Review Article

Carbon footprint is an indicator of sustainability in Rice-Wheat cropping system: A Review

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Abstract
Intensively cultivated rice-wheat cropping system of the Indo Gangetic plain (IGP) is a potential source of greenhouse gas (GHG) emissions.Agriculture sector emits GHGs like methane (CH_4) and nitrous oxide (N_2O). The total amount of GHGs emitted by a product is known as its carbon footprint (CFP).Quantification of CFP of crops will help in identifying management practices to reduce CFP of crop production. Studies related to assessing of CFP of agricultural products are lacking. The present review paper was aimed to discuss about the studies done on GHG emission from rice-wheat cropping system of the Indo Gangetic plains. The paper elaborates on what is CFP, how to calculate CFP of rice-wheat cropping system with the help of different case studies. The paper provides insights about certain agricultural management practices which can help in reducing CFP of rice-wheat cropping system. Discussion from this paper signifies the importance of carbon footprint assessment in maintaining the sustainability of rice wheat cropping system.

Keywords: Rice-wheat cropping system (RWCS), Greenhouse gas (GHGS), Carbon footprint (CFP), Sustainability of RWCS

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Introduction

In recent times continuous rise in the concentration of atmospheric Greenhouse gases (GHGs) like carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O) has led to global warming and associated change in climate. Globally agriculture contributes to about 13.5% of greenhouse gas (GHG) emission [1]. In India, agriculture sector contributes 18% of the total GHG emission [2]. Emission of GHGs from agriculture occurs mainly from enteric fermentation, rice cultivation, soils, manure management and from crop residue burning (**Table 1**). According to IPCC report, agricultural activities like land preparation, crop cultivation, irrigation practices, animal husbandry, fisheries and aquaculture also have significant effect on GHG emission [3].

Table 1 Greenhouse gas emissions from Indian agriculture in 2010

Source	CH_4(kgha^{-1})	N_2O(kgha^{-1})	Global warming potential (GWP, kgha^{-1})
(CO_2 eq.)			
Enteric fermentation	10.90	-	228.9
Manure management	0.13	0.08	27.5
Rice cultivation	3.4	-	85.0
Agricultural soil	-	0.26	77.8
Cropresidue burning	0.30	0.01	9.6
Total	14.73	0.35	417.8
Source: Pathak *et.al* (2014)			

According to United Nation Framework on Climate Change (UNFCCC), global food production is expected to double in the next 30 years [4] ; and the global food demand will be twice as of today by 2050 [5]. Increase in agricultural production is accompanied with heavy usage of irrigation water, fertilizer, pesticide and also increased use of farm machineries which will lead to lot of GHG emission.

Agriculture contributes to GHG emission both due to on-farm and off-farm activities. Submerged rice fields are a major source of CH_4 emission while application of nitrogenous fertilizers leads to N_2O emission. CO_2 is also emitted during burning of fossil fuel in farm machineries and during burning of crop residues. Manufacturing of agrochemicals causes production of CO_2. The total amount of GHG emission associated with a food product or services product is known as its carbon footprint (CFP) and is expressed in terms of carbon dioxide equivalent(CO_2e) [6]. Recently there is a growing interest in reducing the carbon footprint of agricultural products [7]. CFP of a product can be quantified by assessing GHG emissions at all stages like ploughing of field, application of fertilizers and pesticides, harvesting of crop, storage, processing, packaging, transport and finally consumption during its life cycle [8]. GHG emission data can be obtained by direct field measurement, or by estimation based on emission factors given by IPCC.

Rice-wheat cropping system

Rice wheat cropping system (RWCS) is world's largest agricultural production system which covers around10.3Mha in India and 85 percent of this area falls in Indo Gangetic plains (IGP) (**Table 2**) [9, 10]. Food security of India is dependent on the Indo-Gangetic plains (IGP), occupying 53% of area under this system and feeding 40% of the country's population [11, 12]. IGP is the most fertile region and is well known center for the green revolution, spreads over a vast area ranging from Punjab to West Bengal [13]. RWCS is water, labour, capital and energy intensive, and as these resources decline it is becoming less profitable [14]. This intensively cultivated cropping system of the IGP plays a major role in the food security of south Asia, but is a potential source of greenhouse gas (GHG) emission as well and also vulnerable to climate change [15]. In recent past the RWCS has also started showing lower marginal returns, deterioration of physical and chemical properties of soil and decline in groundwater table [16].

