INITIATIVE ON
Transforming Agrifood Systems in South Asia

Energy Use and Global Warming Potential: Evaluating Diverse Cropping Systems

A Field Study in Chapainawabganj District in Bangladesh

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ABOUT THIS NOTE

The Barind Tract, located in the Chapainawabganj region of Bangladesh, spans 13,311 hectares of net cropped area (DAE 2023) and is characterized by a challenging agroecological environment. The areas are victim to high temperatures, limited soil moisture retention, and erratic, low rainfall, contributing to severe water stress. The region's soils are known for their poor drainage, low organic matter content, and susceptibility to drought, all leading to suboptimal crop productivity (Ali et al. 2018; Harun et al. 2017). In this context, addressing these issues through sustainable agricultural practices is crucial to enhance both productivity and resilience in the face of climate change. To tackle the agronomic challenges in Chapainawabganj, a participatory research trial was conducted from 2022 to 2023. The study explored diversified, intensified, and climate-resilient cropping system options, comparing them with traditional farming practices in the region. This brief highlights the key findings on energy use, global warming potential, and emission intensity from the study, offering insights into viable solutions for improving agricultural outcomes in this climate-sensitive area.

KEY STUDY FINDINGS

1. The study found that diversified and intensified cropping systems, like the Rice-Maize intercrop with red amaranth followed by sorghum as fodder, had the highest energy consumption and global warming potential among cropping systems in Chapainawabganj.
2. However, it also demonstrated the lowest emission intensity per unit of yield, mainly due to the high yield of maize.
3. These findings suggest that while intensified cropping systems may require more energy due to higher amounts of fertilizers and pesticides used to increase yield per unit area, they enhance energy efficiency and reduce yield-scaled emissions.
4. Therefore, optimizing energy use and minimizing global warming potential through these systems is essential for sustainable and climate-resilient agriculture.

BACKGROUND

The Barind Tract in Chapainawabganj, Bangladesh, is a crucial agricultural region facing significant environmental challenges, such as high temperatures, low rainfall, and limited soil moisture retention (Ali et al., 2018). Covering 128,342 hectares, it is highly vulnerable to climate impacts due to poor drainage and low organic matter, which result in reduced crop productivity. This emphasizes the urgent need for sustainable farming practices to enhance resilience and minimize environmental impact (Ali et al., 2018).

Agriculture is both a contributor and a victim of climate change effects, especially greenhouse gas emissions. Crop production alone accounts for 27% of global GHG emissions (Ritchie, Rosado, and Roser 2022). Agricultural GHG emissions are a critical concern in climate-sensitive areas like the Barind Tract. Methane (CH_4) emissions from waterlogged, anaerobic soils in rice fields and nitrous oxide (N_2O) emissions from excessive nitrogen-based fertilizers significantly contribute to the global warming potential (GWP) of agricultural systems (Feliciano et al. 2017). The region's reliance on conventional practices exacerbates GHG emissions due to inefficient energy use and inadequate management of soil and water resources. In response to these challenges, implementing climate-resilient and diversified cropping systems could provide pathways for reducing emissions, increasing energy-use efficiency, and mitigating climate change impacts.

Traditionally, Bangladesh's agricultural policies and research have focused on single-crop production, particularly rice, which dominates the region's landscape. However, this monoculture approach has proven increasingly inadequate in the face of climate change, which brings more unpredictable weather patterns, including intense droughts, floods, and temperature extremes. These changes exacerbate existing vulnerabilities, undermining food security and environmental sustainability. For example, the region's reliance on rice cultivation, which requires extensive water resources, has become more problematic as water availability decreases due to changing rainfall patterns and groundwater depletion. Furthermore, extreme weather events, such as erratic rainfall and rising temperatures, reduce crop yields and impact the quality of produce, making food systems more fragile and less resilient (Ali et al., 2018).

Additionally, there has been insufficient attention given to the development of integrated, evidence-based, multisectoral strategies that connect climate-resilient farming practices, markets, and policies. Such strategies are critical for ensuring that agricultural systems can adapt to the impacts of climate change while promoting both economic growth and nutritional security. The lack of coordination between agricultural practices and climate adaptation strategies has further hindered efforts to reduce greenhouse gas emissions and promote sustainable agriculture. As climate change continues to pose increasing challenges, it is essential to embrace diversified cropping systems and integrated solutions that can help mitigate the adverse effects of climate change and support long-term food security (Ali et al. 2018).

Agricultural production is a major contributor to global greenhouse gas (GHG) emissions, accounting for approximately 10-12% of worldwide emissions. Key GHGs from agriculture, including methane (CH_4) and nitrous oxide (N_2O), have global warming potentials significantly higher than carbon dioxide (CO_2), making them especially impactful on climate change. Methane emissions primarily stem from rice production in flooded conditions, as the anaerobic environment in waterlogged paddies encourages microbial processes that release CH_4. Nitrous oxide emissions are largely driven by synthetic and organic fertilizer use, with excess nitrogen from fertilizers often leading to N_2O emissions during soil microbial processes. These GHGs play a prominent role in climate change, contributing to rising temperatures, unpredictable weather patterns, and more frequent extreme weather events that in turn threaten agricultural productivity globally.

