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Greenhouse gases emission trade-offs for benefits gain - An analysis from paddy rice and upland crops cultivation in Hau Giang province, Viet Nam

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ABSTRACT

Agriculture activities require energy for operation and emit greenhouse gases (GHGs) into the atmosphere. However, agriculture provides essential nutrients with carbon sources through its main and by-products. This study used the life cycle assessment methodology to evaluate the carbon balance in agricultural systems of paddy rice (PR), corn, mung bean (MB), and black sesame (BS) in the summer-autumn growing season in the Vietnamese Mekong Delta. The results showed that PR and upland crops produced a net carbon source of 1,280.9–18,915 kg-C ha^{-1}. Corn cultivation achieved the best value in carbon index analyses. To have one calorie from grain, selected crops must trade off 115.19–501.81 mg-CO_2e. This study concluded that four selected crop cultivations achieved carbon analysis benefits. However, corn is a suitable recommendation for adapting to the agricultural conversion from PR farming to better upland crop cultivation.

1. INTRODUCTION

Although agriculture played an essential role in Vietnam's development, it must be restructured to achieve sustainable growth, reduce greenhouse gases (GHGs) emissions, avoid adverse environmental impacts, and utilize ecological benefits. In terms of environmental orientation, the agricultural restructure must focus on enhancing solutions for reducing GHG emissions.

Rice farming is a crucial sector of Vietnam's agriculture, with the Mekong Delta (MD) being the largest and most productive region for paddy rice (PR) cultivation in the country. However, rice production harms the environment by emitting GHGs. In 2021, rice production in Vietnam emitted 35.68 Mt-CO_2e (FAOSTAST database). By the year 2030, emissions from agriculture could reach 85 Mt-CO_2e per year (Hoa et al., 2014).

Enhancing the PR land system is essential for restructuring the crop industry and contributing to the successful implementation of increasing added value for agricultural products and sustainable agricultural development. In the period 2016–2020, about 510,000 ha of PR land was planned for conversion to upland crops or aquaculture combinations. In particular, within the MD, 84,000 ha of summer-autumn (S-A) PR farming area was scheduled for cultivating corn, sesame, vegetables, and other crops (Ministry of Agriculture and Rural Development of Vietnam, 2014).

In Hau Giang province, the government encourages the farmers to convert triple PR farming to other agricultural models, including double PR-one cash crop farming. The total cultivated vegetable area increased by 119.0% in 2020 compared with 2019, in which the grown area of corn increased by 118.7% (Department of Agriculture and Rural Development of Hau Giang Province, 2020). In 2021, corn was cultivated over 2,930 ha and vegetables over 25,159 ha (Hau Giang Statistical Office, 2021).

It is suggested that PR monocultures harm the environment in the long term, while rotation could bring several benefits. Rowing upland crops such as corn or mung bean (MB) helps improve soil properties and plant growth (Linh et al., 2017). A study on GHGs emissions showed a reduction of 52–58% in total emission reduction by rotation with upland vegetables or lotus compared to triple PR farming (Dang et al., 2021).

Research on agriculture's carbon footprint has gained widespread attention, becoming a key focus in efforts to achieve sustainability and adapt to climate change. The carbon footprints of agriculture are measured as agricultural activities' impact on the environment in the number of inputs and outputs measured in the equivalent of CO_2. The optimal and efficient carbon usage in agriculture production will help succeed in the sustainable development goals (SDGs) under SDG12 (Ensure sustainable consumption and production patterns) through the sustainable reuse of agricultural residues. It could help achieve SDG13 (Climate action) by mitigating GHGs emissions to prevent climate change and global warming (United Nations, 2014).

In the period 1961–2014, GHG emissions from rice cultivation in Vietnam increased by 66% (Maraseni et al., 2018). The research on GHG emissions from upland crops in Vietnam is limited. Hung et al. (2021) reported that the emission from leafy vegetable cultivation, including choy sum (132.6–215.6 kg-CO_2e t^{-1}), mustard (37.0 kg-CO_2e t^{-1}), and cabbage (91.4 kg-CO_2e t^{-1}). Liem and Phuoc (2023) showed the emission from sweet potato (15.74 t-CO_2e ha^{-1} $year^{-1}$ and 0.26 kg-CO_2e t^{-1}) and taro (19.66 t-CO_2e ha^{-1} $year^{-1}$ and 0.53 kg-CO_2e t^{-1}) cultivation in Kien Giang province.

This study used the life cycle assessment (LCA) methodology to compare PR and upland crop cultivation in the S-A growing season on carbon footprint, carbon efficiency, and carbon sustainability index. Besides that, the results will show the carbon trade-off for nutrient gain. They provide background information for the carbon footprint calculation of crop variety, supporting planning and decision-making for the agricultural sustainability transition.

