International Journal of Agronomy and Agricultural Research (IJAAR)
ISSN: 2223-7054 (Print) 2225-3610 (Online)
http://www.innspub.net
Vol. 26, No. 5, p. 42-54, 2025

CASE STUDY   OPEN ACCESS

Carbon footprint assessment of rice cultivation of select rice farmers in Isabela, Philippines: A case study

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Article published on May 08, 2025

Key words: Climate change mitigation, Carbon footprint, Environmental efficiency, GHG emission, Rice farming practices

Abstract

Rice cultivation is the major source of GHG emission in the agriculture sector. Absence or insufficient actions to mitigate climate change can further impact the rice sector. Hence, there is a need to estimate carbon footprint in the major rice-farm activities. The main objective of this study was to assess the carbon footprint ha^{-1} generated by rice farmers. Case study and life-cycle assessment in rice production were employed. Data were gathered from household surveys and analyzed through descriptive statistics such as mean and ANOVA. Analysis revealed that the carbon footprint ha^{-1} generated by rice farmers during the dry season was 5,017.80 kg CO_2e ha^{-1}. The top three major sources of GHG emission in rice cultivation were soil emission, from rice cultivation, fertilizer, and fuel with 3,952.79 kg CO_2e ha^{-1}, 944.83 kg CO_2e ha^{-1}, and 52.83 kg CO_2e ha^{-1}, respectively. The different factors that showed significant difference in carbon footprint ha^{-1} generated by rice farmers were: quantity of fertilizer, quantity of insecticide, frequency of insecticide application, and cropping system. It has been demonstrated that GHG accounting provided metrics in carbon footprint and evidence for authorities to determine plans and initiatives, and to employ necessary interventions and mitigations to contribute in curtailing GHG emission and to minimize the impacts of climate change in the rice production sector. The findings suggest that the government can initiate localized plans and programs such as climate change education and skills training. Through this, rice farmers can strengthen their productivity and technical efficiency, and foster environmental efficiency.

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Introduction

Climate change has become a crisis nowadays and its effects have been felt across the globe (UN, 2024). Scientists determined the causes of climate change as natural or anthropogenic.

However, climate change is enhanced due to anthropogenic causes such as deforestation, change in land-use, emission of greenhouse gases (GHG), burning of fossil fuels, urbanization, and agricultural expansion (Fakana, 2020). The Philippines, as one of the vulnerable countries in the world, experiences the extreme impacts of climate change such as decreasing soil moisture, increasing surface temperature, and frequent severe storms limit an increased food production (Stuecker *et al.*, 2018). Expectedly, the agricultural sector especially the rice farmers are the most vulnerable members of the community due to the negative impacts of climate change.

Despite the abrupt change in climatic events, the rice production in the Philippines progressively increased in 2018, 2019, and 2021 (PSA, 2021). The good reports of rice production in the country and in the global context favor the increasing demands of rice. However, as the demand for rice increases, our carbon footprint also increases.

In the global GHG emissions data, the GHG emitted by human activities are: 65% carbon dioxide (CO_2) from fossil fuel and industrial processes, 16% methane (CH_4), 11% CO_2 from forestry and other land use, 6% nitrous oxide (N_2O) and 2% fluorinated gases (F-gases). This generated 54.59 billion tons (Bt) of CO_2 equivalent (e). Electricity and heat production accounts 25% share or 13.65 million Mt CO_2e; agriculture, forestry and other land use (AFOLU) constitutes 24% or 13.10 million Mt CO_2e; industry with 21% or 11.46 million Mt CO_2e, transportation with 14% or 7.46 million Mt CO_2e, other energy sources with 10% or 5.46 million Mt CO2e and building with 6% share or 3.28 million Mt CO_2e. This makes agriculture the second largest contributor of GHG next to electricity and heat production (US EPA, 2020).

