# Chapter 2
# The Extent and Management of Crop Stubble

**Abstract** Burning of farm waste causes severe pollution of land and water on local as well as regional scales. It is estimated that burning of paddy straw results in nutrient losses viz., 3.85 million tonnes of organic carbon, 59,000 t of nitrogen, 20,000 t of phosphorus and 34,000 t of potassium. This also adversely affects the nutrient budget in the soil. It results in the emission of smoke which if added to the gases present in the air like methane, nitrogen oxide and ammonia, can cause severe atmospheric pollution. These gaseous emissions can result in health risk, aggravating asthma, chronic bronchitis and decreased lung function. Burning of crop residue also contributes indirectly to the increased ozone pollution. The chapter puts forth literature on various aspects of residue generated on the field, chemical composition of the residue, volume of pollution caused by residue burning, adverse impact of burning on human and animal health and various ways of crop stubble management.

**Keywords** Crop stubble burning · Chemical composition of residue · Health impact of stubble burning · Stubble burning and soil fertility · Crop stubble management

## 2.1 Introduction

Production and consumption activities generate pollution and waste, and atmospheric environment can absorb pollution/waste up to a limit. Agriculture is one of the important production activities and crop residue burning generates a significant amount of air pollution. Atmospheric environment can absorb this pollution in a particular geographic region given its assimilative capacity. If the burning activities remain confined within the assimilative capacity, the pollution does not create harmful effects. Therefore, in the initial stages when the production and burning activities are limited, pollution caused through these activities is not considered a problem. However, due to technological advancements in the agricultural sector,



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waste concentration has gone beyond the assimilative capacity of the environmental limit, thereby distorting the balance.

Burning of farm waste causes severe pollution of land and water on local as well as regional and global scales. 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. This also adversely affects the nutrient composition of the soil. When crop residue is burnt existing minerals present in the soil are destroyed, which adversely hampers the cultivation of the next crop. Straw carbon, nitrogen and sulphur are completely burnt and lost in the atmosphere in the process of burning. This results in the emission of smoke which when added to the gases present in the air like methane, nitrogen oxide and ammonia can cause severe atmospheric pollution. These gaseous emissions can pose health risks, aggravating asthma, chronic bronchitis and decreased lung function. Burning of crop residue also contributes indirectly to increased ozone pollution.

The chapter is organized as follows: the next section introduces the amount of crop stubble produced and the extent of this being burnt in the field. Section 2.3 presents the pollution caused by crop stubble burning, citing various discussions from the literature, followed by a section on the effects of crop stubble burning on soil fertility. Section 2.5 concentrates on the health impacts of pollution due to residue burning. The last section presents the management of crop stubble, like in situ, alternate uses of crop stubble, cost of alternate uses and end use of rice residue.

## 2.2 The Produce of Crop Stubble and Its Burning

Various studies have brought to the forefront the quantity of crop stubble generated in India and the proportion of wheat and rice stubble in the total crop stubble (Table 2.1). As per different studies, the residues of rice and wheat crops are major contributors in the total stubble loads in India. One such study by Garg (2008) estimates the contribution of rice and wheat stubble loads in the total stubble as 36 and 41 %, respectively in the year 2000, while the contribution of Punjab in the total burnt stubble of rice and wheat to be 11 and 36 %, respectively during the same time period. Table 2.2 provides the estimates of residue management practices followed in Punjab.

According to Mandal et al. (2004), the total amount of crop residue generated in India is estimated at $350 \times 10^6$ kg year$^{-1}$ of which wheat residue constitutes about 27 % and rice residue about 51 %. According to Gupta et al. (2004), the total crop residue produced in India during 2000 was 347 million tonnes, of which rice and wheat crop residues together constituted more than 200 million tonnes.

According to Sidhu and Beri (2005), total production of paddy stubble in Punjab in 2004–2005 reached 18.8 million tonnes, of which 15 million tonnes

**Table 2.1** Total quantity of crop stubble generated in India as per different studies

| Study and year | Total quantity of crop residue produced in India |
|---|---|
| Garg (2008) | 133,138 Gg |
| Mandal et al. (2004) | $350 \times 10^6$ kg year$^{-1}$ |
| Gupta et al. (2004) | 347 million tonnes (2000) |
| Agarwal et al. (2008) | 184,902 Gg |

**Table 2.2** End use of stubble by the farmers

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

*Source* Government of Punjab (2007)

were burnt in open fields. The study further quotes that 80 % of the rice harvested using combined harvester is burnt in open fields. However, according to Singh et al. (2008), around 17 million tonnes of paddy straw are produced every year in Punjab, of which 90 % are burnt in open fields.

Another study by Punia et al. (2008) attempts to estimate district-wise burnt area of agricultural residue by using remote sensing data. The total stubble burnt on the area in Punjab was found to be around 4,315.35 km$^2$ as on 15 May 2005. Among these, Amritsar had 673.99 km$^2$ of burnt area followed by Jalandhar, Ludhiana, Firozpur and Patiala districts while Roop Nagar had the least burnt area (41.36 km$^2$). During the field visit to Punjab, it was discovered that burning is done in two ways. One is partial burning which involves running of combine harvester followed by burning of small stalks and another of complete burning in which the entire field is set on fire while the latter process is mostly practiced. Table 2.3 provides a summary of various studies reporting rice residue burning practices in open field in Punjab. Both practices cause pollution but the impact is more severe in the case of complete burning. The farmers in the region resort to burning of straw due to lack of available economically viable options for managing the residue.

To conclude, although there is no unanimity in analysing the extent of residue generated and the percentage burnt in open fields. However, most of the studies in the literature are in agreement that as high as around two-thirds to three-fourths of the residue are being burnt in the case of paddy, mainly because of uneconomical options available to farmers for any alternate use of the same.

