

Energy Use and Global Warming Potential: Evaluating Diverse Cropping Systems

A Field Study in Rajshahi
District in Bangladesh

Research note 56

December 2024

ABOUT THIS NOTE

The Barind Tract in the Rajshahi region of Bangladesh spans 18,4822 hectares. It is marked by challenging agroecological conditions, including high temperatures, low soil moisture retention, and erratic rainfall, leading to severe water stress. The area's soils have poor drainage and low organic matter, resulting in suboptimal crop productivity (DAE, 2023). To address these issues, a participatory research trial was conducted from 2022 to 2023, exploring diversified, intensified, and climate-resilient cropping systems compared to traditional practices. This brief summarizes key findings on energy use, global warming potential (GWP), and emission intensity, offering insights for improving agricultural outcomes in this climate-sensitive region.

KEY STUDY FINDINGS

1. The study revealed that diversified and intensified cropping systems, such as Rice-Mustard followed by sorghum intercropped with cowpea as fodder (RMuScp), used significantly more energy compared to the traditional Rice-Mustard-Fallow system in Rajshahi.
2. Additionally, the Rice-Maize system intercropped with red amaranth followed by sweet corn showed the highest global warming potential, mainly due to the high amount of fertilizer applied to the maize. However, this cropping system also demonstrated the lowest yield-scaled emission intensity because maize produced the highest yield.
3. These findings suggest that although intensified and diversified cropping systems may require more energy due to increased use of chemical fertilizers and pesticides, they improve energy use efficiency and lower yield-scaled greenhouse gas emissions by achieving higher yields.
4. Optimizing energy use, minimizing global warming potential, and reducing emission intensity through intensified and diversified cropping systems are crucial for promoting environmentally sustainable and climate-resilient agriculture.

BACKGROUND

The Barind Tract in Rajshahi, Bangladesh, is an agriculturally significant region that faces numerous environmental challenges, such as high temperatures, low rainfall, and limited soil moisture retention (Ali et al. 2018). Covering 128,342 hectares, this area is particularly vulnerable to climate impacts due to its poor soil drainage, low organic matter content, and high susceptibility to drought (DAE 2023). These conditions contribute to suboptimal crop productivity, creating an urgent need for sustainable agricultural practices that can enhance resilience and reduce the environmental footprint of farming in the region (Ali et al. 2018).

Agriculture is both a contributor and a victim to climate change effect 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 (CH₄) emissions from waterlogged, anaerobic soils in rice fields and nitrous oxide (N₂O) 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 (CH₄) and nitrous oxide (N₂O), have global warming potentials significantly higher than carbon dioxide (CO₂), 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 CH₄. Nitrous oxide emissions are largely driven by synthetic and organic fertilizer use, with excess nitrogen from fertilizers often leading to N₂O 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. Region-specific research on GHG mitigation is crucial, as climate, soil, and cropping patterns greatly influence emission intensity. Moreover, advanced models, such as the CCAFS-Mitigation Model developed by CGIAR climate scientists, have been instrumental in providing accurate assessments of GHG

emissions and energy use in agriculture, offering valuable insights into how these emissions can be mitigated.

In our study, we conducted researcher-managed trials on different cropping systems across 40 farmers' fields in two villages in Rajshahi district. We applied the BARC fertilizer recommendations and used the CCAFS-Mitigation Model (Feliciano et al. 2017) 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: Farmers uprooting seedlings of BINA dhan 20 (Biofortified) *Kharif 2*, (monsoon), 2023, Bautia, Rajshahi, Bangladesh; photo: Alamgir

OBJECTIVES

1. To quantify the GHG emissions produced by various cropping systems, including 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, Rajshahi 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 m² 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.

