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Emission of Air Pollutants from Crop Residue Burning in India

Niveta Jain[*], Arti Bhatia, Himanshu Pathak

Centre for Environment Science and Climate Resilient Agriculture, Indian Agricultural Research Institute, New Delhi-110012, India

ABSTRACT

Agricultural crop residue burning contribute towards the emission of greenhouse gases (CO_2, N_2O, CH_4), air pollutants (CO, NH_3, NO_x, SO_2, NMHC, volatile organic compounds), particulates matter and smoke thereby posing threat to human health. In the present study a state-wise inventory of crop residue burnt in India and the air pollutants emitted was prepared using the Inter-Governmental Panel on Climate Change (IPCC) national inventory preparation guidelines for the year 2008–09. Total amount of residue generated in 2008–09 was 620 Mt out of which ~15.9% residue was burnt on farm. Rice straw contributed 40% of the total residue burnt followed by wheat straw (22%) and sugarcane trash (20%). Burning of crop residues emitted 8.57 Mt of CO, 141.15 Mt of CO_2, 0.037 Mt of SO_x, 0.23 Mt of NO_x, 0.12 Mt of NH_3 and 1.46 Mt NMVOC, 0.65 Mt of NMHC, 1.21 Mt of particulate matter for the year 2008–09. The variability of 21.46% in annual emission of air pollutants was observed from 1995 to 2009.

Keywords: Crop residue; Air pollution; Biomass burning; Greenhouse gases.

INTRODUCTION

Biomass burning is a global phenomenon and can be an important contributor to poor air quality worldwide (Yang *et al.*, 2008). Biomass burning includes forest fires, prescribed burning of savannas, and crop residue burning in fields. Typically, the biomass burning intensifies in late March, reaching a maximum in May. It represents a significant source of chemically and radiatively important trace gases and aerosols to the atmosphere thereby resulting in a large perturbation to global atmospheric chemistry (Crutzen and Andreae, 1990). This change in composition of the atmosphere may have a direct or indirect effect on the radiation balance of earth affecting its climate and contributing to global climate change (Streets *et al.*, 2003; Koppmann *et al.*, 2005). Satellite observations have revealed elevated levels of O_3, CO and aerosols over vast areas of Central Africa and South America, over the tropical Atlantic, and the Indian Ocean due to long-range transport of pollutants emitted from biomass burning (Fishman *et al.*, 1991). The aerosols affect regional, and possibly global, radiation budgets by their light-scattering effects and influence on cloud microphysical processes. Various studies have been published dealing with the amount of biomass burned from various sources such as deforestation, shifting cultivation, savanna fires, fuel wood and the burning of agricultural residues mainly in tropical regions (Wang *et al.*, 2007, Cao *et al.*, 2008, Zhang *et al.*, 2011). On a global basis, forest burning is the major source of the fire emissions due to its high carbon density and burning of agricultural waste is the second major source, representing nearly 2020 Tg (approx 25% of total biomass burned) (Crutzen and Andreae, 1990; Andreae *et al.*, 2001; Chang *et al.*, 2010).

India is an agrarian country and generates a large quantity of agricultural wastes. This amount will increase in future as with growing population there is a need to increase the productivity also. Agricultural residues are the biomass left in the field after harvesting of the economic components i.e., grain. Large quantities of crop residues are generated every year, in the form of cereal straws, woody stalks, and sugarcane leaves/tops during harvest periods. Processing of farm produce through milling also produces large amount of residues. These residues are used as animal feed, thatching for rural homes, residential cooking fuel and industrial fuel. However, a large portion of the crop residues is not utilized and left in the fields. The disposal of such a large amount of crop residues is a major challenge. To clear the field rapidly and inexpensively and allow tillage practices to proceed unimpeded by residual crop material, the crop residues are burned *in situ.* Farmers opt for burning because it is a quick and easy way to manage the large quantities of crop residues and prepare the field for the next crop well in time. Agricultural residues burning may emit significant quantity of air pollutants like CO_2, N_2O, CH_4, emission of

[*] Corresponding author.
Tel.: 91-11-25841490; Fax: 91-11-25841866
E-mail address: nivetajain@gmail.com

air pollutants such as CO, NH_3, NO_x, SO_2, NMHC, volatile organic compounds (VOCs) and semi-volatile organic compounds (SVOCs) and particulate matter like elemental carbon at a rate far different from that observed in savanna/forest fire due to different chemical composition of the crop residues and burning conditions (Zhang *et al.*, 2011, Mittal *et al.*, 2009). Several researchers have estimated the emission of different species from crop residue burning using IPCC factors, but they have covered only few gaseous pollutants (N_2O, CH_4, NO_x, and SO_2) (Venkataraman *et al.*, 2006; Sahai *et al.*, 2007); or from a specific area and crop (Badrinath *et al.*, 2006; Sahai *et al.*, 2007). Burning of crop residues also causes nutrient and resource loss. The objectives of this study were 1) to estimate the budget of air pollutants emission from burning of agricultural crop residues and nutrients loss and 2) to analyze the inter annual variability of air pollutants emission over a long period.

