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Carbon Footprints and Conventional Rice Cultivation; A Case Study in Thanjavur District

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

Aims: The study aimed to analyse the carbon footprint of conventional rice cultivation and also the carbon economic efficiency.
Study Design: Multi-stage random sampling was used.
Place and Duration of Study: The study was carried out in the Thanjavur district of Tamil Nadu between April and May 2022.
Methodology: Both primary and secondary data were used in the study. The main methodology used in finding the carbon footprint is LCA (Life Cycle Analysis). A well-structured interview schedule was used in the collection of data. Various kinds of literature were referred to find emission factors which were used in the study. A sample of 60 farmers was selected and data was collected. Also, 5 mills were visited to understand the process of milling, storage and transport of rice.
Results: A total carbon footprint of 6720.46 Kg CO_2e/ha was determined from the study for the cultivation, harvest, and post-harvest operations of rice production. Harvest and post-harvest processes result in a carbon footprint of 1851.46 Kg CO_2e/ha, while the carbon footprint of cultivation is 4869 Kg CO2e/ha. In addition, the carbon economic efficiency was shown to be 23.39, meaning that the economic worth of rice production is 23.39 Rs per kg of carbon emission.

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Conclusion: An important factor in greenhouse gas emissions and a bigger carbon footprint is the use of fertilizers, irrigation techniques, and straw management. An important recommendation to reduce the carbon footprint is the alternate wetting and drying method of irrigation. A further way to lessen the environmental impact of rice farming is to use fewer fertilizers and pesticides.

Keywords: Carbon footprint; rice; thanjavur; life cycle analysis; paddy; greenhouse gas emissions; low carbon technologies.

1. INTRODUCTION

Agriculture largely contributes to anthropogenic global warming and reducing agricultural emissions, particularly methane and nitrous oxide, could help combat climate change. The multi-decadal rise trend in atmospheric CH_4 has been driven primarily by natural and anthropogenic sources, with fossil fuel and agricultural emissions accounting for most of the surge since 2007. (IPCC sixth assessment report).

Table 1. Total area, production and carbon footprint of crops studied over 50 years, from 1960 to 2010

S. no.	Crops	Total area (ha)	Total production (tonnes)	Total C footprint per unit area (Tg CE/ha)
	Cereals			
1	Paddy rice (*Oryza sativa*)	2,017,191	9,048,534	23.75
2	Wheat (*Triticum aestivum*)	1,097,534	4,845,973	4.03
3	Sorghum (*Sorghum bicolor*)	709,529	1,695,809	5.94
4	Finger millet (*Eleusine coracana*)	107,702	328,567.1	2.99
5	Maize (*Zea mays*)	302,938	1,098,307	3.01
6	Pearl millet (*Pennisetum glaucum*)	543,769	621,704.9	3.43
7	Barley (*Hordeum vulgare*)	81,765	242,896	3.37
	Total	4,860,428	17,881,791	46.47
	Pulses			
8	Red gram (*Cajanus cajan*)	152,951	608,961.9	2.98
9	Black gram (*Vigna mungo*)	113,955	227,681.4	3.07
10	Lentil (*Lens culinaris*)	45,844	113,037.1	3.45
11	Bengal gram (*Cicer arientinum*)	370,297	798,322.7	6.07
	Total	683,047	1,748,003	15.57
	Oilseeds			
12	Sunflower (*Helianthus annus*)	47,203	103,360.4	6.14
13	Groundnut (*Arachis hypogaea*)	357,235.5	843,568.9	6.16
14	Soybean (*Glycine max*)	138,460.5	303,195.5	3.82
15	Safflower (*Carthamus tinctorius*)	25,007	24,777.86	3.33
16	Sesamum (*Sesamum indicum*)	108,270.7	112,399.6	3.82
17	Rapeseed and mustard (*Brassica* spp.)	229,169.5	728,988.2	3.37
18	Linseed (*Linum usitatissimum*)	64,726.6	70,801.89	4.36
	Total	1,017,275	218,700	31.0

Source: (D Sah and A S Devakumar, 2018)

Currently, the food supply chain contributes 13.7 billion metric tonnes of carbon dioxide equivalents (CO_2eq), representing 26% of all human GHG emissions [1]. Sustainable agriculture gives importance to maintaining the quality of the environment, agronomic production and the mitigation of climate change. Carbon footprint is a breakthrough concept which is essential to understanding the impact caused by a product on the environment throughout its life cycle [2,3]. The evaluation of mitigation measures and emission management is aided by the carbon footprint, which is a measurable expression of GHG emissions from a specific activity. The area, production and carbon footprint of different crops in India during the period 1960 to 2010 are given in Table 1. This gives an idea of the Carbon footprint of different crops thus giving an idea about more sustainable options for the cultivation of different crops.

