

Impact of Diverse Cropping Patterns on Greenhouse Gas Emissions

Assessing Energy Use Efficiency in
Dinajpur District, Bangladesh

Research note 59

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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 Kalapukur and Indropara villages of the Dinajpur 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 Indropara shows significantly higher global warming potential (GWP) of 9069 kg CO₂eq ha⁻¹ compared to Kalapukur of 8796 kg CO₂eq ha⁻¹.
2. Indropara exhibits 6904 MJ ha⁻¹ slightly higher energy use (EU) than Kalapukur 6833 MJ ha⁻¹
3. Kalapukur has a higher emission intensity (EI) of 1.554 kg CO₂eq kg⁻¹ compared to Indropara of 1.516 kg CO₂eq kg⁻¹.
4. Cropping pattern BAP (Boro-Aman-Potato) had the highest GWP of 10594 kg CO₂eq ha⁻¹ and significantly exceeding all other treatments.
5. Cropping pattern MAT (Maize-Aman-Tomato) had the lowest GWP of 7486 kg CO₂eq ha⁻¹, indicating better environmental performance.
6. BAP cropping pattern required the highest energy use of 6934 MJ ha⁻¹, while MAN (Maize-Aman-Napa shak) was the lowest of 6468 MJ ha⁻¹.
7. The BAP showed the highest emission intensity of 1.870 kg CO₂eq kg⁻¹, whereas MAT had the lowest emission intensity of 1.366 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 over a 100-year period, 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 directly 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 Birganj and Chirirbandar upazilas of the Dinajpur 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 Dinajpur district follow a randomized complete block design (RCBD) replicated with 20 farmer households within a village. Each trail 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 Dinajpur 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), *Maize-Aman-Tomato* (MAT), and *Maize-Aman-Napa shak* (MAN) are being compared with the common farmer practice *Boro-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. 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, tomato, napa shak, 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: Aman (BINA dhan 20) season in Dinajpur; photo : Md Arifur Rahaman

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

District	Upazila	Village	Latitude	Longitude	Treatment	Cropping pattern
Dinajpur	Birganj	Kalapukur	25.89677	88.60473	MAC	Maize-Aman-Carrot
	Birganj	Kalapukur	25.89677	88.60473	MAT	Maize-Aman-Tomato
	Birganj	Kalapukur	25.89677	88.60473	MAN	Maize-Aman-Napa shak
	Birganj	Kalapukur	25.89677	88.60473	BAP	Boro rice-Aman-Potato
Dinajpur	Chirirbandar	Indropara	25.65210	88.74749	MAC	Maize-Aman-Carrot
	Chirirbandar	Indropara	25.65210	88.74749	MAT	Maize-Aman-Tomato
	Chirirbandar	Indropara	25.65210	88.74749	MAN	Maize-Aman-Napa shak
	Chirirbandar	Indropara	25.65210	88.74749	BAP	Boro rice-Aman-Potato

Note: Aman (biofortified and short duration) refers to rice grown in the monsoon Kharif-2 season; while boro refers to rice grown in the kharif 1 season.

STUDY FINDINGS

Global Warming Potential (GWP)

ANOVA revealed that Kalapukur has a slightly higher GWP of 3181 kg CO₂eq ha⁻¹ compared to Indropara of 3165 kg CO₂eq ha⁻¹. This means that the greenhouse gas emissions in Kalapukur have a marginally higher warming effect than those in Indropara during the Kharif 1 season. While Kalapukur has a slightly higher GWP than Indropara, the difference is statistically insignificant, indicating that both areas have very similar contributions to global warming during the Kharif 1 season (Figure 1 & Table 2).

In Kharif 2 season, Kalapukur produced a GWP of 3629 kg CO₂eq ha⁻¹, while Indropara produced a higher GWP of 3784 kg CO₂eq ha⁻¹. In the Rabi season, Kalapukur produced

a GWP of 1986 kg CO₂eq ha⁻¹, while Indropara had a GWP of 2120 kg CO₂eq ha⁻¹. The significant difference between these two values indicates that the greenhouse gas emissions in Indropara have a notably higher impact on global warming compared to Kalapukur during the Kharif 2 and Rabi season (Figure 1 & Table 2).

