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A Review on Stubble Burning in Indo - Gangetic Plains, its Impacts and Management Strategies

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Abstract: ***Every year during April - May and October - November, a large amount of crop residue is burnt in the Indo - Gangetic plains, particularly in Punjab, Haryana, and Uttar Pradesh. This has resulted in severe air contamination in these states, besides harming other neighboring areas. This paper talks about the history and causes of stubble burning, its current status in India, its ill impacts on the environment, agricultural productivity, and human health, and various alternatives and suitable practices for its management. In between all these topics, the paper tries to establish a relationship between Stubble burning and different environmental & human health indicators. The data is mostly based on secondary sources, collected from various published studies, reports, surveys, and data published by various government & other agencies such as IARI, NFHS, World Bank reports, etc. The study found that the emission of harmful gases because of burning is several times higher than the recommendations of CPCB and Who. It has also been observed that contrary to many reports, stubble burning has increased in the past couple of years, reversing the trend seen between 2016 - 2019. In the end, the paper talks about the management of stubble burnings and suitable alternatives along with a few suggestions for a way forward.***

Keywords: Stubble, Burning, Emissions, Impacts, Management

1. Introduction

Food is necessary for the survival of human beings, most of which comes from agricultural fields. But production of these foodgrains also means the generation of inedible crop residues, most of which are usually set aflame, thus releasing various harmful emissions (Sharma et al.2010). Reportedly, stubble burning constitutes 25% of total biomass burning around the world (Yadav and Devi, 2019). As per **Street et al. (2003)** 730 MT of crop residues are burnt in Asia annually.

India has always been a primarily agrarian country, whose contribution made it the richest country in the world for a major part of human history (Economic Survey 2020). Indo - Gangetic plains in particular with their extremely fertile soil have remained the backbone of Indian agriculture. Its importance can be understood from the fact that it constitutes about 20% of India's total land area, in which about 40% of the country's population resides. This area produces 41% of food grains in India, in particular cereals (**Abdurahman et al., 2020).**

However, the tradition of agriculture suffered under the British Raj, under whom the major focus was on the production of commercial crops rather than food grains. Consequently, when we gained Independence, we had to import grains to fulfill the needs of the country's population. But things changed in the 1960s when the Green Revolution revolutionized Indian agricultural practices. Changes were so significant that when compared to productions in 1960 - 61, the production capacity of wheat and rice in 2018 - 19 increased by more than 89% and 70%, respectively (**Agricultural Statistics, 2019**). States falling in Indo - Gangetic plains (IGP), particularly the states of Punjab, Haryana, and western Uttar Pradesh (U. P.) benefited the most. However, it also changed the traditional cropping system in these areas to rice - wheat rotation system. According to Sharma et al.2010, this wheat - rice cropping system covers 12 million hectares out of the total 66 million hectares of land area of IGP. Currently, India is the second largest producer of wheat and rice in the world, besides being the biggest exporter of rice as well (**FAOSTAT, 2019**).

