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# Analysis Environmental Viability of Crop-Cattle Integration in Climate Vulnerable Districts of Bangladesh

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## Abstract

Low carbon farming (LCF) through crop-cattle interaction has great impact on climate change. The study presents the findings of environmental viability of LCF sets through crop cattle integration under climate change shocks. Data were collected from 300 low carbon sample farms under three coastal districts of Bangladesh namely Khulna, Satkhira and Bagerhat. The carbon sequestration data were recorded under three alternate options of the treatments from *Boro* and *Aman* rice fields. There were nine and five adaptation options found in the *Boro* and *Aman* rice seasons, respectively. About 27% respondent farmers adopted soil and rice crop management technique with climate stress-tolerant varieties involving ideal fertilizer management and irrigate in *Boro* rice season. On the other hand, about 54% responded farmers chose the adaptation option of soil and rice management involving balanced fertilizer use and irrigation. The estimated highest initiative feasibility of low carbon farm found in Dumuria upazila of Khulna district, where *Boro* and *Aman* rice yield observed 6240 kg and 4510 kg/ha along with a technical feasibility indicator of 1.25% and 1.19% of OC (organic carbon) sequestration in soil, respectively. It recommends that 50% of NPKSZn with bio-solids may be effective for low carbon farming.

**Key words:** Climate change, Environmental viability, Low carbon farming

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## Introduction

The coastal areas of Bangladesh are experiencing several climate change related disaster and most vulnerable to farming (agriculture, fisheries and livestock) to maintain population livelihood, restore sound environment (Minar et al., 2013). Moreover, the agricultural sector has a countless opportunity for a carbon sequestration and contribution to reduce greenhouse gases (GHGs) emission which contributes about 14% of global and 39% of country's GHGs emission (FAO, 2015).

Low carbon farming adaptation practices may provide Bangladeshi farmers with opportunities to benefit from the global carbon market. It has been claimed that LCF adaptation shift farming practices that are more feasible, involve lower input cost, reduce GHGs emission and enhance soil carbon sequestration sinks (Hossain & Ali, 2024).

Several NGOs has been involved to promoting LCF under climate smart agriculture in coastal areas of Bangladesh. To identify the most effective of feasibility of these LCF techniques, tripartite framework is the effective method (Ali & Meisner, 2017; Anwar & Zahan, 2023; Majumder et al., 2024). In this study, several LCF techniques were analyzed whether these were environmental feasibility LCF techniques or not. The concept of environmental feasibility of LCF mainly encompasses three elements includes Technical Potentiality (TP), Initiative Feasibility (IF) and Behavioral Plasticity (BP) (Nielsen et al., 2020) . This research focuses on measuring TP and IF for low carbon rice farming using farm survey data and finding related policy options from GHGs mitigation potentialities data of secondary sources. Therefore, this study is taken to assess the environmental viability of crop-cattle integrations under changing climatic conditions

## Methodology

### Farm survey

The study was conducted using primary data collected through farm survey including interviews focus group discussion (FGD) and key informant interviews (KII) in the south-western districts of Bangladesh. Secondary data and information were also collected from published and unpublished sources.

The present study used farm survey approach to find out the information about crop and cattle at farmer's level. The survey was carried out using a structured questionnaire. The questionnaire was developed and field-tested for necessary modifications before starting data collection in the selected areas. Direct interviews have done by making personal visits to the farmers from January 2017 to December 2022. The sample farmers were interviewed by trained enumerator including the researcher, over the period of data collection. Details of farm input-output data of respondent farmers were recorded in the survey schedule for the period 2017-2022.

The input-output data of latest farming under innovations adoptions were collected over phone to correct discrepancies. The data were then compiled for the final survey according to the need of each research objective. The questionnaire consisted three main sections; the first section related to farmer identification and profile about farm size, family size, and land tenure systems, physical assets, social capital and access to basic facilities etc. The second section is related to cost and revenue patterns of crop and cattle operational activities. The third section was developed to assess the adoption status of innovations.

Since 2010, the selected areas have been covered by the climate change adaptation programs implemented by of three non-government organizations (NGOs); Shushilon, Prodipon and Uttaran as well as by the Department of Agricultural Extension (DAE) of the Government of Bangladesh (GoB).

**Description of the study area**

The field survey was conducted between October 2017 to July 2022 in three coastal districts (Khulna, Satkhira and Bagherhat) of Bangladesh.

Table 1: Major features of the selected Upazilas of the study areas

| District | Khulna | Satkhira | | Bagherhat |
|---|---|---|---|---|
| Upazila | Dumuria | Koyra | Shamnagar | Mongla |
| Area (sq.km) | 454.23 | 1775.41 | 1968.24 | 461.22 |
| Population (000) | 279862<br>M-144334<br>F-135528 | 192534<br>M-95993<br>F-96541 | 313781<br>M-160294<br>F-153487 | 149030<br>M-80819<br>F-68211 |
| Density per sq. km | 616 | 108 | 159 | 102 |
| Literacy rate% | 48.66% | 32.4% | 39.69% | 56.1% |
| Average size of family | 5.64 | 6.02 | 5.70 | 5.90 |
| Agricultural income | 65.3% | 66.64% | 64.98% | 36.31% |
| Means of transport | Van, Easy bike,<br>Motor bike | Van, Easy bike,<br>Motor bike | Van, Easy bike,<br>Motor bike | Van, Easy bike,<br>Motor bike |
| Sanitation | 50.61% | 30.97% | 44.84% | 22.23% |
| NGO activities | BRAC, GB, ASA, Uttaran, Sushilon, Samadhan, Solidaridad, CSS, Prodipan | BRAC, GB, ASA, Uttaran, Sushilon, Samadhan, Solidaridad, CSS, Prodipan | BRAC, GB, ASA, Uttaran, Sushilon, Samadhan, Solidaridad, CSS, Prodipan | BRAC, GB, ASA, Uttaran, Sushilon, Samadhan, Solidaridad, CSS, Prodipan |

Source: District Statistics 2011, Bangladesh Bureau of Statistics 2021

BRAC- Bangladesh Rural Advancement Committee, GB- Grameen Bank, ASA- Association of Social Advancement, CSS- Christian Service Social.

**Sampling design and sample size**

A multi-stage sampling technique was applied to the sample households. In the first stage, 04 upazilas of 03 districts of Bangladesh were selected and used purposive sampling technique based on three considerations Table 1). Firstly, this study area was selected based on the accessibility and proximity to conduct the survey properly. Secondly, in those areas were selected where crop-cattle combination for low carbon farming technique comparatively high. Thirdly, Khulna, Satkhira and Bagherhat districts were selected to represent southwestern region of Bangladesh. Three villages from each upazila were randomly selected. From each village, 25 adapted farm households were randomly chosen for better representation of the population. In total, 300 adapted farm households were selected for the benchmark study, each considered for core trainee of the technology transfer. Given similarities in the socio-economic, agro-ecological zones, and production environment, the sample size was considered a valid representation of the entire population (Table 1).

