Challenges and Opportunities of Low-Carbon Rice Production Systems in Bangladesh

Sharif Ahmed[1], Humnath Bhandari[1], and Virender Kumar[1]

Author affiliation [1]International Rice Research Institute

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The Sustainable Farming science program will address key challenges in agri-food systems by fostering efficient production of nutritious foods and safeguarding the environment to create fair employment opportunities, as we simultaneously tackle climate change, soil degradation, pests, diseases, and desertification.

The program's goals include mitigating the effects of climate change and other shocks, reducing the environmental footprint of agriculture, and generating impact for five million farmers by introducing innovative solutions across two million hectares of land. Additionally, the program aims to minimize farm-related greenhouse gas (GHG) emissions by 15%.

Activities will be implemented in thirty-four focus countries Bangladesh, Benin, Burundi, Cambodia, Colombia, Côte d’Ivoire, Democratic Republic of Congo, Egypt, Ethiopia, Ghana, Guatemala, India, Kenya, Laos, Madagascar, Malawi, Mali, Mexico, Morocco, Mozambique, Nepal, Niger, Nigeria, Pakistan, Peru, Philippines, Rwanda, Senegal, Tanzania, Uganda, Uzbekistan, Vietnam, Zambia, Zimbabwe.

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Abbreviations and acronyms

GHG	Greenhouse Gas
NDC	Nationally Determined Contributions
AWD	Alternate Wetting and Drying
DSR	Direct Seeded Rice
IRRI	International Rice Research Institute
COP	Conference of the Parties
BRRI	Bangladesh Rice Research Institute
BINA	Bangladesh Institute of Nuclear Agriculture
UDP	Urea Deep Placement
RCM	Rice Crop Manager

Introduction

Rice covers 11% of the world's arable land and is responsible for approximately 1.5% of global anthropogenic GHG emissions and around 10-12% of total agricultural emissions. Bangladesh is one of the most rice-dependent countries (cultivates ~ 75 of its arable land) in the world, facing the dual challenge of ensuring food security while minimizing environmental impacts. The country has extensive rice cultivation covering approximately 11.5 million hectares (production ~39 million tons), significantly contributing to greenhouse gas emissions. In Bangladesh, rice cultivation is responsible for approximately 18-22% of the total anthropogenic GHG emissions, where the total agricultural emission (including livestock) is around 28-30%. In the agricultural sector, methane (CH_4) is the major contributor to the GHG emissions, where rice contributes around 62%. The contribution of rice to agricultural N_2O emissions is around 11-13%.

In 2018, Bangladesh developed the Nationally Determined Contributions (NDC) implementation roadmap and action plan, committing to reduce its emissions by 89.47 MtCO2e conditionally and 27.56 MtCO2e unconditionally by 2030, compared to a base year of 2012. The total GHG emission of Bangladesh was estimated 169.06 million tonnes in the base year, which is estimated to have increased to around 409.41 million tonnes by 2030.

In the agricultural sector, the major mitigation approaches are generally considered: reduction of emissions from rice fields, fertilizer use, enteric fermentation, and manure management. Among these, specific crop production strategies encompass upscaling alternate wetting and drying (AWD) in dry-season rice across approximately 150,000 hectares, rice varietal improvement for about 3.24 million hectares, and reducing nitrous oxide emissions from nitrogen-based fertilizer management to 836,000 hectares. Additionally, fertilizer management practices are being improved at 200,000 hectares, and efforts are being made to expand pulse cultivation to increase overall crop diversification.

While Bangladesh's share of global GHG emissions is minimal, its agriculture sector, especially rice production, which occupies 75% of agricultural land, significantly contributes to the global methane issue. Transitioning to low-carbon-emission rice farming systems presents a promising pathway for sustainable agriculture, climate mitigation, and improved rural livelihoods. GHG emissions from rice cultivation could be minimized by adopting several low-emission rice production technologies. This article explores the key challenges and opportunities associated with developing and implementing low-emission rice production practices in Bangladesh, focusing on innovative methods such as alternate wetting and drying (AWD), direct-seeded rice (DSR), the use of short-duration rice varieties, and advanced fertilizer management techniques such as urea deep placement.

Alternate wetting and drying (AWD) irrigation systems

AWD is an effective water management technique where farmers can intermittently dry their rice fields, avoiding continuous flooding that significantly reduces water use and greenhouse gas (GHG) emissions, particularly methane (CH_4), by inhibiting methane-producing bacteria. This practice increases water productivity and can reduce irrigation costs without compromising or even improving rice yields. Studies show that AWD can decrease water consumption in rice cultivation by up to 40% and reduce methane emissions by up to 50%, depending on conditions.