METHODOLOGY

A state wise inventory of air pollutants such as CO_2, CO, SO_x, NO_x, NH_3, $PM_{2.5}$, BC, PAH, NMVOC and NMHC (organic compounds containing only C and H excluding methane) emissions from burning of crop residues was prepared for the year 2008–09 using the IPCC 2006 inventory preparation guidelines. The primary crop considered for inventory preparation was rice, wheat, cotton, maize, millet, sugarcane, jute, rapeseed-mustard and groundnut. Emission from crop residue burning was calculated using the following equation.

$$FBCR = \Sigma_{crops}(A \times B \times C \times D \times E \times F) \quad (1)$$

where, FBCR is the Emissions from residue burning, A is the Crop production, B is the Residue to crop ratio, C is the Dry matter fraction, D is the Fraction burnt, E is the Fraction actually oxidized, F is the Emission factors for air pollutants.

The estimation of emission of targeted species was arrived at by first estimating the amount of biomass burnt in the field using the IPCC inventory preparation guidelines. State-wise crop production data for above mentioned crops were obtained from MoA (2011) and ratio of residue to economic yield was taken from Bandyopadhayay *et al.* (2001) (Table 1). As per IPCC methodology fraction of crop residues burned in field was taken as 25% for all the crops. In revised method fractions of residues burned in field was taken from Gadde *et al.* (2009) for rice and for other crops based on expert judgment and surveys (Table 1). Fraction of residues oxidized was obtained from IPCC, Streets *et al.* (2003a, b) and Venkatraman *et al.* (2006) (Table 1). The emission factors for different pollutants emitted from residue burning were taken from Andreae and Merlet (2001).

RESULTS AND DISCUSSION

Crop Residue Generation

Residue generated by different crops was grouped in four categories based on the type of crop, namely cereals (rice, wheat, maize, jowar, bajra, ragi and small millets), oilseeds (groundnut and rapeseed mustard), fibers (jute, mesta and cotton) and sugarcane. The amount of crop residue generated was estimated as the product of crop production, residue to crop ratio and dry matter fraction in the crop biomass. The residue to grain ratio varied 1.5–1.7 for cereal crops, 2.15–3.0 for fiber crops, 2.0–3.0 for oilseed crops and 0.4 for sugarcane (Table 1). Total amount dry crop residue generated by nine major crops was 620.4 Mt (Table 1). There was a large variation in crop residues generation across different states of India depending on the crops grown in the states, their cropping intensity, and productivity. Generation of cereal crop residues was highest in the states of Uttar Pradesh (72 Mt) followed by Punjab (45.6 Mt), West Bengal (37.3 Mt), Andhra Pradesh (33 Mt) and Haryana (24.7 Mt). Uttar Pradesh contributed maximum to the generation of residue of sugarcane (44.2 Mt) while residues from fibre crop was dominant in Gujarat (28.6 Mt) followed by West Bengal (24.4 Mt) and Maharashtra (19.5 Mt). Rajasthan and Gujarat generated about 9.26 and 5.1 Mt residues respectively from oilseed crops (Table 2).

Among the different crop categories 361.85 Mt of residue was generated by cereal crops followed by fibre crops (122.4 Mt) and sugarcane (107.5 Mt) (Table 2). The cereals

Table 1. Crop wise production, residue generated and coefficients used for inventory.

Crop	Annual production	Dry residue generated	Residue to crop ratio	Dry matter fraction	Fraction burnt
	Mt/yr				
Rice paddy	153.35	192.82	1.50	0.86	0.08–0.8#
Wheat	80.68	120.70	1.70	0.88	0.1–0.23*
Maize	19.73	26.75	1.50	0.88	0.10
Jute	18.32	31.51	2.15	0.80	0.10
Cotton	37.86	90.86	3.00	0.80	0.10
Groundnut	7.17	11.44	2.00	0.80	0.10
Sugarcane	285.03	107.50	0.40	0.88	0.25
Rapeseed &Mustard	7.20	17.28	3.00	0.80	0.10
Millets	18.62	21.57	1.50	0.88	0.10
Total	627.96	620.43			

Gadde *et al*. (2009).

