Indian Journal of Agricultural Sciences **85** (6): 807–16, June 2015/Article

Global warming potential of rice (*Oryza sativa*)-wheat (*Triticum aestivum*) cropping system of the Indo-Gangetic Plains

D K GUPTA[1], A BHATIA[2], A KUMAR[3], B CHAKRABARTI[4], N JAIN[5] and H PATHAK[6]

Indian Agricultural Research Institute, New Delhi 110 012

Received: 13 November 2014; Accepted: 1 January 2015

ABSTRACT

The Indo-Gangetic plains (IGP) of India are dominated by rice (*Oryza sativa* L.)-wheat (*Triticum aestivum* L.) cropping system (RWCS). Soil, climate, intensity and methods of rice and wheat cultivation differ in different parts of the IGP. So, the emission of greenhouse gases (GHG) will also differ. Present study quantified GHG emission and global warming potential (GWP) of RWCS of Haryana (Upper-IGP) and Bihar (Middle-IGP). A survey of rice-wheat growing farmers in three districts of Haryana (Kaithal, Karnal and Kurukshetra) and Bihar (Begusarai, Bhagalpur and Khagaria) was conducted. The survey data was used as inputs in InfoRCT model to simulate GHG emission in rice-wheat systems of different districts. The selected areas in the IGP significantly differed in nitrogen, water and tillage inputs resulting in differences in emission of methane (CH_4), nitrous oxide (N_2O) and carbon dioxide (CO_2) and the GWP. The simulated average GWP of conventional RWCS was 4268±179 kg CO_2 equivalent/ha in Middle-IGP (Bihar) and 10605±680 kg CO_2 equivalent/ha in the Upper-IGP (Haryana). However, with use of resource conserving technologies (RCTs) such as system of rice intensification (SRI), direct-seeded rice (DSR) and zero tillage wheat (ZTW), there was lowering in GWP than conventional puddled transplanted rice and tilled wheat. Rice had higher contribution than wheat towards GWP in both the states. The continuous flooded puddled transplanted rice (CFTPR), use of electric pump for irrigation and application of high amount of nitrogenous fertilizer were identified as main contributors of GWP. The site-specific intervention of RCTs may be recommended to reduce the emission of GHG in the RWCS in the IGP.

Key words: Bihar, Global warming potential, Greenhouse gas, Haryana, IGP, Rice-wheat

Agriculture sector is being frequently cited as major source of Greenhouse Gases (GHG) and reported to contribute about 24% of total global anthropogenic GHGs emission (IPCC 2014). Rising concern about global warming and climate change is forcing nations to reduce GHGs emission. India is second largest producer of foodgrains and has largest percentage area under cultivation in the world (DoES 2013). Due to high agricultural activities, Indian agriculture also contributes significantly (17%) to the total anthropogenic GHG emission of the country (INCCA 2011). Being signatory to the United Nation Framework Convention on Climate Change (UNFCCC) India has responsibility to reduce its GHG emissions. Internationally, yet Indian Government has not committed to reduce any fixed amount of GHG emission but has voluntarily announced its intent to reduce the emissions intensity by 20-25% of its gross domestic product (GDP) between 2005 and 2020 (MoEF 2010 and Pahuja *et al.* 2014). Several GHGs mitigation techniques such as improved feed quality for ruminant livestock, greater N use efficiency, improved manure management, soil C-sequestration and better water management in rice cultivation have been suggested for Indian agriculture sector (Aggarwal 2008). However, India is agro-ecologically very diverse country and to develop region specific suitable GHG mitigation technology, proper understanding of prevailing crop cultivation practices and quantification of GHG emission from different agro-ecosystem is required.

Many workers have reported emission of CH_4 and N_2O from rice or wheat crop or RWCS of upper IGP. However, very few studies have quantified emission from middle and lower IGP (Adhya *et al.*2000, Majumdar *et al*. 2002, Pathak *et al.* 2002, Ghosh *et al*. 2003, Bhatia *et al.* 2005, Malla *et al*. 2005, Bhatia *et al.* 2012). Among these, most of the studies have been carried out either for rice (*Oryza sativa* L.) or wheat (*Triticum aestivum* L.) while very few have taken RWCS as whole. Due to difference in soil, climate, mechanization, availability of electricity, method of cultivation and economic status of farmers; productivity

[1]Scientist (e mail: dipakbauiari@gmail.com), Regional Research Station, Central Arid Zone Research Institute, Pali 306 401, [2]Principal Scientist (e mail: artibhatia.iari@gmail.com), [3]Research Associate (e mail: amit_bio80@yahoo.com), [4]Senior Scientist (e mail: bidisha2@yahoo.com), [5]Senior Scientist (e mail: nivetajain@gmail.com), [6]Principal Scientist (e mail: hpathak.iari@gmail.com), Center for Environment Science and Climate Resilient Agriculture

and intensity of RWCS is also different in different parts of IGP. As compared to lower (West Bengal) and middle (eastern Uttar Pradesh, Bihar and Jharkhand) IGP, the RWCS in the upper IGP has become largely mechanized and fertilizer, irrigation and energy intensive (Aggarwal *et al*. 2004, Biswas *et al*. 2006, Gupta and Seth 2007, Koshal *et al*. 2014). As a consequence GHG emission from RWCS will also differ in different parts of the IGP.

A comparative analysis of GHG emitted from RWCS of different parts of IGP is required for intervention of GHGs mitigation technologies in these areas. Furthermore, only soil is not responsible for GHG emission from RWCS, other activities like consumption of fossil fuel during on farm activities and production of inputs may also contributes significantly to the CO_2 emission. Thus it is necessary to quantify emission of GHG from all possible sources to estimate their total GWP and to identify input efficient technologies.