In the context of a full cropping cycle, Kalapukur produced a Global Warming Potential (GWP) of 8796 kg CO₂eq ha⁻¹, while Indropara produced a GWP of 9069 kg CO₂eq ha⁻¹. The difference between these two values is 273 GWP units, and it is stated that there is a significant difference between them. This indicates that Indropara's agricultural activities have a higher impact on global warming compared to Kalapukur over the time.



Above: Women working in rice mills in Dinajpur; Photo : CIMMYT



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; MAT: Maize-Aman-Tomato; MAN: Maize-Aman-Napa shak; BAP: Boro-Aman-Potato

of a complete cropping cycle (Figure 1 & Table 2).

Cropping pattern BAP (Boro) has produced the highest significant GWP of 4922 kg CO₂eq ha⁻¹ in Kharif 1 season. MAC (Maize) and MAN (Maize) have relatively close GWP values of 2920 kg CO₂eq ha⁻¹ and 2896 kg CO₂eq ha⁻¹, respectively, but these are still considerably lower than BAP (Boro) cropping pattern. MAT (Maize) has the lowest GWP of 1952 kg CO₂eq ha⁻¹, showing that it has the smallest climate impact among the four cropping pattern (Figure 1 & Table 2). The high GWP in BAP (Boro) indicates that this region likely uses agricultural practices that result in high emissions, such as more intensive fertilizer use, flooded fields. Normally, Boro rice used more fertilizers, particularly nitrogen-based fertilizers, are a significant source of nitrous oxide (N₂O), a potent greenhouse gas, contributing to its higher GWP. Flood irrigation, especially in rice, can increase methane (CH₄) emissions due to anaerobic conditions in the soil. If rice uses more flood irrigation compared to the other crop, this could explain in its higher GWP. That's why BAP (Boro) produced the highest emission as well as GWP (Feliciano et al., 2017). On the other hand, MAT (Maize) with the lowest GWP due to early harvested of maize plant which was only used for feed purpose not grain.

In kharif 2 season only Aman was cultivated and among the treatment there is no significant difference.

However, significant results were observed in Rabi season. MAC (Carrot) produces the highest GWP of 3199 kg CO₂eq ha⁻¹, which suggests that this region is emitting more potent GHGs

than the others. MAN (Napa shak), with the lowest GWP of 1222 kg CO₂eq ha⁻¹, likely employs more sustainable or efficient agricultural practices. BAP (Potato) and MAT (Tomato) have moderate GWPs of 1966 kg CO₂eq ha⁻¹ and 1826 kg CO₂eq ha⁻¹, respectively.

In system (one full cropping cycle) BAP produces the highest significant GWP, meaning it generates the most GHG emissions in the system. BAP may involve intensive use of nitrogen-based fertilizers, which leads to increased emissions of nitrous oxide (N₂O), a potent GHG. MAC has the second-highest GWP. While it is lower than BAP, its GHG emissions are still high. MAN produces a GWP slightly lower than MAC. While still significant, the emissions are not as high as BAP and MAC. MAT has the lowest GWP among the cropping patterns in the system (Table 2 & Figure 1).

In interaction, cropping pattern BAP in both location of Kalapukur and Indropara produced highest significant GWP difference among the other cropping patten.

Energy Use (EU)

ANOVA revealed that Kalapukur and Indropara have very similar energy use of 2531 MJ ha⁻¹ and 2548 MJ ha⁻¹ respectively, with no statistically significant difference between them. Similar trend follow the kharif2 as well as one full cropping system. The fact that there is no significant difference except Rabi in energy use between the villages suggests that the energy inputs for both Kalapukur and Indropara are similar. Rabi season produced the significant different results due to crop variation. 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).

In kharif 1 season found that energy use varies across different treatment, with the lowest value being 2515 MJ ha⁻¹ and the highest being 2607 MJ ha⁻¹. BAP (Boro) produced significant amount of energy compared to MAC, MAT and MAN. In kharif 2 season, the values are very close to each other, ranging from 2564 MJ ha⁻¹ to 2566 MJ ha⁻¹, indicating that the energy requirements for each cropping system are almost identical. The fact that there is no significant difference between the energy use of these cropping systems suggests that, despite minor numerical differences, the energy consumption across the cropping patterns is largely similar.