**Table 2.3** Various studies reporting rice residue burnt in open fields in Punjab

| Literature and year of study | Percentage of rice and wheat crop harvested using a combined harvester in Punjab | Dry fodder yield per hectare or aggregate production in Punjab | | Quantity of rice residue burnt in open fields in Punjab |
|---|---|---|---|---|
| | | Rice | Wheat | |
| Badarinath and Chand Kiran (2006) | 75–80 % | 6.2–11.8 t $ha^{-1}$ | 3.2–5.6 t $ha^{-1}$ | 70–80 million tonnes |
| Mandal et al. (2004) | More than 75 % | Data not available | Data not available | 10 t $ha^{-1}$ |
| Sidhu et al. (1998) | 88.6 % for rice 56.6 % for wheat | Data not available | Data not available | Varies according to different districts, the highest being for Bhatinda where all the rice stubble is burnt, followed by Faridkot at 97.6 %, Ludhiana and Sangrur at 95 %, each |
| Gupta et al. (2004) | 75 % | 78 million tonnes (2000) | 85 million tonnes (2000) | Data not available |
| Sidhu and Beri (2005) | More than 75 % | Data not available | Data not available | 80 % of the total harvested using combined harvesters |
| Badve (1991) | Data not available | 134.35 million tonnes (1983–1984) | 67.71 million tonnes (1983–1984) | Data not available |
| Venkataraman et al. (2006) | Data not available | Data not available | Data not available | 30–40 % straw burnt in Indo-Gangetic Plain (IGP) |
| Sarkar et al. (1999) | 75 % combine harvested | Data not available | Data not available | 100 % combined harvested burnt |

**Table 2.4** Residue to product ratio according to various studies

| References | RPR ratio/quantity | Reason |
|---|---|---|
| AIT-EEC (1983) | 0.416 | If only the top portion of the rice stem along with 3–5 leaves is cut, leaving the remaining in the field |
| Bhattacharya and Shrestha (1990) | 0.452 | |
| Bhattacharya et al. (1993) | 1.757 | When the rice is cut at about 2 inches from the ground |
| Vimal (1979) | 1.875 | |
| Sidhu et al. (1998) | 1.5:1 | For both the crops |
| Gadde et al. (2009) | 0.75 | |
| Gupta et al. (2004) | 1.5:1 | Every 4 t of rice or wheat grain produces about 6 t of rice or wheat straw |
| Njie (2006) | 1.25 | For rice |
| Bhattacharya et al. (1993) | 1.76 | For rice |
| Singh and Rangnekar (1986) | 1.5:1 | For both rice and wheat |
| Koopman and Koppejan (1997) | 1.757 and 0.267 | For paddy straw and rice husk respectively |
| Badarinath and Chand Kiran (2006) | (3.2–5.6 t/ha and 6.2–11.8 t /ha) | For wheat and rice respectively |
| Sidhu and Beri (2005) | 18.75 Mt | Of rice residue in the entire Punjab |

### *2.2.1 Straw/Residue to Grain Ratio*

To obtain the average amount of paddy straw generated and burnt in the state, the Residue to Product Ratio (RPR) must be known. Different studies on the subject of crop stubble in India have considered different residue/stubble to product ratio (RPR). As per these studies, the residue to product ratio (RPR) varies from 0.416 to 3.96. Table 2.4 provides the estimates of RPR obtained in various studies. The variation in the residue to product ratio is due to the overtime improvements in technology in the form of HYVs, irrigation, fertilizers, etc.[1] While estimating the quantity of straw produced, basmati rice varieties were not considered purposely as harvesting of basmati paddy is cultivated manually. Therefore, no straw is left behind for open burning in the field in the case of basmati. The principal reason for not having the practice of basmati straw being burnt is its use as feed for the animals. This also indicates that if the technology develops, making paddy straw silica free and nutritious for serving it as feed for the animals, farmers may stop burning the same, although it would also require an economical bailing system for its post combine harvest collection.

[1] Improvement in technology alone cannot explain such a large variation in RPR.

### 2.2.2 Chemical Composition of Rice and Wheat Stubble

Crop residue is not a waste but rather a useful natural resource. 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. Sidhu et al. (2007) estimated 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. When transformed into monetary values it becomes Rs. 424 $ha^{-1}$ of N, Rs. 96 $ha^{-1}$ of P and Rs. 231 $ha^{-1}$ of S, i.e., a sum equal to Rs. 751 $ha^{-1}$.

Sidhu and Beri (2005) shared their experience with managing rice residues in intensive rice-wheat cropping system in Punjab. According to them, the approximate amount of the nutrients present in the straw, which was burnt in 2003–2004 were 106, 65 and 237 thousand tonnes respectively of N, $P_2O_5$ and $K_2O$ in addition to secondary and micronutrients. Tables 2.5, 2.6, 2.7 and 2.8 show the nutrient content of rice and wheat straw and amounts removed with 1 t of straw residue and their chemical compositions.[2]

**Table 2.5** Nutrient content of paddy straw and amounts removed with one tonne of straw residue

| | N | $P_2O_5$ | $K_2O$ | S | Si |
|---|---|---|---|---|---|
| Content in straw, percent dry matter | 0.5–0.8 | 0.16–0.27 | 1.4–2.0 | 0.05–0.10 | 4–7 |
| Removal with 1 t straw, kg/ha | 5–8 | 1.6–2.7 | 14–20 | 0.5–1.0 | 40–70 |

*Source* ‘Rice straw management’; Dobermann and Fairhurst (2002)

**Table 2.6** Nutrient content in rice residue

| Rice | N | $P_2O_5$ | $K_20$ |
|---|---|---|---|
| Nutrient Content in % | 0.61 | 0.18 | 1.38 |

*Source* Mandal et al. (2004)

**Table 2.7** Moisture and other factors in rice residue

| Literature study | Moisture content in percent | C percent | N percent | LHV (lower heating value) MJ/kg | Ash percent |
|---|---|---|---|---|---|
| AIT-EEC (1983) | 27.00 | – | – | 15.10 | 16.98 |
| Strehler and Stutzle (1987) | 12–22 | 41.44 | 0.67 | 10.90 | 17.40 |
| Bhattacharya and Shrestha (1990) | 12.71 | 24.79 | – | 16.02 | 21.05 |
| Bhattacharya et al. (1993) | 12.71 | 39.84 | – | 16.02 | – |

[2] The nutrient contents will vary as per the agro-biological and soil conditions.

