JETIR.ORG ISSN: 2349-5162 | ESTD Year : 2014 | Monthly Issue
JOURNAL OF EMERGING TECHNOLOGIES AND INNOVATIVE RESEARCH (JETIR)
An International Scholarly Open Access, Peer-reviewed, Refereed Journal

A Review Paper on Burning of Crop Residue with Its Effect on Ambient Aerosol Characteristics and Environmental Health

Dr. Basant Shubhankar[1*], Kanchan Rani[1] and Dr. K. K. Singh[2]

1*. Asst. Prof., Univ. Deptt. of Chemistry, Kolhan Univ., Chaibasa, Jharkhand-831002, INDIA

1. Univ. Deptt. of I.R.P.M, T.M Bhagalpur university, Bihar-812007, INDIA.

2. Retd. Prof., Univ. Deptt. of I.R.P.M, T.M Bhagalpur university, Bihar-812007, INDIA

Abstract

The crop residue burning is an uncontrolled combustion process that is inexpensive, widespread and commonly practiced to clear the land. Some of the locations of crop residue burning are tropical forests, temperate forests, boreal forests, savanna grasslands and agricultural field after the harvest. In India, crop residue is burnt on large scale especially in the Indo-Gangatic plane in the form of agricultural wastes or crop residues like rice straw, wheat straw and sugar cane husk, In addition, north eastern region of India is also characterized as the region of crop residue burning. The burning of crop residue adds to the fertility of the soil because of the high mineral contents of the ashes. This also controls insects, diseases, and the emergence of invasive weed species. The residue burning causes nutrient and resource loss and adversely affects soil properties. The crop residue burning also affects the pedology Thus; the crop residue management is posing a serious problem in the rural areas. However the burning of crop residues may lead to considerable nutrient loss. Despite the obvious economic and practical benefits of the burning of crop residues, the environmental and health impact of this activity remains uncertain. The crop residue burning is a significant global source of greenhouse gases, chemically active gases and atmospheric aerosols that can substantially influence the atmospheric chemical composition and may modify the weather and climate. Many toxicological and epidemiological studies have established adverse impact of particulates matter and gaseous emission on the human health.

Keywords: Crop Residue; Indo-Gangatic Plane; Agriculture Waste; Burning; Nutrient Loss; Climate; Environmental Health

Introduction

The crop residue burning is an uncontrolled combustion process that is inexpensive, widespread and commonly practiced to clear the land (Jung et al., 2011). Although the burning of crop residue is widespread across the world, it is especially prevalent in the low latitude zones (Crutzen et al., 2016). Some of the locations of crop residue burning are tropical forests (Brazil, Indonesia, Colombia, Ivory Coast, Thailand, Laos, Nigeria, Philippines, Burma, and Peru), temperate forests (U.S. and Europe), boreal forests (Alaska, Canada, Siberia, and China), savanna grasslands (Africa) and agricultural field after the harvest (U.S. and Europe). In India, crop residue is burnt on large scale especially in the Indo-Gangatic plane in the form of agricultural wastes or crop residues like rice straw, wheat straw and sugar cane husk (Shan et al., 2008, Badrinath et al., 2006, Punia et al., 2008). In addition, north eastern region of India is also characterized as the region of crop residue burning (Badarinath et al., 2010). The crop residue burning is either initiated by human beings or by natural events. It is generally believed that more than 90% of crop residue burning is initiated by human beings (www.science.larc.gov.in) and this crop residue burning has increased significantly over the last century (Mittal et al., 2009). It has been estimated that out of 5613 Tg of dry mass of crop residue burnt in year 2000 globally, 2814 Tg of dry mass was attributed to open burning and the rest with bio-fuels (Ito et al., 2007).

Crop Residue Burning

After harvesting, the crop residues are burnt in situ by the farmers to speed up the crop rotation. This burning of residues also releases nutrients for the next growing season as the ashes of crop straw contains potassium (Gangwar et al., 2006, Yang et al., 2006). Therefore, the burning of crop residue adds to the fertility of the soil because of the high mineral contents of the ashes. This also controls insects, diseases, and the emergence of invasive weed species. The remaining uncollected crop residues not burnt in the field is subsequently ploughed into the soil. It also serves as a fertilizer for the next cropping season. The anaerobic decomposition of residues in soil directly affects the amount of methane released from the process. Although the soil incorporation of rice straw provides a source of nutrients for the next crop, it has also shown to be conducive to crop diseases (Mowlick et al., 2017, Shubhankar et al., 2016). This is one of the reasons why open field burning is often practiced by the farmers for disposal of crop residues.