Table 2 Area under rice-wheat cropping system in different countries

Country	Area (Mha)	Area (%)	
		Rice	Wheat
China	13.0	31	35
India	10.3	23	40
Pakistan	2.2	72	19
Bangladesh	0.5	5	85
Nepal	0.6	35	84

Source: (Timsina and Connor, 2001)

Conventionally rice is grown by transplanting rice seedlings in puddle soil, while wheat is sown by broad casting seed in tilled rice residue burnt fields [17]. Rice fields submerged with water are potential source of methane (CH_4) and application of nitrogenous fertilizers is the main source of nitrous oxide (N_2O) in fertilized soils [18]. Application of chemical fertilizers not only contributes to N_2O emission but also has an impact on emission of CO_2 and CH_4 [1]. Soil management through tillage operations lead to emission of carbon dioxide (CO_2) from soil through biological decomposition of soil organic matter [8]. Fuel use for various agricultural operations and burning of crop residues is a source of carbon dioxide emission. Burning of agricultural residues emit significant amount of CO_2, N_2O and CH_4 with CO_2 accounting for 91.6% of the total emissions [19] and maximum were from Uttar Pradesh followed by Punjab and Haryana.

In India puddled rice fields emit 3.37 Mt of CH_4 that accounts for 24% of total agricultural GHG emission [20]. Nitrous oxide emission from Indian agriculture is 0.14 Mt. Methane emission has remained constant over the years, but N_2O emission has increased from 169 to 217 thousand tons during 1995 to 2007.The productivity of RWCS is different in different parts of IGP due to the variation in climate, soil, cultivation methods and level of mechanization [21]. Nitrous oxide emission from agriculture is higher in states like Punjab, Haryana and Uttar Pradesh in upper IGP due to heavy usage of nitrogenous fertilizers. Emission of methane varies with different rice ecosystems with continuously flooded rice system emitting maximum CH_4.

Carbon footprint of Rice-Wheat cropping system

Crop production, food processing, and marketing of produce causes GHG emission contributing to global climate change [22]. The amount of GHG emission expressed as CFP of crops is assessed by taking into account the GHG emission in the whole cycle of crop production [23] and it is measured in terms of carbon dioxide equivalents [24]. Several researchers referred CFP as GHG intensity and indicated that it is a measure to correlate agricultural practices with GHG emission [25-27]. Dipak et al (2016) estimated the GHG intensity of conventional rice and wheat cultivation in IARI, New Delhi and reported that rice-wheat cropping system had GHG intensity of 0.19 and 0.213 kg CO_2 eq. kg^{-1} grain yield respectively in two years of study. According to HU et al [28], GWP of conventional rice-wheat cropping system in Jiangning District of China was 275 kg CO_2 eq. Mg^{-1}grain yield. In Haryana, soil-borne emissions are the major source of GHG emission contributing to 53% of the GWP in rice [29]. Pathak et al. (2010) reported that rice based food products have higher CFP than wheat based products.

Estimation of CFP in Rice-Wheat cropping system

GHG emission occurs from different stages of crop production. Various standards for estimating GHG emission such as GHG protocol of World Resource Institute [30], IPCC 2006 guidelines [31],GHG accounting methods given by ISO 14064 [32, 33], Publicly Available Specifications-2050 [34, 35] of British Standard Institution (BSI) and ISO 14067 [36] are available [37].