**Table 2.8** Chemical composition in rice and wheat straw

| Name of the crop | Organic matter | Crude protein | Crude fibre | Ash |
|---|---|---|---|---|
| | Percentage composition | | | |
| Rice straw | 82.0 | 4.0 | 37.0 | 18.0 |
| Wheat straw | – | 3.5 | – | 7.5 |

*Source* Agarwal et al. (2008)

## 2.3 Volume of Pollution Caused by Crop Stubble Burning

Open field burning of crop stubble results in the emission of many harmful gases in the atmosphere, like carbon monoxide, $N_2O$, $NO_2$, $SO_2$, $CH_4$ along with particulate matter and hydrocarbons. These trace gases have adverse implications not only on the atmosphere but also on human and animal health (Gupta and Sahai 2005; Lal 2006; Agarwal et al. 2006; Canadian Lung Association 2007). These also result in the loss of plant nutrients and thus adversely affect soil properties. It has been estimated that for the year 2000, the emission of $CH_4$, CO, $N_2O$ and $NO_2$ was 110, 2306, 2 and 84 Gg respectively, from the field-burning of rice and wheat straw (Mandal et al. 2004).

A study conducted by the National Remote Sensing Agency in Punjab reported that wheat crop residue burning contributed about 113 Gg (Giga gram = 10 billion gram) of CO, 8.6 Gg of $NO_2$, 1.33 Gg of $CH_4$, 13 Gg of $PM_{10}$ and 12 Gg of $PM_{2.5}$ during May 2005 and paddy straw/stubble burning was estimated to contribute 261 Gg of CO, 19.8 Gg of $NO_2$, 3 Gh of $CH_4$, 30 Gg of $PM_{10}$ and 28.3 Gg of $PM_{2.5}$ during October 2005 (Badarinath and Chand Kiran 2006).

The information provided by Punjab Agricultural University (PAU) to the State Environmental Council also estimated that the crop residues contained about 6.0 million tonnes of carbon that on burning could produce about 22.0 million tonnes of carbon dioxide in a short span of 15–20 days. Additionally, the smoke fumes contain particulates of partially combusted materials as soot, which become airborne and are transported downwind, especially during winters when inversion sets in. Studies conducted by the Punjab Pollution Control Board in 2006 in villages, namely, Dhanouri, Simbro and Ajnouda Kalan in the district of Patiala also indicated that CO and pollutant particulates were of major concern (PPCB 2007). CO appeared to be most critical as concentrations of 114.5 mg/m$^3$ or more were observed at 30 m distance from burning fields and 20.6 mg/m$^3$ CO was recorded at residences even 150 m away. Given that the permissible limit of CO in ambient air is 4.0 µg/m$^3$, this was a major health hazard for residents and road travellers in the area. Further, particulates were also being released in large quantities. $PM_{2.5}$ ranged between 146 and 221 µg/m$^3$ in critically affected areas and average $PM_{10}$ values were found 300 µg/m$^3$, against a permissible limit of 60 µg/m$^3$ for residential rural areas. Significant amounts (40–50 µg/m$^3$) of $NO_2$ and $NH_3$ were also recorded during burning, at residences located 200–4,000 m away from burning site, though concentration of $SO_2$ was less. Further, concentrations of organic pollutants were also found to be significantly high. The smoke was also found to be toxic due to presence of heavy metals, especially iron and zinc. Iron concentrations were in the range of 6,778–13,240 μg/m$^3$, whereas zinc concentrations were in the range of 1,021–4,854 μg/m$^3$.

One tonne of straw on burning releases 3 kg of particulate matter, 60 kg of CO, 1,460 kg of $CO_2$, 199 kg of ash and 2 kg of $SO_2$ (Gupta et al. 2004). According to Singh et al. (2008), the major pollutants that are emitted during crop residue burning are given in Table 2.9. Further, in the year 2000, around 78 million tonnes of rice and 85 million tonnes of wheat straw were generated in India of which around 17–18 million tonnes ended up being burnt in the field.

Badrinath et al. (2008) used Indian Remote Sensing Satellite (IRS-P6) Advanced Wide Field Sensor (AWFS) data during May and October 2005 for estimating the extent of burnt areas and the resulting Green House Emissions (GHG) from crop residue burning. The authors found that the emissions from wheat residue in Punjab were relatively low as compared to the paddy residue. Roughly around 75–80 % of the rice was machine harvested, leaving behind large quantities of organic matter.

Venkataraman et al. (2006) calculated the state-wise crop waste generated using crop production data for 13 different crops for India. The waste to grain ratio or residue to product ratio was used as reported in various literatures such as Koopman and Koppejan (1997), Singh and Rangnekar (1986), and Bhattacharya et al. (1993) to calculate the waste generated. Dry matter fraction and combustion efficiency specific to crop waste types were used as reported in Koopman and Koppejan (1997), Smill (1999) and Streets et al. (2003). The study finds that the estimated crop waste generated was largely from cereal straws, with the waste generation being highest in north and western India. Most of the crop land fires took place in the western Indo-Gangetic plain which reaches its peak in May and October, the harvest season of *kharif* (sown in the monsoon season) and *rabi*

**Table 2.9** Major pollutants emitted during crop residue burning

| Category | Pollutants | Source |
|---|---|---|
| Particulars | SPM ($PM_{100}$) | Incomplete combustion of in organic material, particle on burnt soil |
| | RPM ($PM_{10}$) | Condensation after combustion of gases and incomplete combustion of organic matter |
| | FPM ($PM_{2.5}$) | |
| Gases | CO | Incomplete combustion of organic matter |
| | $NO_2$ | Oxidation of $N_2$ in air at high temperature |
| | $N_2O$ | |
| | $O_3$ | Secondary pollutant, form due to Nitrogen Oxide and Hydrocarbon |
| | $CH_4$/Benzen | Incomplete combustion of organic matter |
| | PAHs | Incomplete combustion of organic matter |

*SPM* Suspended particulate matter; *PM* particulate matter; *FPM* fine particulate matter
*Source* Singh et al. (2008)

(sown in winter) crops, respectively. On an all-India basis, 18–30 % of the crop waste is burnt, but for the Gangetic plain the figure is much higher at 30–40 %. According to the findings of the study, all crop waste is burnt in the field in the states of Punjab, Uttar Pradesh and Haryana. In all these states not only the unutilized cereals namely, rice, wheat, barley, etc., and sugarcane waste are burnt in the field but waste from oilseeds, fibre crops, and pulses are also burnt. The study assumes that cereal straws and sugarcane straws are completely burnt in the field.

