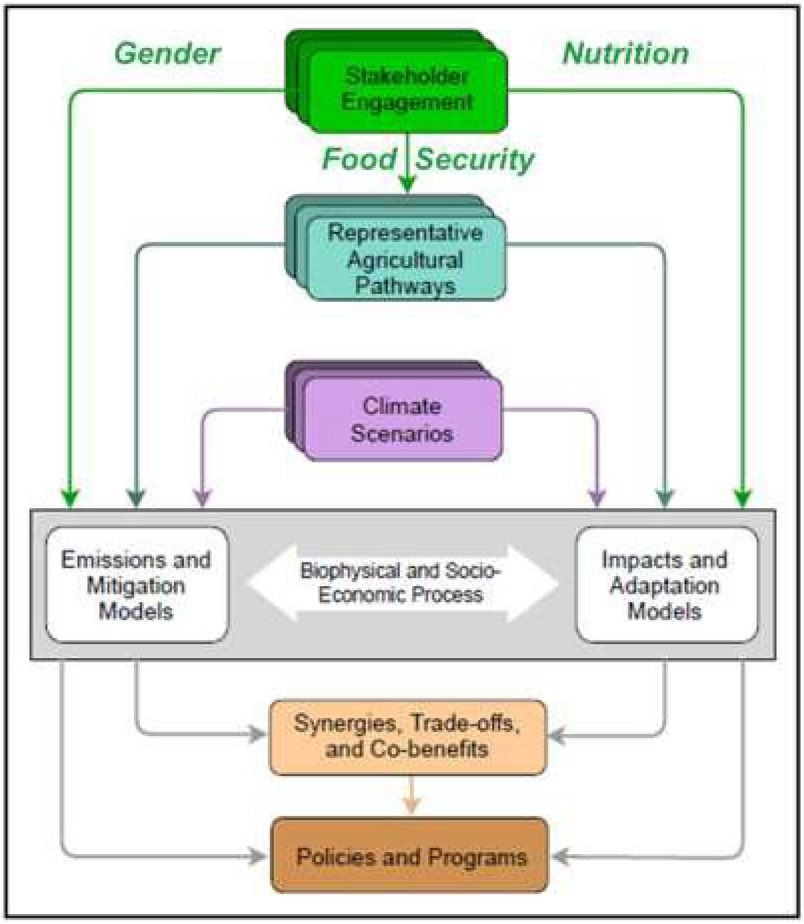


Figure 2. MAC-B Assessment Framework

Dr. Krupnik then explained that the AgMIP and MAC-B project is unique in terms of crop modelling in Bangladesh, elsewhere in South Asia, and perhaps even globally. The project has chosen research locations in Lalmonirhat, Rangpur, Rajshahi, Kishoreganj, Faridpur and Gopalganj, based on the large-scale data set available. The project uses combined data from over 6000 farmers, including their production, management, and economic practices, to assess rice production throughout the country. The dataset also considers high elevation, medium elevation and medium low elevation, because in order to increase mitigation and adaptation it is important to understand how rice production responds under these differing conditions. Dr. Tim Krupnik said that "in this project we want to develop plans that will provide both mitigation and adaptation benefits, and include different crop and rice management options. Farmers don't manage rice alone: they manage a basket of different crops, so the implication of climate change on the whole farming system is important. We want to ensure the capacity exists fully within the countries that we work in, including Bangladesh, so we can essentially be self-reliant when it comes to this modelling effort".

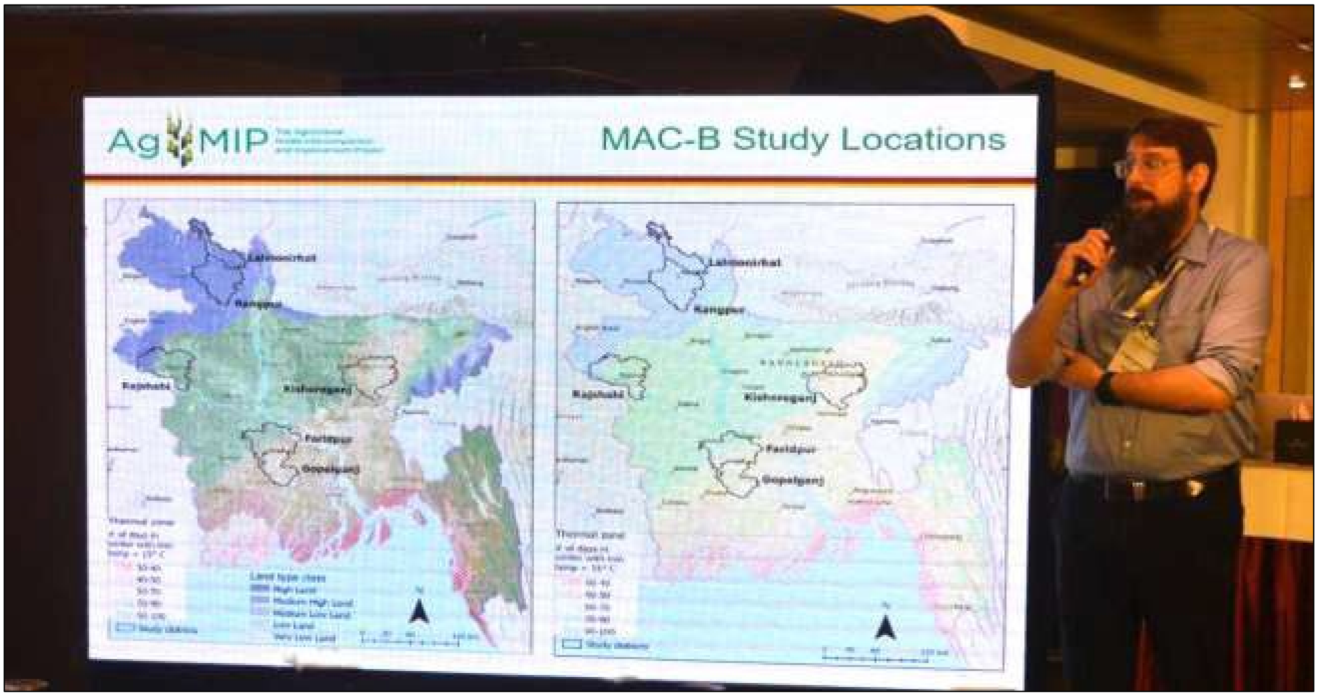


Figure 3. MAC-B Study Locations

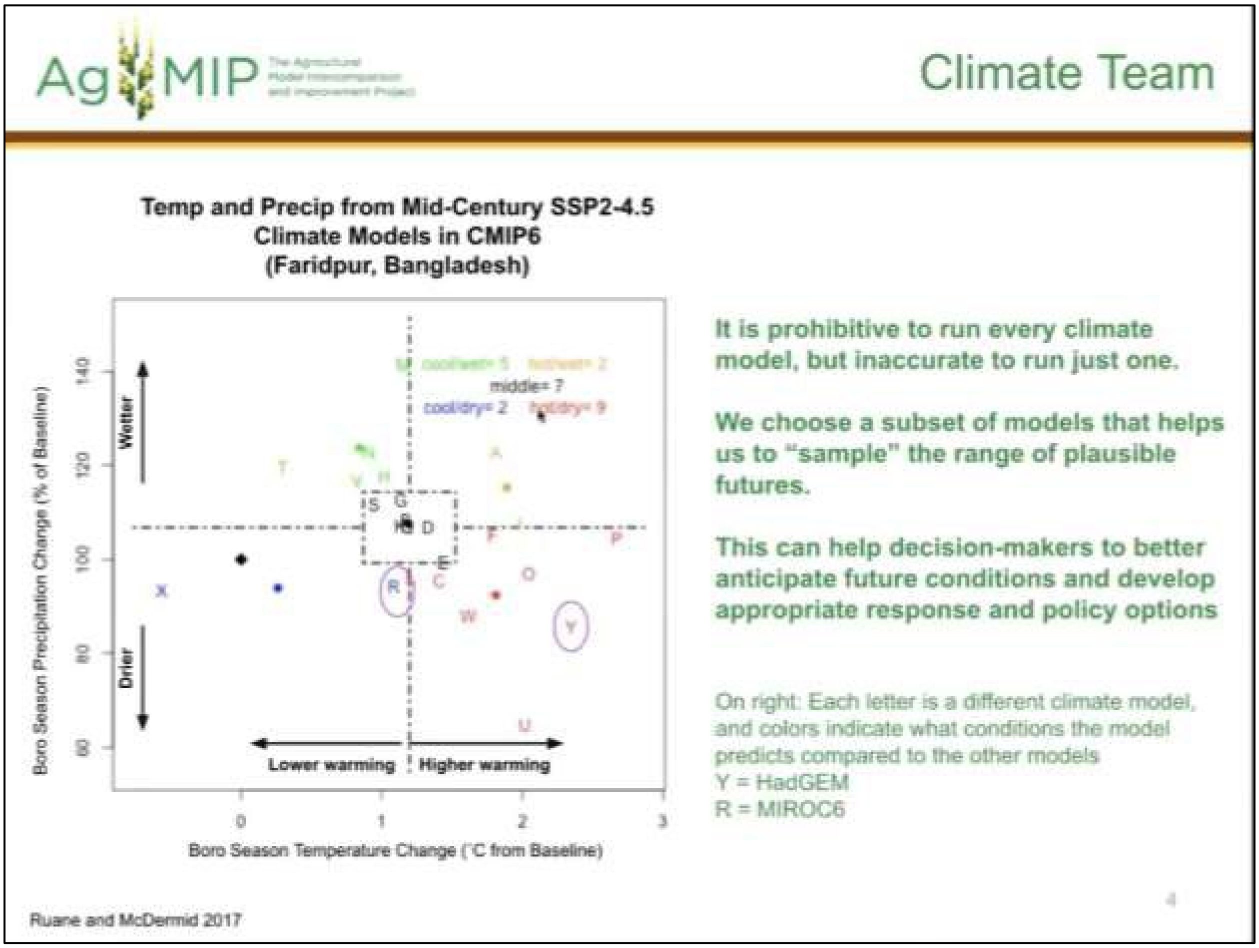
Presentations of preliminary findings of research into mitigation and adaptation co-benefits (11:00–13:00)

Presentation 1 (11:00–11:20): Climate Team by Dr. Sonali McDermid (NYU) and Md. Bazlur Rashid (BMD):

Dr. Sonali McDermid (NYU) presented on the climate analysis for the MAC-B project. The main objectives of the Climate Team are to:

1. Provide scenarios of future climate change for MAC-B assessment at the site level
2. Understand how uncertainty in climate scenarios impacts decision-making

3. Demonstrate how modelled mitigation potentials may provide feedback on the climate system.



Climate Team

It is prohibitive to run every climate model, but inaccurate to run just one.

We choose a subset of models that helps us to "sample" the range of plausible futures.

This can help decision-makers to better anticipate future conditions and develop appropriate response and policy options

On right: Each letter is a different climate model, and colors indicate what conditions the model predicts compared to the other models
Y = HadGEM
R = MIROC6

Ruane and McDermid 2017

Figure 4. Temperature and Precipitation from Mid-Century Climate SSP2-4.5 Models in CMIP6 (Faridpur, Bangladesh)

The Climate Team compared multiple SSP2-4.5 climate models in CMIP6 and found that the MIROC6 and HadGEM models work very well to capture future climate projections in the Bangladesh region. This can help decision-makers to anticipate future conditions better and develop appropriate responses and policy options.

Presentation 2 (11:20–11:40): Crop, GHG and Soils Team by Dr. Tao Li (DNDC), Dr. Tek Bahadur Sapkota CIMMYT), Dr. Umme Aminun Naher (BRRI) and Dr. Apurbo Kumar Chaki (BARI)

Dr. Tek Sapkota (CIMMYT) presented by Zoom on some of the preliminary results of the modelling exercise, which used crop management, soil, and climate data (Fig 5). DNDC, DNDC-ORYZA and APSIM models were used. These models were calibrated and validated to capture uncertainties and to establish the confidence of model predictions.

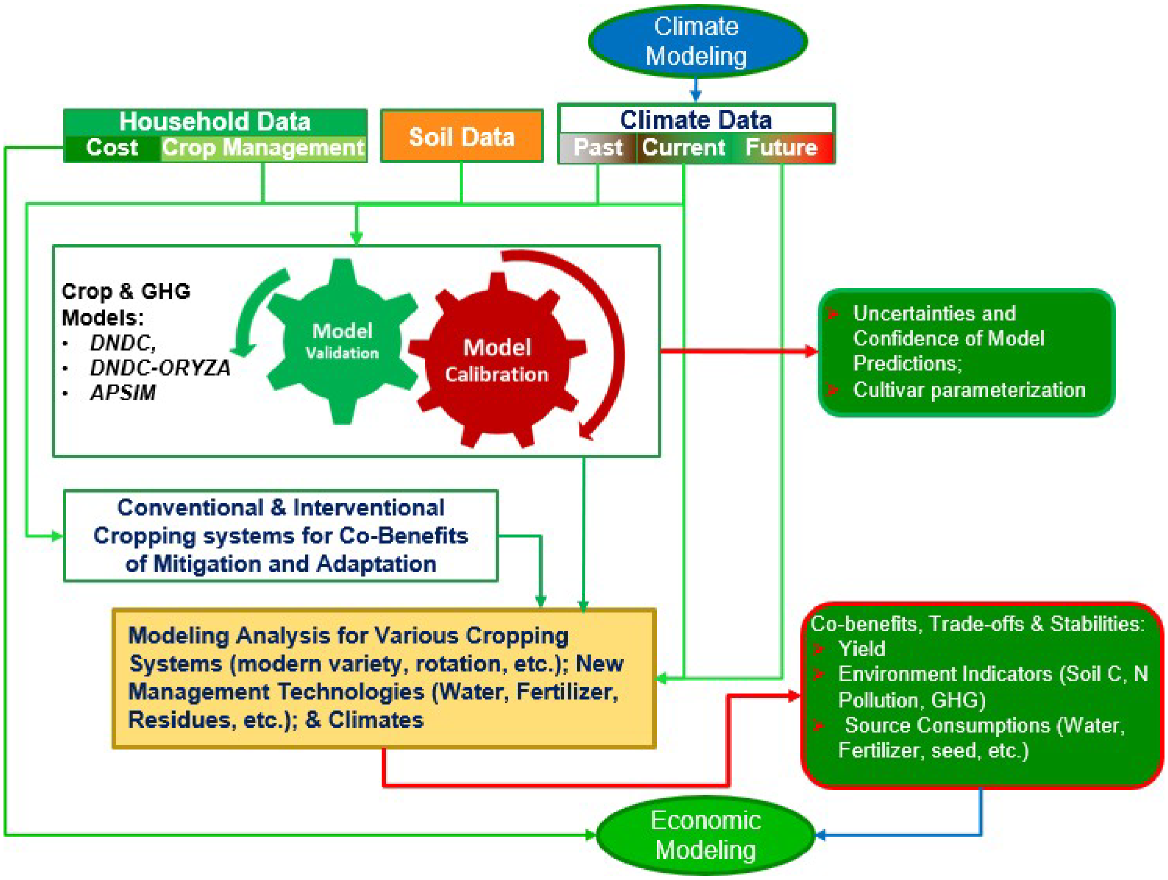


Figure 5. The framework of crop and greenhouse gases (GHG) modeling

The models showed the effect of different management practices on a range of economic and environmental indicators, such as crop yield, crop water requirement, carbon sequestration, and GHG emissions. Such information could be very important for decision-making at different levels. Specifically, this preliminary modeling exercise shows that climate change will negatively impact yield and soil fertility as well as increase GHG emissions under business-as-usual scenarios and thus change in management practices is important for climate adaptation as well as mitigation. Our modeling results showed a substantial amount of irrigation water and CH4 emissions reduction through the adoption of alternate wetting and drying (AWD) rice albeit with minor yield penalty both under current and future climate (Fig. 6). However, a uniform AWD won't be suitable for all fields and therefore it is worth developing site-specific AWD.

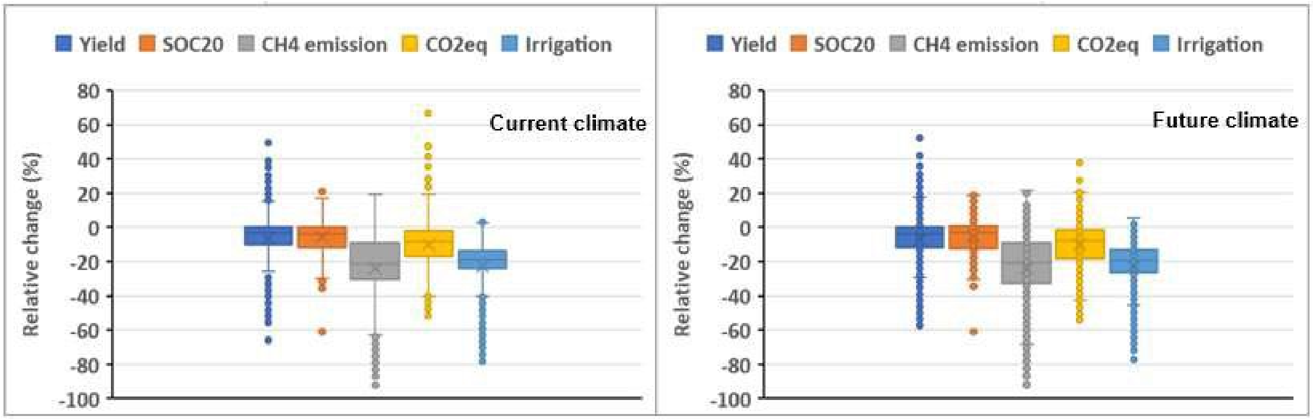


Figure 6. Effect of alternate wetting and drying on yield, C sequestration, irrigation water requirement and GHG emissions in rice production under current and future climate

Presentation 3 (11:40–12:00): Economics Team by Dr. Roberto Valdivia (OSU) and Dr. Md. Rajibul Alam (Ministry of Public Administration, Dhaka, Bangladesh)

Dr. Roberto Valdivia addressed the socio-economic modelling aspect of the methodology in his presentation. The Economics Team integrates the climate, soil, and crops results into the TOA-MD model (Trade-off Analysis for Multi-Dimensional Model Impact Assessment). He explained that through the AgMIP's Regional Integrated Assessment (RIA), a framework that links crops, livestock, and socio-economic data and models, the MAC-B project evaluates pathway/scenario uncertainties under current and future climate, biophysical and socioeconomic conditions. The goal of the socio-economic modelling is to capture the relevance of local contexts by co-designing, with scientists and stakeholders, adaptation and mitigation strategies that are of interest and suitable for specific farming systems.

Dr. Valdivia then presented the preliminary results in Bangladesh from the economic modelling, which show (1) the impacts of climate change on conventional rice cultivation technique (Figure 7), and (2) adoption of SRI/AWD under current climate (Figure 8). It is important to note that, for this pilot study, SRI/AWD have been selected as the "alternative" technology to be tested, while acknowledging that there are several other management options that could be tested. The purpose of this pilot project is to demonstrate how the AgMIP MAC-B framework can be used to produce information (e.g., key socio-economic and environmental) indicators to support policy decision making.

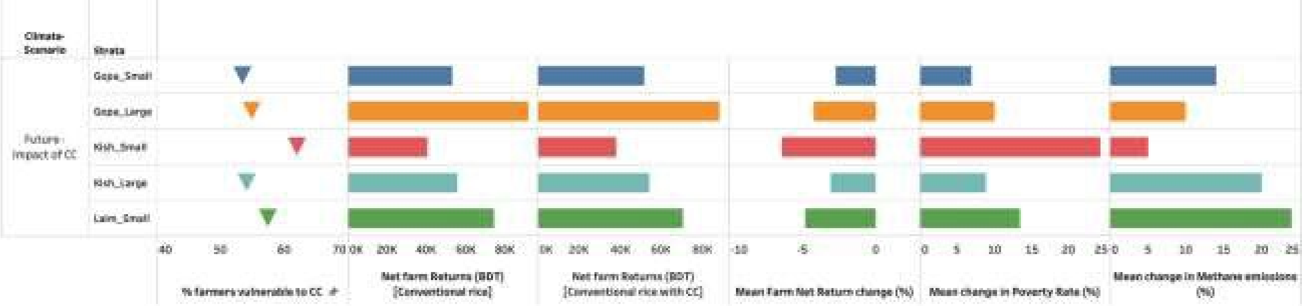


Figure 7. Preliminary results showing climate change impacts on conventional rice production systems in the districts of Gopalganj, Kishoreganj and Lalmonirhat. Data was stratified in Small farms with less than 1 ha with rice and Large farms with more than 1 ha of land under rice.

The socio-economic data used was extracted from a survey collected by BRAC and Monash University (Barrett et al., 2021) which includes both farmers' information on using conventional rice systems and farmers' adoption of SRI/AWD in three districts of Bangladesh (Gopalganj, Lalmonirhat, and Kishoreganj). Outputs from the crop simulation team were used to estimate the relative change in crop yields and GHG emissions due to climate change and due to switching from conventional rice production to SRI/AWD.

The climate change impact results show that:

(1) 50%-60% of the farm population in these three districts risk agricultural loss
(2) Farmers' income is projected to decrease by 3%-6%
(3) Poverty rate is projected to increase between 7% to 25%
(4) Methane emissions on conventional rice system are projected to increase with climate change between 5% to 24%.

The adaptation analysis using the TOA-MD showed that if SRI/AWD technology is introduced, the potential adoption rates range between 36% and 70% across the districts and farm type. Mean farm income increases between 7% and 25% which contribute to reduce poverty rates between 20% to 40%. Adoption of SRI/AWD contributes to reduce GHG (methane) emissions between 25% to 35%. While the results are preliminary, they show the importance of capturing the heterogeneity inherent to these production systems. In this case, the regional differences and farm type indicate that there are gainers and losers with respect to climate change, and some may have larger benefits by adopting SRI/AWD. Further analysis incorporating other regions and more detailed production costs, climate projections will be conducted and presented in the final project report.