To address these issues, numerous studies have explored the mitigation of agricultural GHG emissions through optimized cropping systems, improved nutrient management, and efficient energy use. For example, studies indicate that conservation agriculture, crop diversification, and the adoption of precision agriculture technologies can reduce emissions while maintaining or even enhancing productivity. Research on GHG mitigations that are specific to regions is essential, as climate, soil, and cropping patterns have a significant impact on emission intensity. Additionally, advanced models like the CCAFS-Mitigation Options Tool developed by CGIAR climate scientists have been crucial in providing precise assessments of greenhouse gas emissions and energy use in agriculture, offering significant insights into strategies for mitigating these emissions.

In our study, we conducted researcher-managed trials on different cropping systems across 40 farmers' fields in two villages in Chapainawabganj district. We applied the BARC fertilizer recommendations and used the CCAFS-Mitigation options tool to calculate energy use, energy-use efficiency, global warming potential, and emission intensity for each cropping system. By quantifying emissions from these cropping systems, we aim to shed light on how different agricultural practices impact GHG emissions and identify effective mitigation strategies.

Above: A Farmer threshing rice during Kharif 2 (monsoon) 2023 (left), and a farmer spreading fertilizer in the field with crop residues as mulch (right), Bashbaria, Chapainawabganj, Bangladesh; photo: Juel Rana

OBJECTIVES

1. To quantify the GHG emissions produced by various cropping systems, including both methane and nitrous oxide contributions.
2. To assess energy use and energy-use efficiency across different cropping systems, providing insight into the role of efficient energy management in emission reduction.
3. To measure the global warming potential and emission intensity of each cropping system to understand its environmental footprint.
4. To contribute to the development of evidence-based policy measures that support sustainable agricultural practices, focusing on reducing GHG emissions through optimized fertilizer application and efficient energy use.

DATA AND METHODS

SITE DESCRIPTION

Researcher-managed and farmer-participatory field trials were conducted across rainfed and partially irrigated environments in the Barind Tract, Chapainawabganj district of northwest Bangladesh. The trials spanned three cropping seasons: the 2022-23 winter 'rabi,' pre-monsoon 2023 'kharif 1,' and monsoon 2023 'kharif 2.' The Barind Tract is known for its challenging agroecological conditions, including limited rainfall, high temperatures, and declining groundwater levels. These trials were set up to assess the potential of diversified and intensified cropping patterns in improving crop productivity and resilience under these environmental conditions.

TREATMENT SELECTION

The cropping patterns for the study were chosen through a participatory process involving 50 farm households in each village. Before the selection of the cropping patterns, a brief discussion was made among the participating farmers to address the importance of local demand, profitability, nutrition, and balanced diets. Farmers ranked various cropping options, and the three highest-scoring patterns were selected for the trials. These patterns were then compared against the existing common cropping pattern used in the region. This method ensured that the chosen cropping systems reflected farmer preferences, increasing the likelihood of adoption if the trials proved successful (Cheesman et al., 20212).

EXPERIMENTAL DESIGN

The on-farm research trials followed a random complete block design (RCBD), with 20 farm households serving as replicates within each village. Four cropping patterns (three diversified patterns and the farmers' traditional practice) were compared. The plot sizes ranged from 150 to 300 m^2 per treatment. Each of the selected cropping systems was implemented and managed across the different farms, ensuring that the trials accounted for local variations in soil, water availability, and other environmental factors.

CROP MANAGEMENT

The trials covered three distinct cropping seasons:

a. ***Kharif 1 (Pre-monsoon):*** The planting of crops such as sweet corn, sorghum, and cowpea occurred between February 15 and March 1-15, 2023.