* 0.23 is for Haryana, Punjab, H.P., U.P.

Table 2. Crop wise residue generated in various states of India.

States	Crop residue generated (Mt/yr)			
	Cereal crops	Fiber crops	Oilseed crops	Sugarcane
Andhra Pradesh	33.07	16.07	2.50	5.80
Arunanchal Pradesh	0.56	0.00	0.06	0.01
Assam	8.15	2.01	0.29	0.41
Bihar	19.87	3.27	0.20	1.87
Chhattisgarh	8.87	0.01	0.11	0.01
Goa	0.24	0.00	0.01	0.02
Gujarat	8.18	28.62	5.06	5.85
Haryana	24.73	7.58	2.15	1.93
Himachal Pradesh	1.95	0.00	0.01	0.02
Jammu & Kashmir	2.76	0.00	0.11	0.00
Jharkhand	7.34	0.00	0.09	0.13
Karnataka	11.73	3.55	0.81	8.80
Kerela	1.14	0.01	0.00	0.10
Madhya Pradesh	16.05	3.51	2.13	1.12
Maharashtra	8.75	19.51	0.57	22.87
Manipur	0.78	0.00	0.00	0.01
Meghalaya	0.44	0.13	0.01	0.00
Mizoram	0.10	0.00	0.00	0.01
Nagaland	0.89	0.01	0.06	0.07
Orissa	13.38	0.56	0.16	0.24
Punjab	45.58	9.32	0.08	1.76
Rajasthan	22.19	2.96	9.26	0.15
Sikkim	0.14	0.00	0.01	0.00
Tamil Nadu	11.69	0.78	1.56	12.37
Tripura	1.22	0.02	0.00	0.02
Uttar Pradesh	72.02	0.04	2.49	41.13
Uttarakhand	2.40	0.00	0.03	2.11
West Bengal	37.26	24.43	0.95	0.62
A & N Islands	0.04	0.00	0.00	0.00
D & N Haveli	0.05	0.00	0.00	0.00
Delhi	0.17	0.00	0.00	0.00
Daman & Diu	0.01	0.00	0.00	0.00
Pondicherry	0.10	0.00	0.00	0.06
All India	**361.85**	**122.37**	**28.72**	**107.50**

crops generated 58% of residue while rice crop alone contributed 53% and wheat ranked second with 33% of cereal crop residues (Figs. 1(a) and (b)). Fibre crops contributed 20% of residues generated with cotton ranking first (90.86 Mt) with 74% of crop residues. Sugarcane residues generated 17% of the total crop residues.The oilseed crops generated 28.72 Mt of residue annually (Fig. 1(a)). Our estimates are in line with the reports in literature (Pathak *et al.*, 2006; MNRE, 2009, Pathak *et al.*, 2010). Sahai *et al.* (2011) have estimated 253 Mt of crop residue generation in the year 2010. Their estimates were extremely low as compared to other researchers. The highly lower estimates by these workers may be attributed to the different conversion factors used, the inclusion or deletion of different crops and many other factors which might also have introduced some amount of uncertainty in the estimates.

Crop Residue Burning

Large uncertainties exist in the estimates of on-farm/open burning of crop residues depending upon the crops considered, residue to grain ratio and fraction of residues subjected to burning. The crop residue burnt on farm in different states is highly variable depending upon the usage pattern in the respective states. According to IPCC the 25% of the crop residues are burnt on farm. In the present study the fraction of crop residue subjected to burning ranged from 8–80% for rice paddies across the states. In the states of Punjab, Haryana and Himachal Pradesh 80% of rice straw was burnt *in situ* followed by Karnataka (50%) and Uttar Pradesh (25%), which can be attributed to the mechanized harvesting with combine harvesters (Gupta *et al.*, 2003). At present 75–80% of rice-wheat area in Punjab is harvested with combines. Approximately 23% wheat straw was taken as fraction burnt in the states of Haryana, Himachal Pradesh, Punjab and Uttar Pradesh and for rest of the states it was 10%. For sugar cane trash it was considered that 25% of the trash is burnt in the fields. For rest of the crops the fraction of crop residues burnt on farm was taken as 10% across the states based on expert judgment. The amount of residue burned on