Table 2. Selection of sample under multi-stage sampling technique

| District/ Upazila | No. of village | No. of farm per village | Total no. of sample farms |
|---|---|---|---|
| Khulna | | | |
| Dumuria | 3 | 25 | 75 |
| Koyra | 3 | 25 | 75 |
| Satkhira | | | |
| Shamnager | 3 | 25 | 75 |
| Bagherhat | | | |
| Mongla | 3 | 25 | 75 |
| Total | 12 | - | 300 |

**Other data sources**

Primary and secondary both data were used in the study. The rainfall, humidity and temperatures of 2017-2022 were collected from the nearest weather stations (Khulna, Satkhira and Mongla) and the Bangladesh Agricultural Research Council (BARC). Besides, this study used various secondary data from various sources

The notable sources included Bangladesh Ministry of Agriculture, Department of Agricultural Extension (DAE), Upazila Agricultural Office (UAO), Bangladesh Metrological Department (BMD), Bangladesh Rice Research Institute (BRRI), Bangladesh Bureau of Statistics (BBS), Intergovernmental Panel on Climate Change (IPCC), and Food and Agricultural Organization (FAO). In addition, expert opinions and field-level experiences of relevant officials and academics also considered for providing valuable information.

**Data coding, entry and cleaning**

The collected data were coded and entered into the Microsoft Excel spreadsheet before being converted to Stata program for analysis. Data entry was organized by region and then pooled according to the analysis framework. The data was cleaned by producing frequency distributions and examined for outliers. When data found consistent, it was then prepared for further analysis.

**Data analyzing methods and tools**

Collected data were arranged and analyzed primarily using quantitative methods including descriptive statistics and farm management analytical tools. The statistical and econometric used various test statistics.

**Methods for analysis of environmental viability of crop-cattle integration**

Different statistical tools including mean, standard deviations, maximum or minimum values, frequencies and percentages were used for quantitative assessment. Additionally, qualitative assessment of LCF adaption techniques was conducted by expert opinion, internet sources and published literature.

## Results and Discussion

**GHG emissions reduction potentialities by practicing LCF of sample rice farms**

The farming is responsible for GHGs emission under four ways and the most common GHGs emission is from rice field in where methane and nitrous oxide are formed by the microbial cavities in the soil. The carbon storage in the soil is affected by direct and indirect $CO_2$ emissions collectively associated with on-farm and off-farm energy production.

Low carbon rice farming involves cultivation of rice that reduce and or optimize GHGs emission from production activities. The most common LCF practice affects the three key management domains, namely soil and crop management, fertilizer management and irrigation water management. The low carbon farming is practiced through minimum tillage, anaerobic fermentation, application of organic fertilizer, mulching, crop rotation, intercropping, rational water use and a set of techniques in production life cycle designed for specific climatic zones.

Farmers in the study area were practiced LCF within the soil and crop management domain by combination of minimum tillage and IPM (Integrated Pest management), crop rotation with legumes and the use of salinity tolerant varieties. Crop rotation on the same land support biodiversity. Appropriate crop mixtures, based on science and demonstrated evidence, develop resilience by balancing in farm ecology and reduce the risk of crop failure due to pesticide side effects. These cultivations also reduce farm households' vulnerability against erratic and spatial rainfall, temperature shocks and salinity intrusion.

The fertilizer management includes use of balance fertilizer dose and organic fertilization with vermicompost and bio-solids. The main mitigation options in farming are the reduction of excess nutrient application and balanced fertilization. Organic fertilizer have potentiality to improve soil against methane production (a GHG) from the soil (Zhou G. et al., 2020) .

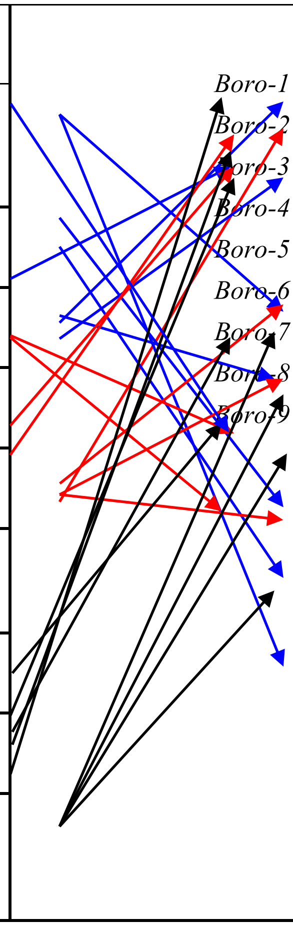
Irrigation management includes efficient irrigation and rain water harvesting by building water reservoir and diversion ditches. Properly maintained alternate wetting and drying irrigation can also minimize methane emission depending water regulation, soil type and cultivation practices (Sriphirom et al., 2019). Intermittent aeration makes the soil environment toxic which results in the oxidation of methane, methanotrophs, causing a drop in methane emission. It has been reported that up to 80% of the methane produced during the rice-growing season is oxidized by the methanotrophs (Singh et al., 2010). In contrast, LCF rice cultivation often creates the soil environment anaerobic, resulting in decreasing redox potential (-150 mV), which leads to the anaerobic decomposition of complex organic substrates by methanogens that finally drive methane production (Minamikawa et al., 2006; Wang et al., 2009).

**Adaptation options of *Boro* season in coastal region of Bangladesh**

*Boro* is main rice growing season considering in terms of total cultivated area and production which starts from mid-December and harvests in mid-April. Good quality seed of high yielding varieties (HYV), organic and inorganic fertilizer, and underground water used in *Boro* production technology. However, saline water and seasonal drought create the challenges for *Boro* cultivation in coastal region of Bangladesh. So, farmers choose saline free water for irrigation and cultivate *Boro* seeds that are tolerant to temperature, drought and salinity.