However, Jain et al., (2014) pointed out that residue burning causes nutrient and resource loss and adversely affects soil properties. The crop residue burning also affects the pedology. The heat from burning crop residue can penetrate into the soil up to 1 cm, elevating the temperature as high as 33.8-42.2 0C. About 32-76% of the straw weight and 27-73% of nitrogen are lost in burning (Jat et al., 2009). Bacterial and fungal populations are decreased immediately and substantially only in the top 2.5 cm of the soil upon burning (Agarwal et al., 2011). Repeated burning in the field permanently diminishes the bacterial population by more than 50%, but fungi appear to recover and also decrease soil respiration. Long-term burning reduces total nitrogen and carbon, and potentially mineralized nitrogen in the 0-15 cm soil layer (Lafond et al., 2009). Thus, the crop residue management is posing a serious problem in the rural areas. The pattern of agriculture has changed now to mechanized and intensive farming from traditional. Practice of intensive farming results in multiple cropping patterns that generate the exhaustive residues and deplete the soil nutrient contents heavily; e.g. a rice-wheat sequence that yields 7 tons/ha of rice and 4 tons/ha of wheat removes more than 300 kg/ha Nitrogen (N), 30 kg/ha Phosphorus (P) and 300 kg/ha Potassium (K) from the soil (Holland et al., 2008). Though little is known about the effect of burning on nutrient loss and dynamics in the rice and wheat cropping pattern, it has been reported that 40-80% of the Nitrogen is lost as ammonia when wheat crop residue is burnt in the field (Sarkar et al., 2011, Shubhankar et al., 2016). In United Kingdom, it has been observed that the emission of ammonia declined from 20 Giga gm (Gg) N per year in 1981 to 3.3 Gg N per year in 1991, pertaining to imposed ban on the burning of crop residue (Sarkar et al., 2011). According to them, for every ton of wheat residue burnt, 2.4 kg of N was lost in New Zealand. Likewise, sulphur (S) losses from the burning of high S and low S rice-crop residues in Australia were found 60% and 40% of its content respectively (Zoi et al., 2011). About 25% of N and P, 50% of S and 75% of K uptake by cereal crops are retained in crop residues, making them viable nutrient sources (Holland et al., 2011). Therefore, crop residues are a good source of plant nutrients and are important components for the stability of the agricultural ecosystem. However, the burning of crop residues may lead to considerable nutrient loss. Despite the obvious economic and practical benefits of the burning of crop residues, the environmental and health impact of this activity remains uncertain (Zhang et al., 2011).

The agricultural practices in India have also experienced significant increasing level of farm mechanization over the last 25 years (Badrinath et al., 2006) that has increased grain production and hence crop residues. As per common agricultural practices in India, crop residues are left standing in the field after harvesting. The residues generated are utilized mainly as industrial/domestic fuel, fodder for animals, packaging, bedding, wall construction, roofing, household heating, green manuring, thatching etc. and the rest is allowed for open burning in the field only. However, in case of combine harvesting almost all the residues generated are left in the field that finally ends up into open burning. The amount of residues left over for burning and other uses differ from crop to crop and are directly related to the yield obtained. For every 4 tons of rice or wheat grain, about 6 tons of straw is produced (Thakur, 2003). In northern India, wheat straw is preferred for fodder while in South India rice straw is fed to livestock (Thakur, 2003). In India too, the crop residues are usually burnt to enable tillage and seeding machinery to work effectively. It is difficult to estimate the quantity of residue used for different uses, which varies largely from year to year and region to region and is therefore characterized by great uncertainty.

The burning of crop residues reduces the availability of straw to livestock, which is already in short supply by more than 40% in India (Thakur, 2003). Around 25 percent of the crop residues generated during the cultivation is burnt in the agricultural fields in India (Reddy et al., 2002, Shubhankar et al., 2016). The total agricultural residue production in India in year 2000 was 347 million tons, of which rice and wheat straw accounted for more than 200 million tons (Thakur, 2003) but according to Sarkar et al., (1999), the wheat and paddy cultivation accounts for nearly one-fourth of the crop residues production in India. The major contributing states are Uttar Pradesh, Madhya Pradesh, Punjab, Bihar, Maharashtra, Haryana, Gujarat, and HP. The crop residue generated from wheat and paddy cultivation in 1994 from these states is about 133 million tons (Thakur, 2003).

