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Impact of Open Crop Residue Burning and Alternate Options for Mitigation: A Review

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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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Review Article

ABSTRACT

Burning of crop residues in field include unavailability of labour, high cost in residue removing process and use of combined in rice-wheat cropping system especially in the Indo-Gangetic plains (IGP). Primary crop types whose residues are typically burned include rice, wheat, maize, millet, sugarcane, jute, rapeseed-mustard and groundnut. Farmers in northwest India dispose a large part of rice straw by burning in situ. The 'rice-wheat cropping system' is the dominant cropping system in South Asia [1]. This system involves growing rice and wheat in rotation throughout the year where rice and wheat is either grown in the same plot in the same year or in different plots in the same year or in the same plot in different years. Uttar Pradesh, Punjab, Haryana, Bihar, Madhya Pradesh and Himachal Pradesh have the largest areas under this system among the Indian states. Approximately 500-550 Mt of crop residues are produced per year in the country. With a production of 93.9 million tons (Mt) of wheat, 104.6 Mt of rice, 21.6 Mt of maize, 20.7 Mt of millets, 357.7 Mt of sugarcane, 8.1 Mt of fibre crops (jute, mesta, cotton), 17.2 Mt of pulses and 30.0 Mt of oilseeds crops, in the year 2011-12. Emission of greenhouse gases (GHGs) such as carbon dioxide, methane and nitrous oxide causing global warming, loss of plant nutrients such as N, P, K and S, adverse impacts on soil properties and wastage of valuable C and energy rich residues. Black carbon emissions are the second largest contributors to current global warming, after carbon

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dioxide emissions [2]. Using IPCC emission coefficients, the CH_4 released from this source was found to be about 167 Gg [3]. Agricultural crop residues are burnt during the months of October and November every year in the Indo-Gangetic Plains (IGPs) in huge quantities which has a significant impact on greenhouse gas emissions and aerosol loading [4]. In the IGP region of India, 12 million hectares is accounted for rice-wheat crop rotation and harvesting of these crops with combine harvesters is very popular with the farmers of Punjab, Haryana and western Uttar Pradesh [4]. Crop residue management is one of the best options for maintaining the ecological sustainability of farms. There are several options which can be practiced such as composting, generation of energy, production of biofuel, mulching, baling, biochar production and recycling in soil to manage the residues in a productive manner. Conservation agriculture (CA) offers a good promise in using these residues for improving soil health, increasing productivity, reducing pollution and enhancing sustainability and resilience of agriculture.

Keywords: Crop residue burning; stalks; stubble; pollution and crop residue management.

1. INTRODUCTION

The burning of agricultural field residue, such as stalks and stubble, after during the wheat and rice harvesting seasons in the Indo-Gangetic plains results in substantial emissions of trace gases and particles. Use of coarse varieties of rice as opposed to fine-grained varieties such as Basmati increases the likelihood of farmers using the combine-harvester technology, which in turn makes burning almost certain. Although a ban on burning residue was in effect in Amritsar district during the year of the survey, it had little impact on burning [5,6]. 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) [7,8,9]. Carbon dioxide (CO_2) methane (CH_4) and nitrous oxide (N_2O) are important greenhouse gases (GHG) contributing 60, 15 and 5%, respectively, towards the enhanced global warming [10]. Methane is about 25 times more effective than CO_2 as a heat-trapping gas. In the present study the fraction of crop residue subjected to burning ranged from 8–80% for rice paddies across the states [11,12]. 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 [13]. 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