In recent past, simulation models have been used to estimate GHGs emissions from rice and wheat fields (Matthews *et al*. 2000, Aggarwal *et al*. 2006 a and b, Giltrap *et al*. 2010, Bhatia *et al.* 2012). They are easy to use, give reliable results and save time from conducting repeated experiment. InfoRCT (Information on use of Resource-Conserving Technologies) developed by Pathak *et al*. (2011) is one of such simulation models which has been successfully validated (Saharawat *et al*. 2012) and used for estimation of GHG emission from RWCS in India. Present study quantifies and compares the GHG emission from RWCS of upper and middle IGP of India using InfoRCT model and has tried to identify the different activities that lead to differences in GHG emission and their related global warming potential (GWP). This study may lead to intervention of different low carbon techniques in RWCS of the IGP.

MATERIALS AND METHODS

Present study is survey and simulation model based approach for the quantification of GHGs emission and GWP. Total 332 farmers [80 - 90% (< 2 ha), 5-10% (2-4 ha) and 1-5% (>4 ha)], practicing RWCS were surveyed in 18 randomly selected villages of 6 districts in Haryana (Upper-IGP) and Bihar (Middle-IGP) during 2011-2012 cropping season. The locations and characteristics of surveyed villages are given in Table 1. The survey inputs were used in InfoRCT model for simulating GHGs emission and GWP. Soil samples were also collected from agricultural field of each surveyed villages and analysed for physico-chemical parameters [soil texture, pH, electrical conductivity (EC), soil organic carbon (SOC), available nitrogen (N), phosphorous (P) and potassium (K)] by standard methods. The Duncan multiple range test (DMRT) was used to compare the means of GHGs and GWP of villages and districts by statistical software SPSS-16.

The climate of Haryana is semi-arid type with annual average rainfall of 650 mm. The mean temperature ranged from 31-32ºC during rainy season (July to September) and 11-16°C during winter (October to February). Bihar has subtropical climatic condition with annual average rainfall of 1200 mm. The mean temperature ranged from 24-35 ºC during rainy season and 7-16 ºC during winter. In Haryana, RWCS is highly irrigation and energy intensive as compared to Bihar however, both have similar trends of fertilizer consumption (~1 Mt) (DoES 2013). Total irrigated area under rice and wheat crop is higher in Haryana (99.8% of rice and 99.4% of wheat) than Bihar (55.6% of rice and 93.2% of wheat). In both states tube well is major source of irrigation and meets more than 60% of irrigation demand (DoES 2014). Consumption of electricity in agriculture is very high in Haryana as compared to Bihar and accounted for about 34% in Haryana and 7% in Bihar of total electricity use (DoES 2013).

The InfoRCT is a Microsoft Excel based model, developed for simulating GHG emissions, C, and N fluxes in the RWCS under different tillage and crop establishment practices. Model is based on input-output relationship and integrates biophysical, agronomic and socioeconomic data to simulate the results. The spreadsheet model works on target yield based approach but in this study, model has been amended to simulate GHGs emission and GWP based on agricultural inputs like on-farm and off farm energy, fertilizer, pesticide, irrigation etc. For this purpose, the layout of InfoRCT model was modified keeping all equations same (except for irrigation) to feed survey data as inputs for obtaining GHG emission and GWP as output. Equation for CO_2 emission from irrigation water pump was modified and method given by Nelson *et al*. (2009) was adopted. According to Nelson *et al.* (2009) the energy needed to lift 1 000 m^3 of water through a distance of 1 meter is 2.724 kWh with zero efficiency loss and the carbon emission factor for diesel and coal based electricity are 0.0732 and 0.4062 kg C/kWh respectively. In this calculation we assumed 5% energy loss for electricity transmission and 30% use efficiency for both diesel and electric pumps.

The GHGs emission factors for different techniques of rice and wheat cultivation were adapted from various published works in India (Pathak *et al*. 2003, Bhatia *et al*. 2010, Pathak *et al*. 2013 and Jain *et al*. 2014). The N_2O and CH_4 emission from conventional methods of rice and wheat cultivation, i.e. continuous flooded transplanted puddled rice (CFTPR) and conventional tillage wheat (CTW) were taken as unit emission factors (1) and emission factors for other cultivation technologies were derived by comparing with it. The following N_2O emission factors 1.13, 1.22, 1.19, and 1.13 and CH_4 emission factors 0.6, 0.4, 0.07 and 0 were used for simulating GHGs emission from intermittent wetting and drying in transplanted puddled rice (IWDTPR), system of rice intensification (SRI), direct seeded rice (DSR) and zero tillage wheat (ZTW) respectively. The GWP of CH_4 (34) and N_2O (298) was adopted from IPCC report (IPCC 2013).

RESULTS AND DISCUSSION

Soil characteristics

Most of the soil samples of villages of Haryana were

Table 1 Geography, climate and soil information of surveyed villages of Bihar and Haryana.