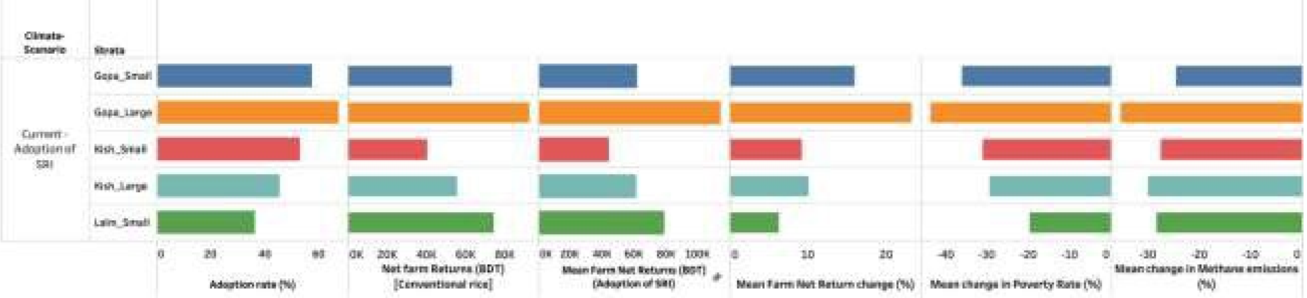


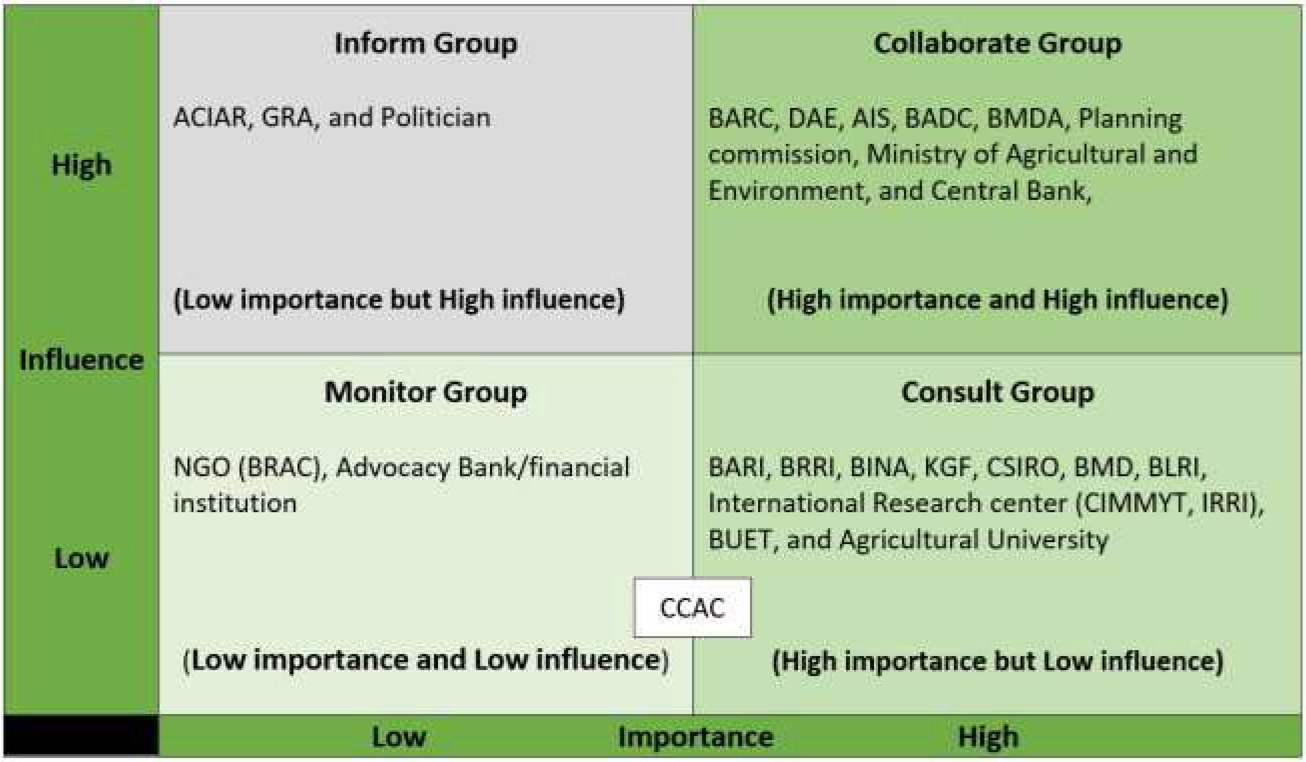
Figure 8. Preliminary results showing benefits of adopting SRI/AWD under current climate in the districts of Gopalganj, Kishoreganj and Lalmonirhat. Data was stratified in Small farms with less than 1 ha with rice and Large farms with more than 1 ha of land under rice.

Presentation 4 (12:00–12:20): Stakeholder Engagement by Dr. Sk. Ghulam Hussain (CIMMYT–BD)

Dr. Sk. Ghulam Hussain started by explaining stakeholder engagement as a systematic process of identifying, analysing, planning, prioritizing, and implementing actions intended to engage and influence, and that engagement is essential because of its goals to simplify stakeholder communications and ensure that communication resources are used efficiently and effectively.

Dr. Hussain stated that engaging appropriate stakeholders will provide an improved understanding of the MAC-B integrated assessment modelling system and possible MAC-B interventions. The stakeholder engagement process will enable stakeholders to identify additional interventions for the MAC-B modelers to test in current and future conditions. Stakeholders will then understand the MAC-B framework and advocate for its use in national planning documents such as the National Adaptation Plan (NAP), Nationally Determined Contributions, etc. Bangladesh's researchers are encouraged to learn how to improve and test ideas generated by MAC-B modelling efforts. Stakeholders and regional researchers will then be more likely to adopt the MAC-B framework and create practices to achieve development impacts. The goal is for MAC-B to enhance regional capacity for implementation of mitigation and adaptation practices.

Potential stakeholders include Bangladesh Meteorological Department, Bangladesh Agricultural Research Council, Bangladesh Agricultural Research Institute, Bangladesh Rice Research Institute, Bangladesh Livestock Research Institute, Krishi Gobeshona Foundation, Jahangirnagar University, London School of Economics, University of Eastern Finland. Based on the stakeholders' importance and their influence on research, they were grouped as Informing, Collaborating, Consulting, and Monitoring Groups. After conducting a participatory mapping exercise with a range of experts and institutional groups, a stakeholder analysis matrix was developed (Fig. 9).



High	**Inform Group** ACIAR, GRA, and Politician **(Low importance but High influence)**	**Collaborate Group** BARC, DAE, AIS, BADC, BMDA, Planning commission, Ministry of Agricultural and Environment, and Central Bank, **(High importance and High influence)**
Influence		
Low	**Monitor Group** NGO (BRAC), Advocacy Bank/financial institution CCAC **(Low importance and Low influence)**	**Consult Group** BARI, BRRI, BINA, KGF, CSIRO, BMD, BLRI, International Research center (CIMMYT, IRRI), BUET, and Agricultural University **(High importance but Low influence)**
	Low Importance	**High**

Figure 9. Stakeholder analysis matrix

Presentation 5 (12:00–12:20): Social Aspects by Dr. Hom Gartaula (CIMMYT-India)

Dr. Hom Gartaula discussed evaluating interventions to improve farmers' livelihoods and nutrition, and described how the vulnerability context and benefits structures are different for men, women, and youth. Interventions that result in equal access and benefits will impact livelihoods overall. He offered a framework for gender-informed modelling (Fig. 10), including the key social variables that should be part of the analysis such as age, education, land ownership, household headship, gender roles, gendered decision making, migration, ethnicity and language, and intra-household consumption pattern, which are not necessarily considered in the existing frameworks. He also presented some variables selected for integrating gender and social inclusion in the analysis leading to more equitable outcomes and highlighted the challenges for an effective integration due to data availability, scale issues, and translating gender-data into policy language, especially the one generated through non-numerical means.

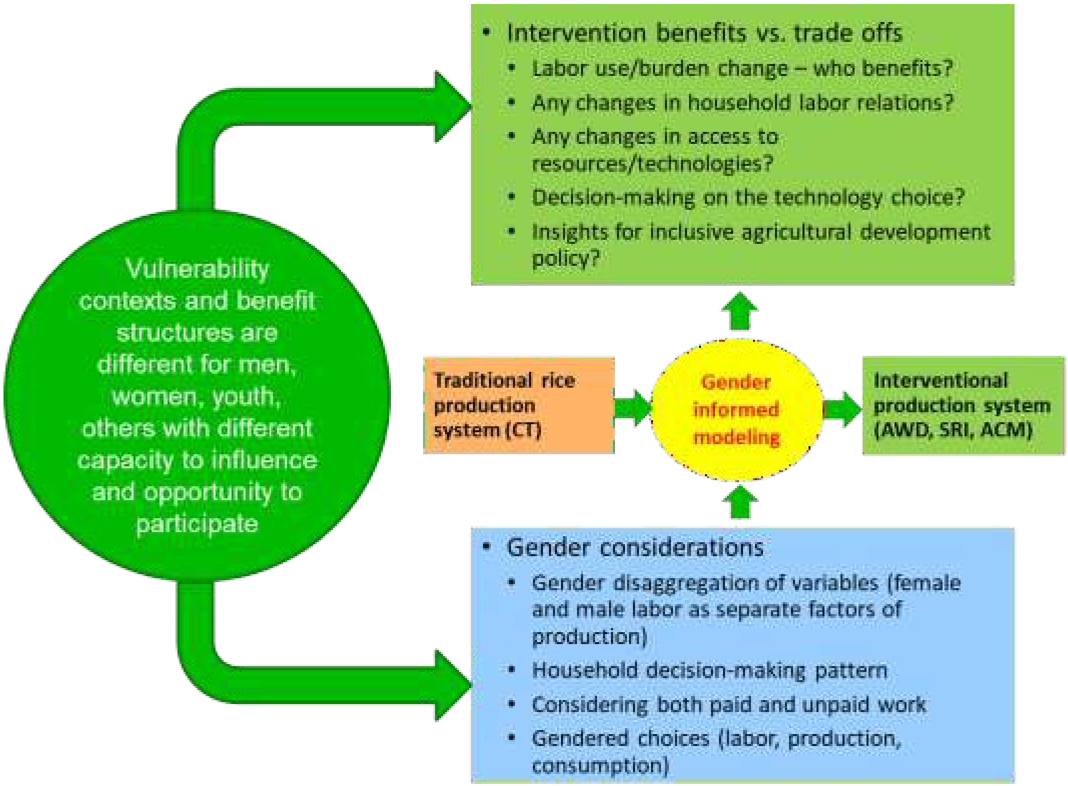


Figure 10. Framework for gender-informed modelling.

Remarks by the Session Chair, Dr. Debasish Sarker, Director-General, Bangladesh Agricultural Research Institute (BARI) **(12:50–13:00):**

Dr. Debasish Sarker, Director-General, BARI first expressed his gratitude and then provided his valuable observations on the five presentations.

Dr. Sarker believes that partnerships between national and international stakeholders will open new windows to fight and minimize climate change risk, and develop mitigation and adaptation measures for Bangladesh's agriculture sector. The research findings will expose new options.

He drew attention to the increasing incidence of floods, droughts, and cyclones that have caused extensive economic damage to agriculture livelihoods in Bangladesh. Agriculture accounts for 20% of the GDP and impacts 65% of the workforce. Mitigation and adaptation are therefore the key strategies by which to combat the impacts of climate change and ensure and food security.

Dr. Sarker also expressed his firm hope that the separate strands of the MAC-B project can work together closely to formulate initiatives or create a platform for long-term collaboration with advanced technologies, leading to the establishment of artificial intelligence in agriculture and the digital transformation of data.

Panel Discussion: Mitigation and Adaptation Co-Benefits (14:00-15:00 pm)

Panellist 1: Dr. Md. Abdur Rashid Sarker, Professor, Department of Economics, University of Rajshahi

Dr. Md. Abdur Rashid Sarker asked the presenters whether the 'co-benefit' mentioned in the MAC-B project is qualitative or quantitative, whether it involves only private or social benefits, and how farmers and stakeholders perceive the co-benefits of the project.

He believes that a district level model is needed because different areas of Bangladesh are impacted differently. He explained that in Bangladesh coastal areas are affected by cyclones, the north of the country by droughts, and the Sylhet area by flash floods. As a result, the same model may not be applicable to each district or area, making area-specific modelling a pre-requisite.

He reported having found that the adoption rate of alternate wetting and drying (AWD) irrigation – which is cost-saving, water-saving and helps to reduce GHG – is very low in Bangladesh, because (1) most farmers are unaware of AWD technology, and (2) those who do know about AWD technology do not use it because there is no financial incentive to save water when farmers do not pay for water volumetrically. Farmers thus pay the same whether they use AWD technology or not. Because of a lack of good governance, poor coordination among farmers and stakeholders in the field, and a lack of proper policy and policy application, the AWD adaptation rate is not increasing in Bangladesh, in contrast to the Philippines and India where it is very successful. Dr. Sarker requested the presenters and participants to investigate why AWD is not working in Bangladesh. His research reveals that the net revenue of production by using AWD does not decrease; sometimes it is the same or a little higher, making AWD profitable. Farmers should therefore use AWD technology and it is our duty as scientists and policymakers to work out how to make AWD successful in Bangladesh.

Panellists discussing Mitigation and Adaptation Co-Benefits

Next, Dr. Sarker mentioned agroforestry technology and that it should be considered as part of the MAC-B project. According to him, agroforestry technology can avoid damage and be one of the adaptation strategies to be analysed in the MAC-B project. Agroforestry has the potential to absorb carbon, increase farm income, provide fruits and wood, and also protect the soil from erosion.

He also thinks that conservation agriculture should be considered as it can bring no or minimum tillage for non-rice crops and is also an environment-friendly and climate-smart technology.

He stated that rice yield and productivity have not increased in the last five years compared to China and India, and that new technology should therefore be introduced. Farmers are shifting from *boro* rice to maize production, not because of climatic reasons but because of economic reasons, as maize involves less cost and less water, making the net return high.

Finally, he mentioned that in this time of energy crisis, solar irrigation should be awarded greater emphasis as it is environment friendly, and Bangladesh has no sunlight problem.

Panellist 2: Dr. S.M. Mofijul Islam, Senior Scientific Officer, Soil Science Division, BRRI, Joydebpur, Gazipur

Dr. Mofijul discussed the significant global increase of about 33% in carbon dioxide, methane and nitrogen oxide since the pre-industrial era, and the main focus of the Paris Agreement of keeping the global temperature rise to 1.5 degrees Celsius. He also highlighted the COP26 Summit on Food Security in Glasgow.

The Bangladesh Nationally Determined Contribution (NDC) highlights both conditional and unconditional projections based on which Bangladesh expects to reduce 100 million tons of carbon dioxide.

To reduce methane emissions from rice fields there are technologies such as fertilizer management, water management, conservation agriculture, improved cropping patterns and nanotechnologies. AWD is an excellent technology, with effective impacts on greenhouse gas emissions, significantly decreasing global warming potential.

Panellist 3: Dr. Sohela Akhter, Director (TCRC), BARI

Dr. Akter provided the following suggestions:

- MAC-B can be used to gather views from stakeholders focusing on sustainable rice management.
- Modern technologies can be used in model verification.
- To mitigate the vulnerability of the country to temperature and rainfall extremes, heat tolerant varieties, among others, can be used.
- Conservation agriculture and climate-smart agriculture need to be adopted. Cover crops and crop rotation can be used.
- Integrated plant nutrition systems can be upgraded.
- Rainwater harvesting can be extended.

In regard to the impact of the climate crisis on current agricultural conditions, if the gradual drifting of the rice season due to drought and delayed production continues, this will hamper rice and wheat production.

Panellist 4: Mr. Malik Fida A. Khan, Executive Director, Centre for Environmental and Geographic Information Services (CEGIS).

Mr. Khan first stated that a quick assessment using models indicates that Bangladesh's agricultural sector can be changed and co-benefited by adopting mitigation and adaptation measures.

The Bangladesh NDC and National Adaptation Plan are his current prominent project. In national adaptation, the plan has six goals and one of them is food, nutrition, and livelihood security with interventions of water, agriculture, and fisheries. Of the 47 interventions that provide mitigation co-benefits, twelve or thirteen are climate-smart agriculture interventions. He asked that the MAC-B project check with this assessment for the climate-smart agriculture interventions and how the project could contribute to interventions that provide both mitigation as well as adaptation co-benefits.

Conclusion by Dr. Mohammed Asaduzzaman, Professorial Fellow, Bangladesh Institute of Development Studies (BIDS):

The conclusion of the presentations of preliminary findings of research on mitigation and adaptation co-benefits was presented by Dr. Mohammed Asaduzzaman. He said:

"The sum of the presentation is that there is no magic bullet; conditions, sites, and situations are important for bringing a change. Actual implementation in the field is the real problem because a farmer is managing many factors. A few key issues need to be considered always. How water is supplied, how water is used, net income, etc. Payment for ecosystem services must be done in this country but has not started yet. Again, there is no magic bullet, the conditions of the farmer need to be understood. Science needs to be feasible technically, socially, and economically."

Breakout sessions on the MAC-B focus areas (15:00–15:50 pm):

Group 1: Biophysical Impacts (Crop, GHG, Soils)

Climate-smart soil, water and fertilizer management

Biophysical Impacts (Crop, GHG, Soils) break-out group

Important note: In ensuring food security, the group agreed not to sacrifice rice yield.

Suggestions included the use of:

- Short instead of long-duration crop varieties in the *aman* season
- Minimum tillage with crop residue management
- AWD during the *boro* season (according to soil type)
- Satellite-based irrigation system to ensure precise water management
- Solar irrigation system
- Proper management of irrigation channels to prevent water loss
- Deep placement of urea
- Sulphur/neem costed-urea
- Biochar
- Biofertilizer
- Nano fertilizer
- Compound fertilizer
- Real-time N application

- Machine transplanters with deep placement of fertilizer
- Crop rotation
- Direct seeded rice where applicable
- Early warning system for disease and pest management to reduce pesticide use

Group 2: Economic Impacts

The economic group outlined why the MAC-B project uses the TOA-MD model and SRI/AWD. The TOA-MD Model is a unique simulation tool for a multi-dimensional impact assessment that uses a statistical description of a heterogeneous farm population to simulate the adoption and impacts of a new technology or a change in environmental conditions and poverty. The MAC-B research team aims to investigate AWD when all the activities under changing climate and environmental conditions were considered.

For the team, selecting a comprehensive data set was a major challenge, as the aim was to analyse impact assessment on specific issues.

The group discussion identified the following prospects for the economic aspect of the project:

- Evaluate the effects of interventions related to climate change on the current farming system using multiple measures of adaptation, mitigation and development co-benefits.
- Evaluate the effects of the interventions related to climate change on the current farming system considering the future climate scenario in advance.
- Utilize TOA-MD because this economic model can be run using currently available data, resulting in lower costs compared to other models.
- Discussed options for future research (e.g., a second phase of this project) to involve other partners to have access to additional data to represent other management options for rice systems and possibly, expanding the analysis to other systems, like maize-based systems

The Economic Impacts Breakout Group found that the workshop had been useful in finalizing their analysis and that it had provided them with new ideas about the technologies that they could include in the future.

Group 3: Gender and Social Aspects

One of today's most pressing challenges which emerged from the discussion is the link between gender and nutrition. Men, women, and children come under distinct categories of vulnerability, meaning that gender inequality impedes progress and impacts on both household and national food and nutrition security. In addition, risk factors are growing every day. MAC-B focuses on mitigation and adaptation to reduce vulnerability. The danger factors will inevitably decline if climate change is reduced. The technology tested in this project is AWD. Children suffer the most throughout puberty, and it has a long-term impact on them. A lack of nutrient-rich food will lead to problems for the country in the future.

The group pointed out the impossibility of imagining a healthy, ecologically friendly world without agriculture, and that it is impossible to improve agriculture and agricultural products without considering the contribution of women to the industry. Female workers are primarily involved in postharvest activities, a crucial aspect of farming. They also contribute to pre-mechanization procedures, and the fact that they are not fully acknowledged is regrettable.

However, women's requirements vary according to area; for example, natural catastrophes affect many regions, where women's needs should be considered accordingly.

The group emphasized that to achieve equality for all genders in society including under-represented women, opportunities should to be made available based on need. They also highlighted the importance of a healthy diet, and that women should be encouraged to work in agriculture, which should be a primary focus.

Synthesis, reflections and next steps by Dr. Timothy Krupnik (CIMMYT):

Dr. Krupnik said he had found the workshop interesting and useful. He pointed out that seeing colleagues and stakeholders face-to-face is remarkably important, and that the debate about SRI was also important.

He reflected that not only SRI is projectable: other approaches are also relevant. The data set on SRI is impressive; however, the focus does not have to be on SRI as the only adaptation measure.

In response to the biophysical group, he identified two interesting findings:

(1) Scientist are very focused on approaching interventions in a package, speaking of best management practices such as soil and water. Models can be used for some but not all interventions;
(2) Farmers rarely employ the entire package of recommended practices; this is an idea for scientists not farmers. How farmers are using AWD and other components of SRI should be examined.

Dr. Krupnik added "We need to identify socio-economic and adoption patterns, where we can look at models of adaptation in terms of components rather than as technical packages. There needs to be adaptation in addition to adoption. Farmers rarely, if ever, use the same package approach season after season." Dr. Krupnik asked participants to challenge themselves in this regard.

He stated that the socio-economic group had raised some important queries. Although the project might have utilized rich data about rice production, it might not have enough national or global data linked to fisheries and livestock production. He said, "We shouldn't use these concepts to ask for more funding. But I think there are some advantages to collecting this new data, which will help us in the next phase of this research. It can help to link rice with multiple other crops or livestock. Rice will always be king and will always be the most important thing that will ever be considered for modelling context."

On gender inclusion, Dr. Krupnik said, "We don't often count women in the agricultural system, or how they are working regarding seed maintenance, in post-harvesting activities. But if you look at the livestock sector, the role of women is increasing, which is why I think we need to collect some additional primary data. We would like to create a more advanced data set on gender roles, and present it in the next 6 months and use it with secondary data sets".

Wrap-up and closing by Professor Dr. Ainun Nishat, Professor Emeritus, BRAC University, Bangladesh

Professor Dr. Ainun Nishat stated that the impact of climate change on the agricultural sector is highly significant, even though Bangladesh produces only 0.3% of global GHG. This needs to be recognized. Scientists assume that total global rainfall will increase, resulting in more frequent short-duration, very heavy rain, as well increases in the number of extreme events such as cyclones, storms and flash flooding. Crops react to these changes, with just one degree increase in the temperature having a significant impact. Livestock and fisheries are other important areas most affected by climate change. A main goal of the Paris Agreement, agreed upon by 197 countries, is to ensure food security.