From Table 1, it can be seen the carbon footprint for rice is the maximum among the crops considered and rice is also the crop with a larger area. Also, cereals are the crops which emit a higher amount of greenhouse gases and have a high carbon footprint. Red gram has the least Carbon footprint among the considered crops. Elimination of cultivation practices which emits more greenhouse gases can help in reducing the carbon footprint [3,4].

1.1 Research Carried Out Globally to Estimate the Carbon Footprint of Rice Cultivation

Various studies have been carried out in different parts of the world to calculate the carbon footprint of rice. Some of such studies and their results are given as follows

Xu et al. [5] in their research, studied the carbon footprint of rice in five provinces of China namely Jiangsu, Heilongjiang, Sichuan, Guangdong and Hunan province. The study found that the carbon footprints were found to be 2504.20 kg carbon dioxide equation per ton of rice (kgCO_2eq/t) in Guangdong province, 2326.47 kgCO_2-eq/t in Hunan province, 1889.97 kgCO_2eq/t in Heilongjiang province, 1538.90 kgCO_2eq/t in Sichuan province and 1344.92 kgCO_2eq/t in Jiangsu province respectively.

Arunrat et al. [6] conducted research in Thailand on different footprints of organic and conventional rice cultivation. The study concluded that the net greenhouse gas emissions were less in organic rice farming when compared to conventional rice farming (3289.1 kg CO_2eq ha^{-1} $year^{-1}$ and 4921.7 kg CO_2eq ha^{-1} $year^{-1}$ respectively.

Champrasert et al. [7] conducted research on the carbon footprint of upland rice production through Life Cycle Analysis from planting to harvesting in the Karen and Lawa region of Thailand. The Karen produced 0.26 tonnes of CO_2equivalent per hectare (0.13 kilograms of CO_2-equivalent per kilograms of unmilled rice) and the Lawa produced 0.37 tonnes (0.19 kilograms of CO_2equivalent per kilograms of unmilled rice) of greenhouse gas emissions from upland brownrice production.

Farag et al. [8] calculated the emissions arising from the paddy fields. The study was carried out in Egypt. Paddy was found to have a carbon footprint of 1.90 Kg CO_2eq per Kg. Kashyap and Agarwal [9] estimated the carbon footprint in Punjab, India. The carbon footprint of rice was found to be 8.80± 5.71 t CO_2 eq/ha. Nitrogen fertilizers were found to be a major contributor to emissions.

1.2 Rice Cultivation in Thanjavur District

Thanjavur, with 2.13 lakh hectares, was the highest paddy-growing land in Tamil Nadu year 2020–2021. (Season and crop report 2020-2021). From the primary survey, it was found that the main rice varieties grown in Thanjavur are BPT 5204, CO 51, IR 20, TPS 5and ADT 53. The cropping pattern followed is rice-rice-pulses. After harvest, the paddy harvested is sold to Direct Procurement Centres. Each village has DPCs within a 2 km radius. The paddy grown is harvested using a combine harvester and is brought to the DPC by tractors. The paddy thus collected is then sent to modern rice mills for processing and after processing, the processed paddy is packed in the automated facility and then sent to different locations. The paddy thus processed is mostly stored in godowns before they reach the hands of the consumer.

1.3 Study Problem

Over 65% of the population consumes rice, making it the most important staple food in the nation. With 17.95 per cent of the world's rice production, India ranks second in both production and consumption [10]. Methane and carbon dioxide, two of the main greenhouse gases, are both produced and stored in large quantities in rice fields (CH_4 and CO_2). Nitrous oxide (N_2O) and methane emissions into the atmosphere come from paddy fields (CH_4). In a nutshell, carbon footprint assessment in rice can help to find ways to reduce greenhouse emissions and promote climate-smart methods of rice cultivation. Thanjavur is one of the largest producers of paddy in Tamil Nadu and this study has attempted to find the carbon footprint of conventional paddy cultivation in the Thanjavur district.