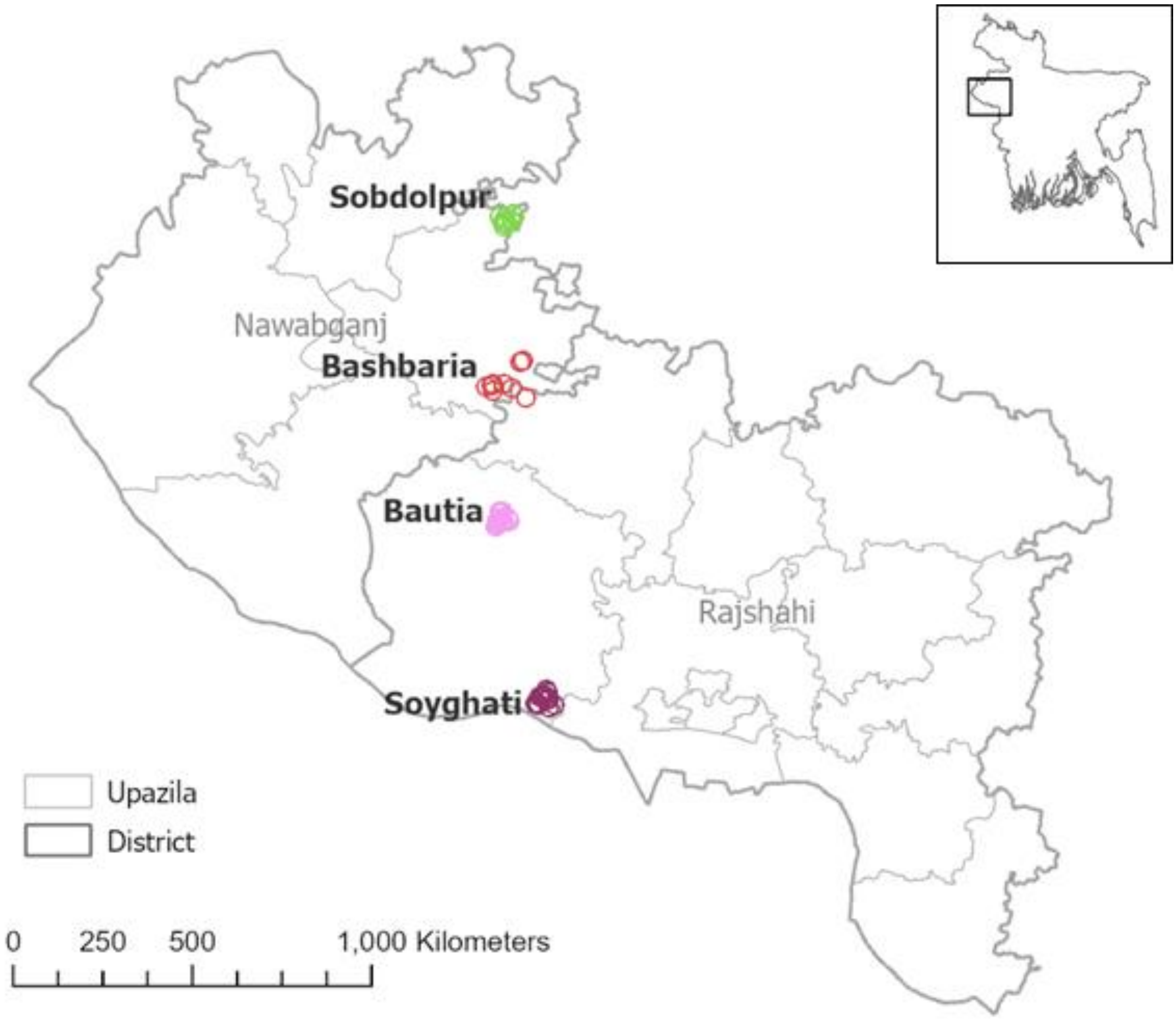

Figure 1: Small circles indicate the farmers' participatory trial fields at Bashbaria and Sobdolpur villages in Chapainawabganj district

Table 1: Treatments in Chapainawabganj district

Treatment code	*Kharif-2*	*Rabi*	*Kharif-1*
RLSc	Rice	Lentil	Sweet corn
RMraS	Rice	Maize+red amaranth	Sole sorghum (Fodder)
RCScp	Rice	Chickpea	Sorghum + cowpea (Fodder)
RWF	Rice	Wheat	Fallow

Table note: **RLSc:** Rice-Lentil-Sweet corn; **RMraS:** Rice-Maize intercrop with red amaranth-Sole sorghum (fodder), **RCScp**: Rice-Chickpea-Sorghum intercrop with cowpea (fodder), **RWF:** Rice-Wheat-Fallow.

b. *Kharif* 2 (Monsoon): Rice transplantation took place on August 20, 2024, using 20–25-day-old seedlings.

c. *Rabi* (Winter): Crops such as maize, lentil, and chickpea were sown between November 10 and November 20, 2023.

All crops were fertilized according to the recommendations in the Bangladesh Fertilizer Recommendation Guide (FRG 2018), and standard agronomic practices were implemented for managing weeds, pests, and irrigation. This approach ensured consistency in input management across all treatment plots, allowing for accurate comparisons of energy uses, yield, global warming potential, and yield scale greenhouse gases.

INPUT USE, YIELD, ENERGY USE, GLOBAL WARMING POTENTIAL, AND YIELD-SCALED GHG EMISSIONS

Data on input and labor use were collected for each treatment plot, covering activities viz. tillage, seedbed preparation, sowing, transplanting, irrigation, fertilizer and pesticide applications, hand weeding, harvesting, and threshing.

The CCAFS-mitigation options tool (CCAFS-MOT) is designed to evaluate the environmental impacts of agricultural practices, particularly in terms of energy use, global warming potential (GWP), and greenhouse gases (GHG) emission intensity. The model incorporates various factors related to agricultural inputs, practices, and outputs to determine how different farming practices contribute to energy consumption and climate change through GHG emissions. Here's a detailed discussion of how the model calculates these key parameters:

1. ENERGY USE CALCULATION

Energy use in agriculture refers to the total amount of energy consumed during the farming process. This includes direct energy inputs, such as fuel used for machinery, irrigation pumps, and transportation, and indirect energy from inputs like fertilizers, pesticides, and seeds (Sapkota et al, 2021).

