

Impact of Diverse Cropping Patterns on Greenhouse Gas Emissions

Assessing Energy Use Efficiency in
Rangpur District, Bangladesh

Research note 58

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ABOUT THIS NOTE

Bangladesh relies heavily on rice-based cropping systems to maintain food security. Additionally, crop diversification, which also contribute to enhance agricultural productivity and profitability in a nation with a high population density and scarce arable land. However, greenhouse gas emissions from the agricultural sector is remain unclear. On-farm research trials briefly summarize the results of greenhouse gas emissions from a diversified cropping systems after one full cropping cycle. This trial was conducted in the Chargonai and Shibdeb villages of the Rangpur district, addressing total global warming potential, total energy use, and emissions intensity, which are crucial for achieving TAFSSA's goals. Therefore, the trial aims to emphasize climate change effects to identify strategies to mitigate greenhouse gas emissions from agricultural land.

KEY STUDY FINDINGS

1. After successfully completing one full cropping cycle, it was noted that Shibdeb shows significantly higher global warming potential (GWP) of 8602 kg CO₂eq ha⁻¹ compared to Chargonai of 8168 kg CO₂eq ha⁻¹.
2. Shibdeb exhibits 7366 MJ ha⁻¹ slightly higher energy use (EU) than Chargonai 6695 MJ ha⁻¹.
3. Shibdeb has a higher emission intensity (EI) of 1.92 kg CO₂eq kg⁻¹ compared to Chargonai of 1.85 kg CO₂eq kg⁻¹.
4. Cropping pattern MAC (Maize-Aman-Carrot) had the highest GWP of 9787 kg CO₂eq ha⁻¹ and significantly exceeding all other treatments.
5. Cropping pattern GAN (Groundnut-Aman-Napa shak) had the lowest GWP of 7113 kg CO₂eq ha⁻¹, indicating better environmental performance.
6. MAC cropping pattern required the highest energy use of 7127 MJ ha⁻¹, while GAN was the lowest of 6753 MJ ha⁻¹.
7. The GAC showed the highest emission intensity of 2.05 kg CO₂eq kg⁻¹, whereas MAC had the lowest emission intensity of 1.61 kg CO₂eq kg⁻¹.

BACKGROUND

Climate change is one of the most significant challenges confronting our planet today. The increase in the emissions of greenhouse gases (GHGs), such as carbon dioxide (CO₂), nitrous oxide (N₂O), and methane (CH₄), have amplified the global warming potential (GWP) of the atmosphere (Alam et al., 2023). Although CH₄ and N₂O are emitted in smaller quantities than CO₂, they have a higher GWP than CO₂, their global warming potential is 21 and 298 times greater than that of CO₂ above hundred years, respectively (Chataut et al., 2023; Rahaman et al., 2021). Agriculture is responsible for roughly 12% of global anthropogenic GHG emissions. Total GHG emissions are projected to increase by around 50% from 2000 to 2030, leading to additional effects on weather and climate (Chataut et al., 2023). Agriculture is estimated to be responsible for more than 60% of anthropogenic N₂O emissions (Rahaman et al., 2021) and 70% of anthropogenic NH₃ emissions (Chataut et al., 2023), which are primarily caused by the application of livestock manure and chemical fertilizer, as well as around 38-53% of anthropogenic CH₄ which is primarily caused by enteric fermentation, manure management, rice cultivation (Global Methane Initiative, 2010; Smith et al., 2021). So, it is very urgent to mitigate GHG emissions from the agriculture land. Sometimes, it is very difficult to collect gas sample direct from the field due to unavailability of the equipment's or technical support. There are various methods available to estimate GHG emissions in the agriculture and forestry sectors. According to IPCC guidelines, several

software tools included the Cool Farm Tool, EX-ACT, USAID FCC, Holos, and ClimAgri® have recently been developed to assess GHG emissions from agricultural land at smaller scales. The CGIAR's Climate Change, Agriculture, and Food Security (CCAFS) research program promotes the development of accessible, science-driven decision-making tools to assist policy advisers in creating policies that effectively reduce GHG emissions in agriculture. This tool is called CCAFS-MOT (CCAFS-Mitigation Option Tool). Unlike other tools, the CCAFS-MOT estimates GHG emissions based on a specific baseline of management practices and ranks the most effective mitigation options for reducing GHG emissions (Feliciano et al., 2017). Therefore, an on-farm trial was conducted in the Kaunia and Pirgacha upazilas of the Rangpur district to identify the total global warming potential, total energy use, and emissions intensity to mitigate greenhouse gas emissions without crop yield penalty from agricultural land.

OBJECTIVES

Test, adapt, target and position agronomic technologies and practices supporting crop diversification across the region's farming systems. This study seeks to determine strategies that mitigate GHG emissions without risking food security. Preliminary results from the first year of diversified cropping pattern are described in this research brief.

RESEARCH QUESTIONS

At the farm level, can crop diversification be managed to reduce the greenhouse gas emissions while conserving natural resources.

DATA AND METHODS

The on-farm research trials in Rangpur district follow a randomized complete block design (RCBD) replicated with 20 farmer households within a village. Each trial farmer has 20-30 decimals (~800-1200m²) of their land to the on-farm trial. This area will be split equally to the four cropping patterns and each plot size is ~200 m². This area (~800-1200m²) would be in one piece or in different fields but not further apart than 50-100m. This on-farm research trials are hosted by smallholder farming households in two villages across Rangpur district of northern Bangladesh (Table 1).