1.4 Objectives

i. Assessing the carbon footprint of conventional rice cultivation using Life Cycle Analysis (LCA)
ii. Evaluating the carbon economic efficiency of conventional rice cultivation
iii. To suggest recommendations which reduce the emissions encountered**.**

2. METHODOLOGY

2.1 Data Sources

A sample size of 60 farmers was chosen from the Orathanadu and Ammapettai blocks of Thanjavur District and a primary survey was conducted with the assistance of a well-crafted interview schedule. Also, the data from TNCSC and the direct procurement centres were collected. In addition, 5 modern rice mills were visited to know the processing of rice in detail. Secondary data from the pieces of literature were used to find the emission factors used for the study.

2.2 Method of Data Analysis

The various methods used in the analysis are given as follows

2.2.1 Life Cycle Analysis (LCA)

A "cradle-to-grave" method of evaluating industrial systems, life cycle evaluation starts with the collection of raw materials from the earth to make the product and concludes with the return of all elements to the earth. LCA assesses every stage of a product's life from the viewpoint that they are interrelated, which means that one action triggers another. LCA makes it possible to calculate the overall environmental effects of all phases of the product life cycle, frequently taking into account effects that are not taken into account in more conventional studies (e.g., raw material extraction, material transportation, ultimate product disposal, etc). A more accurate picture of the real environmental trade-offs in product and process selection is provided by LCA, which offers a full view of the environmental characteristics of the product or process [11].

The carbon footprint of paddy agriculture can be computed as follows using the LCA method [12].

i. Set the system boundaries
ii. Define the greenhouse gases
iii. Establish the calculation formula
iv. Interpret the result

2.2.1.1 Set the system boundaries

In this study, the boundaries are set as the total production stage of paddy and also its harvest and post-harvest practices.

2.2.1.2 Define the greenhouse gases

Greenhouse gases are emitted during different stages of paddy production. This includes fertilizer application, herbicide spraying, manure stacking etc. The important greenhouse gases emitted during the production of paddy are carbon dioxide, nitrous oxide and methane.

2.2.1.3 Establishing the calculation formula

The formulae for estimating the carbon footprint of rice are given in Table 1.

Where

- EF = technology-specific emission factor (area-scaled or input-scaled).
- SF= technology-specific scaling factor (unit-less).
- CoF= technology-specific conversion factor (quantity-scaled).
- Seed_Rate, N_Rate, Straw_Rate = rate of seeds; N-Fertilizer, straw (incorporated).
- Cult_Per = cultivation period (in days; used as rate in WSM equation).
- OA = organic amendments.
- $CFOA_{Straw}$, ROA_{Straw} = conversion factor and rate of straw (incorporated), respectively.
- CFOAAdd_Org, ROA_{Add_Org} = conversion factor and rate of additional OA, respectively.

- Q_{Harv}, Q_{Dry}, Q_{Sto}, Q_{Prod} = quantities after harvest, drying, storing as well as product, respectively.
- $Dist_{Truck}$, $Dist_{Tract}$, $Dist_{Ship}$, $Dist_{Boat}$ = distance transported by truck, tractor/trailer, ship, boat, respectively.

Table 2. Formulae for estimation of carbon footprint [13]