AWD was first introduced in Bangladesh in 2004 with the support of the IRRI, and the first trials were conducted by BRRI. Since the introduction, the adoption rate of AWD in Bangladesh has not been widespread. Less adoption of AWD in Bangladesh is due to the lack of economic incentives for farmers for water saving, as irrigation is often charged per area rather than volume, and the lack of flexible irrigation controls, unreliable electricity for pumps, the high costs associated with managing increased weed growth that comes with the practice, chance of large soil cracks consequently require more water, strong policy, and insufficient knowledge among farmers about the technology's full benefits and proper implementation.

Photo 1: A field in Rajshahi, Bangladesh, practiced AWD and measured GHG emissions. Photo credit: Abdul Haque, IRRI

The primary focus of AWD was on water conservation before COP 21 in 2015. At this conference, participating countries committed to limiting global warming to well below 2 °C above pre-industrial levels, with a preference for capping it at 1.5°C. This commitment involves reducing greenhouse gas emissions, adapting to the impacts of climate change, and increasing financial support for developing nations. During

COP 21, countries were also encouraged to develop and submit their own nationally determined contributions (NDCs) for cutting emissions and to update these regularly to enhance their commitments. After COP 21, with water saving, AWD became a significant aspect of greenhouse gas mitigation tools.

Bangladesh is already committed to its NCD to upscaling AWD in dry-season rice across approximately 150,000 hectares of land. But to date, it looks like the adoption rate is low, and it has previously been mentioned that the possible reasons. Our suggestions for overcoming the adoption barriers are:

- Suitability mapping is essential for identifying areas where AWD is feasible and effective. While *Aman* (wet-season rice) relies on rainfall, it is generally unsuitable for AWD due to unpredictable rainfall and uncontrolled water conditions. *Boro* (dry-season rice) is the most appropriate choice for AWD application. However, there are specific regions, such as *Haor* and saline, where AWD may not be practical even in *boro*. Conducting suitability mapping, which considers factors like land type, irrigation systems, and soil type, facilitates the quicker adoption of AWD.
- Raising nationwide awareness about AWD is essential to encourage its widespread adoption among farmers. Many farmers practice intermittent drainage unknowingly of AWD, but with the lack of knowledge, they miss out on its full benefits. Awareness and educating farmers about its advantages can significantly improve water use efficiency and reduce GHG. Strong policies supporting AWD, along with extension services and training, are vital for its wider adoption.
- Incentives or carbon credits can motivate farmers to adopt AWD by providing financial benefits for water-saving practices.
- Effective collaboration, cooperation, and mutual support among pump owners, local leaders, and the farming community are essential.

Direct-seeded rice (DSR)

DSR is considered a climate-smart rice production technology due to it has the potential to cut methane emissions, a major contributor to GHG emissions from flooded rice, resulting in a lower global warming potential. In addition to GHG reduction, it also has the potential to save energy, water, and labor. Rice-growing South-East Asian countries (e.g., Cambodia, Vietnam, Malaysia, Thailand) have already shifted their major rice production systems to DSR. Compared to puddled and flooded rice, it has the potential to reduce GHG emissions by up to 70%, even higher than the AWD in flooded rice.

Photo 2: An *Aman* DSR field in Nilphamari, Bangladesh, where farmers cultivated mechanized DSR in 200 acres of land from the Sustainable Farming program in 2025. Photo credit: Bappy Kumar, IRRI

In Bangladesh, a traditional form of DSR known as broadcasting rice has largely been replaced by puddled and flooded rice cultivation. Currently, only about 8% of rice cultivation utilizes DSR, primarily in the form of broadcasting rice. When researchers discuss DSR, a common concern is why we would reconsider this practice, given that it is often associated with lower yields and higher weed infestations. However, this is not the case for modern DSR. By employing improved rice varieties, mechanized seeding, effective chemical weed control, and better agronomic practices, studies have shown that well-managed DSR can yield results comparable to transplanted rice. Additionally, it offers other benefits, including reduced labor, less water usage, and lower emissions. In addition, it can be established without sufficient rainfall in *aman* resulting in an advanced season, which helps in crop intensification. Despite these advantages, several reasons contribute to the low adoption of modern DSR in Bangladesh:

- **Boro:** winter season rice cultivates 40% areas. The initial couple of months of this season temperature remains low. The risk of seedling emergence and damage due to cold is a major hindrance to DSR establishment in the *boro* season.
- **Aman:** Rainy season rice cultivars in 50% areas. Crop establishment through DSR is at high risk of seed mortality due to certain excessive rain and flooding. Soils may also be too wet or flooded to permit mechanical seeding.
- **Aus:** Comparatively suitable for DSR, but the *aus* season covers only around 10% of areas.
- Lack of technical knowledge among farmers on modern DSR.
- Less research and extension work on it.