There were nine types of adaptation practices were recorded in the study area. Greenhouse gas emissions associated with pesticide applications against invasive pest species having an environmental cost which has remained largely unrecognized. For ranking, one or more sub-components from each adaptation option is ranked as one, at least one chosen sub-component from two adaptation obtain is ranked as two and three main adaptation option sat least one sub- component chosen from each will be ranked 3. The detailed discussion is presented in following sub-sections.

| Coping factors by LCF |
|---|
| **1. Soil and crop management** |
| Integrated crop management Minimum tillage and IPM |
| Crop rotation with legumes |
| Use of saline tolerant variety |
| **2. Best fertilizer management** |
| Use of balance fertilizer dose |
| Organic fertilization with vermicompost/ bio-solids |
| **3. Irrigation water management** |
| Irrigation and rain water harvesting |
| Water reservoir and diversion ditches |



| Option choice | Performance score (0-3) | Percentage of adopt |
|---|---|---|
| *Boro-1* | 3 | 27 |
| *Boro-2* | 3 | 16 |
| *Boro-3* | 3 | 19 |
| *Boro-4* | 1 | 5 |
| *Boro-5* | 2 | 10 |
| *Boro-6* | 1 | 6 |
| *Boro-7* | 2 | 5 |
| *Boro-8* | 2 | 9 |
| *Boro-9* | 1 | 3 |

Source: Own Farm Survey- 2017-2022

Fig. 1. Low carbon farming performance in *Boro* season

**Soil and rice management technique with climate stress-tolerant varieties involving ideal fertilizer management and as well as watering:**

This adaptation includes three basic elements of alternative management such as salt tolerant seed, ideal fertilizer management and watering from deep tube well. This adaptation system consists of two main components, balanced fertilizer dose and organic fertilizer application increased soil porosity, soil pH, exchangeable K and Ca, available P and S, soil carbon storage and essential nutrients availability to the rice plant and sustaining rice yield, while improving salinity level by decreasing electroconductivity values in saline soils in coastal region. Currently, deep tube well of 300 meters in depth provide non-saline irrigation water and seasonal drought negatively affects to the *Boro* rice cultivation. So, the farmers choose those techniques which confirm non-saline water to irrigate crop field and temperature stress tolerant varieties of rice.

The respondent farmers used to cultivate salt tolerant modern varieties by applying optimal fertilizer rates and irrigation water in *Boro* season rice cultivation. Figure 1 reveals the performance score of 3 with 27% of sample farmers adopted it.

**Soil and rice management through salt-tolerant varieties and best fertilizer use by nitrogen deep placement with water harvesting**

Under this adaptation practice three alternative cultivation practices applies to reduce impact of climate shocks. The initial inspiration of the farmer is soil and rice management by maintaining soil health. The second components is balanced fertilizer use which means proper application of all necessary macro- and micronutrients in a balanced proportion at different stages of crop growth (Zewide & Sherefu, 2021). The farmers of the study area use irrigation in the rice field by shallow tube wells. They use water reservoirs and diversion ditches to drain for additional water. Farmers keep the reservoir or small pond at the middle enclosed by the rice lands. Harvested rain water is applied 2/3 times for irrigation in rice fields. The lands are also enclosed by earthen embankment to protect entry of saline water intrusion. The practice rank is 3 and 16% of the respondent farmer practice this technique.

**Rice management by salt-tolerant varieties, best fertilizer uses with urea deep placement as well as irrigation by water reservoir and diversion ditches**

Three primary adaptations are processes involve soil-rice management, balance fertilizer uses and irrigation. Best fertilizer management practice by nitrogen deep placement in the roots of plants. The system helps to apply fertilizer on irrigated rice fields efficiently and at the same time protects methane emissions. Balance doses of fertilizer application along with mitigation technique that protect nitrogen losses and methane emission from the crop field. It also improves nitrogen use efficiency, delay the nitrogen release (Huda, 2015). The integrated rice and soil management includes salt tolerant varieties, judicial urea application, and application of two or three times harvested rain water for irrigation. Its rank 3 and 19% sample farmer adopt it.

**Zero or minimum tillage-based integrated rice management with saline-tolerant varieties**

Tillage encourages methane emission, soil erosion and soil nutrition loss from the rice field. Zero or minimum tillage reduces production costs and an effective way of protecting soil nutrition in crop land which is a tool of mitigation technique. The farmers in the coastal region cultivated HYV salt tolerant seed varieties developed by BINA dhan-8, BINA dhan-10, BRRI dhan36, BRRI dhan47 and BRRI dhan55. Figure 1 and 2 represents that adaptation option score is 1 and only 5% of farmer apply it. This adaptation option is not widely adopted in coastal region of Bangladesh.

**Crop management, balance fertilizer management exercise by urea deep placement involving water reservoir**

Three basic components are present in this adaptation options. In the study area, farmers adopted to cultivate modern salt tolerant crop varieties, least amount of fertilizer and non-saline water for irrigation. This adaptation option rank is 2 and 10% of the respondent farmers practiced it.

**Water management (Irrigation) with water reservoir and diversion ditches**

The respondent farmers applied only one adaptation option and saline-free water management. This practice decreases irrigation water use and carbon foot print in the crop production system having mitigation effects. This adaptation option rank is 1 and only 6 percent respondent's farmers adopted this option.

**Soil and rice management practice with saline tolerant varieties linked with irrigating with water reservoir and diversion ditches**

Here, soil and rice crop management used that protect the seed and soil from the adverse effects of salinity. The irrigation water is managed from the rain water reservoir. This adaptation option rank is 2 and only 6% of the respondent farmers received this choice.