Direct Energy Use: The CCAFS-MOT model first calculates the energy used by farming machinery (e.g., tractors, harvesters), fuel consumption for irrigation pumps, and energy consumed for other activities like transportation. The energy used for these activities is determined by multiplying the amount of fuel consumed by an energy factor (usually expressed in terms of energy per liter or kilogram of fuel).

Indirect Energy Use: The CCAFS-MOT also considers the energy embedded in agricultural inputs such as fertilizers, seeds, pesticides, and herbicides. For instance, producing fertilizers—especially nitrogen, phosphorus, and potassium fertilizers—requires significant amounts of energy, which is included in the total energy consumption. Each input is assigned an energy equivalence based on its composition and the energy required for its production. This indirect energy is calculated by multiplying the quantity of each input by its corresponding energy factor (e.g., energy per kilogram of fertilizer or pesticide).

The total energy use is then the sum of the direct and indirect energy inputs, providing a comprehensive estimate of the total energy consumption for the agricultural system being evaluated.

2. GLOBAL WARMING POTENTIAL CALCULATION

GWP quantifies the impact of different GHG emissions on global warming, relative to carbon dioxide (CO_2). Various GHGs have different GWPs, with methane (CH_4) and nitrous oxide (N_2O) being significantly more effective at trapping heat in the atmosphere than CO_2 over 100 years.

Methane: Methane (CH4) is primarily emitted from flooded rice fields due to anaerobic conditions that promote the microbial production of methane. The model calculates the methane emissions based on factors such as the area of rice fields, the duration of flooding, and organic matter content, as well as specific emission factors for methane from rice paddies (Yan et al. 2005).

Nitrous Oxide: Nitrous oxide (N2O) is emitted during the application of nitrogen fertilizers, both synthetic and organic. The model calculates N_2O emissions using fertilizer application rates, soil properties, and climate conditions. When excess nitrogen is applied, N_2O is produced through microbial processes like nitrification and soil denitrification. The emission factor for N_2O is typically provided based on the amount of nitrogen applied, and the model multiplies the fertilizer inputs by this factor to calculate N_2O emissions (Stehfest and Bouwman 2006).

Carbon Dioxide: Carbon dioxide (CO_2) emissions primarily arise from the combustion of fossil fuels (e.g., diesel for machinery) and soil organic matter decomposition. The tool accounts for CO_2 emissions from fuel consumption during field operations and also considers CO_2 released from the decomposition of organic materials in the soil, particularly when soil organic carbon is disturbed through tillage or other soil management practices (Ogle, Breidt, and Paustian 2005; Smith et al. 1997)

After calculating the individual emissions of CH_4, N_2O, and CO_2, the CCAFS-MOT computes the total GWP by multiplying the emissions of each gas by its respective GWP factor. The IPCC's standard values are typically used (Eggleston 2006):

1. CH_4 has a GWP factor of 25.
2. N_2O has a GWP factor of 298.
3. CO_2 has a GWP factor of 1.

Thus, the total GWP for a given agricultural system is calculated by summing the contributions of each gas, weighted by their respective GWP factors.

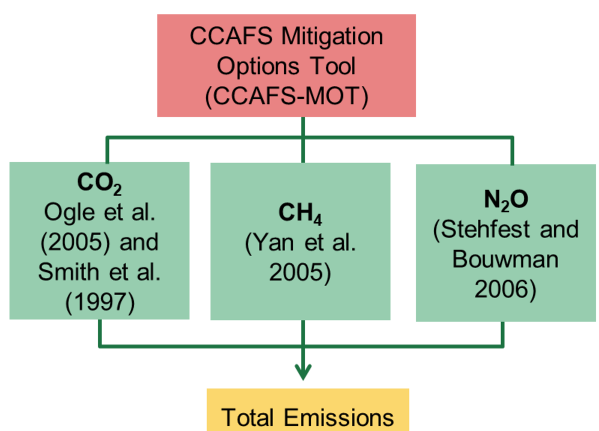

Figure 2: CCAFS-MOT models to estimate GHG emissions

3. GHG EMISSIONS INTENSITY CALCULATION

GHG emission intensity refers to the amount of GHG emissions produced per unit of agricultural output (e.g., crop yield) or input (e.g., energy consumption). This measure is critical in understanding the environmental efficiency of agricultural systems.

Emission Intensity per Crop Yield: The CCAFS-MOT model calculates the total GHG emissions for a particular cropping system (in terms of CO_2-eq) and divides it by the crop yield (Table 1, tone yield produced per hectare). This provides a measure of how much GHG is emitted for every unit of crop produced.