The study selected cropping patterns based on the preferences of 50 farm households, who ranked their choices. The top three cropping patterns, as chosen by the farmers, were selected for comparison with the commonly used cropping pattern. In each village, three diversified cropping patterns *Maize-Aman-Carrot* (MAC), *Groundnut/peanut-Aman-Napa shak* (GAN), and *Groundnut/peanut-Aman-Carrot* (GAC) are being compared with the common farmer practice *Groundnut/peanut-Aman-Potato* (GAP) (Table 1).

We applied the CCAFS' Mitigation Options Tool (CCAFSMOT) (Feliciano et al., 2017) which includes set of empirical models to estimate GHG emissions associated with crop production system until the farm-gate level. This tool uses plot-level information on input and crop management from the trails and

corresponding soil and climatic information to estimate GHG emissions. We used a version of the CCAFS-MOT scripted in R 4.4.1 (R Core Team, 2024). Crop yield data were calculated based on the reference of Cheesman et al., 2022. Fuel use for land preparation as well as irrigation, were measured according to the farmer common practice. Only considered the energy used from diesel, not considered the energy from manual labor and other inputs or outputs. All GHGs were converted into CO₂-equivalent (CO₂eq) using 100-year global warming potential (IPCC, 2013). Yield-scaled emissions (YSE) /emission intensity (EI) for each treatment was determined as in Equation 1.

Rice fields produce three types of emissions such as N₂O, CO₂, and CH₄ emissions were estimated under various floodwater and irrigation conditions, depending on soil pH, climate, and the use of organic amendments or residues (Krupnik et al., 2022). N₂O emissions from fertilizer were based on Stehfest & Bouwman (2006), while CO₂ emissions from nutrients and irrigation were estimated by the (IPCC, 2006). For crops such as maize, carrot, napa shak, groundnut, and potato the model only estimated N₂O and CO₂ emissions, as these crops did not experience prolonged flooding, and no manure was applied, or crop residues were burned. Data have been computed for each of the three main cropping seasons in Bangladesh (*Kharif-1*, *Kharif-2*, *Rabi*) and combined to represent the entire cropping cycle.

$$\text{Yield-scaled emissions /Emission Intensity} = \frac{\text{Total GWP Kg CO}_2 \text{ ha}^{-1}}{\text{Grain yield Kg ha}^{-1}} \quad (\text{Eq. 1})$$

STATISTICAL ANALYSES

Statistical analyses were performed using R 4.4.1 (R Core Team, 2024). The data were analyzed separately for each seasons for using a Randomized Complete Block Design with 20 farmer's fields in each location considering replication as a random effect. The village, treatment, and their interaction are considered fixed effects (Gomez et al., 1984). The inputs and outputs of component of GWP, EU, YSE/EI for three different seasons and systems means were compared using Tukey's HSD significant difference test at $P \leq 0.05$. Data were expressed as the mean \pm standard error.



Above: Potato harvesting in Rangpur district; photo: Alanuzzaman Kurishi

Table 1: Villages hosting on-farm research trials and description of the diversified cropping patterns in Rangpur district.

District	Upazila	Union	Village	Latitude	Longitude	Treatment	Cropping pattern
Rangpur	Kaunia	Tepamadhupur	Chargonai	25.74775	89.46054	MAC	Maize-Aman-Carrot
	Kaunia	Tepamadhupur	Chargonai	25.74775	89.46054	GAN	Groundnut-Aman-Napa shak
	Kaunia	Tepamadhupur	Chargonai	25.74775	89.46054	GAC	Groundnut-Aman-Carrot
	Kaunia	Tepamadhupur	Chargonai	25.74775	89.46054	GAP	Groundnut-Aman-Potato
Rangpur	Pirgachha	Chhaola	Shibdeb	25.67345	89.50165	MAC	Maize-Aman-Carrot
	Pirgachha	Chhaola	Shibdeb	25.67345	89.50165	GAN	Groundnut-Aman-Napa shak
	Pirgachha	Chhaola	Shibdeb	25.67345	89.50165	GAC	Groundnut-Aman-Carrot
	Pirgachha	Chhaola	Shibdeb	25.67345	89.50165	GAP	Groundnut-Aman-Potato

Note: Aman (biofortified and short duration) refers to rice grown in the monsoon Kharif-2 season.



Above: On-farm trial, Md. Iman Ali, Pirgacha, Rangpur; photo: CIMMYT

STUDY FINDINGS

Global Warming Potential (GWP)

ANOVA revealed that Chargonai has a slightly higher GWP of 2193 kg CO₂eq ha⁻¹ compared to Shibdeb of 2186 kg CO₂eq ha⁻¹. This means that the GHG in Chargonai have a marginally higher warming effect than those in Shibdeb during the Kharif 1 season. While Chargonai has a slightly higher GWP than Shibdeb, the difference is statistically insignificant, indicating that both areas have very similar contributions to global warming during the Kharif 1 season. The significant difference in GWP between Chargonai (3786 kg CO₂eq ha⁻¹) and Shibdeb (4175 kg CO₂eq ha⁻¹) during the Kharif 2 season suggests that there are notable factors contributing to the

variation in GHG emissions between these two villages. The type of soil and its organic matter content could have been more conducive to CH₄ and N₂O production in Shibdeb fields. However, no significant results were produced between two villages in Rabi season. The significant difference in GWP between Chargonai (8168 kg CO₂eq ha⁻¹) and Shibdeb (8602 kg CO₂eq ha⁻¹) over a full cropping cycle suggests that the GHG emissions associated with these two systems differ, leading to a higher overall GWP for Shibdeb. This GWP reflects the cumulative impact of all GHGs released during the entire cropping process, from planting through to harvesting and post-harvest management (Figure 1 & Table 2).