Districts	Villages	Location	Elev. (m)	Average climatic parameter			Average soil parameters						
				Kharif temp. (ºC)	*Rabi* temp. (ºC)	Annual rainfall (mm)	Texture	pH	EC (dS/m)	SOC (%)	Avail. N (kg/ha)	Avail. P (kg/ha)	Avail. K (kg/ha)
Bihar													
Begusarai	Nagarpara	25°33' - 25°39' N	90-100	28	20	1380	Clay loam	7.8	1.3	0.65	274	10.6	113
	Narayanpur	86°02' - 86°22' E					Clay loam	7.7	1.3	0.57	269	10.5	114
	Raipur						Clay loam	7.6	1.3	0.54	269	10.5	111
Bhagalpur	Bhikhari	25°21'- 25°24' N	35-50	28.5	21	1166	Clay loam	7.6	1.2	0.52	262	10.4	266
	Dubiyahi	86°53'- 86°68' E					Clay loam	7.7	1.7	0.64	272	10.6	281
	Roun						Clay loam	7.6	1.6	0.69	294	11.2	223
Khagaria	Bahor Chak	25°38' - 25°42' N	90-120	28	20	1225	Clay loam	7.4	1.6	0.59	270	10.2	110
	Maheswara	86°21'- 86°29' E					Clay loam	7.5	1.8	0.44	262	10.1	114
	Mohanpur						Clay loam	7.4	1.3	0.48	263	10.1	112
Haryana													
Kaithal	Keorak	29°45' - 29°54' N	245-255	30	17	563	Sandy loam	8.2	1.8	0.32	227	7.5	160
	Pabnawa	76°28' - 76°41' E					Sandy loam	8	1.7	0.35	230	7.7	155
	Rasina						Sandy loam	8.3	1.9	0.3	227	7.4	155
Karnal	Bastali	29°41'- 29°53' N	275-255	30	17	528	Sandy loam	7.9	2.1	0.3	223	8.2	150
	Kalheri	76°39' - 77°06' E					Sandy loam	8.2	1.9	0.28	215	7.8	155
	Taraori						Sandy loam	8.2	1.9	0.32	218	8.5	155
Kurukshetra	Amin	29°57'- 29°59' N	300-390	30	17	582	Sandy loam	8.1	1.9	0.35	198	7.8	140
	Baloch Pura	76°37' - 76°46' E					Sandy loam	8.2	2	0.32	212	7.6	145
	Jotisar						Sandy loam	8.1	1.9	0.32	212	8	140

sandy loam in texture and slightly alkaline and moderately saline in nature. Haryana soil was rich in K while poor in SOC, N and P content (Table 1). The alkalinity, salinity and, low C and N content might be due to semiarid climatic condition and intensive irrigated RWCS. Bihar soil samples were clay loam in texture with normal pH range and slight to moderate salinity. The nutrient status was rich as compared to Haryana soils. Soil samples from Bihar were medium in SOC, slightly low in N and rich in P and K content (Table 1).

Rice and wheat cultivation practices

In both states, majority of farmers followed similar practice of wheat cultivation but differ in rice cultivation. The CTW was most common method, in which wheat seed was sown on soil prepared by repeated tillage, harrowing and planking. In Haryana, CFTPR was most common method of rice cultivation in which 25-30 days old seedlings were transplanted into puddled soil and field was kept flooded with either rainfall or irrigation during entire crop growth. Puddling is done by repeated tilling of soil flooded with water. Some farmers of Haryana also practiced resource conserving technologies (RCTs) such as DSR and ZTW. In DSR farmers avoid puddling and transplanting, and directly sowed water soaked seed on aerated seed bed prepared by tilling and planking. Need based irrigation is given when field get dry. In ZTW farmers avoid tilling of soil and seed were directly sown in a shallow furrow opened by zero till seed drill with minimum disturbance of soil.

In contrast to Haryana, in Bihar, most of farmers practice IWDTPR. In this practice, farmers transplant rice seedling on puddled soil but do not keep field flooded and crop remain dependent on rain water. Irrigation is provided only when field get dry in absence of rainfall. Few farmers had also started to adopt SRI due to subsidy and facilities provided by Bihar government. In SRI, farmers transplant one 12-18 days old seedling per hill on moist soil. Flooding was avoided and field was kept moist for whole crop duration.

In both states ground water was main source of irrigation. Due to subsidised and good availability of electricity in Haryana, farmers used electric motor pumps and practice CFTPR which require more frequent irrigation. While, due to poor availability of electricity and high price of diesel, farmers of Bihar apply very less number of irrigation, mainly by diesel pump in IWDTPR. In both the states application of organic manure was very less and only applied before rice transplanting by few farmers. However, in both states, high amount of nitrogenous fertilizer is applied in both crops (Table 2 and 3). Tilling of soil with disc harrow and cultivator by tractor was common practice in both states while there were differences in type of machine used for harvesting and threshing. In Haryana, combine and electric thresher were commonly used for harvesting and threshing respectively in both crops (except basmati rice) while in Bihar, manual harvesting and threshing was most prevalent.

Greenhouse gases emission

Both states significantly differed in GHGs emission from rice and wheat cultivation (Table 4 and 5). However there was insignificant difference among most of districts within respective states (Table 5). This was due to similar management practices, soil and climatic condition within the states and differences between the states. However observed significant differences among some of the districts within a state were due to differences in FYM and fertilizer application; number of irrigation and depth of bore well (Table 1, 2 and 3).

CH_4 emission from soil

Wheat is not considered as significant contributor of CH_4 so in present study CH_4 emission was quantified only from rice. Simulated average CH_4 emission was highest for CFTPR (56.4±9.7 kg CH_4/ha) followed by IWDTPR (46.8±3.8 kg CH_4/ha), SRI (27.3±1.8 kg CH_4/ha) and DSR (3.8±0.4 kg CH_4/ha) (Table 4). The average CH_4 emission from most common method, i.e. CFTPR in Haryana was about 20.5% higher than most common method, i.e. IWDTPR in Bihar and it ranged from 41.2 to 47.5 kg CH_4/ha and 54 to 60.6 kg CH_4/ha in districts of Bihar and Haryana respectively (Table 5).