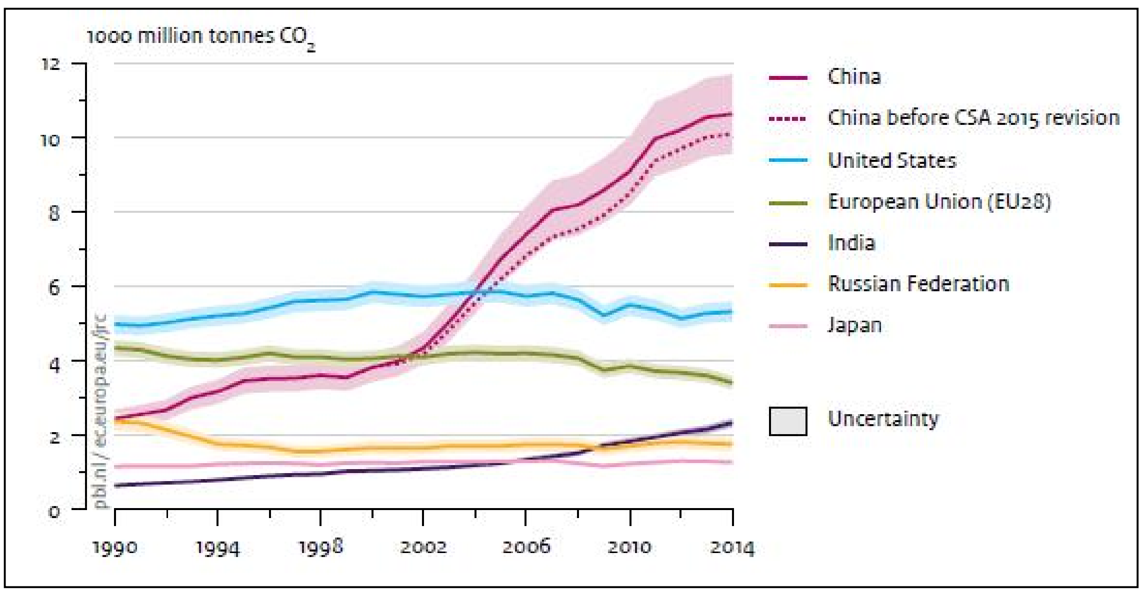

Fig. 1. CO_2 emissions from fossil-fuel use and cement production in the top 5 emitting countries and the EU [19]

Pradesh, Punjab and Uttar Pradesh and for rest of the states it was 10%. According to different estimates 72 Mt–127 Mt of crop residues are burnt on-farm [14,15,16]. Global carbon emissions from fossil fuels have significantly increased since 1900. Since 1970, CO_2 emissions have increased by about 90%, with emissions from fossil fuel combustion and industrial processes contributing about 78.5% of the total greenhouse gas emissions increase from 1970 to 2014. Since the Industrial Revolution, however, energy-driven consumption of fossil fuels has led to a rapid increase in CO2 emissions, disrupting the global carbon cycle and leading to a planetary warming impact. Global warming and a changing climate have a range of potential ecological, physical and health impacts, including extreme weather events (such as floods, droughts, storms, and heat waves); sea-level rise; altered crop growth; and disrupted water systems [17]. Agriculture, deforestation, and other land-use changes have been the second-largest contributors [18]. The six largest emitting countries/regions in 2014 were: China (with 30%), the United States (15%), the European Union (EU-28) (9.6%), India (6.6%), the Russian Federation (5.0%) and Japan (3.6%). Remarkable trends were seen in the top three emitting countries/regions, which account for 54% of total global emissions. In China and the United States, emissions increased by 'only' 0.9%. The European Union saw a large decrease of 5.4% in 2014, compared to 2013, which offset the 7.8% growth in India. The Russian Federation and Japan saw their CO_2 emissions decline by 1.5% and 2.6%, respectively [19] (Fig. 1).

2. GREENHOUSE GAS EMISSION FROM INDIAN AGRICULTURE

It is also important that role of agricultural activities in increasing the levels of GHGs is often overlooked [20]. The updated inventory for the year 2010 showed that the agricultural sector, including crop and animal husbandry, emitted 406 Mt of CO_2 eq. (Table 1), the enteric fermentation constituted 52% of the total CO2 eq. emissions from this sector. Agricultural soils emitted 23% of the total CO_2 eq. emission from agriculture, whereas rice cultivation contributed 17%. Livestock manure management contributed 6% of the emissions and 2% was attributed to the burning of crop residues in field. The direct and indirect N_2O emissions from Indian agricultural soils were 259 Gg and 45 Gg (94 Tg CO2 eq.), respectively in 2010. Fertilizer was the largest source contributing 77% to the total direct nitrous oxide emissions.