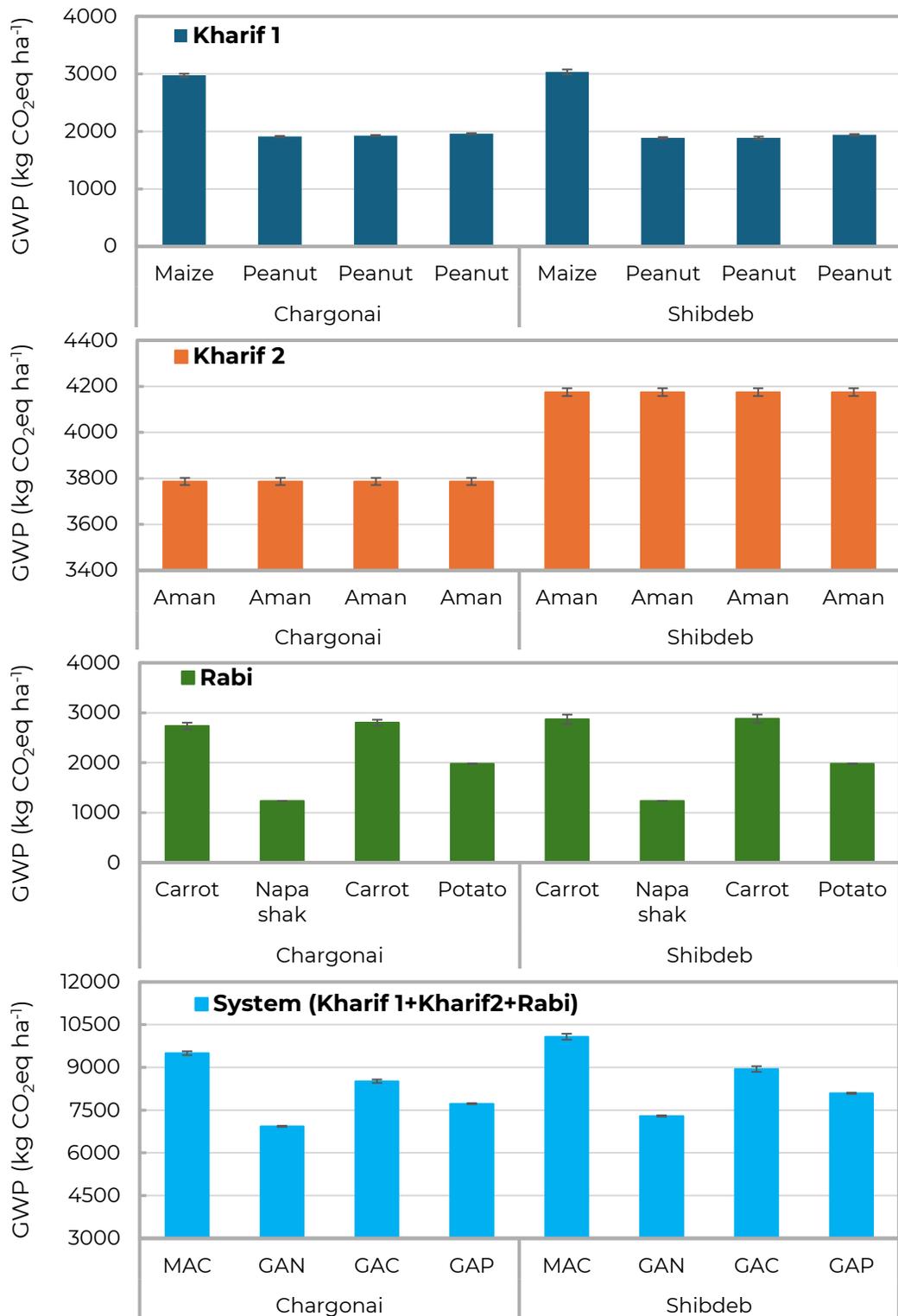


Figure 1: GWP (kg CO₂eq ha⁻¹) showing for different crop in Kharif1, Kharif2, Rabi season, and System (one full cropping cycle) by cropping pattern. MAC: Maize-Aman-Carrot; GAN: Groundnut/Peanut-Aman-Napa shak; GAC: Groundnut/Peanut-Aman-Carrot; GAP: Groundnut/Peanut-Aman-Potato.