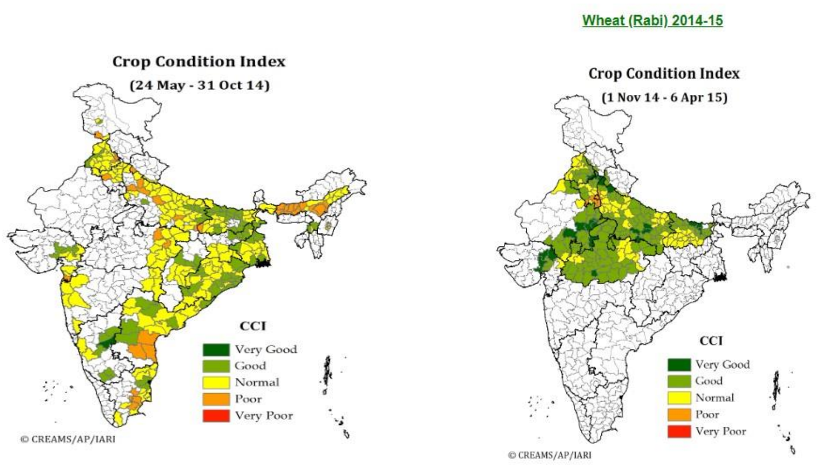

Figure 1: Rice and wheat growing regions of India (*Source:* CREAMS - IARI*)*

Since wheat and rice form the staple diet of most Indians, rice - wheat cropping system is very profitable for farmers. Profit further increases when we consider that even the central government provides a healthy minimum support price (MSP) for wheat and rice, besides providing subsidies for electricity, water, and chemical fertilizers, like urea, DAP, etc. Therefore, eyeing maximum profits, farmers in these regions began to wheat and rice even more, going as far as cultivating paddy crops 2 times a year, which led to groundwater scarcity in the region (**Chand, 1999; Rahi, 2011**).

The other problem with these crops is that they generate lots of crop residues, e. g., for every kg of rice, almost 1.5 kg of residues is generated (**Gadde et al., 2009**; **Gupta et al., 2004; Sahai et al., 2007**). According to **Batra, 2017**, 1 acre of a rice field generates 2.5 to 3 Mt of paddy straw. Earlier these residues were few enough to be removed by hand and were usually used as fodder and bedding material for cattle, but with the arrival of combine harvesters in the 1980s, a large amount of almost 15cm tall residues were now being left in the field (**Pratika and Sandhu, 2020),** ultimately prompting farmers to take the route of stubble burning beginning in 1986 (**Sarkar et al, 2005; Kaskaoutis et al., 2014**).

Since groundwater resources had become severely scarce because of paddy cultivation, in 2009, the Punjab government had to legislate the **Punjab Preservation of Subsoil Water Act (PPSWA, 2009).** This law mandated the late transplanting of paddy, only after June 20^{th}, which meant a very small time frame of 2 - 3 weeks was now available to farmers between harvesting paddy and transplanting wheat crops. This compelled more and more farmers to burn stubble, thus making stubble - burning cases worse than ever.

This is problematic because the burning of stubble emits greenhouse gases (GHGs) like CH_4, CO, CO_2, NOx, Sox, etc. (Gadde et al., 2009**).** This can severely pollute the atmosphere, critically impact human health and mortality (Sharma et al.2010) and cause global warming. It is the third major source of air pollution behind vehicular and industrial emissions (**Krishna et al.2011; Gurjar et al., 2016**). It is also known to decrease the soil and overall agricultural productivity by burning up essential nutrients and killing important microbes (**Jain et al., 2014**). It can impact human health in various ways, ranging from eye irritation to lung cancer and even death (**Arbex et al., 2004**) with children being the most susceptible population **(Awasthi et al., 2010**).

Consequently, several crop management strategies have been discovered and implemented, and several legislative steps have been taken as well, including banning stubble burning by the National Green Tribunal (NGT) in 2015 and making it a criminal offense under section 188 of IPC, although in 2021 it was decriminalized.

Despite all of this, stubble burning is still taking place on a large scale. Some major reasons for that include -

- It is a cheap, quick, and efficient way to get rid of stubble for an ordinary farmer.
- Mechanised harvesters leaving behind 1 - 2 feet tall stubbles, and a shortage of agricultural labourers.
- Small time frame available to farmers between harvesting of paddy and sowing of wheat, especially after the legislation of PPSWA, 2009.
- Planting of crops like rice and wheat that generate lots of stubbles.
- Sowing high - duration paddy varieties like PUSA - 44.
- Very high installation costs of other technological alternatives such as happy seeders, rotavators, straw balers, etc.
- Paddy residues have higher silica content, making them unfit for fodder usage.
- Loose implementation of government policies.