Stage	GHG Calculation and Input Parameters
Crop establishment and protection	$GHGCEP = GHG_{Wet} + GHG_{Seed} + GHG_{Pest} = EF_{Wet} + EF_{Seed} \times @Seed\_Rate + EF_{Pest}$
Water/soil management (WSM)	$GHGWSM = EF_{CH4} \times @Cult\_Per \times Sc_{FW} \times Sc_{FP} \times (1 + @ROAStraw \times CFOAStraw + @ROAAdd\_Org \times CFOAAdd\_Org)$ 0.59
Fertilizer applications (Fer)	$GHGFert = GHG_{N2O} + GHG_{CO2\_F} = (EF_{N\text{-}N2O} + EF_{CO2\text{-}N}) \times @N\_Rate$
Machine operations (MO)	$GHG_{MO} = EF_{MO}$
Harvest (H)	GHGHarv = EFHarv
Straw management (SM)	$GHG_{Straw} = EF_{Straw} \times @Straw\_Rate$
Drying (D)	GHGDry = CoFDry × QHarv
Storage (S)	GHGSto = CoFSto × QDry
Milling (M)	GHGMill = CoFMill × QSto
Packaging (Pk)	$GHG_{Pk} = CoF_{Pk} \times Q_{Prod}$
Transport (Tr)	GHGTr = GHGTruck + GHGTract + GHGShip + GHGBoat = (CoFTract × DistTract + CoaTruck × DistTruck + CoFBoat+ × DistBoat + CoFShip × DistShip) × QProd

2.2.1.4 Interpretation of the result

Using the formulae given in Table 2, the results are assessed and interpreted based on the emissionsaccounted.

2.2.1.5 Emission factors

Table 3. Emission factors used in the study

Particulars	Emission factor	Source
CH_4 emission	0.85 Kg CH_4/ha/day	[14]
N_2O emission from nitrogen fertilizer	2.341 g CO_2e/Kg N	Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories,2006
CO_2 emission from Nitrogen Fertilizer	5.68g CO_2e/Kg N	[15]
Regular pumping	97 Kg CO_2e/ ha	[16]
Field operations	234 Kg CO_2e /ha	[17]
Drying	168 Kg CO_2/ton of rice	[16]
Storage	24.4 Kg CO_2/ton of rice	[17]
Milling	23 Kg CO_2/ton of rice	[17]
Packaging	2 Kg CO_2/ton of rice	[18]
Transport (Truck)	0.4 g CO_2e / Kg rice /Km	[18]
Transport (Tractor)	0.257 g CO_2e / Kg rice /Km	[18]

2.2.3 Carbon Economic Efficiency [12]

The ratio of the entire value of paddy yield to carbon emissions is known as carbon economic efficiency. It calculates the economic gains associated with each unit of carbon dioxide produced by a paddy growing method. The calculation formula is as follows:

$$JC = T/CE$$

Where, JC is the carbon economic efficiency (Rs/ kgce); T and CE are the total output value (Rs/hm^2) and total carbon emission (kgce /hm^2), respectively. A large JC value indicates great economic benefits per unit of carbon dioxide emission.

3. RESULTS AND DISCUSSION

3.1 Descriptive Statistics of Respondents Interviewed in the Primary Survey

From Table 4, it can be seen that the respondents of the survey were mostly distributed between the age group of 69 and 33. The average age of the respondents was found to be 50. The education of the respondents was divided into six categories. The categories are as given as follows, Illiterate, Primary (1-5), Secondary (9-10), Higher secondary (10-12) and diploma/ Graduate. The average education level is found to be of category 2. The experience of the farmers was distributed between 6 to 46 years. The average experience of the respondents was 23 years. The land holdings of the farmers were distributed between 0.4 to 4.86 hectares. The average land size of the farmers was found to be 1.36 Ha. The family size of the respondents ranges between 2 to 8 persons. The average number of people in the family of respondents was found to be 4.

3.2 Carbon Footprint of Conventional Rice Cultivation

From the formulae given in the methodology, the carbon footprint during various stages of rice cultivation has been found. The result of the study is presented as follows with the help of tables and figures.

The greenhouse gas emission during various stages of cultivation is shown in Fig. 1. The seed rate of paddy is 100 Kg/ha. Water management practices contribute the most to the emission of greenhouse gases which accounts for 3226.6 Kg/ha. The majority of the farmers in Thanjavur irrigate their fields once in two days. Fertilizer application is the second-largest contributor to greenhouse gas emissions. Machines are used for harvesting and ploughing the field. The conventional method of rice cultivation requires intensive use of fertilizers and pesticides which generates an average of 802.1 Kg CO_2e/ha. Equipment operations include the operations of pumps and tractors. The major pesticides used in rice cultivation are fipronil and pretilachlor. FYM is one of the important organic amendments applied at the rate of 7 tonnes per hectare. Urea is the main source of nitrogen fertilizer which is applied at the rate of 95 Kg/ ha at various stages.