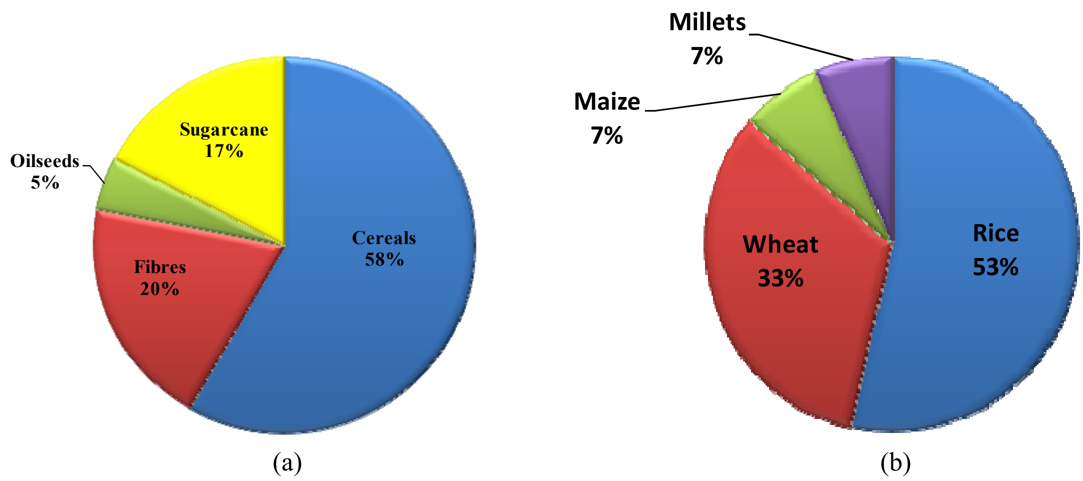


Fig. 1. (a) Contribution of different crops categories in residue generation. (b) Contribution of different cereal crops in residue generation.

farm ranged from 98.4 Mt (using our coefficients) to 131.9 Mt (using IPCC coefficients). Fig. 2 represents the state wise distribution of crop residues burnt. With IPCC coefficients the contribution of Uttar Pradesh was maximum, followed by West Bengal, Andhra Pradesh, Punjab, Maharashtra and Haryana. But with our coefficients maximum amount of crop residues were burnt in the states of Uttar Pradesh (22.25 Mt) and Punjab (21.32 Mt), followed by Haryana (9.18 Mt) and Maharashtra (6.82 Mt) (Table 3). Highest amount of cereal crop residues were burnt in Punjab followed Uttar Pradesh and Haryana. Uttar Pradesh contributed maximum to the burning of sugarcane trash followed by Karnataka. Oil seed residues were burnt in Rajasthan and Gujarat while burning of fibre crop residue was dominant in Gujarat (28.6 Mt) followed by West Bengal (24.4 Mt) Maharashtra and Punjab (Fig. 2). Among the different crop residue major contribution (93%) was from rice (43%), wheat (21%) and sugarcane (19%). Similar results were also reported by Sahai *et al.* (2011).

According to Street *et al.* (2003) approximately 730 Tg of biomass burned annually, from both anthropogenic and natural sources in Asia with 18% contribution from India. According to different estimates 72 Mt–127 Mt of crop residues are burnt on-farm (Mehta, 2004; Pathak *et al.*, 2006; Pathak *et al.*, 2010) Recently Sahai *et al.*(2011) have estimated that 32, 48, 45, 57, 60 and 63 Tg of crop residues were burnt on farm during the years 1980, 1985, 1990,1994, 2000, 2005 and 2010, respectively.

Emission of Gaseous and Aerosol Species

In the present estimates, on farm burning of 98.4 Mt of crop residues led to the emission of 8.57 Mt of CO, 141.15 Mt of CO_2, 0.037 Mt of SO_x, 0.23 Mt of NO_x, 0.12 Mt of NH_3 and 1.46 Mt NMVOC, 0.65 Mt of NMHC, 1.21 Mt of particulate matter for the year 2008–09 (Table 4). CO_2 accounted for 91.6% of the total emissions. Out of the rest (8.43%) 66% was CO, 2.2% NO, 5% NMHC and 11% NMVOC (Fig. 3(a)). Burning of rice straw contributed the maximum (40%) to this emission followed by wheat (22%) and sugarcane (20%) (Fig. 3(b)). Highest emissions were from the IGP states with Uttar Pradesh accounting for 23%, followed by Punjab (22%) and Haryana (9%). Fig. 4 shows the inter-annual variability in crop residue burning emissions over last 14 years. Estimates of various pollutants ranged from 0.002 to 149 Mt. A dip in emission was observed during 2000–01 and 2002–03 due to less biomass production because of drought in these years. An 21.46% increase in emission was observed from 1995–2009; this was proportional to the increase in biomass burned. The annual variability in emissions is dependent on generation of biomass and the quantity burnt.