The Global Warming Potential (GWP) values for the four cropping patterns during the Kharif 1 season are discussed here. The MAC (maize) cropping pattern recorded a GWP of 3004 kg CO₂eq ha⁻¹, GAN (groundnut) showed a GWP of 1899 kg CO₂eq ha⁻¹, GAC (groundnut) exhibited a GWP of 1908 kg CO₂eq ha⁻¹, and GAP (groundnut) had a GWP of 1950 kg CO₂eq ha⁻¹. These significant differences highlight how variations in farming practices, resource inputs, and environmental management contribute to greenhouse gas (GHG) emissions. The higher GWP of MAC, suggests heavier use of nitrogen-based fertilizers. Excessive application leads to higher emissions of nitrous oxide (N₂O), a potent greenhouse gas. In the Kharif 2 season, the GWP values for the four cropping patterns were identical, with MAC, GAN, GAC, and GAP each recording a GWP of 3981.

Since there is no significant difference in GWP among the patterns, it suggests that these cropping systems shared similar practices, environmental conditions, and management approaches that contributed to comparable greenhouse gas (GHG) emissions. In the Rabi season, the GWP values for the cropping patterns were as follows: MAC recorded a GWP of 2803 kg CO₂eq ha⁻¹, GAN had a GWP of 1234 kg CO₂eq ha⁻¹, GAC showed a GWP of 2842 kg CO₂eq ha⁻¹, and GAP exhibited a GWP of 1980 kg CO₂eq ha⁻¹. These significant differences highlight variations in agricultural practices, crop types, and resource management, which directly impact greenhouse gas (GHG) emissions (Figure 2 & Table 2).



Above: On-farm trial, Rangpur; photo: CIMMYT

In a complete cropping cycle, the GWP values for the four cropping patterns show substantial variation: MAC recorded a GWP of 9787 kg CO₂eq ha⁻¹, GAN had a GWP of 7113 kg CO₂eq ha⁻¹, GAC showed a GWP of 8730 kg CO₂eq ha⁻¹, and GAP exhibited a GWP of 7910 kg CO₂eq ha⁻¹. These significant differences highlight the influence of diverse agricultural practices and management strategies on greenhouse gas (GHG) emissions. The highest GWP in MAC likely results from high rates of nitrogen fertilizer application, contributing significantly to nitrous oxide (N₂O) emissions. GAN, with the lowest GWP, may utilize efficient fertilization practices, reducing nitrogen losses. GAC and GAP, with GWPs, likely fall between these extremes, reflecting moderate fertilizer use (Figure 2 & Table 2).

The GWP values for the cropping patterns—MAC, GAN, GAC, and GAP—across the two villages, Chargonai and Shibdeb, exhibit notable variations within each village but no significant interaction between village and cropping pattern. Despite differences in absolute values, the lack of significant interaction between village and treatment indicates that the relative differences in GWP across cropping patterns are consistent between the two villages. This consistency suggests that cropping patterns influence GHG emissions similarly in both locations, regardless of local environmental or management differences. MAC consistently has the highest GWP in both villages, likely due to intensive resource inputs such as nitrogen fertilizers and water usage, which result in high N₂O. The higher GWP in

Shibdeb suggests slightly more resource-intensive practices compared to Chargonai (Figure 2 & Table 2).

Energy Use (EU)

ANOVA revealed that Chargonai and Shibdeb have very similar energy use of 2492 MJ ha⁻¹ and 2489 MJ ha⁻¹ respectively, with no statistically significant difference between them. Similar trend follow the Rabi season. The fact that there is no significant difference except kharif2 and one cropping cycle in energy use between the two villages suggests that the energy inputs for both locations are similar. Energy use in agriculture refers to the amount of energy consumed through various inputs and practices such as fuel for tillage and irrigation purpose (Table 2 & Figure 2).

Regarding the cropping pattern (MAC, GAN, GAC, GAP) in kharif 1 season found that energy use varies across different crops, with the lowest value being 2486 MJ ha⁻¹ and the highest being 2496 MJ ha⁻¹. Significant different found only between GAN and GAP. In kharif 2 season, the values are same, indicating that the energy requirements for each cropping system are identical. The fact that there is no significant difference between the energy use of these cropping systems. This indicates that the farming practices, inputs, and management strategies across these four cropping systems (MAC, GAN, GAC, GAP) in Kharif 2 season are very similar, and there is no major factor that causes one system to consume significantly more or less energy than the others (Table 2 & Figure 2).