2. MATERIALS AND METHOD

The pilot field experiments on corn, MB, and black sesame (BS) were separately conducted in Chau Thanh A district and Vi Thanh City, Hau Giang province, from March to June 2022. The total experiment area was 3,950 m^2 of corn, 1,800 m^2 of BS, and 2,350 m^2 of MB (Figure 1). Because we established only one model for each crop, we used the average values of agricultural inputs and outputs results from two experimented areas for analysis. Our experiments were conducted on Gleyic Fluvisols, a specific soil classification (Hau Giang People Committee, 2022). To collect the PR cultivation data, we randomly selected and interviewed 240 households from February to March 2022 in Long My district, Hau Giang province. The surveyed sample size and the selection method were adapted to assess life cycle GHG emissions from the horticultural product, following the guide by the British Standards Institution (The British Standards Institution - BSI, 2012).

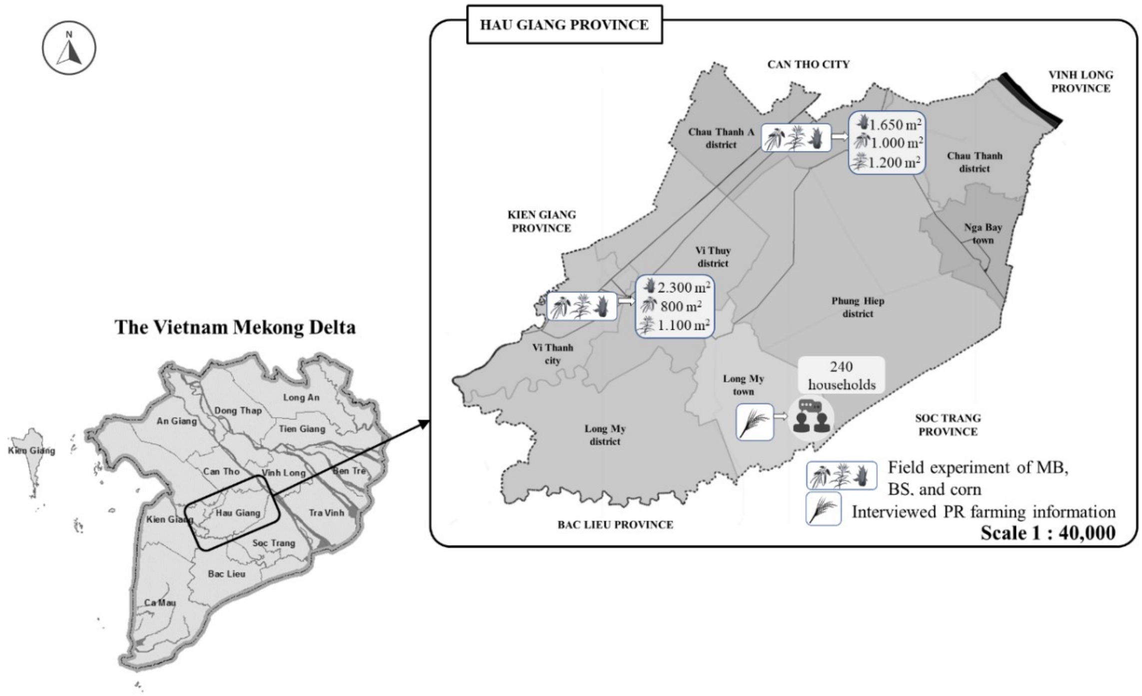

Figure 1. Research area and activities

The Walkley-Black method was used for plant biomass carbon analysis at the Laboratory of Environmental General Analysis, Center for Management of Practice and Analysis, Kien Giang University, Vietnam.

The LCA methodology was applied to estimate GHGs for producing and applying agricultural inputs. The system boundaries were set to 100 years, and all emissions were converted to CO_2 equivalents using the Intergovernmental Panel on Climate Change (IPCC) coefficients guideline (IPCC, 2013).

While using emission and conversion factors specific to Vietnam would be the most accurate approach for estimating GHG emissions and carbon sequestration, publications in this field from Vietnam remain limited. To our knowledge, many previous studies conducted in Vietnam used the emission factors/conversion factors from foreign countries (Phong & Loi, 2014; Le & Ha, 2015; Truong et al., 2017; Liem et al., 2022). We also used the default emissions from (IPCC, 2006) and published papers in this research.