Statistical analysis

The data were analyzed using a randomized complete block design (RCBD), with the 20 farmer fields in each location serving as replications (random effect). Fixed effects included village, treatment (cropping pattern), and their interaction. The statistical analyses were performed using JMP14 (SAS Institute Inc., San Francisco). Means of the inputs and outputs across the cropping systems were compared using Tukey's Honestly Significant Difference (HSD) test at a significance level of $P \leq 0.05$ to determine if the differences in yields and economic returns were statistically significant (Gomez and Gomez 1984).

Table 2: Yield of component crops of cropping system options from field trials 2022-23, Chapainawabganj

Village	Cropping system	Crop yield (t ha^{-1})		
		Kharif 2	*Rabi**	*Kharif 1*
Bashbaria	RLSc	3.55	1.83	4.15
	RMraS	3.56	13.76 (4.6)	
	RCScp	3.55	1.91	
	RWF	3.55	4.07	
Sobdolpur	RLSc	3.86	2.00	4.42
	RMraS	3.87	13.73 (5.4)	
	RCScp	3.85	1.85	
	RWF	3.84	3.88	

Table note: **RLSc:** Rice-Lentil-Sweet corn; **RMraS:** Rice-Maize intercrop with red amaranth-Sole sorghum (fodder), **RCScp**: Rice-Chickpea-Sorghum intercrop with cowpea (fodder), **RWF:** Rice-Wheat-Fallow.

Above: Farmers preparing land by two-wheel tiller (top) and during final land preparation applying basal fertilizer (bottom) in Bashbaria, Chapainawabganj, Bangladesh; Photo: Shanto

STUDY FINDINGS

4.1 TOTAL ENERGY USE

In the studies, total energy use varied significantly across cropping systems, influenced by agronomic management and cropping intensity. The Rice-Maize intercropped with red amaranth followed by sorghum (RMraS) system required the highest energy input (3,028 Mj ha^{-1}), primarily due to the intensive management practices associated with maize cultivation during the rabi season and the subsequent sorghum crop. These practices, including frequent irrigation and high fertilizer application rates, contribute to the system's elevated energy demand.

Conversely, the Rice-Chickpea-Sorghum+Cowpea (RCScp) system utilized less energy, benefiting from the inclusion of legumes like chickpeas and cowpeas, which require lower nutrient inputs, especially nitrogenous fertilizer. The Rice-Lentil-Sweet corn (RLSc) system also demonstrated moderate energy use due to the relatively lower input requirements for lentils. The Rice-Wheat-Fallow (RWF) system had the lowest energy use (Figure 3, 4, and Table 3) largely owing to the absence of a crop during the fallow season, which minimized resource utilization.

These findings highlight the trade-offs between productivity and energy efficiency. While systems like RMraS incur higher energy costs, they deliver greater yields, suggesting that energy efficiency must be evaluated alongside other metrics to determine the overall sustainability of cropping systems.

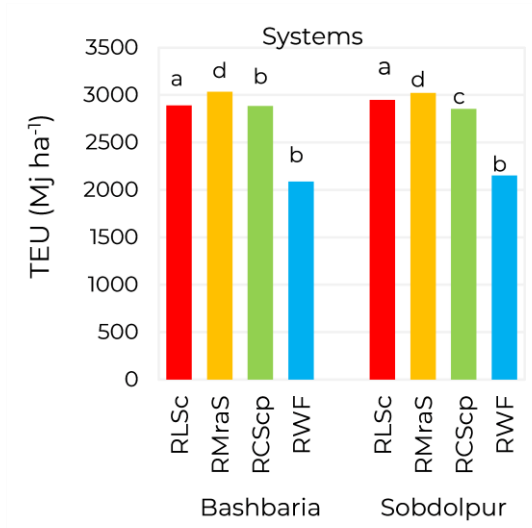

Figure 3: Total energy use by cropping Systems in Bashbaria and Sobdolpur villages, Chapainawabganj, 2022-23. The means of cropping system options followed by the different lower-case letter (s) in bars are significantly different (at p<0.05) according to Tukey's HSD test.

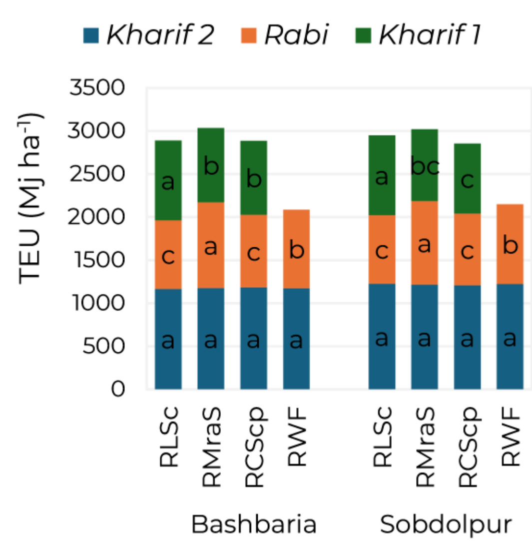

Figure 4: Total energy use by component crops in different cropping systems Bashbaria and Sobdolpur villages, Chapainawabganj, 2022-23, Means of component crops of a season in cropping system options followed by the different lower-case letter (s) in the same color bars are significantly different (at p<0.05) according to Tukey's HSD test.