In the Philippines, there is an estimated 269.93 million Mt CO_2e GHG emission in 2021. The energy sector has the highest GHG contribution with 52%, followed by agriculture with 32% contribution, industrial processes with 8% contribution, waste with 7% contribution, and land-use change and forestry with 1% contribution (Climate Transparency, 2021). Based on the foregoing data, it shows that the country contributes a very small amount of carbon footprint in relation to the global carbon footprint. Also, the global carbon footprint vis-a-vis the Philippine carbon footprint is consistent from the various sectors with the energy sector as the largest contributor followed by the agricultural sector. Hence, these two sectors are the major sources of GHG emission that need appropriate mitigations to curtail their dramatic increase. In this study, agriculture's rice production is its main focus.

The largest sources of GHG emissions in the agricultural sector in 2021 comes from rice cultivation with 62% or 33.8 Mt CO_2e followed by livestock manure with 13% GHG contribution. The third largest contributor is the enteric fermentation with 12% GHG contribution. The use of synthetic fertilizers is the next contributor with 9% GHG contribution while crop residues share 4% GHG contribution. This generates a total of 55 Mt CO_2e from this sector (Climate Transparency, 2021). The four aspects of the rice sector such as rice cultivation, enteric fermentation, use of synthetic fertilizer, and crop residue were the main areas of focus of this study in estimating the GHG emission contribution.

Globally, many rice farmers practice unsustainable management in rice cultivation. These unsustainable practices include fertilizer management, water management, and rice straw burning (RSB). Fertilizer management influences GHG emissions in rice cultivation. The 35% emission from rice is traced from N_2O of N cycling of fertilizer. Meanwhile, continuous flooding results from the large emission of CH_4 which accounts for about 65% of global CO_2 emission due to anaerobic decomposition (Allen *et al.*, 2020). On the other hand, Alternate Wetting and

Drying (AWD) considerably decreased CH_4 fluxes due to the lowered abundance of methanogens and methanotrophic bacteria (Kwon *et al.*, 2016). Lastly, rice straw burning (RSB) or open-field burning of straw is prevalent postharvest practice across the globe (Singh *et al.*, 2021). In the Philippines, including Isabela, it has long been observed that rice farmers practice RSB. This practice has been found out as one of the major sources of carbon emissions as well as other gases that are detrimental to human health and environment. The research of Mendoza (2015) reported that it takes 30 years or more to stop RSB in the Philippines or to encourage farmers in withdrawing the burning habit. It also found out that about 32% of the 22 million tons of rice straws generated are burned and 76% of rice farmers burn rice straw.

Rice cultivation, as the major source of GHG emission in the agriculture sector, contributes a considerable amount of GHG in the atmosphere. Absence or insufficient appropriate actions to mitigate the ill effects of climate change can further impact the agriculture sector, especially rice farmers. Hence, this study aimed to address gaps in GHG calculation in major farm activities by rice farmers. There is a need to estimate the actual GHG emissions in the major rice-farm activities. This serves as a basis in managing the context of how GHGs emission can be lowered.

The results of the study would offer benefits to the Department of Agriculture (DA), Provincial Government of Isabela (PGI), higher education institutions (HEIs), and rice farmers. The results would be utilized by the government to craft a policy that will guide rice farmers to practice sustainable management in rice cultivation. It could also contribute data in the nationally determined contributions (NDCs) for climate transparency in Isabela. In addition, it could provide a basis in implementing relevant extension programs of HEIs. Finally, rice farmers would be provided with a handy tool to strengthen, improve, and enrich their existing rice-farming practices to nurture productivity, technical efficiency, and environmental efficiency.

This study generally aimed to assess the carbon footprint ha^{-1} being generated by rice farmers during the dry season in 2024. Specifically, it aimed:

1. To estimate the carbon footprint ha^{-1} generated by rice farmers during the dry season;
2. To determine the major sources of GHG emissions in rice cultivation generated by the rice farmers; and
3. To determine the different factors that influenced the generation of high carbon footprint ha^{-1}.