The mass of by-products was estimated based on the crop-to-residues ratio (CRR). This study qualified straw, stover, cob, and shell of rice, corn, bean, and sesame through their dry grain. The CRR is as follows $CRR_{Rice\ straw}$ = 1.53 (Purohit, 2009), $CRR_{Corn\ stover}$ = 2.5 (Soni et al., 2013), $CRR_{Corn\ cob}$ = 0.15 (Honorato-Salazar & Sadhukhan, 2020), $CRR_{MB\ stover}$ = 1.35 (Wang et al., 2013), $CRR_{MB\ shell}$ = 0.323 (Soni et al., 2013), $CRR_{BS\ stover}$ = 3.8 (Honorato-Salazar & Sadhukhan, 2020), and $CRR_{BS\ shell}$ = 1.86 (Ali & Jan, 2014).

$$C_{Net}\ (\text{kg-C ha}^{-1}) = C_O\ (\text{kg-C ha}^{-1}) - C_I\ (\text{kg-C ha}^{-1})$$

In which:

C_I is total carbon inputs (kg-C ha^{-1}) based on CO_2e emission and was determined by $C_I = CO_2$e emission × 0.27 (12/44 as the mass of C and CO_2); CO is total carbon outputs (kg-C ha^{-1}; including product and by-products) and was determined CO = Σ (Yj × %Cj) (Yj: yield of plant j part – grain, stalk/straw, and shell in kg-C ha^{-1}; %C: carbon content of plant j part is presented in Table 1).

Table 1. The carbon content of outputs

Outputs	%C	References	Outputs	%C	References
1. Rice			3. MB		
1.1 Grain	43.8–46.6	This study	*3.1 Grain*	42.1–44.8	This study
1.2 Straw	45.7–61.4	(Fu et al., 2012; Biswas et al., 2017; Maguyon-Detras et al., 2020)	*3.2 Stover*	45.7–47.3	This study
2. Corn			*3.3 Shell*	45.1–46.5	This study
2.1 Grain	46.2–46.8	This study	4. BS		
2.2 Stover	43.65–43.8	(Shuangning et al., 2005; Ioannidou et al., 2009)	*4.1 Grain*	40.8–42.4	This study
2.3 Cob	42.1–43.77	(Ioannidou et al., 2009; Biswas et al., 2017)	*4.2 Stover*	44.5–52.43	(Ateş et al., 2006; Khairy et al., 2023)
			4.3 Shell	43.98–44.02	(Sellami et al., 2008)

Emission from inputs production and application (internal gasoline combustion) was qualified by the MiLCA software application (Japan Environmental Management Association for Industry - JEMAI, 2014).

GHGs emission from inputs application = Σ [m_k (kg-input$_k$ ha^{-1}) × EF_k (kg-CO_2e kg-input$_k^{-1}$)

GHGs emission from manage soil = Σ [m_q (kg-gas$_q$ ha^{-1}) × $ConF_q$ (kg-CO_2e kg-gas$_q^{-1}$)

m_k is the mass of input k; EF_k is the emission factor of inputs k production and application; m_q is the mass of soil emission from gas q (CH_4 and N_2O); $ConF_q$ is the conversion factor of gas q to CO_2e (1 kg-N_2O = 265 kg-CO_2e and 1 kg-CH_4 = 28 kg-CO_2e) (IPCC, 2013).

m_{N2O} (kg-N_2O ha^{-1}) = $m_{N\text{-}CF}$ (kg-N-CF ha^{-1}) × EF_z (kg-N_2O-N kg-N-CF^{-1}) × 1.57

$m_{N\text{-}CF}$ is the amount of N-CF applied; EF_z is the emission factor applied for farming system type [0,93 (Yan et al., 2003) - 1% N_2O-N for the upland crop (IPCC, 2006) and 0.59 (0,3% kg-N, IPCC) – 0.768 (Vo et al., 2020) kg N_2O ha^{-1} season^{-1} for PR farming]; 1.57 is the value of 44/28 – the mass of N_2O and N.

m_{CH4} (kg-CH_4 ha^{-1}) = D (days) × EF_{CH4} (kg-CH_4 ha^{-1} day^{-1})

D is PR farming days; EF_{CH4} is 1.167–2.78 kg-CH_4 ha^{-1} day^{-1} (Sandin, 2005; Le & Ha, 2015; Vo et al., 2018). The EFs from Vietnamese PR farming were priority applied.

Carbon efficiency: CE = C_O (kg-C ha^{-1}) / C_I (kg-C ha^{-1})

Carbon sustainability index: CSI = [C_O (kg-C ha^{-1}) – C_I (kg-C ha^{-1})] / C_I (kg-C ha^{-1})

$Nu_{j\text{-}g}$ (kcal ha^{-1}) = $m_{j\text{-}g}$ (t ha^{-1}) × $NuC_{j\text{-}g}$ (kcal t^{-1})

$m_{j\text{-}g}$ is the mass of crop j grain (t ha^{-1}); $NuC_{j\text{-}g}$ is the nutrient conversion of crop j grain (kcal t^{-1}). In which, we use a nutrient conversion base on grain weight to calculate nutrient gain, including 3,600 × 10^3 kcal t-rice^{-1}, 3,470 × 10^3 kcal t-MB grain^{-1} (Namiki, 1995), 3,356 × 10^3 kcal t-corn grain^{-1} (Nuss & Tanumihardjo, 2010), and 5,590 × 10^3 kcal t-BS grain^{-1} (Elleuch et al., 2011). In the case of PR, rice was 80.4% rice grain (data in this study).