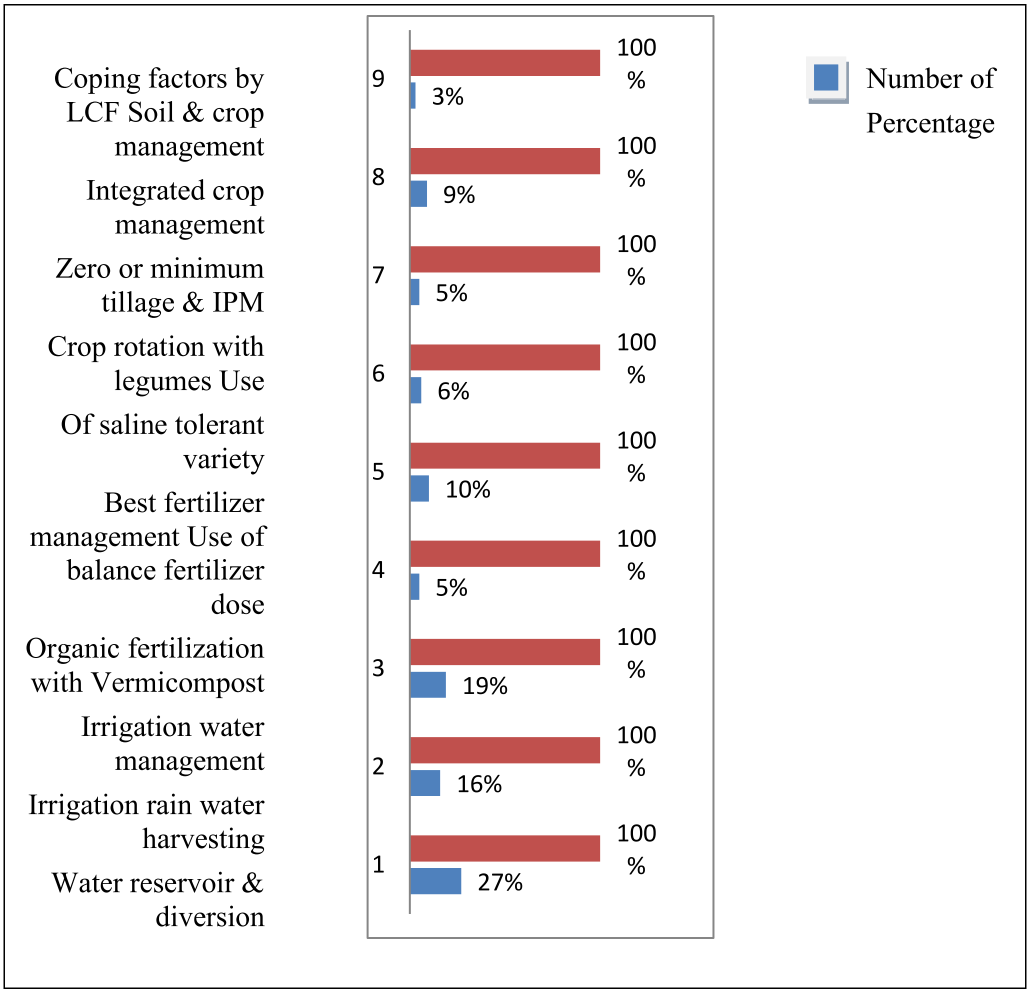
**Zero tillage-based integrated rice management with saline tolerant varieties with water reservoir and diversion ditches**

In the study area farmers transplant *Boro* rice without tillage or minimum tillage. Farmers cultivate salt tolerant varieties to overcome the risk of soil salinity and unsafe canal rain water for irrigation. The adaptation option rank is 2 and 8% farmers adopted it.

**Balanced fertilizer management practices used by the appropriate fertilizer**

*Boro* rice yield depends on the proper utilization of inputs such as irrigation and fertilizer.

The best fertilizer management is the exercise of balanced fertilizer refers to a blanket dose of fertilizer for a certain crop field based on actual crop requirements and soil fertility status (Miah et al., 2005). This adaptation option score 1 out of 3 and only 3% of the respondent farmers adopted it.




Source: Own Farm Survey- 2017-2022

Fig 2. Selected LCF of *Boro* rice farming practices in study areas

## Adaptation of *Aman* season in coastal region of Bangladesh

*Aman* rice season is a rain-fed rice growing season in coastal region. The *Aman* rice farmers wait for heavy rainfall to decrease the soil salinity. Heat stress (e.g., high temperatures), less precipitation and salinity shocks hamper to *Aman* rice growth. To reduce climate variability shocks, the coastal farmers adopting alternative production technique. Five adaptation option` was recorded in *Aman s*eason. Each option consists of several sub- components. Three sub-components in the coping factor for soil and crop management: zero or minimum tillage and IPM based integrated crop management, crop rotation with legumes and use of saline tolerant variety. The option of best fertilizer management makes by two sub-components: use of balance fertilizer dose and organic fertilization and irrigation water management consist of irrigation and rain water harvesting.

Soil and rice management with saline tress seed varieties

Zero or minimum tillage decrease production cost and emission of greenhouse gases from the cultivated land. It helps to restore soil nutrition in the cultivation land. Farmers of this area are interested in salt tolerant seed varieties such as BRRI dhan40, BRRI dhan41, BRRI dhan53 and BRRI dhan54. Crop rotation helps to gain three benefits: maintaining soil nutrition, increase rice and legume production and mitigating greenhouse gases emission from the cultivated land. *Khesari* is the most common legume crop in the coastal region of Bangladesh. This adaptation score is 1 and 17% respondent farmer of the study area adopt this option.

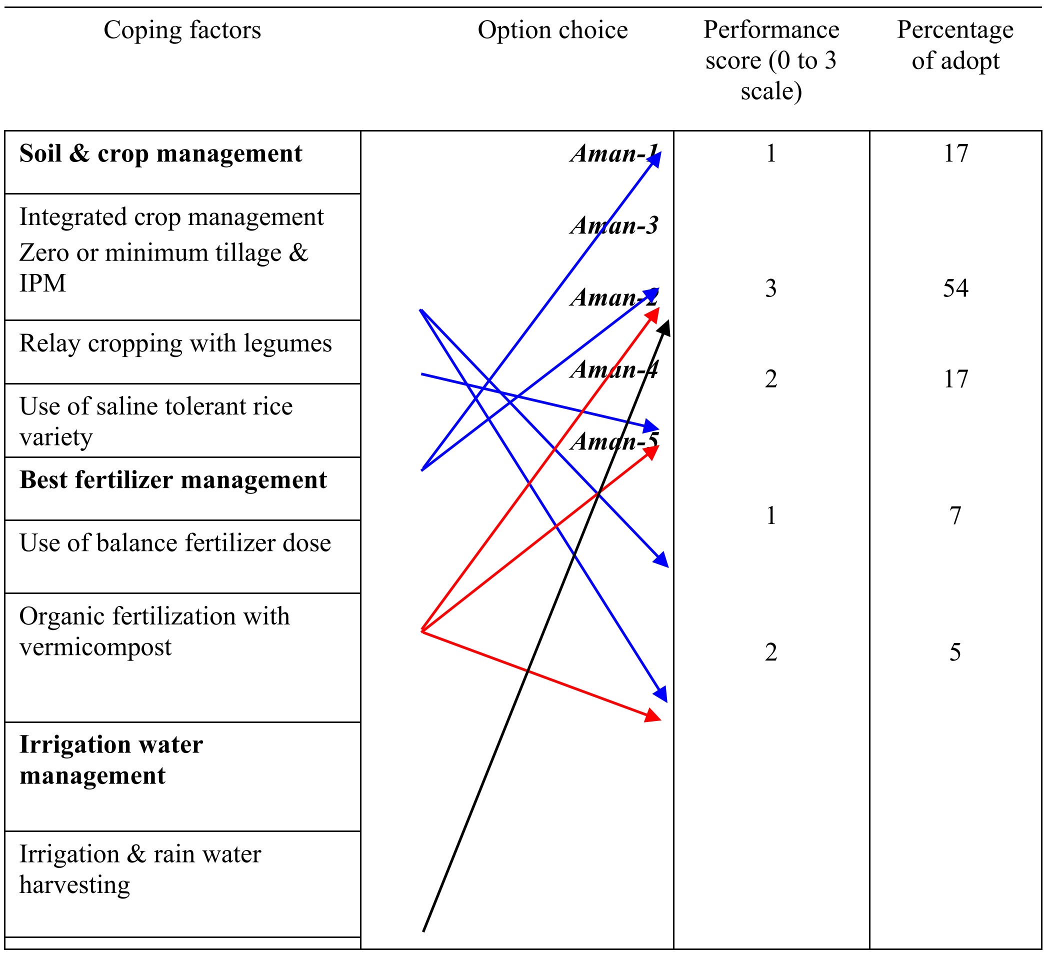



Fig. 3. Low carbon farming performance in *Aman* season

Nowadays farmer interested to cultivate climate stress and salt tolerant rice varieties such as BRRI dhan40, BRRI dhan41, BRRI dhan53 and BRRI dhan54. Department of Agricultural Extension and NGOs disseminated those varieties which maintain grain yield under climate shocks.