Materials and methods

This study employed a case study research design to attain the objectives set. The household survey gathered quantitative descriptions of the major rice-farm activities from land preparation to harvesting through life-cycle assessment. The major criterion in selecting the study sites was the top five municipalities with the largest rice production area and volume of production. These municipalities were as follows: Alicia, City of Cauayan, Ramon, City of Santiago, and San Mateo (PhilRice, 2022). The said municipalities represented 34.23% of the total rice production area in the province which contributed 259% in terms of average yield ha^{-1} which is above the overall yield ha^{-1} and shared 34.99% in the overall yield. Table 1 below shows the average yield per hectare, total area harvested and volume of rice production in Isabela. The study focused on the rice farmers' current rice management practices during the dry season in 2024 of the five leading rice-producing municipalities in the Province of Isabela, Philippines It involved the GHGs accounting in the major rice-farm activities.

The participants of the study were rice farmers from the five study sites. The rice farmers are owner, tenant or lessee, have cultivated rice paddies less than one hectare or more for at least 10 years. Based on these criteria, the participants were purposely selected from the list provided by the Municipal Agriculture Office (MAO). The selected rice farmer-participants were identified by the researchers through the help of Barangay Council, particularly the Barangay Councilor-in charge with Agriculture. The rice farmer-participants involved were interviewed during the household survey.

Table 1. The average yield/ha, total area harvested and volume of production of Isabela for 2022

Municipality	Average yield ha^{-1} (Metric tons ha^{-1})	Total area harvested (ha)	Total yield (Metric tons)
Alicia	4.67	27,207	127,057
City of Cauayan	4.46	22,546	100,555
Ramon	4.85	17,822	86,437
City of Santiago	4.48	18,551	83,108
San Mateo	4.71	17,635	83,061
San Manuel	4.73	16,926	80,060
Roxas	4.61	14,747	67,984
Burgos	4.59	11,807	54,194
Mallig	4.43	12,187	53,988
Cordon	5.56	9,700	53,932
Quezon	4.37	12,188	53,262
Delfin Albano	4.43	11,334	50,210
San Isidro	4.69	10,533	49,400
City of Ilagan	4.28	11,030	47,208
Cabatuan	4.58	9,814	44,948
Quirino	4.41	9,721	42,870
Echague	4.03	10,539	42,472
Tumauini	4.28	9,262	39,641
Gamu	4.33	7,221	31,267
Luna	4.51	6,049	27,281
Angadanan	4.17	6,324	26,371
Aurora	4.59	4,120	18,911
Jones	4.34	3,654	15,858
Naguilian	4.05	3,907	15,823
Cabagan	4.12	3,772	15,541
Reina Mercedes	4.42	2,873	12,699
Santo Tomas	4.21	2,678	11,274
Santa Maria	4.25	1,822	7,744
San Pablo	4.45	1,604	7,138
San Agustin	4.45	1,304	5,803
Benito Soliven	4.36	1,158	5,049
San Mariano	3.88	959	3,721
Palanan	3.67	883	3,241
Dinapigue	3.76	411	1,545
Maconacon	3.24	433	1,403
Divilacan	3.50	362	1,267
San Guillermo	4.00	31	124
Average	4.34	8,192.27	37,093.13

The instrument used adopted some of the items provided in the reports written by IRRI (2016). It was subjected to two rounds of validation. The first round of validation was participated by the three faculty members from the Philippine Normal University who critiqued the face and content validity, and reliability of the questionnaire. After the researchers incorporated the suggestions and recommendations of the first set of validators, the researchers submitted the revised questionnaire for the second round of further face validation and content validation to two personnel from the Department of Agriculture-Cagayan Valley Research Center (DA-CVRC).

The carbon footprint of the rice farmers in rice cultivation was estimated by adopting the equations formulated by Bautista and Saito (2016) vis-à-vis the standard GHG emissions guidelines from 2019 Intergovernmental Panel for Climate Change (IPCC) Guidelines and literature review. Table 2 shows the sources of GHG emissions with their corresponding emission factors. The data obtained from household surveys of the rice farmers were utilized for the quantification of the GHG emissions in rice cultivation to arrive at the calculation of carbon footprint. Data were interpreted using descriptive statistics particularly the mean and Analysis of Variance (ANOVA). The results of the carbon footprint assessment were validated by an expert from PhilRice to attain more reliable and valid findings.