Venkataraman et al. (2006) found that the percentage of crop stubble in the animal feed was based on the estimated roughage in the diet and ranged from 74 to 85 % for dairy and non-dairy cattle, 50–60 % for pigs and a minor 0–5 % for sheep and goats. The state-wise cattle and livestock population for 2000–2001 in the four major states was obtained from the 1992 cattle census. Animal fodder was found mainly from the cereal straws at 85 % with the balance from pulses and oilseeds.

Another study by Sidhu and Beri (2005) focuses on the impact of wheat yield through different rice residue management practices for an 11-year period from 1993–1994 to 2003–2004. The study shows that the yield of wheat crop is 0.50 t/ha higher on an average for all the 11 years, if the rice residue is incorporated in the soil 2–3 weeks before sowing wheat than if it is burnt. This implies that there are tradeoffs, and it seems the private benefits from burning outweigh the costs associated with non-burning; implying a need for social benefit cost analysis. There are tradeoffs, and it seems the private benefits from burning outweigh the costs associated with non-burning. A social analysis may generate opposite results.

The study by Butchaiah et al. (2009), estimated a total of 22,289 Gg of paddy straw surplus production in India of which 13,915 Gg was estimated to be burnt in the field. The study makes use of the proportion of the paddy straw subject to open burning, rough rice production and straw to grain ratio to arrive at the above figure. An RPR of 0.75 was used in the study. The production of rough rice was obtained by multiplying the rice production data by a factor 1.5. The rice production data was calculated as an average of 6 year period from 1999–2000 to 2004–2005. According to the study, the amount of rice stubble burnt in the field was calculated as per the surplus rice stubble left in the fields. According to the National Biomass Resource Assessment (NBRA), 23 % of the total amount of paddy straw produced in the field is in surplus. The states of Punjab and Haryana contribute 48 % and Uttar Pradesh 14 % to the total that is subject to open field burning. This study estimates 13.92 Tg quantity of paddy straw burnt in the open fields. Furthermore, this study estimates the emission of different harmful gases and particulate matter in the air using emission factors of different gases and particulate matter in g/kg, combustion factor, which is assumed to be 0.80 for all the gases and multiplying this with the quantity of rice stubble burnt in the open fields to obtain the estimates.

Sidhu et al. (1998) undertook a survey covering 11 districts in Punjab surveying a total of 237 farmers. The results of the study indicate that about 99.5 % area of the surveyed farmers was irrigated. Farmers did not have accurate information on the quantity of rice and wheat straw produced. However information on the yields of crops in the previous years obtained from the farmers was used to calculate the quantity of rice and wheat stubble produced. Only 6 % of the farmers owned a combine but a large number of farmers used combines for rice and wheat crop harvesting and 14 % of the farmers used shredders for cutting the stubble after combine harvesting the rice. Out of the total area owned by the farmers, 75 % was under rice and 80.7 % was under the wheat crop. Out of total cropped area, 88.6 % of the rice and 56.6 % of wheat in 11 districts covered in the survey were harvested using combine harvesters and reapers. The highest area harvested by combine was around 99.4 % of rice in Ferozepore and 65.4 % of wheat in Jalandhar. Total quantity of the paddy straw for the surveyed farmers ranged from 43.8 t $farmer^{-1}$ in Jalandhar to 73.1 t $farmer^{-1}$ in Patiala district with an average of 59.2 t $farmers^{-1}$. The quantity of wheat straw ranged from 42.3 t $farmer^{-1}$ in Gurdaspur to 64.6 t $farmer^{-1}$ in Amritsar. The average land holding of the surveyed farmers in all the 11 districts was 10.26 ha with the highest average land holding being in Gurdaspur at 12.3 ha.

Out of all the 11 districts surveyed, the quantity of rice and wheat residue was highest in Sangrur at 1942.1 and 1,544.6 t, respectively followed by Patiala and Amritsar at 1,656.8 and 1,532.3 t, respectively for rice and Amritsar and Ludhiana districts at 1,291.1 and 1,205.6 t for wheat, respectively. Based on the study, on an average, for all the 11 districts surveyed in the study, 90 % of the rice stubble and 48 % of the wheat stubble was burnt. The study used the rice and wheat yields in the year 1995–1996 to calculate the proportion of rice and wheat stubble burnt and also the annual loss of N through burning of straw. Assuming that both rice and wheat straw contained 0.5 % N, the total N lost was estimated to be 85,506 t $year^{-1}$.

Open burning contributed to 25 % of black carbon, organic matter and carbon monoxide emissions, 9–13 % to $PM_{2.5}$ and $CO_2$ emissions and 1 % to $SO_2$ emissions (Venkataraman et al. 2006). Table 2.10 gives the estimates of biomass burned and emission of Aerosols and Trace gases for crop waste open burning. The crop waste burned in the fields range from 18 to 30 % and has strong regional variations.

A study by Gupta et al. (2004), estimated the emission of the following trace gases from the burning of rice and wheat residues in the years 1994 and 2000 as given in Table 2.11. Similarly an another study by Badrinath et al. (2008) indicates that nearly 5,504 $km^2$ of wheat crop area was burnt during May 2005, with the average biomass in the field after harvesting at about 5.94 t $ha^{-1}$. While for paddy about 12,685 $km^2$ of area was burnt during that period. The results of the study are summarized in Table 2.12.