This indicates that the farming practices, inputs, and management strategies across these four cropping systems (MAC, MAT, MAN, BAP) 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).

In the Rabi season, the significant differences in energy use between MAC, MAT, MAN, and BAP suggest that the cropping systems vary greatly in terms of input efficiency. MAT has the highest (2643 MJ ha⁻¹) energy use, possibly due to more intensive farming practices, while MAN has the lowest (1889 MJ ha⁻¹), indicating a more energy-efficient system. MAC (2264 MJ ha⁻¹) and BAP (2264 MJ ha⁻¹) fall between these extremes, with MAC



Above: A rice farmer in Dinajpur; photo : CIMMYT

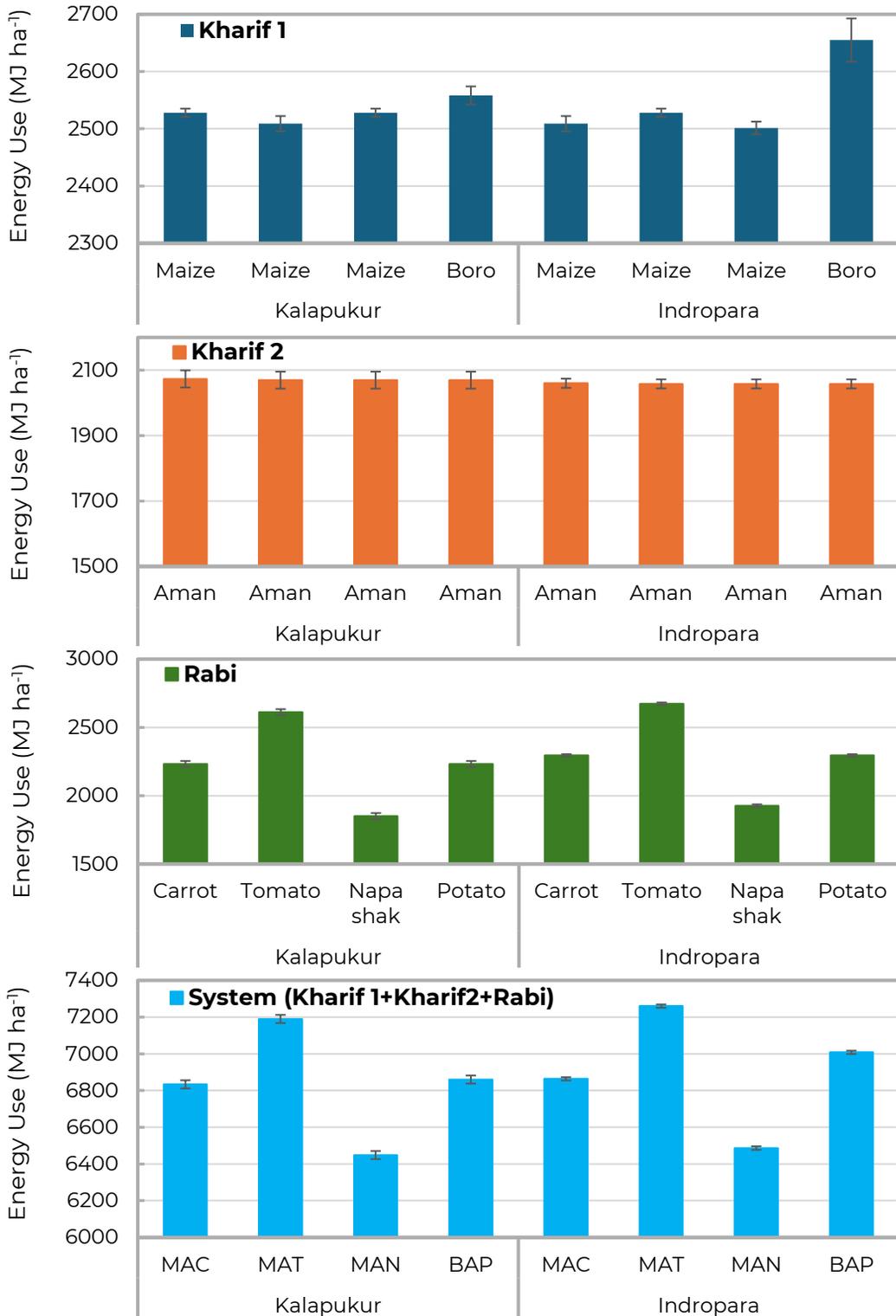


Figure 2: Energy Use (MJ ha⁻¹) showing for different crop in Kharif1, Kharif2, Rabi season, and System (one full cropping cycle) by cropping pattern. MAC: Maize-Aman-Carrot; MAT: Maize-Aman-Tomato; MAN: Maize-Aman-Napa shak; BAP: Boro-Aman-Potato

and BAP sharing similar energy use values (Table 2 & Figure 2).

In system (one full cropping cycle), cropping pattern of MAT has the highest energy use of 7225 MJ ha⁻¹. This suggests that this cropping system involves more intensive farming practices or inputs that require a greater amount of energy. MAT involve crops that require more frequent irrigation, more intensive fertilization, or higher mechanization. Additionally, MAT might involve practices that are resource-intensive or crops with high water, fertilizer, or pesticide demands. Another cropping pattern, BAP has the second-highest energy use. While its energy use is not as high as MAT, it still requires considerable energy. MAC has a relatively lower energy use than MAT and BAP. MAN has the lowest energy use among all cropping systems. This suggests that MAN 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 cropping pattern MAT in both location of Kalapukur and Indrapara produced highest energy use and significant difference among other cropping pattern (Table 2 & Figure 2).

Emission Intensity (EI)

In the Kharif 1 season, both Kalapukur and Indrapara have identical emission intensity values of 0.409 kg CO₂eq kg⁻¹. The lack of significant difference suggests that both varieties have a similar environmental impact in terms of greenhouse gas emissions during the Kharif 1 season. Both varieties likely

