*International Research Journal of Earth Sciences*
Vol. **1(1),** 24-30, April **(2013)** *Int. Res. Earth Sci.*

***Review Paper***

# Emissions from Crop/Biomass Residue Burning Risk to Atmospheric Quality

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**Available online at: www.isca.in**
Received 6th November 2012, revised 27th December 2012, accepted 4th February 2013

## Abstract

*Recent crop harvesting practices use mechanical harvesters in the rice and wheat farm system in India. These practices leave behind large quantities of crop residue in the field. However, there is no suitable method available for managing the crop residues. Crop residues / biomass burning are cheap and easiest method to dispose the leftover crop residues (wheat, rice, sugarcane etc.) after harvesting, for land clearing and pest control. Burning of crop residues is a common approach to eliminate waste after harvesting all over the world. Burning of these residues emit gases like sulphur dioxide ($SO_2$), oxides of nitrogen (NOx), carbon dioxide ($CO_2$), carbon monoxide (CO), black carbon (BC), organic carbon (OC), methane ($CH_4$), volatile organic compounds (VOC), non-methane hydrocarbons (NMHCs), ozone ($O_3$), and aerosols etc which affect the global atmospheric chemistry and climate. Crop residues / biomass burning not only influence the atmospheric air quality including climate, it also affects the human health. This review covers the burning of crop residues / biomass and its affect on atmospheric quality and climate and also suggested some management options for crop residue/biomass besides burning which may be reducing the air pollution, climate as well as possibility of risk on human health.*

**Keywords:** Crop residues burning; atmospheric quality; climate.

## Introduction

Burning is an easiest and economical option for management of crop/biomass residues. Due to lack of awareness or not availability of suitable technologies it is generally practices everywhere. Burning of crop residues not only degrade the atmospheric quality but also affect the climate and ultimate 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 halogen compounds[1].

Biomass burning is a major source of gaseous pollution such as carbon monoxide (CO), methane ($CH_4$), nitrous oxides (NOx) and hydrocarbons in the troposphere[2,3]. It is also a significant source of aerosol in the atmosphere, having potential impact on global air quality and chemistry of climate[4-7]. Open agricultural crop residues, burning release a great amount of pollutants to the atmosphere, which includes aerosols and hydrocarbons[8,9]. Singh et al.[10] were studied the impact of rice crop residue burning on levels of SPM, $SO_2$ and $NO_2$ in the ambient air in and around the Patiala, Punjab (India). It was observed that levels of SPM, $SO_2$ and $NO_2$ increases during the burning months (October–November) incorporated with the effect of meteorological parameters especially wind direction, precipitation and atmospheric temperature.

Researchers found that most of the particulate released due to agriculture crop residue burning (ACRB) are smaller than 10 microns ($PM_{10}$), and easily enter into the lungs, causing heart problems[11-16]. Generally crop residues/biomass burning is practices by farmers for clearing of their agriculture land, control of weeds and brush on crop lands, nutrient regeneration in crop or grazing lands, however instead of burning it may be use as production of energy such as charcoal, alcohol, producer gas, biogas etc.

The review paper has been prepared in the following sub heading to explain the complexities of biomass burning and its threats to atmospheric environment and climate. Impact of open burning of crop residue/biomass on particulates matters. Impact of open burning of crop residue/biomass on gaseous pollution. Impact of open burning of crop residue/biomass on Climate.

**Impact of open crop residue/biomass burning on particulates matters:** Awasthi et al.[17], Studied on size and mass distribution of particulate matter in aerosol due to crop residue burning with seasonal variation in rural area of Punjab, India. They reported that the concentration levels of different size particulate matter are greatly affected by types of agricultural crop residue burning; however the total distribution of the particulate matter remains almost constant.

Calvo et al.[18], worked on aerosol size distribution and gaseous products from combustion of oats and barley straw. They found that burning of barley generates a high number of fine particles with a diameter of less than 0.5 µm than oats. The distributions of particles emitted during the flaming phase, as well as during the previous and subsequent phases also have been characterized. The average geometric diameter of aerosol particles during the flaming phase were 0.53 ± 0.10 µm and 0.44 ± 0.04 µm for oats and barley, respectively. However after flaming phase, oat straw generates coarser particles than barley.