Professor Dr. Nishat said he was very glad that the MAC-B project considers both mitigation and adaptation: to ensure food security, a link must be established between the two. Government policy should be developed in such a way that the adaptation rate and food production are increased and GHG emissions reduced. He also referred to AWD as the best technology for mitigating methane emissions. To ensure adaptation, Bangladesh needs rice varieties that are tolerant to stress (from salt, drought, and submergence) and short-duration varieties. Professor Dr. Nishat also said that maize can be a potential crop to include in the climate change adaptation strategy in Bangladesh as it can tolerate high temperature levels compared to other crops. He indicated that the Bangladesh National Adaptation Plan has mainly focused on the agriculture sector in order to secure food security. He encouraged scientists, policymakers, and stakeholders to come up with an effective combination of adaptation and mitigation strategies, and work on these to save agriculture in Bangladesh.

Finally, **Dr. Ghulam Hussain** thanked everyone for their enthusiastic participation and for providing their valuable feedback, which would help to improve and modify the integrated assessment approach and the MAC-B project.

List of Participants

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11.2 Appendix 2: MAC-B Concluding Stakeholder Roundtable

Mitigation and Adaptation Co-Benefits Modelling Trial in Bangladesh Project

Proceedings of the MAC-B Stakeholder Roundtable

Mitigation measures and Adaptation Co-Benefits Modeling Trial in Bangladesh Project

MAC-B Stakeholder Roundtable Agenda

Meeting Room, Training Complex (First Floor)
Bangladesh Rice Research Institute, Joydebpur, Gazipur
April 05, 2023
9:30-13:00 hrs. local time in Bangladesh

9:30- 10:00	Registration	
10:00-10:10	Welcome and Introductions	Tim Krupnik, Country Representative, CIMMYT-Bangladesh Erik Mencos, Columbia University
Opening Remarks		
10:10-10:20	Dr. Pratibha Singh, ACIAR Regional Manager in South Asia on behalf of Dr. Veronica Doerr (ACIAR, virtually)	
10:20-10:30	Dr. M.A. Yousuf Akhond, Director (Research), on behalf of Dr. Debasish Sarker, Director General, Bangladesh Agricultural Research Institute (BARI)	
10:30-10:40	Dr. Mohammad Khalequzzaman, Director Research, on behalf of Dr. Md. Shahjahan Kabir, Director General, Bangladesh Rice Research Institute (BRRI)	
10:40-10:55	Climate Change Challenges in Agriculture: Overview of AgMIP and MAC-B Project	Cynthia Rosenzweig (NASA/Columbia University, virtually) and Tim Krupnik (CIMMYT)
10:55-11:10	Group Photo Coffee/Tea Break	All Participants
Presentations of Findings of Research on Mitigation and Adaptation Co-Benefits		
11:10-13:00	Session Chair: Dr. Mohammad Khalequzzaman (Director of Research, Bangladesh Rice Research Institute (BRRI) Facilitator: Dr. Moin Salam, Senior Consultant, CIMMYT-BD	
11:10-11:20	Climate Team	Sonali McDermid (NYU) and Md. Bazlur Rashid (BMD)
11:20-11:45	Biophysical (Crop, GHG, Soils) Team	Tao Li (DNDC), Tek Bahadur Sapkota CIMMYT), Umme Aminun Naher (BRRI), and Apurbo Kumar Chaki (BARI)
11:45-12:10	Economics Team	Roberto Valdivia (OSU) and Md. Rajibul Alam (Ministry of Public Administration)
12:10-12:30	Presentations by BRRI Scientist on Carbon Absorption by Rice Plants and Pros and Cons of Alternate Wetting and Drying	Dr. Mofijul Islam, Senior Scientific Officer, Soil Science Division, Bangladesh Rice Research Institute, Joydebpur, Gazipur.
12:30-13:10	Questions and Discussion	All Participants
	Stakeholder Engagement	Survey: While participants are sharing ideas, a survey link will be shared via email and on the screen with several questions on MAC-B about its potential, challenges, and recommendations. Facilitators: Sk. Ghulam Hussain (CIMMYT-BD)
13:10-13:20	Synthesis, reflections and next steps	Tim Krupnik (CIMMYT)
13:20-13:30	Wrap-Up and Closing by the Session Chair	Dr. Mohammad Khalequzzaman (Director of Research, Bangladesh Rice Research Institute (BRRI)
13:30-14:00	Lunch and Prayer	

Draft report on the MAC-B Stakeholder Roundtable

The MAC-B Stakeholder Roundtable, part of the ACIAR-funded 'Mitigation and Adaptation Co-Benefits (MAC-B) Modelling Trial in Bangladesh' project, was held on April 05, 2023, at the Training Complex of the Bangladesh Rice Research Institute (BRRI), Joydebpur, Gazipur, Bangladesh. Forty-six experts and scientists from different organizations in Bangladesh and abroad joined the meeting, of which 30 participated physically and 16 virtually. This hybrid event was designed to share and discuss the project's final results with the stakeholders. The half-day meeting was designed so that the stakeholders could provide feedback for improving the project's outcomes.

Welcome and Introductions by Dr. Timothy J. Krupnik (CIMMYT) and Erik Mencos (Columbia U)

Dr. Timothy J. Krupnik, Associate Director, Sustainable Agrifood Systems (SAS) Program, Asia and Country Representative (Research & Partnerships) Bangladesh, International Maize and Wheat Improvement Center (CIMMYT), and Erik Mencos, Senior Research Associate at Columbia University and AgMIP Program Manager, welcomed everyone who was participating in person and virtually in the MAC-B stakeholder Roundtable workshop. Dr. Krupnik also expressed his gratitude to the Bangladesh Rice Research Institute (BRRI) and appreciated BRRI's willingness and generosity in providing their training room and logistics to hold this event.

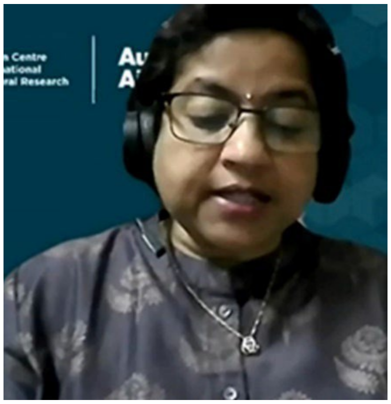
He mentioned, "I also want to appreciate everyone who has attended, I think there are more people here than we expected which is great. I know it's also very difficult to have meetings during the Ramadan period so we will try to be brief and focused on our discussions today but I want to thank everyone for giving their time and for being here in person. He then announced some small changes in the program and added that “we will have esteemed guests who will be representing and speaking from the perspective of BRRI and from BARI this morning the discussion today which is about.”

At the end of his introductory remarks, Dr. Timothy said that "this effort involves a lot of Bangladeshi partners; we have contributions from groups at BRRI and BARI, for instance. It is possible to sequester carbon while simultaneously taking Bangladesh's need for adaptation measures into account. This work varies from a lot of the other research we all conduct on an experimental and field plot basis in that we used data from extremely large-scale surveys involving thousands of farmers throughout Bangladesh. We are employing data from observed farmers, which were collected from those thousands of farmers and used for modeling efforts in a variety of various places. In a nutshell, what we hope to achieve with this meeting is to share with you the modeling work that a group of multidisciplinary social and natural scientists have been doing."

Opening remarks:

Dr. Pratibha Singh on behalf of Veronica Doerr from ACIAR:

On the behalf of Veronica Doerr, ACIAR Program Manager, Dr. Pratibha Singh, ACIAR Regional Manager in South Asia from Delhi gave opening remarks. She was happy to see partners from across the globe in the workshop. She started by making a statement that “the latest IPCC synthesis emphasizes that we aren't going fast enough on either mitigation or adaptation and thus we need to urgently scale out existing technologies.



At the moment we seem to be doing too little on too many different things rather than putting enough effort into a few technologies or management or practice changes. Given this need to concentrate efforts, the IPCC also emphasizes scaling new technologies and management or practice changes that deliver both adaptation and mitigation benefits. She mentioned that "many interventions are studied separately to see if we deliver both benefits but if we study each one individually before deciding where to focus, we will be delaying significant action for too long; we need a simpler process for identifying the best bet technologies; the ones that will deliver the best balance between adaptation and mitigation benefits so we can concentrate on all the signs and action to scale out and make these new normal ways of doing things. This is what Mac-B is really all about." She requested the participants to pay attention to the way the MAC-B approach works, the way it tries to quickly provide evidence about best-bet technologies to focus on, and provide feedback on how this approach worked: was it quicker or less costly than lots of individual experiments or where the data requirements so large that it didn't really save much time and effort? Would this type of analysis convince senior decision makers to focus their efforts more and could it be used more broadly to identify where to focus in other areas not just sustainable intensification in rice. At the end of her speech, she congratulated all the partners all across the globe for this meeting and also looked forward to hearing their findings of the research.

Dr. M.A. Yousuf Akhond, Director of Research, BARI

Dr. M.A. Yousuf Akhond (Director of Research, Bangladesh Agricultural Research Institute (BARI)) made the opening remarks on behalf of the Director General of BARI, Dr. Debasish Sarker. He expressed his feelings about joining the Stakeholder's Roundtable discussion of the mitigation adaptation co-benefits modeling trial in Bangladesh. He was also very proud that his organization (BARI) has been an active part of this project and that its scientists have contributed through simulation analysis conducted by the combined model suit of the DNDC and TOA-MD economic regional farming system models. As he mentioned, Bangladesh's population has more than doubled since independence, but the country's infrastructure still needs to catch up. In his speech, he addressed that Bangladesh has also achieved significant and remarkable development and progress in agricultural production. Still, now, as in previous years, the agriculture sector is facing challenges due to rapid climate change. Bangladesh is one of the world's most vulnerable climate-affected countries. Our government policymakers and scientists are constantly working with different strategies to cope with this problem. He mentioned that the Bangladesh government is committed to two percent of its own domestic GDP to climate Finance established a National cross-sectoral Climate Change strategy and action plan and as well as emphasized climate response in its 10-year collaboration strategy with ACIAR. He said that "Our intention is to identify and transfer improvements in rise-based farming systems, but there are consequences of these only rice-based cultivation systems where we are growing in some places like consecutively three rice crops. There are some concerns have been raised from some quarters about whether to reduce this rice cultivation in Bangladesh or replace rice with some other crops, but I believe it will not be wise to replace this system with rice as rice is the major crop of the country and we need to try to think about mitigating the problems associated with rice." According to him, this project provides a platform for scientists to evaluate those effects, and because it is modeling work, one can predict future needs and suggest to policymakers what intervention to do for the future sustainability of this system. He noticed some interventions already reported in the project, such as alternative wetting and drying, have produced significant outcomes like reducing greenhouse gas emissions with a minimal yield penalty. In addition, he thinks mechanization can be more efficient for small-scale rice planters. He also believes "there is a scope for studying intercropping which can affect greenhouse gas emissions and climate change-related effects to get complete and robust outputs. As in the workshop, the preliminary results of the models would be showing, so we still need to go further. The more input we provide, the more efficient the modeling system will be, so we need to go to more places and try to generate more data in that area so that our modeling will be accurate and it will also help us help policymakers to make better policies, and there is another area as I am a plant breeder and biotechnologist whether the plan bidders can explore that like in developing rice varieties that require less water probably and with the use of genetic engineering."

Dr. Mohammad Khalequzzaman, Director of Research, BRRI

Dr. Mohammad Khalequzzaman, Director of Research of Bangladesh Rice Research Institute (BRRI) attended and chaired the roundtable event. On the behalf of Dr. Md. Shahjahan Kabir, Director General of BRRI he read out the opening remarks. He began by saying that in this country, "Rice security" is synonymous with "Food security." Since its birth in 1970, BRRI worked hard to develop the rice sector and finally has made the country self-reliant from chronic food shortages. Bangladesh is now the 3rd in rice production in the world and the 1st in producing average yield in South Asia and similar yield as the world standard. Since independence population increased by two and half folds but rice production has increased about four folds which reflect the success story of scientists, extension agents, farmers and the pro-agriculture government. Therefore, the economy of Bangladesh is rice-centric and the development of the agricultural sector mainly depends on rice-led research and development. So, rice should be included in any policies and strategies in Bangladesh for short, medium, and long-term planning. During 2021-22, Bangladesh has produced 39.70 MT of clean rice meeting the requirements of 170 million people. If it didn’t happen, millions of people would have become food refugees and would have created a global crisis. But, in reality, we have shown the courage of sheltering and feeding 1.2 million odd Rohingyas.

Despite Bangladesh being highly vulnerable to climate change and climate-induced disasters, the country contributes less than 0.35% of global emissions. Nonetheless, Bangladesh wants to actively participate in global collective action to reduce future GHG emissions. GHG emissions from rice could be reduced before it reaches the atmosphere by combining multiple approaches, i.e., efficient water management, fertilizer, variety, cropping pattern, and modification of internal spaces (limited aerenchyma). Therefore, since 2013 the scientists of the Soil Science division of BRRI have been measuring GHG emissions from rice fields. The results of various studies showed that alternate wetting and drying (AWD) irrigation significantly reduces global warming potential (GWP) by 36% compared to continuous flooding (CF) conditions.

Moreover, it reduces water use by up to 38% without a significant yield penalty, which helps reduce farmers' production costs. Therefore, AWD practice is expected to be widely adopted by farmers in the country for Boro rice cultivation. Although most of the farmers in our country are not habituated to formal AWD practice, they dry their land 2-3 times during Boro rice throughout the rice-growing season, that have an almost similar effect to AWD practice. Extrapolation of this technology in 100% of Boro area (4.8 million ha) can reduce 9 Mt CO2 eq GHG emissions from rice cultivation.

Another study by BRRI showed that urea deep placement (UDP) significantly reduced GWP by 9% compared to broadcast prilled urea (PU). In addition, UDP saves N fertilizer use by about 25-30% and increases rice yield by about 10-15%. However, the main problem for extrapolating this technology is associated with the unavailability of briquettes on a large scale and the need for suitable applicators. To overcome this problem, BRRI already advanced rice transplanter cum fertilizer applicator. Therefore, a rice transplanter cum fertilizer applicator is expected to be widely accepted by farmers in the country for Aman and Boro rice cultivation. Extrapolation of UDP technology in 100% of cultivated area (11.6 Mha) can potentially reduce 8 Mt CO2 eq GHG emissions from rice cultivation.

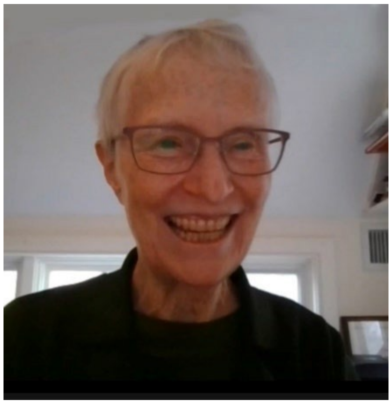
In Bangladesh, in three rice seasons, i.e., Aus, Aman, and Boro, a total of 50 Mt of rice is produced; carbon dioxide, methane, and nitrous oxide emissions are 33.3, 2.65, and 0.025 Mt, respectively. The carbon dioxide equivalent emissions of these three greenhouse gases are 106.2 Mt.

On the other hand, rice plants absorb 2200 grams of carbon dioxide per kg of rice production in the photosynthesis process. So, in total production of 50 million tons of rice, about 110 Mt of CO2 is absorbed from the atmosphere. According to the above calculations, it is clear that paddy fields absorb 3.8 (110.0-106.2) million tons more greenhouse gases from the atmosphere than emitted. Therefore, rice cultivation does not pollute; rather, it cleans the atmosphere.

He then informed the audience about other promising technologies to mitigate CH4 emissions from rice cultivation, including oxidation of CH4 and aerenchyma formation or modification. In rice roots, aerobic CH4 oxidizing bacteria (methanotrophs) consume up to 30% of CH4 before it reaches the atmosphere. Rice plants develop aerenchyma against low O2 stress in submerged conditions, which provides a channel for gaseous exchange between aerial and flooded parts. However, up to 90% of CH4 released from rice fields into the atmosphere is through aerenchyma, suggesting that aerenchyma are responsible for CH4 emission. Limited aerenchyma formation in rice plants can reduce CH4 emissions by about 27%.

In this context, BRRI is working on a plan and has taken several steps to implement it. For example, BRRI is working to develop a variety with reduced aerenchyma that can mitigate a large amount of CH4 emissions. BRRI is also working to develop a variety that can absorb a large amount of CO2. Because we know that rice is a C3 plant, as the amount of CO2 increases in the atmosphere, rice absorbs more CO2 and produces more carbohydrates resulting in an increased rice yield. To innovate more CO2-absorbing varieties, BRRI has already identified varieties from germplasm stored in BRRI Gene Bank that are more responsive to CO2 and more productive. This germplasm will be used in the future to invent more CO2-absorbing and more productive varieties. Besides, BRRI is working on nanotechnology to reduce GHG emissions from rice cultivation. He concluded by recommending that "we emphasize how to reduce GHG emissions by keeping everything in order."

Dr. Cynthia Rosenzweig (NASA/Columbia University, virtually)

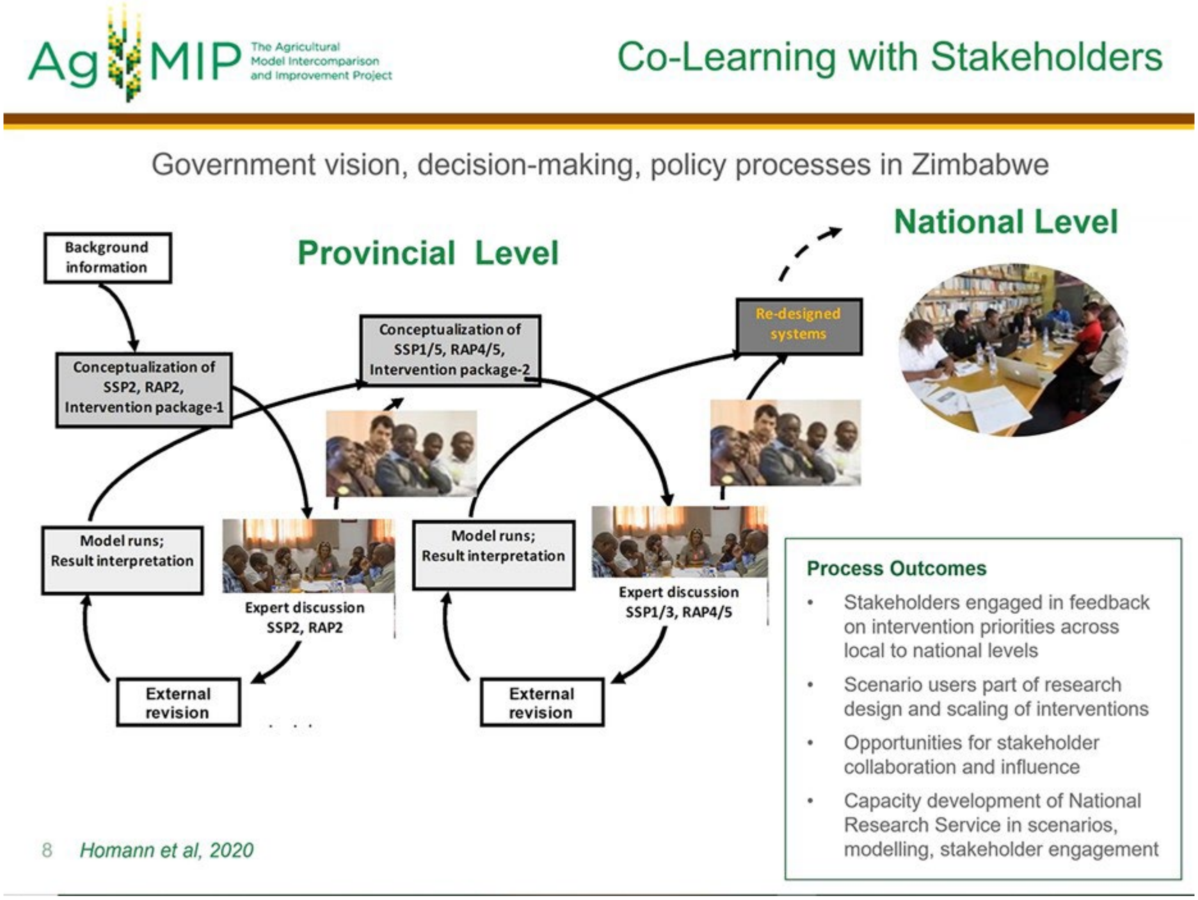


In her pre-recorded video, Dr. Cynthia Rosenzweig of NASA/Columbia University introduced herself as the Agricultural Model Intercomparison and Improvement Project (AGMIP) co-leader. She extended a warm welcome to everyone attending the stakeholder roundtable meeting.

She stated that "the MAC-B project began in September 2021, and now we are working on wrapping up the project. But before the project ends, it's crucial to get the stakeholders' feedback on its results as they stand now and thinking about next". She added that "we are a Global Network of over 1,000 agriculture, climate, and food researchers, and what we do together is as we have in this MAC-B project to convene scientifically based agricultural decision-making models and assessments of climate change to achieve local to global food security. First of all, I want to thank the project partners; it's been a great joy to work with all of my colleagues from the many Bangladesh institutions and other institutions around the world. The feedback from the stakeholders has been invaluable to the project, and we look forward to getting your last words of wisdom at the stakeholder Roundtable, so I'm going to give an overview of AgMIP." Then she talked about the AgMIP mission, which is to provide science-based agricultural decision-making models and assessments of climate change to achieve to conduct multi-model assessments, which are assessments of both the biophysical and economic sides of things.

She invited the audience to see the crop modeling results, hear about the economic impacts, and learn about the economic outcomes as well as the practices—in this case, some alternative wetting and drying and other management practices and technologies—which will prompt to consider incentives for the current and future climate conditions to create effective responses and create chances for stakeholders to participate in initiatives and have a genuine impact. One of the objectives is to establish national scale capability for scenario modeling stakeholder interaction and national adaptation strategies, to prevent a spiral of activities from the project team presenting the results and plans to the stakeholders.