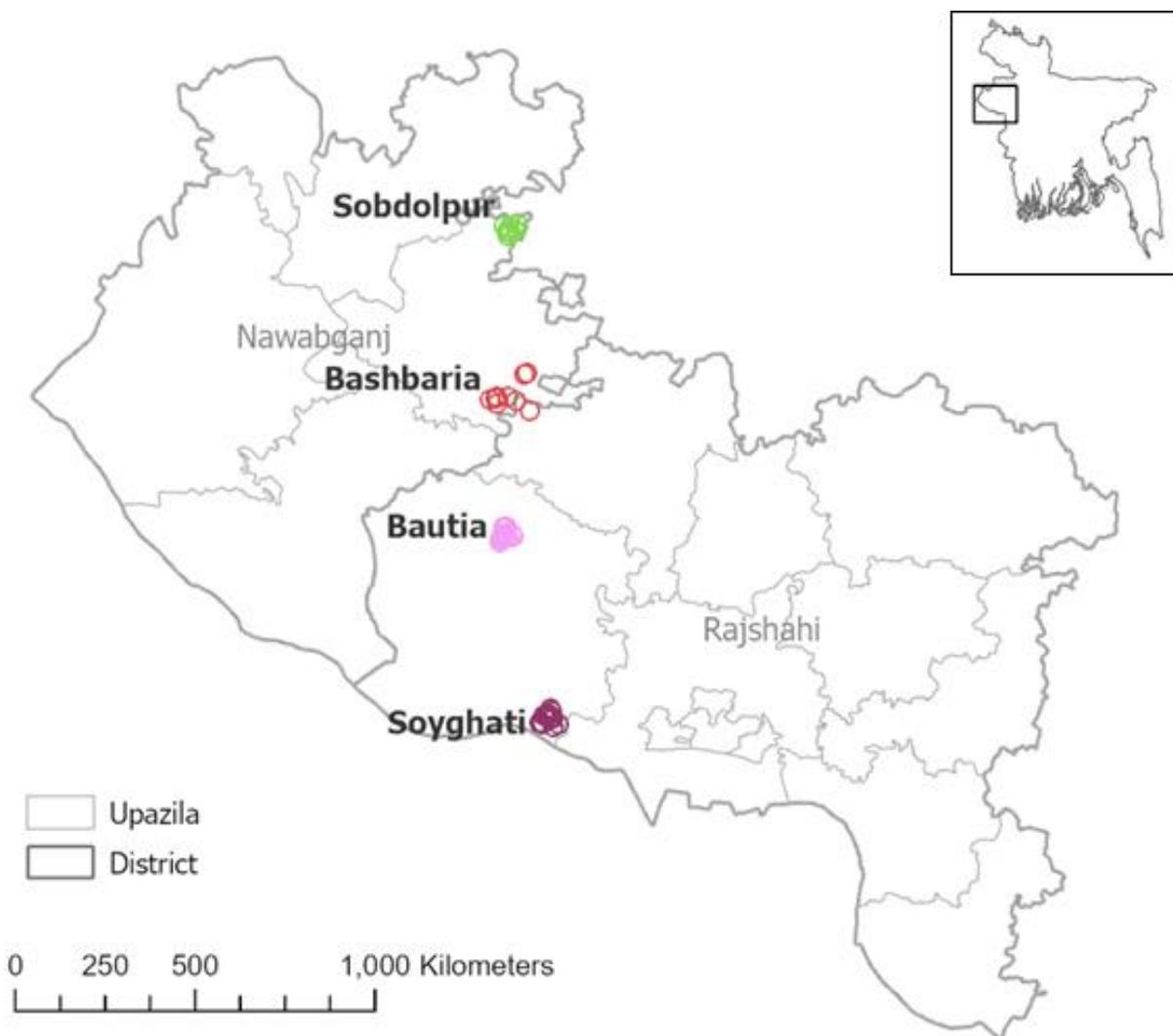


Figure 1: Small circles indicate the farmers' participatory trial fields at Bautia and Soyghati villages in Rajshahi district

Table 1: Treatments in Rajshahi district

Treatment code	<i>Kharif-2</i>	<i>Rabi</i>	<i>Kharif-1</i>
RLSc	Rice	Lentil	Sweet corn
RMraS	Rice	Maize+red amaranth	Sole sorghum (Fodder)
RMuScp	Rice	BARI Mustard 14	Sorghum + cowpea (Fodder)
RMuF	Rice	BARI Mustard 18	Fallow

Table note: **RLSc:** Rice-Lentil-Sweet corn; **RMraS:** Rice-Maize intercrop with red amaranth-Sole sorghum (fodder), **RMuScp:** Rice-Mustard (BARI 14) -Sorghum intercrop with cowpea (fodder), **MuF:** Rice-Mustard (BARI 18)-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 and mustard were sown between November 10 and November 20, 2023.

All crops were fertilized following the recommendations from the Bangladesh Fertilizer Recommendation Guide (FRG 2018), and standard agronomic practices were used for managing weeds, pests, and irrigation. This ensured uniformity in input management across all treatment plots, facilitating accurate comparisons of yield and economic performance.