As per the standards following four steps are suggested for calculating CFP described below:

- Identification of GHGs: In agriculture the significant GHGs are CH_4 and N_2O. CO_2 emission from use of farm machineries is also considered for calculation of CFP.
- Boundary setup: Defining the boundary is important as it determines the steps and activities that will be included for calculation of CFP [38]. The selection of boundary depends upon the level up to which CFP of rice and wheat crop is to be calculated. For estimating CFP of rice and wheat cultivation, GHG emission data should be collected for ploughing of field, application of agrochemicals and harvesting of crop. Amount of GHG emitted during production of agri-inputs like fertilizers, pesticides etc. also need to be quantified. Extending this boundary up to the food product i.e. rice and chapatti on the table will include activities like transportation, processing, packaging and also food preparation methods.
- Collection of GHG emission data: As per IPCC guidelines, GHG emission from agricultural land can be calculated using Tier 1, Tier 2 or Tier 3 approach. In Tier 1 approach, GHG emission is calculated using default parameter values while in Tier 2, country and region-specific data on emission factors are considered. In Tier 3 approach, models and inventory measurement systems are used to estimate GHG emission. Calculation of CFP using higher tier approaches improves the accuracy of and reduces uncertainty. Collection of gas samples from rice and wheat fields at regular time intervals and analysis of those samples in laboratory can be done to collect actual GHG emission data from rice-wheat cropping system. If collection of actual GHG data from the field is not feasible then GHG emission can be calculated using emission factors suggested by IPCC. Besides this crop models can also be used to quantify emission of GHGs from rice and wheat crop grown under different management practices.
- Calculation of CFP: GHG data collected is converted to global warming potential (GWP) in terms of carbon dioxide "equivalent" (CO_2eq) based on the GWP of each GHG relative to that of CO_2 [39]. Based on a 100-year time horizon the GWP for CH_4 and N_2O is 25 and 298 respectively when the GWP value for CO_2 is taken as 1. CFP of rice and wheat crop is calculated by dividing the GWP by respective yield of each crop (eqution 1& 2) [38],

$$CFP_{rice} = GWP_{rice}\ (CO_2\ eq.) / \text{Rice yield (kg)} \quad (1)$$
$$CFP_{wheat} = GWP_{wheat}(CO_2\ eq.) / \text{Wheat yield (kg)} \quad (2)$$

Management options to reduce the CFP in RWCS

Conservation agricultural (CA) practices involving minimum soil disturbance, permanent soil cover and diversified crop rotations provides opportunities for obtaining sustainable crop yield, increasing input use efficiency, improving soil properties and also mitigating greenhouse gas (GHG) emissions [40]. CA based resource conserving technologies (RCTs) are being practised over 3.9M ha area of South Asia [41]. Technologies such as zero tillage (ZT), raised bed planting, laser levelling, direct seeded rice, direct drilling of crop residues, brown manuring, crop diversification, site-specific nutrient management, etc are such crop management options which are based on the principles of CA [42].

Different resource conserving technologies like intermittent wetting and drying (IWD) in rice, direct seeded rice (DSR), zero tillage in wheat, application of crop residue, mid-season drainage in rice, use of nitrification inhibitor etc. have been identified for mitigating GHG emission from rice-wheat cropping system [19, 42-46].

Tillage operation

During tillage operation soil aggregates are broken, increasing oxygen supply which promotes the decomposition of organic matter and evolution of more CO_2 from a tilled than an undisturbed soil [47]. On the other hand conservation tillage leads to organic carbon enrichment of soils [48]. Zero tilled wheat (ZTW) is an option which allows earlier planting of the crop helps in controlling weeds, reduces CO_2 emission, saves water and fuel and enhances soil carbon stock [49-51]. Jat et al [41] observed that CA based tillage practices led to enhancement in yield and C sustainability index value in all the cereal based cropping systems. However the C sustainability index was lower in rice than wheat and maize crop. Researchers have reported that zero tillage could reduce the oxidation of soil organic matter to $CO_2$and this may help in mitigating soil emissions and increase soil organic carbon [52, 53]. An experimental study was carried out by Dipak et al [15] to analyze the GWP of rice-wheat cropping system under different management practices. It concluded that zero tilled wheat followed by direct seeded rice (ZTW-DSR) had significantly lower GWP than other management practices. GHG intensity (kg CO_2eq kg^{-1} yield) as calculated by Dipak et al (2016) was lowest (0.11 kg CO_2 eq kg^{-1} produce) in ZTW-DSR cropping system showing that adopting ZTW followed by DSR in place of conventional tilled wheat (CTW) followed by transplanted rice (TPR) can be an efficient low carbon option in the IGP (**Figure 1**).