N_2O emission from soil

Organic matter decomposition and N-fertilizer application are two major source of N_2O emission from soil. In this study emission of N_2O from both the source were estimated. Inorganic fertilizer application was the major contributor of N_2O-N emission as compared to manure application in all the cultivation technologies in both the crops. The average contribution of fertilizer ranged from 65% to 80% in rice and 80% to 92% in wheat (Fig 1). Among different rice technologies, IWDTPR showed highest emission (0.57±0.02 kg N_2O-N/ha) followed by DSR

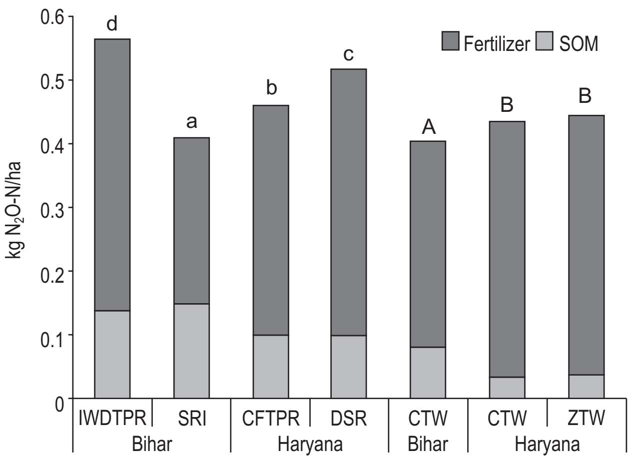

Fig 1 Nitrous oxide emission from rice and wheat cultivation technologies and share of different sources.
According to DMRT column followed by different letter on top are significantly different (P=0.05), lower and upper case are for comparison among rice and wheat technologies respectively.

Table 2 Input and output of conventional rice cultivation in surveyed villages of Bihar and Haryana*

Districts	Villages	FYM (kg/ha)		Fertilizer: N (kg/ha)		Fertilizer: P_2O_5 (kg/ha)		Fertilizer: K_2O (kg/ha)		Fertilizer: Zn (kg/ha)		Number of irrigation		Irrigation pump energy use (kwh/ha)		Grain yield (tonnes/ha)	
		Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE
Bihar																	
Begusarai	Bahor Chak	528	160	171	6.0	76	0	26	6	1.4	0.9	5	0.3	869	73	4.4	0.31
	Maheswara	432	190	170	7.0	71	5	25	7	1.4	0.9	5	0.5	810	72	3.7	0.34
	Mohanpur	480	200	179	6.0	90	5	33	9	0.7	0.7	7	3.0	1 225	46	3.9	0.42
Bhagalpur	Nagarpara	96	46	147	5.5	58	1	32	8	2.5	1.0	4	0.5	784	76	4.4	0.30
	Narayanpur	672	90	185	5.0	96	5	27	7	2.5	2.0	7	2.5	1 300	624	3.9	0.41
	Raipur	240	152	151	6.0	58	1	38	4	2.5	3.0	3	0.6	610	47	4.2	0.26
Khagaria	Bhikhari	432	192	145	4.0	60	6	26	6	2.0	0.9	5	2.0	874	17	4.8	0.32
	Dubiyahi	528	160	130	4.5	52	12	33	2	1.5	0.8	4	0.7	761	43	4.6	0.43
	Roun	480	155	141	4.0	63	5	28	7	1.5	0.9	4	0.6	777	24	5.1	0.61
Haryana																	
Kaithal	Keorak	413	202	140	3.0	52	4.8	26	8.4	5.5	1.7	21	0.5	3 778	156	4.6	0.17
	Pabnawa	306	206	145	9.0	39	5.8	20	9.1	5.5	1.7	21	0.8	2 752	104	4.3	0.20
	Rasina	640	220	153	8.0	49	5.5	52	9.8	7.5	1.6	22	0.9	4 293	276	4.5	0.25
Karnal	Bastali	280	220	142	6.0	32	1.2	25	7.9	8.2	0.0	23	0.9	3 290	112	5.6	0.15
	Kalheri	600	203	142	6.0	31	1.3	31	6.2	8.2	0.0	19	0.6	3 778	208	4.5	0.24
	Taraori	480	223	174	5.0	41	5.2	41	1.7	6.2	0.9	22	0.8	3 525	226	4.9	0.21
Kurukshetra	Amin	368	242	145	4.0	47	6.4	30	7.9	4.3	1.8	22	0.6	4 026	107	4.8	0.14
	Baloch Pura	384	247	156	9.0	47	6.4	49	6.5	9.1	0.8	23	1.0	4 397	313	4.5	0.30
	Jotisar	240	240	148	10	41	6.6	16.	9.2	4.9	2.0	22	0.9	2 754	127	4.4	0.23

*Conventional rice cultivation methods: Bihar-IWDTPR and Haryana-CFTR

Table 3 Input and output of conventional wheat cultivation in surveyed villages of Bihar and Haryana