Emission Composition

Rice straw has a very high fly ash content (18.67%), high silica content (74.67%), fixed carbon (15.86%), CaO (3.01%), MgO (1.75%), Na_2O (0.96%) and K_2O (12.30%) (**Binod et al., 2010).** In general, burning of crop residues emits particulate matter (PM_{10} and $PM_{2.5}$), GHGs like methane, carbon mono - and di - oxides, NOx, Sox, volatile organic compounds (VOCs), etc (**Gadde et al., 2009; Badrinath et al., 2006).** They are also reported to generate aerosols, mainly organic carbon and black carbon (**Ryu et al., 2004).** Besides them, it also comprises ions and inorganic salts (**Ryu et al., 2004; Saarikoski et al., 2006).**

Studies say that residue - burning emissions are composed of 70% CO_2, 7% CO, 0.66% CH_4, and 2.09% N_20 (**NPMCR, 2014**; **Gupta et al., 2004).** Besides them, they are also composed of NPK which forms harmful oxides in the presence of heat and oxygen (**PPCB, 2018**). **Jain et al., 2014** report that CO_2 forms 91.6% of total emissions while CO forms 66% of the remaining 8.4% of emissions.

A kg of dry rice straw is reported to emit 1460 gm CO_2, 1.20gm CH_4, 0.07gm N_2O, 34.7gm CO, 3.10gm NOx, 2.0gm SO_2, and 12.95gm $PM_{2.5}$ (Satyendra et al., 2013). As per **Gupta et al., 2004,** a tonne of straw is capable of emitting 3kg PM, 60kg CO, 1460 kg CO_2, 199kg ash, and 2kg SO_2. These are huge numbers when we consider that India produced 129.66 Mt of rice in 2021 - 22 (**Ministry of Agriculture and Farmers Welfare, 2022)** which generated 194.49 Mt of straw.

Current Status of stubble burning in India

Based on the data released by the Ministry of Agriculture and Farmers Welfare (MoAg&FW), we get the following data.

Table 1: Data of Rice Production and the Consequent Stubble Generation in India

Year	Rice Production (Mt)	Stubble generation (Mt)
2011 - 12	105.30	157.95
2012 - 13	105.20	157.80
2013 - 14	106.70	160.05
2014 - 15	105.5	158.25
2015 - 16	104.4	156.60
2016 - 17	110.2	165.30
2017 - 18	94.5	141.75
2018 - 19	115.63	173.445
2019 - 20	117.94	176.91
2020 - 21	120.00	180.00
2021 - 22	129.66	194.49
2022 - 23	135.76	203.64

Stubble burning has remained a major source of air pollution in Northern India. It is considered the third biggest source of air pollution behind industrial and vehicular emissions (**Gurjar et al., 2016; Krishna et al.2011**). Since the 1990s, several North Indian cities including the national capital Delhi have been featured in the list of the world's most polluted cities regularly (**Sikarwar and Rani, 2020**). Stubble burning has been a major cause for that, as it is observed that burning periods along with the accumulated industrial and vehicular emissions in combination with the stable meteorological conditions of post - monsoon periods, are the reason behind heavy haze formation and degradation of air quality in India (**Ghosh et al., 2019; Khwaja et al., 2012).** According to the data released by SAFAR (System of Air Quality and Weather Forecasting and Research), in between November 9 - November 13, 2021, the total share of stubble burning in Delhi's $PM_{2.5}$ amounted to 30%.

According to the National Policy on Management of Crop Residues (**NPMCR, 2014**), the top 3 states that generate most of the crop residues are the U. P., Punjab, and Maharashtra. The same document reports that states where the majority of stubble - burning events are observed include U. P., Punjab, West Bengal, Andhra Pradesh, and Haryana. Out of the total stubble - burning events that take place, 22% include wheat crops and 34% include rice crops (**Indian Agricultural Research Institute (IARI, 2012), 2012; Singh et al., 2018). Jain et al., 2014** reported rice stubbles to constitute 40% of total stubble - burning events. **IARI, 2012** reports that 14 out of the total 22Mt rice residues are burnt, 48% of them taking place in Punjab and Haryana alone.