Then she explained the Integrated Assessments features, including stakeholder-driven activities focused on farming systems. She then narrated the development pathways, transdisciplinary- biophysical/socio-economic modeling, multi-scale and multi-model- field, farm, regional, and global assessments, and distributional results, e.g., impacts on poverty rates. She cited an example of Co-Learning with Stakeholders from Zimbabwe. She showed how in every aspect of the process, the Stakeholders are engaged in feedback on intervention priorities across local to national levels.



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Co-Learning with Stakeholders

Government vision, decision-making, policy processes in Zimbabwe

Provincial Level

National Level

Background information

Conceptualization of SSP2, RAP2, Intervention package-1

Model runs; Result interpretation

Expert discussion SSP2, RAP2

External revision

Conceptualization of SSP1/5, RAP4/5, Intervention package-2

Model runs; Result interpretation

Expert discussion SSP1/3, RAP4/5

External revision

Re-designed systems

Process Outcomes

- Stakeholders engaged in feedback on intervention priorities across local to national levels
- Scenario users part of research design and scaling of interventions
- Opportunities for stakeholder collaboration and influence
- Capacity development of National Research Service in scenarios, modelling, stakeholder engagement

8 *Homann et al, 2020*

Timothy J. Krupnik, Country Representative (CIMMYT-Bangladesh):

After Dr. Cynthia Rosenzweig's powerful speech, Dr. Timothy J. Krupnik (CIMMYT-Bangladesh) explained that "in terms of the emissions issues that we have focused on, this is basically the agri-food systems in Bangladesh in general; it is not specific to rice. Crop management practices may affect rice productivity and adaptation and mitigation co-benefits in Bangladesh at a large geographic scale. Compared to the global configuration of greenhouse gas emissions, Bangladesh emits a relatively small amount of greenhouse gases. And in many instances, Bangladesh is, of course, a far greater victim of climate change and of emissions that larger and more industrialized countries have mostly initiated. Several nations may benefit from what Bangladesh has accomplished in terms of producing enough rice to meet their own needs on a year-round basis. Everyone rarely benefits from a single technology or a single management practice when it comes to mitigating and adapting Bangladesh's rice production systems to climate change while also looking at the socioeconomic consequences in terms of profitability and how changes in rice production may affect men and women or different types of farmers and groups of farmers differently. We'd want to know whether you find the simulations plausible and if you believe they might assist in a direct future study, particularly the usage of younger seedlings when transplanting. Bangladesh's rice-based systems will be able to adapt while also reducing and minimizing some of the long-term effects of greenhouse gas emissions."

Talking about Key Challenges in Bangladesh Dt. Tim said, "Water is one of the most stressed resources in Bangladesh. Significant challenges are sustainable water resources management and water resources markets. Increasing vulnerability to extreme events, over-extractions, growing urban demand, climate change, land-use changes, and environmental requirements. Bangladesh must feed a large population from declining agricultural land and water resources. Moreover, the staple food rice requires massive amounts of water and is grown under submerged conditions. Then he talked about Bangladesh MAC-B Objectives and Key Activities, touching upon the following points:

- Directly integrate stakeholder feedback into the MAC-B assessment process and co-develop feasible interventions (focused on sustainable rice management and intensification) that may generate adaptation and mitigation co-benefits
- Evaluate the effects of these interventions in current farming systems using multiple measures of mitigation, adaptation, and development benefit, including measures of greenhouse gas emissions, resilience to climate variability, farmer livelihoods, gender, and nutrition
- Evaluate the effects of the interventions on the multiple measures of benefit under future climate scenarios
- Support policy development by convening a policy-maker's round table to communicate the findings from the project and discuss policy implications for mitigation and adaptation programs
- Strengthen the capacity of all partners in using and applying AgMIP Regional Integrated Assessment methods

Presentations of Findings of Research on Mitigation and Adaptation Co-Benefits

Session Chair: Dr. Mohammad Khalequzzaman (Director of Research, Bangladesh Rice Research Institute (BRRI)

Facilitator: Dr. Moin Salam, Senior Consultant, CIMMYT-BD

Climate Team:

Md. Bazlur Rashid, Meteorologist, Bangladesh Meteorological Department

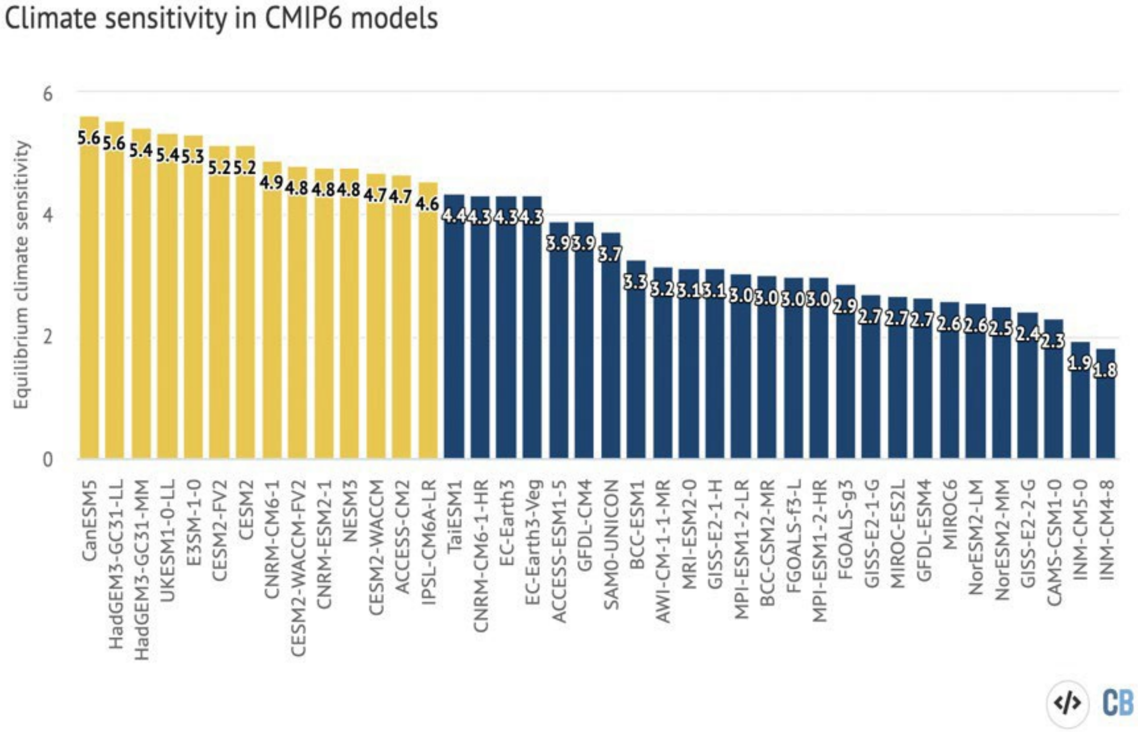
Sonali Shukla McDermid, PhD Associate Professor, New York University, USA

Sanketa Kadam, Columbia University, USA

Dr. Sonali McDermid virtually presented the climate team's activities. The information they generated has been passed to the biophysical and economic modeling teams to carry out their simulation/modeling work. The Climate Team's first objective is to provide future climate change scenarios (e.g., the 2050s, fossil-fuel development) for MAC-B assessment at the site level.

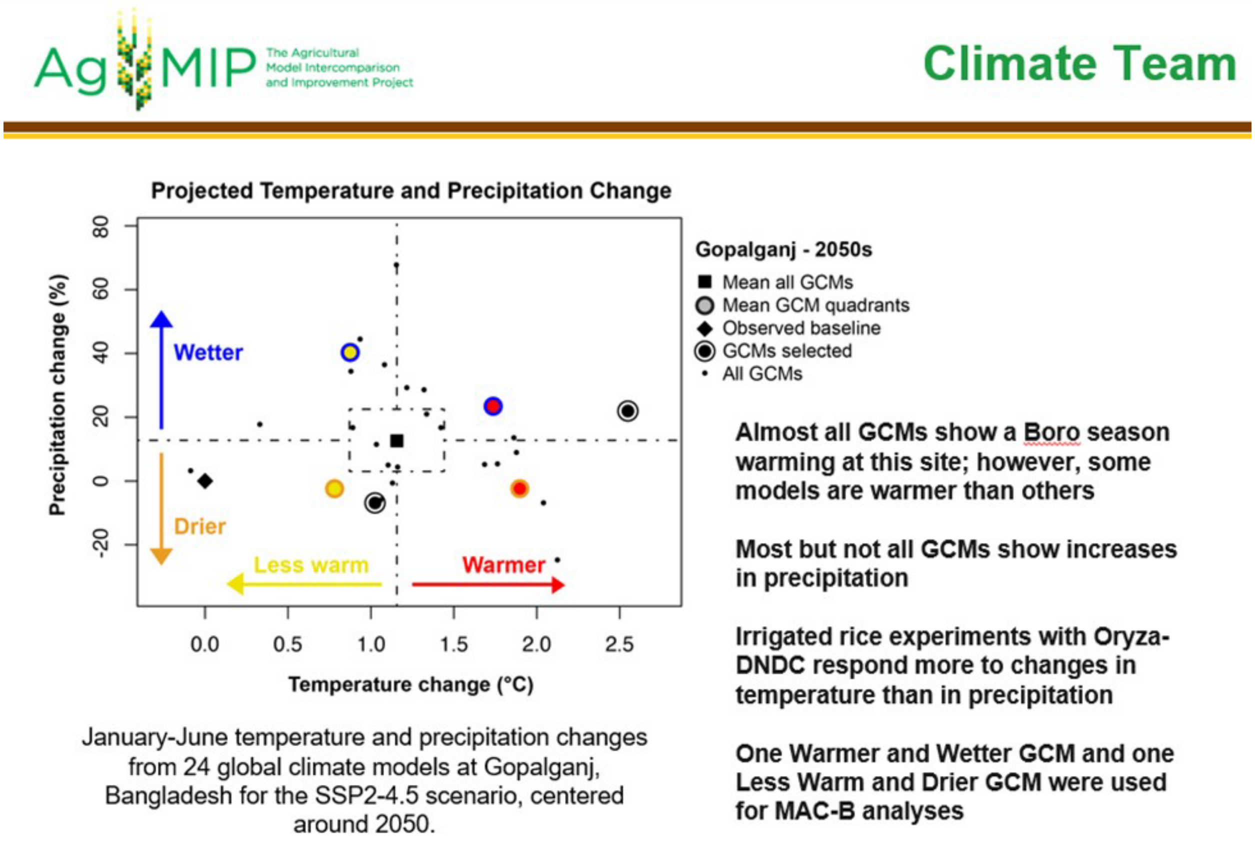
The second objective is to understand how uncertainty in these future climate scenarios and projections impacts the crop and socioeconomic outcomes, and the third objective is to consider how modeled mitigation potentials may provide feedback on the climate system. The third objective was not presented in the meeting. Dr. Sonali then added that "more of an aspect of future work that we'd like to explore a bit more. I'll walk you through now how we set up the climate data and scenarios for the crop and economic modeling assessments and so, as you might know, the latest version of the IPCC.

The Climate Team uses climate model projections from the latest Coupled Model Intercomparison Project (6), which conforms the UNFCCC Climate Reports, which have been downscaled as part of the NASA Global Daily Downscaled Projections (NEX-GDDP-CMIP6).



IPCC AR6

The models show climate sensitivity, so the amount of warming that they achieve for a certain amount of carbon dioxide is quite high. In other words, several of the models in this climate assessment round are hotter and hotter than what has been seen previously. So, one recommendation that has been passed down from the climate community is to be careful about using these hot models in assessments of impact because they might skew the assessment results, so they may not be representative of the physical response of the climate system and so what we have done is two things one we've still used these projections from the sixth couple model intercomparison project which informed the latest IPCC report. These models have been further downscaled from their native resolutions which are about 100 kilometers by 100 kilometers they've been downscaled to a 25 kilometer resolution data set as part of the NASA Global daily downscale projections data and then what we've done is a step further to that that down scaling we've subset the models to eliminate some of the hotter models that you're seeing here sort of the top five models in this category in order to achieve a model population or a subset that we feel is more physically representative now future work could also include some of these hotter models and in fact we did run some previous model simulations with these hotter models in order to understand the full range of sensitivity but for right now we have some physical reasons to think that the hotter models may not be representative of the kinds of changes we'd like to examine, so with this subset of models we now take another step forward to subset or select specific models for the climate scenarios we'd like to test so again we're looking for now only at an SSP2 4.5 scenario so again this is our middle range to more ambitious mitigation climate scenario but it's sort of impossible to run this many models even if we're eliminating some of them through crop and then the economic components of the project to run every single climate model there are now about 44 climate models maybe a little bit more than that it would be rather prohibitive so we need to figure out a reasonable strategy to select just a few models that capture the range of change that we're seeing across the model space for a given climate scenario in this case SSP2 4.5.



Climate Team

January-June temperature and precipitation changes from 24 global climate models at Gopalganj, Bangladesh for the SSP2-4.5 scenario, centered around 2050.

Almost all GCMs show a Boro season warming at this site; however, some models are warmer than others

Most but not all GCMs show increases in precipitation

Irrigated rice experiments with Oryza-DNDC respond more to changes in temperature than in precipitation

One Warmer and Wetter GCM and one Less Warm and Drier GCM were used for MAC-B analyses

Dr. Sonali then narrated that, "We are currently driving the climatic findings from these two models via our biophysical (crop, soil and GHG emission) model inputs and then into our socioeconomic model and results. With that, I'll conclude here and answer any questions you may have about our technique, which is used at every site we have studied.

Biophysiological Team:

Dr. Tao Li, DNDC

Dr. Tek Bahadur Supkota, CIMMYT

Dr. Umme Aminur Nahar, BRRI and

Dr. Apurba Kumar Chaki, BARI

The Biophysiological Team is represented by Dr. Tao Li, a renowned modeler working at DNDC (DeNitrification DeComposition) and Dr. Tek Bahadur Supkota a greenhouse gas emission expert in working at CIMMYT Mexico and Dr. Umme Aminur Nahar a soil scientist working at BRRI and Dr. Apurba

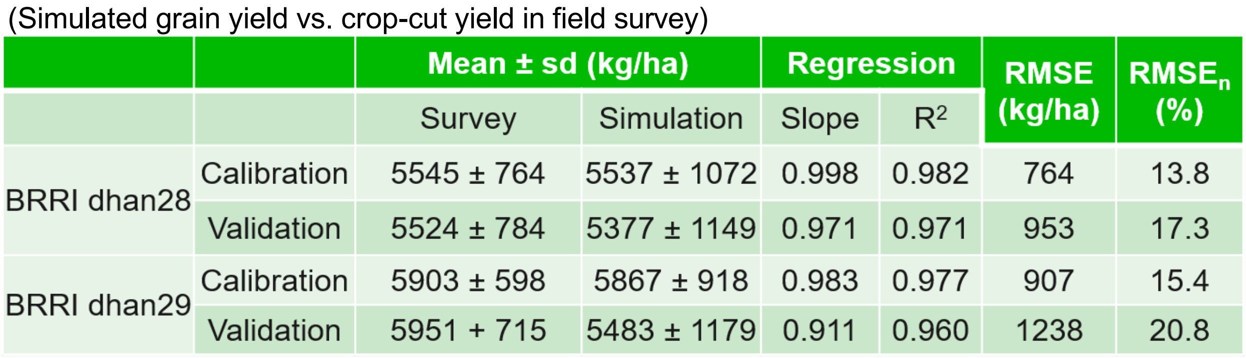
Kumar Chaki, cropping system agronomist and crop modeler working at BARI. Dr. Apurbo Kumar Chaki on behalf on the team presented the modeling findings that highlight the benefits of both adaptation and mitigation for rice production in Bangladesh. He narrated that "We need crop management data, detailed soil profile data, and temperature data, rainfall data, thus we obtained both historical and future records for the climate modeling datasets from the climate modeling team. Before doing any scenario analysis, we went through an iterative process of model calibration to examine the uncertainties and the level of confidence in the model's predictions. As a result, we performed cultivar parameterizations. The breeds that we employed in our modeling study were two popular rice varieties, BRRI dhan28 and BRRI dhan29." We haven't really done any rotations but the economic team has done some so we have applied some new interventions of management that's the alternate wetting and drying and system of rice intensification, and we have run those simulations for 30 years in the historical climate as well as two future climate supplied by the climate modeling team.
Data used for this study were:

- **Rice yield and cropping management:** Field survey conducted in Bangladesh from 2019 to 2021;
- **Soil data:** Extracted from SoilGrid2.0 of ISRIC, and corrected by a few soil profile data from field experiments;
- **Weather:** 30-year timeseries for historical (AgMERRA 1980-2010) and future scenarios from two downscaled CMIP6 climate models for SSP2-4.5

Design of crop modeling evaluation

- **Model calibration and validation:**
- ***Varieties:*** BRRI dhan28 & BRRI dhan29
- ***Data sites:*** 1489 sites selected from 4427 sites of field survey from CMMIYT
- ***Calibration and validation data sites:*** Randomly split data site into 66% for calibration, 34% for validation

Model calibration and validation results



(Simulated grain yield vs. crop-cut yield in field survey)

		Mean ± sd (kg/ha)		Regression		RMSE (kg/ha)	$RMSE_n$ (%)
		Survey	Simulation	Slope	R^2		
BRRI dhan28	Calibration	5545 ± 764	5537 ± 1072	0.998	0.982	764	13.8
	Validation	5524 ± 784	5377 ± 1149	0.971	0.971	953	17.3
BRRI dhan29	Calibration	5903 ± 598	5867 ± 918	0.983	0.977	907	15.4
	Validation	5951 + 715	5483 ± 1179	0.911	0.960	1238	20.8

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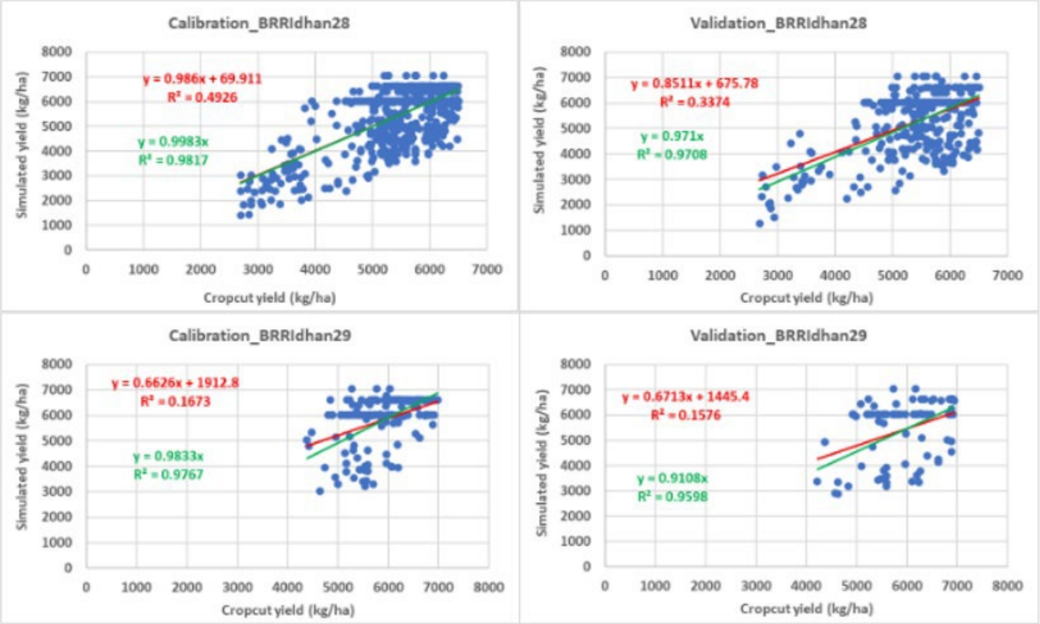
Model calibration and validation results



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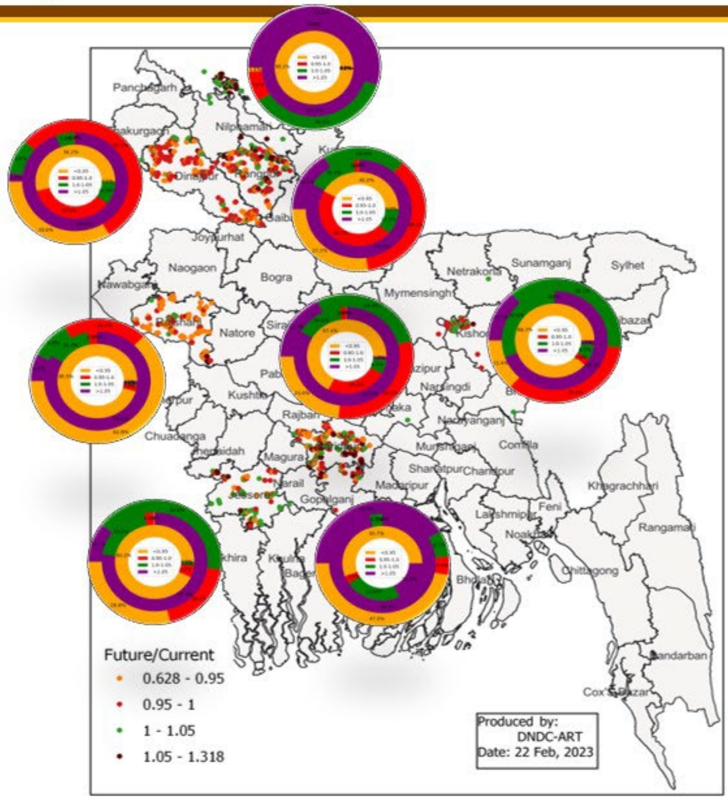
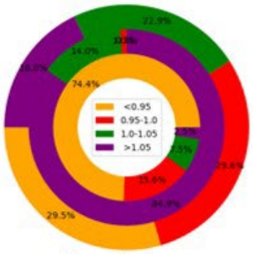
Results (Group 1)