Emission trade-offs for nutrient gains (g-CO_2e kcal^{-1}) = Emission for 1 tonnage of product (g-CO_2e t^{-1}) / Nutrient in one tonnage of grain (kcal t^{-1})

GHGs emission for fertilizer elements gain (En-FG and Em-FG) index calculation

The Em-FG index was recommended to clearly explain the relationship between how much emission trade-off and fertilizer elements are applied for one hectare of growing area to produce one tonnage of the main product (Liem et al., 2022).

Em-FG of growing area: Em-FG (kg-CO_2e kg-elements^{-1} ha^{-1}) = GHGs emission (kg-CO_2e ha^{-1}) / [nitrogen element (kg-N ha^{-1}) + phosphate element (kg-P_2O_5 ha^{-1}) + potassium element (kg-K_2O ha^{-1})]

Em-FG of grain: Em-FG (kg-CO_2e kg-elements^{-1} t^{-1}) = GHGs-FG (kg-CO_2e kg-nutrients^{-1} ha^{-1}) / Productivity (t ha^{-1}).

3. RESULTS AND DISCUSSION

3.1. Crop yields and resource consumption

Table 2 summarizes the inputs requirement and product achievement from agricultural cropping systems. Corn was the highest total biomass selected crop and was 45,698 kg ha^{-1}. The corn grain yield was 12,520 kg ha^{-1}, which was 2.65 times lower than by-product yield and was 27.4% of total biomass. Rice was the second largest biomass in the cultivation area, with 13,425 kg ha^{-1}. Rice grain was 5,306 kg ha^{-1}, accounting for 39.5% of total biomass. The total biomass of MB was 4,704 kg ha^{-1} including 37.4% grain (1,760 kg ha^{-1}) and 2,944 kg ha^{-1} of by-products. Although BS grain only accounted for 15.0% of total biomass, 920 kg ha^{-1}, the by-product yield of BS was 5,207 kg ha^{-1}. The total biomass was 6,127 kg ha^{-1} higher than the MB biomass yield.

Table 2. Input-Output from one hectare of crop cultivation

	PR	Corn	MB	BS
A. Inputs				
1. Human labor (h)	55	200	278	316
2. Agricultural machines (h)	95	57	120	209
3. Fossil fuels and electricity				
3.1 Gasoline (l)	0	9.5	7.5	0
3.2 Diesel (l)	252.2	662.5	468.3	321.4
3.3 Electricity (kwh)	2.34	0	7.5	0
4. Chemical fertilizers (kg)	224.6	533.3	204.2	157.8
4.1 Nitrogen (kg-N)	124.5	233.2	95	71.5
4.2 Phosphate (kg-P_2O_5)	64.7	137.6	68.6	50.1
4.3 Potassium (kg-K_2O)	35.4	162.5	40.6	36.2
5. Agrochemicals (kg)	10.8	18	27.1	28.6
6. Seeds (kg)	120	13	25	4
6.1 PR	120	-	-	-
6.2 Corn	-	13	-	-
6.3 MB	-	-	25	-
6.4 BS	-	-	-	4
B. Outputs				
1. Total biomass of rice (kg)	13,425	-	-	-
1.1 Grain	5,306	-	-	-
1.2 Straw	8,118	-	-	-
2. Total biomass of corn (kg)	-	45,698	-	-
2.1 Grain	-	12,520	-	-
2.2 Stover	-	31,300	-	-
2.3 Cob	-	1,878	-	-
3. Total biomass of MB (kg)	-	-	4,704	-
3.1. Grain	-	-	1,760	-
3.2 Stover	-	-	2,376	-
3.3 Shell	-	-	568	-
4. Total biomass of BS (kg)	-	-	-	6,127
4.1 Grain	-	-	-	920
4.2 Stover	-	-	-	3,496
4.3 Shell	-	-	-	1,711