GHG emissions estimation

The GHG emissions from agricultural inputs such as fertilizer, pesticides and fuel, water buffalo, and machines were estimated based on the 2019 IPCC Guidelines and literature review. The total GHG emissions of rice production in Isabela was estimated in terms of carbon dioxide equivalence (CO_2e) through the use of the following equation:

$$GHG_r = \sum(GHG_{rc} + GHG_{fe} + GHG_{cf} + GHG_{fu} + GHG_{pe} + GHG_{ma}) \quad (1)$$

Where

GHG_r = total GHG emissions of the rice cultivation in Isabela, kg CO_2e

GHG_{rc} = GHG emissions from soil during rice cultivation, kg CO_2e

GHG_{fe} = GHG emissions from fertilizer application, kg CO_2e

GHG_{cf} = GHG emissions from carabao enteric fermentation and carabao manure, kg CO_2e

GHG_{fu} = GHG emissions from fuel used by machinery, kg CO_2e

GHG_{pe} = GHG emissions from pesticides, kg CO_2e

GHG_{ma} = GHG emissions from machinery, kg CO_2e

GHG emissions from rice cultivation

CH_4 emissions from the soil were estimated by using the emission factors in Table 2. Since most of the rice farmers practice in-situ straw incorporation, 1.22 kg CH_4 d^{-1} ha^{-1} was used.

CH_4 emissions were calculated by multiplying the emission factors by the total harvested area for a 120-day cultivation period. The Global Warming Potential of CH_4 was 27. Equation 2 was used:

$$GHG_r = \sum(EF_{i+s} \times A_i) \times t \times 27 \quad (2)$$

where

GHG_{rc} = GHG emissions from soil during rice cultivation, kg CO_2e

EF_{i+s} = emission factors for CH_4 from irrigated with rice straw

t = cultivation period of rice, 120 days/season

A_i = area of irrigated, ha

GHG emissions from fertilizer application

Inorganic fertilizers were used in this study. Table 2 shows the emission factors for the production of inorganic fertilizers containing nitrogen (N), phosphorus (P) and potassium (K). Separate computations were done for the amounts of N, P, and K from the four common fertilizers applied by the rice farmers such as urea (46-0-0), ammonium sulfate (21-0-0), ammonium phosphate (16-20-0), and complete (14-14-14) fertilizers. Emissions from N_2O of N fertilizers were estimated by multiplying the emission factor of N_2O of the N content with the amount of N applied in the rice field. The Global Warming Potential of N_2O used was 273. The Equation 3 was utilized as follows:

$$GHG_{fe} = \sum((EF_a \times AF) \times 273 + (EF_p \times AF)) \quad (3)$$

where

GHG_{fe} = GHG emissions from fertilizer application, kg CO_2e

EF_a and EF_p = emission factor of N_2o due to N fertilizer application and that due to production of NPK fertilizers, respectively

AF = amount of fertilizer to rice production, kg

GHG emissions from pesticides application

The pesticides applied by the rice farmers ranged from herbicides, insecticides, fungicides, molluscicides, rodenticides, and other substances in controlling pests and diseases. The emission factor used was 5.5 kg CO_2e kg^{-1} for the production and application of pesticides. Refer to Table 2 shown above. To estimate the GHG emissions from pesticides, the emission factor is multiplied by the amount of pesticides applied. Equation 4 was used as follows:

$$GHG_{pe} = EF_p \times A_p \quad (4)$$

Where

GHG_{pe} = GHG emissions from pesticides, kg CO_2e

EF_p = emission factor of pesticides, g CO_2 kg^{-1}

A_p = amount of pesticides used in rice cultivation, kg

GHG Emissions in the use of water buffaloes in rice farming

Water buffaloes were largely used before for land preparation and hauling inputs and rice paddies. However in the present study, they were utilized mostly on harrowing and hauling rice paddies. Water buffaloes were included in the estimation of GHG emission because they emit CH_4 and their manure is a source of CH_4 emissions. The estimation of GHG emissions from water buffaloes enteric fermentation and water buffaloes manure was determined by using Equation 5.

$$GHG_{cf} = \sum((EF_c \times C) + (EF_m \times C)) \times t \times 27 \quad (5)$$

Where

GHG_{cf} = GHG emissions from water buffaloes enteric fermentation and water buffaloes manure, kg CO_2e