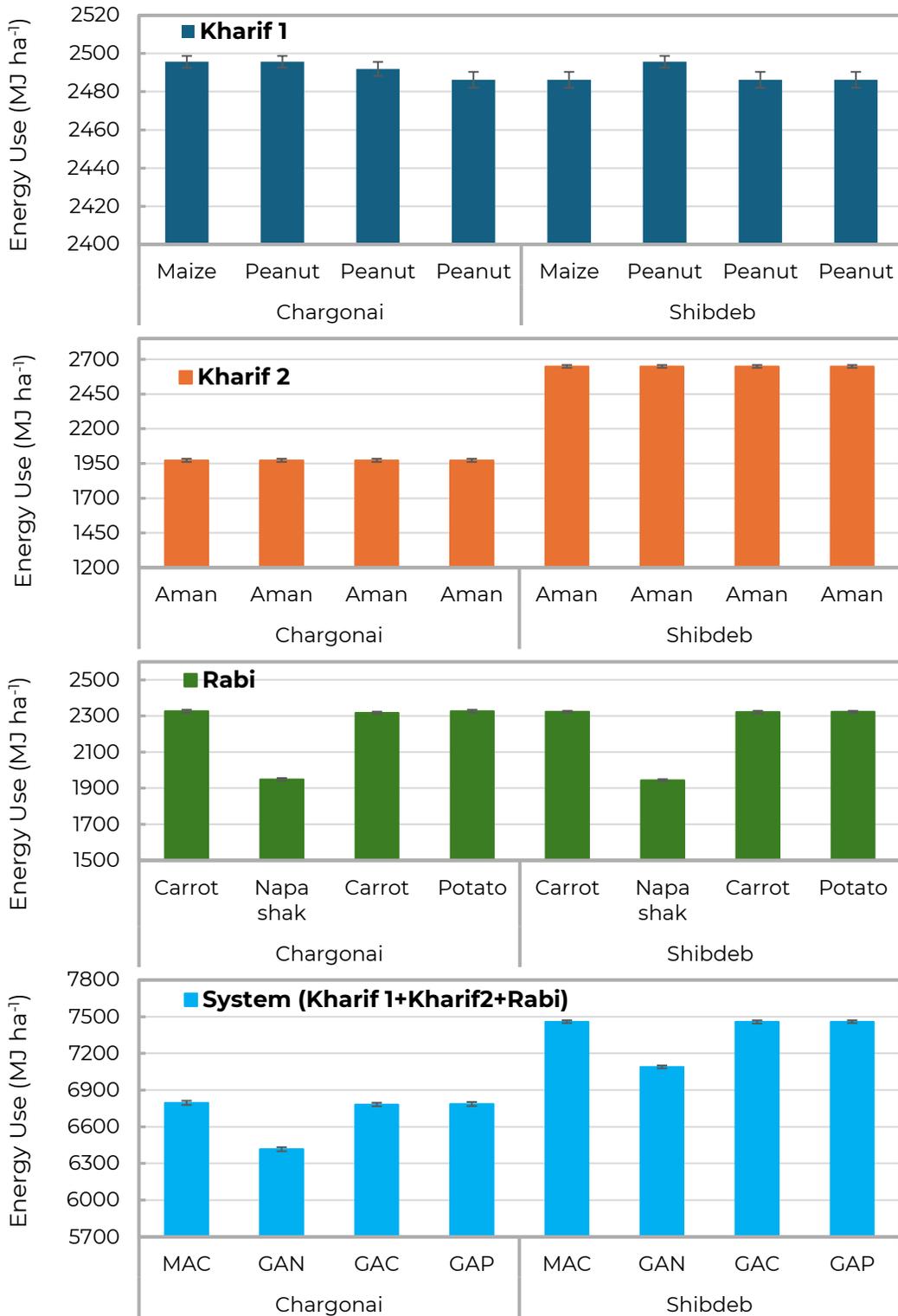


Figure 2: Energy Use (MJ ha⁻¹) showing for different crop in Kharif1, Kharif2, Rabi season, and System (one full cropping cycle) by cropping pattern. MAC: Maize-Aman-Carrot; GAN: Groundnut/Peanut-Aman-Napa shak; GAC: Groundnut/Peanut-Aman-Carrot; GAP: Groundnut/Peanut-Aman-Potato.

In the Rabi season, the significant differences in energy use between MAC, GAN, GAC, and GAP suggest that the cropping systems vary greatly in terms of input efficiency. MAC and GAP has the highest (2325 MJ ha⁻¹ and 2325 MJ ha⁻¹) energy use, possibly due to more intensive farming practices, while GAN has the lowest (1946 MJ ha⁻¹), indicating a more energy-efficient system. GAC had the moderate energy use values of 2319 MJ ha⁻¹. (Table 2 & Figure 2).

In system (one full cropping cycle), cropping pattern of MAC has the highest energy use of 7127 MJ ha⁻¹ in the full cropping cycle. This suggests that this cropping system involves more intensive farming practices or inputs that require a greater amount of energy. MAC involve crops that require more frequent irrigation, more intensive fertilization, or higher mechanization. Additionally, MAC might involve practices that are resource-intensive or crops with high water, fertilizer, or pesticide demands. Another cropping pattern, GAP has the second-highest energy use. While its energy use is not as high as MAC, it still requires considerable energy. GAC has a relatively lower energy use than MAC and GAP. GAN has the lowest energy use of 6753 MJ ha⁻¹ among all cropping systems. This suggests that GAN is the most energy-efficient system in terms of total energy consumption during the full cropping cycle. The lower energy use could be due to several factors, such as crops that require minimal irrigation, lower fertilization needs, or the use of less energy-intensive farming practices (Table 2 & Figure 2).

The energy use values for the four cropping patterns (MAC, GAN, GAC, and GAP) in Chargonai and Shibdeb show some variation, but the absence of significant interaction between village and treatment indicates that the cropping patterns have a similar effect on energy use across both villages. The increase in energy use from Chargonai to Shibdeb for most cropping patterns suggests that Shibdeb might have more demanding environmental or operational conditions (e.g., soil type, climate) that require more energy-intensive inputs. MAC consistently shows the highest energy use, with a notable increase in Shibdeb. GAN, on the other hand, consistently has the lowest energy use in both villages, GAC and GAP show similar patterns in energy use to MAC, with higher values in Shibdeb than Chargonai (Table 2 & Figure 2).