According to Gadde et al. (2009), the annual contribution from crop residue burning in Asia is calculated to be 0.10 Tg of $SO_2$, 0.96 Tg of $NO_2$, 379 Tg of $CO_2$, 23 Tg of CO and 0.68 Tg of $CH_4$. Gupta et al. (2004) indicated that burning of straw also emits large amount of particulates that are composed of a wide variety of organic and inorganic species. One tonne straw on burning releases 3 particulate matter, 60 kg CO, 1,460 kg $CO_2$, 199 kg ash and 2 kg $SO_2$. These gases and aerosols consisting of carbonaceous matter have an important role to play in

**Table 2.10** National estimates of biomass burned and emission of aerosols and trace gases for crop waste open burning

| Pollutants | Crop waste burning (Emission factors Gg $year^{-1}$) | | | | |
|---|---|---|---|---|---|
| | Cereals | Sugarcane | Others | Total crop waste | Total open burning |
| Biomass Burned Tg $year^{-1}$ | 67–189 | 32–70 | 17–30 | 116–289 | 148–350 |
| BC | 55–292 | 19–49 | 12–31 | 86–372 | 102–409 |
| OC | 134–770 | 48–122 | 39–79 | 211–970 | 399–1,529 |
| OM | 287–1,250 | 97–247 | 60–143 | 444–1,639 | 663–2,303 |
| $PM_{2.5}$ | 369–1,913 | 125–289 | 78–191 | 572–2,393 | 851–3,317 |
| $CO_2$ Tg $year^{-1}$ | 102–353 | 48–131 | 25–55 | 175–539 | 224–638 |
| CO, Tg $year^{-1}$ | 6–49 | 3–18 | 2–8 | 10–74 | 13–81 |
| $SO_2$ | 27–113 | 13–42 | 7–18 | 46–172 | 66–238 |
| $NO_X$ | 168–845 | 80–313 | 42–132 | 289–1,290 | 393–1,540 |
| $CH_4$ | 181–762 | 86–283 | 45–119 | 313–1,164 | 420–1,486 |
| NMVOC | 1,055–4,430 | 500–1,644 | 263–693 | 1,818–6,767 | 2,039–7,406 |
| $NH_3$ | 87–367 | 41–136 | 22–57 | 151–560 | 189–661 |

*Source* Venkataraman et al. (2006)

**Table 2.11** Emission of trace gases from burning of rice and wheat residue

| Year | $CH_4$ | CO | $N_2O$ | $NO_X$ |
|---|---|---|---|---|
| 1994 | 102 | 2138 | 2.2 | 78 |
| 2000 | 110 | 2,305 | 2.3 | 84 |

*Source* Gupta et al. (2004)

**Table 2.12** Total emission by burning of rice and wheat crop

| Name of the crop | Total Emissions Gg | | | | |
|---|---|---|---|---|---|
| | CO | $NO_X$ | $CH_4$ | $PM_{10}$ | $PM_{2.5}$ |
| Wheat | 113 | 8.6 | 1.33 | 13 | 12 |
| Rice | 261 | 19.8 | 3 | 30 | 28.3 |

*Source* Badarinath et al. (2008)

the atmospheric chemistry and can affect regional environment that also has linkages with global climate change.

Gupta et al. (2004) in their study estimated that burning of straw raises the soil temperature up to 33.8–42.2 °C (1-cm depth). About 23–73 % of nitrogen is lost and the fungal and bacterial population are decreased immediately up to 2.5 cm depth of soil. According to a study conducted by the Department of Soils, PAU, 2006, Punjab produces around 23 million tonnes of paddy straw and 17 million tonnes of wheat straw, annually. The burning of straw raises the temperature of the soil in the top 3 inches to such a high degree that the carbon-nitrogen equilibrium in soil changes rapidly. The carbon as $CO_2$ is lost to atmosphere, while nitrogen is converted to nitrate. This leads to a loss of about 0.824 million tonnes of NPK from the soil.

The above discussed studies clearly establish that mass agricultural residue burning in the fields is seriously damaging the environment. Further, open burning of residue in the fields also leads to death of soil micro flora and fauna and may also damage nearby trees in addition to adjoining standing crops. Further, the ash left after burning is a very good absorbent and if not fixed properly, absorbs the applied weedicides, which results in decreased efficacy of herbicides.

Thus, the on-site impact of burning includes removal of a large portion of the organic material, denying the soil an opportunity to enhance its organic matter and incorporate important chemicals such as nitrogen and phosphorus, as well as, loss of useful micro flora and fauna. The off-site impacts are health related due to general air quality degradation of the region resulting in aggravation of respiratory like cough, asthma, bronchitis, eye and skin diseases. Fine particles also can aggravate chronic heart and lung diseases and have been linked to premature deaths in people already suffering from these diseases. The black soot generated during burning also results in poor visibility which could lead to increased road side incidence of accidents. It is thus essential to mitigate impacts due to the burning of agricultural waste in the open fields and its consequent effects on soil, ambient air and living organisms.

## 2.4 Effects of Crop Stubble Burning on the Fertility of the Soil

As per the Department of Agriculture of the Punjab government, the soils of Punjab are generally low in nitrogen content, low to medium in phosphorus and medium to high in potassium. The soil organic carbon in Punjab has been reduced to very low and inadequate levels due to the inadequate application of organic manures and non-recycling of crop residues. A rice-wheat sequence that yields 7 t $ha^{-1}$ of rice and 4 t $ha^{-1}$ of wheat removes more than 300 kg of nitrogen, 30 kg of phosphorus and 300 kg of potassium per hectare from the soil. Another study estimates that a 10 t $ha^{-1}$ crop yield removes 730 kg NPK from the soil.

The burning of crop stubble in open fields has adverse impact on the fertility of the soil, eroding the amount of nutrients present in the soil. Burning also kills soil borne deleterious pests and pathogens. According to the Department of Soil, Punjab Agricultural University, burning results in the soil organic carbon being lost to the atmosphere as $CO_2$, nitrogen equilibrium in the soil changes rapidly and nitrogen is converted to nitrate. As a result, there is a loss of 0.824 million tonnes of NPK from the soil.