EF_c and EF_m = emission factor for water buffaloes enteric fermentation and water buffaloes manure, respectively
t = cultivation period of rice, 120 days/season
C = number of water buffaloes involved in rice cultivation

GHG emissions from diesel fuel consumption in the use of agricultural machinery

The fuel consumption was taken from various rice-farm activities such as land preparation, crop establishment, irrigation, and harvesting and threshing. Rice farmers used diesel and the mean usage from the aforementioned activities was 141.34 L. In estimating the GHG emissions from diesel fuel used by various machinery, Equation 6 was used as follows:

$$GHG_{fu} = EF_d \times A_d \times NCV \quad (6)$$

Where
GHG_{fu} = GHG emissions from fuel used by agricultural machinery, kg CO_2e
EF_d = emission factor of diesel oil, t C TJ^{-1}
A_d = amount of diesel used by machinery, L ha^{-1}
NCV = net calorific value, TJt^{-1}

GHG emissions from the manufacture and use of agricultural machinery in rice farming

The different agricultural machineries used in this study were two-wheel tractor, four-wheel tractor, combine harvester, water pump, and grass cutter. Their emission factors are reflected in Table 2. Through literature review, the weight of four-wheel tractor is 3,215 kg with a life span of 10,000 h; two-wheel tractor weighs 286 kg with a lifespan of 12,000 h; water pump weighs 94 kg with a lifespan of 43,800 h; grass cutter has a weight of 7.3 kg with a lifespan of 8,760 h; and combine harvester weighs 3,3333 kg with a lifespan of 4,500 h. To determine the value of GHG emissions from machinery manufacture, Equation 7 was used;

$$GHG_{ma} = \sum((EF_{ma} \times W_{ma} \times T_u) / (LS)) \quad (7)$$

where
GHG_{ma} = GHG emissions from agricultural machinery, kg CO_2e
EF_{ma} = emission factor for agricultural machinery, kg CO_2 kg^{-1}
W_{ma} = weight of machine, kg
T_u = total time of operation, h ha^{-1}
LS = lifespan of machine, h

Table 2. Sources of GHGs emissions in the rice production and their emission factors

Sources of GHG emission in the rice production		Emission factors	Sources
Non-CO_2 GHG	Straw incorporation in irrigated farms	1.22 kg CH_4 ha^{-1} d^{-1}	IPCC (2019)
	Fertilizer application, N	0.003 kgN_2O-N kg N^{-1}	Bautista and Saito (2016)
	Carabao enteric emission	60 kg CH_4 yr^{-1} $head^{-1}$	IPCC (2019)
	Carabao manure emission	60 kg CH_4 yr^{-1} $head^{-1}$	IPCC (2019)
CO_2 from fossil energy	Fertilizer production, N	1.3 kg CO_2e kg N^{-1}	Bautista and Saito (2016)
	Fertilizer production, P	0.2 kg CO_2e kg P^{-1}	
	Fertilizer production, K	0.2 kg CO_2e kg K^{-1}	
	Pesticides (insecticide and herbicide)	5.5 kg CO_2e kg^{-1}	
	Diesel oil	20.2 t C TJ^{-1}	
	Manufacture of farm machinery (hand tractor and axial flow thresher)	12.8 kg CO_2e kg^{-1}	
	Herbicide	23.3 kg CO_2e kg^{-1}	Thanowong, Perret, Basset-Mens (2014)
	4-Wheel tractor with implement	12.7744 kg CO_2e kg^{-1}	Lips (2017), Yanmar Philippines
	Combine harvester	12.389 kg CO_2 eq. kg^{-1}	Hou *et al.* (2019), Akter *et al.* (2024), Yanmar Philippines
	Portable fresh water pump	0.99 kg CO_2 eq. kg^{-1}	El-Gafy and El Bably (2015),Yanmar Philippines
	Grass cutter	1.638 kg CO_2 eq. kg^{-1}	Banks and McConnell (2015)