Emission Intensity (EI)

The identical emission intensities in Kharif 1 (0.589 kg CO₂eq kg⁻¹) and the negligible difference in Rabi (0.089 kg CO₂eq kg⁻¹ for Chargonai vs. 0.090 kg CO₂eq kg⁻¹ for Shibdeb) indicate that the farming practices, input usage, and environmental factors influencing emissions were highly consistent across both locations for these seasons. The emission intensity in Kharif 2 was 1.17 kg CO₂eq kg⁻¹ for Chargonai and 1.24 kg CO₂eq kg⁻¹ for Shibdeb, a statistically significant difference. This suggests that subtle variations in agricultural practices, environmental conditions, or resource use between the two locations had a measurable impact on emission intensity during this season (Table 2 & Figure 3).



Above: Carrots harvested in Rangpur district; photo: CIMMYT

In one full cropping system, Chargonai exhibited a lower emission intensity of $1.85 \text{ kg CO}_2\text{eq kg}^{-1}$ compared to $1.92 \text{ kg CO}_2\text{eq kg}^{-1}$ in Shibdeb. This significant difference suggests variations in agricultural practices, resource efficiency, or environmental conditions across the two locations. Soil properties such as pH, and organic content vary between locations and can influence the microbial activity responsible for nitrous oxide and methane emissions (Table 2 & Figure 3).

In terms of across the cropping pattern revealed that Kharif 1 season, significant differences in emission intensity were observed, with MAC having the lowest value ($0.301 \text{ kg CO}_2\text{eq kg}^{-1}$) compared to GAN, GAC,

and GAP (all around $0.69 \text{ kg CO}_2\text{eq kg}^{-1}$). The results suggest that MAC is more efficient in terms of greenhouse gas emissions, likely due to optimized resource use or less emission-intensive crops. Kharif 2 season, emission intensities were higher across all other season, ranging from $1.20 \text{ kg CO}_2\text{eq kg}^{-1}$ for MAC and GAN to $1.23 \text{ kg CO}_2\text{eq kg}^{-1}$ for GAP. This season shows smaller differences, but the significant variation indicates that GAP involves practices or crops leading to higher emissions. Rabi season, emission intensities were much lower compared to the Kharif seasons, but significant differences were still observed. GAP had the lowest value ($0.05 \text{ kg CO}_2\text{eq kg}^{-1}$), while MAC and GAC had the highest ($0.11 \text{ kg CO}_2\text{eq kg}^{-1}$) (Table 2 & Figure 3).