– The effects of climate change



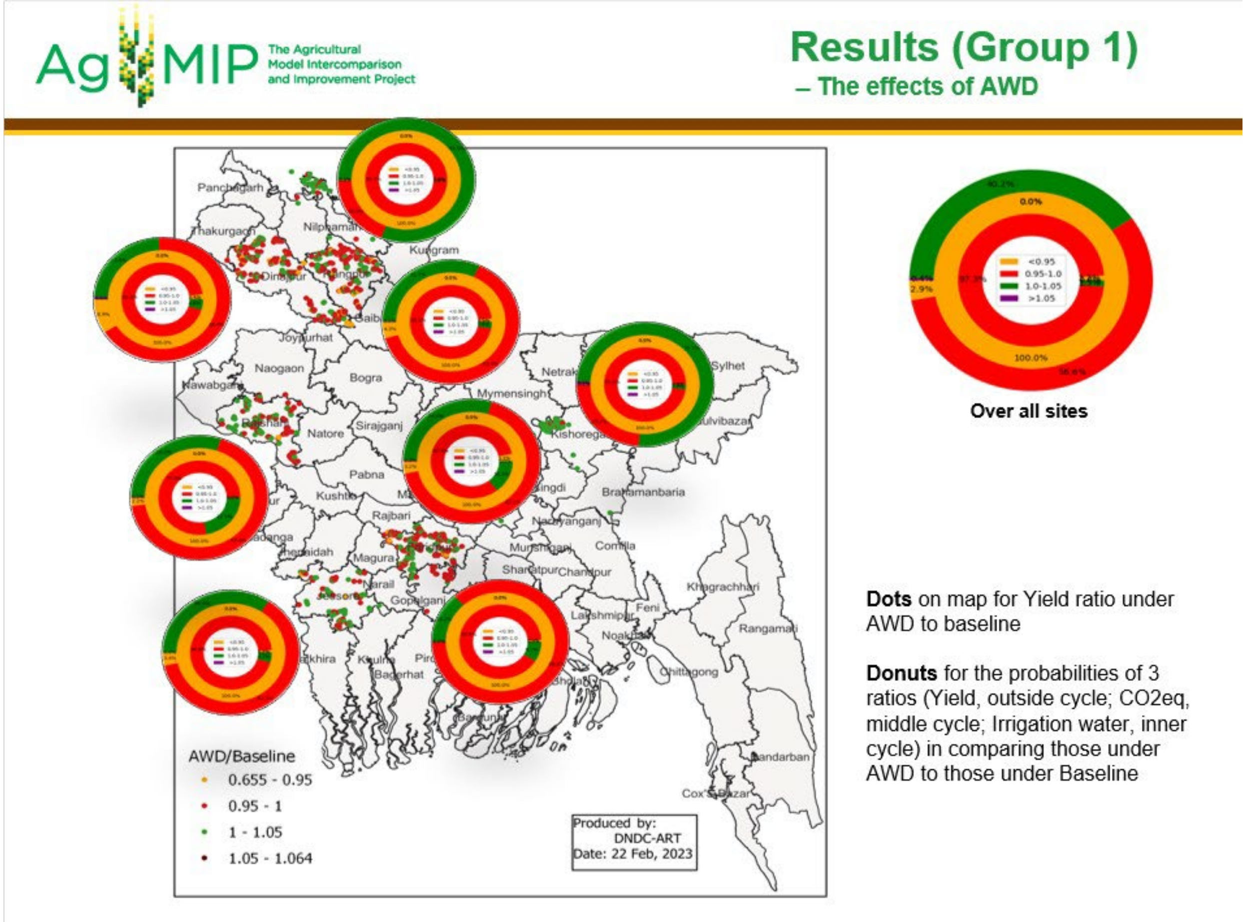


Over all sites

Dots on map for Yield ratio under future climate to the current climate

Donuts for the probabilities of 3 ratios (Yield, outside cycle; CO2eq, middle cycle; Irrigation water, inner cycle) in comparing those under future climate to those under current climate

Climate change would decrease grain yields by 1 to 7% in districts Rangpur, Dinaipur, and Rajshahi, but the yields in other districts changed insignificantly. Significant increases in CO_2 and CH_4 by up to 40%, but decreases on N_2O emission up to 7%. However, 10 to 20% increases in CO_2eq at all districts.



Results (Group 1)

– The effects of AWD

Dots on map for Yield ratio under AWD to baseline

Donuts for the probabilities of 3 ratios (Yield, outside cycle; CO2eq, middle cycle; Irrigation water, inner cycle) in comparing those under AWD to those under Baseline

At the district level, the application of AWD did not remarkably change the grain yield but showed significant reductions in GHG emissions, particularly about a 50% decrease in the yield-emission indices The CO2eq decreased by more than 10% at all sites.

In conclusion Dr. Apurba said that climate change will impact yield and soil fertility, as well as increase GHG emissions if the crop management practice is not changed. AWD showed minor yield change (about 90% of sites within ± with 5% yield changes). AWD could significantly reduce CH4 emission and global warming potential of GHG emissions in all field sites under both current and future climatic conditions. One type of AWD won't be suitable for all fields, it is worth developing site-specific AWD techniques. On the other hand, SRI management increased yield, soil carbon sequestration, and also GHG emission because of the large increases in organic fertilizer application. The SRI could be optimized based on the local biophysical conditions and practical feasibility for co-benefits of yield and GHG emission.

The outcomes from this crop modeling team are unsatisfactory in terms of advantages, trade-offs, and stability of yields environmental metrics like soil organic carbon sequestration over a period of 30 years in both the historical climate and two future climates.
Presentation link:

After Dr. Apubo's presentation, Dr. Jiban Krishna Biswas asked a quick question to Dr. Apurbo, saying that two of BRRI scientists have their PhD on SRI and two published in the Field Crops journal and he has gone through a lot of papers also BRRI result says it has no impact on yield contribution issue. He has seen an article where the author concluded SRI as a myth or in reality something like that also a controversial topic so why did you consider SRI in this simulation study where BRRI is not much interested on doing research? He added "in fact the original work of the Madagascar technique suggested SRI is good for one of the poorest soil in the world and the seedling age should be seven days old and in one square meter there should be only four seedings in fact that system will not work in our system what you are we are doing here may be the modified SRI or something like that this is nothing different from our BRRI developed system. He suggested not to use that word SRI. Even AWD, it's nothing but the system basically developed at BRRI in the 1980s, what is followed by IRRI by Dr. T.P. Tuong. Therefore, you should recognize these systems as BRRI developed systems first and also this is one of the most controversial agronomic issues so maybe what you have done it's okay. He suggested not to proceed further with this SRI technology.

Dr. Timothy Krupnik supplemented by saying, "I'm also no stranger to SRI, and I have very mixed feelings about it. I worked on SRI for three years in Africa, not in Bangladesh. Still, it's not an appropriate system for many agroecologies within Bangladesh, especially considering the labor constraints and other associated issues. The data set BRAC provided came from a study implemented by BRAC and by Cornell University that has since been published by Christopher Barrett et al., a well-known Economist working globally. He's also done some of the early papers on SRI. Let me finish Barrett; as you will know from the literature review, some of the earlier studies of SRI in Madagascar as well as those studies that were done by Moser et al. under the direction of Barrett, indicated that there were a lot of problems with the system and that it had a lot of challenges. As we know, development organizations often like to grab on topics; they like to say we are doing climate-smart agriculture, site-specific nutrient management, system of rice intensification, and they want to say that we are doing many different things. Several years ago, the data set was available if you read the papers that were published by Barrett et. al., published their work in top economic journals their results are robust but the results in my humble opinion, they do not test the effect of SRI they test the impact of training farmers on principles of good agronomic management so as exactly as you say these principles are principles of good agronomic management they are not necessarily principles of SRI when you looked at the presentation that Dr. Apurbo provided essentially the main differences in crop management that were observed by Farmers that had been trained to do SRI were AWD and increasing nutrient management there was not a substantial observation of Farmers making use of certainly single seedlings of younger seedlings or of modifying plant's geometry and spacing and plant populations which are other supposed principles of SRI so in reality what Farmers did is like if this is what SRI is meant to be in reality what BRAC achieved Farmers doing was very different and so where I would agree with you Dr Biswas is that the principles of what they did are much closer to good agronomic management principles and much further away from what SRI is in its ideal state and that's what we see in many countries where SRI is promoted that farmers apply only a few of the principles but rarely all of the principles and they apply very rarely all of their principles because they're challenging to implement and they're not always necessarily better than all of the other work so the work that Dr Latif did and teams many years ago in what 20 2005-6 no six five six five six and others that were done the those results hold still very valid right when you compare the whole set of practices Some Things Fall apart but I don't think anyone in this room would argue that in the right Landscapes alternate wetting and drying is a good thing that in principle where farmers can afford labor for access to organic matter that applying more organic matter is not a good thing so these principles hold true. Arguably in this analysis we had a lot of discussions within the team of whether we should actually call it SRI or not because again what Farmers did in the data set is very different from the ideal state of SRI they essentially attempted alternate wetting and drying and nutrient management but what you see nonetheless from the patterns that come and it actually supports your indication all this is a modeling study that was applied with an existing data set we didn't go and do a field study and ask farmers to try to practice SRI we used a data set that was available from Breck and we applied that data set and actually the results for these practices if you reflect upon the last point that Dr. Apurbo presented are actually quite challenging to SRI and they actually indicate that there are problems with SRI practice under future climate so it actually supports I think a lot of your concerns and it supports some of the early research that was done almost 20 years ago we're getting old on SRI but nonetheless the value in this work is still looking at what is the potential implication of alternate wetting and drying and of nutrient management in the future given these issues and given the availability of that prior data set. So your concern and this concern generally is noted. It's something that we should be communicating to BRAC, who again kindly provided the data set, and to Cornell University, which kindly provided the data sets that may be in the future looking at randomized control trials around the training of farmers and things should focus much more on the principles of good Agronomy rather than applying the term as a whole.

Dr. Siraj of IRRI supplemented as the name BRAC came repeatedly. He added that the data set is also from BRAC. He was also with BRAC, worked with the SRI practices in BRAC, and conducted massive demonstration trials of the SRI technology concept or the approach in the farmers' field. Dr. Tmothy has rightly mentioned that basically on the adoption of SRI technologies, providing the training, you know, the facilities to the farmers, but I want to add something because the BRAC approach on the SRI is repeatedly we are saying that SRI it is not a technology it's an approach or methodology and the methodology BRAC followed in the name of SRI we followed three six components of SRI first one is the single seedling definitely the second one is the younger seedling it's not the seven days old seedling what Dr. Jibon mentioned. In most of BRAC's experiments, it was 18 to 20 days old seedlings, and wider spacing is not 50 by 50 cm; it was only 20 to 25 cm plant-to-plant and line-to-line spacing. Another approach is the AWD, the AWD in a real sense; what is AWD developed from IRRI the T.P. Tuong that's a different thing. Also, the AWD referred by the presenter, Dr. Apurbo, mentioned five days of draining and seven days of drying, which differs from the AWD technology. Also, this technology that IRRI developed is based on the magic pipe, so you have to consider that issue, not only the drying and wetting. The fourth component was the mechanical weeding component, and the fifth, sixth, and sixth were the organic matter applications. But Dr. Apurba said that some farmers applied 10 tons of organic matter in the soil, which is very high in the real sense. Dr. Jibon talked about Professor Moazzem, but the advocator of SRI is Norman Uphoff, Senior Advisor for the SRI International Network and Resources Center (SRI-Rice), a program at Cornell University so when he demonstrated this SRI technologies in Madagascar especially, they showed that around 40 tons of organic matter were applied in their SRI fields. Hence, these are the real things that happen in the name of SRI, and BRAC also advocated the BRRI technologies. There are three treatments one is the SRI in the name of Sri, another is the BRRI technologist and is conventional, which means we name that as the farmer's practice, but Farmers do. We found a huge difference between the SRI versus Farmers' practices, but the difference between the BRRI recommended practices and the SRI is insignificant. That needs to be also noticed here it is not significant is these technologies are the concept it is nothing new, so if you compare all these individual components like the younger seedling, it is always good. There are a lot of experiments done in BRRI also that younger selling is good. Hence, this is the practice, so what SRI is actually, that's why Dr. Timothy also mentioned in his earlier speech in the morning session that some controversial issues will arise. Hence, this is one of the controversial issues raised here, but the BRAC paper is different—the technology demonstration of what BRAC actually has done. The data set you have taken is also different, so try to understand these things before you comment.

Economics Team:

Dr. Roberto Valdivia (Oregon State University)

Dr. Md. Rajibul Alam (Ministry of Public Administration)

The Economics Team is represented by Dr. Roberto Valdivia (Oregon State University) and Dr. Md. Rajibul Alam (Ministry of Public Administration). Dr. Md. Rajibul Alam, made the presentation for the

Economics Team. The goals of economic modelling are to assess the impacts of climate change on rice-based production systems, that is, to calculate gains and losses because of climate change. Determine the proportion of households vulnerable to climate change (i.e., at risk of losing because of climate change) and estimate the impacts on socio-economic and environmental outcomes associated with climate change (gains and losses). Another goal is to assess the main advantages and trade-offs of changing the rice management system. Specifically, to determine what would happen if the rice management is switched from the conventional system to an alternative management system and determine at which point the potential adoption rates for switching from conventional rice management system to alternative rice management systems. Also, estimate the economic benefits associated with the adoption of the alternative system(s) and evaluate the trade-offs and co-benefits between socio-economic (e.g., farm net returns) and environmental outcomes (GHG emissions) due to alternative rice management systems.

In this study for economic modelling, the TOA-MD (TradeOff Analysis for Multi-Dimensional Impact Assessment) Model was used, which is a unique simulation tool for a multi-dimensional impact assessment that uses a statistical description of a heterogeneous farm population to simulate the adoption and impacts of (a) New technology (e.g., new crop variety or change in crop management) (b) Change in environmental conditions (e.g., climate change), (c) Policy interventions such as Payments for Ecosystem Services (e.g., carbon sequestration). This tool is not a farm-level model. It models distributions of outcomes (e.g., net farm returns) of a population of farms. TOA-MD is designed to simulate experiments for a population of farms using a “base” production system (System 1) and an alternative System 2. It captures the socio-economic, biophysical and environmental heterogeneity, allowing to estimate potential adoption rates and associated outcomes for adopters, non-adopters and the whole population (or for gainers and losers in the case of climate change impacts).

Then he narrated the methodology, describing the data sources for each system, plot and farm-level economic data for rice production and for other crops grown on the farm, farm household characteristics and other social data. He shared some of the important findings of the economic group highlighting the following:

Impacts of climate change and Benefits of adaptation on economic outcomes; contribution of crop returns to total farm net returns; tradeoffs and co-benefits of economic vs environmental outcomes; and economic analysis –CIMMYT data on per ha basis.

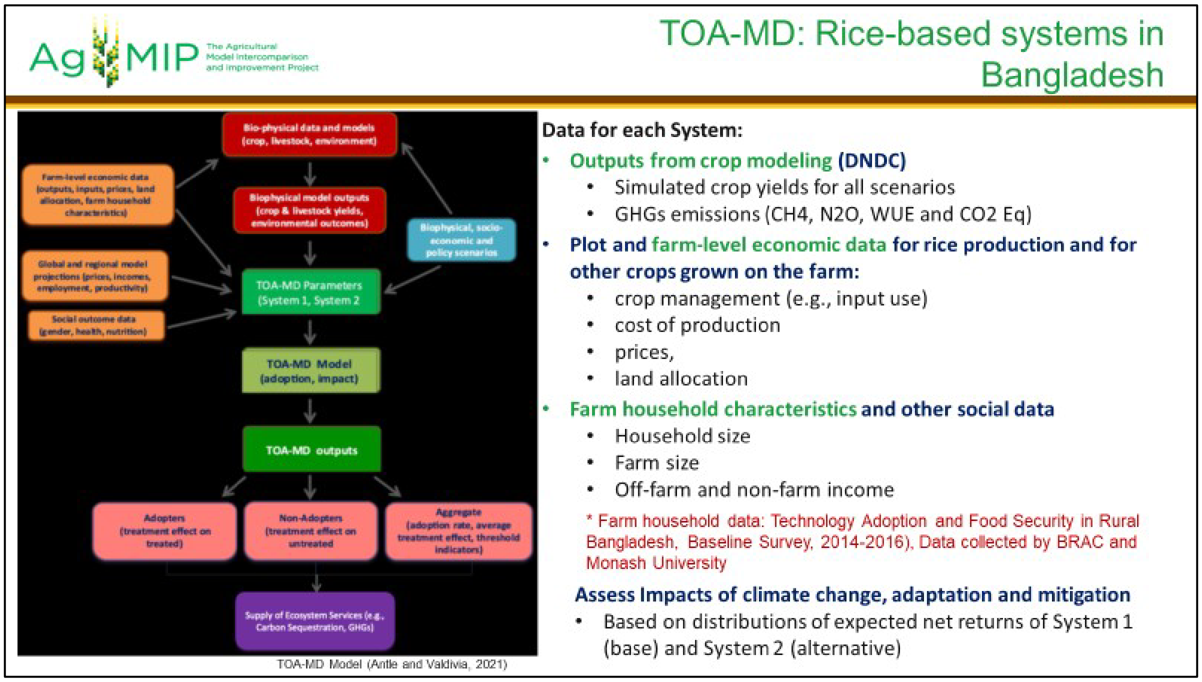
Finally, he concluded his presentation by highlighting the Tradeoffs between socio-economic and environmental outcomes:

Future hot conditions (climate XP) reduce farm net returns and increase poverty rates in most sites (there are some that gain from CC) and increase GHG emissions. However, a less warm future climate may have small positive impacts on farm income.

Adoption of Conventional AWD or SRI-AWD under current or future climate show strong reductions in GHG emissions like methane and CO2eq. N2O emissions vary across sites and farm types (small vs large). Water requirements for irrigation are reduced.

Both Conventional AWD and SRI-AWD show potential co-benefits in reducing GHG emissions and increasing income and reducing poverty rates in the region (win-win outcomes). SRI shows the larger benefits. These two systems are likely to be more resilient to CC compared to conventional continuous flood systems.

However, in practice, there are factors limit the full benefits of AWD and SRI systems (e.g., access and control to water).



TOA-MD: Rice-based systems in Bangladesh

TOA-MD Model (Antle and Valdivia, 2021)

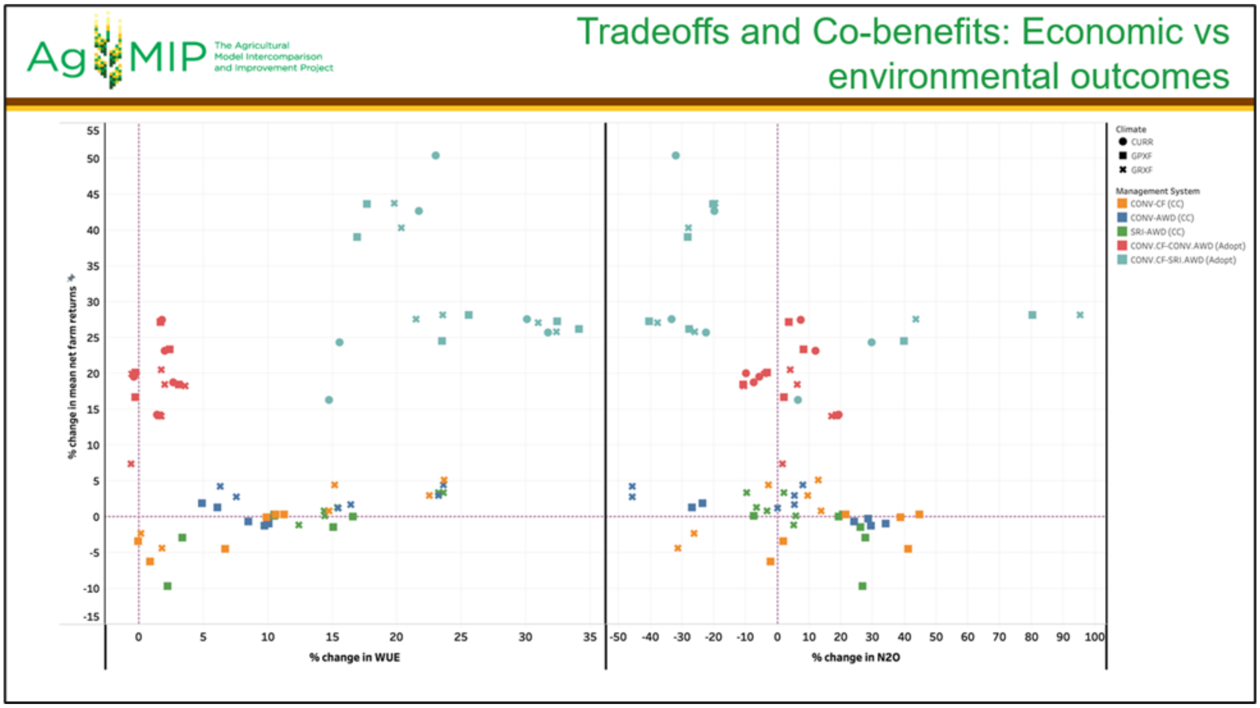
Data for each System:

- **Outputs from crop modeling (DNDC)**
  - Simulated crop yields for all scenarios
  - GHGs emissions (CH4, N2O, WUE and CO2 Eq)
- **Plot and farm-level economic data for rice production and for other crops grown on the farm:**
  - crop management (e.g., input use)
  - cost of production
  - prices,
  - land allocation
- **Farm household characteristics and other social data**
  - Household size
  - Farm size
  - Off-farm and non-farm income

* Farm household data: Technology Adoption and Food Security in Rural Bangladesh, Baseline Survey, 2014-2016), Data collected by BRAC and Monash University