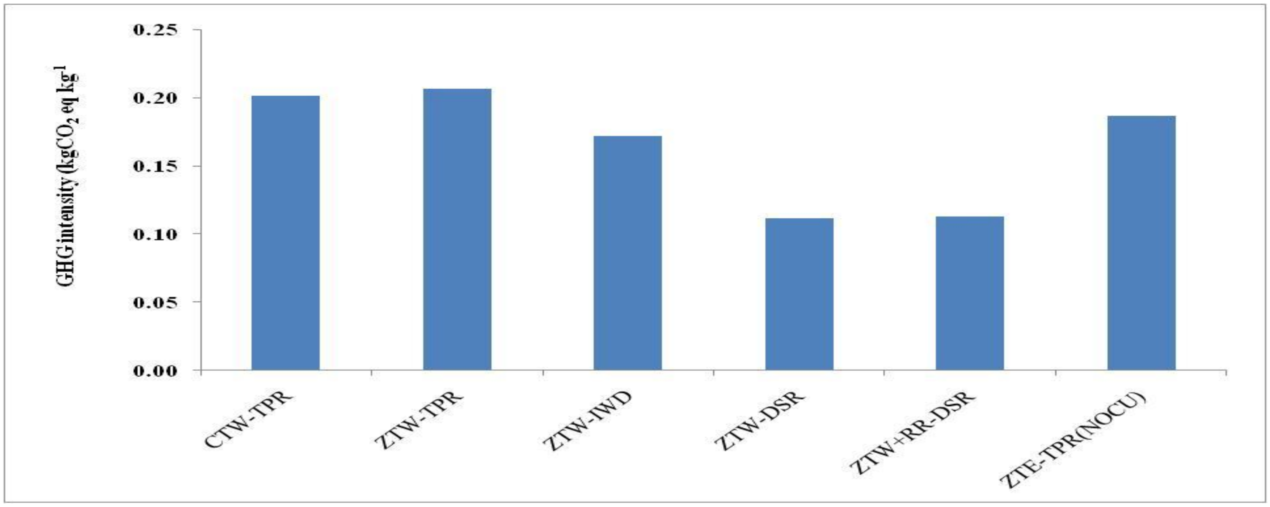

Figure1 GHG intensity of different management practices in rice-wheat cropping system (Source: Dipak et al, 2016) [CTW-TPR: conventionally tilled wheat followed by transplanted rice; ZTW-TPR: zero tilled wheat followed by transplanted rice; ZTW-IWD: zero tilled wheat followed by rice with intermittent wetting and drying; ZTW-DST: zero tilled wheat followed by direct seeded rice; ZTW+RR-DSR: zero tilled wheat with rice residue retention followed by direct seeded rice; ZTW-TPR (NOCU): zero tilled wheat with neem coated urea application followed by transplanted rice with neem coated urea applied.]

Water management

According to Chauhan and Opeña [54], puddling in transplanted rice consumes up to 30% of the total rice water requirement. In DSR, seeds are directly sown in soil and do not require puddling hence this technology is reported to reduce CH_4 emission and save labour and water [42]. It has got better adaptive capacity to climate change, and growing DSR could reduce methane emission as fields are not continuously submerged with water. A study conducted in Karnal, Haryana showed that yield of transplanted rice was 10-12% higher than DSR but practicing DSR caused labor and cost saving of 97% and 80% [55].

Intermittent wetting and drying (IWD) of soil in rice also saves irrigation water and reduces CH_4 emission [56]. Data from meta-analysis in Asia has found that IWD is responsible for 43% reduction in Global Warming Potential [57]. Richards and Sander [58] estimated that global CH_4 emissions will be reduced by 4.1 Mt per year if continuously flooded rice fields are drained at least once during the crop growth period.