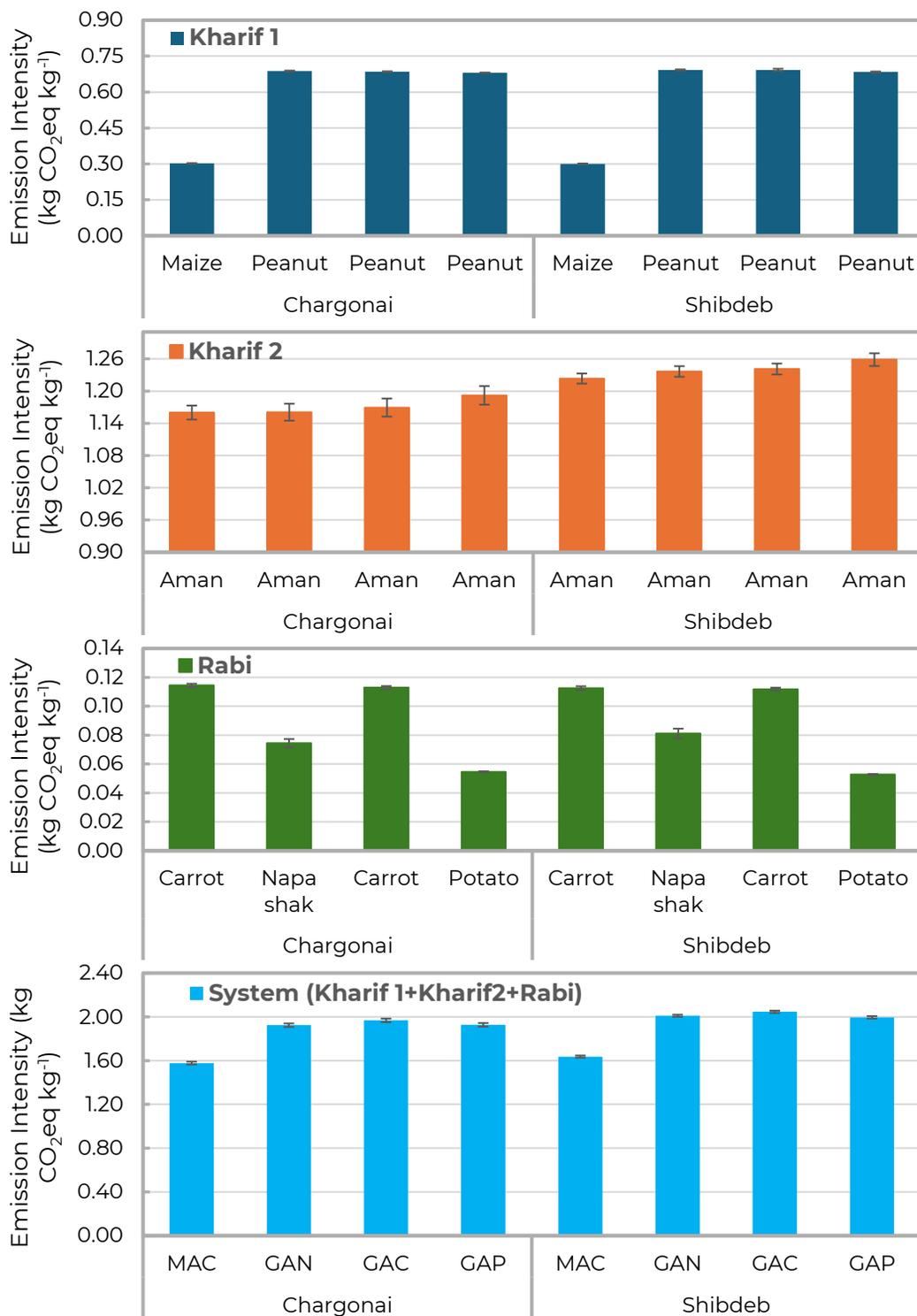


Figure 3: Emission Intensity (kg CO₂eq kg⁻¹) showing for different crop in Kharif1, Kharif2, Rabi season, and System (one full cropping cycle) by cropping pattern. MAC: Maize-Aman-Carrot; GAN: Groundnut/Peanut-Aman-Napa shak; GAC: Groundnut/Peanut-Aman-Carrot; GAP: Groundnut/Peanut-Aman-Potato.

The emission intensity for the full cropping system varied significantly among the four cropping patterns. MAC, with the lowest emission intensity of 1.61 kg CO₂eq kg⁻¹, appears to be the most environmentally sustainable pattern, likely due to optimized resource use and efficient management practices. In contrast, GAC, with the highest emission intensity of 2.01 kg CO₂eq kg⁻¹, reflects inefficiencies or practices that lead to increased greenhouse gas emissions. GAN and GAP showed intermediate values (1.97 kg CO₂eq kg⁻¹ and 1.96 kg CO₂eq kg⁻¹, respectively), but still significantly higher than MAC (Table 2 & Figure 3).

Regarding interaction in both Chargonai and Shibdeb, the cropping

pattern MAC demonstrated the lowest emission intensities (1.58 kg CO₂eq kg⁻¹ in Chargonai and 1.64 kg CO₂eq kg⁻¹ in Shibdeb), indicating it is the most efficient in reducing greenhouse gas emissions. Conversely, GAC exhibited the highest emission intensities (1.97 kg CO₂eq kg⁻¹ in Chargonai and 2.05 kg CO₂eq kg⁻¹ in Shibdeb), making it the least efficient. Despite these variations, the interaction between villages and treatments did not reveal any significant differences. This suggests that while the absolute values differ slightly between Chargonai and Shibdeb, the patterns of emissions among the cropping systems remain consistent across locations.



Above: Harvesting of Napa shak in Rangpur district; photo: Alanuzzaman Kurishi

Table 2: Global Warming Potential (GWP), Energy Use (EU), Emission Intensity (EI) showing for different crops in Kharif1, Kharif2, Rabi season, and System (one full cropping cycle) by cropping pattern in Rangpur district.

Source	Total GWP (kg CO ₂ eq ha ⁻¹)			Total Energy Use (EU) (MJ ha ⁻¹)			Emission Intensity (EI) (kg CO ₂ eq kg ⁻¹)					
	Kharif1	Kharif 2	Rabi	System	Kharif 1	Kharif 2	Rabi	System	Kharif1	Kharif2	Rabi	System
Village (V)												
Chargonai	2193	3786 b	2188	8168 b	2492	1973 b	2230	6695 b	0.589	1.17 b	0.089	1.85 b
Shibdeb	2186	4175 a	2241	8602 a	2489	2649 a	2228	7366 a	0.592	1.24 a	0.090	1.92 a
Treatment (T)												
MAC	3004 a	3981	2803 a	9787 a	2491 ab	2311	2325 a	7127 a	0.301 c	1.20 b	0.11 a	1.61 c
GAN	1899 c	3981	1234 c	7113 d	2496 a	2311	1946 b	6753 b	0.690 a	1.20 b	0.08 b	1.97 b
GAC	1908 bc	3981	2842 a	8730 b	2489 ab	2311	2319 a	7120 a	0.689 a	1.21 ab	0.11 a	2.01 a
GAP	1950 b	3981	1980 b	7910 c	2486 b	2311	2325 a	7122 a	0.682 b	1.23 a	0.05 c	1.96 b
V×T												
Chargonai, MAC	2974 a	3786	2737	9498	2496	1973	2327	6795	0.302	1.16	0.11 a	1.58
Chargonai, GAN	1911 b	3786	1234	6932	2496	1973	1948	6416	0.688	1.16	0.07 b	1.92
Chargonai, GAC	1928 b	3786	2802	8517	2492	1973	2318	6782	0.685	1.17	0.11 a	1.97
Chargonai, GAP	1960 b	3786	1980	7727	2486	1973	2327	6786	0.680	1.19	0.05 c	1.93
Shibdeb, MAC	3033 a	4175	2869	10077	2486	2649	2323	7459	0.300	1.22	0.11 a	1.64
Shibdeb, GAN	1886 b	4175	1234	7295	2496	2649	1944	7089	0.692	1.24	0.08 b	2.01
Shibdeb, GAC	1887 b	4175	2881	8943	2486	2649	2321	7457	0.693	1.24	0.11 a	2.05
Shibdeb, GAP	1939 b	4175	1980	8093	2486	2649	2323	7459	0.684	1.26	0.05 c	1.99
F-values												
V	ns	228***	ns	120***	ns	1367***	ns	977***	ns	25***	ns	28***
T	1629***	ns	381***	710***	4.12*	ns	262.4***	1908***	24780***	4**	522***	690***
V × T	3*	ns	ns	ns	ns	ns	ns	ns	ns	ns	2.75*	ns