Districts	Villages	FYM (kg/ha)		Fertilizer N (kg/ha)		Fertilizer P_2O_5 (kg/ha)		Fertilizer K_2O (kg/ha)		Fertilizer Zn (kg/ha)		Number of irrigation		Irrigation energy use (kwh/ha)		Grain yield (tonnes/ha)	
		Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE
Bihar																	
Begusarai	Bahor Chak			135	7	62	6	7	4			3	0.4	503	62	4.3	0.31
	Maheswara			142	7	66	8	7	4			3	0.2	472	38	5.1	0.34
	Mohanpur			125	3	61	6	10	5			3	0.1	578	46	4.1	0.42
Bhagalpur	Nagarpara			137	5	57	1	14	4			4	0.2	745	16	4.2	0.3
	Narayanpur			135	4	96	5	10	4			3	0.2	624	55	4.0	0.41
	Raipur			137	5	57	2	7	4			4	0.2	679	26	4.6	0.26
Khagaria	Bhikhari			150	9	85	10	7	4			3	0.4	452	39	5.1	0.32
	Dubiyahi			140	7	71	5	10	4			2	0.2	400	40	4.5	0.43
	Roun			144	5	68	7	7	4			2	0.2	405	35	5.2	0.61
Haryana																	
Kaithal	Keorak			168	9	50	5	21	10			4	0.4	743	80	4.9	0.13
	Pabnawa			165	9	41	5	14	9			4	0.3	509	22	5.1	0.13
	Rasina			168	7	50	5	13	8			4	0.4	766	73	4.8	0.10
Karnal	Bastali			187	5	50	5	13	8			4	0.2	527	47	4.9	0.16
	Kalheri			142	6	33	1	25	8			4	0.2	826	29	4.9	0.10
	Taraori			184	6	54	4	21	8			4	0.3	657	77	5.1	0.12
Kurukshetra	Amin			168	11	48	6	33	8			4	0.4	765	72	4.9	0.12
	Baloch Pura			164	8	53	5	15	9			4	0.4	755	89	4.7	0.11
	Jotisar			166	10	43	6	17	10			4	0.3	501	25	5.1	0.14

*Conventional wheat cultivation methods: Bihar-CTW and Haryana-CTW

Table 4 GHG emission and GWP of different techniques of rice and wheat cultivation in Bihar and Haryana

Crop	State	Technologies	CH_4 (kg/ha)		N_2O-N (kg/ha)		CO_2-C (kg/ha)		GWP* (kg CO_2 eq./ha)	
			Mean	SE	Mean	SE	Mean	SE	Mean	SE
Rice	Bihar	IWDTPR	46.8c	3.8	0.57d	0.02	326b	22	3052b	136
		SRI	27.3b	1.8	0.41a	0.01	203a	11	1865a	35
	Haryana	CFTPR	56.4d	9.7	0.46b	0.02	1716d	79	8425d	569
		DSR	3.8a	0.4	0.52c	0.01	1280c	75	5065c	233
Wheat	Bihar	CTW			0.41A	0.01	280A	13	1217A	37
	Haryana	CTW			0.44B	0.02	539B	24	2180B	112
		ZTW			0.45B	0.02	505B	23	2062B	92

*GWP_{total}=Σamount of GHG emitted (kg/ha). *GWP of respective GHG. According to DMRT, mean followed by different letter (s) in a column are significantly different (P=0.05), lower and upper case is for comparison among rice and wheat technologies respectively.

(0.52±0.01 kg N_2O-N/ha), CFTPR (0.46±0.02 kg N_2O-N/ha) and SRI (0.41±0.01 kg N_2O-N/ha) (Table 4). The emission of N_2O-N from CTW in Bihar, CTW in Haryana and ZTW was 0.41, 0.44 and 0.45 kg N_2O-N/ha respectively (Table 4). The average emission of N_2O-N from conventional IWDTPR in Bihar was about 24% higher than conventional CFTPR in Haryana. However emission from wheat cultivation in Bihar was about 7% less than both CTW and ZTW in Haryana (Table 4 and 5). The emission from rice in Bihar was higher due to practice of intermittent wetting and drying that led to less emission of CH_4 but more emission of N_2O (Pathak *et al*. 2003). The less emission from wheat in Bihar was due to low application of nitrogenous fertilizer as compared to Haryana (Table 3).

CO_2 emission from on-farm and off-farm activities

The amount of CO_2 emitted was dependent on energy consumption by various on-farm and off-farm activities. The contribution of different sources varied according to technologies of cultivation and region (Fig 2). The use of irrigation pump and fertilizer production significantly contributed to total CO_2-C emission from both the crops in the two states. The use of electric pump for irrigation (50-85%) was highest contributor followed by fertilizer production (12-43%) in Haryana. While emission from fertilizer production (55-70%) followed by diesel irrigation pump (14-24%), was highest contributor in Bihar (Fig 2). The average emission of CO_2-C from different technologies of both crops in Haryana was very high as compared to Bihar (Table 4). The emission from conventional CFTPR and CTW in Haryana was about 5 and 2 times respectively higher than conventional IWDTPR and CTW of Bihar. It was due to use of electric pump and frequent irrigation in Haryana. In India, the carbon emissions from coal-fired electricity are almost six times greater than from diesel (Nelson *et al*. 2009).

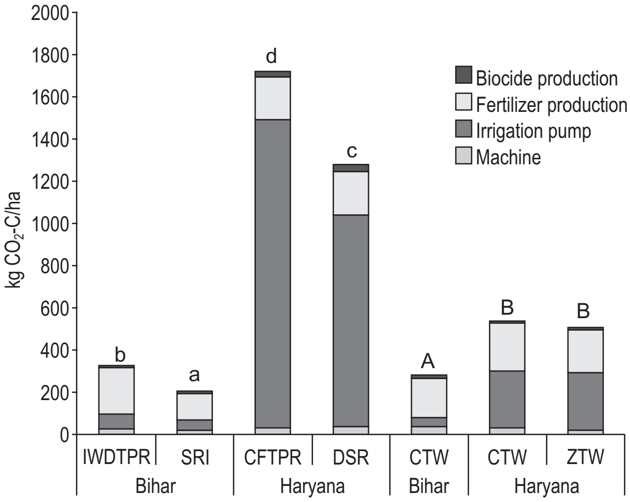

Fig 2 Carbon dioxide emission from rice and wheat cultivation technologies and share of different sources.
According to DMRT column followed by different letter on top are significantly different (P=0.05), lower and upper case are for comparison among rice and wheat technologies respectively.