Burning of agricultural residues, resulted in 70, 7 and 0.66% of C present in rice straw as CO_2, CO and CH_4, emission respectively, while 20, 2.1% of N in straw is emitted as NO_x and N_2O, respectively, and 17% as S in straw is emitted as SO_x upon burning (Carlson *et al.*, 1992). According to Yevich and Logan (2003) 91, 4.1, 0.6, 0.1 and 1.2 Tg/yr of CO_2, CO, CH_4, NO_x and total particulate matter were emitted due to burning of crop residues in India in the year 1985. Emissions from open biomass burning over tropical Asia were evaluated during seven fire years from 2000 to 2006 by Chang *et al.* (2010). Venkataraman, (2006) have inventoried the emissions from open biomass burning including crop residues in India using Moderate Resolution Imaging Spectroradiometer (MODIS) active-fire and land cover data approach. Badrinath *et al.* (2006) estimated the greenhouse gas (GHG) emissions from rice and wheat straw burning in Punjab during May and October 2005 and suggested that emissions from wheat crop residues in Punjab are relatively low compared to those from paddy fields. Sahai *et al.* (2007) have measured the emission of trace gases and particulate species from burning of wheat straw in agricultural fields in Pant Nagar, Uttar Pradesh. Sahai *et al.* (2011) have estimated that burning of 63 Mt of crop residue emitted 4.86 Mt of CO_2 equivalents of GHGs 3.4 Mt of CO and 0.14 Mt of NO_x.

Loss of Residues Nutrient

Burning of crop residue not only leads to pollution but also results in loss of nutrients present in the residues. The