According to Gupta et al. (2004), 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.

**Table 2.13** Nutrient losses due to burning of rice residues in Punjab, 2001–2002

| Nutrient | Concentration in straw (g/kg) | Percentage lost in burning | Loss (kg/ha) |
|---|---|---|---|
| C | 400 | 100 | 2,400 |
| N | 6.5 | 90 | 35 |
| P | 2.1 | 25 | 3.2 |
| K | 17.5 | 20 | 21 |
| S | 0.75 | 60 | 2.7 |

*Source* Singh et al. (2008)

As per Mandal et al. (2004), burning of rice and wheat residue results in the loss of about 80 % of nitrogen, 25 % of phosphorus, 21 % of potassium and 4–60 % of sulphur from the soil. It also kills soil-borne deleterious pests and pathogens.

Burning also results in the loss of important nutrients present in the crop stubble. About 25 % of nitrogen and phosphorus, 50 % of sulphur and 75 % of potassium uptake by cereal crops are retained in crop residues, making them viable nutrient sources (Gadde et al. 2009). According to Singh et al. (2008), nutrient loss due to burning of rice residues in Punjab in 2001–2002 was 2,400 kg of carbon, 35 kg of nitrogen, 3.2 kg of phosphorus, 21 kg of potassium and 2.7 kg of sulphur in 1 ha. While loss of carbon and nitrogen was almost total, the loss of phosphorus, potassium and sulphur was partial (around 20–60 %) as described in Table 2.13.

### *2.4.1 International Experience*

In the United Kingdom a ban on the burning of crop stubble resulted in a decline in the emission of ammonia from 20 Gg nitrogen per year in 1981 to 3.3 Gg nitrogen per year in 1991. According to Gupta and Sahai (2005), 40–80 % of the wheat crop residue nitrogen is lost as ammonia when it is burnt. Similarly, Samra et al. (2003) observed in the case of New Zealand, a ton of wheat residue burnt releases 2.4 kg of nitrogen. Likewise, sulphur (S) losses from the burning of high sulphur and low sulphur rice crop residues in Australia were 60 and 40 % of sulphur content, respectively. Thus, burning may lead to considerable nutrient loss also. According to a study by Heard and Hay (2006), on an average, 98 to 100 % of the nitrogen, 24 % of the phosphorus and 35 % of the potassium and 75 % of the sulphur was lost through burning in the province of Manitoba in Western Canada.

## 2.5 Health Impacts of Pollution Due to Residue Burning

According to Gadde et al. (2009), open burning of crop stubble results in the emissions of harmful chemicals like polychlorinated dibenzo-p-dioxins, polycyclic aromatic hydrocarbons (PAH’s) and polychlorinated dibenzofurans (PCDFs) referred to as dioxins. These air pollutants have toxicological properties and are potential carcinogens. Furthermore, the release of carbon dioxide in the atmosphere due to crop stubble burning results in the depletion of the oxygen layer in the natural environment causing green house effect. Burning of crop waste also has adverse implications on the health of milk producing animals. Air pollution can result in the death of animals, as the high levels of $CO_2$ and CO in the blood can convert normal haemoglobin into deadly hemoglobin. There can also be a potential decrease in the yield of the milk producing animals.

Burning of crop stubble has severe adverse impacts especially for those people suffering from respiratory disease, cardiovascular disease. Pregnant women and small children are also likely to suffer from the smoke produced due to stubble burning. Inhaling of fine particulate matter of less than $PM_{2.5}$ μg triggers asthma and can even aggravate symptoms of bronchial attack. According to Singh et al. (2008), more than 60 % of the population in Punjab live in the rice growing areas and is exposed to air pollution due to burning of rice stubbles. As per the same study, medical records of the civil hospital of Jira, in the rice-wheat belt showed a 10 % increase in the number of patients within 20–25 days of the burning period every season.

## 2.6 Management of Crop Stubble

### *2.6.1 In Situ Incorporation*

Though the crop stubble has various alternate uses but the area which is harvested by using combine harvester is left behind with scattered residues which farmers find difficult to remove from the fields. After combine harvesting farmers are left with only two alternatives, either in-situ incorporation of the remains of crop stubble or open burning in the field. Farmers don't prefer in-situ incorporation as the stubble takes time to decompose in the soil that may adversely affect the wheat productivity because of time loss in sowing. As per the Department of Agriculture of the Punjab government, less than 1 % of the farmers incorporate crop stubble because of more tillage operations required in the case of incorporation than of post burning.

As per Singh et al. (1996), if the rice residue is incorporated immediately before sowing the wheat crop, then the crop yield is significantly lowered because of immobilization of inorganic nitrogen and its adverse effect due to nitrogen deficiency. However, in few studies it was found that wheat yield lowered in the first 1–3 years when the rice stubble was incorporated in the soil 30 days prior to sowing of wheat crop, mainly because of the immobilization of soil nitrogen in presence of crop residues with wide C/N ratio. However, in later years rice stubble incorporation did not affect wheat crop yield.

According to another study by Sidhu and Beri (2005), the best alternative available to burning of rice residue is in-situ incorporation. The results of a

6-year study period showed that if the rice residue is incorporated in the soil 10, 20 or 40 days before sowing the wheat crop, then the productivity of the subsequent wheat and rice crops is not adversely affected. Paddy straw incorporated in wheat did not show a residual effect on the succeeding rice crop. Several reports show similar rice and wheat yields under different residual management practices such as burning, removal, or incorporation (Walia et al. 1995; Singh et al. 1996, Singh and Singh 2001). Singh et al. (1996) reported that the incorporation of paddy straw 3 weeks before sowing significantly increased wheat yield on clay loam soil but not on sandy loam soil. Studies conducted by Sharma et al. (1985, 1987) showed no adverse effect of straw incorporation on the grain yield of wheat and the following rice.