Among different rice technologies, in Bihar emission from SRI (203±11 kg CO_2-C/ha) was about 38% lesser than IWDTPR (326±22 kg CO_2-C/ha) and in Haryana emission from DSR (1280±75 kg CO_2-C/ha) was about 25% lesser than CFTPR (1716±79 kg CO_2-C/ha) (Table 4). This was due to less fertilizer and irrigation application in SRI and DSR as compared to IWDTPR and CFTPR (Fig 2). In wheat, CTW of Haryana showed highest emission (539±24 kg CO_2-C/ha) followed by ZTW (505±23 kg CO_2-C/ha) of Haryana and CTW (280±13 kg CO_2-C/ha) of Bihar.

Global warming potential (GWP)

Haryana and Bihar significantly differed in average GWP however there was insignificant difference among districts of respective states (Table 4 and 5). Haryana had higher GWP than Bihar for both the crops as well as cropping system as whole (Table 4 and 5). The GWP of conventional technologies of rice, wheat and RWCS of Haryana was 2.8, 1.8 and 2.5 times respectively higher than Bihar (Table 5). The average GWP of conventional RWCS ranged from 10 308±479 kg CO_2 eq./ha to 10 828±835 kg CO_2 eq./ha in different districts of Haryana and 3 781±121 kg CO_2 eq./ha to 4 619±227 kg CO_2 eq./ha in different districts of Bihar (Table 5). The higher GWP of Haryana for both the crops

Table 5 GHGs emission and GWP of conventional rice and wheat cultivation practices in Bihar and Haryana

States	Districts	Rice						Wheat				GWP					
		CH_4 (kg/ha)		N_2O-N (kg/ha)		CO_2-C (kg/ha)		N_2O-N (kg/ha)		CO_2-C (kg/ha)		Rice (kg CO_2 eq./ha)		Wheat (kg CO_2 eq./ha)		Rice-wheat system (kg CO_2 eq./ha)	
		Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE
Bihar	Begusarai	47.5ab	4.26	0.62b	0.02	349a	10	0.40ab	0.02	281a	11	3187a	95	1218a	17	4405a	189
	Bhagalpur	51.5abc	3.39	0.61b	0.02	360a	34	0.43ab	0.01	290a	13	3357a	228	1263a	57	4619a	227
	Khagaria	41.3a	3.69	0.47a	0.01	269a	21	0.38a	0.01	270a	16	2612a	84	1169a	38	3781a	121
	Mean	46.8A	3.78	0.57A	0.02	326A	22	0.40A	0.01	280A	13	3052A	136	1217A	37	4268A	179
Haryana	Kaithal	60.6c	9.75	0.45a	0.02	1698b	79	0.43ab	0.02	539b	28	8499b	597	2181b	128	10680b	725
	Karnal	54.6bc	8.85	0.46a	0.02	1654b	77	0.45b	0.01	536b	18	8135b	407	2173b	74	10308b	479
	Kurukshetra	54.1bc	10.56	0.46a	0.02	1797b	79	0.43ab	0.02	541b	25	8641b	704	2188b	134	10828b	835
	Mean	56.4B	9.72	0.46B	0.02	1716B	78	0.44B	0.017	539B	24	8425B	569	2181B	112	10605B	680

According to DMRT mean followed by different letter (s) in a column are significantly different (P=0.05), lower and upper case is for comparison among rice and wheat technologies respectively.

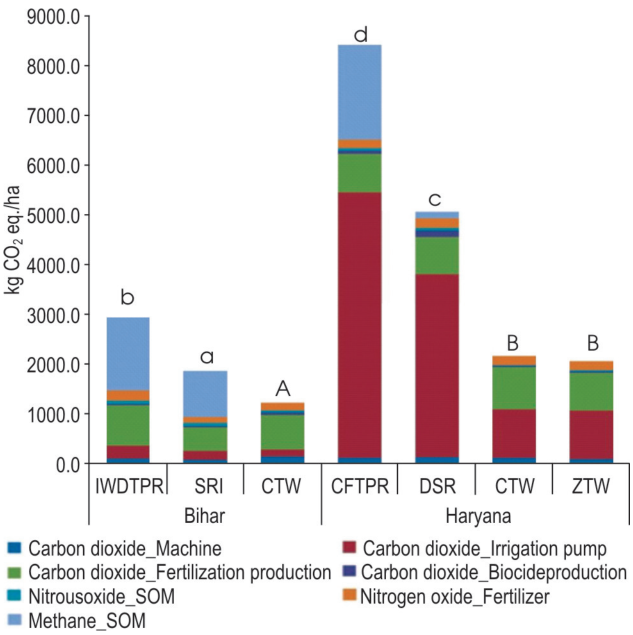

Fig 3 Global warming potential of rice and wheat cultivation technologies and share of different sources. According to DMRT column followed by different letter on top are significantly different (P=0.05), lower and upper case are for comparison among rice and wheat technologies respectively.

was mainly contributed by high emission of CO_2 from electric pump for irrigation (Fig 3). Rice contributed higher than wheat to the total GWP of RWCS in both the states (Fig 3). Flooding was identified as major activity that had higher GWP in rice due to its direct and indirect impact. Flooding had direct impact on GWP due to CH_4 emission and indirect impact due to emission of CO_2 during pump irrigation and puddling.