Shen G. et al.[19] studied the emission factors of particulate and gaseous phase polycyclic aromatic hydrocarbons (PAHs) for indoor crop residue burning in a typical rural stove and found as 35 ± 23 and 27 ± 13 mg/kg respectively. They also reported that 80 ± 6% of PAHs joined with $PM_{2.5}$, and the mass percentage of (PAHs) in fine particles enlarged as the molecular weight increased.

Zhang et al.[20] studied on Impact of anthropogenic emissions and open biomass burning on regional carbonaceous aerosols in South China and got the highest carbonaceous aerosols EC (elemental carbon) and OC (organic carbon) in the coastal site closed to the most industrialized and urbanized region in south China. While, low level of carbonaceous aerosols found in remote background stations in China. They also observed distinct seasonal patterns but higher concentrations during the winter, and lower concentrations during the summer time.

Li et al. [21] studied on biomass burning emission originating from fire over Asian agriculture areas and its transport into the downwind atmosphere, aerosols and major trace gases were measured in May–June 2009. They observed that Water-soluble K material contained in aerosols showed a clear day-to-day pattern with an average of 1.25 ± 1.48 μg/$m^3$. K ion loading and ratio of K ion to $PM_{10}$ drastically increased during 'K event' days, (periods when daily average $K^+$ concentration exceeded background value) associated with high $PM_{10}$, $SO_2$, and $NO_2$ levels.

Singh et al.[10] studied two rice burning episodes between September 2006 to January 2008, and found great deterioration in ambient atmospheric quality and increase the level of SPM during period of crop residue burnings. It was also reported that the gaseous molecules stay in the ambient air for a longer duration than that of SPM.

Singh et al.[22] analysed the loss on ignition (LOI) and organic tarry matter (OTM) content in ambient air during crop residue burning (CRB) months and non-crop residue burning (NCRB) months for the period of 2006-2007. They observed high levels of OTM and LOI during rice and wheat crop residue-burning periods at all the tested sites. It was also noted that the LOI and OTM levels were higher in rice crop residue-burning period than the wheat residue-burning period.

Mittal et al.[23] did the ground level study on the contribution of wheat (*Triticum aestivum*) and rice (*Oriza sativa*) crop stubble burning on $SO_2$, $NO_2$ and aerosols concentration levels in ambient air at five different sites such as agricultural, commercial and residential areas of Patiala (India). GMF/A and QMF/A (Whatman) sheet were used to collect the aerosols for 24 hours period throughout the year in 2007. Simultaneously, $SO_2$ and $NO_2$ sampling was conducted and result obtained during period of stublle burning were compared with non stubble burning periods. Finally, it was concluded that $SO_2$, $NO_2$ and aerosols levels increase during the crop residue stubble burning periods.

Guoliang et al.[24] noted that wheat straw had the top emission factor for the total PM (8.75 g/kg) among the four crop residues, while, highest emission factor of corn stover and wheat straw for EC (elemental carbon) (0.95 g/kg) and OC (organic carbon) (3.46 g/kg) respectively.

Zhang et al.[25] observed that mean emission factors of particle number (PN) 1.8 x $10^{13}$, 1.0 x$10^{13}$, and 1.7 x $10^{13}$ particles/ kg for rice, wheat, and corn straws, respectively. It was suggested that for exact quantitative emission estimations, aerosol chamber experiments can be use; however they need to be validated further through domestic and open burning studies and compared with other investigations.

Lee et al.[26] studied on particle size characteristics of levoglucosan in ambient aerosols from rice straw burning and found that levoglucosan concentrations were during the active rice straw burning episode (up to 1400 ng/$m^3$), fairly high values of the smoke tracer were measured throughout the entire study period. It was also observed that unusually high levoglucosan levels present in aerosol particles with aerodynamic diameters larger than 10 mm ($PM_{>10}$), possibly influenced by the ambient atmospheric conditions, such as high relative humidity, in addition to unique properties of rice straw smoke and the specific burning practices of rice fields.