As shown in Fig. 2, harvesting operations contribute the most amount of GHG in the segment of harvest and post-harvest operations. A combine harvester is used in the harvesting of paddy which requires around 2.5 hours to harvest a hectare of paddy. One hectare of paddy cultivation yields 100 rolls of straw. Each roll weighs approximately 45 Kg. The straw obtained is sold as a commodity and is not incorporated directly into the soil. Hence, the quantity of GHG emitted from straw management is null. Heavy incorporation of straw into the soil gives rise to a larger quantity of GHG. Drying is done in stages. The harvested paddy is sold to Direct Procurement centres which are at a distance of 2 Km from each village. The paddy thus sold is then dried using a flatbed drier during the milling process. Milling yields 99.9 Kg CO_2e/ha GHG. Paddy harvested is processed in modern rice mills in Thanjavur. Packaging of processed rice is by the automated facility and then transported to various parts of the state by lorries or trucks. These products are then stored in godowns.

From Table 2 it is found that the GHG emission is higher in the cultivation stage of paddy when compared to Harvest and post-harvest stages (4859 and 1851.46 Kg CO_2e/ha respectively). This is mainly due to irrigation practices, and the application of pesticides and fertilizers.

From Table 3, it is observed that the CH_4 emission is 3226.6 Kg CO_2e/ha, CO_2 emission is 3259.76 and N_2O emission is 234.1 Kg CO_2/ha respectively. A low N_2O emission shows that the fields are not over-fertilized [13].

Table 4. Descriptive statistics of respondents interviewed in the primary survey

S. No	Variables	Mean	Maximum	Minimum	Standard deviation
1	Age (years)	50.14	69	33	10.6
2	Education (categories of 1-6)	2.68	6	1	1.7
3	Experience(years)	23.15	46	6	9.43
4	Land size(ha)	1.36	4.86	0.4	0.92
5	Family size (no of people)	4.17	8	2	1.03

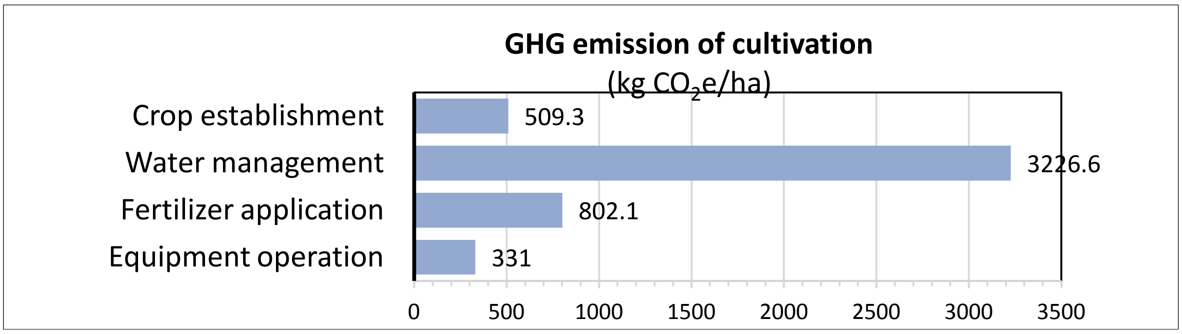

Fig. 1. Green House Gases emissions during different stages of rice cultivation
Source: Calculations carried out from primary data