Crop cultivation requires labor for almost activities from seedling/drilling, irrigation, fertilization, agrochemicals application, and harvest. In this study, BS required the highest total working hours with 316 h ha^{-1} and was 5.75 times higher than the lowest crop care hours of PR farming (55 h ha^{-1}). MB and corn were the second largest group of labor requirements with 278 and 200 h ha^{-1}, respectively. Fossil fuel was used for machine operation, water pump, and agrochemicals application. At the same time, electricity was only used for water pumps. The corn farmers primarily used gasoline-propelled handheld reaper machines to cut corn stalks. The diesel water pumps were the most popular agricultural pumps in the local area. Corn required the most diesel and gasoline in cultivation activities, with 662.5 and 9.5 l ha^{-1}, respectively. MB cultivation required three types of power 468.3 l-diesel ha^{-1}, 7.5 l-gasoline ha^{-1}, and 7.5 kwh ha^{-1}. BS only required diesel fuel with 321.4 l ha^{-1}. Agrochemical applications included herbicides, fungicides, and pesticides. BS and MB required total agrochemicals of 28.6 and 27.1 kg ha^{-1} higher than the two other crops. Corn cultivation used 18 kg ha^{-1}, while rice consumed the lowest agrochemicals quantity (10.8 kg ha^{-1}). Corn cultivation used total fertilizers 2.4–3.4 times higher than other crops. Nitrogen fertilizer was the most consumed fertilizer, followed by phosphate fertilizer and potassium fertilizer. Although corn cultivation used much fertilizer, it gained high-yield grain.

3.2. GHGs emission

Rice and corn growing areas emitted GHGs (7,514.2 and 5,263.9 kg-CO_2e ha^{-1}) higher than MB and BS cultivation (3,122.8 and 2,368.8 kg-CO_2e ha^{-1}) (Figure 2). However, based on the grain yield crops, the emission of one tonnage of BS and MB grain (2,574.8 and 1,774.3 kg-CO_2e t^{-1}) was higher than rice grain and corn grain (1,416.1 and 420.4 kg-CO_2e t^{-1}) (Figure 2).