In the year 2000, about 78 million tons dry rice and 85 million tons wheat straw were generated in India, out of which about 17 million tons and 19 million tons respectively may end up in open field-burning (Gupta et al., 2003). As far as total biomass consumption in India is concerned, bio- fuels accounts for 93 % and forest fires contributing only 7 percent (Reddy et al., 2002). In bio-fuel segment, about 281 million tons (Mt) of fuel-wood, 62 Mt of dung-cakes, 36 Mt of agricultural residues and 39 Mt of forest biomass were consumed annually as the traditional bio fuels and about 70-80 % energy requirement in rural India is met by combustion of these traditional bio-fuels (Saud et al., 2012, Kumar et al., 2011, Reddy et al., 2002). The national average of bio-fuel mix is 56%, 21 % and 23% of fuel-wood, crop waste and dung-cake respectively (Reddy et al., 2002).

According to Sixth Five Year Plan (1980-85), India, about 1000 million tons of organic waste in the form of crop residue and about 300 to 400 million tons of animal excreta are available annually. It is estimated that if all these materials are utilized, about 70,000 million cubic meters of methane gas equivalent to about 160 million of tons of fuel-wood can be produced. This can meet nearly 50% of the rural domestic fuel requirements of the country. This total crop residue might yield approximately 6 million tons of nitrogen, 2.5 million tons of potassium and 50 million tons of compost fertilizer.

The burning of crop residues is associated with conversion of ligneous bio-mass to the fire. In recent years, the area under the open burning of crop residues has significantly increased. The agricultural wastes burning periods are often characterized by smoke hanging above and near the farmland. Therefore, the agricultural waste burning is important in the harvesting season as it causes the emissions of the harmful air pollutants, including gases and particulates matter to the atmosphere, which can cause severe impacts on human health along with regional and global climate change (Solarzano et al., 2012, Shubhankar et al., 2016).

Impact of Crop Residue Burning on aerosol characteristics

The impact of crop residue burning on air pollution and climate has been recognized in the late 1970s (Langmann et al., 2009). The crop residue burning is a significant global source of greenhouse gases (carbon dioxide and methane, etc.), chemically active gases (nitric oxide, carbon monoxide, hydrocarbons and methyl bromide) and atmospheric aerosols that can substantially influence the atmospheric chemical composition and may modify the weather and climate (Crutzen et al., 2016, Langmann et al., 2009, Shubhankar et al., 2016). It also affects the bio-geo-chemical cycling of nitrogen and carbon compounds from the soil to the atmosphere, the hydrological cycle, i.e., run off and evaporation, the reflectivity and emissivity of the land, and hence the stability of ecosystems and ecosystem biodiversity etc. Therefore, crop residue burning has both short-term and long-term impacts on the environment. Thus, the large amount of particulates and gases, including greenhouse gases emitted from burning crop residue to the atmosphere influencing the earth's atmosphere and global climate. Simmonds et al., (2005) revealed a strong correlation of crop residue burning with the emission of CO_2, CO, CH_4, H_2, O_3, CH_3Cl and aerosols.

Globally, 40 % of carbon dioxide, 38 % of tropospheric ozone, 39 % of particulate organic carbon, and more than 86 % of elemental carbon is emitted from the crop residue burning (Levine et. al, 1995). The total global emission from the crop residue burning are 2290 Tg of carbon per year as CO2, 496 Tg of CO per year, 32.2 Tg CH4 per year, 38 Tg NMHC per year, 11.5 Tg HCHO per year, 9.2 Tg of CH_3OH per year, 21.7 Tg CH_3COOH per year, and 38.3 Tg of $PM_{2.5}$ per year (Ito et al., 2004). In Asia, about 0.37 Tg of SO_2, 2.8 Tg of NO_x, 1100 Tg of CO_2, 67 Tg of CO and 3.1 Tg of CH_4 are estimated to be released annually from the open burning of the crop residue. In which crop residue burning alone contributes about 0.10 Tg of SO_2, 0.96 Tg of NOx, 379 Tg of CO_2, 23 Tg of CO, and 0.68 Tg of methane (Streets et al., 2003).