Opportunities for DSR adoption

- Needs cold-tolerant short-duration rice varieties for *boro* and anaerobic gemination ability variety for *aman*.
- Availability of suitable seed drills for DSR
- Community-based and synchronized DSR production
- Suitability mapping of DSR areas
- DSR-based cropping systems development
- Socio-economic impact study on DSR
- Work with the irrigation pump owner
- Farmers' training and capacity development
- Farmers' incentives and carbon credit
- Include DSR as a priority work in the next NDC plan.

Short-duration rice varieties

Short-duration rice varieties can significantly reduce methane emissions in rice cultivation by shortening the crop cycle. These varieties typically require less water and less time in the field, leading to reduced methane production and nitrous oxide emissions from fertilizer use. Additionally, early harvesting minimizes the period of anaerobic decomposition, further lowering emissions. Studies suggest that adopting short-duration varieties can reduce methane emissions by approximately 20-30%.

Photo 3: A field on the right side of the photo matured a short-duration rice variety (BRRI dhan75) earlier than the long-duration variety on the left side. This is the outcome of IRRI's crop intensification and diversification activities from the Sustainable Farming Program. Photo credit: Bappy Kumar, IRRI

The rice-rice is the dominant cropping pattern in Bangladesh, covering around 27% of the country's total area. However, in certain areas, especially in northern Bangladesh, this pattern covers over 50% of the land. In the *aman* season, farmers primarily cultivate long-duration rice varieties, which account for over 75% of the total areas. The most popular cultivar is the local *Gutiswarna*. In recent years, the Bangladesh Rice Research Institute (BRRI) and the Bangladesh Institute of Nuclear Agriculture (BINA) have developed several high-quality short-duration *aman* rice varieties, such as BRRI dhan75, BRRI dhan87, BRRI dhan103, and Binadhan-17. These new varieties yield similar results to the long-duration Gutiswarna but require roughly 20 to 30 days less to mature. If we can transition a significant portion of land from long-duration to short-duration rice varieties during the *aman* season, it could lead to a considerable reduction in greenhouse gas (GHG) emissions. Additionally, this shift would promote crop intensification and diversification during the dry season, contributing to carbon sequestration. In the boro season, many farmers also cultivate long-duration varieties, which typically take 150 to 170 days to mature. However, recent developments have introduced several short and medium-duration varieties (maturing in 130 to 150 days) that have strong yield potential, making it feasible to replace the long-duration varieties. In the 2018 NDC, Bangladesh already planned to convert 3.24 million hectares to improved varieties. Here, it is important to consider short-duration varieties when selecting improved varieties.

In the 2025 season, IRRI distributed 5,000 kg of short-duration *aman* variety seeds, specifically BRRI dhan75, to approximately 1,000 farmers practicing the rice-fallow-rice cultivation pattern in three northern districts: Rangpur, Nilphamari, and Dinajpur. Farmers were able to harvest their crops by October, enabling them to transition from fallow land to planting *rabi* crops. As a result, these farmers increased their annual crop production from two to three crops per year.
To know more about the short-duration varieties, visit the link at:
https://www.irri.org/news-and-events/news/unlocking-agricultural-diversification-and-intensification-northern-bangladesh

Fertilizer management: Urea deep placement (UDP)

Efficient nutrient management is crucial for reducing emissions while maintaining high yields. Conventional urea application via broadcasting often results in significant volatilization losses and inefficient nitrogen use, which can contribute to increased greenhouse gas emissions and environmental pollution. Applying fertilizers based on crop demand (e.g., RCM App by IRRI), soil testing, use of slow-release or coated fertilizers, deep placement of urea, and spraying of nano urea are possible options to increase nitrogen fertilizer efficiency and reduce emissions. Once, Bangladesh tried to expand *Guti* Urea but failed primarily due to a suitable applicator, supply chain issues, lack of information, soil type limitations, and higher labor costs for its application. Recently, BRRI developed Prilled urea deep placement innovations that involve inserting controlled amounts of urea into moist soil using an applicator, typically directly below the soil surface. This targeted approach improves nitrogen use efficiency by reducing volatilization and runoff, ultimately lowering GHG emissions. Limitations of the applicator is required line transplanting and maintaining a specific line-to-line distance. In Bangladesh, large-scale adoption of urea deep placement can significantly contribute to low-carbon rice systems, especially when integrated with site-specific fertilizer management and precision agriculture practices.

Photo 4: Prilled urea deep placement by using the BRRI-developed urea deep placement applicator. Photo credit: Kamruzzaman Milon, BRRI

Conclusion

Bangladesh is at a pivotal moment where sustainable, low-carbon rice production can enhance climate resilience, environmental protection, and economic stability. The country can reduce greenhouse gas emissions, conserve water, and boost productivity by adopting practices like AWD, DSR, short-duration rice cultivars, and advanced fertilizer management. Collaboration among policymakers, researchers, extension workers, and farmers is essential to achieve this. By overcoming barriers and promoting innovation, Bangladesh can ensure food security while safeguarding the environment for future generations.

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IRRI International Rice Research Institute