Figure note: **RLSc**: Rice-Lentil-Sweet corn; **RMraS**: Rice-Maize intercrop with red amaranth-Sole sorghum (fodder), **RCScp**: Rice-Chickpea-Sorghum intercrop with cowpea (fodder), **RWF**: Rice-Wheat-Fallow.

4.2 GLOBAL WARMING POTENTIAL

Global warming potential (GWP) quantifies the greenhouse gas emissions generated by agricultural activities, including methane (CH_4) and nitrous oxide (N_2O), which are particularly prominent in rice-based systems (Feliciano et al. 2017; Krupnik et al. 2022).

The study revealed significant differences in GWP among cropping systems, reflecting the variability in emissions due to management practices and crop characteristics. The RMraS system exhibited the highest GWP (0.63 kg CO2 eq kg-1 yield). This was primarily driven by the highest dose nitrogen fertilizer applications during the rabi season and the anaerobic conditions associated with rice cultivation in the kharif 2 season, which promote CH_4 emissions.

In contrast, the RLSc and RCScp systems demonstrated lower GWP levels, benefiting from the reduced use of synthetic fertilizers and the inclusion of legumes that contribute to nitrogen fixation (Figure and able). The RWF system recorded the lowest GWP due to its reduced input use and the absence of emissions during the fallow period (Figure and Table).

These results emphasize the environmental challenges associated with high-input systems like RMraS. While they deliver higher productivity, targeted interventions, such as improved nitrogen-use efficiency and alternate wetting and drying techniques for rice, are necessary to mitigate their environmental impact.

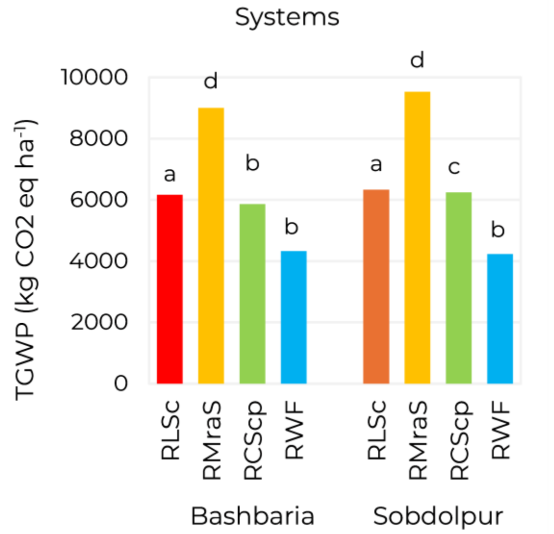

Figure 5: Total global warming potential (TGWP) by different cropping systems in Bashbaria and Sobdolpur villages, Chapainawabganj, 2022-23. The means of cropping system options followed by the different lower-case letter (s) in bars are significantly different (at p<0.05) according to Tukey's HSD test.

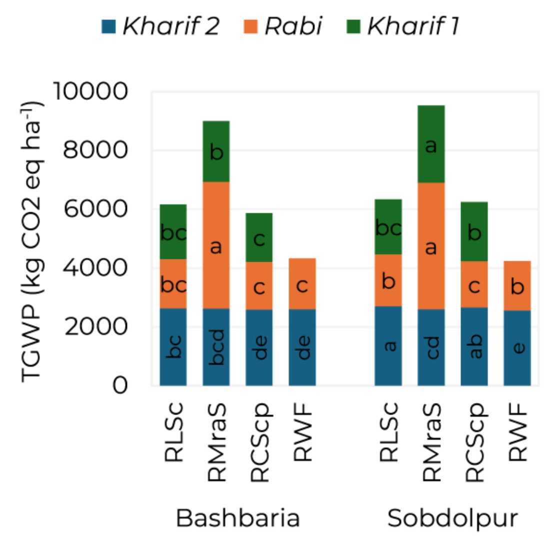

Figure 6: Total global warming potential (TGWP) by component crops in different cropping systems in Bashbaria, and Sobdolpur, Chapainawabganj,2022-23, Means of component crops of a season in cropping system options followed by the different lower-case letter (s) in the same color bars are significantly different (at p<0.05) according to Tukey's HSD test.

Figure note: **RLSc**: Rice-Lentil-Sweet corn; **RMraS**: Rice-Maize intercrop with red amaranth-Sole sorghum (fodder), **RCScp**: Rice-Chickpea-Sorghum intercrop with cowpea (fodder), **RWF**: Rice-Wheat-Fallow.

4.3 YIELD-SCALED EMISSION INTENSITY

Yield-scaled emission intensity provides a nuanced perspective on environmental efficiency, linking greenhouse gas emissions to crop productivity. This metric is particularly valuable for assessing the trade-offs between productivity and sustainability in diverse agricultural systems (Krupnik et al. 2022; Tirol-Padre et al. 2016; Gathala et al. 2016).