Table 2: Estimated Number of Stubble Burning Events in Punjab and Haryana

Year	Stubble - burning events in Punjab and Haryana
2016	99, 946
2017	68, 094
2018	65, 938
2019	50, 028
2020	80, 699
2021	86, 806
2022	68.094
2023	50, 319

(*Sources: NASA VIIRS375m Satellite data, Stubble Burning Data by Punjab government, Various Newspaper Reports)*

Inefficient paddy cultivation has been a reason why despite having the largest rice growing area in the world, India can only produce less than 25% of global rice. However, the Ministry of Environment, Forest and Climate Change (**MoEFCC**, 2021), stated in October 2021 that because of central and state governments' interventions, the total paddy area in U. P., Punjab, and Haryana came down by 7.72% as compared to 2020.

As evidenced from various studies and available satellite data, stubble burning in India steadily increased between 2000 - 2016, however owing to institutional interventions these events were reduced significantly by 2019. But since 2020, a reversal of this trend has been seen and 2021 turned out to be a year that saw the highest number of stubble burning events since 2016 (**TOI, 2021**). However, thanks to efforts such as the State Action Plan launched by the Punjab Government, and various measures adopted by the Central government and various pollution control boards, environmental agencies, NGOs, etc, the numbers are seeing decreasing trends (PIB Report, Oct.2023).

2. Effects of stubble burning

1) Impact on Air Quality

Biomass burning is a major source of air pollution, and an estimated 90% of it happens because of anthropogenic activities (**Kaskaoutis et al., 2014**). According to a source appointment study conducted on PM2.5 by the **World Bank (WB)** in **2001**, biomass burning contributed 9 - 28%, 23 - 29%, 24%, and 37 - 70% of total $Pm_{2.5}$ in Delhi, Mumbai, Chandigarh, and Kolkata respectively.

Stubble burning emits significant amounts of gaseous pollutants and aerosols, resulting in the degradation of air quality (**Kaskaoutis et al., 2014**). As mentioned previously, stubble burning is the third major source of air pollution in many countries (**Krishna et al.2011; Gurjar et al., 2016**).63Mt of stubble burning is reported to produce 4.8Mt of CO_2 equivalent to GHGs (**Sahai et al., 2011**). The major emissions include CO_2, CO, CH_4, NOx, Sox, particulate matter, organic compounds, hydrocarbons, etc (**Gupta et al., 2004; Sahai et al., 2011; Jain et al., 2014; Gadde et al., 2009; Ryu et al., 2004).**

Because of vehicular and industrial emissions already present in the air, the air quality in urban areas is impacted more (**Mishra, 2019).** As per various studies, these emissions in combination with the post - meteorological conditions significantly degrade North India's air quality (**Banerjee et al., 2011; Guttikunda and Gurjar, 2012; Krishan et al., 2019; Resmi et al., 2020**). This period also sees the formation of smog which has been linked to stubble burning (**Ghosh et al., 2019; Khwaja et al., 2012**). According to the Energy Policy Institute, University of Chicago (**EPIC, 2020**), between 1998 and 2016, IGP witnessed a 65% increase in air pollution. The study also found the PM concentrations to be twice more than any other region on the Earth.

$PM_{2.5}$ concentrations in Delhi were reported to increase by 78% and 43% during rice and wheat stubble - burning periods respectively (**Awasthi et al., 2010**). **Singh (2015**) reported an hourly increase of 300mg/m^3 in PM_{10} levels during burning periods. Based on the air quality index (**AQI**) data released by the Central Pollution Control Board, the air quality of most Indian cities falls in the poor category which turns severe during stubble burning in November.50% of India's population has to breathe in air that has PM concentrations much higher than WHO limits (**Liu et al.2018; Ghosh et al., 2019; TERI).**

As per the latest studies, a worrisome trend has been observed that stubble burning not only degrades the air quality of its source region but also affects other areas (**Dumka et al., 2013; Kaskaoutis et al., 2014). Sarkar et al., 2018** reported that the air quality of even some of the southern cities has been affected because of the stubble burning in the IGP. **Masud et al. (2016)** even found pollution from Bangladesh significantly contributing to PM_{10} concentrations in Ghazipur in India.