Table 1. Greenhouse gas emissions from Indian agriculture in 2010

Source	GWP (CO_2 eq.)
Enteric fermentation	211
Manure management	27
Rice cultivation	68
Agricultural soil	94
Crop residue burning	6
Total	406

The greenhouse gases CO_2 and CH_4 directly influence the global warming, while changes in oxidizing capacity to CO variability could perturb the growth rates of greenhouse gases. Recent study by Gustafsson et al. [21] highlighted that biomass burning is one of the main causes for dense "brown clouds" in South Asia and 50–90% of the South Asian BC originates from fossil fuel combustion [22]. The burning of crop stubble in open fields has an adverse impact on the fertility of soils, reducing the amount of nutrients available for plants in the soil. Crop residue is not a waste but rather a useful natural resource. It is estimated that burning of paddy straw results in annual nutrient losses to the tune of 3.85 million tonnes of organic carbon, 59,000 t of nitrogen, 20,000 t of phosphorus and 34,000 t of potassium at the aggregate [23]. About 25% of nitrogen (N) and phosphorus (P), 50% of sulphur (S) and 75% of potassium (K) uptake by cereal crops are retained in crop residues, making them valuable nutrient sources [24]. The quantity of nutrients available in rice. According to his study, the paddy straw has 39 kg/ha N, 6 kg/ha P, 140 kg/ha K and 11 kg/ha S. A large proportion of nutrients thus removed are removed in the straw portion and thus can be effectively returned to the soil if the residues are recycled by way of retention, incorporation, composting and subsequent application or by animal consumption and subsequent recycling of animal dung in the field after appropriate decomposition. At the same time, biomass burning is one of the significant global source of atmospheric aerosols and trace gas emissions, which have a major impact on climate and human health [25,26,27]. Burning of crop residues not only degrades the atmospheric quality but also affects the climate and ultimately the human health. Crop residue and biomass burning (forest fires) are considered as a major source of carbon dioxide (CO_2), carbon monoxide (CO), methane (CH_4), volatile organic compounds (VOC), nitrogen oxides and

Table 2. End use of stubble by the farmers

End use	Rice (% of total stubble production)	Wheat (% of total stubble production)
Fodder	7	45
Soil incorporation	1	<1
Burnt	81	48
Rope making	4	0
Miscellaneous	7	7

halogen compounds. Ban of crop burning will not be only reducing the atmospheric pollution but also be helpful to fulfil the energy demand with improvement in the economic condition of the country. Due to lack of awareness and unavailability of suitable technologies, it is practiced to facilitate timely sowing of wheat after the harvest of the rice crop. In India, the primary end-uses of crop residue are as animal fodder, industrial and domestic fuel, thatching, packaging, bedding, construction of walls/ fences, and as green-manure and compost [28] (Table 2).

3. EMISSION OF GREENHOUSE GASES FROM BIOMASS BURNING

India being an agriculture-dependent country generates a large quantity of agro-wastes. Burning crop residues is practiced as a means of clearing land rapidly and inexpensively and allowing tillage practices to proceed unimpeded after removal of crop residues. The primary crop types whose residues are typically burnt in India are rice, wheat, maize, millet, sugarcane etc. Crop residue burnt is converted to gases, such as carbon dioxide, methane, nitrous oxide, SOx, NOx, CO; aerosols and ash.

4. HOW MUCH CROP RESIDUES ARE CONSUMED AND REMAIN SURPLUS FOR BURNING IN INDIA?

Ministry of New and Renewable Energy [29], Govt. of India estimated that about 500 Mt of crop residue is generated every year (Table 3). There is a large variability in crop residues generation and their use depending on the cropping intensity, productivity and crops grown in different states of India. Residue generation is highest in Uttar Pradesh (60 Mt) followed by Punjab (51 Mt) and Maharashtra (46 Mt). The uses for various residues are different in different states. Farmers use residue either themselves or sell it to other landless households or intermediaries, who in turn sell the residues to industries. The remaining residues are left unused or burned in field. Remaining 19% is from sugarcane, pulses, oilseeds and other crops. Out of 82 Mt surplus residues from the cereal crops, 44 Mt is from rice followed by 24.5 Mt of wheat which is mostly burned in fields (Table 3).