follow similar agronomic practices in this season (e.g., irrigation, fertilizer use, crop management) that result in comparable emission intensity. In the Kharif 2 season, Kalapukur had an emission intensity of 1.079 kg CO₂eq kg⁻¹ and Indrapara had 1.047 kg CO₂eq kg⁻¹. Even though there is a minor difference in the emission intensity values, the difference is not statistically significant. This suggests that the emissions of both varieties are still quite similar, even though Kalapukur has a slightly higher emission intensity than Indrapara. In Rabi season, there is a significant difference in emission intensity between Kalapukur (0.066 kg CO₂eq kg⁻¹) and Indrapara (0.060 kg CO₂eq kg⁻¹), with Kalapukur having slightly higher emissions. Additionally, Kalapukur produced an emission intensity of 1.554 kg CO₂eq kg⁻¹, while Indrapara produced 1.516 kg CO₂eq kg⁻¹ over the course of a full cropping cycle. The lack of significant difference in emission intensity between the two crops suggests that the environmental impact, in terms of greenhouse gas emissions, is comparable for both varieties throughout the entire cropping cycle (Table 2 & Figure 3).

In terms of treatment, MAC, MAT, and MAN all have relatively lower emission intensities compared to BAP, with MAN having the lowest emission intensity of 0.286 kg CO₂eq kg⁻¹ in Kharif 1 season. This suggests that MAC, MAT, and MAN are more efficient in terms of greenhouse gas emissions relative to the output compared to BAP. BAP, on the other hand, has a significantly higher emission intensity (0.747 kg CO₂eq kg⁻¹), meaning it is associated with greater greenhouse gas emissions per unit of crop yield

(Table 2 & Figure 3). In Kharif 2 season, all four cropping systems (MAC, MAT, MAN, and BAP) have similar emission intensities. This suggests that, for this particular season, the agricultural practices associated with these systems have led to roughly equivalent levels of greenhouse gas emissions relative to the crop yields. Since the differences are not statistically significant, it indicates that factors like fertilizer use, irrigation, and crop management practices did not vary enough between the systems to produce a meaningful difference in emission intensity (Table 2 & Figure 3)..