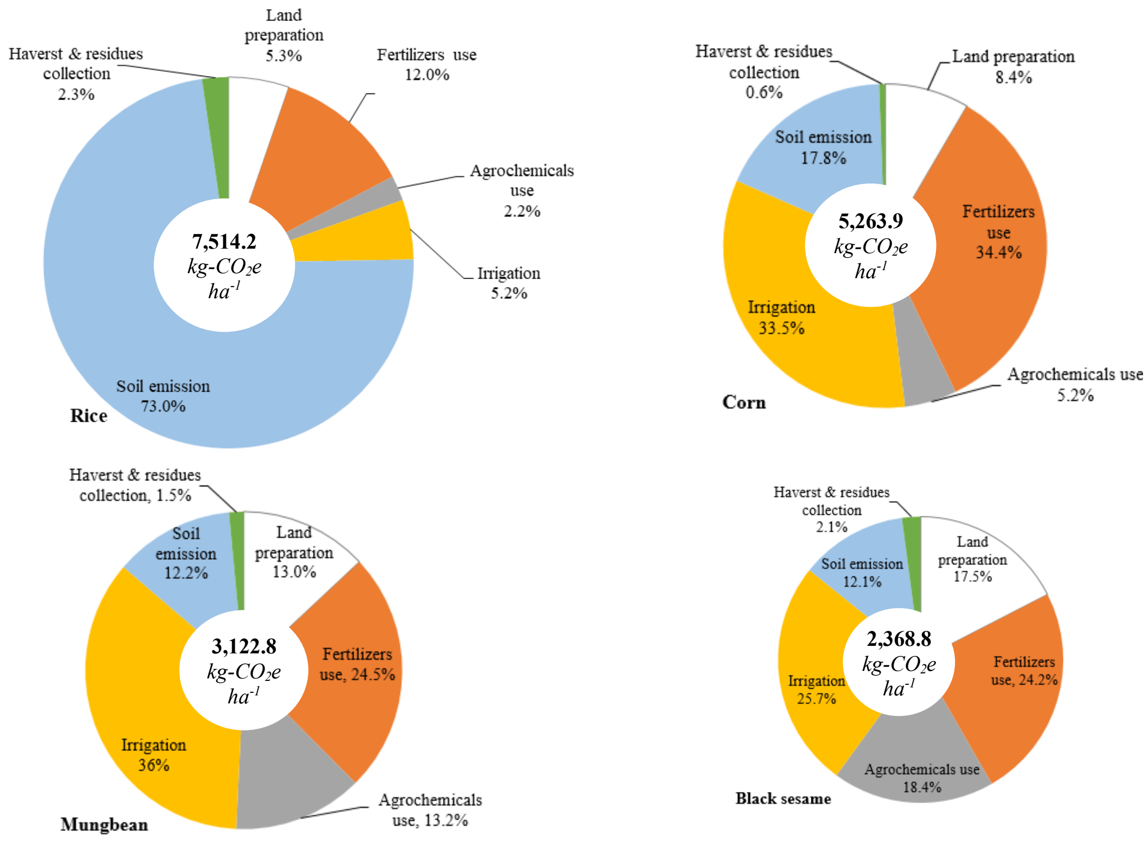

Figure 2. GHGs emission from agricultural activities

Soil management was the most significant emission source of rice farming (73%), while it accounted for 12.1–17.8% of other crop cultivation. From rice farming, soil emissions also included high emissions from CH_4 under the flooded cultivating condition. Irrigation was the highest proportion of MB, corn, and BS cultivation (36.0%, 33.5%, and 25.7%). In detail, irrigation emissions included electricity/fossil fuel produced emissions and fuels combusted emissions by water pumps. Fertilizer production's emission was the second significant source of all selected crop cultivated (12.0–34.4%). Land preparation activities through fuels consumption for agricultural machines operation were estimated. Emissions from agrichemicals (herbicides, insecticides, and fungicides) used included manufacturing production and gasoline consumed for sprayers. The emission from land preparation and agrochemicals use was highest in BS cultivation (17.5% and 18.4%) and lowest in rice farming (5.3% and 2.2%). Harvest and residue collection emission was estimated through fuels consumed by the combine harvester, self-propelled round straw baler machine (rice farming), and self-propel handheld reaper machine (corn cultivation). The lowest accounted for 0.6% in corn cultivation, and the highest accounted for 3.2% in PR farming.

Soil emission was the significant emission source from PR cultivation, while irrigation and fertilizers were two essential sources for mitigating. The flooded farming condition of PR emitted a high rate of methane. It has been found that by applying biochar alone or alternate wetting and drying water management will decrease methane emissions (Mohammadi et al., 2016; Sriphirom et al., 2020). Additionally, organic practice with green manure incorporation for rice farming in the early mid-season drainage can mitigate GHGs emissions (Toma et al., 2021). The deep-band fertilizer practice enhances the efficiency of nitrogen fertilizer application for corn (Wu et al., 2021). Depending on the acidic soil condition of Hau Giang province, the application of nitrification inhibitors fertilizer was recommended for improving the efficient use and potential to increase the upland crop yield (Thapa et al., 2016). Besides, applying nitrification inhibitors fertilizer also reduces N_2O emission compared with conventional nitrogen fertilizers (Halvorson et al., 2014; Thapa et al., 2016). Changing the irrigation method to drip irrigation and fertigation can reduce N_2O emissions (Yao et al., 2019). To reduce soil emission, enhance N fertilizer efficiency, and optimize irrigation activity to decrease total C input to get a better CSI of selected crop cultivation systems.

3.3. Input-output carbon

We found that PR farming required the highest carbon input (2,049.3 kg-C ha^{-1}), followed by corn cultivation (1,435.6 kg-C ha^{-1}), MB cultivation (851.7 kg-C ha^{-1}), and BS cultivation (646.0 kg-C ha^{-1}). Corn cultivation produced 23,350.6 kg-C ha^{-1} was 3.5 times higher than rice farming (6,745.8 kg-C ha^{-1}), 8.3 times higher than BS cultivation (2,829.8 kg-C ha^{-1}), and 10.9 times higher than MB cultivation (2,132.6 kg-C ha^{-1}). Crops cultivation produced significant carbon sources through their biomass, including grain and by-products. The grain carbon source was highest in corn (5,821.8 kg-C ha^{-1}, 28.6% total biomass carbon), followed by rice farming (2,398.4 kg-C ha^{-1}, 32.5%), MB cultivation (767.4 kg-C ha^{-1}, 35.6%), and BS cultivation (382.7 kg-C ha^{-1}, 11.6%). By-products carbon source was higher than the marketable products carbon. Rice straw carbon was 4,347.4 kg-C ha^{-1} and was 1.8 times higher than the rice grain. Corn cultivation produced 14,483.8 kg-C ha^{-1} through corn by-products and was 2.5 times higher than corn grain. Carbon from by-products of MB and BS cultivation were 1,365.2 and 2,447.1 kg-C ha^{-1}. They were 1.8 and 6.4 times higher than grain carbon sources (Table 2).

After combined harvesting, MB and BS seeds were separated, and around 2 cm or smaller biomass debris from stover and shells were sprayed on the topsoil. They were plowed into the soil to improve its fertility. Corn stover and rice straw are used for several purposes, including feedstock, mushroom cultivation, and soil orchard mulching. With any corn or rice cultivation area expansion, biomass-produced by-products will increase. This source will be a recycled material for other industry production, such as biomass gasification, biofuel, ethanol, and biochar.