Soil and rice management through relay cropping with legume and best fertilizer use. Farmers use three types of inorganic fertilizer like as urea, triple super phosphate (TSP) and mutate of potash (MoP) in rice field. The doses recommended by the DAE. The management system ensures cautious apply of urea for climate variability adaptation and mitigation. Bangladeshi farmers are not aware of balanced fertilizer use according to the needs of their land (Basak, 2010). Urea is cheaper, quick responsive and more available than other inorganic fertilizers such as TSP and MoP. Crop rotation helps to gain three benefits: maintaining soil nutrition, increase rice and legume production and mitigating greenhouse gases emission from the cultivated land. *Khesari* is the most common legume crop in the coastal region of Bangladesh. This adaptation option rank is 2 and 17% sample adopt it.

Soil and rice management involving balanced fertilizer use and watering. Soil amendments with organic fertilizer increased soil porosity, soil. Organic carbon (%) content, soil pH, exchangeable K and Ca content in coastal region. But a few farmers use organic fertilizer in *Aman* season.

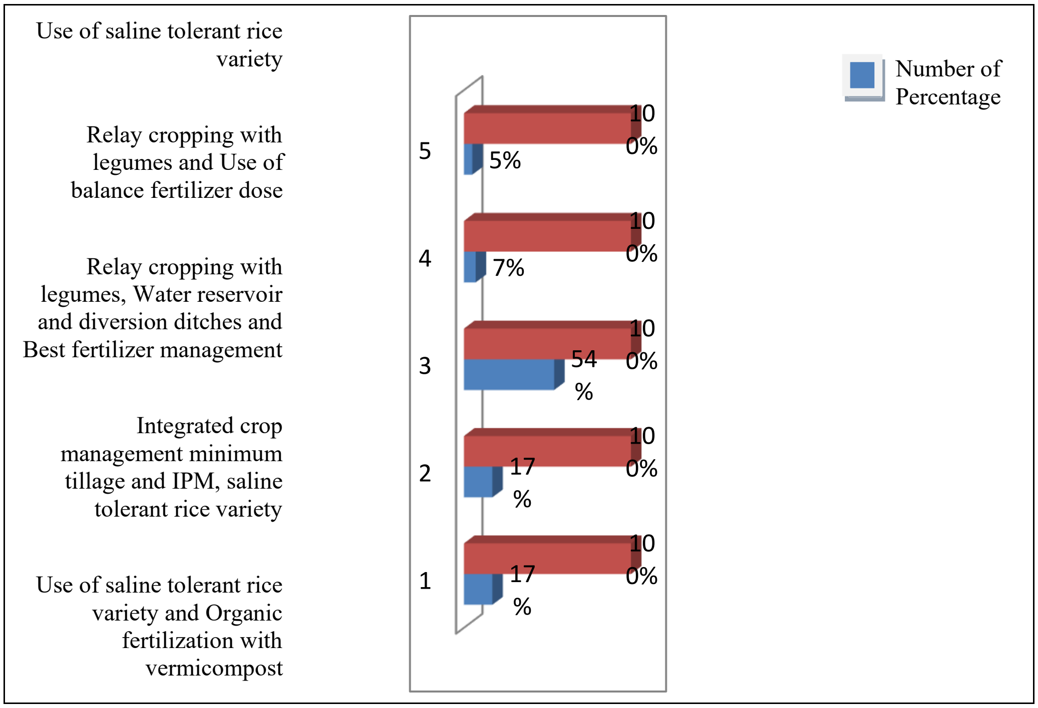
There are two sub-components for irrigation water management such as irrigation and rain water harvesting. The coastal area is saline-prone and watering by shallow tube wells severely so. Irrigation by deep tube wells and rain to ensure saline-free water. About 54% respondent farmer chose the adaptation option and the adaptation rank is 3.

**Integrated pest management with saline stress seed varieties.**

Integrated pest management is one of the best practices prescribed and practiced from last three decades for rice farmers in Bangladesh. It is more popular adaption option to manage climate shocks. The main objectives are behind IPM to minimize agro-chemicals and commercial pesticide. Because pesticide manufacture, transport and application of insecticides cause of greenhouse gases emission. In the study area farmers used various salt tolerant varieties. The adaptation option score 1 is and 7% sample farmer took it.

**Zero or minimum tillage based integrated rice management with saline stress varieties and balanced fertilizer management technique by urea deep placement**

Tillage creates soil erosion and nutrition loss in the field. Minimum or zero tillage decline production cost. Farmers used salt–tolerant seed varieties and balance fertilizer management technique by nitrogen deep placement. The practice helps to use nitrogen on flooded rice fields. This adaptation option rank is 2 and only 5% farmer adopts this model.




Source: Field Survey

Fig. 4. Selected LCF of *Aman* rice farming practices in study areas

**Insight of low carbon emitting farming technique under *Boro* and *Aman* seasons**

Soil amendments with bio-solids increased soil porosity, soil OCcontent, soil pH, exchangeable K and Ca content in Khulna, Satkhira and Bagherhat, although exchangeable Na decreased significantly. Mixed application of inorganic fertilizer and bio-solids maximized *Boro* and *Aman* season which may be due to the higher availability of soil nutrients such as exchangeable K, exchangeable Ca, available P and available S to *Boro* and *Aman* season. Mixed application of inorganic and organic fertilizer could be a feasible option for increasing soil storage, nutrients availability to *Boro* and *Aman* and sustaining rice yield, while improving salinity level by decreasing Ec (Electrical conductivity) values in saline soils.