As per a study by Singh et al. (1996), the incorporation of rice residue 3 weeks before sowing the wheat crop actually increased the wheat yield only on clay loam soil and not on sandy loam soil. This study further shows that incorporation of crop residues, increased organic carbon by 14–29 %.

According to Verma and Bhagat (1992), incorporation of rice residue 30 days before sowing of wheat crop resulted in lower wheat yields as compared to the wheat yields when the rice residue is burnt or removed from the fields. Furthermore the incorporation of rice stubble in the soil has favorable impact on the soil's physical, chemical and biological properties such as pH, organic carbon, water holding capacity and bulk density of the soil.

The study conducted by Sidhu and Beri (2005) in Ludhiana over an 11-year period to measure the impact of different residue management practices on soil fertility of a sandy loamy soil is revealed in Table 2.14.

As per Mandal et al. (2004), the effect of different crop residue management practices on the physiochemical properties of the soil for 7 years are given in Table 2.16. Paddy straw was incorporated in the soil. From Table 2.15 it is quite clear that, in-situ incorporation of the rice residue is the best crop residue management practice followed by removal of rice residue from the fields and burning for retaining the nutrients in the soil.

### *2.6.2 Alternative Uses of Crop Stubble*

The crop stubble produced during the harvesting of rice and wheat crops can be used for various alternative uses if it is not burnt. These include use of crop stubble as fodder for animals, use of crop stubble for the generation of electricity, use as input in the paper/pulp industry etc. The use of rice residue as fodder for animals is relatively low in Punjab as compared to the wheat stubble. This is because the rice residue is high in silica content which in turn is not good for animal health. However, very often the crop stubble is treated with urea before it is fed to the animals. As per Badve (1991), treating crop residues with 4 % urea and 45–50 % moisture improves the nutritive value by increasing digestibility, palatability and crude protein content.

**Table 2.14** Effect of crop residue management on organic C and total N content of soil under the rice-wheat cropping system

| References | Types of crop residues | Duration of study (years) | Residue management | Organic C (%) | Total N (%) |
|---|---|---|---|---|---|
| Beri et al. (1995) | Rice straw in wheat | 10 | Removal | 0.38 | 0.051 |
| | | | Burned | 0.43 | 0.055 |
| | | | Incorporated | 0.47 | 0.056 |
| Sharma et al. (1987) | Rice straw in wheat and wheat straw in rice | 6 | Removed | 1.15 | 0.144 |
| | | | Incorporated | 1.31 | 0.159 |
| Singh et al. (2004) | Wheat straw green manure, and wheat straw + green manure (GM) in rice | 6 | Removed | 0.38 | – |
| | | | Incorporated | 0.49 | – |
| | | | GM | 0.41 | – |
| | | | Straw | 0.47 | – |

**Table 2.15** Impact of different residue management practices in Ludhiana (Punjab)

| Soil property | Crop residue management | | |
|---|---|---|---|
| | Burned | Removed | Incorporated |
| Total P (mg $kg^{-1}$) | 390 | 420 | 612 |
| Total K (g $kg^{-1}$) | 17.1 | 15.4 | 18.1 |
| Olsen P (mg $kg^{-1}$) | 14.4 | 17.2 | 20.5 |
| Available K (mg $kg^{-1}$) | 58 | 45 | 52 |
| Available S (mg $kg^{-1}$) | 34 | 55 | 61 |

*Source* Sidhu and Beri (2005)

**Table 2.16** The effect of different crop residue management practices on the soil

| Physiochemical properties of the soil | Residues | | |
|---|---|---|---|
| | Incorporated | Removed | Burnt |
| pH | 7.7 | 7.6 | 7.6 |
| EC ($dSm^{-1}$) | 0.18 | 0.13 | 0.13 |
| Organic C (%) | 0.75 | 0.59 | 0.69 |
| Available N (kg $ha^{-1}$) | 154 | 139 | 143 |
| Available P (kg $ha^{-1}$) | 45 | 38 | 32 |
| Available K (kg $ha^{-1}$) | 85 | 56 | 77 |
| Total N (kg $ha^{-1}$) | 2,501 | 2,002 | 1,725 |
| Total P (kg $ha^{-1}$) | 1,346 | 924 | 858 |
| Total K (kg $ha^{-1}$) | 40,480 | 34,540 | 38,280 |

*Source* Mandal et al. (2004)

According to Venkataraman et al. (2006), the use of crop waste as fodder was seen high in states where the crop waste generation was high. Also the crop waste is not transported over long distances because of its low bulk density and high transportation costs. The use of crop waste for domestic cooking ranged from 36 to 67 $Tg^{-1}$ with a 95 % confidence interval uncertainty of 86 % (at 95 % confidence interval). The use of crop waste as thatching material was only minor at 2 % of the generated paddy straw.

### *2.6.3 Cost of Alternate Uses*

The use of crop stubble as fodder for animals or for the generation of electricity requires various on-farm and off-farm operations, including collection, packing, handling, transportation, storage and pre feeding processing. For collection of straw after combining, imported conventional field bailers are available.

According to Owen and Jayasuriya (1989) the bulky nature of the straw makes them expensive to transport even for short distances. According to a study by Gupta et al. (2004), the bailing cost is around Rs. 800 $ha^{-1}$. The total cost of operation, including bailing, collection, transportation up to a 5-km distance and stacking is Rs. 1,300 $ha^{-1}$ or Rs. 650 $t^{-1}$ of straw. However, the problem with these bailers is that they recover only 25–30 % of the potential straw yield after combining, depending upon the height of plant harvested by combines. According to a study by Owen and Jayasuriya (1989), the use of crop stubble in bio-thermal plants has not been very successful. This is mainly due to the lack of any technical and economic feasibility studies, lack of assured markets for processed by-products, shortage of funds to undertake research and development, etc.