2) Effect on Soil Productivity

It has been found that stubble burning decreases the productivity of soil, as it burns the essential mineral nutrients (**Singh et al., 2018**) and by raising the soil temperature to almost 42 C, kills important microbes up to a depth of 2.5 cm (**Jain et al., 2014**). As per **Mandal et al., 2004**, stubble burning causes more nutrient loss than any other method of stubble management.

In general crop residues contain 80%N, 25% P, 50% S, and 20% K (**NPMCR, 2014).** Production of 7t/ha of rice consumes more than 300kg N, 30kg P, and 300kg K from the soil per hectare (**Poriccha et al., 2021**). Hence, by burning an acre of a field that generates 2.5 - 3.0 Mt of stubble, we are losing 32kg Urea, 5.5 kg DAP, and 51kg Potash manure (**Batra, 2017**). As per **NPMCR, 2014,** burning 1 tonne of rice stubble destroys 5.5kg N, 2.3kg P, and 300kg K per hectare. **Jain et al., 2014** reported that burning rice stubble leads to a loss of 0.445 Mt of NPK. **Parmod et al.2015,** estimated that there are losses of 59 Mn kg N, 20Mn kg P, and 34Mn kg K.

A study carried out by **Valzano et al. (1997)** reported a 50% decrease in sorptivity, final infiltration rate, and hydraulic conductivity in the burnt plots when compared to adjacent unburnt plots. This study proves that stubble burning directly affects the hydraulic properties of soil, thus reducing its productivity.

3) Effects on Agricultural productivity

Various reports have pointed to the theory that stubble burning can influence agricultural productivity and thus in turn affect food production (**Abdurahman et al., 2020**). Stubble burning can directly influence agricultural productivity via air pollution in the form of injury to the leaves, grains, and assimilation of heavy metals (**Ghosh et al., 2019).** In addition, air pollution can also damage plants via acid rain (**Augustaitis et al., 2010**). Stubble burning can also impact agricultural productivity by impacting soil productivity as discussed in the previous section.

In addition, stubble burning can create suitable conditions for diseases and pests to grow, thus impacting agricultural productivity indirectly (**Ghosh et al., 2019**). The emissions from stubble burning, such as VOCs and NOx can react in the presence of oxygen and sunlight to generate ground - level ozone which can penetrate and destroy leaves and impact plant metabolism. Even in India, there have been several reports of low wheat and soybean production because of this phenomenon (**Sharma et al., 2019**).

4) Effects on Climate

Release of GHGs, PM, etc from stubble burning leads to global warming, and in the long run, climate change. Reportedly, agriculture contributes about 17 - 32% of total GHG emissions around the world (Bellarby et al., 2008) . Stubble burning generates hydrocarbons and reactive nitrogen emissions, which react to form tropospheric ozone (**IPCC, 2006**).

Burning of stubble produces a smoke of aerosols that can have a warming or cooling effect, with a net effect of positive radiative forcing (**Andreae et al., 2005).** According to **Berringer et al. (2003),** fire reduces the albedo of the land surface for several areas causing warming of the area.