Dipak et al (2015) quantified the GWP of rice-wheat cropping system using modeling approach and concluded that the GWP of conventional technologies of Haryana was higher than that of Bihar due to high CO_2 emission from electric pump used for irrigation purpose. Among different technologies studied RCTs like DSR, SRI, DSR and ZTW had lower GWP than conventional practices (**Figure 2a, b**).

Nutrient management

Application of chemical fertilizers not only contributes to N_2O emission, but may also have impact on CO_2 and CH_4 emission contributing towards enhanced global warming [1]. Hence improved fertilizer application techniques, are needed to reduce GHG emission and enhance crop yield. Bhatia et al [59] reported that, leaf colour chart (LCC) based urea application caused reduction in N_2O emission in rice and wheat crop. Site-specific nutrient management in rice has been found to be more efficient than the conventional methods in reducing nutrient losses and improving nutrient use efficiency [60, 61]. According to Gan et al [62], improved crop management practices in wheat such as soil test based fertilization, reduction in summer fallow and rotation with grain legumes could lower CFP by 256 kg CO_2eq ha $^{-1}$ yr-1and sequester0.027–0.377 kg CO_2eq in the soil.

Pathak and Aggarwal, [42] estimated the GWP of rice and wheat crop under different management practices in the IGP. Some technologies such as direct seeded rice, mid-season drainage, nitrification inhibitor, site-specific nutrient management and use of leaf color chart based nitrogen application were able to reduce GHG emission while in lower IGP, zero tillage, sprinkler irrigation, nitrification inhibitor, site-specific nutrient management reduced GWP (**Figure 3**). But some of these technologies required additional cost while some were found to be economically feasible.

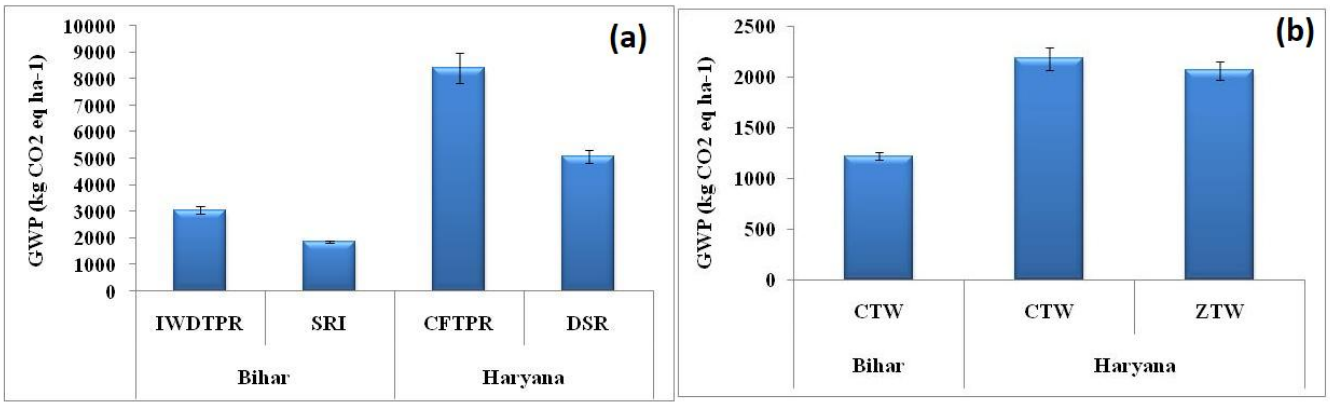

Figure 2 Global warming potential of different technologies in rice and wheat in Bihar and Haryana (Source: Dipak et al, 2015) [IWDTPR: intermittent wetting and drying in transplanted puddled rice; SRI: system of rice intensification; CFTPR: continuous flooded puddled transplanted rice; DSR: direct-seeded rice; CTW: conventional tillage wheat; ZTW: zero tillage wheat]