Critical reviews of above literature indicate that in general burning of crop residues / biomass residues significantly emits particulate matter/aerosols in the atmosphere and ultimately degrade the atmospheric air quality. Crop residue burning is not a suitable method for crop residue management. It could be utilized as soil mulching, incorporation, getting energy through the rout of thermo-chemical conversion or biochemical conversion. One of the estimate indicate that even half of the surplus biomass available, if utilised for power generation, it may cater the more than half of the electrical energy requirement of India.

**Impact of open crop residue/biomass burning on gaseous pollution:** Shen et al.[19] worked on emissions of polycyclic aromatic hydrocarbons (emission factors, size distributions, and gas-particle partitioning) from indoor crop residue burning in a typical rural stove. It was found that the emission factors (EFs) of polycyclic aromatic hydrocarbons (PAHs) for nine commonly used crop residues burned in a typical Chinese rural cooking stove were 63 ± 37 mg/kg (ranging from 27 to 142 mg/kg), which were higher than those measured in chamber experiments, implying that the laboratory experiment-based emission and risk assessment should be carefully reviewed. EFs of gaseous and particulate phase PAHs were 27 ± 13 and 35 ± 23 mg/kg, respectively.

Calvo et al.[18] reported that chemical compounds such as $CO_2$, $NO_2$ and NO and gravimetric variations are found during the combustion processes.

He et al[27], studied on influence of biomass burning on composition of semi-volatile organic compounds in the urban atmosphere of Singapore. They found that on an average, 35.7% of n-alkanes came from plant wax emission or biomass combustion during October 2006; in contrast, only 9.6% of alkanes were of plant wax input from August to September 2006. The influence of biomass burning on the regional air quality is supported by the general increasing tendency of PAH diagnostic ratios during October 2006 as compared to those investigated in other months i.e. August to September 2006.

Singh et al.[10] studied on impact of rice crop residue burning on levels of SPM, $SO_2$ and $NO_2$ in the ambient air of Patiala (India) and found that the level of SPM (Suspended particulate matter), $SO_2$ and $NO_2$ increases with burning of rice residue during period of September 2006–January 2008. The average concentrations (24 hour) of SPM, $SO_2$ and $NO_2$ varied from 100±11 $\mu g/m^3$ to 547±152 $\mu g/m^3$, 5±4 $\mu g/m^3$ to 55±34 $\mu g/m^3$ and 9±5$\mu g/m^3$ to 91±39 $\mu g/m^3$ respectively. They also reported that significantly higher concentration was recorded at the commercial area site as compared to the other sampling sites (Sensitive site, Semi-urban site, rural site and Commercial site) for all the targeted air pollutants.

Yamaji et al.[28] reported that daily open crop residual burning (OCRB) emissions over CEC (Central Eastern China) in June were approximately 40% of the annual total. Approximately 14% of monthly total (about 6% of annual total) of the OCRB emissions were concentrated in 7 June. On 7 June, OCRB emissions formed large contributions to total pollutant concentrations, constituting 26% of $O_3$, 62% of CO, 79% of EC (elemental carbon ) and 80% of OC (organic carbon).

Badarinath et al.[29] studied the variations in CO, $O_3$ and black carbon aerosol mass concentrations associated with planetary boundary layer (PBL) over tropical urban environment in India. They suggested significant raise in CO and BC concentrations during early morning hours. BC, CO and ozone concentration was observed higher during pre-monsoon, postmonsoon and winter and lowest concentrations exhibited during monsoon season. NCEP/ NCAR reanalysis winds suggested long range transport of aerosols and trace gases from forest fires are increasing the pollutant concentrations over the study area.

Gadde et al.[30] reported that open field burning of rice straw and other crop residues emits species such as $CO_2$, nitrous oxide ($N_2O$), $CH_4$, CO, non-methane hydrocarbons (NMHC), NO*x*, $SO_2$, particulate matter (PM) and few others species (table 1 and 2).