5. EFFECTS OF CROP STUBBLE BURNING ON FERTILITY OF THE SOIL

The soil organic carbon has been reduced to very low and inadequate levels due to the inadequate application of organic manures and non-recycling of crop residues. According to [30], burning of crop stubble increases the temperature in the soil up to 33.8–42.2°C. Burning also results in the loss of 27–73% of nitrogen present in the soil and reduces the bacterial and fungal populations on the top 2.5 cm of the soil. Furthermore, repeated burning can diminish the bacterial population by more than 50%. Long-term burning also reduces total nitrogen and carbon and potentially mineralized nitrogen in the 0–15 cm soil layer along with a loss in the soil organic matter. It has been reported that the fire gradually decreased soil organic matter and biological activity. One reason suggested for reducing the activity of micro-organisms, destroying them by fire.

6. ALTERNATIVES TO AGRICULTURAL WASTE BURNING

Ban of crop burning will not be only reducing the atmospheric pollution and climate problem but also be helpful to fulfil the energy demand improving the economic condition of the country. Other options for harnessing energy from crop residue are incorporation, surface retention (CA based) and mulching, baling and removing the straw, no tillage, fodder etc. Recent research efforts have attempted to develop conservation agriculture (CA)-based crop management technologies, which are more resource efficient, use less inputs, improve production and income, and reduce GHG emission compared to the conventional practices [32].

Table 3. Generation and surplus of crop residues in various states of India

States	Residue generation (MNRE, 2009)	Residue surplus (MNRE, 2009)	Residue burned (IPCC coeff.)	Residue burned (Pathak et al. 2010)
	Mt yr^{-1}			
Andhra Pradesh	43.89	6.96	5.73	2.73
Arunachal Pradesh	0.4	0.07	0.06	0.04
Assam	11.43	2.34	1.42	0.73
Bihar	25.29	5.08	3.77	3.19
Chhattisgarh	11.25	2.12	1.84	0.83
Goa	0.57	0.14	0.08	0.04
Gujarat	28.73	8.9	6.69	3.81
Haryana	27.83	11.22	5.45	9.06
Himachal Pradesh	2.85	1.03	0.20	0.41
Jammu and Kashmir	1.59	0.28	0.35	0.89
Jharkhand	3.61	0.89	1.11	1.10
Karnataka	33.94	8.98	2.85	5.66
Kerala	9.74	5.07	0.40	0.22
Madhya Pradesh	33.18	10.22	3.46	1.91
Maharashtra	46.45	14.67	6.27	7.41
Manipur	0.9	0.11	0.14	0.07
Meghalaya	0.51	0.09	0.10	0.05
Mizoram	0.06	0.01	0.01	0.01
Nagaland	0.49	0.09	0.11	0.08
Orissa	20.07	3.68	2.57	1.34
Punjab	50.75	24.83	8.94	19.62
Rajasthan	29.32	8.52	3.58	1.78
Sikkim	0.15	0.02	0.01	0.01
Tamil Nadu	19.93	7.05	3.55	4.08
Tripura	0.04	0.02	0.22	0.11
Uttarakhand	2.86	0.63	13.34	21.92
Uttar Pradesh	59.97	13.53	0.58	0.78
West Bengal	35.93	4.29	10.82	4.96
India	**501.76**	**140.84**	**83.66**	**92.81**

Table 4. 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	0.450
Wheat	0.079	0.004	0.061	0.140
Sugarcane	0.079	0.001	0.033	0.118
Total	**0.394**	**0.014**	**0.295**	**0.708**

Source- Aerosol and Air Quality Research [31]