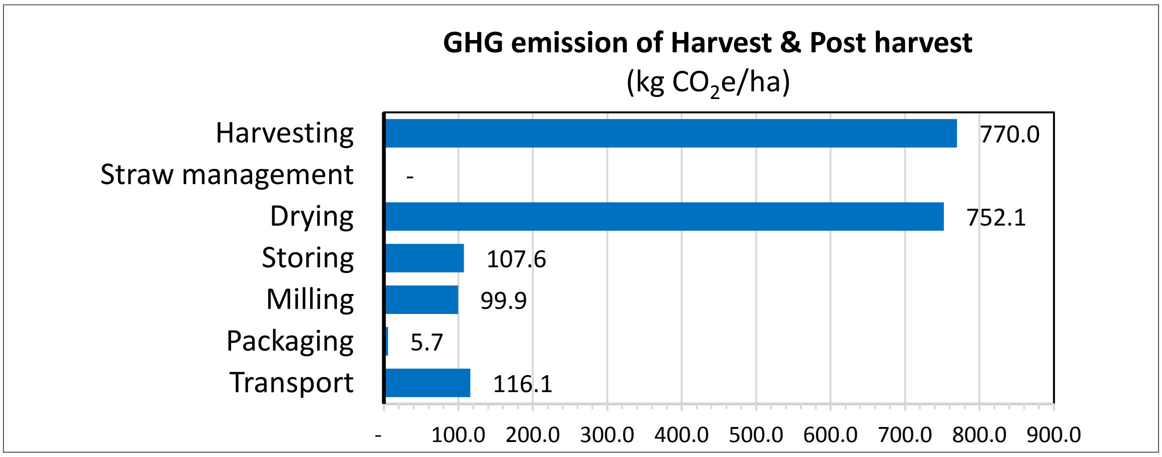

Fig. 2. Green House Gases emissions during harvest and post-harvest operations
Source: Calculations carried out from primary data

Table 5. Segment-wise GHG emissions

Segment GHG emission	kg CO_2e/ ha
Cultivation	4,869.00
Harvest and post-harvest	1,851.46
Total	6,720.46

Source: Calculations carried out from primary data

Table 6. Types of gases emitted

GHG emissions by gas	kg CO_2e/ha
CH_4 emission	3,226.60
N_2O emission	234.10
CO_2 emission	3,259.76
Total	6,720.46

Source: Calculations carried out from primary data

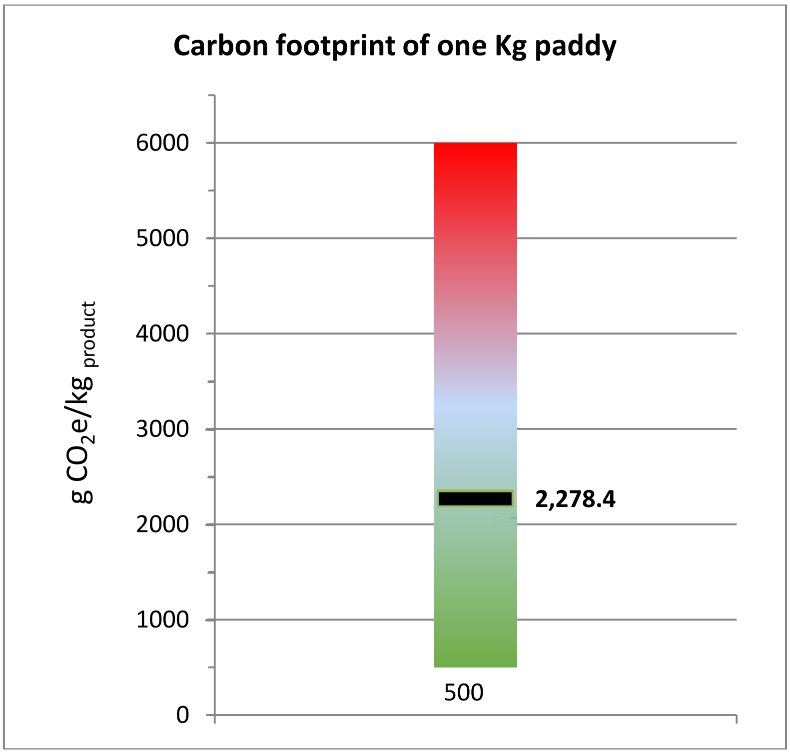

Fig. 3. The carbon footprint of one kg of paddy
Source: Calculations carried out from primary data