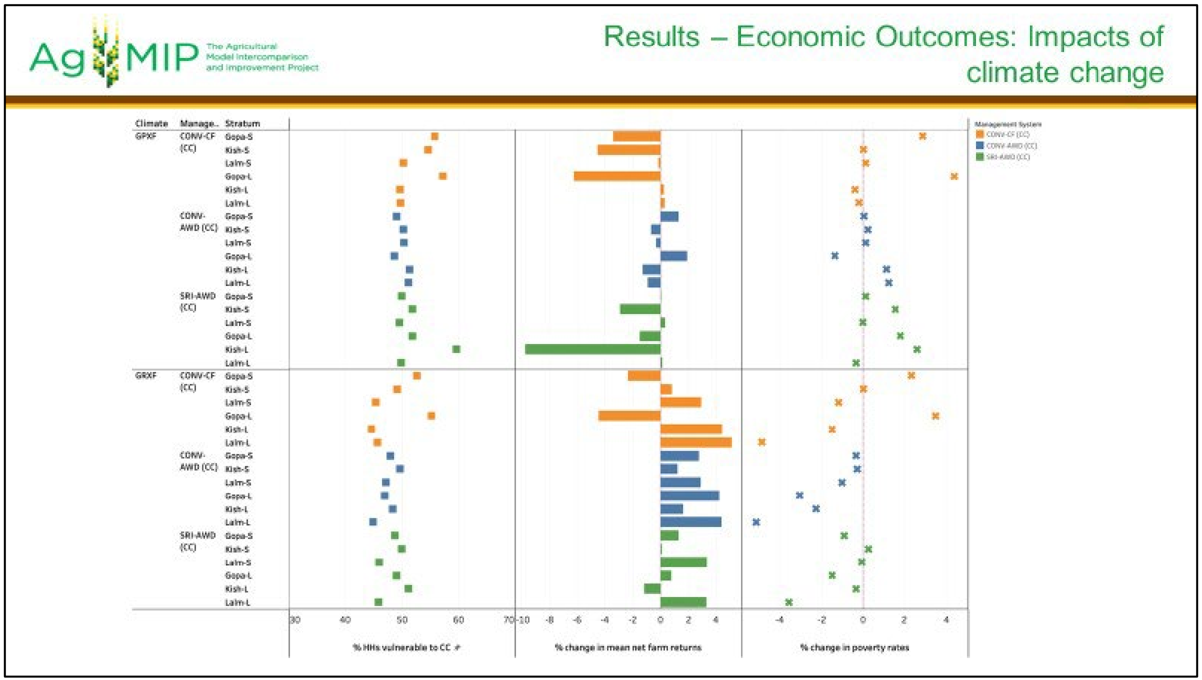
Assess Impacts of climate change, adaptation and mitigation

- Based on distributions of expected net returns of System 1 (base) and System 2 (alternative)

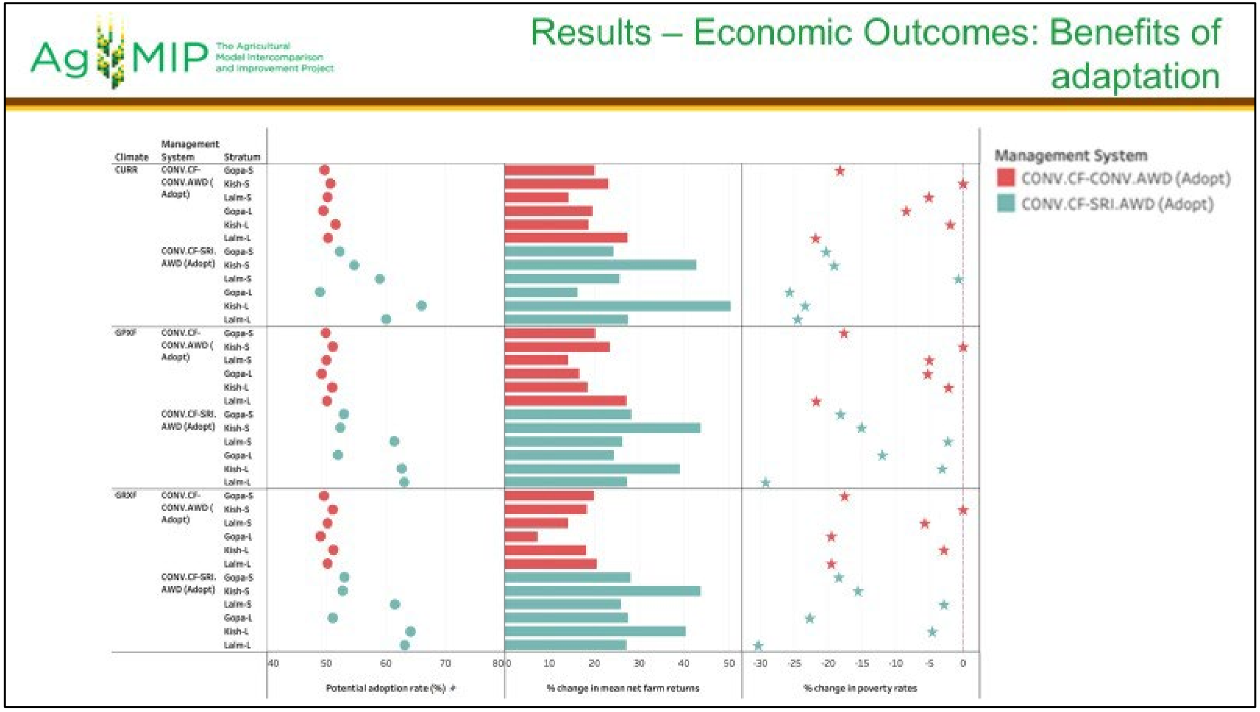


Tradeoffs and Co-benefits: Economic vs environmental outcomes

Figure . Tradeoffs between socio-economic and environmental outcomes



Results – Economic Outcomes: Impacts of climate change

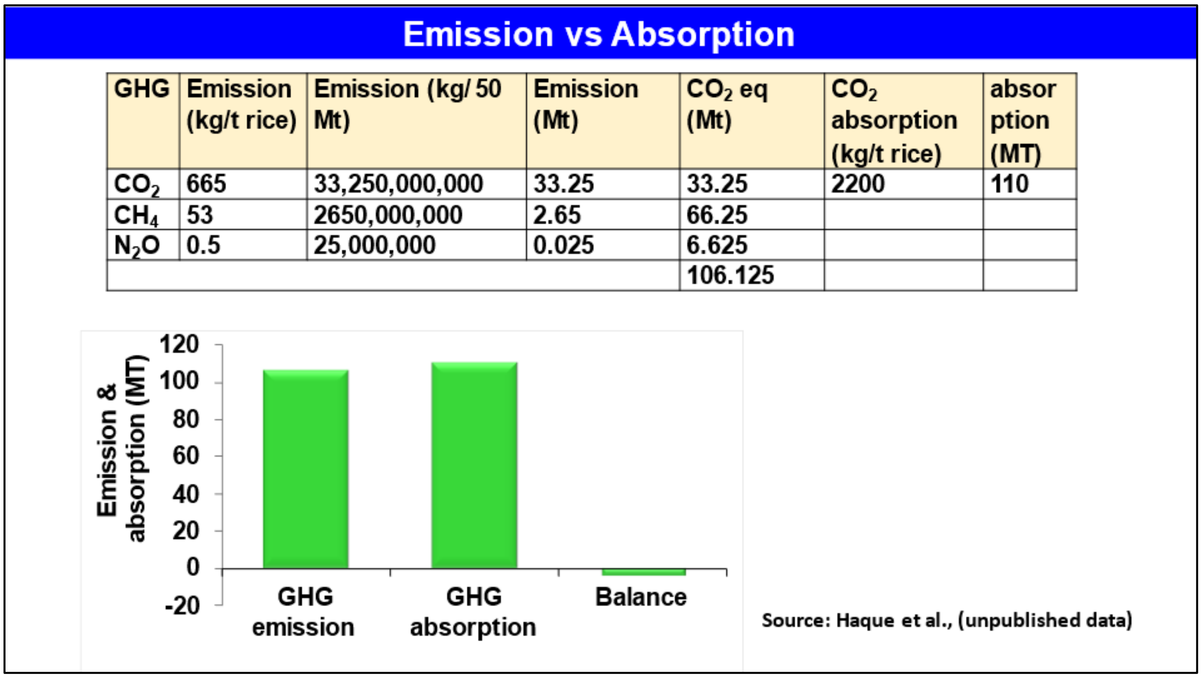


Results – Economic Outcomes: Benefits of adaptation

Guest Presentation:

Dr. S.M. Mofijul Islam, Senior Scientific Officer, BRRI

Dr. S.M. Mofijul Islam, Senior Scientific Officer, Soil Science Division of the Bangladesh Rice Research Institute (BRRI) made a guest presentation titled Alternate Wetting and Drying and Carbon Absorption by Rice Plant. He informed the audience that this presentation does not belong to MAC-B project activities this is the activities of Soil Science Division of BRRI with direct field measurement data. He started by saying that some national and international media are attempting to attribute massive methane emissions to rice cultivation. Last year, a prominent international media outlet published a report on methane emissions in Bangladesh, claiming that Bangladesh is a major source of methane emissions and identifying three sources: rice fields, gas fields, and landfills. But the big question is that these types of sources are available in our neighboring countries, such as India, China, and Pakistan, and they have personally identified Bangladesh, so now is the time to address this issue in case our food security be compromised. Food security is directly or indirectly correlated with rice security; Bangladesh is self-sufficient in rice; however, we face multiple biotic and abiotic challenges, such as an increase in climate sensitivity and the occurrence of natural disasters. For this reason, we must produce more rice on less land in order to feed the expanding population. Nonetheless, rice cultivation has been identified as a significant anthropogenic source of greenhouse gas emissions. Likewise, rice cultivation consumes a comparable quantity of carbon dioxide, and the balance is nearly zero or occasionally positive or negative.



Emission vs Absorption

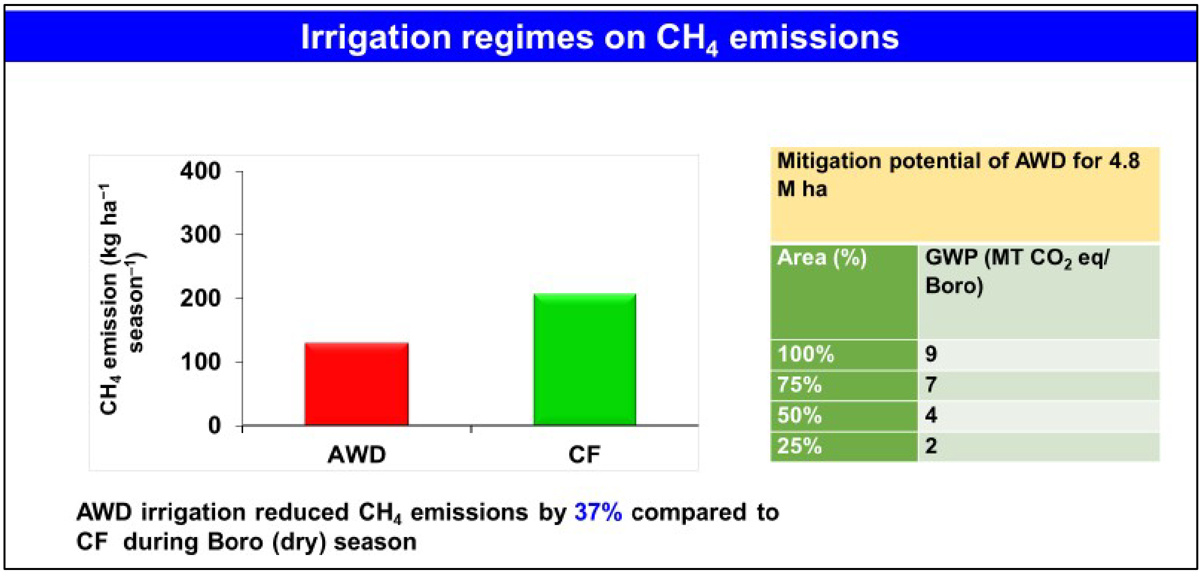
GHG	Emission (kg/t rice)	Emission (kg/ 50 Mt)	Emission (Mt)	CO_2 eq (Mt)	CO_2 absorption (kg/t rice)	absorption (MT)
CO_2	665	33,250,000,000	33.25	33.25	2200	110
CH_4	53	2650,000,000	2.65	66.25		
N_2O	0.5	25,000,000	0.025	6.625		
				106.125		

Source: Haque et al., (unpublished data)

Although we have some popular technologies but we could not get any carbon credit by using this technology wetting and drying and urea deep placement. So we have to raise this issue in the global climate sense from now the some features of major greenhouse gases everybody knows the issue so it is better to skip this presentation this slide

He then explained why AWD is so much popular in South Asian countries. because it improves water use efficiency and saves 25 to 30 fuel cost. It does not decrease rice yield rather it increases. AWD increases fertilizer use efficiency particularly sulfur and zinc. It improves rice root morphology and physiology, it enhances soil uerase activity and increases oxygen concentration in the soil also increase nitrogen content in the rhizosphere soil because of maintaining some aerobic spell. Finally, it is carbon friendly technology due to significantly reduce global warming potential compared to conventional practice.

Using closed gas chamber technique, Gas sample was collected using a 50 ml air-tight syringe with a 3-way stop cock once a week at 15 min intervals (0,15 and 30 min). Gas concentration was measured using GC Analyzer (Shimadzu GC-2014, Japan). Emission rates was determined from the slope of the linear regression curves of CH4 and N2O concentration against the chamber closer time and expressed as mg m-2 d-1. Then he talked about effect irrigation regime on methane emission, AWD irrigation significantly reduced cumulative methane emission by 37 percent compared to continuous flooding irrigation. If AWD technology adopted in 4.8 Mha in boro rice area about 9 Mt carbon dioxide equivalent could be mitigated if we extrapolate this technology at least in 50% boro area mitigate about 4 Mt carbon dioxide equivalent GHG emission during season boro season.



Irrigation regimes on CH_4 emissions

Mitigation potential of AWD for 4.8 M ha	
Area (%)	GWP (MT CO_2 eq/ Boro)
100%	9
75%	7
50%	4
25%	2

AWD irrigation reduced CH_4 emissions by 37% compared to CF during Boro (dry) season

To conclude his deliberation, he said that AWD practice showed comparable rice yield with CF irrigation under safe AWD principle and AWD irrigation reduced about 37% GWP over CF condition. Rice cultivation consumes more CO2 than is emitted. Therefore, rice cultivation does not pollute rather it clean the atmosphere.

Stakeholder engagement and discussion:

With the permission of the chairperson, Dr. Jatish Biswas actually, I like to talk regarding the presentation of Dr. Apurbo Chaki. They are using the DNDC model, and they have calibrated and validated the result, but what I have seen is that the calibration result was almost around 15 percent error, so I think they should recalibrate the model before validation because you know the DNDC model is very much sensitive to organic carbon and soil texture so please take care of those issues; otherwise it will be a misleading one. Dr. Apurbo thanked Dr. Jatish for his question and replied by saying, "I think the normalized RMS, if you see the survey data, there is high variability in the grain yield, as well the normalized RMS for the calibration dataset was around 15 percent considering the high volume of data we believe that the normalized RMS of 15 percent is within the acceptable range for any model calibration and validation for grain yield to go for the scenario analysis. The data is not like the experimental data sets, so there is very high variability in soil texture, management, and estimated grain yield.

Dr. Jatish said, "So I think 15 % of a normalized RMS, we believe that's the acceptable range, but to go for the scenario analysis, that's okay what I wanted to mean to meet DNDC model to organic matter content, yes and texture they look especially the clay content so you can divide the country based on soil texture it will give more robust result than as a whole. Dr. Apurba thanked Dr. Jatish and agreed to consider his suggestions.

Dr. Asaduzzaman, who could not join the meeting physically, asked a relevant question based upon the last two presentations directed to Dr. Roberto, in particular, to potentially respond to the question because his question is about the interface of modeling and policy and markets and what these things mean for these systems. so the question that Dr. Asad also asked why AWD which is known for so many years has not been accepted by farmers whereas the answer lies in the nature of water markets in which no matter what water is applied, the farmer has to pay the same price by water area which was discussed in the last presentation and is a very valid point. Hence, he asks where the incentive is he also asked SRI is not practical as it involves co-management by farmers as a group. Dr. Timthy added, "I assume that he's assuming that this is around the management of seed beds or of organic matter management and that group management is hardly practical in the context of Bangladesh, so the suggestion that he brought is that modeling should include water market characteristics or perhaps assumptions around cooperative management by communities and he asks if this has been done or could be done in economic modeling.

Dr. Roberto gave it a short clue to answer the many aspects there, and he said, "I totally agree. I mean, sometimes, even though we try to represent reality with our models, that was a comment at the beginning. I think you said the team right simulation service simulations and depending what you enter as input decides what you what we get as outputs; the approach that we follow will it's basically trying to link climate, crop in some cases livestock modeling and economics as an integrated approach to assess what would happen with farming systems if they have let's say a shock it could be climate change could be a new technology a new probability and of course there are things that we cannot model like in the crop models have some issues for example incorporating pests and diseases to predict yields so there is some bias there likewise, in economic modeling there are also teams that we cannot model like human behavior although there is now a exciting branch of the economics looking at behavioral economics and how behavior may influence adoption for example but there are things that we cannot model or incorporate in a model approach like the ones we are doing so aspects for example as whether farmers have access or control to water right it's things that are difficult to model we can make assumptions and in terms of what does that represent and how farmers use water or irrigations whether they have access to irrigation things like that but other aspects in terms of factors that may limit or what we call barriers to adoption might be difficult to incorporate in some cases so the way that we like to interpret this kind of results is what we are showing is a potential adoption rate where we may not include all the barriers or limitations for adoption but this approach is one of the few that exists that predicts a

potential adoption rate which is based on expected returns so basically we have a base system that produces expected returns to farmers so farmer say with my current system let's say I earn 100 per hectare and then with a new system the Spectator tool says you are going to get 120 dollars so farmers make that rational choice that okay I'm gonna be better off with that new system so we adopt and that's the process that we follow to estimate a potential adoption rate on a population of farms but I agree there are some factors that limit that that adoption and in some cases we can do other types of analysis like a market analysis in terms of water right in some case we've done a life cycle analysis where we go further in terms looking at the value chain to see how things improve how what are the feedbacks in terms of prices and to create an incentive for farmers but the basic approach is that looking at those distributions of expected returns in system one we call system one and system two and not only that but this approach also allow us to look at what are the consequences of that adoption process meaning we have in a population of farms now we have adopters and what are the potential outcomes for each one of those meaning those may emit more greenhouse gases those systems system one and those the system two may emit less greenhouse gases and then in the aggregate these will be different as well so we can model that with this approach and I think this is what we can provide to to policy makers to see. You have this management system or you have this new technology this needs new crop variety and this is the potential adoption rate and these are the potential sequences or impacts and then we can identify; but what are the barriers for adoption and then that's where we can put investments on how we change that how we remove those barriers with the modeling we can do many other things like put subsidies put taxes look at sensitivities in terms of investments that farmers would have to do those kind of things but those outputs should be helpful to decision makers to look at so this new technology or this new management or these new crop variety shows that a potential for benefits or to benefit farmers, a population of farmers so let's identify what are the next steps what are the barriers for adoption and invest on those that's the kind of information that we want to provide and likewise with climate change we know that there will be gainers and losers but then trying to identify adaptation strategies for decision makers to invest on or create the incentives like markets for example for farmers to adopt those adaptation strategies so that's the kind of information that we want to provide with this this project. I wonder if that answers the question.

Dr. Asad thanked Dr. Roberto for trying to explain, in broad terms, I do not contest much of the scientific evidence for or against AWD or SRI or the various types of organic management and all these kinds of things; I do not contest that. Still, after all, when we present the evidence to a policymaker, he would be asking. Hence, what shall I do? The answer lies very simply, a popular idea, but AWD or SRI in the context of Bangladesh he will those who know the water market here; the irrigation water market is basically private water market with shallow tubewells as the main equipment, and the payment is by area; you provide me water for the whole season-- I pay you this amount for so much of area no matter what. So I have no incentive to conserve water because I have already paid the water seller. So the best solution that can be if you want to minimize or lower water use through AWD, of course, training and demonstration and all of these you will have to be there, no doubt about it and when we talk to the Upazila Agriculture Officer (field level extension) or even some of the farmers some they do know about AWD but the next question is so why shall we have to pay the same amount at the end of the season. Hence, what do they do are they don't bother about it? Now if we tell them that okay, you have to pay, say some less money if you want to lower your water use, okay he agreed but the water seller would not agree because then his income ffalls so how can we compensate, I mean there are instances in Latin America and some other places in China and also in some places in India where there are things called payment for ecosystem services, if you conserve water that's a kind of ecosystem service and under this climate change scenario whatever various SSPs and RCPs whichever you look at it conserving water is a major issue because that becomes problematic in most places so if you do that if you compensate the water sellar in some way or other why you would do that had to be found out and though the name seems exotic payment for ecosystem services in Bangladesh we do actually practice that in case of fishery you see in case of Hilsa fishry and now the week or about two weeks all the fishermen would refrain from catching Hilsa fish and for that they are paid in kind so much of water so much of edible oil and so much of other things. However, there are management problems with that, but in principle, that is already accepted and practiced in Bangladesh, so something like this will have to be done in the case of AWD. SRI is a different ball game altogether because it's not simply seedbed but for water management, the levels of the various fields will have to be at the same level or things like that. So that's why SRI becomes more difficult in the farming community, but AWD certainly can be done if you can provide the proper incentive, and that's what I am telling you about. If we provide the incentive, what would be the result? If we don't provide the incentive, what would be the result? If we can put that up to the policymakers, they would be interested in it.

Dr. Roberto agreed completely with what Dr. Asad said. In fact, when he visited Bangladesh in September last year, Dr. Ghulam Hussain took him to visit some farms and talked to one farmer that had tried different managements, including SRI and AWD. He said, for example, concerning AWD he would like to have AWD, but the problem is that he didn't have control over water. So the water is one of the issues. Dr. Roberto said, but for example, Dr. Hussain told me that there is a project that they're working on ways to improve these conditions in some parts of Bangladesh in terms of the market water and but that's the kind of conversation that we need to have, and that's where these model results hopefully will help to see benefits and trade-offs between different types of management and not just rice there are other crops. In the slide that Rajibul presented one of the first slides showed that for most of these farms, rice contributes to farm income between 35 in some cases, it's a little bit more but in average it's 35 to 40 percent, but then they have wheat, pulses, maize other crops. So we also need to be aware of that, and regarding ecosystem services, that's also been done in some places. By the way, our modeling approach, our economic model, can estimate the potential also the potential economics of ecosystem services in a region. Hence, I agree with your statement. Thank you, anybody, in-house.

Dr. Faruque made some comments on all of the presentations adding, "I can realize that AWD is the solution for methane emission or GHG emission; Dr. Mofijul Islam has already shown in his presentation that in the AWD system, there are some problems that mean there is some barrier due to that this type of technology not accepted at farmers level so far. Although I have less knowledge of rice farming regarding methane emission, rice growth stages might have some influence on methane emission; maybe at the booting or flowering stages, rice emits higher methane. AWD follows throughout the growth stages of the crop, so if there is some data on the methane emission by the growth stage of rice, then that would be helpful for us as researchers. Besides, varietal selection might have some genetic potential, and the variety those are less responsible for methane emission. In the morning session, Dr. Khalequzzaman mentioned some technology that may be in the pipeline of BRRI. They are working on reducing air and aerenchyma cells in rice plants, so this type of attempt may be helpful for future respiratory development, which will be fit for the future climates and reduce methane emission so the AWD system is already established through all of the presentations that it is a promising technology so as a research organization how could BRRI can take the initiative to resolve those barriers like pricing of the irrigation water or like that so in that: cases may be BRRI may take initiative to the responsible authority or resolve these issues.