7. CA-BASED CROP MANAGEMENT TECHNOLOGIES

Conservation agriculture involving continuous minimum mechanical soil disturbance, permanent organic soil cover with crop residues or cover crops and diversified, efficient and economical viable crop rotations provides opportunities for saving on inputs, improving resource use efficiency and mitigating greenhouse gas (GHG) emission and climate change adaptation. Recent research efforts have attempted to develop conservation agriculture (CA)-based crop management technologies, which are more resource efficient, use less inputs, improve production and income, and reduce GHG emission compared to the conventional practices [32]. The CA-based crop management technologies include zero tillage (ZT) with residues recycling, laser assisted precision land levelling, direct drilling into the residues, direct seeding of rice with *Sesbania*, unpuddled mechanical transplanted rice, raised bed planting, These technologies are being increasingly adopted by farmers in the rice-wheat belt of the Indo-Gangetic plains (IGP) because of advantages in saving of labour, water, fuel, cost along with timeliness in operations/practices, particularly early planting of wheat. Potential benefits of CA based crop management technologies on resource conservation, use efficiency of external inputs, yield enhancement, soil health improvement, and adaptation to changing climates [13,33,34].

8. ENERGY EXTRACTION AND BIOFUEL PRODUCTION

There are a number of ways commonly used to extract energy from biomass, such as corn, sugar cane, wood, grasses and some agricultural waste. There are two basic alternatives to obtaining energy from biomass: burning it or converting it into fuel. Even though it is preferable for the environment, converting biomass into biofuel continues to be somewhat inefficient and particularly costly, and at this time burning biomass to produce energy is more affordable.

9. BIOCHAR PRODUCTION THROUGH CROP STUBBLE AND ITS USES

Biochar is defined as the carbon-rich product produced by “so-called thermal decomposition of organic material under limited supply of oxygen and at relatively low temperatures (<700ºC) [35]. Biochar is a carbon rich charcoal-like substance created by heating plant matter in low oxygen conditions by a process known as pyrolysis. It has been observed that the recovery of biochar is approximately 50- to 60% of the weight of the total biomass. The size of the biochar material is reduced to 1-4” sizes by hand before application in the field. The land is tilled with tractor drawn disc. The biochar is applied on the surface of the soil and incorporated into soil with disc or spade to a depth of 15 cm. It is also important to assure that waste is as dry as possible before burning. The advantage of using “stubble cultivation” is to spread out more than 50% of the waste (leaves, stalks and brush) from the previous harvest in the land plot, and in this way: reduce the use of agro chemicals and conserve soil moisture.

10. BENEFITS OF BIOCHAR APPLICATION IN SOIL

It was reported that that the application of biochar to soil led to a reduction of N leaching by 60 per cent and increases of crop productivity by 38 to 45 per cent, which we assume to translate into a 20 per cent saving in fertilizer and 10 per cent savings in irrigation and seeds [36]. Nevertheless, the yield increased up to 140 per cent on poor soils under recommended fertilization [37]. The availability of nutrients such as Ca and Mg was greater with biochar, and crop tissue analyses showed that Ca and Mg were limiting in this system. Soil pH increased, and exchangeable acidity showed a decreasing trend with biochar application.