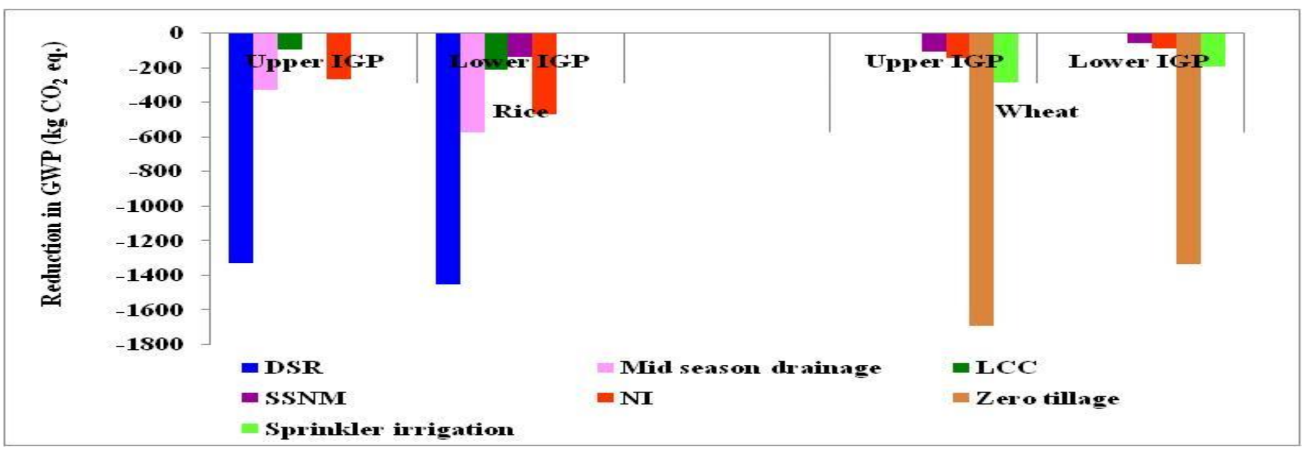

Figure 3 Reduction in GWP over conventional practice in rice and wheat under different technologies (Source: Pathak et al, 2012)

Crop residues management

The huge amount of residue produced from rice-wheat cropping system is one fourth of the total residue produced in India [63]. Rice residue management is a tedious task since there are very less time gap between rice harvesting and sowing of next wheat crop. Besides this rice residue is not used as animal feed due to its high in silica content. Hence it is burnt on field to save time and cost of removal. Burning of crop residue causes emission of GHGs like CO_2 (70%) and N_2O (2.09%) which can alter the radiation balance of the atmosphere [19]. Residue incorporation in soil is the easiest and successful method to improve water productivity, retain soil moisture, suppress weeds and regulate soil temperature [64-66].Now a day's Happy Seeder Planter is keeping a pace in residue management by following conservation agricultural practices [67]. Haque et al. [68] carried an experiment in Jinju, South Korea and found that intermittent wetting and drying along with biomass incorporation is an effective strategy for GWP mitigation in rice crop.

Pathak and Wassman (2007) used the modelling tool Techno GAS and assessed the GHG mitigation potential of different technologies in rice and wheat crop in Haryana, Results showed that 13 technologies have the potential to reduce the GWP compared to current farmers' practice in rice crop. Up scaling of the estimates showed that modifications in nutrient, water, and rice straw management could reduce the GWP by 15–41% in Haryana. According to the study proper management of rice straw can help in reducing the GWP of rice-wheat cropping system. Incorporation of straw in upland crops, straw fed to cattle and straw sequestered as construction material will help in reducing GWP by 19.1, 20.4 and 42.4% respectively as compared to conventional system (**Figure 4**).