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 gas (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 energy consumed throughout 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 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 model also considers the energy embedded in agricultural inputs like fertilizers, seeds, pesticides, and herbicides. For example, fertilizers (particularly nitrogen, phosphorus, and potassium fertilizers) require significant amounts of energy during their production, and this energy is factored into total energy use. Each input is assigned an energy equivalence based on its composition and production requirements. This indirect energy is calculated by multiplying the quantity of each input by its corresponding energy factor (e.g., energy per kg 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 (GWP) CALCULATION

Global warming potential is a measure of how much energy the emissions of a greenhouse gas (GHG) contribute to global warming compared to carbon dioxide (CO₂). Different GHGs have varying GWPs, with methane (CH₄) and nitrous oxide (N₂O) being much more potent than CO₂ 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 N₂O emissions using fertilizer application rates, soil properties, and climate conditions. When excess nitrogen is applied, N₂O is produced through microbial processes like nitrification and soil denitrification. The emission factor for N₂O is typically provided based on the amount of nitrogen applied, and the model multiplies the fertilizer inputs by this factor to calculate N₂O emissions (Stehfest and Bouwman 2006).

Carbon Dioxide: Carbon dioxide (CO₂) emissions primarily arise from the combustion of fossil fuels (e.g., diesel for machinery) and soil organic matter decomposition. The model accounts for CO₂ emissions from fuel consumption during field operations and also considers CO₂ 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 CH₄, N₂O, and CO₂, the CCAFS-MOT model 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. CH₄ has a GWP factor of 25.
2. N₂O has a GWP factor of 298.
3. CO₂ 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.

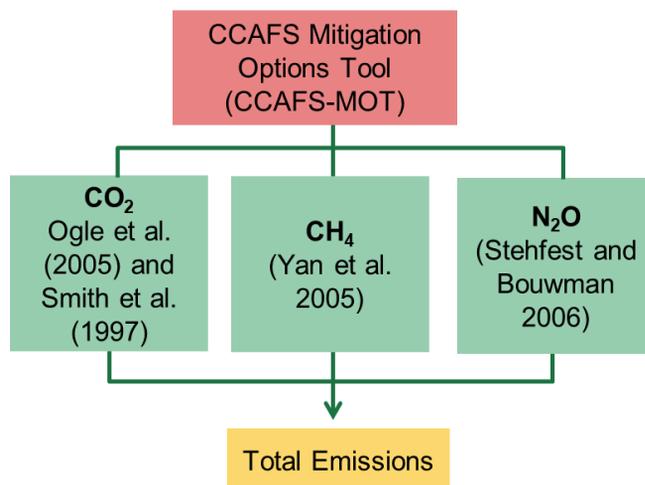


Figure 2: CCAFS-MOT models to estimate GHG emissions

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 CO₂-eq) and divides it by the crop yield (Table 2, 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, Rajshahi

Village	Cropping system	Crop yield (t ha ⁻¹)		
		<i>Kharif 2</i>	<i>Rabi*</i>	<i>Kharif 1</i>
Bautia	RLSc	2.86	1.83	4.15
	RMraS	2.75	12.16 (3.35)	6.5
	RMuScp	2.63	1.75	4.5 (2.5)
	RMuF	2.58	1.17	
Soyghati	RLSc	4.75	1.70	4.42
	RMraS	4.59 (4.35)	9.16 (4.35)	6.8
	RMuScp	4.54	1.87	4.7 (2.6)
	RMuW	4.34	1.32	



Above: Pudding for rice transplanting in *Kharif 2*, (monsoon), 2023, Bautia, Rajshahi, Bangladesh; photo: Alamgir

STUDY FINDINGS

4.1 TOTAL ENERGY USE

In this study, total energy use varied significantly across cropping systems and locations, influenced by the management intensity and crop combinations employed. The Rice-Mustard followed sorghum intercropped with cowpea as fodder (RMuScp) system required the highest energy input (3479 Mj ha⁻¹), primarily due to the intensive management practices associated with mustard cultivation during the Rabi season and the subsequent cowpea intercropped with sorghum crop (Figure 3, 4, and Table 3). These practices, including frequent irrigation and high fertilizer application rates, contribute to the system's elevated energy demand.

Conversely, the Rice-Lentil-Sweet corn (RLSc) system utilized lower energy among the diverse and intensified cropping systems, benefiting from the inclusion of legumes like lentils, which require lower nutrient inputs. The Rice-Mustard-Fallow (RMuF) system had the lowest energy use (Figure 1, and Table 2) largely owing to the absence of a crop during the fallow season, Kharif 1 (monsoon) which minimized resource utilization (Figure 3, 4, and Table 3).