3.4. Net carbon and CSI

The agroecosystem carbon analysis is presented in Table 3. The carbon footprint or net carbon, which was considered carbon sequestration, was highest in corn cultivation with 18,915 kg-C ha^{-1} and was 4.0 times higher than PR farming (4,696.5 kg-C ha^{-1}), 8.6 times higher than BS cultivation (2,183.8 kg-C ha^{-1}), and 14.8 times higher than MB cultivation (1,280.9 kg-C ha^{-1}). Corn was the most carbon-effective cultivated crop produced at 14.2 kg-C based on one kg-C input. The CE of rice and BS differed slightly with 3.3 and 4.4. MB cultivation was the minor CE crop that produced only 2.5 kg-C through one kg-C input. In this study, corn cultivation was the most sustainable selected crop, getting a CSI of 13.2. BS cultivation achieved the CSI at 3.4, higher than the 2.3 value of BS cultivation. MB cultivation was the lowest sustainable crop system in this study when CSI received 1.5.

Table 3. Input-output carbon and carbon relationship of crop cultivation

Crop type		C_O kg-C ha^{-1}			C_I kg-C ha^{-1}		C_{Net} kg-C ha^{-1}	CE	CSI
		Low–High	**Medium**	**Total**	**Low–High**	**Medium**			
PR	Grain	2,324.1–2,472.7	2,398.4	6,745.8	1,451.6–2,647.1	2,049.3	4,696.5	3.3	2.3
	Straw	3,710.1–4,984.8	4,347.4						
Corn	Grain	5,784.2–5,859.4	5,821.8	20,350.6	1,426.3–1,444.9	1,435.6	18,915	14.2	13.2
	Stover	13,662.5–13,709.4	13,678.1						
	Cob	790.6–822	805.7						
MB	Grain	741–788.5	767.4	2,132.6	847.9–855.4	851.7	1,280.9	2.5	1.5
	Stover	1,085.8–1,123.8	1,104.8						
	Shell	256.4–264.3	260.4						
BS	Grain	375.4–390.1	382.7	2,829.8	643.2–648.9	646.0	2,183.8	4.4	3.4
	Stover	1,555.7–1,833	1,694.2						
	Shell	752.6 – 753.3	752.9						

3.5. Environmental trade-offs for grain yield and nutrient gain

In S-A growing season, corn produced the highest nutrients through corn grain at 457.0 × 106 Kcal ha^{-1}. Rice provided 149.7 × 106 Kcal ha^{-1} and was 1.5 times higher than nutrients from MB grain (101.7 × 106 Kcal ha^{-1}). One hectare of BS cultivation supplied 51.4 × 106 Kcal (Figure 3).

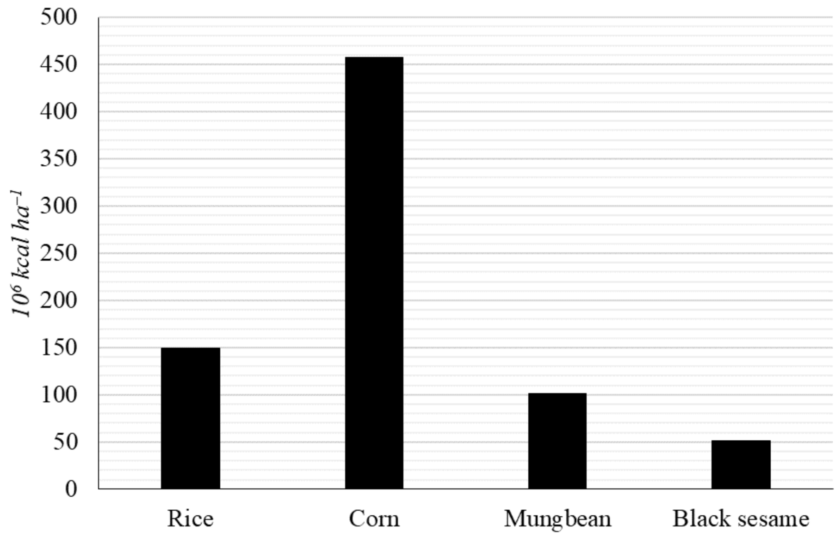

Figure 3. Nutrients gain from crops grain

Producing one calorie from grain, corn cultivation only traded off 115.19 mg-CO_2e, while PR needed to trade off 501.81 mg-CO_2e. MB had to trade off higher GHGs than BS to produce one calorie (406.61 and 306.97 mg-CO_2e Kcal^{-1}) (Figure 4).