The increased soil OC stock under mixed organic and inorganic amendments indicates the lower C emissions from *Boro* and *Aman* land to the atmosphere compared to sole organic and inorganic sources. (Busari et al., 2015) reported that maintenance of SOM/SOC in crop field is important, not only for improvement of agricultural productivity but also for reduction in C emission and mixed application of gypsum with cyanobacterial inoculums additions in soils would be a good practice for reducing methane emissions, improving soil nutrients availability to rice plant and also increasing rice yield attributes even under saline stress condition.

Soil redox potential (Eh), pH, Ec, TDS, iron (Fe) conc. and conc. were measured at every fortnight interval during rice cultivation in coastal region of Bangladesh. Soil OC carbon (Begum et al., 2018; Walkley & Black, 1934) ), %Total N (Micro-Kjeldahi method, (Keeney & Nelson., 1982), available P (Colorimetric method, (Watanabe & Olsen, 1965) available S (by the Calcium chloride extraction method (Williams & Steinbergs, 1959) were determined following standard methods. Exchangeable calcium (Ca), sodium (Na) and potassium (K) were extracted from soil using 1M $CH_3COONH_4$ solution. At the harvesting stage, soil bulk density was analyzed using cores (volume 100 cm3, inner diameter 5 cm), filled with fresh moisture soils. The collected soil core samples were oven dried at 1058ºC for 24 h and then weight of dried core samples, soil porosity were calculated using the bulk density and particle density according to the equation porosity (%) = (1-BD/PD) x100.

Mixed practice of inorganic fertilizer (50% of recommended NPKSZn) and bio-solids produced maximum rice grain yield, which may be due to the higher presence of soil nutrients like as exchangeable K, presence Ca, P and S to rice plant. In addition, soil Ec and exchangeable Na content decline with bio-solids materials. Therefore, mixed practice of inorganic and organic fertilizer could be an effective option for increasing soil carbon storage, nutrients presence to rice plant and sustaining rice yield, while progress salinity level by decrease Ec values in saline soils. The increased soil organic C stock under mixed organic and inorganic materials indicates the lower C emission from rice fields to the atmosphere compared to sole organic or inorganic sources.

**The mitigation potentialities of sample rice farm by LCF**

The mitigation possibilities of LCF are main indicators of feasibility that recognize whether a certain initiative improve the adaptation. The idea of environmental probability readily addresses like a question, which methods would be scaled to gain certain mitigation objectives? Which initiative would be performed at a cost that makes them catching technically? The sample LCF performed carbon capture and storage for greenhouse gases emission to adopt climate mitigation. The technical and initiative chance were evaluated by using Tripartite Framework, so carbon dealing policies within a nation would be justified to climate footprint from farmhouse level.

Table 3. Comparative assessment of wise yield and soil properties after amendment in Khulna

| Locations | Treatments for LCF | *Boro* | | | | | | *Aman* | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | IF | | | TP | | | IF | | | TP | | |
| | | Grain yield (kg/ha) | Soil porosity (%) | Ec (dS/m) | Soil pH | %OC | %TN | Grain yield (kg/ha) | Soil porosity (%) | Ec (dS/m) | Soil pH | %OC | %TN |
| Khulna (Dumuria) | $V_1$ | 6120 | 45 | 4.8 | 7.1 | 1.10 | 0.20 | 4470 | 47 | 4.7 | 7.2 | 1.08 | 0.18 |
| | $V_2$ | 6240 | 48 | 4.6 | 7.4 | 1.25 | 0.17 | 4510 | 50 | 4.5 | 7.6 | 1.19 | 0.16 |
| | $V_3$ | 4690 | 50 | 4.3 | 7.6 | 1.23 | 0.10 | 4230 | 51 | 4.1 | 7.8 | 1.17 | 0.09 |

Source: Field experiment; $V_1$ - (Business-as-usual); $V_2$ - (50% recommended NPKSZn with bio-solids amendment) and $V_3$ - (No NPKSZn, 100% Bio-solid amendment); TP- Technical Potential; IF – Initiative Feasibility

In Dumuria upazila under Khulna district, *Boro* rice yield was 6120 kg, 6240 kg and 4690 kg/ha, respectively for treatment $V_1$ (business-as-usual), $V_2$ (50% recommended NPKSZn with bio-solids amendment) and $V_3$ (no NPKSZn, 100% Bio-solid amendment). Here soil porosity was 45%, 48% and 50%, salinity was 4.8, 4.6 and 4.3 dS/m, soil pH was 7.1, 7.4 and 7.6, %OC was 1.10, 1.25 and 1.23 and %TN was 0.20, 0.17 and 0.10 respectively for treatment $V_1$, $V_2$ and $V_3$. In *Aman* rice yield was 4470 kg, 4510 kg and 4230 kg/ha respectively for treatment $V_1$ (business-as-usual), $V_2$ (50% recommended NPKSZn with bio-solids amendment) and $V_3$ (No NPKSZn, 100% Bio-solid amendment). Here soil porosity was 47%, 50% and 51%, salinity was 4.7, 4.5 and 4.1 dS/m, soil pH was 7.2, 7.6 and 7.8, %OC was 1.08, 1.19 and 1.17 and %TN was 0.18, 0.16 and 0.09 respectively for treatment $V_1$, $V_2$ and $V_3$ (Table 3).

Table 4. Comparative assessment of wise yield and soil properties after amendment in Khulna

| Location s | Treatments for LCF | *Boro* | | | | | | *Aman* | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | IF | | | TP | | | IF | | | TP | | |
| | | Grain yield | Soil porosity | Ec (dS/m) | Soil pH | %OC | %TN | Grain yield | Soil porosity | Ec (dS/m) | Soil pH | %OC | %TN |
| Khulna (Koyra) | $V_1$ | 5530 | 43 | 4.6 | 7.2 | 1.04 | 0.19 | 4110 | 44 | 4.5 | 7.1 | 1.03 | 0.20 |
| | $V_2$ | 5820 | 46 | 4.4 | 7.4 | 1.15 | 0.16 | 4350 | 46 | 4.2 | 7.3 | 1.18 | 0.17 |
| | $V_3$ | 4490 | 47 | 4.1 | 7.5 | 1.19 | 0.08 | 3870 | 48 | 4.1 | 7.5 | 1.21 | 0.10 |

Source: Field experiment; $V_1$ - (Business-as-usual); $V_2$ - (50% recommended NPKSZn with bio-solids amendment) and $V_3$ - (No NPKSZn, 100% Bio-solid amendment); TP- Technical Potential; IF – Initiative Feasibility

In Koyra upazila under Khulna district, *Boro* rice yield (Table 3). 5530 kg, 5820 kg and 4490 kg/ha, respectively for $V_1$ (business-as-usual), $V_2$ (50% recommended NPKSZn with bio-solids amendment) and $V_3$ (no NPKSZn, 100% Bio-solid amendment) treatment. Here soil porosity treatment 43, 46 and 47%, salinity was 4.6, 4.4 and 4.1 dS/m, soil pH was 7.2, 7.4 and 7.5, %OC was 1.04, 1.15 and 1.19 and %TN was 0.19, 0.16 and 0.80 gradually for treatment $V_1$, $V_2$ and $V_3$. In *Aman* rice yield was 4110 kg, 4350 kg and 3870 kg/ha respectively for treatment $V_1$ (business-as-usual), $V_2$ (50% recommended NPKSZn with bio-solids amendment) and $V_3$ (No NPKSZn, 100% bio-solid amendment). Here soil porosity was 44%, 46% and 48%, salinity was 4.5, 4.2 and 4.1 dS/m, soil pH was 7.1 7.3 and 7.5, %OC was 1.03, 1.18 and 1.21 and %TN was 0.20, 0.17 and 0.10, respectively for the treatment $V_1$, $V_2$ and $V_3$ (Table 4).