5) Effects on human health and mortality

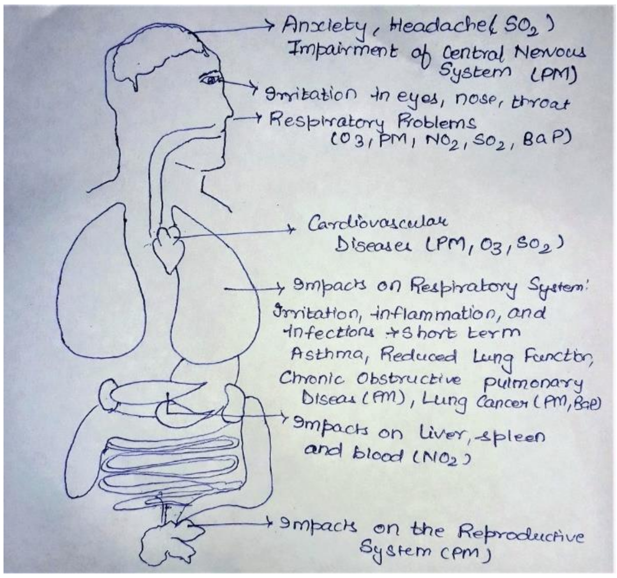

Figure 2: Various Health Conditions Possible Due to Unregulated Stubble Burning and Consequent Air Pollution

Several studies have revealed that air pollution caused by stubble burning can impact human health, especially children, pregnant women, elderly people, and people with pre - existing medical conditions (**Saggu et al., 2018**). Various respiratory disorders reported to be caused due to air pollution include asthma, bronchial asthma, bronchitis, acute respiratory infection (ARI), emphysema, lung capacity loss, and even lung cancer. (**Arbex et al., 2004; Ghosh et al., 2019**). Besides them, those exposed to stubble smoke often experience eye and lung irritation, eye - watering, conjunctival hyperemia, etc (**Kumar et al., 2015; Arbex et al., 2004**). Other possible diseases that can be caused include tuberculosis, stroke, cardiac arrest, etc (**Saggu et al., 2018).**

According to the Punjab Pollution Control Board (**PPCB, 2018),** a few pollutants emitted via stubble burning cause serious diseases, e. g., Sulphur and Nitrogen oxides can impact skin, blood, and respiratory activities and may even lead to lung cancer. Similarly, CO_2 can lead to irritation in the eyes, while if CO combines with red blood cells (RBCs) then it can reduce the efficiency of blood to take up oxygen (**Kumar et al., 2015**).

Out of all the pollutants, $PM_{2.5}$ has the most deleterious effect as it can penetrate through the trachea and get incorporated into the bloodstream (**Ghosh et al., 2019**). **TERI** reports a 4 times increase in $PM_{2.5}$ concentration during stubble - burning periods. This is important because $PM_{2.5}$ pollution causes 21% of the total deaths in South Asia (**Ghosh et al., 2019**). **NFHS - 4** data revealed that people residing closer to sources of stubble burning were more infected with acute respiratory infection (ARI) than people living farther away.

As per **TERI** report, youngest (aged 10 - 18 years old) and eldest (40 - 60 years old) people are more impacted. In general, females show more decline (15 - 18%) in lung function than males who show a decline of 10 - 14%. Also, people with high and low body mass index (B. M. I.) are more impacted (**Gupta et al., 2017**). Higher respiratory rates in children have been cited as a major reason why they are more susceptible when compared to an average adult (**Awasthi et al., 2010**). The report also suggests a higher probability of children staying outdoors during afternoons as another reason for the same.

6) Mortality

The Energy and Resources Institute (2019) reported that air pollution led to 5 million deaths in South Asia in 2012, which accounts for 22% of total deaths. South Asia is the part of the world where the highest number of premature deaths have been taking place. In India alone, 600, 000 people are dying prematurely every year (**Lelieveld et al., 2015; Ghude et al., 2016).**

What's unsettling is that **Liu et al. (2018), report** that 50% of the Indian population is forced to breathe in the air with very high $PM_{2.5}$ levels, while 49% don't have access to good healthcare facilities. **Kapil, 2019** reported that the average life expectancy of inhabitants of IGP was 7 years lower than people living in other parts of India. The average life expectancy of Delhi residents is reported to go down by 6.4 years (**Ghude et al., 2016**). As estimated by **EPIC (2020) ,** the life expectancy of Delhi residents can increase by 6 years if **NAAQS** limits are followed and 9 years if **WHO** standards are followed.