These findings highlight the trade-offs between productivity and energy efficiency. While systems like RMraS incur 2nd 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 (Gathala et al. 2020).

Figure note: **RLSc:** Rice-Lentil-Sweet corn; **RMraS:** Rice-Maize intercrop with red amaranth-Sole sorghum (fodder), **RMuScp:** Rice-Mustard (BARI 14)-Sorghum intercrop with cowpea (fodder), **RMuF:** Rice-Mustard (BARI 18) -Fallow.

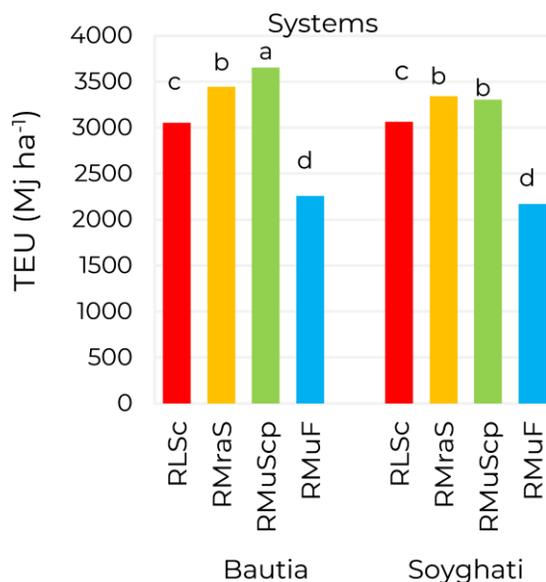


Figure 3: Total energy use by different cropping Systems in Bautia and Soyghati villages, Rajshahi, 2022-23. Means of cropping system options followed by the different lower-case letter (s) in bars are significantly different (at p<0.05) according to Tukey's

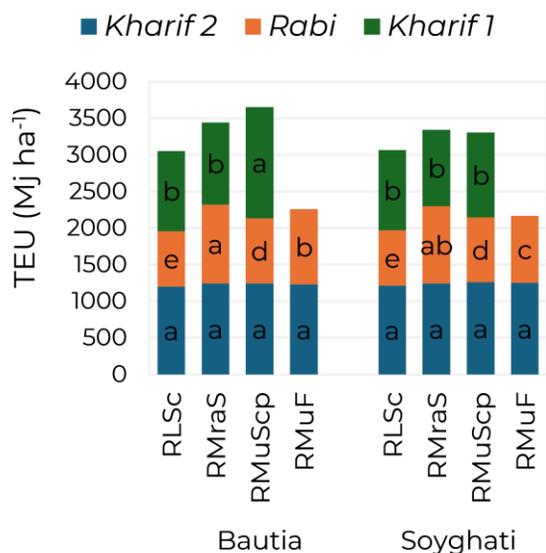


Figure 4: Total energy use by component crops in different cropping systems in Bautia and Soyghati villages, Rajshahi, 2022-23, Means of component crops of a season in cropping system options followed by the different lower-case letter (s) in the same color bars are significantly different (at p<0.05)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

4.2 GLOBAL WARMING POTENTIAL

Global warming potential (GWP) quantifies the greenhouse gas emissions generated by agricultural activities, including methane (CH₄) and nitrous oxide (N₂O), which are particularly prominent in rice-based systems (Feliciano et al. 2017; Krupnik et al. 2022).

The study revealed significant differences in GWP among locations and cropping systems, reflecting the variability in emissions due to management practices and crop characteristics. The RMraS system exhibited the highest GWP 8930 kg CO₂ eq ha⁻¹. This was primarily driven by the highest dose of nitrogen fertilizer applications during the rabi season and the anaerobic conditions associated with rice cultivation in the *kharif 2* season, which promote CH₄ emissions.

In contrast, the RLSc 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 RMuF system recorded the lowest GWP due to its reduced input use and the absence of emissions during the fallow period ((Figure 6, 6, and Table 3)

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 (Krupnik et al. 2022).

Figure note: **RLSc:** Rice-Lentil-Sweet corn; **RMraS:** Rice-Maize intercrop with red amaranth-Sole sorghum (fodder), **RMuScp:** Rice-Mustard (BARI 14)-Sorghum intercrop with cowpea (fodder), **RMuF:** Rice-Mustard (BARI 18) -Fallow.