Table 5. Comparative assessment of wise yield and soil properties after amendment in Satkhira

| Locations | Treatments for LCF | *Boro* (Robi Season) | | | | | | *Aman* (Kherif 2 Season) | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | IF | | | TP | | | IF | | | TP | | |
| | | Grain yield (kg/ha) | Soil porosity % | EC (dS/m) | Soil pH | %OC | T-N% | Grain yield (kg/ha) | Soil porosity % | EC (dS/m) | Soil pH | %OC | T-N% |
| **Satkhira** (Shamnogor) | $V_1$ | 4650 | 44 | 5.7 | 7.1 | 1.18 | 1.07 | 3990 | 47 | 5.4 | 7.2 | 1.05 | 0.16 |
| | $V_2$ | 4830 | 49 | 5.1 | 7.3 | 1.15 | 1.18 | 4270 | 50 | 5.2 | 7.4 | 1.13 | 0.13 |
| | $V_3$ | 4570 | 51 | 4.8 | 7.7 | 1.07 | 1.25 | 4010 | 51 | 4.9 | 7.7 | 1.19 | 0.06 |

Source: Field experiment; $V_1$ - (Business-as-usual); $V_2$ - (50% recommended NPKSZn with bio-solids amendment) and $V_3$ - (No NPKSZn, 100% Bio-solid amendment); TP- Technical Potential; IF – Initiative Feasibility

In Shamnagar upazila under Satkhira district, *Boro* rice yield was 4650 kg, 4830 kg and 4570 kg/ha, respectively for treatment $V_1$ (business-as-usual), $V_2$ (50% recommended NPKSZn with bio-solids amendment) and $V_3$ (no NPKSZn, 100% Bio-solid amendment). Here soil porosity was 44%, 49% and 51%, salinity was 5.7, 5.1 and 4.8 dS/m, soil pH was 7.1, 7.3 and 7.7, %OC was 1.18, 1.15 and 1.07 and %TN was 1.07, 1.18 and 1.25, respectively for treatment $V_1$, $V_2$ and $V_3$. In *Aman* rice yield was 3990 kg, 4270 kg and 4010 kg/ha, respectively for treatment V1 (business-as-usual), $V_2$ (50% recommended NPKSZn with bio-solids amendment) and $V_3$ (No NPKSZn, 100% Bio-solid amendment). Here soil porosity was 47%, 50% and 51%, salinity was 5.4, 5.2 and 4.9 dS/m, soil pH was 7.2, 7.4 and 7.7, %OC was 1.05, 1.13 and 1.19 and %TN was 0.16, 0.13 and 0.06, respectively for the treatment $V_1$, $V_2$ and $V_3$ (Table 5).

In Mongla upazila under Bagherhat district, *Boro* rice produced was 4750 kg, 5060 kg and 4470 kg/ha respectively for treatment $V_1$ (business-as-usual), $V_2$ (50% recommended NPKSZn with bio-solids amendment) and $V_3$ (no NPKSZn, 100%

Bio-solid amendment). Soil porosity was 43, 44 and 49%, salinity was 6.7, 6.3 and 5.9 dS/m, pH was gradually 7.3, 7.5 and 7.8, %OC was 1.05, 1.05 and 1.20 and %TN was 0.15, 0.13 and 0.09, for the treatment $V_1$, $V_2$ and $V_3$ respectively (Table 6)

Table 6. Comparative assessment of wise yield and soil properties after amendment in Bagherhat

| Locations | Treatments for LCF | *Boro* | | | | | | *Aman* | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | IF | | | TP | | | IF | | | TP | | |
| | | Grain yield (kg/ha) | Soil porosity % | Ec (dS/m) | Soil pH | %OC % | T-N% | Grain yield (kg/ha) | Soil porosity % | Ec (dS/m) | Soil pH | %OC % | T-N% |
| Bagherhat (Mongla) | $V_1$ | 4750 | 43 | 6.7 | 7.3 | 1.05 | 0.15 | 4340 | 45 | 5.5 | 7.2 | 0.89 | 0.13 |
| | $V_2$ | 5060 | 44 | 6.3 | 7.5 | 105 | 0.13 | 4410 | 46 | 5.9 | 7.4 | 1.12 | 0.12 |
| | $V_3$ | 4470 | 49 | 5.9 | 7.8 | 1.20 | 0.09 | 4070 | 47 | 6.1 | 7.5 | 1.10 | 0.09 |

Source: Field experiment; $V_1$ - (Business-as-usual); $V_2$ - (50% recommended NPKSZn with bio-solids amendment) and $V_3$ - (No NPKSZn, 100% Bio-solid amendment); TP- Technical Potential; IF – Initiative Feasibility

On the other hand, *Aman* rice production was 4340 kg, 4410 kg and 4070 kg/ha respectively for the treatment $V_1$, $V_2$ and $V_3$. Soil porosity was 45%, 46% and 47%, salinity was 5.5, 5.9 and 6.1, pH was gradually 7.2, 7.4 and 7.5, %OC was 0.89, 1.12 and 1.10 and %TN was 0.13, 0.12 and 0.09, for the treatment $V_1$, $V_2$ and $V_3$, respectively (Table 6).

**Storing carbon in the soil by LCF**

As the climate changes, farmers are facing many challenges such as, heavy and uneven distribution of raining, sudden drought and extreme temperature, storm, soil degradation by salinity intrusions and outbreak of new or different insect and diseases infestations. The low carbon agriculture would help to farmers to adapt on climate changes in various ways, such as high soil organic matter content and soil cover which have various advantages against nutrient and water related damages that increase soil capability to be more resilient to floods, droughts and soil degradation processes through salinity intrusions.