Results and discussion

Carbon footprint ha^{-1} generated during dry season

Results showed that the carbon footprint ha^{-1} generated by rice farmers in Isabela during the dry season was 5,017.80 kg CO_2e ha^{-1}. The top five major rice-farm activities that generated high GHG emissions include: soil emission from rice cultivation, fertilizer application from crop establishment, and crop care and maintenance, harvesting and threshing, plowing, and water management. The carbon footprint generated by rice farmers Isabela is comparable with conventional farming in Japan with 6,300.00 kg CO_2e ha^{-1} (Hokazono and Hayashi, 2012). The similarity of the two studies is directly associated with the intensive use of fertilizer, fuel, machinery as well as soil emission from rice cultivation. In the overall carbon footprint, conventional farming in Japan practiced more intensive cropping compared to the present study which gives rise to higher carbon footprint.

Table 3. Sources of emissions with their corresponding values and % share

Sources of emissions	kg CO_2e ha^{-1}	% Share	Rank
Soil emission	3,952.79	78.78	1
Fertilizer	944.83	18.83	2
Fuel	52.83	1.05	3
Machines	47.93	0.96	4
Carabao	14.06	0.28	5
Pesticides	5.36	0.11	6
Total	5,017.80	100.00	

Major sources of GHG emissions

The sources of GHG emissions in rice production is shown in the following Table 3. Among the major sources of GHG emission, soil emission from rice cultivation had the highest GHG emission. It comprised 3,953.79 kg CO_2e ha^{-1} with 78.77% share in the overall carbon footprint. The very high generation of GHG was rooted from the farmer's lack of knowledge and skills in the quantity of RS incorporated in rice paddies. The emission originated from CH_4 in the soil. All rice farms were under irrigated water management. This means the rice farms were irrigated when rice farmers started preparing the rice field and before harvesting season. It was revealed in this study that rice farmers did not burn RS. Instead, all of them practiced straw incorporation. The total amount of RS by rice farmers was 204,955.60 kg ha^{-1}. Much of these RS were in-situ incorporated. This in-situ postharvest management increased CH_4 emission in the next cropping season (Bautista and Saito, 2016). Also, the amount of carbon footprint generated from this practice was directly associated with the quantity of the RS incorporated and timing of application (Maneepitak *et al.*, 2018). Another reason for the very high generation of GHG was rooted from the farmer's lack of knowledge and skills in the timing of application of RS in rice paddies. Launio *et al.* (2014a) suggested that RS should be incorporated 30 days before the establishment of the rice paddies. Through this way, it would reduce the cumulative CH_4 and N_2O emissions. Finally, the depth of RS incorporation would reduce CH_4 emission. Dominguez-Escriba and Porcar (2010) required rice farmers to incorporate RS in dry fallow fields on a depth of up to 10 cm. This allows aerobic decomposition in the rice field contributing to various farm benefits not only reduced CH_4 emission.

Following the highest GHG emission contributor is the fertilizer application that was utilized both from crop establishment, and crop care and maintenance. It had a total of 944.83 kg CO_2e ha^{-1}. The relative high amount of GHG contributed by fertilizer resulted from the amount of fertilizer applied and the frequency of application. There was a large amount applied during crop establishment with a mean of 27.85kg and crop care and maintenance with a mean of 495.79kg. On average, rice farmers utilized 10.47 sacks with 50 kg of fertilizers in the dry season. Reported by PSA

(2021), the average fertilizer usage for all grades ranged from 5.56 bags to 5.83 bags of 50 kg ha^{-1}. Despite the increased fertilizer application reported by PSA, the rice farmers in Isabela applied almost twice the amount of fertilizer. Given this data, over application of fertilizers by the rice farmers may be attributed to the higher amount of fertilizer application during the dry season. Moya *et al.* (2017) revealed that farmers apply a higher amount of fertilizer during the dry season because of the higher solar energy resulting in a higher yield.

The frequency of fertilizer application is another apparent cause of the high amount of fertilizer application. On average, rice farmers applied fertilizers in the rice fields in four splits which is contrary to the report published by IRRI (2016) with three splits only. Few farmers applied fertilizers up to five splits. Thus, timing, quantity, and frequency of fertilizer of application are valuable considerations in the generation of a great amount of GHG emissions. This is where rice farmers should mitigate the N_2O emission to reduce the overall GHG contribution.