Among different technologies of rice and wheat, RCTs like SRI, DSR and ZTW showed lower GWP than conventional methods (Table 4). In Haryana, DSR (5 065±233 kg CO_2 eq./ha) had 40% lesser GWP than conventional CFTPR (8 425±569 kg CO_2 eq./ha) and ZTW (2 062±92 kg CO_2 eq./ha) had 5% lesser GWP than CTW (2 180±112 kg CO_2 eq./ha). In Bihar SRI (1 865±35 kg CO_2 eq./ha) showed about 39% less GWP than conventional IWDTPR (3 052±136 kg CO_2 eq./ha). The share of GHGs and different activities in total GWP varied with techniques of cultivation and region (Fig 3). Among different GHGs, share of CO_2 was highest (>80%) in wheat for both the states however share of GHGs differ in rice. In Bihar, CH_4 was highest contributor (> 50%) in both IWDTPR and SRI. However in Haryana, CO_2 was highest contributor (74% and 93% respectively) in both CFTPR and DSR.

The upper and middle IGP of India significantly differed in GHG emission from RWCS. This difference was found to be due to difference in soil, climate, level of mechanization, method of cultivation and amount of input applied. The control of climate in field condition is very difficult however other factors can be controlled and managed for lowering GHGs emission. In present study use of infoRCT model led to identification of different activities responsible for higher GHG emission from RWCS of the IGP. The activities like continuous flooded transplanted rice, use of electric pump, application of high amount of nitrogenous fertilizer, conventional tillage by tractor were the major activities responsible for higher GWP of RWCS in upper IGP as compared to the middle IGP. The site specific intervention of RCTs like SRI, DSR, zero tillage, integrated nutrient and past management may lead to reduction in GHG emission from different parts of the IGP.

REFERENCES

Adhya T K, Mishra S R, Rath A K, Bharati K, Mohanty S R, Ramakrishnan B, Rao V R and Sethunathan N.2000. Methane efflux from rice-based cropping systems under humid tropical conditions of eastern India. *Agriculture, Ecosystems and Environment* **79**: 85–90.

Aggarawal P K. 2008. Global climate change and Indian agriculture: impacts, adaption and mitigation. *Indian Journal of Agricultural Sciences* **78**(10): 911–9.

Aggarwal P K, Banerjee B, Daryaei M G, Bhatia A, Bala A, Rani S, Chander S, Pathak and Kalra N. 2006b. InfoCrop: A dynamic simulation model for the assessment of crop yields, losses due to pests, and environmental impact of agro-ecosystems in tropical environments. II. Performance of the model. *Agricultural Systems* **89**: 47–67.

Aggarwal P K, Joshi P K, Ingram J S I and Gupta R K. 2004. Adapting food systems of the Indo-Gangetic plains to global environmental change: key information needs to improve policy formulation. *Environmental Science & Policy* **7**: 487–98.

Aggarwal P K, Kalra N, Chander S and Pathak H. 2006a. InfoCrop: A dynamic simulation model for the assessment of crop yields, losses due to pests, and environmental impact of agro-ecosystems in tropical environments. I. Model description. *Agricultural Systems* **89**: 1–25.

Bhatia A, Aggarwal P K, Jain N and Pathak H. 2012. Greenhouse gas emission from rice- and wheat-growing areas in India: spatial analysis and upscaling. *Greenhouse Gases: Science and Technology* **2**(2): 115–25.

Bhatia A, Pathak H, Jain N, Singh P K and Singh A K. 2005. Global warming potential of manure amended soils under rice-wheat system in the Indo Gangetic plains. *Atmospheric Environment* **39**: 6 976–84.

Bhatia A, Pathak H, Jain N, Singh P K and Tomer R. 2012. Greenhouse gas mitigation in rice–wheat system with leaf color chart-based urea application. *Environmental Monitoring and Assessmen*t **184**(5): 3 095–107.

Bhatia A, Sasmal S, Jain N, Pathak H, Kumar R and Singh A. 2010. Mitigating nitrous oxide emission from soil under conventional and no-tillage in wheat using nitrification inhibitors. *Agriculture, Ecosystems and Environment* **136**: 247–53.

Biswas B, Ghosh D C, Dasgupta M K, Trivedi N, Timsina J and Dobermann A. 2006. Integrated assessment of cropping systems in the Eastern Indo-Gangetic plain. *Field Crops Research* **99**: 35–47.

Dhillon B S, Kataria P and Dhillon P K. 2010. National food security vis-à-vis sustainability of agriculture in high crop productivity regions. *Current Science* **98**: 33–6.

DoES. 2013. *Agriculture statistics at a glance-2013*. Directorate of economics and statistics, Department of Agriculture and Coperation, Ministry of Agriculture, Government of India. http://eands.dacnet.nic.in/latest_2006.htm.

DoES. 2014. *Land use statics at a glance 2002-03 to 2011-12*. Directorate of economics and statistics. Department of Agriculture and Coperation, Ministry of Agriculture, Government of India. http://eands.dacnet.nic.in/LUS_1999_2004.htm.

Frolking S E, Mosier A R, Ojima D S, Li C, Parton W J, Potter C S, Priesack E, Stenger R, Haberbosch C, Do¨rsch P, Flessa H and Smith K A. 1998. Comparison of N_2O emissions from soils at three temperate agricultural sites: simulations of year-round measurements by four models. *Nutrient Cycling in Agroecosystems* **52**: 77–105.