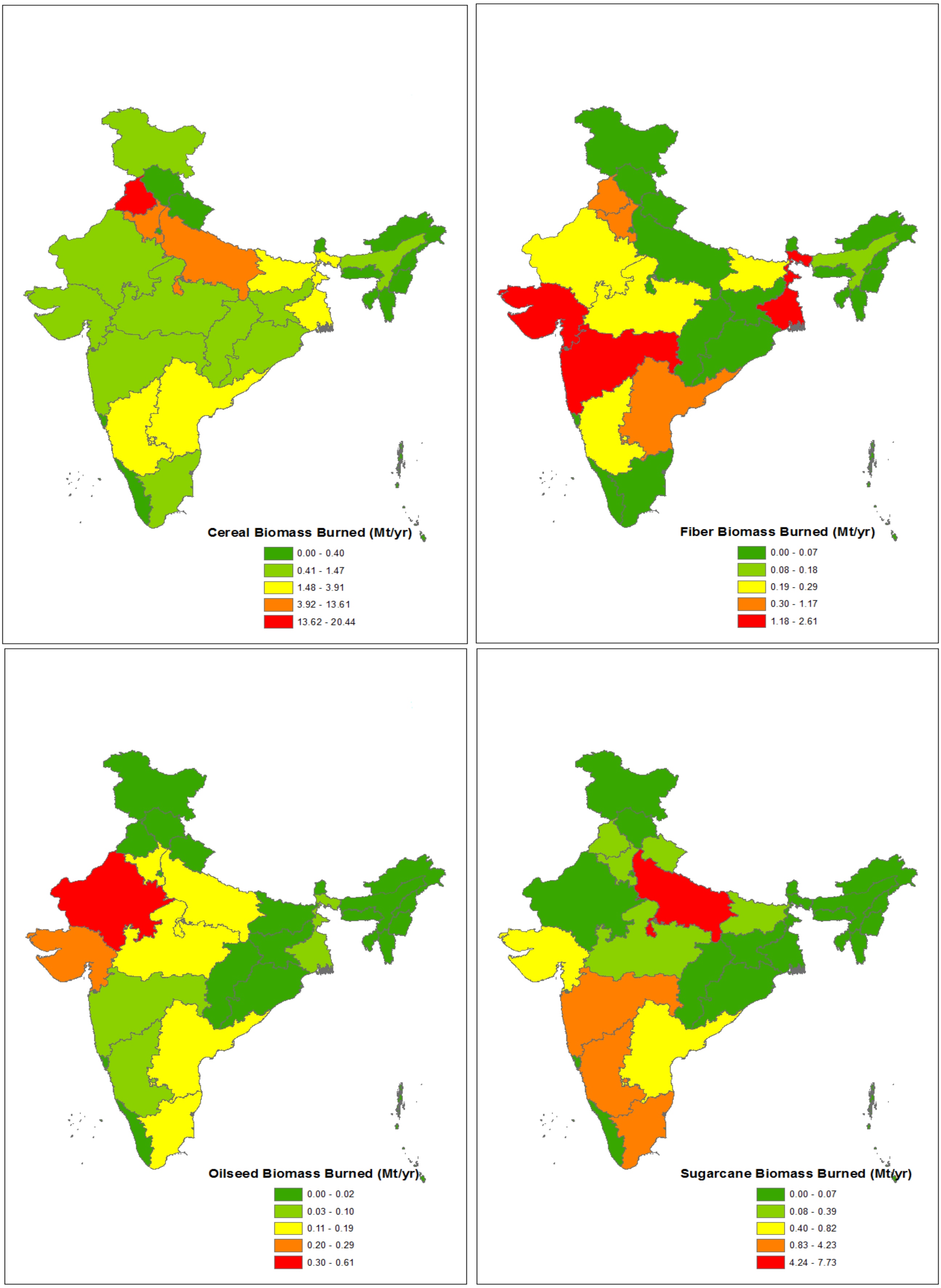


Fig. 2. State-wise distribution of crop residues burnt in India.

Table 3. Crop residues burnt in various states of India in 2008–09.

States	Residue burned (based IPCC default coefficients)	Residue burned (based on our coefficients)
	Mt/yr	
Andhra Pradesh	12.60	5.29
Arunanchal Pradesh	0.16	0.05
Assam	2.65	0.96
Bihar	5.21	3.35
Chhattisgarh	2.39	0.73
Goa	0.17	0.03
Gujarat	9.63	4.51
Haryana	6.85	9.18
Himachal Pradesh	0.25	0.42
Jammu & Kashmir	0.47	0.23
Jharkhand	1.90	1.28
Karnataka	5.52	5.93
Kerela	0.55	0.12
Madhya Pradesh	3.86	2.00
Maharashtra	10.96	6.82
Manipur	0.21	0.07
Meghalaya	0.14	0.05
Mizoram	0.03	0.01
Nagaland	0.21	0.09
Orissa	3.84	1.31
Punjab	13.30	21.32
Rajasthan	4.27	2.77
Sikkim	0.02	0.01
Tamil Nadu	5.57	3.37
Tripura	0.63	0.11
Uttar Pradesh	22.38	22.25
Uttarakhand	1.07	0.76
West Bengal	14.85	5.43
A & N Islands	0.01	0.00
D & N Haveli	0.01	0.00
Delhi	0.04	0.02
Daman & Diu	0.00	0.00
Pondicherry	2.11	0.02
All India	**131.86**	**98.49**

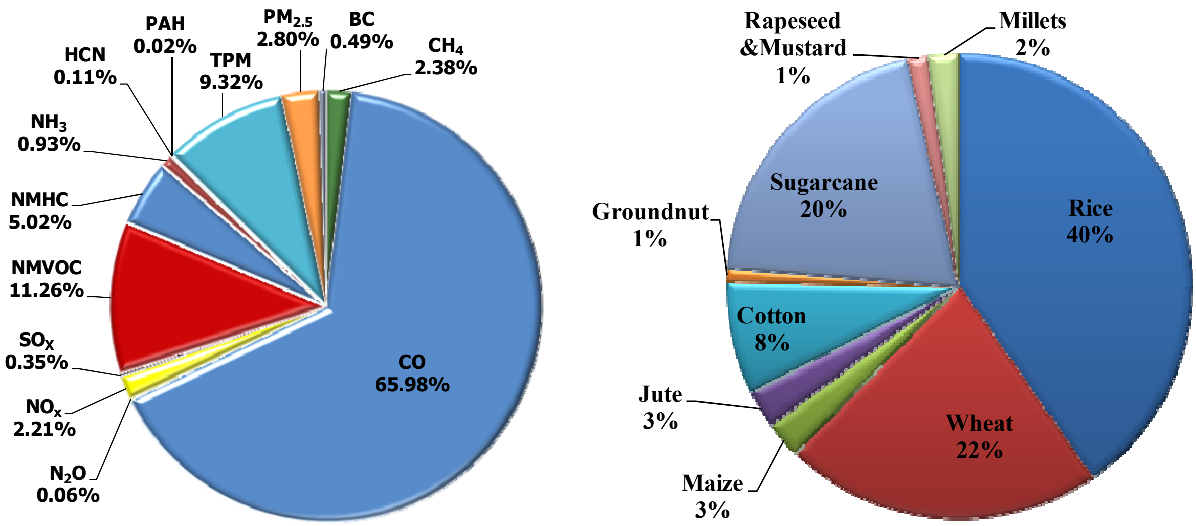
entire amount of C, approximately 80–90% N, 25% of P, 20% of K and 50% of S present in crop residues are lost in the form of various gaseous and particulate matters, resulting in atmospheric pollution (Raison, 1979; Ponnamperuma, 1984; Lefroy, 1994). In the present study the amount of different nutrients lost due to on farm burning of rice straw, wheat straw and sugarcane trash were also estimated. Maximum loss of nutrient was due to sugarcane trash burning followed by rice and wheat straw. Burning of sugar cane trash led to the loss of 0.84 Mt, rice residues 0.45 Mt and wheat residue 0.14 Mt nutrient per year out of which 0.39 Mt was nitrogen, 0.014 Mt potassium and 0.30 Mt was phosphorus (Table 5).