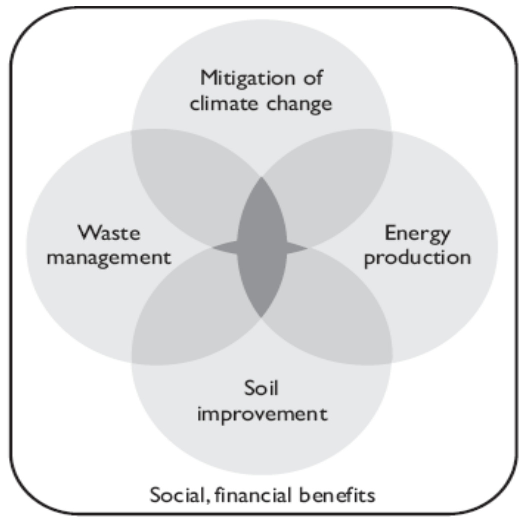

Fig. 2. Source-Lehmann and Joseph, 2009

11. USE OF HAPPY SEEDER/TURBO SEEDER

Happy Seeder is a tractor-mounted machine that cuts and lifts the rice straw, sows wheat into the bare soil, and deposits the straw over the sown area as mulch. However, sowing of a crop in the presence of residues of preceding crop is a problem. But new variants of zero-till seed-cum-fertilizer drill/planters such as Happy Seeder/turbo seeder has been developed for direct drilling of crops in surface residue (loose and anchored) conditions. It has rotating blades on the rotor in front of the tynes/openers which cuts/shreds the residues ahead of the furrow openers and spread over the sown area behind the seed-cum-fertilizer drill [38]. This drill/planter can seed in the surface residues load up to 10 t/ha. Similarly, there are other planters such as rotary-disc drill for direct drilling in residue conditions. The rotary discs cut the residues and place the seeds and fertilizer in the narrow slit. These machines are very useful for conserving moisture, nutrients and controlling weeds as well as moderating soil temperature [38]. Farmers can therefore sow wheat immediately after the rice harvest, precluding the need for burning rice residue. The Happy Seeder technology will spread only slowly since it has no strong advantage or disadvantage from the point of view of the private profitability of the farmer. Accordingly, there is a strong case for promoting the machine through extension and possibly subsidies in order to reduce residue burning, the costs of which are mostly external to the farmer.

12. COMPOSTING OF VARIOUS CROP RESIDUES FOR GOOD QUALITY MANURE

The crop residues have been traditionally used for preparing the compost. The different crop residues can be composted by using it as animal bedding and then heaping in dung pit. Each kg of straw absorbs about 2-3 kg of urine from the animal shed. It can also be composted by alternative methods on the farm itself. The residues of rice crop from one hectare land, on composting, give about 3.0 to 3.5 tons of manure as rich in nutrients as farmyard manure (FYM) [24]. The decomposition process, which is hastened by a consortium of microorganisms, takes 75-90 days.

13. USE AS LIVESTOCK FEED

In India, the crop residues are traditionally utilized as animal feed as such or by supplementing with some additives. However, crop residues, being unpalatable and low in digestibility, cannot form a sole ration for livestock. Crop residues are low-density fibrous materials, low in nitrogen, soluble carbohydrates, minerals and vitamins with varying amounts of lignin which acts as a physical barrier and impedes the process of microbial breakdown. To meet the nutritional requirements of animals, the residues need processing and enriching with urea and molasses, and supplementing with green fodders, grasses (leguminous/non-leguminous) and legume (sunhemp, horse gram, cowpea, and gram) straws.

Other alterative of surface crop residue are as under-

- In situ incorporation being the best option may be further investigated for fast decomposition of residue.
- Modification of combine harvesters, whereby the residue also is separately collected and removed from the field.
- Capacity building through training and teaching in under- and post-graduate levels and also through training of farmers to use residue conservation practices and facilitate technology transfer.
- Government should monitor and discourage burning of crop residue through incentives and technology transfer and utilization.
- Fuels, such as ethanol and biogas (methane), Compost preparation and making of feed block from surface crop residue.

14. CONCLUSION

The crop residues are of great economic as well as significant value as livestock feed, fuel and industrial raw material. However, problems with the crop residues are different in different region and associated with the socio-economic needs. The residues might be used as various products such as retention, incorporation in the fields, bio-energy fuel, biochar production etc. and this is possible only if residue is collected and managed properly. Awareness must be created amongst the farming communities regarding the negative impacts of crop biomass burning and importance of crop residues incorporation in soil for maintaining sustainable agricultural productivity. The resource conserving technologies (*RCTs)* involving no- or minimum-tillage, direct seeding, bed planting, crop diversification with innovations in residue management, participation of farmers and their collectives, and partnership and support of political and Govt. organizations and NGOs are possible alternatives to the conventional energy and input intensive agriculture. The technologies can improve the sustainability of agriculture by mitigating GHG emission and adapting to climate changes. Besides these elements, what are of paramount importance are value-orientation and perception of practitioners towards climate-friendly sustainable agriculture.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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