Ghosh S, Majumdar D and Jain M C. 2003. Methane and nitrous oxide emission from irrigated rice of North India. *Chemosphere* **51**: 181–95.

Giltrap D L, Li C and Saggar S. 2010. DNDC: A process-based model of greenhouse gas fluxes from agricultural soils. *Agriculture, Ecosystems and Environment* **136**: 292–300.

Gupta R and Seth A. 2007. A review of resource conserving technologies for sustainable management of the rice–wheat cropping systems of the Indo-Gangetic plains (IGP). *Crop Protection* **26**: 436–47.

INCCA. 2011. *India: greenhouse gas emission 2007*. Indian Network for Climate Change Assessment, Ministry of Environment and Forests, Government of India, Print Process**,** New Delhi, India.

IPCC. 2013. *Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report*. Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, United Kingdom and New York, USA, pp 11 and 714.

IPCC. 2014. *Summary for Policymakers.* (*In*) *Climate Change 2014, Mitigation of Climate Change. Contribution of Working Group III to the Fifth Assessment Report.* Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, United Kingdom and New York, USA, p 8.

Jain N, Dubey R, Dubey D S, Singh J, Khanna M, Pathak H and Bhatia A. 2014. Mitigation of greenhouse gas emission with system of rice intensification in the Indo Gangetic Plains. *Paddy and Water Environment* **12**(3): 355–63.

Koshal A K. 2014. Changing current scenario of rice-wheat System in Indo-Gangetic Plain Region of India. *International Journal of Scientific and Research Publications* **4**(3): 1–13.

Kumar A G. Mehta R. Pullabhotla H. Prasad S K. Ganguly K and Gulati A. 2012. Demand and Supply of Cereals in India 2010-2025. Discussion Paper 01158, International Food Policy Research Institute, New Delhi Office.

Majumdar D, Pathak H, Kumar S and Jain M C. 2002. Nitrous oxide emission from a sandy loam Inceptisol under irrigated wheat in India as influenced by different nitrification inhibitors. *Agriculture, Ecosystems and Environment* **91**: 283–93.

Malla G, Bhatia A, Pathak H, Prasad S, Jain N and Singh J. 2005. Mitigating nitrous oxide and methane emission from soil in rice-wheat system of the Indo Gangetic plains with nitrification and urease inhibitors. *Chemosphere* **58**: 141–7.

Matthews R B, Wassmann R and Arah J. 2000. Using a crop/soil simulation model and GIS technique to assess methane emission from rice field in Asia: I. Model development. *Nutrient Cycling in Agroecosystem* **58**: 141–59.

MoEF 2010. *India: taking on climate change post-copenhagen domestic actions*. Ministry of Environment and Forests, Government of India.

Nelson G C, Robertson R, Msangi S, Zhu T, Liao X and Jawajar P. 2009. *Greenhouse gas mitigation: Issues for Indian agriculture, discussion paper 00900*. International Food Policy Research Institute, Environment and Production Technology Division, Washington DC, USA.

Pahuja N, Pandey N, Mandal K and Bandyopadhyay C. 2014. GHG mitigation in India: an overview of the current policy landscape. Working Paper, World Resource Institute, Washington, DC.

Panigrahy S, Upadhyay G, Ray S S and Parihar J S. 2010. Mapping of cropping system for the Indo-Gangetic plain using multi-date SPOT NDVI-VGT data. *Journal of the Indian Society of Remote Sensing* **38**(4): 627–32.

Pathak H, Bhatia A, Prasad S, Singh S, Kumar S, Singh J, Jain M C and Kumar U. 2002. Emission of nitrous oxide from rice-wheat systems of Indo-Gangetic plains of India. *Environmental Monitoring and Assessment* **77**: 163–78.

Pathak H, Prasad S, Bhatia A, Singh S, Kumar S, Singh J and Jain M C. 2003. Methane emission from rice–wheat cropping system in the Indo-Gangetic plain in relation to irrigation, farmyard manure and dicyandiamide application. *Agriculture, Ecosystems and Environment* **97**: 309–16.

Pathak H, Saharawat Y S, Gathala M and Ladha J K. 2011. Impact of resource-conserving technologies on productivity and greenhouse gas emissions in the rice-wheat system. *Greenhouse Gas Science and Technology* **1**: 261–77.

Pathak H, Sankhyan S, Dubey D S, Bhatia A and Jain, N. 2013. Dry direct-seeding of rice for mitigating greenhouse gas emission: field experimentation and simulation. *Paddy and Water Environment* **11**(1-4): 593–601.

Saharawat Y S, Ladha J K, Pathak H, Gathala M, Chaudhary N and Jat M L. 2012. Simulation of resource-conserving technologies on productivity, income and greenhouse gas GHG emission in rice-wheat system. *Journal of Soil Science and Environmental Management* **3**(1): 9–22.

Smith P, Martino D, Cai Z, Gwary D, Janzen H, Kumar P, McCarl B, Ogle S, O'Mara F, Rice C, Scholes B, Sirotenko O, Howden M, McAllister T, Pan G, Romanenkov V, Schneider U, Towprayoon S, Wattenbach M and Smith J. 2008. Greenhouse gas mitigation in agriculture. *Philosophical Transactions of the Royal Society B* **363**: 789–813.

Wassmann R, Neue H U, Ladha J K and Aulakh M S. 2004. Mitigating greenhouse gas emissions from rice-wheat cropping systems in Asia. *Environment, Development and Sustainability* **6:** 65–90.