The significant differences in emission intensity between MAC, MAT, MAN, and BAP in the Rabi season highlight how different agricultural practices and cropping patterns impact greenhouse gas emissions. MAT

represents the most efficient cropping system in terms of emissions, while MAC shows the highest emissions per unit of crop yield. The cropping pattern MAC shows the highest emission intensity of $0.107 \text{ kg CO}_2\text{eq kg}^{-1}$. It suggests that MAC is the least efficient system in terms of minimizing emissions relative to crop yield. The cropping pattern MAT shows the lowest emission intensity of $0.031 \text{ kg CO}_2\text{eq kg}^{-1}$, indicating that its practices were most efficient in terms of minimizing emissions relative to the crop yield (Table 2 & Figure 3).

The significant differences in emission intensity between MAC, MAT, MAN, and BAP in a system (full cropping cycle) reflect the influence of different agricultural practices on greenhouse gas emissions. By understanding and



Above: Men working in rice mills in Dinajpur; photo : CIMMYT

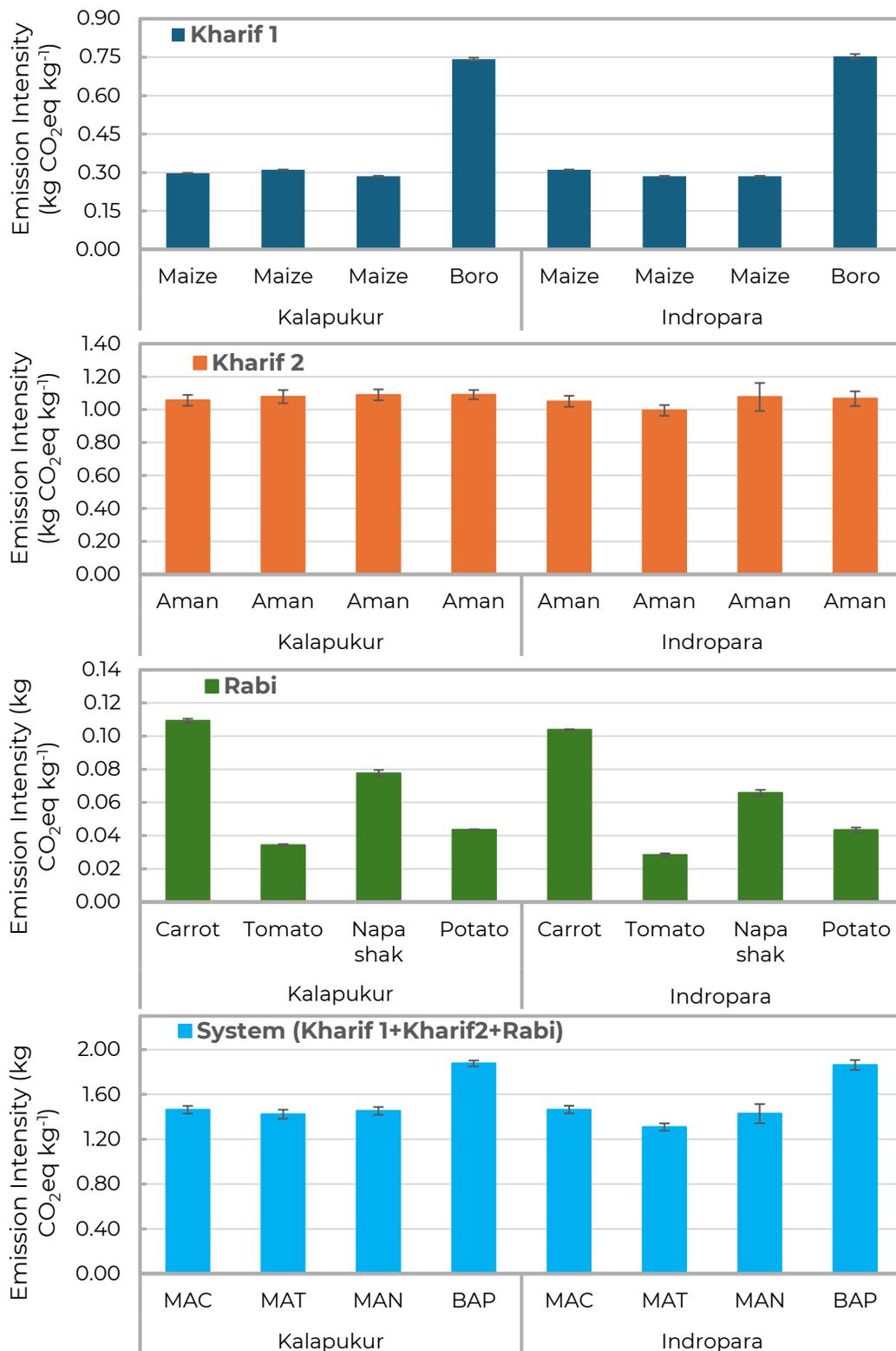


Figure 3: Emission Intensity (kg CO₂eq kg⁻¹) showing for different crop in Kharif1, Kharif2, Rabi season, and System (one full cropping cycle) by cropping pattern. MAC: Maize-Aman-Carrot; MAT: Maize-Aman-Tomato; MAN: Maize-Aman-Napa shak; BAP: Boro-Aman-Potato

addressing the key practices contributing to higher emissions in BAP of $1.870 \text{ kg CO}_2\text{eq kg}^{-1}$ and other high-emission systems, it may be possible to improve the sustainability of agricultural production. Conversely, MAT of $1.366 \text{ kg CO}_2\text{eq kg}^{-1}$ represents a more environmentally efficient cropping system that can serve as a model for minimizing emissions while maintaining or even increasing crop productivity. Sustainable agriculture management practices such as optimized fertilizer application, efficient irrigation, and improved soil health could help mitigate emissions across all cropping systems (Table 2 & Figure 3).

In interaction, Kalapukur and Indropara show different patterns of