Lai et al.[31] find out that the concentrations of total PAHs (sum of 21 gases + particles) at the Jhu-Shan site (Sin-Gang site) and obtained 523 ±111 ng/ $m^3$ and 330 ± 17 ng/ $m^3$ during burning and non-burning periods, respectively, accounting for a roughly 58% increase in the concentrations of total PAHs due to rice-straw burning. On average, low-weight PAHs (about 87%) represent the largest proportion of total PAHs, followed by medium-weight PAHs (7%) and high-weight PAHs (6%). Combustion-related PAHs during burning periods were 1.5-2.6 times greater than those during non-burning periods.

Anjali et al.[32] reported that CO increases during burning of biomass associated with grassland burning, festivals (Pongala) and campus cleaning. They estimated that carbon monoxide (CO) emission from the above mentioned event increase 30-fold on burning of fresh biomass (mean CO= 6.16 ppm) whereas a 27-fold increase in CO (mean CO=5.74 ppm) was found on dry biomass burning compared to a normal day in winter (mean CO=0.206 ppm). An empirically estimation of CO found 0.287 $kg/m^2$ emission from burning of fresh biomass and 0.198 $kg/m^2$ from burning of dry biomass. Finally, the measured and estimated CO both was found higher on fresh biomass burning compared to the dry biomass burning.

**Table -1**
**Emissions from Rice Straw Open Burning**

| Name of Pollutant | Emissions from Rice Straw Open Burning | | | |
|---|---|---|---|---|
| | EF($g/kg_{dm}$) | India (Gg) | Thailand (Gg) | Philippines (Gg) |
| $CO_2$ | 1,460 | 16,253 | 11,850 | 11,850 |
| $CH_4$ | 1.20 | 13 | 10 | 10 |
| $N_2O$ | 0.07 | 1 | 1 | 1 |
| CO | 34.70 | 386 | 290 | 282 |
| NMHC | 4.00 | 45 | 33 | 32 |
| NOx | 3.10 | 35 | 26 | 25 |
| $SO_2$ | 2.00 | 22 | 17 | 16 |
| Total particulate matter (TPM) | 13.00 | 145 | 109 | 106 |
| Fine particulate matter ($PM_{2.5}$) | 12.95 | 144 | 108 | 105 |

**Table -2**
**Emissions from Open Burning of other Crop Residues**

| Name of Pollutant | Emissions from Crop Residues Open Burning | | | |
|---|---|---|---|---|
| | EF ($g/kg_{dm}$) | India (Gg) | Thailand (Gg) | Philippines (Gg) |
| $CO_2$ | 1,515 | 127,260 | 11,666 | 10,757 |
| $CH_4$ | 2.70 | 227 | 21 | 19 |
| $N_2O$ | 0.07 | 5.88 | 0.54 | 0.50 |
| CO | 92.00 | 7,728 | 708 | 653 |
| NMHC | 7.00 | 588 | 54 | 50 |
| NOx | 3.38 | 322 | 29 | 27 |
| $SO_2$ | 0.40 | 34 | 3 | 3 |
| Total particulate matter (TPM) | 13.00 | 1092 | 100 | 92 |
| Fine particulate matter ($PM_{2.5}$) | 3.90 | 328 | 30 | 28 |

Gg- Giga gram, $g/kg_{dm}$ = gram per kg of dry matters

Li et al.[33] worked on characterization of non-methane hydrocarbons emitted from open burning of wheat straw and corn stover in China and analysed that emission factors of the total NMHCs from maize stover and wheat straw are 1590 ± 430 mg/ kg and 1690 ± 580 mg/ kg, respectively. Whereas propane, *n*-pentane, 2,3-dimethylbutane, 2-methylpentane, propene, benzene and toluene are the chief species, together accounting for 55.3%–68.0% of the total NMHCs. Ozone forming potential (OFP) of speciated NMHCs on the basis of measured emission factors and the published maximum incremental reactivity values for NMHCs was also estimated. Result show that propene, 1-butene, isoprene, toluene and *m, p*-xylene have high OFP values and account for about 50% of the total OFP.