Rice and corn are the most cereal crops worldwide. In Asia, MB is a future innovative food crop (Li & Siddique, 2020). BS is an oil-rich oil vegetable and an animal feedstock supplied through its meal after extracting oil. Parallelly providing nutrients for world consumption, crop cultivation impacted the environment through several inputs used to produce and apply. Selected crop cultivation emitted a large amount of GHGs into the atmosphere through their production. This study showed the GHGs emission trade-off for crop nutrient gain. Although the previous studies compared data could not be found, this research result was the first step to improving the negative trade-off for positive gain. However, with a whole agricultural ecosystem of crop cultivation, it is possible to conclude that four selected crop cultivations had benefited in carbon net. Crop by-products provided a huge biomass source for secondary use - recycling activities that adapt to SDG12.

In our study, we applied a range of emission rates followed by low, medium, and high intensity. The medium values were used for evaluation trade-offs and presented in Figure 4. The estimation of low and high GHGs emission exchange for benefits gain range from 1,003–1,829.2 kg-CO_2e t^{-1} in PR farming, 417.7–423.2 kg-CO_2e t^{-1} in corn cultivation, 1,766.4–1,782.2 kg-CO_2e t^{-1} in MB production, and 2,563.5–2,586.1 kg-CO_2e t^{-1} in planting BS. BS and MB cultivation has had a high range of trade-off for grain gain because of its low yield. While PR farming got a high yield, its total high emission also led this model to get a high index. High-value emissions from PR farming are primarily caused by flooded farming conditions and lead to methane gas emissions. In the case of nutrients, for achieving one calorie PR, corn, MB, and BS cultivation must swap 355.43–648.18, 114.44–115.93, 305.61–308.34, and 458.58–462.63 mg-CO_2e, respectively. Lower nutrient content in rice grain compared with other selected crop grains in this study causes the PR nutrient trade-off index to be higher than other crops. Corn production had a high yield and grain nutrient content, so this model cultivation consistently achieved a good trade-off index.

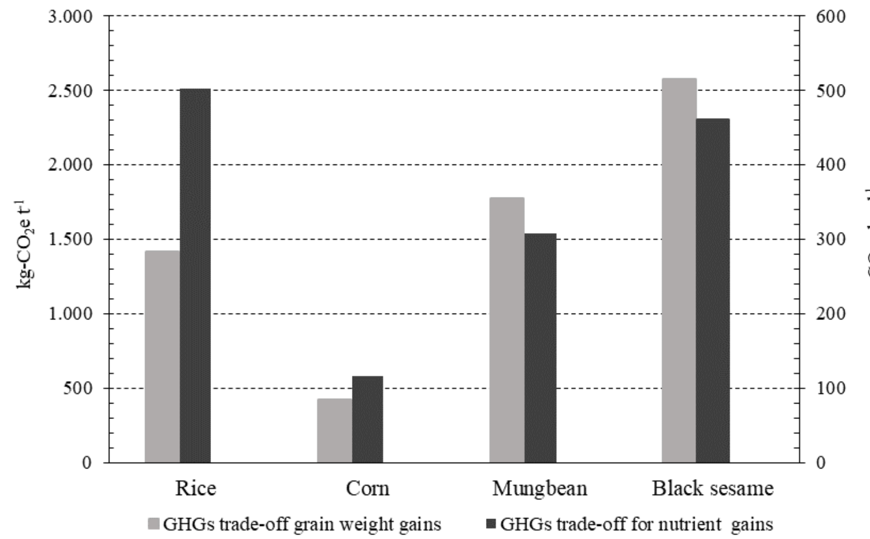

Figure 4. The environmental trade-off for grain yield and nutrient gain

4. CONCLUSION

PR is the most important crop in Vietnam and a staple in Mekong Delta agriculture. However, the practice of growing three rice crops annually has led to several negative environmental impacts. This study focuses on the Spring-Autumn growing season, aiming to recommend upland crop alternatives by examining carbon balance processes and nutrient outcomes. To assess the environmental impact of agricultural activities, the Life Cycle Assessment (LCA) methodology was applied. Overall, all crops studied showed positive results in achieving carbon targets. Corn is the best benefit upland crop that reaches the best value of carbon outcome, net carbon, CE, and CSI. One hectare of cultivated PR emitted the most jeopardous GHGs; however, through its high yield of grain and straw, PR is the second-high benefit in the carbon balance, CE, and CSI.

To produce grain together with nutrient gain, corn must trade-off the lowest GHGs emission. This study is the first publication to show the GHG emissions trade-off index for nutrient achievement. Comparing PR and MB, one unit of rice weight is exchanged for a lower GHGs emission than MB. However, a higher GHGs emission traded off one PR calorie than MB.

People must trade off emissions to get nutrients from the grain. However, this study's results underline the benefit of produced carbon in the S-A agricultural systems case study in the MD. Additionally, to enhance the benefits of transitioning from rice production to other crops, corn is recommended as a viable alternative and could be strategically planned for cultivation

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