emission intensity for the same cropping systems, with Indropara consistently showing slightly lower emissions for most cropping patterns compared to Kalapukur. For example, in both locations, BAP has the highest significant emission intensity, but Kalapukur has $1.877 \text{ kg CO}_2\text{eq kg}^{-1}$, while Indropara has $1.863 \text{ kg CO}_2\text{eq kg}^{-1}$. The difference, although small, suggests that the location-specific conditions are influencing emission intensity. MAT, which shows the lowest emission intensity in Indropara, could serve as a model for emission reduction in both locations. In Kalapukur, it has an emission intensity of 1.423, while in Indropara, it is lower at 1.309 (Table 2 & Figure 3).



Above: Carrot field in Indropara, Dinajpur; photo credit: 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 Dinajpur 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	Kharif2	Rabi	System	Kharif1	Kharif2	Rabi	System	Kharif1	Kharif2	Rabi	System
Village (V)												
Kalapukur	3181	3629 b	1986 b	8796 b	2531	2070	2232 b	6833	0.409	1.079	0.066 a	1.554
Indrapara	3165	3784 a	2120 a	9069 a	2548	2058	2298 a	6904	0.409	1.047	0.060 b	1.516
Treatment (T)												
MAC	2920 b	3704	3199 a	9822 b	2518 b	2066	2264 b	6849 c	0.304 b	1.053	0.107 a	1.464 b
MAT	1952 c	3708	1826 c	7486 d	2518 b	2064	2643 a	7225 a	0.298 b	1.037	0.031 d	1.366 c
MAN	2896 b	3709	1222 d	7828 c	2515 b	2064	1889 c	6468 d	0.286 c	1.083	0.072 b	1.441 bc
BAP	4922 a	3705	1966 b	10594 a	2607 a	2064	2264 b	6934 b	0.747 a	1.079	0.043 c	1.870 a
V×T												
Kalapukur, MAC	3053 c	3629	2964 b	9647 d	2528 b	2073	2232	6833 c	0.298 bc	1.056	0.109 a	1.463
Kalapukur, MAT	1951 e	3629	1815 d	7396 g	2509 b	2069	2611	7190 a	0.311 b	1.079	0.034 e	1.423
Kalapukur, MAN	2981 c	3629	1212 e	7823 e	2528 b	2069	1851	6449 d	0.285 c	1.090	0.078 b	1.453
Kalapukur, BAP	4737 b	3629	1954 cd	10320 b	2558 b	2069	2232	6860 c	0.742 a	1.091	0.044 d	1.877
Indrapara, MAC	2786 d	3778	3434 a	9998 c	2509 b	2060	2295	6864 c	0.311 b	1.051	0.104 a	1.465
Indrapara, MAT	1953 e	3786	1837 cd	7576 f	2528 b	2058	2674	7260 a	0.285 c	0.995	0.028 f	1.309
Indrapara, MAN	2811 d	3790	1233 e	7834 e	2501 b	2058	1927	6487 d	0.286 c	1.077	0.066 c	1.428
Indrapara, BAP	5108 a	3782	1978 c	10868 a	2655 a	2058	2295	7008 b	0.753 a	1.067	0.043 d	1.863
F-values												
V	ns	93***	33***	74***	ns	ns	7.5*	ns	ns	ns	60***	ns
T	7546***	ns	1291***	2906***	15***	ns	7258***	657***	5795***	ns	1366***	75***
V × T	95***	ns	24***	16***	6***	ns	ns	5**	9***	0.466	7***	ns