CONCLUSIONS

This study presents the national and state wise estimates of air pollutants emitted from field burning of crop residues in India. Emission of different air pollutants due to crop residue burning varied greatly among the different states of India depending on the residue generated, their utilisation pattern and fraction of residues subjected to burning. The major states where maximum amount of crop residues were burnt on farm are Punjab, Uttar Pradesh, Haryana and Maharashtra. Rice, wheat and sugarcane are the major crops whose residues are subjected to on farm. Large scale burning of crop residues from rice-wheat system of Punjab, Haryana and western Uttar Pradesh is a matter of serious concern not only for GHG emission but also for problems of pollution, health hazards and loss of nutrients. There is a need to validate the emission estimates experimentally and the associated uncertainty in the estimates. The residues can be put to various productive usage such as incorporation in the fields, bio-energy etc. and this is possible only if residue is collected and managed properly. Awareness must be created amongst the farming communities about the negative impacts of crop biomass burning and importance of crop residues incorporation in soil for maintaining sustainable agricultural productivity.

Table 4. State wise emissions of air pollutants from crop residue burning for the year 2008–09.

States	CO_2	CO	NO_x	SO_x	NMVOC	NMHC	NH_3	HCN	PAH	TPM	$PM_{2.5}$	BC
	Gg/yr											
Andhra Pradesh	8009.96	486.41	13.22	2.11	83.01	37.01	6.87	0.79	0.13	68.73	20.62	3.65
Arunanchal Pradesh	80.78	4.91	0.13	0.02	0.84	0.37	0.07	0.01	0.00	0.69	0.21	0.04
Assam	1460.41	88.69	2.41	0.39	15.13	6.75	1.25	0.14	0.02	12.53	3.76	0.67
Bihar	5077.03	308.31	8.38	1.34	52.61	23.46	4.36	0.50	0.08	43.57	13.07	2.31
Chhattisgarh	1110.69	67.45	1.83	0.29	11.51	5.13	0.95	0.11	0.02	9.53	2.86	0.51
Goa	39.19	2.38	0.06	0.01	0.41	0.18	0.03	0.00	0.00	0.34	0.10	0.02
Gujarat	6835.92	415.12	11.28	1.80	70.84	31.59	5.87	0.68	0.11	58.66	17.60	3.11
Haryana	13907.71	844.56	22.95	3.67	144.13	64.26	11.93	1.38	0.23	119.34	35.80	6.33
Himachal Pradesh	635.45	38.59	1.05	0.17	6.59	2.94	0.55	0.06	0.01	5.45	1.64	0.29
Jammu & Kashmir	1403.12	85.21	2.32	0.37	14.54	6.48	1.20	0.14	0.02	12.04	3.61	0.64
Jharkhand	1939.61	117.78	3.20	0.51	20.10	8.96	1.66	0.19	0.03	16.64	4.99	0.88
Karnataka	8987.46	545.77	14.83	2.37	93.14	41.53	7.71	0.89	0.15	77.12	23.14	4.09
Kerala	184.66	11.21	0.30	0.05	1.91	0.85	0.16	0.02	0.00	1.58	0.48	0.08
Madhya Pradesh	3032.18	184.13	5.00	0.80	31.42	14.01	2.60	0.30	0.05	26.02	7.81	1.38
Maharashtra	10335.70	627.65	17.06	2.73	107.11	47.76	8.87	1.02	0.17	88.69	26.61	4.71
Manipur	109.00	6.62	0.18	0.03	1.13	0.50	0.09	0.01	0.00	0.94	0.28	0.05
Meghalaya	76.61	4.65	0.13	0.02	0.79	0.35	0.07	0.01	0.00	0.66	0.20	0.03
Mizoram	15.56	0.95	0.03	0.00	0.16	0.07	0.01	0.00	0.00	0.13	0.04	0.01
Nagaland	141.23	8.58	0.23	0.04	1.46	0.65	0.12	0.01	0.00	1.21	0.36	0.06
Orissa	1984.66	120.52	3.28	0.52	20.57	9.17	1.70	0.20	0.03	17.03	5.11	0.90
Punjab	32299.31	1961.41	53.30	8.53	334.72	149.24	27.72	3.20	0.53	277.16	83.15	14.71
Rajasthan	4202.19	255.18	6.93	1.11	43.55	19.42	3.61	0.42	0.07	36.06	10.82	1.91
Sikkim	18.95	1.15	0.03	0.01	0.20	0.09	0.02	0.00	0.00	0.16	0.05	0.01
Tamil Nadu	5099.67	309.68	8.42	1.35	52.85	23.56	4.38	0.50	0.08	43.76	13.13	2.32
Tripura	173.76	10.55	0.29	0.05	1.80	0.80	0.15	0.02	0.00	1.49	0.45	0.08
Uttar Pradesh	33701.42	2046.55	55.61	8.90	349.25	155.72	28.92	3.34	0.56	289.19	86.76	15.35
Uttarakhand	1146.20	69.60	1.89	0.30	11.88	5.30	0.98	0.11	0.02	9.84	2.95	0.52
West Bengal	8219.03	499.11	13.56	2.17	85.17	37.98	7.05	0.81	0.14	70.53	21.16	3.74
A & N Islands	5.66	0.34	0.01	0.00	0.06	0.03	0.00	0.00	0.00	0.05	0.01	0.00
D & N Haveli	6.81	0.41	0.01	0.00	0.07	0.03	0.01	0.00	0.00	0.06	0.02	0.00
Delhi	25.40	1.54	0.04	0.01	0.26	0.12	0.02	0.00	0.00	0.22	0.07	0.01
Daman & Diu	1.61	0.10	0.00	0.00	0.02	0.01	0.00	0.00	0.00	0.01	0.00	0.00
Pondicherry	30.07	1.83	0.05	0.01	0.31	0.14	0.03	0.00	0.00	0.26	0.08	0.01
All India	**149240.68**	**9062.80**	**6.90**	**246.27**	**39.40**	**1546.59**	**128.06**	**14.78**	**2.46**	**1280.61**	**384.18**	**67.97**