Note: MAC: Maize-Aman-Carrot; GAN: Groundnut/Peanut-Aman-Napa shak; GAC: Groundnut/Peanut-Aman-Carrot; GAP: Groundnut/Peanut-Aman-Potato; *, **, and *** indicates $P < 0.05$, 0.01, and 0.001, respectively. Same letter are not significantly different according to Tukey's HSD test at $P \leq 0.05$ and ns = not significant. Trials were placed in 20 farmers each at Chargonai and Shibdeb in Rangpur district.

CONCLUSIONS AND RECOMMENDATIONS

The findings in this research brief are based on a full cropping cycle conducted over one year. The system-level data reveals notable differences in the environmental impacts (GWP, Energy Use, and Emission Intensity) across villages (Chargonai and Shibdeb), treatments (MAC, GAN, GAC, and GAP), and the interaction between village and treatment. The system-level data aggregates the results from all seasons, providing a comprehensive view of the overall sustainability across treatments and locations.

For village wise analyses found that Chargonai shows a lower total GWP (e.g., 8168 kg CO₂eq ha⁻¹ for the system) compared to Shibdeb, which has 8602 kg CO₂eq ha⁻¹. This trend is consistent across treatments, suggesting that the agricultural practices or environmental factors in Chargonai are more efficient or less emission-intensive. Shibdeb shows higher energy use in the system, with 7366 MJ ha⁻¹ compared to 6695 MJ ha⁻¹ in Chargonai, indicating that agricultural practices in Shibdeb are more energy-intensive. The emission intensity in Shibdeb is higher, with a system-level emission intensity of 1.92 kg CO₂eq kg⁻¹, compared to Chargonai at 1.85 kg CO₂eq kg⁻¹. This reflects that Shibdeb's agricultural system has higher emissions per unit of product.

MAC has the highest total GWP, with 9787 kg CO₂eq ha⁻¹ for the system, followed by GAC at 8730 kg CO₂eq ha⁻¹, GAP at 7910 kg CO₂eq ha⁻¹, and GAN at 7113 kg CO₂eq ha⁻¹. The results

indicate that MAC have a significant impact on increasing total emissions. MAC consumes the most energy in the system, with 7127 MJ ha⁻¹, followed by GAC (7120 MJ ha⁻¹) and GAP (7122 MJ ha⁻¹). GAN has the lowest energy use, with 6753 MJ ha⁻¹, which is a benefit for areas aiming to reduce energy consumption. MAC has the lowest emission intensity at 1.61 kg CO₂eq kg⁻¹, reflecting more efficient output per unit of emission, despite its high total GWP and energy consumption. GAC has the highest emission intensity with 2.01 kg CO₂eq kg⁻¹, indicating that, emissions per unit of product are high. GAN and GAP offer moderate results in terms of emission intensity, with 1.96 kg CO₂eq kg⁻¹ for GAP and 1.97 kg CO₂eq kg⁻¹ for GAN (Table 2 & Figure 3).

Interactions between villages and treatments showed that Shibdeb, MAC showed the highest system-level GWP of 10077 kg CO₂eq ha⁻¹, demonstrating a combination of high-input farming and location-specific inefficiencies. Chargonai, GAN had the lowest system-level GWP of 6932 kg CO₂eq ha⁻¹, indicating its suitability for low GHG farming. Shibdeb, MAC/GAP had the highest energy use of 7459 MJ ha⁻¹, further validating the energy-intensive nature of this treatment. Chargonai, GAN had the lowest energy use of 6416 MJ ha⁻¹ among all combinations. Shibdeb, GAC exhibited the highest emission intensity of 2.05 kg CO₂eq kg⁻¹, emphasizing its inefficiency. Chargonai, MAC had lowest emission intensity of 1.58 kg CO₂eq kg⁻¹, making it the most sustainable combination.

Promote GAN as a sustainable farming practice across both villages due to its low GHG emissions and high efficiency. Reassess the GAP treatment to reduce its energy and emissions footprint. Further studies should explore how practices under GAN could be scaled while maintaining productivity. Currently, we have data from only one full cropping cycle, which is insufficient. A more comprehensive analysis over several years, including the environmental impacts, is essential to validate these findings.



Above: Post harvesting of groundnut in Rangpur district; photo : Md Arifur Rahaman



Above: A Carrot field in Chargonai, Rangpur; photo : Alanuzzaman Kurishi

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