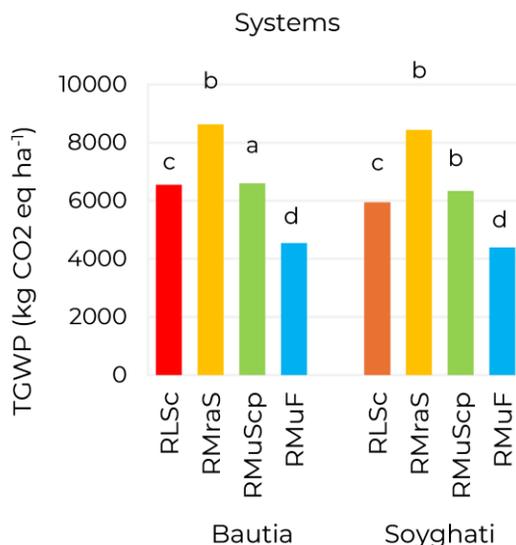


Figure 5: Total global warming (TGWP) by cropping Systems in Bautia and Soyghati villages, Rajshahi, 2022-23. Means of cropping systems options followed by the different lower-case letter (s) in bars are significantly different (at $p < 0.05$) according to Tukey's HSD test.

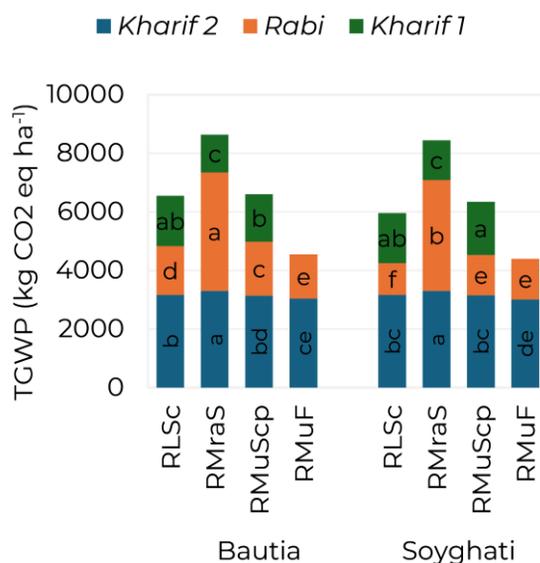


Figure 6: Total global warming potential (TGWP) by component crops in different cropping systems in Bautia and Soyghati villages, Rajshahi, 2022-23. Means of component crops of a season in cropping system options followed by the different lower-case letter (s) in the same color bars are significantly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

4.3 YIELD-SCALED EMISSION INTENSITY

Yield-scaled emission intensity (EI) provides a nuanced perspective on environmental efficiency, linking greenhouse gas emissions to crop productivity (Krupnik et al. 2022; Tirol-Padre et al. 2016; Gathala et al. 2016).

The EI varied significantly among locations and also different cropping systems due to variations in crop management, soil characteristics, and crop species. The RMuF system exhibited the highest emission intensity, reflecting its relatively lower productivity compared to its emissions. In the RLSc cropping system, there was 2nd higher EI, where sweet corn, despite its market value, contributes less efficiently to yield relative to its resource use. The RMuScp and the RMuF system showed intermediate levels of emission intensity, with productivity gains offsetting some of their emissions ((Figure 7, 8, and Table 3)

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 as fodder, which ensures that the emissions are distributed across a larger output, enhancing the system’s overall sustainability.

These results highlight the importance of selecting cropping systems that optimize both productivity and environmental impact. Diversified systems like RMraS, with their low emission intensity, provide a model for achieving sustainable agricultural intensification (Gathala et al. 2020).

Figure note: **RLSc:** Rice-Lentil-Sweet corn; **RMraS:** Rice-Maize intercrop with red amaranth-Sole sorghum (fodder), **RMuScp:** Rice-Mustard (BARI 14)-Sorghum intercrop with cowpea (fodder), **RMuF:** Rice-Mustard (BARI 18) -Fallow.