The agriculture sector in India contributed 83% of the total methane emissions in 2005; out of which about 10 % of methane were emitted from crop residue burning. While more than 80 % of the total N2O emissions were coming from agriculture sector out of which about 12% came from agriculture residues burning during the same period (Garg et al., 2006).

The field-burning of rice and wheat straw in India resulted the emissions of 102, 2138, 2.2 and 78 Gg of CH_4, CO, N_2O and NO_x respectively in 1994 that went up to 110, 2306, 2.3 and 84 Gg respectively in 2000 (Gupta et al., 2003, Gupta et al., 2004). In this estimate it was assumed that the one-fourth of the available residue is burnt in the field. According to Ministry of Environment and Forests, rice and wheat straw burning contribute about 1.24 % of N_2O and 0.56 % of CH_4 in India's net national emission of N_2O and CH_4 from all the sources in 1994 respectively.

Thus, the crop residue burning plays a vital role in the regional as well as global climate change. The atmospheric aerosols, in particular, affect the global radiation balance (Jung et. al., 2011), climate and hydrologic cycling (Akagi et al., 2011) and visibility (Tao et al., 2009). The two major chemical components of aerosols coming out from crop residue burning are black carbon and organic carbon (Reddy et al., 2002). On the global basis, the major source of carbonaceous aerosols is the crop residue burning and it is estimated to be 23-27 % of total aerosol mass concentration (Sharma, 2009). Black carbon absorbs solar radiation whereas organic carbon scatters the solar radiation. The strongest negative force is associated with regions of intense crop residue burning activities and differs from regions where the sulphate radiative force is the strongest. The global annual, mean radiative force caused by crop residue burning aerosols is estimated as 0.2 Watt/m2 (Houghtrar et al., 2001). The dust particles contained in the to particulate air pollution (Tiwary et al., 2009, Shubhankar et al., 2016). Wu et al., (2006) assessed the personal exposures to $PM_{2.5}$ emitting from agricultural burning smokes for asthmatic adults in Pullman, USA. The average personal exposure to $PM_{2.5}$ was found to be 13.8) lg/m^3, which was on average 8.00) lg/m^3 higher during the agricultural burning episodes (19.0) lg/m^3 than non-burning episodes (11.0) lg/m^3). Thus, the aerosols generated from burning adversely affect the human health especially respiratory system (Biswas et al., 2011, Dutta et al., 2014, Shubhankar et al., 2016). smoke of crop residue combustion frequently induces spontaneous convection resulting in the production of rain, but this usually evaporates before reaching the ground. The finer smoke particles are eventually widely distributed through the global troposphere; some enter the stratosphere, where they remain suspended for longer duration. In the stratosphere, they serve to scatter incoming short wave radiation, and can thus exert a cooling effect on the planetary temperature.

Impact of Crop residue burning on Human Health

Many toxicological and epidemiological studies have established adverse impact of particulates matter and gaseous emission on the human health. The effects of the aerosols that include ultrafine particles, fine particles and coarse particles on the health depend on their size. There is increasing evidence of several adverse effects of ultrafine particles on health and sometimes it can penetrate the cell membranes and pulmonary alveoli, enter into the blood and even reach the brain ((Borm et. a1., 2006; Shubhankar et al., 2016). The particulates matter can also induce inheritable mutations. Smoke, from crop residue burning, is particularly dangerous, since most of the particulates are smaller than 10 microns in size (PM10), and are easily able to travel deep into lungs and may penetrate the respiratory system beyond the larynx (Smith, 2002). Both long and short-term exposures to ambient levels of particulates matter in the air are associated with respiratory and cardiovascular illness and mortality. People with pre-existing lung and heart disease, the old and the children are particularly sensitive.

Conclusions

The ambient aerosols characteristics changed significantly due to crop residue burning after the rice and wheat crop harvesting. Therefore, in order to prevent the environmental pollution caused by burning of crop residues there is calling for sustainable management of crop residues. Crop waste burial and its compo sting may be the more efficient mechanism for crop waste management, as it controls the aerosols and gaseous emissions into the atmosphere.

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