The third highest source of emission was fuel consumption with GHG emission of 52.83 kg CO_2e ha^{-1}. Mechanization in rice farming has replaced intensive physical labor of rice farmers and farm animals. High adoption of machines involved in the accomplishment of major rice farm activities was reported by Launio *et al.* (2015b). Machines and equipment used in the various farm activities were four-wheel tractors with rotavators, two-wheel tractors, portable freshwater pumps, grass cutters, and combine harvester, and hauling trucks. These sets of farm machines and equipment consumed large amounts of diesel to perform efficiently. Likewise, the more machines utilized in the performance of major rice-farm activities, the more fuel consumption is required.

The different factors that influenced the generation of high carbon footprint in rice farming

To determine the different factors that influenced the generation of high carbon footprint, a test of difference through ANOVA was used. The variables that showed significant differences were quantity of fertilizer, cropping system, quantity of insecticide application, and frequency of insecticide application whereas category of land holdings, rice cultivar, type of soil, planting method, water management, herbicide application, molluscicide application, rodenticide application did not show significant difference.

The test of difference on the carbon footprint ha^{-1} generated when data were aggregated according to fertilizer management is summarized Table 4. The results of this study showed that the quantity of fertilizer applied in the rice field showed a significant difference while the frequency of fertilizer application did not. This suggests that one of the considerable factors that greatly influenced the production of high carbon footprint was the quantity of fertilizer applied. The quantity of fertilizer is directly proportional to the carbon footprint. Thus, the higher the quantity of fertilizer applied in the rice field, the higher the probability of generating a higher carbon footprint. In the study conducted by Bautista and Saito (2016), they reported that the second highest emitter originated from fertilizer. This finding supported the results of the present study. The quantity of the fertilizer applied is a significant variable in the generation of high carbon footprint. The higher the quantity of fertilizer applied in the rice field, the higher the generation of GHG emissions. Rice farmers should efficiently utilize the results of the soil analysis for them to determine, select, and apply the right amount and type of fertilizer to be applied in the rice field. In doing so, they will reduce GHG emission caused by fertilizer.

Summarized in Table 4 is the test of difference on the carbon footprint ha^{-1} generated when data were aggregated in terms of insecticide management. The results of the study showed that quantity of insecticide and frequency of insecticide application showed significant difference. This indicates that the quantity of insecticide applied in the rice field and frequency of the insecticide application positively influenced the production of higher carbon footprint. Thus, the higher quantity of insecticide applied in the rice field and the extensive use of insecticides resulted in higher generation of carbon footprint. In the present study, there is a high and intensive insecticide use which contributed to the high generation of carbon footprint among pesticides. Accordingly, Sampaothong and Punyawattoe (2024) shared that insecticide resistance management exhibited lower carbon footprint. This indicates that if rice farmers use insecticide sparingly coupled with insect management, the use of insecticide will be lowered and hence, reducing carbon footprint. Furthermore, it is noteworthy that rice farmers should consider the primary insects that infest rice crops to adapt sustainable practices to minimize their infestation and if not to completely eradicate them.

Table 4. Test of difference on the carbon footprint ha^{-1} when grouped according to the indicated variables