Guoliang et al.[34] investigated the emission factors of particulate matter and gaseous pollutants from crop residue burning. It was observed that Corn Stover have the highest emission factors of NO, NO*x* and $CO_2$, however, wheat straw, rice straw, and cotton stalk shown highest emission factors of $NO_2$, $SO_2$, and CO, respectively. They also reported that the water-soluble ions, $Cl^-$ and $K^+$, had the highest emission factors (EF) from all the crops. Wheat straw had a relatively higher emission factor of cation species and $F^-$, $Cl^-$, $NO_2^-$ than other crop residues.

Sahai et al. reported that field burning of crop residue (FBCR) generated an estimated 284 teragrams (Tg) of residue in India, of which 40% was responsible wheat straw in the year 2000. Approximately 7.5% of this total wheat straw was subjected to on-site burning that is expected to emit large amounts of particulate matter (PM) and trace gases to the atmosphere. The emission factors (EFs) of $CO_2$, $CH_4$, CO, $N_2O$, $NO_x$, NO and $NO_2$ were found to be 1787±36, 3.6±2.7, 28.1 ±20.1, 0.74±0.46, 1.70±1.68, 0.78±0.71 and 0.56± 0.47 g/kg, while those for organic carbon (OC), black carbon (BC) and total carbon (TC) were 0.3±0.1, 0.2±0.1, and 0.5±0.2g/kg, respectively. Further, the complete emissions of $CH_4$, $CO_2$, CO, $N_2O$, $NO_x$, NO, $NO_2$, OC, BC and TC from burning of wheat straw in India for the year 2000 was estimated as 68 ± 51, 34435 ± 682, 541 ± 387, 14± 9, 33 ± 32, 15 ± 14, 11 ± 9, 6 ± 2, 3 ± 1 and 10 ± 4 Gg, respectively.

From above references it may be safely concluded that crop residue/biomass residue burning not only emits poisonous gases such as $SO_2$, $CH_4$, $CO_2$, CO, $N_2O$, $NO_x$, NO, $NO_2$, OC, BC, TC, NMHCs, SVOCs, VOCs, $O_3$ etc; but also influences the quality of environment at large.

**Impact of open crop residue/biomass burning on Climate:** Cheewaphongphan et al.[35] observed that in Thailand open burning of rice residues is mainly found in the rain-fed area, and generally occurred in month of March to May. Approximately 22 Mt of rice residue is burned annually that emits green house gases (GH) in term of carbon dioxide ($CO_2$) equivalent to 27 Mt.

Gadde et al.[36] estimated that in India, 23% of rice straw residue produced is surplus and is either left in the field as uncollected or to a large extent open-field burnt. About 48% of this residue produced is subjected to open-field burning in Thailand, and in the Philippines it is 95%. The GHG emissions contribution through open-field burning of rice straw in India, Thailand, and the Philippines are 0.05%, 0.18%, and 0.56%, and the mitigated GHG emissions when generated electricity is used would be 0.75%, 1.81%, and 4.31%, respectively, when compared to the total country GHG emissions.

Gadde et al.[30] reported that crop residue burning emits not only CO, non-methane hydrocarbons (NMHC), NO*x*, $SO_2$, particulate matter (PM), and green house gases ($CO_2$, $N_2O$ and $CH_4$); it also contribute to global warming and climate change. However, $CO_2$ emitted from biomass burning is considered to have a neutral effect due to its photosynthetic uptake during plant growth (table-1).

Badarinath et al.[37], estimating the extent of burnt areas and thereby greenhouse gas (GHG) emissions from crop residue burning using the data of Indian Remote Sensing Satellite (IRS-P6) Advanced Wide Field Sensor (AWiFS) during May and October 2005. They found that emissions from wheat crop residues burning in Punjab are relatively low compare to paddy fields.