Note: MAC-Maize-Aman-Carrot; MAT-Maize-Aman-Tomato; MAN-Maize-Aman-Napa shak; BAP-Boro-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 Kalapukur and Indrapara in Dinajpur district.

CONCLUSIONS AND RECOMMENDATIONS

The findings in this research brief are based on a full cropping cycle conducted over one year. For village wise analyses found that Indropara has a higher system-level GWP of 9069 kg CO₂eq ha⁻¹ compared to Kalapukur 8796 kg CO₂eq ha⁻¹. Indropara exhibits 6904 MJ ha⁻¹ slightly higher energy use than Kalapukur 6833 MJ ha⁻¹, although the difference is not statistically significant at the system level. Differences across seasons were minimal, suggesting similar energy consumption patterns for villages. Kalapukur has a higher system-level emission intensity of 1.554 kg CO₂eq kg⁻¹ compared to Indropara of 1.516 kg CO₂eq kg⁻¹. This indicates Kalapukur's production systems are slightly less efficient in terms of GHG emissions per unit of yield.

For treatment wise analyses revealed that BAP treatment had the highest GWP of 10594 kg CO₂eq ha⁻¹, significantly exceeding all other treatments. The MAT treatment had the lowest system-level GWP of 7486 kg CO₂eq ha⁻¹, indicating better environmental performance. The BAP treatment required the highest system-level energy of 6934 MJ ha⁻¹, while MAN treatment was the lowest of 6468 MJ ha⁻¹. High energy use in the BAP treatment correlates with its high GWP, suggesting energy-intensive management practices. The BAP treatment again showed the highest emission intensity of 1.870 kg CO₂eq kg⁻¹, reflecting inefficiency in translating inputs into yield. The MAT treatment had the lowest emission intensity of 1.366 kg CO₂eq kg⁻¹,

suggesting it is the most efficient in terms of emissions per unit of yield.

Interaction between villages and treatments observed that Indropara, BAP showed the highest system-level GWP of 10868 kg CO₂eq ha⁻¹, demonstrating a combination of high-input farming and location-specific inefficiencies. Kalapukur, MAT had the lowest system-level GWP of 7396 kg CO₂eq ha⁻¹, indicating its suitability for low GHG farming. Indropara, BAP had the highest energy use of 7008 MJ ha⁻¹, further validating the energy-intensive nature of this treatment. Kalapukur, MAN had the lowest energy use of 6449 MJ ha⁻¹ among all combinations. Indropara, BAP exhibited the highest emission intensity of 1.863 kg CO₂eq kg⁻¹, emphasizing its inefficiency. Indropara, MAT had lowest emission intensity of 1.309 kg CO₂eq kg⁻¹, making it the most sustainable combination.

Promote MAT as a sustainable farming practice across both villages due to its low GHG emissions and high efficiency. Reassess the BAP treatment to reduce its energy and emissions footprint. Further studies should explore how practices under MAT 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.

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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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