(a) (b)

Fig. 3. (a) Emission of different pollutants and GHGs due to field burning of crop residues. (b) Contribution of different crops in burning.

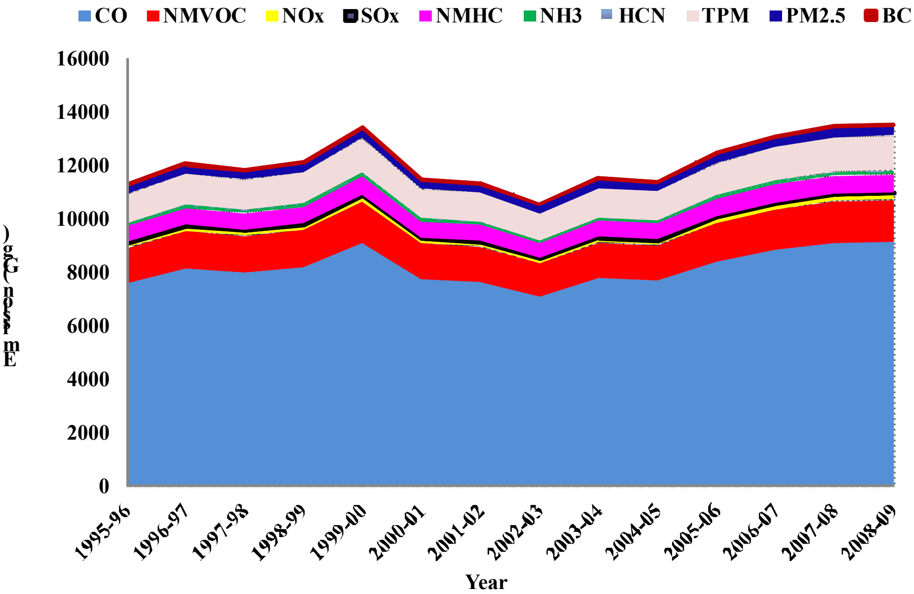


Fig. 4. Inter annual variability in emission of air pollutants due to field burning of crop residues during 1996–2009.

Table 5. Loss of nutrients due to burning of crop residues.

Crop Residues	N loss	P loss	K loss	**Total**
	Mt/Yr			
Rice	0.236	0.009	0.200	0.45
Wheat	0.079	0.004	0.061	0.14
Sugarcane	0.079	0.001	0.033	0.84
Total	**0.394**	**0.014**	**0.295**	**1.43**

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