Jacobson et al.[38], reported that during burning, emitted aerosol particles cause a short-term cooling of global climate, whereas longer-lived greenhouse gases may cause warming (or cancel the cooling) after several decades. As such, on reducing biomass burning may cause short-term warming while long-term cooling or no change in temperature. They also point out that all $CO_2$ may be reduced after 100 years due to stop biomass burning. It was calculated that about 94%–97% $CO_2$ may be reduced due to eliminating permanent forest burning/decay, 2%–4% $CO_2$ may be reduced due to eliminating temporary forest burning/decay, 0.8%–2% $CO_2$ may be reduced due to eliminating savannah burning, and 0.1%–0.3% $CO_2$ may be reduced due to eliminating agricultural burning. While, their result though, is subject to model and emission uncertainties and require further verification.

There is no clear picture on impact of crop residue/ biomass burning on climate. More work need to be carried out in this particular area. Climate has a very significant role in our life. Today, global warming is a Universal problem. Open agricultural residues/biomass burning is one of the culprits for it. Researchers indicated that crop residue / biomass burning releases the green house gases (GHGs) such as $CO_2$, $CH_4$ and $N_2O$, however much more work need to be done for exploring the impact of open burning on climate as well as environment.

**Some suggestive measures for managing crop residue:** Power generation from biomass has huge potential to provide electricity for rural energy with sustainable environmental benefits. Therefore, the main constrain is the collection of left over crop residue. To collect this left over crop residue, technologies are available; however it is not economical in Indian conditions. Crop like cotton leaves, woody residue (stalks) need a different type of arrangement for collection which is not available[39].

If once crop residue would be collected then for utilization of it, there are different technologies available both at the national and international level for the valuable utilization of biomass such as thermo-chemical process and biochemical.

Crop residue management options such as burning, incorporation, surface retention and mulching, baling and removing the straw and as industrial/domestic fuel, and fodder etc while, its incorporation shows the better result for soil fertility and crop production point of view. All researchers show negative impact on soil about removing or burning the crop residue. Crop residue burning is not the suitable option for the crop residue management. There are no appropriate technologies available for managing the crop residue.

## Conclusion

Review of available literature shows that open crop residue/biomass burning causes the emissions of air pollutants such as particulate matter and gases and ultimately influence atmospheric quality and climate. Almost all researchers agreed that open burning of crop residue / biomass significantly increases the level of particulate matter, gaseous pollutants ($SO_2$, NOx, VOCs, and PAHs etc) in atmosphere. However some researchers believe that impact of crop residue/biomass burning have a minor role in climate change.

Instead of, burning of crop residue/biomass can be avoided by adopting different biochemically / thermo-chemically induced techniques. Technologies are available for harnessing energy from crop residues are direct combustion, gasification, carbonisation, ethanol production, liquefaction, bricking and pyrolysis. It will not be only reducing the atmospheric pollution and climate problem but also helpful to fulfil the energy demand with improve the economic condition of the country. Other options for harnessing energy from crop residue are incorporation, surface retention and mulching, baling and removing the straw, no tillage, fodder etc. Whereas, incorporation shows the superior result for soil fertility and crop production than other methods. Realising the impact of crop residues burning on air quality authors also initiated study for exploring more avenues to find out the facts on “Impact of crop residue burning on the ambient aerosol and soil of rural area”.

**Abbreviations:** ACRB-Agriculture crop residue burning, AOD-Aerosols optical depth, AWiFS-Advanced Wide Field Sensor, BC - Black carbon, EC - Elemental carbon, EF- Emission factor, FBCR - Field burning of crop residue, Gg- Giga gram, HVS- High volume sampler, IRS- Indian Remote Sensing Satellite, NCEP / NCAR - National Center for Environmental Protection/National Center for Atmospheric Research), NCRB - Non - crop residue burning, NMHCs- Non-methane hydrocarbons, OCRB- Open crop residual burning, OFP- Ozone forming potential, OTM- Organic tarry matter, PAHs-Polycyclic aromatic hydrocarbons, PBL- planetary boundary layer, $PM_{2.5}$-Particulate $matter_{2.5}$, PN- Particle number, RWS-Rice–wheat system, SVOCs- Semi-volatile organic compound, TC- Total carbon, Tg - Tera gram

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