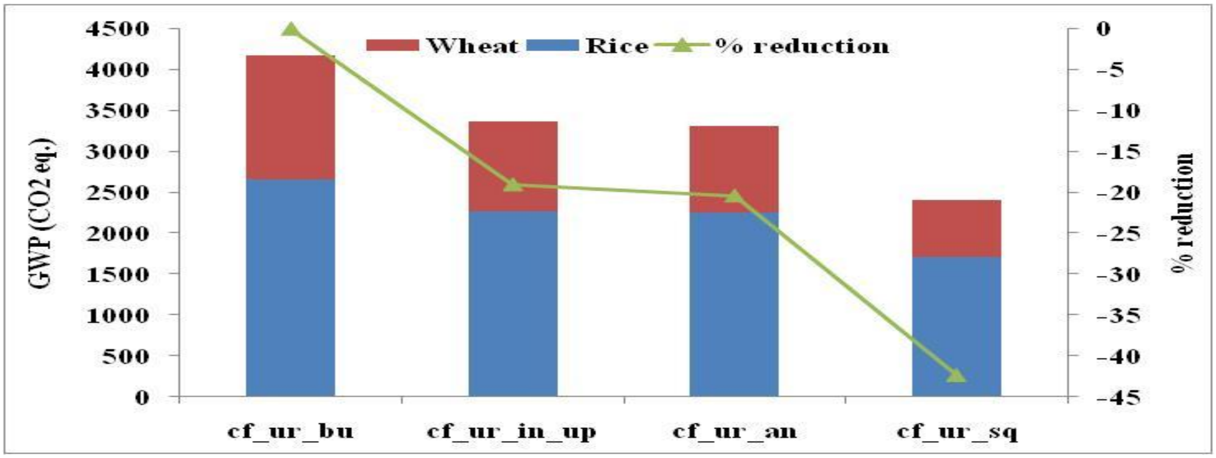

Figure 4 Global warming potential of rice-wheat cropping system under different management practices (Source: Pathak and Wassman, 2007) [cf_ur_bu: continuous flooding, urea application and straw burnt; cf_ur_in_up: continuous flooding, urea application and straw incorporated in upland crop; cf_ur_an: continuous flooding, urea application and straw fed to cattle; cf_ur_sq: continuous flooding, urea application and straw sequestered as construction material]

Crop diversification

Diversification of cropping system can help in reducing the CFP of crops by 32 % to 315% [69, 70]. Gan et al [71] reported that in durum wheat, diversification of cropping system with oilseeds and legumes lowered the carbon footprint. Durum wheat grown in a pulse–pulse–durum system had carbon footprint 0.27 kg CO_2eq kg^{-1} which is 34%lower than that of cereal–cereal–durum systems. Tonwane et al [72] reported that in South Africa, cereal production accounted for 68% of GHG emission while legume and oilseed contributed 11% and vegetables 7%.

Yan M [73] showed that early rice had lower carbon footprint values (0.62 t CO_2-eq. t^{-1}) than late rice (1.1 t CO_2-eq.t^{-1}) system. Indica and japonica rice varieties were compared in Chinese rice fields and japonica varieties were found to have lower CFP (0.71t eq. t^{-1}) than Indica rice varieties having 1.1t CO2 eq.t^{-1} [74]. Pathak et al [6] calculated the GWP of different crop production from the data generated from different field experiments conducted at Indian Agricultural Research Institute, New Delhi [75-78] and reported that CFP values of wheat, pulse, oilseed, cauliflower, brinjal, and potato are 0.12, 0.31, 0.42, 0.03, 0.03, and 0.02 kg CO_2 eq. kg^{-1} produce respectively.

Different workers have studied the impact of various crop management practices for lowering the GWP of rice wheat cropping system. Results of those studies showed that the CFP of rice-wheat cropping system varies under with changes in water nutrient, tillage and residue management techniques. The CFP of rice-wheat cropping system under different management practices is given in Table 2. Leaf colour chart (LCC) based N application lowered CFP from 0.13 kg CO_2eq kg^{-1}grain to 0.10 and 0.10 kg CO_2 eq kg^{-1}grain in rice wheat cropping system in experiment conducted at IARI, New Delhi (**Table 3**) [59].