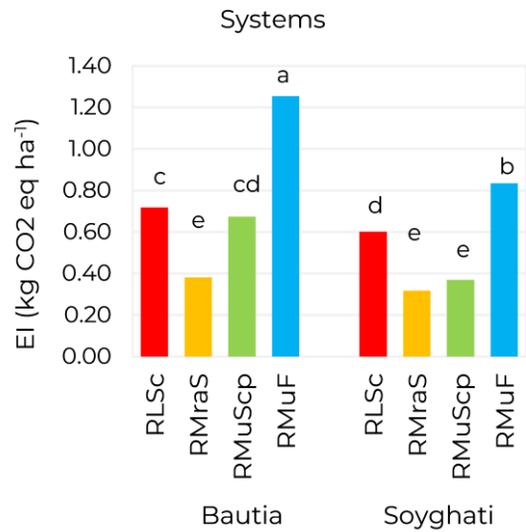


Figure 7: Yield scale emission intensity(EI) by cropping systems in Bautia and Soyghati villages, Rajshahi, 2022-23. Means of cropping system options followed by the different lower-case letter (s) on the bars are significantly different (at p<0.05) according to Tukey’s HSD test.

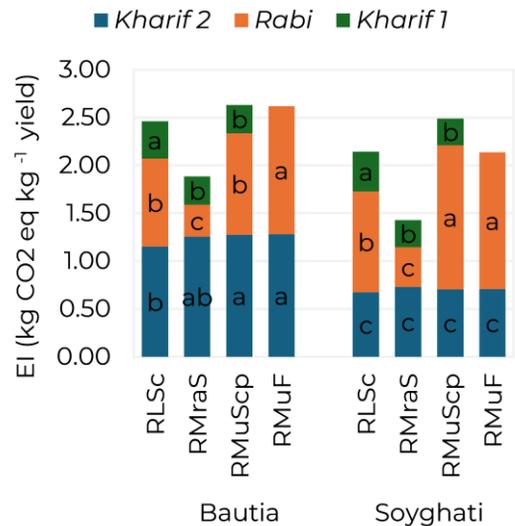


Figure 8: Yield scale emission intensity(EI) by component crops in different cropping systems in Bautia and Soyghati villages, Rajshahi, 2022-23. Means of component crops of a season in cropping system options followed by the different lower-case letter (s) in the same color bars are significantly different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

Table 3: Energy use, total global warming potential (GWP), and yield-scaled emission intensity (EI) assessed by different cropping systems in Bautia and Soyghati village, Rajshahi district, Rajshahi district, 2022-23

Sources of variation	TE (Mj ha ⁻¹)			GWP (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)												
Bautia	1229a	939a	1246a	3413a	3162a	2261a	1546b	7075a	1.24a	0.91b	0.33a	0.76a
Soyghati	1241a	904b	1099b	3245b	3156a	1909b	1624a	6842b	0.70b	1.10a	0.33a	0.56b
Cropping systems (T)												
RLSc	1206b	758d	1094b	3058c	3158b	1382c	1710a	6249c	0.91b	0.99c	0.40a	0.66b
RMraS	1242ab	1069a	1081b	3392b	3302a	3910a	1326b	8930a	0.99a	0.38d	0.29b	0.35d
RMuScp	1253a	884c	1342a	3479a	3147b	1604b	1718a	6469b	0.99a	1.28b	0.29b	0.52c
RMuF	1239ab	974b	-	2213d	3027c	1444c	-	4471d	0.99a	1.38a	-	1.04a
V × T												
Bautia, RLSc	1201a	758e	1094b	3053c	3159b	1670d	1717ab	6546bc	1.15b	0.92b	0.39a	0.72c
Bautia, RMraS	1241a	1081a	1121b	3443b	3304a	4033a	1298c	8635a	1.25ab	0.34c	0.29b	0.38e
Bautia, RMuScp	1245a	887d	1523a	3654a	3143bd	1836c	1621b	6600b	1.27a	1.06b	0.30b	0.67cd
Bashbaria, RMuF	1229a	1028b	-	2257d	3041ce	1503e	-	4544e	1.28a	1.34a	-	1.25a
Soyghati, RLSc	1211a	758e	1095b	3064c	3157bc	1094f	1702ab	5952d	0.67c	1.05b	0.42a	0.60d
Soyghati, RMraS	1242a	1057ab	1042b	3341b	3301a	3787b	1354c	8442a	0.73c	0.42c	0.28b	0.32e
Soyghati, RMuScp	1261a	882d	1161b	3304b	3152bc	1371e	1815a	6338c	0.71c	1.50a	0.28b	0.37e
Soyghati, RMuF	1250a	919c	-	2169d	3013de	1385e	-	4398e	0.71c	1.43a	-	0.84b
Sources of variation												
V	0.454	<.001	0.001	<.001	0.886	<.001	0.044	<.001	<.001	<.001	0.824	<.001
T	0.008	<.001	<.001	<.001	<.001	<.001	<.001	<.001	0.094	<.001	<.001	<.001
V × T	0.912	<.001	<.001	<.001	0.306	<.001	0.073	<.001	0.292	<.001	0.062	<.001