Variable	Source of variation	F value (F)	P-value (P)	Decision	Interpretation
Category of land holdings	Between groups Within groups Total	2.01	0.153	Accept Ho	Not significant
Rice cultivar	Between groups Within groups Total	0.48	0.496	Accept Ho	Not significant
Type of soil	Between groups Within groups Total	1.31	0.286	Accept Ho	Not significant
Planting method	Between groups Within groups Total	2.14	0.154	Accept Ho	Not significant
Quantity of fertilizer	Between groups Within groups Total	16.43	0	Reject Ho	Significant
Frequency of fertilizer application	Between groups Within groups Total	2.15	0.118	Accept Ho	Not significant
Source of irrigation	Between groups Within groups Total	1.54	0.233	Accept Ho	Not significant
Frequency of irrigation	Between groups Within groups Total	0.34	0.799	Accept Ho	Not significant
Quantity of herbicide	Between groups Within groups Total	0.10	0.426	Accept Ho	Not significant
Frequency of herbicide application	Between groups Within groups Total	0.78	0.385	Accept Ho	Not significant
Quantity of insecticide	Between groups Within groups Total	4.02	0.029	Reject Ho	Significant
Frequency of insecticide application	Between groups Within groups Total	3.46	0.030	Reject Ho	Significant
Quantity of fungicide	Between groups Within groups Total	1.32	0.287	Accept Ho	Not significant
Frequency of fungicide application	Between groups Within groups Total	1.49	0.244	Accept Ho	Not significant
Quantity of molluscicide	Between groups Within groups Total	0.36	0.702	Accept Ho	Not significant
Frequency of molluscicide application	Between groups Within groups Total	0.10	0.754	Accept Ho	Not significant
Quantity of rodenticide	Between groups Within groups	1.88	0.181	Accept Ho	Not significant

	Total				
Frequency of rodenticide application	Between groups	1.88	0.181	Accept Ho	Not significant
	Within groups				
	Total				
Quantity of other pesticides	Between groups	1.35	0.275	Accept Ho	Not significant
	Within groups				
	Total				
Frequency of other pesticides application	Between groups	1.38	0.269	Accept Ho	Not significant
	Within groups				
	Total				
Cropping system	Between groups	4.79	0.037	Reject Ho	Significant
	Within groups				
	Total				
Postharvest method	Between groups	1.22	0.32	Accept Ho	Not significant
	Within groups				
	Total				

Presented in Table 4 is the test of difference in the production of carbon footprint ha^{-1} when data were grouped in terms of cropping system. Results show that the cropping system showed significant difference. This indicates that cropping systems positively influenced the generation of higher carbon footprint. Monocropping or rice-rice systems produced a higher carbon footprint compared to the crop rotation. Diversified crop rotation systems are potential mitigating ways in decreasing carbon footprint. This is revealed by the study conducted by Yang *et al.* (2014) where diversified crop rotation systems significantly lowered carbon footprint in contrast with the intensive rice-rice system. In application, rice farmers should practice crop rotation where rice fields are planted with corn and/or vegetables. This cropping system does not only contribute to carbon footprint reduction but also provides an economic opportunity for rice farmers.

Conclusion

It has been demonstrated that GHG accounting provides carbon footprint metrics in rice production. In addition, the various factors that affect the generation of carbon footprint ha^{-1} were quantity of fertilizer, quantity of insecticide, frequency of insecticide application, and cropping system. The GHG accounting and determination of the factors that influenced the generation of high carbon footprint helped in the determination of the major sources and variables that impact the generation of high amounts of GHG emissions. Through this, it presented facts and evidence for authorities to determine plans and initiatives, and mitigations to curtail GHG emissions and minimize the impacts of climate change especially in rice farming.

Recommendations

Based on the foregoing conclusions, it is recommended that results of the GHG accounting can serve as a basis for the national government in contributing the facts and figures in the national determined contributions (NDCs) in the Philippines. Consequently, it can help define the climate pledge of the Philippines in the future targets of the Paris Agreement. Local Government Units (LGUs) must revisit their local plans and strategies in mitigating the effects of climate change in reference to the mandate reflected in the RA 9729 also known as Climate Change Act of 2009 and DA Policy in Implementation of Climate Change, and revise it accordingly to suit the present circumstance of rice production and rice farmers. Furthermore, LGUs along with potential partners can provide capacity building activities such as climate change education, and skills training for rice farmers in the farm management especially crop residues. Ultimately, rice farmers should actively participate and involve in any capacity-building activities conducted by DA and LGU in order to learn, unlearn and relearn valuable knowledge, skills, and attitude in sustainable rice farming needed in enhancing productivity, increasing technical efficiency, and fostering environmental efficiency, and mainstream proven approaches and strategies in rice farming.

Acknowledgments

Commission on Higher Education- Staff and Instructors' Knowledge and Advancement Program (CHED-SIKAP) is well acknowledged for the financial support given throughout the course of the study and completion of the degree to the corresponding author.

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