A study done by Pathak et al [79, 56] effect of both water as well as nitrogen management on GWP of rice-wheat cropping system was studied in IARI, New Delhi. Lower CFP values were observed under intermittent wetting and drying conditions as compared to saturated rice cultivation (Table 3). This is attributed to the fact that less CH_4 emission in IWD condition than saturated one lowered the CFP. Substitution of inorganic N with organic sources increased CH_4 emission resulting in higher CFP whereas application of nitrification inhibitor (NI) caused lower N_2O emission thereby reducing the CFP values.

An experimental study conducted by Zhang et al [80] in Jiangsu Province (China) concluded that rotary tillage in wheat followed by ploughing in rice was an optimum management practice for increasing yield and lowering GHG emission hence lowering the CFP of the system. However application of straw increased the CFP irrespective of tillage practices (Table 3).

In the study conducted by Bhatia et al [59] the GWP of RWCS was calculated by considering CH_4, N_2O and CO_2 emission during the crop growth period while in other 2 studies only CH_4 and N_2O emission was quantified. Hence CFP values of RWCS were found to be higher in the study done by Bhatia et al [59] as compared to others.

Table 3 Carbon footprint of rice-wheat cropping system under different management practices

Location	Crop management				CFP (kg CO_2eq kg^{-1} produce)			References
					Rice	Wheat	Rice + Wheat	
IARI, New Delhi	**N management**							Bhatia et al (2011)
	Dose (kg ha^{-1})	Source & No. Of splits						
	0	0			0.25	0.04	0.15	
	120	Urea (3)			0.19	0.06	0.13	
	120	Urea (4) (LCC based)			0.15	0.04	0.10	
	150	Urea (5) (LCC based)			0.14	0.04	0.10	
IARI, New Delhi	**Water & N management**							
	Rice		**Wheat**					
	Saturated	100% Urea	5 irrigations	100% Urea	0.14	0.04	0.36	Pathak et al, 2002, 2003
		50% Urea + 50% FYM		50% Urea + 50% FYM	0.21	0.04	0.39	
		90% Urea + 10% DCD (NI)		90% Urea + 10% DCD (NI)	0.09	0.03	0.34	
		No N		No N	0.18	0.03	0.38	
	IWD	100% Urea	3 irrigations	100% Urea	0.14	0.04	0.34	
		50% Urea + 50% FYM		50% Urea + 50% FYM	0.18	0.04	0.37	
		90% Urea + 10% DCD (NI)		90% Urea + 10% DCD (NI)	0.08	0.03	0.33	
		No N		No N	0.09	0.03	0.34	
Jiangsu Province, China	**Tillage and crop residue management**							
	Rice		**Wheat**					
	Ploughing plus rotary tillage		Rotarytillage		0.39	0.10	0.29	Zhang et al, 2014
	Rotary tillage twice		Notillage		0.51	0.11	0.37	
	Ploughing plus rotary tillage with wheat straw		Rotarytillage with rice straw		0.66	0.08	0.45	
	Rotary tillage twice with wheat straw		Notillage with rice straw		0.89	0.07	0.58	

Note: We have calculated the carbon footprint of rice wheat cropping system followed in different agricultural practices in the above illustrated Table 3, referred to the author mentioned above namely;Bhatia et al.(2011), Pathak et al (2002, 2003) and Zhang et al (2014).

Conclusions

This intensively cultivated rice-wheat cropping system of the IGP plays a major role in the food security and is a potential source of greenhouse gas (GHG) emission. Quantification of carbon footprint of this cropping system can be helpful in assessing the GHG emission due to crop production along with identification of low carbon options to improve the sustainability of the cropping system. This review signifies the importance of assessment of CFP of rice-wheat cropping system for reducing GHG emission while maintaining productivity of the system. In recent times adoption of certain conservation agricultural practices could help in reducing the CFP while maintaining productivity and better resource utilization. Crop management practices like managing nitrogen application with crop demand, conservation tillage, residue incorporation, direct seeded rice, drip irrigation etc. improves resource use efficiency by decreasing losses of inputs to the surrounding environment. Quantification of CFP will help in increasing awareness towards the changing climate and help scientists to compare the effect of different crop management options on the environment. There is a need to develop low C intensive technologies for maintaining the sustainability of RWCS.

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