### *2.6.4 End Use of Rice Residue in Different Districts of Punjab*

In Bhatinda district the paddy straw was totally burnt with no other end use. In Amritsar district the use of rice residue for other uses apart from burning is the maximum with 18.2 % being used for fodder, 19.6 % being sold in the market and 9.4 % given to poor landless families. In the Gurdaspur district, 20.6 % of the rice residue is provided to poor landless families, 12.9 % used as fodder almost the rest of the rice stubble burnt. In Patiala district 11.7 % of the rice stubble is used as fodder for animals and 5.9 % sold in the market and the rest 81.5 % being burnt. In the Ferozepore district, 18.8 % of the rice stubble is provided to poor landless families, 8.8 % is incorporated in the soil and the rest 68.1 % is burnt. It can be observed that except Ferozepore district, the rice stubble is hardly incorporated in the soil in rest of the state.

However for the wheat crop, a significant proportion of the stubble is used as fodder for animals, in 7 districts of Amritsar, Bhatinda, Faridkot, Gurdaspur, Kapoorthala, Ludhiana and Sangrur, the average being 47 %. Only in the Gurdaspur district 2.4 % of the wheat stubble is incorporated in the soil.

From the literature it is clear that farmers seldom incorporate rice and wheat stubble in the soil. Wheat stubble is used as fodder for animals, but the usage of rice stubble as fodder for animals is not much. The paper mills procured rice-straw at a rate of Rs. 200–300 $t^{-1}$. The wheat straw was generally sold after making chaff. The price of chaff varied between Rs. 2,500 and 3,700 $ha^{-1}$.

According to Singh and Singh (2001), incorporation of cereal crop residues immediately before sowing/transplanting into wheat/rice significantly lowers crop yield because of immobilization of inorganic N and its adverse effect due to N deficiency. However, in few studies, wheat yields were lower during the first one to three years of paddy straw incorporation 30 days prior to wheat planting, but in later years straw incorporation did not affect wheat yields adversely.

The incorporation of the straw in the soil has a favorable effect on the soil's physical, chemical and biological properties such as Ph, organic carbon, water holding capacity and bulk density of the soil. On a long-term basis it has been seen that it increases the availability of zinc, copper, iron and manganese content in the soil and it also prevents the leaching of nitrates. By increasing organic carbon it increases bacteria and fungi in the soil. In a rice-wheat rotation, Beri et al. (1992), Sidhu et al. (1995) observed that soil treated with crop residues held 5–10 times more aerobic bacteria and 1.5–11 times more fungi than soil from which residues were either burnt or removed. Due to increase in microbial population, the activity of soil enzymes responsible for conversion of unavailable to available form of nutrients also increases. Mulching with paddy straw has been shown to have a favorable effect on the yield of maize, soybean and sugarcane crops. It also results in substantial savings in irrigation and fertilizers. It is reported to add 36 kg/ha of nitrogen and 4.8 kg/ha of phosphorous leading to savings of 15–20 % of total fertilizer use.

In cognizance of this fact, Department of Farm Power and Machinery, Punjab Agricultural University has developed Happy Seeder machine to solve the problem of straw management in collaboration with CSIRO Land and Water Resources, Australia, under financial assistance from Australian Centre for International Agricultural Research (ACIAR). The machine is compact and lightweight and is tractor mounted. It consists of two separate units, a straw management unit and a sowing unit. The Happy Seeder can handle the paddy straw and do the sowing job without any tillage. It consists of straw cutting and chopping unit and a sowing drill combined in one machine. It sows the seed of next crop in one operational pass of the field, while retaining the rice residue as surface mulch.

Though there are some apprehensions such as increased chances of rodents, etc., the many advantages of adopting the technology are as under:

1. Allows sowing of wheat even when stubble is standing in the field. This is finally incorporated into the soil.
2. Mulching effect of straw causes weed suppression.

3. Possibility of saving first irrigation by sowing wheat in residual moisture.
4. Leads to conservation of water due to moisture retention. There is no loss of nutrients.

This environment friendly technology will prove a boon to the farmer community and the state can help them in making provision of this tool for improving soil health and environment for sustainable agriculture. The Happy Seeder machine has low adoption because of its high price and less popularity among the farmers. The state although is providing subsidy on Happy Seeder but it needs to make the farmers educated on the various benefits of Happy Seeder machine. The state needs to undertake demonstration of this technology to make the farmers understanding this technology appropriately. There is also need to encourage farmers adopting Happy Seeder by developing cooperatives or farmers groups and provide the facility to the small and marginal farmers through custom hiring basis.

## 2.7 Summary of the Chapter

The chapter puts forth literature on various aspects of residue generated on the field, chemical composition of the residue, volume of pollution caused by residue burning, adverse impact of burning on human and animal health and various ways of crop stubble management. Burning of farm waste causes severe pollution of land and water on local as well as regional scale. It is estimated that burning of paddy straw results in nutrient losses viz., 3.85 million tonnes of organic carbon, 59,000 t of nitrogen, 20,000 t of phosphorus and 34,000 t of potassium. This also adversely affects the nutrient budget in the soil. Straw carbon, nitrogen and sulphur are completely burnt and lost to the atmosphere in the process of burning. It results in the emission of smoke which if added to the gases present in the air like methane, nitrogen oxide and ammonia, can cause severe atmospheric pollution. These gaseous emissions can result in health risk, aggravating asthma, chronic bronchitis and decreased lung function. Burning of crop residue also contributes indirectly to the increased ozone pollution. It has adverse consequences on the quality of soil. When the crop residue is burnt the existing minerals present in the soil get destroyed which adversely hampers the cultivation of the next crop.

Crop residue burning is one among the many sources of air pollution. The on-field impact of burning includes removal of a large portion of the organic material, denying the soil an opportunity to enhance its organic matter and incorporate important chemicals such as nitrogen and phosphorus, as well as, loss of useful micro flora and fauna. The off-field impacts are related to human health due to general air quality degradation resulting in aggravation of respiratory (like cough, asthma, bronchitis), eye and skin diseases. Fine particles also can aggravate chronic heart and lung diseases and have been linked to premature deaths in people already suffering from these diseases. The black soot generated during burning also results in poor visibility which could lead to increased road side incidences of accident. It is thus essential to mitigate impacts due to the burning of agricultural waste in the open fields and its consequent effects on soil, ambient air and living organisms.



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