Table note: **RLSc:** Rice-Lentil-Sweet corn; **RMraS:** Rice-Maize intercrop with red amaranth-Sole sorghum (fodder), **RMuScp:** Rice-Mustard (BARI 14)-Sorghum intercrop with cowpea (fodder), **RMuF:** Rice-Mustard (BARI 18) -Fallow. Means of component 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 across various locations in the Rajshahi district of Bangladesh. Four different cropping systems were tested: Rice-Lentil-Sweet Corn, Rice-Maize intercropped with red Amaranth and Sorghum as fodder, Rice-Mustard-Sorghum intercrop with cowpea as fodder, and Rice-Mustard-Fallow. Among these, the Rice-Mustard-Fallow system represents the common practice of local farmers, while the other three cropping systems are intensive and diversified alternatives.

The experiment was carried out on 40 farmers' fields in two villages, Bautia and Soyghati in the Rajshahi district. The study measured total energy use, global warming potential, and 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-Mustard-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 90% and 92% higher than the Rice-Mustard-Fallow system. Likewise, the GWP of the intensified and diversified systems was significantly greater, with the Rice-Maize+red amaranth-sorghum system delivering the highest net return among all systems. However, despite the second

higher GWP, the Rice-Mustard-Sorghum intercropped with cowpea system has a great opportunity in this region due to the huge market demand for sorghum as fodder and its resilience to drought and hailstorms. In contrast, the Rice-Lentil-Sweet corn system demonstrated the lowest GWP and energy use and produced the highest emission intensity among the intensified and diversified cropping systems. RMuF shows yield-scaled highest emission intensity (EI) due to its lowest yield due to the absence of a crop in a monsoon season 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-Lentil-Sweet corn to offer a middle ground between productivity and energy resource efficiency. By combining diverse crop options with targeted resource management strategies (Krupnik et al. 2022), agricultural systems can be tailored to meet the dual challenges of food security and environmental sustainability in regions like the Barind Tract.

REFERENCES

- Ali, M. S., Rahman, S. M. M., Mohammad, A., Saha, S. B., Arif-Ul-Haque, S. A. M., Nazma, M., & Ahmed, A. (2018). Land use and land cover changes and their geo-environmental impacts in Nachole Upazila, under Chapai Nawabganj District of Bangladesh: A remote sensing and GIS approach. 6(9). <https://doi.org/10.5281/zenodo.1451859>
- Cheesman, S., Islam, M. S., Kurishi, A., Hossain, M. S., Fedous, M. Z., Huda, M. S., Gathala, M. K., & Krupnik, T. J. (2022). *TAFSSA on-farm research trials Bangladesh - Protocol for field implementation*. International Center for Maize and Wheat Improvement.
- Department of Agricultural Extension (DAE). (2023). *Cropping area 2023 in Chapainawabganj, Rajshahi*. Rajshahi: Ministry of Agriculture (MOA).
- Eggleston, H. S. (2006). *2006 IPCC guidelines for national greenhouse gas inventories*. Institute for Global Environmental Strategies. <http://www.ipcc-nggip.iges.or.jp>
- Feliciano, D., Nayak, D. R., Vetter, S. H., & Hillier, J. (2017). CCAFS-MOT - A tool for farmers, extension services, and policy advisors to identify mitigation options for agriculture. *Agricultural Systems*, 154, 100–111.
- Gathala, M. K., Laing, A. M., Tiwari, T. P., Timsina, J., Islam, S., Bhattacharya, P. M., Dhar, T., et al. (2020). Energy-efficient, sustainable crop production practices benefit smallholder farmers and the environment across three countries in the Eastern Gangetic Plains, South Asia. *Journal of Cleaner Production*, 246.
- Gathala, M. K., Timsina, J., Islam, M. S., Krupnik, T. J., Bose, T. R., Islam, N., Rahman, M. M., et al. (2016). Productivity, profitability, and energetics: A multi-criteria assessment of farmers' tillage and crop establishment options for maize in intensively cultivated environments of South Asia. *Field Crops Research*, 186, 32–46.
- Gomez, K. A., & Gomez, A. A. (1984). *Statistical procedures for agricultural research* (2nd ed.). New York: John Wiley and Sons.
- Harun, M., Rashid, A., Islam, A. B. M. J., Shirazy, B. J., & Shahidullah, S. M. (2017). Cropping systems and land use pattern in Rajshahi Region. *Bangladesh Rice Journal*, 21(2), 237–254.
- Krupnik, T. J., Hossain, M. K., Timsina, J., Gathala, M. K., Sapkota, T. B., Yasmin, S., Shahjahan, M., et al. (2022). Adapted conservation agriculture practices can increase energy productivity and lower yield-scaled greenhouse gas emissions in coastal Bangladesh. *Frontiers in Agronomy*, 4.
- Ogle, S. M., Breidt, F. J., & Paustian, K. (2005). Agricultural management impacts on soil organic carbon storage under moist and dry climatic conditions of temperate and tropical regions. *Biogeochemistry*, 72(1), 87–121.
- Ritchie, H., Rosado, P., & Roser, M. (2022). Environmental impacts of food production. *Our World in Data*.
- Sapkota, T. B., Khanam, F., Mathivanan, G. P., Vetter, S., Hussain, S. G., Pilat, A. L., Shahrin, S., et al. (2021). Quantifying opportunities for greenhouse gas emissions mitigation using big data from smallholder crop and livestock farmers across Bangladesh. *Science of the Total Environment*, 786.