Dr. Sohela Akhter thanked the MAC-B team for taking the time demanding-project and thanked all the presenters for the valuable project findings. Then she made some suggestions; "as I understand the project will primarily focus on mitigation and adaptation for benefits of sustainable boro rice management, I would suggest a few more simulation options to study in the future, maybe in the next phase of the project or the feature project like considering simulating cropping systems that are boro - transplanted aman or wheat – mung bean- transplanted aman rice or mustard-boro-t. aman rice, rather than focusing on a single rice crop as we cultivate several cereal crops for food and nutrition security, consider intensifying the rice-based system that will ensure nutrition security and be good for soil health, like the rice pulse system. As the simulation modeling requires advanced knowledge and skill, I would appreciate it if the project also focuses on capacity building of Bangladeshi scientists through training Ph.D. post-doc etc.

Professor Adbul Kader, National Senior Lead Agronomist, FAO, thanked all the presenters for their nice presentation and congratulated them for their wonderful work; at the same time, He thanked the organizer for organizing this wonderful event. He then added that "We understand that under these current climate change context, this workshop is concerned about the issues which are the result of greenhouse gas emission, and we are concerned about our cropping systems and how these cropping systems or farming systems are contributing to GHG emission and particularly with this project what I understood in this modeling trial we would like to make some future initiative so that we can take proper agronomic management practices for our crops by having these core benefits of yield increase, maybe water use efficiency, fertilizer use efficiency, and also at the same time very notably by minimizing the greenhouse gas emission.

I have a few very quick questions. So first one is whether you considered not the amount of precipitation but the pattern of the precipitation, like the changes like erratic rainfall that we are experiencing in Bangladesh, and this is very critical impacting agricultural systems, so I would request that you can consider this issue. The second question is to Dr. Apurbo and also with this socio-economic study in both the cases, you have shown that this alternate AWD and also SRI you compared all the time with continuous flooding. I am wondering what you mean by continuous flooding and do we have continuous flooding in the farmers' fields; to my understanding probably, this is not the practice in the farmer's fields, at least in the majority of the fields, except in low-lying areas you get continuous flooding but in the other areas like you consider during February, March, and April when you don't have any rainfall people even they cry for irrigation water. It would be better if you considered the farmer's practice and as far as I know the farmers practice during the boro season in many areas this is not continuous flooding so when you compare this one, please consider that thing and another point is like in some cases you have shown that in case of methane and nitrous oxide emission, there is huge variability among the sides so did you look at what are the reasons because of this high variability among this, is it only because of the treatments you used or there are some other factors like agroecological factors or soil factors which can influence this one. So this is my concern about this study otherwise this is wonderful.

He thanked Dr. Mofijul Islam for his nice work and presentation and congratulated him for his wonderful publications. He added, "You have shown that with this AWD technology, we can tremendously minimize the greenhouse gas emission in rice; that is a very good answer for the people talking about the negative effect of rice cultivation in greenhouse gas emission. Then he asked, did you ever compare GHG emission in the case of rice to other crops so that one may argue that it's not only rice; rice is much better than some other crops?

Finally, he said we heard about many technologies, and these are very effective in terms of yield benefit in terms of water efficiency and some other things; maybe the GHG emission, but now we need to think about how to get these technologies into the field so that farmers adopt it and they accept it then only we will get those benefits.

Dr. Ashraf, Professor of Animal Nutrition at Veterinary and Animal Science University and a member of the GRA who came from New Zealand last two years back, commented that the MAC-B project is a flagship project of GRA; we know that there are a lot of technologies which can reduce the greenhouse gas emission, but the problem is that the policy level implementation. So I would like to request all of the Authority regarding this project that we need to collaborate with the policy level people and make the rules and regulations as an Act for the farmer's level; otherwise, it is very difficult to implement this type of technology in the field level, and it is it would be very difficult to minimize the methane or greenhouse gas emission. I request the Authority that you collaborate with the policy level people and DAE or other stakeholders.

Synthesis, reflections and next steps

The Session chair requested Dr. Timothy Krupnik to reflect on the roundtable and the way forward. Dr. Timothy started by saying, "Well, I think that's a lot to respond to all very good comments; it's impossible to address the depths and breadth of comments the last two colleagues provided. Although I think particularly the last point is valid and around the importance of actually fostering approaches that move this work into actual use, perhaps through collaborations with extension or policy and so on, which is duly noted. This MAC- B project was essentially a small pilot project, and this work was done over, I think, in practice less than 15 months, 12 months, give or take, intensively again with existing rice-based data sets that we had from the field; hence the focus on rice. The points that were raised with respect to modeling cropping systems by two colleagues I think are very valid and very important; we did not address that though in this preliminary work, but it is important to note that yes, indeed, if you want to adapt and save water and if you're going to mitigate against greenhouse gas emissions then potentially looking at options to shift into alternative crops and away from rice may be something that is worth investigating in further studies and has a solid justification and approach notwithstanding that must also be balanced with respect to the very valid preoccupation that we have in Bangladesh of maintaining national food security and stocks of rice that is very important politically and needs to be recognized.

A few comments were made with respect to the perhaps unusual climatic conditions that we're experiencing right now, and I've also noticed this over the last few years; what the work has done, however, has focused on current conditions based upon existing models that simulate current conditions and also futuristic conditions looking very far into the future. Although these issues concerning intense precipitation events are important and worth addressing, that is again duly noted. I want to make just one last comment, though, which I think is an important observation; again, I commented earlier that I've never met a farmer who says I am an AWD farmer, nor have I met a farmer who says I am a urea deep placement farmer or an SRI farmer or any other of the categories that we as researchers often place on farmers. I do think that in a number of locations in Bangladesh we have AWD as being applied but not because farmers want it but because of logistic problems and failures in how water is distributed to farmers and when they are able to access water that however is not alternate it's not what I guess I should say is scientific alternate wetting and drying as has been researched by colleagues at BRRI and that a range of different international institutes that approach is around the strategic reduction of water to the crop at particular times when rice is phenologically less susceptible to water stress and that means primarily during the vegetative stage and before booting and that is it's a precision approach to water management and not necessarily a reflection of just overall drought but having said that in the model comparisons, we did choose to go with an assumption around continuous flooding which is at least from a farmer's perspective. I think, in many cases, what Boro farmers would prefer to have but your point around the feasibility of that in practice and the problems around water distribution. I think are very noted and important but I do want to distinguish that importantly and I think our colleagues from BRRI will agree that a lack of water does not mean alternate wetting and drying these are two different things; alternate wedding and drying is a well-managed system of water and irrigation frequency but not drought and not a lack of water. So I've again said more than I promised that I would, and I also recognize that it's Ramadan and we're 30 minutes over schedule, so I want to move us towards completion. I hope that this was useful and certainly, by the debate and the discussions that we've had, we've managed to do one thing that's important in science, and that is to stimulate your critiques and your comments and your suggestions and to get all of the participants to think and to give a range of important suggestions around what could be done next.

I think we've also been successful in indicating that, generally, there's an interest in seeing work like this continue and this is something we will very happily take back to our colleagues at ACIAR and suggest for potential work moving into additional projects and around again looking at a cropping systems-based approach and not just a rice-based approach that also needs to be linked very well to policy is what will we do next the team of scientists that were involved in this work this again these are preliminary results we are writing it up currently into a report that will be made public after ACIAR's approval that report I hope will also find its way in streamline form into the peer-reviewed literature but also will be distributed to all of you and to colleagues that are interested in seeing the results of this work communicated in simple form and easy to understand formats for policymakers. Moving us to a conclusion, I want to thank everybody for staying and giving your comments and heartfelt debate. Science only moves forward if we disagree with each other and we challenge each other around the data that are shown. It's always positive when we have discussions such as this and modeling in particular because it is about scenarios really, the importance of modeling is to stimulate discussion. I think we've been successful in stimulating discussion and debate here and we'll take that in terms of the next steps and bring this information back to ACIAR. I'm assuming Dr. Pratibha is still listening and that there is an interest in this work I'd like to thank again our colleagues at BRRI for hosting this today and I'd like to thank also our colleagues at BARI and at BRRI and that have generally been involved in this work I'd like to thank Dr. Apurbo and Rajibul for their work in engaging and I'd like to also thank Sonali and Roberto and Eric and others who are with Columbia University with NASA with NYU and with Oregon State University also for engaging in this work with that I think we can say we will close and keep you informed if there are next steps and I will pass for the formal final closing to our colleagues from BRRI.

Wrap-Up and Closing by the Session Chair

Dr. Khalequzzaman, as the session chairperson, thanked all the presenters who presented virtually and physically here and those who attended the roundtable. He added, "Actually, they all made various informative presentations and mostly the model-based result which needs to be validated, and they rightly mentioned *that these are simulation outputs of these models. Therefore, we need to find out what is the simulation study about and see the confidence level of the predictions. It should be more than 95 percent;* this model is perfect or can be applied in future implications. The other thing that Dr. Kader said about precipitation sometimes increasing and warmer and cooler that pattern is fine, but for the most part, the precipitation also increases; that's my concern how it's predicted these; I don't know that's whether models are defective or need to be checked or whether it really predicted these things and other things the agriculture sector. Dr. Timothy said 21.5 percent contribution comes from the agriculture sector, but our findings at BRRI say it is 14 percent; it's almost all right for rice. The most important thing in our case is food security; we do not want to lose in any situation, and we don't want our country to face any food insecurity. We must ensure output security anyway; that's why whatever we think are applying, we must also think about rice security, not only food security alone, but our rice security.

If rice security becomes wrong, then our political security also be unstable, so we must think about the security of rice. In this Workshop we discussed many mitigation options, including AWD, which is a nice technology; everybody knows these things, but the reality is that Dr. Mofijul mentioned some social problems and some adaptation problems. There are other technology like urea deep placement also that reduce greenhouse gas emissions and other things also; we look through the advancements like low water consuming variety as well as the low carbon dioxide emitting and high temperature tolerant varieties we are trying to develop, we are searching this germplasm for these things, and we got some of those. Develop a variety with reduced aerenchyma that can mitigate a large amount of CH_4 emissions. We hope to find a suitable variety to mitigate the GHG emission, developing high-yielding varieties with these special characteristics, and anyway, I should conclude here.

Finally, the results shared here are very interesting and impressive, but it needs to convince the main policymakers so that they support these issues. In my sense, this meeting is not enough to find the solution to everything, and we need further long-term commitment with higher policymakers. Finally, I should thank the organizers for selecting BRRI as the venue and the participant from home and abroad, CIMMYT, Columbia University, New York University, Oregon State University and other partner organizations, for sharing your knowledge and experience. Thank you very much, everybody, for your patience in hearing. I should say this is the end of this Roundtable meeting. Thank you very much.

List of Participants

MAC-B Stakeholder Roundtable Workshop

Wednesday, April 05, 2023
Meeting Room, Training Complex (First Floor)
Bangladesh Rice Research Institute, Joydebpur, Gazipur, Bangladesh

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Abbreviations

ACIAR		Australian Center for International Agricultural Research
AgMIP		Agricultural Model Intercomparison and Improvement Project
BARC		Bangladesh Agricultural Research Council
BARI		Bangladesh Agricultural Research Institute
BIDS		Bangladesh Institute of Development Studies
BMD		Bangladesh Meteorology Department
BRAC		Bangladesh Rural Advancement Committee
BRRI		Bangladesh Rice Research Institute
BWMRI		Bangladesh Wheat and Maize Research Institute
CEGIS		Center for Environmental and Geographic Information Service
CIMMYT-BD		International Maize and Wheat Improvement Center

FAO		Food and Agriculture Organization of the United Nations
IRRI		International Rice Research Institute
KGF		Krishi Gobeshona Foundation
MoPA		Ministry of Public Administration
NYU		New York University
OSU		Oregon State University

11.3 Appendix 3: Tradeoffs and co-benefits: disaggregated results

This appendix includes disaggregated results (by strata) for all the climate change impacts and adoption scenarios.

Climate change analysis

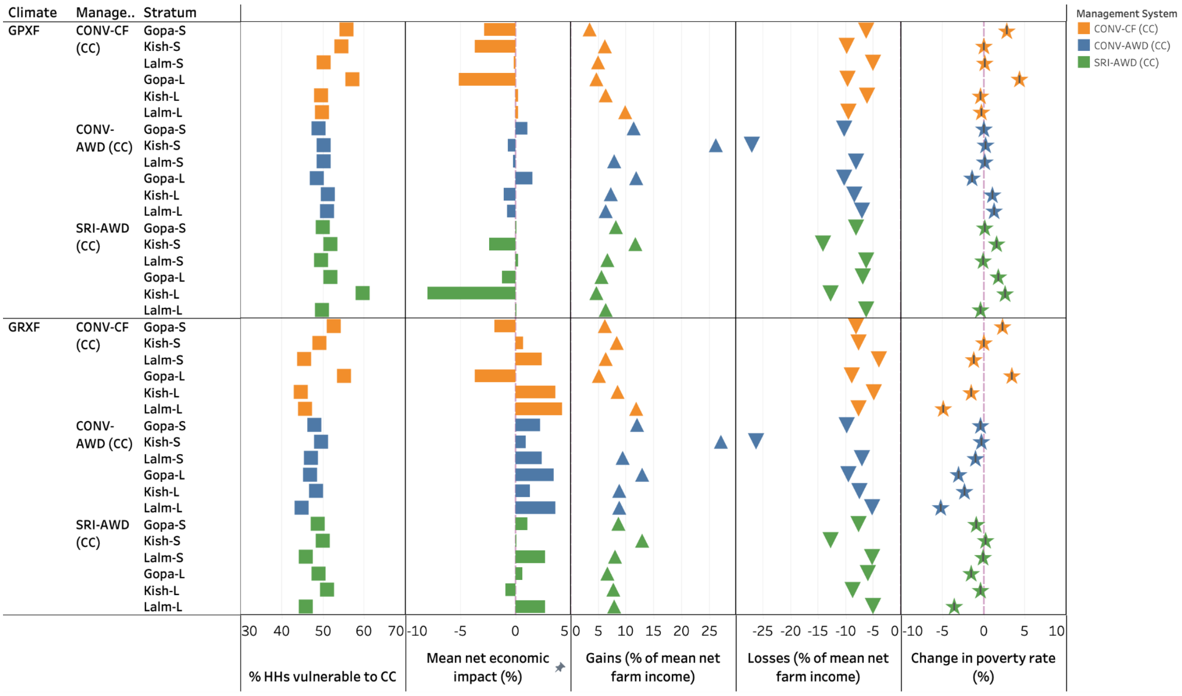

Figure A3.1. Climate change impacts on conventional CF, AWD and SRI management systems by strata and farm type. Vulnerability is measured by the % of households that may lose income due to climate change. Gains and Losses are the mean gains or losses in mean net farm returns for those who benefit from climate change (gainers) and those who lose (losers). The Net economic impact is the mean net economic effect (gains-losses) in the population. Net economic impact, gains and losses are measured as a % of farm net returns. Poverty rate represents the % of the population that is below a poverty line.

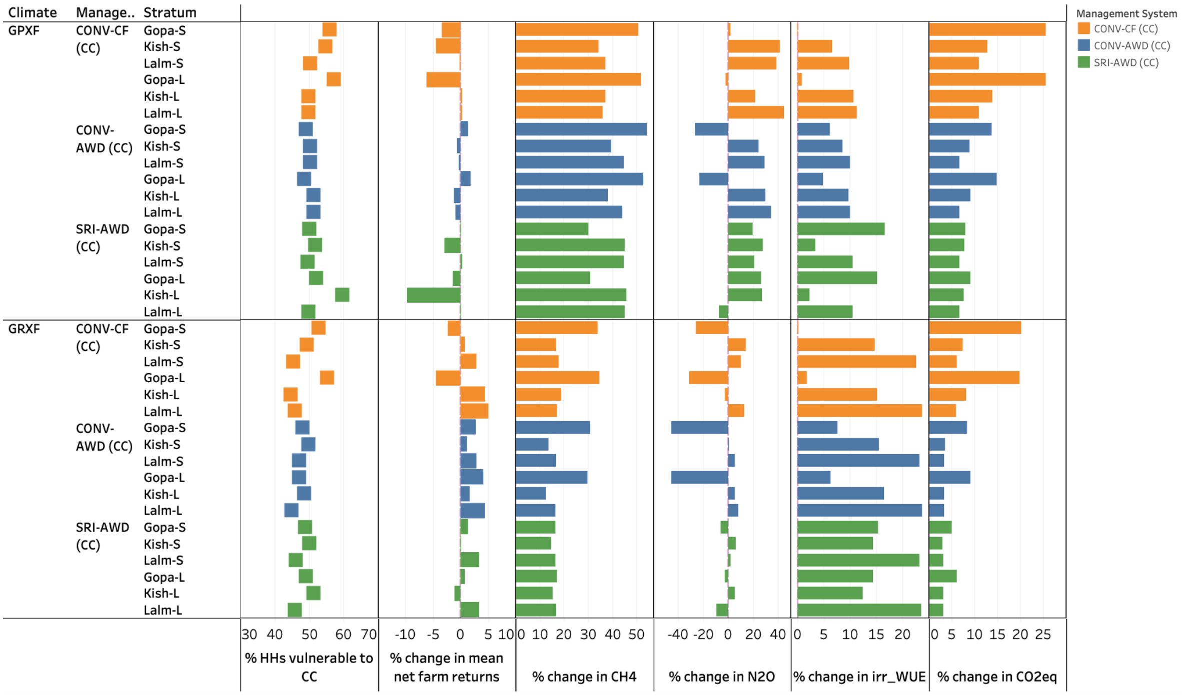

Figure A3.2. Climate change impacts on conventional CF, AWD and SRI management systems by strata and farm type. Vulnerability is measured by the % of households that may lose income due to climate change. The change in mean net farm returns is compared to the relative changes in GHG emissions (CH4, N2O, irr WUE, and CO2eq) due to climate change.

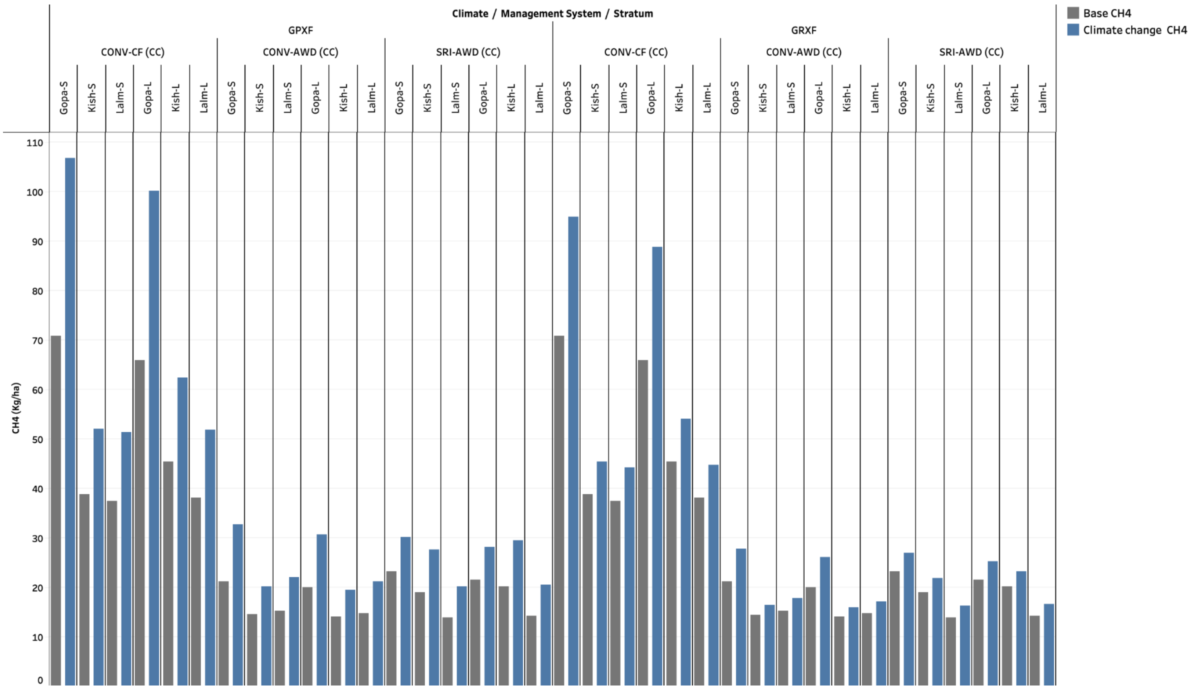

Figure A3.3. Climate change impacts on methane emissions (CH4) for conventional CF, AWD and SRI management systems by strata and farm type. *Base CH4* are emissions without climate change, and *Climate change CH4* shows the absolute mean value of emissions under climate change.