The farmers are adopting in LCF systems by applying cattle dung that have some extra advantages to increase crop resistance against insects and diseases along with increasing soil organic matter content. Moreover, it helps to develop soil fertility status and encourage farmers to introduce new cropping systems to adapt to climatic changed conditions. Besides, organic fertilization enables farmers to minimize risk of production and results a stable agro-ecosystems, economic yields, and lowers production costs.

## Conclusion

The climatic variability shocks of temperature, heavy rainfall, drought and salinity intrusion hampers *Boro* and *Aman* seasons. The farmers are more interested in maximum production profit by maintaining yields up to the optimal threshold levels. Among the 14 adaptation options found for *Boro* and *Aman* season in the study area, about 27% respondent farmers chose *Boro*-1 adaption option during the *Boro* season and 54% respondent farmers chose *Aman*-3 adaptation options during the *Aman* season. All the adaptation options have various advantages as sound agricultural systems, easy traceable to the extension worker in the farmhouse, etc. The $V_2$ (50% recommended NPKSZn with bio-solids amendment) treatment is found better than the treatments ($V_1$ and $V_3$) and in *Boro* and *Aman* yield. Organic fertilization helps farmers to minimize various probable risks resulting stable agro-ecosystems and ensure profitable yields by minimizing costs of production.

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## References

Ali, Y., & Meisner, C. (2017). Climate-smart agriculture in Bangladesh. In *Technical Report* (p. 29). https://doi.org/10.13140/RG.2.2.35102.84805

Anwar, M., & Zahan, T. (2023). *Climate-Smart Agriculture Technologies and Practices in Bangladesh*. https://www.researchgate.net/publication/376812477

Basak, J. K. (2010). Future fertiliser demand for sustaining rice production in Bangladesh: a quantitative analysis. *Unnayan Onneshan-The Innovators, Dhaka*.

Begum, K., Kuhnert, M., Yeluripati, J., Ogle, S., Parton, W., Kader, M. A., & Smith, P. (2018). Model based regional estimates of soil organic carbon sequestration and greenhouse gas mitigation potentials from rice croplands in Bangladesh. *Land*, *7*(3). https://doi.org/10.3390/land7030082

Busari, M. A., Kukal, S. S., Kaur, A., Bhatt, R., & Dulazi, A. A. (2015). Conservation tillage impacts on soil, crop and the environment. *International Soil and Water Conservation Research*, *3*(2), 119–129.

FAO. (2015). Food and Agriculture Organization of the United Nations. In *Food and Agriculture Organization of the United Nations Statistics Division (FAOSTAT).AO publications*. www.fao.org/publications

Hossain, M. M., & Ali, M. S. (2024). Climate Change Adaptation Initiatives in Bangladesh: Navigating Towards Resilience and Sustainability. In *International Law, Climate Change and Bangladesh* (pp. 45–69). Springer.

Keeney, D. R., & Nelson., D. W. (1982). Nitrogen—Inorganic Forms. *Methods of Soil Analysis. Part 2. Chemical and Microbiological Properties*, *5*(9), 643–698.

Majumder, M. K., Rahman, M. S., Mondal, R. K., & Akter, M. S. (2024). Climate-smart agriculture and food security in climate-vulnerable coastal areas of Bangladesh.

*Heliyon*, *10*(22). https://doi.org/10.1016/j.heliyon.2024.e39885

Miah, M., Jahiruddin, M., Islam, M. F., & Razia, S. (2005). Fertilizer recommendation guide-2005. In *Bangladesh agricultural research council Farmgate. New Airport Road. Dhaka-1215. 260p* (1st ed., Vol. 1, Issue 1).

Minamikawa, K., Sakai, N., & Yagi, K. (2006). Methane Emission from Paddy Fields and its Mitigation Options on a Field Scale. *Microbes and Environments*, *21*(3), 135–147. https://doi.org/10.1264/jsme2.21.135

Minar, M. H., Hossain, M. B., & Shamsuddin, M. D. (2013). Climate change and coastal zone of Bangladesh: Vulnerability, resilience and adaptability. *Middle East Journal of Scientific Research*, *13*(1), 114–120. https://doi.org/10.5829/idosi.mejsr.2013.13.1.64121

Nielsen, K. S., Stern, P. C., Dietz, T., Gilligan, J. M., van Vuuren, D. P., Figueroa, M. J., Folke, C., Gwozdz, W., Ivanova, D., Reisch, L. A., Vandenbergh, M. P., Wolske, K. S., & Wood, R. (2020). Improving Climate Change Mitigation Analysis: A Framework for Examining Feasibility. *One Earth*, *3*(3), 325–336. https://doi.org/10.1016/j.oneear.2020.08.007

Singh, J. S., Pandey, V. C., Singh, D. P., & Singh, R. P. (2010). Influence of pyrite and farmyard manure on population dynamics of soil methanotroph and rice yield in saline rain-fed paddy field. *Agriculture, Ecosystems and Environment*, *139*(1–2), 74–79. https://doi.org/10.1016/j.agee.2010.07.003

Sriphirom, P., Chidthaisong, A., & Towprayoon, S. (2019). Effect of alternate wetting and drying water management on rice cultivation with low emissions and low water used during wet and dry season. *Journal of Cleaner Production*, *223*, 980–988. https://doi.org/10.1016/j.jclepro.2019.03.212

Walkley, A., & Black, I. A. (1934). An examination of the Degtjareff method for determining soil organic matter, and a proposed modification of the chromic acid titration method. *Soil Science*, *37*(1), 29–38.

Wang, J., Mendelsohn, R., Dinar, A., Huang, J., Rozelle, S., & Zhang, L. (2009). The impact of climate change on China's agriculture. *Agricultural Economics*, *40*(3), 323–337. https://doi.org/10.1111/j.1574-0862.2009.00379.x

Watanabe, F. S., & Olsen, S. R. (1965). Test of an ascorbic acid method for determining phosphorus in water and NaHCO3 extracts from soil. *Soil Science Society of America Journal*, *29*(6), 677–678.

Williams, C. H., & Steinbergs, A. (1959). Soil sulphur fractions as chemical indices of available sulphur in some Australian soils. *Australian Journal of Agricultural Research*, *10*(3), 340–352.

Zewide, I., & Sherefu, A. (2021). Review paper on effect of micronutrients for crop production. *J. Nutr. Food Process*, *4*(7), 1–8.

Zhou G., Z. G., Gao SongJuan, G. S., Xu ChangXu, X. C., Dou FuGen, D. F., Shimizu, K., & Cao WeiDong, C. W. (2020). Rational utilization of leguminous green manure to mitigate methane emissions by influencing methanogenic and methanotrophic communities. *Geoderma*, *361*(114071 ref. 65), 65. https://doi.org/10.1016/j.geoderma.2019.114071