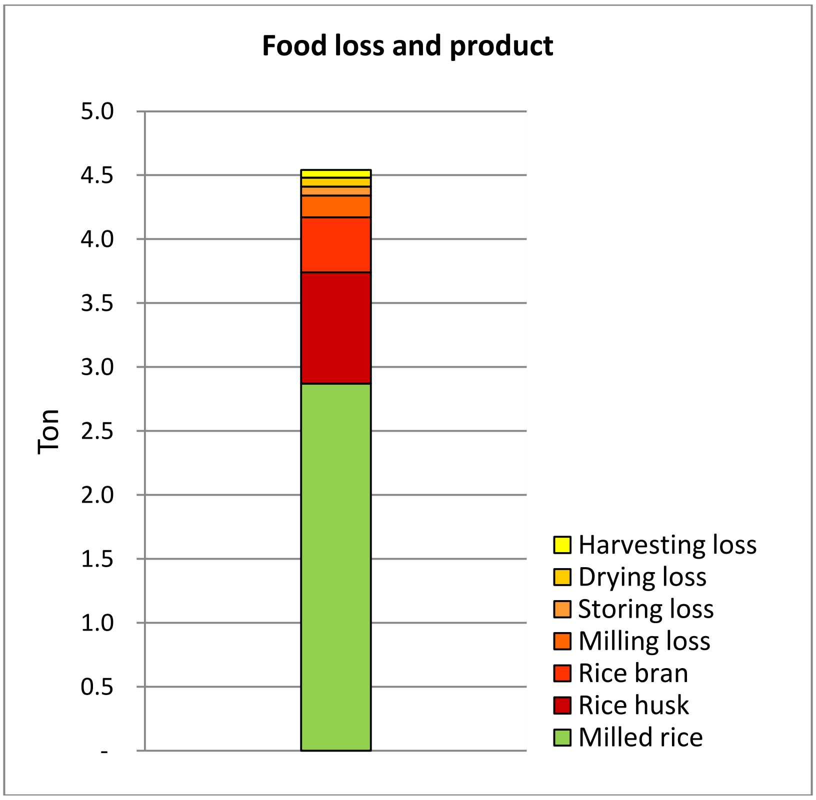

Fig. 4. Food loss and byproducts obtained during milling of paddy
Source: Calculations carried out from primary data

Fig. 3 shows that the carbon footprint of one Kg of paddy produced is 2278.4 g CO_2/Kg.

From Fig. 4, it is evident that from processing a quantity of 5 tonnes of harvested paddy, we get 2.9 tonnes of milled rice, 0.9 tonnes of rice husk, and 0.4 tonnes of rice bran. The losses occurred during the harvest and post-harvest stages including harvesting loss, drying loss, storing loss and milling loss at a quantity of 0.1,0.1,0.1,0.2 tonnes respectively.

3.2 Carbon Economic Efficiency

The carbon economic efficiency of paddy was found to be 23.39. This means that the economic value of rice cultivation is 23.39 Rs per 1 kgce carbon emission.

4. CONCLUSION

From the study, it was found that the total carbon footprint of rice production in terms of cultivation, harvest and post-harvest operations was found to be 6720.46 Kg CO_2e/ha which is a bit higher when compared to the values given in the previous studies. The carbon footprint of cultivation is 4869 Kg CO_2e/ha and that from harvest and post-harvest operations is 1851.46 Kg CO_2e/ha. The carbon footprint of one Kg of paddy produced is 2278.4 g CO_2/Kg. This shows that the carbon footprint per kg of rice produced is also higher when compared to the studies mentioned initially. Moreover, the carbon economic efficiency was found to be 23.39 which implies that the economic value of rice cultivation is 23.39 Rs per kgce carbon emission. As found in the previous studies, Fertilizer application, irrigation practices and straw management has a major role in contributing to greenhouse gas emissions and thus contributing to a higher carbon footprint. Using paddy straws as a commodity has been more helpful to reduce emissions than burning them. Alternate wetting and drying can be practised to reduce the carbon footprint and thus reduce the carbon footprint of rice cultivation. Reducing the quantity of fertilizers and pesticides applied can also aid in reducing the impact of rice cultivation on the environment.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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APPENDIX

TNCSC: Tamil Nadu Civil Supplies Corporation DPC: Direct Procurement Centre
KGCE: Kilo Gram of Carbon Equivalent
IPCC: Intergovernmental Panel on Climate Change GHG: Green House Gas
FYM: Farm Yard Manure LCA: Life Cycle Analysis CE: Carbon equivalent
Tg CE: Tera grams of Carbon Equivalent

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