The RLSc system exhibited the highest emission intensity, reflecting its relatively moderate productivity compared to its emissions. Sweet corn, despite its market value, contributes less efficiently to yield relative to its resource use. The RCScp and the RWF system showed intermediate emission intensity levels, with productivity gains offsetting some of their emissions.

The RMraS system recorded the lowest emission intensity, showcasing its ability to balance high yields with relatively moderate GWP. This efficiency is attributed to the high-yielding nature of maize and sorghum, which ensures that the emissions are distributed across a larger output, enhancing the system's overall sustainability (Figure 7, 8 and Table 3)

These results highlight the importance of selecting cropping systems that optimize productivity and environmental impact. Diversified systems like RMraS, with their low emission intensity, provide a model for achieving sustainable agricultural intensification.

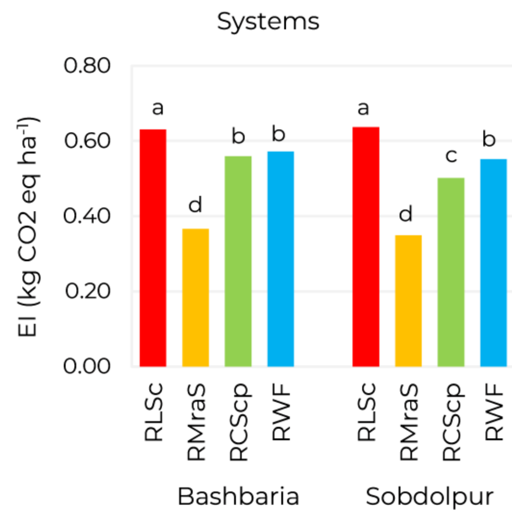

Figure 7: Yield scale emission intensity (EI) by cropping systems in Bashbaria, and Sobdolpur, Chapainawabganj, 2022-23. Means of cropping systems options followed by the different lower-case letter (s) on the bars are significantly different (at p<0.05) according to Tukey's HSD test.

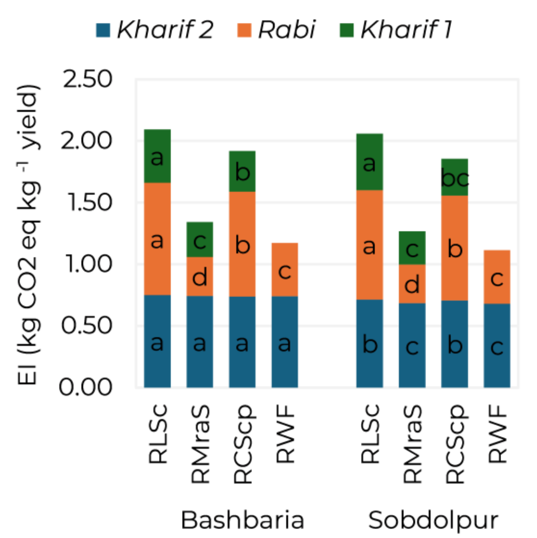

Figure 8: Yield scale emission intensity by component crops in different cropping systems in Bashbaria, and Sobdolpur villages, Chapainawabganj, 2022-23, Means of component crops of a season in cropping system options followed by the different lower-case letter (s) in the same color bars are significantly different (at p<0.05) according to Tukey's HSD test.

Figure note: **RLSc**: Rice-Lentil-Sweet corn; **RMraS**: Rice-Maize intercrop with red amaranth-Sole sorghum (fodder), **RCScp**: Rice-Chickpea-Sorghum intercrop with cowpea (fodder), **RWF**: Rice-Wheat-Fallow**.**

Table 3: Energy use (TEU), total global warming potential (TGWP), and yield-scaled emission intensity (EI) assessed by different cropping systems in Bashbaria and Sobdolpur village, Chapainawabganj district, 2022-23.