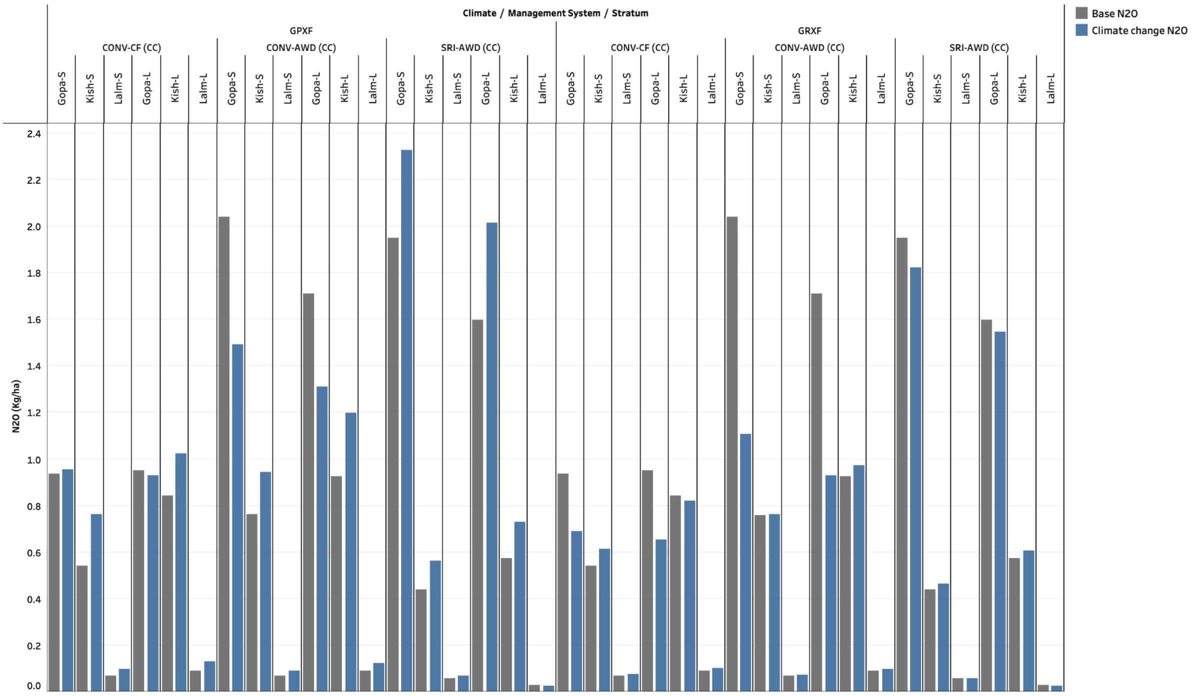

Figure A3.4. Climate change impacts on Nitrous oxide (N2O) for conventional CF, AWD and SRI management systems by strata and farm type. *Base N2O* are emissions without climate change, and *Climate change N2O* shows the absolute mean value of emissions under climate change.

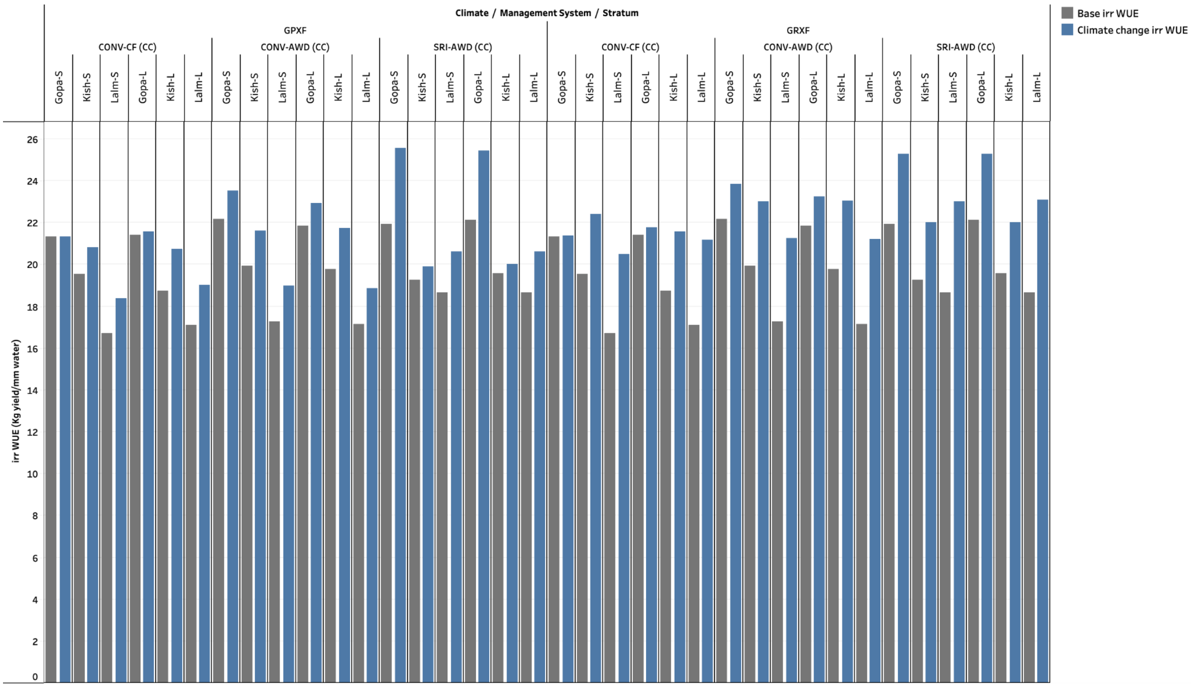

Figure A3.5. Climate change impacts on irrigation water use efficiency (irr WUE) for conventional CF, AWD and SRI management systems by strata and farm type. *Base irr WUE* is the water efficiency without climate change, and *Climate change irr WUE* shows the absolute mean value of WUE under climate change.

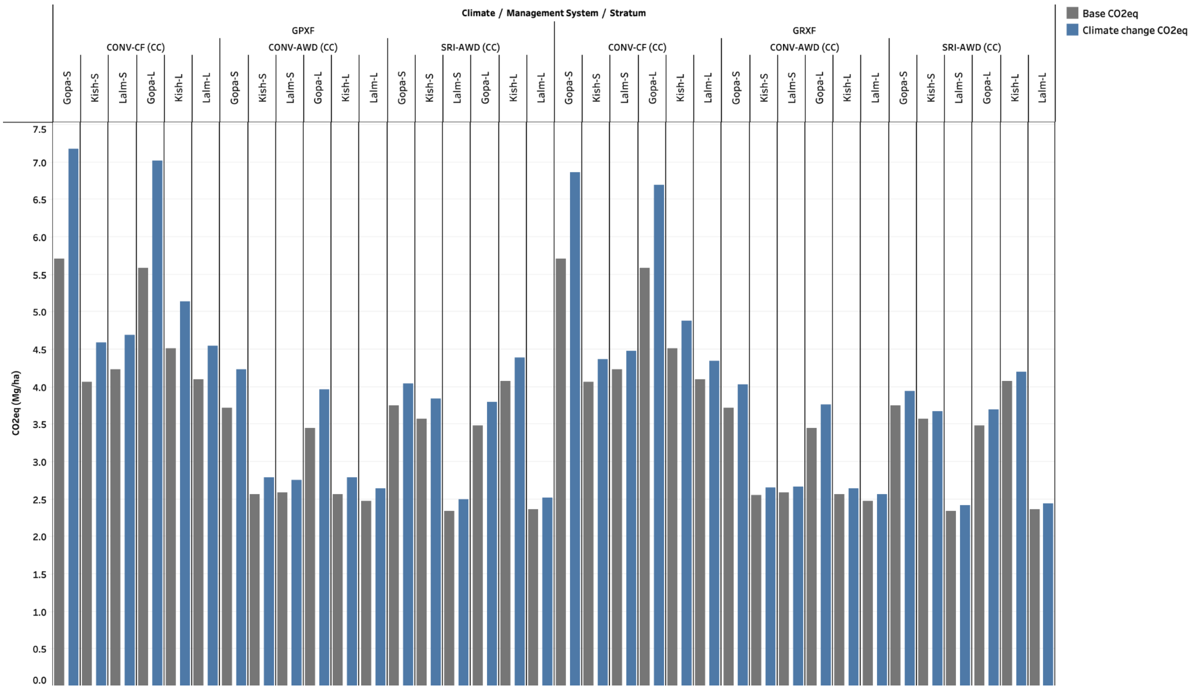

Figure A3.6. Climate change impacts on CO_2 equivalent global warming potential (CO2eq) for conventional CF, AWD and SRI management systems by strata and farm type. *Base CO2eq* are emissions without climate change, and *Climate change CO2eq* shows the absolute mean value of emissions under climate change.

Adoption results

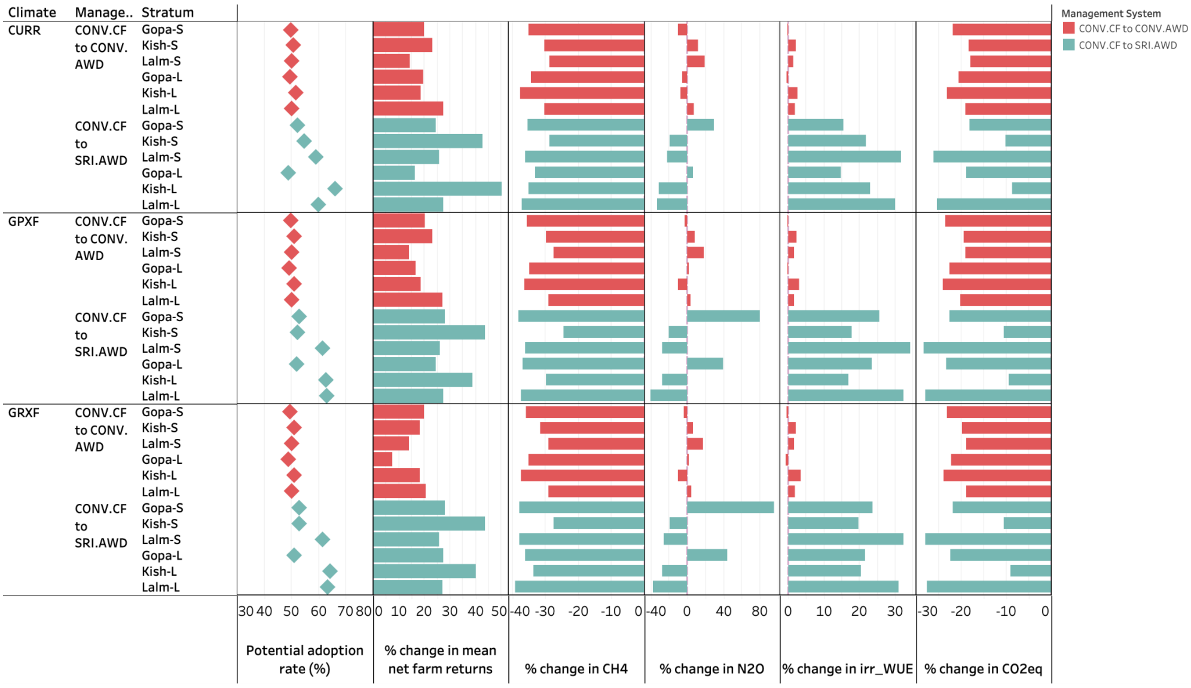

Figure A3.7. Adaptation analysis by strata and farm type: switching from conventional CF to AWD and SRI management systems. Potential adoption rate represents the proportion of farms that would adopt AWD (*CONV.CF to CONV.AWD*) or SRI (*CONV.CF to SRI.AWD*). The change in mean net farm returns is compared to the relative changes in GHG emissions (CH4, N2O, irr WUE, and CO2eq) due to the adoption process where some farms switch to the alternative management practice and others stay under the conventional CF management.

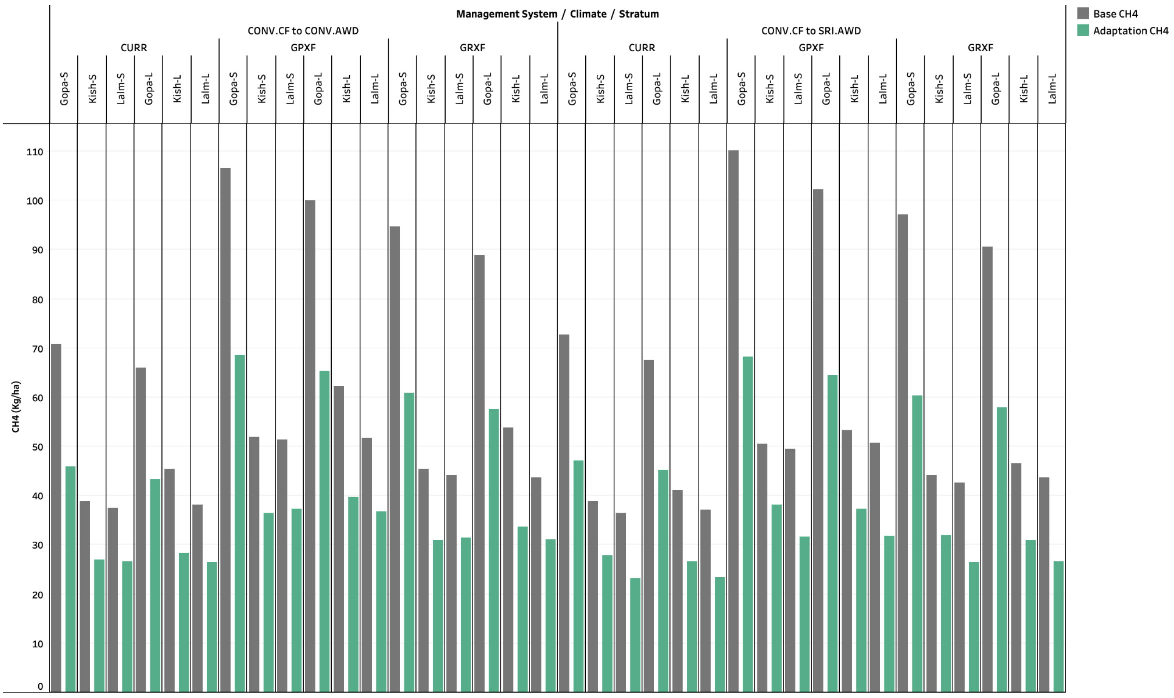

Figure A3.8. Impacts of adopting AWD or SRI on methane emissions (CH4) by strata and farm type. *Base CH4* are emissions under conventional CF management, and *adaptation CH4* shows the absolute mean value of emissions in the population after adoption of AWD or SRI. Note: the population is comprised of adopters and non-adopters, the values presented here represent the mean for the entire population.

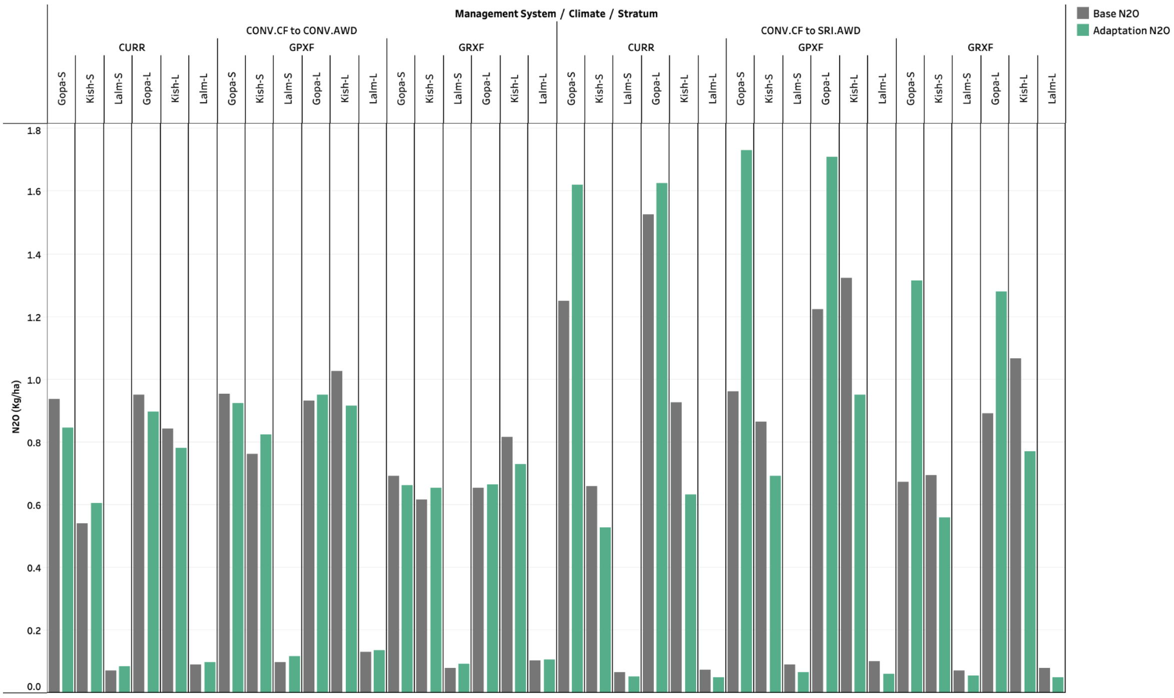

Figure A3.9. Impacts of adopting AWD or SRI on Nitrous oxide (N2O) by strata and farm type. *Base N2O* are emissions under conventional CF management, and *adaptation N2O* shows the absolute mean value of emissions in the population after adoption of AWD or SRI. Note: the population is comprised of adopters and non-adopters, the values presented here represent the mean for the entire population.

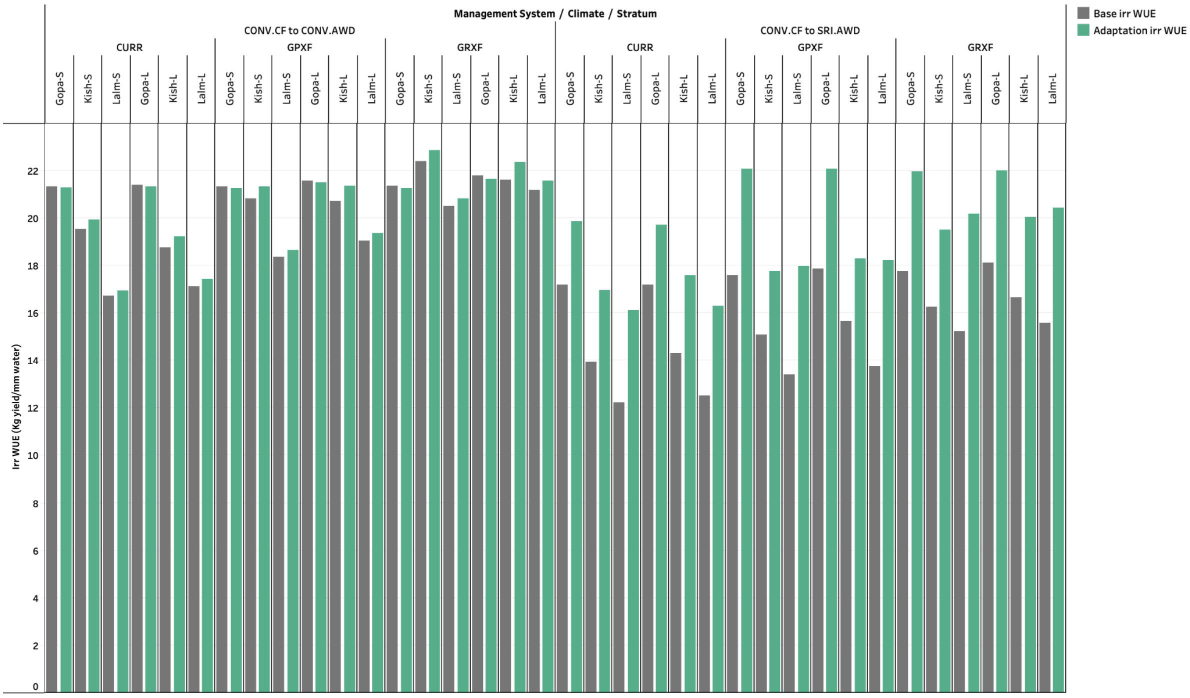

Figure A3.10. Impacts of adopting AWD or SRI on irrigation water use efficiency (irr WUE) by strata and farm type. *Base irr WUE* is the water efficiency under conventional CF management, and *adaptation irr WUE* shows the absolute mean value of WUE in the population after adoption of AWD or SRI. Note: the population is comprised of adopters and non-adopters, the values presented here represent the mean for the entire population.

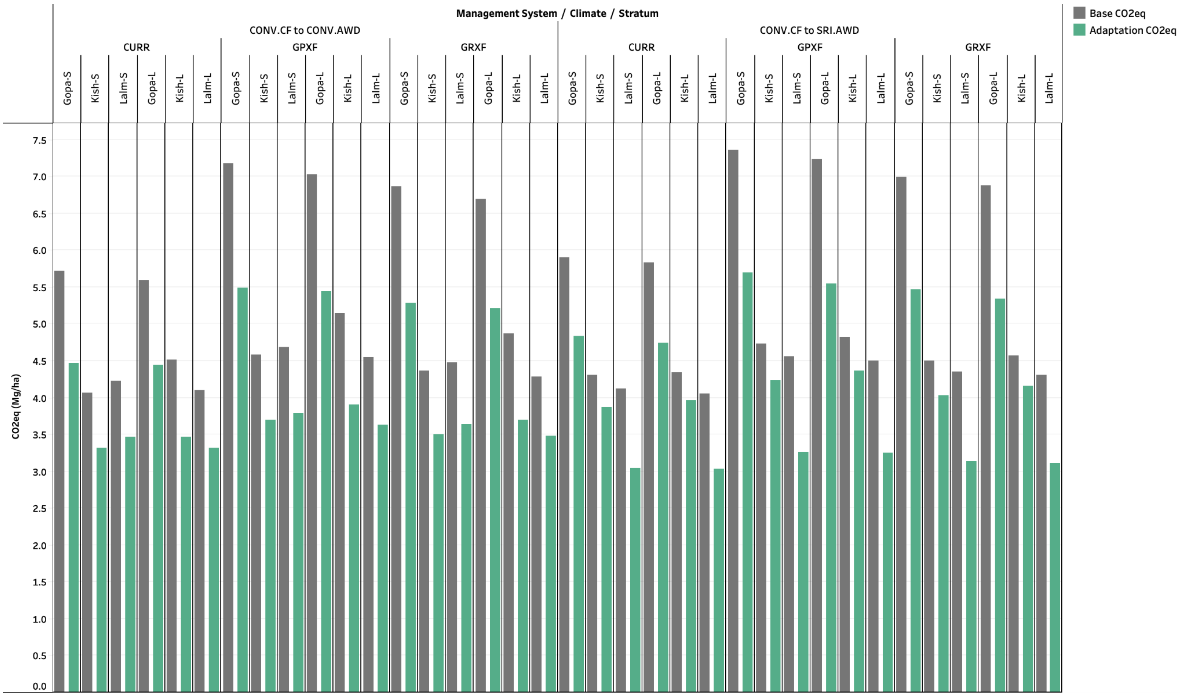

Figure A3.11. Impacts of adopting AWD or SRI on CO_2 equivalent global warming potential (CO2eq) by strata and farm type. *Base CO2eq* are the emissions under conventional CF management, and *adaptation CO2eq* shows the absolute mean value of emissions in the population after adoption of AWD or SRI. Note: the population is comprised of adopters and non-adopters, the values presented here represent the mean for the entire population.