Smith, P., Powlson, D., Glendining, M., & Smith, J. (1997). Potential for carbon sequestration in European soils: Preliminary estimates for five scenarios using results from long-term experiments. *Global Change Biology*, 3(1), 7–79. <https://doi.org/10.1046/j.1365-2486.1997.00055.x>

Stehfest, E., & Bouwman, L. (2006). N₂O and NO emission from agricultural fields and soils under natural vegetation: Summarizing available measurement data and modeling of global annual emissions. *Nutrient Cycling in Agroecosystems*, 74(3), 207–228.

Tirol-Padre, A., Rai, M., Kumar, V., Gathala, M., Sharma, P. C., Sharma, S., Nagar, R. K., et al. (2016). Quantifying changes to the global warming potential of rice-wheat systems with the adoption of conservation agriculture in Northwestern India. *Agriculture, Ecosystems & Environment*, 219, 125–137.

Yan, X., Yagi, K., Akiyama, H., & Akimoto, H. (2005). Statistical analysis of the major variables controlling methane emission from rice fields. *Global Change Biology*, 11(7), 1131–1141.



Above: Farmers threshing (left), and transplanting rice in the field (right), Soyghati, Rajshahi, Bangladesh; photo: Maruf Hossen Shanto



INITIATIVE ON

Transforming Agrifood
Systems in South Asia

AUTHORS

Saiful Islam, Research Coordinator, CIMMYT

Stephanie Cheesman, former Associate Scientist,
and Cropping Systems Agronomist, CIMMYT

Maruf Hossen Shanto, Agriculture Development
Officer, CIMMYT

Md. Arifur Rahaman, Research Associate, CIMMYT

Khaled Hossain, Research Associate, CIMMYT

Md. Shakhawat Hossain, Senior Scientific Officer,
On-Farm Research Division, BARI, Rajshahi

Mahesh Kumar Gathala, Senior Scientist and
Cropping System Agronomist, CIMMYT

Timothy J. Krupnik, Regional Director, Sustainable
Agrifood Systems Program, Asia, CIMMYT Country
Representative for Bangladesh

SUGGESTED CITATION

Islam, S., Cheesman, S., Shanto, M. H., Rahaman, M. A., Hossain, K., Hossain, M. S., Gathala, M. K., & Krupnik, T. J. (2024). *Energy use and global warming potential: Evaluating diverse cropping systems—A field study in Rajshahi District in Bangladesh* (Research Note 56). Transforming Agrifood Systems in South Asia (TAFSSA).

ACKNOWLEDGEMENTS

We would like to thank all funders who supported this research through their contributions to the CGIAR Trust Fund: <https://www.cgiar.org/funders/>

To learn more, please contact:
ms.islam@cgiar.org

To learn more about TAFSSA, please contact:
t.krupnik@cgiar.org; p.menon@cgiar.org

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.

ABOUT CGIAR

CGIAR is a global research partnership for a food secure future. Visit <https://www.cgiar.org/research/cgiar-portfolio> to learn more about the initiatives in the CGIAR research portfolio

DISCLAIMER

The views and opinions expressed in this publication are those of the author(s) and are not necessarily representative of or endorsed by CGIAR, centers, our partner institutions, or donors.

Generative AI was used to improve the grammar of this document