Source	TEU (Mj ha^{-1})				TGWP (kg CO_2 eq ha^{-1})				EI (Kg CO_2 eq kg^{-1} yield)			
	Kharif2	Rabi	Kharif1	System	Kharif2	Rabi	Kharif1	System	Kharif2	Rabi	Kharif1	System
Villages (V)												
Bashbaria	1174a	887a	885a	2946a	2609a	2332a	1866b	6808b	0.74a	0.63a	0.35a	0.53a
Sobdolpur	1218a	882a	858b	2958a	2629a	2327a	2177a	7133a	0.70a	0.62a	0.34a	0.51b
Cropping systems (T)												
RLSc	1197a	796d	927a	2920b	2664a	1719b	1870b	6253b	0.73a	0.90a	0.44a	0.63a
RMraS	1196a	983a	850b	3028a	2610b	4305a	2353a	9269a	0.71bc	0.31d	0.28b	0.36d
RCScp	1195a	839c	837c	2870c	2627b	1589c	1841b	6058c	0.72ab	0.85b	0.32c	0.53c
RWF	1197a	922b	-	2120d	2576c	1705b	-	4282d	0.71c	0.43c	-	0.56b
V × T												
Bashbaria, RLSc	1167a	796c	928a	2891bc	2630bc	1668bc	1869bc	6168c	0.75a	0.91a	0.43a	0.63a
Bashbaria,RMraS	1175a	995a	865b	3035a	2623bcd	4310a	2071b	9003b	0.74a	0.31d	0.29c	0.37d
Bashbaria,RCScp	1182a	843c	861b	2886bc	2591de	1617bc	1659c	5866d	0.74a	0.85b	0.33b	0.56b
Bashbaria, RWF	1172a	916b	-	2088d	2594de	1735bc	-	4328e	0.74a	0.43c	-	0.57b
Sobdolpur,RLSc	1227a	796c	926a	2949b	2698a	1769b	1871bc	6338c	0.71b	0.89a	0.46a	0.64a
Sobdolpur', RMraS	1217a	971a	835bc	3022a	2598cd	4300a	2636a	9534a	0.68c	0.31d	0.27c	0.35d
Sobdolpur, RCScp	1207a	834c	813c	2854c	2664ab	1562c	2024b	6249c	0.71b	0.85b	0.30bc	0.50c
Sobdolpur,RWF	1223a	929b	-	2151d	2559e	1676b	-	4235e	0.68c	0.43c	-	0.55b
Sources of variation	**Value of probability**											
V	0.069	0.195	0.003	0.445	0.075	0.877	<.001	0.001	0.107	0.335	0.360	0.005
T	0.981	<.001	<.001	<.001	<.001	<.001	<.001	<.001	<.001	<.001	<.001	<.001
V × T	0.117	0.012	0.013	<.001	<.001	0.131	<.001	<.001	<.001	0.089	0.013	<.001

Table note: RLSc: Rice-Lentil-Sweet corn; **RMraS**: Rice-Maize intercrop with red amaranth-Sole sorghum (fodder), **RCScp**: Rice-Chickpea-Sorghum intercrop with cowpea (fodder), **RWF**: Rice-Wheat-Fallow**.** Means of component crops and cropping systems options followed by the different lower-case letter (s) in the columns are significantly different (at $p<0.05$) according to Tukey's HSD test

CONCLUSIONS AND RECOMMENDATIONS

A comparative study of various cropping systems was conducted through a participatory experiment involving farmers from different locations in the Chapainawabganj district of Bangladesh. Four distinct cropping systems were tested: Rice-Lentil-Sweet corn, Rice-Maize intercropped with Red Amaranth and Sorghum as fodder, Rice-Chickpea-Sorghum intercropped with Cowpea as fodder, and Rice-Wheat-Fallow. Among these, the Rice-Wheat-Fallow system represents the common practice among local farmers, while the other three cropping systems offer more intensive and diversified alternatives.

The experiment was carried out on 40 farmers' fields in two villages, Basbaria and Sobdolpur in the Chapainawabganj district. The study measured total energy use global warming potential and yield scaled emission intensity, and analyzed the variance across these cropping systems, and locations.

The results revealed that the energy use of all the intensive and diversified alternative systems was significantly higher than that of the farmers' traditional Rice-Wheat-Fallow system. The Rice-Maize with intercrop with red amaranth-Sorghum system demonstrated the highest global warming potential (GWP) among all the cropping systems, achieving GWP between 108% and 125% higher than the Rice-Wheat-Fallow system. Likewise, the net returns of the intensified and diversified systems were significantly greater, with the Rice-Maize+red amaranth-sorghum system delivering the highest net return among all cropping systems. However, despite the second higher GWP, the Rice-Lentil-Sweet corn system is not feasible in this region due to the lack of market demand for sweet corn and its vulnerability to drought and hailstorms. In contrast, though the Rice-Maize intercropped with red amaranth-Sorghum system uses the highest energy use and produces the highest GWP, it reduces yield scaled emission intensity due to its highest economic yield, and also it appears more viable, given the high demand for maize and the ability to grow sorghum on fallow land before the monsoon season. Sorghum is in demand for silage preparation in dairy farming.

These results suggest that intensifying and diversifying rice-based cropping systems, compared to traditional systems like Rice-Wheat-Fallow, can sustainably enhance smallholder yield scaled emission intensity. However, a strong marketing strategy, especially for products like sweet corn and sorghum used in silage, is crucial for the success of these diversified cropping systems. These findings hold significant implications for marginal farmers in the area.

The findings also highlight the potential of systems incorporating legumes, such as Rice-Chickpea-S+Cowpea, to offer a middle ground between productivity and energy resource efficiency. By combining diverse crop options with targeted resource management strategies, agricultural systems can be tailored to meet the dual challenges of food security and environmental sustainability in regions like the Barind Tract.

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Above: Aman rice in Kharif 2 season in Sobolpur village, Rajshahi, Bangladesh; photo: Juyal Rana

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ABOUT TAFSSA

TAFSSA (*Transforming Agrifood Systems in South Asia)* is a CGIAR Regional Integrated Initiative to support actions that improve equitable access to sustainable healthy diets, improve farmers' livelihoods and resilience, and conserve land, air, and water resources in South Asia.

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