7) Economic impacts

From the discussions above it is pretty easy to conclude that the economy of the whole world is impacted because of the ill impacts of stubble burning. **World Bank (2016)** reported that in 2013 global economic loss owing to air pollution amounted to 225 billion dollars, most of which came from developing countries owing to their technological limitations in managing air pollution. **Ghosh et al., 2019** reported the global economic loss to be as much as 5 trillion dollars. Indian government stated that air pollution management and welfare cost 14 billion dollars annually (**Kumar et al., 2015**).

Stubble burning causes loss of nutrients and microbes, to compensate which farmers have to spend lots of money. This also hikes food prices, causing overall inflation and increasing poverty in the nation. Besides, because of the health impacts caused by stubble burning, people are compelled to bear the expenses of healthcare facilities. **Chakrobarthy et al., (2019)** state that health damages because of air pollution annually cost 30 billion dollars.76 million rupees are spent alone on stubble burning - induced air pollution (**Kumar et al., 2015**). Poor air quality reduces visibility and causes sickness, negatively impacting the productivity of workers (Sharma et al.2010). All these factors can also impact the tourism sector. It is documented that tourist inflow to Delhi decreased by 25 - 30% percent owing to air pollution (**Abdurahman et al., 2020).**

Management Strategies

1) In situ incorporation of stubble into the soil

Integrating rice stubble in the soil is one of the very effective ways to manage crop stubble, sometimes asserted to be even the best management strategy (**Sindhu and Beri, 2005).** Reportedly, the incorporation of soil stubble preserves more nutrients than the removal of stubble or burning it (**Mandal et al., 2004).** As per a study conducted by **Singh et al., 2018,** wheat production increased by 14 - 29% if rice stubble was incorporated into the soil 3 weeks prior to the sowing of wheat. However, wheat yield was found to be low if paddy straw was added immediately before sowing the wheat seeds**.** This was attributed to the stubble leading to the arrest of nitrogen in the soil leading to a nitrogen deficit.

Many machines are now available that can help incorporate stubble into the soil -

- Straw baler – It collects the paddy straw from the field and makes bales of straw in compact form. A stubble shaver is used to harvest the stubble from base levels and then the lining operation is performed by a rake machine.
- Paddy straw chopper - It chops the paddy straw into small pieces and spreads it in the field, which can then be incorporated into the field with plowing. It can be incorporated in a wet/irrigated field using a rotavator or disc harrow and decomposed with time. Then, wheat sowing is done 2 - 3 weeks later with no zero till drill. Also, dry mixing of chopped stubbles can be done directly via moldboard plowing.
- Happy seeder - It can not only harvest the crop and chop the straw; it can also mulch the chopped straw and sow the wheat seeds. However, there are issues with its operation. It can generate weeds, and because of the presence of straw in the soil, nitrogen becomes immobile leading to nitrogen deficiency, ultimately leading to low wheat yields. Also, this process requires manpower, which is neither cheap nor readily available, and in its operation, energy and petroleum are also consumed, making it too expensive for an average farmer.
- PUSA Bio decomposer - Farmers generally don't favor stubble incorporation into the soil as stubble really takes a long time to degrade. To solve this problem, scientists at **ICAR, IARI** have developed a microbial solution in the form of tablets, popularly called PUSA Biodecomposer containing 7 strains of fungi in a pack of 4 tablets costing Rs.20. At the cost of Rs.1000/acre (**Reddy et al., 2020**) , it can help degrade the stubble in merely 25 days (**Bhatnagar, 2020**). According to the Ministry of Environment, Forest and Climate Change (**PIB, 7th April 2022**), Punjab, Haryana, U. P. and N. C. T. of Delhi have applied it on a total area of 978, 713 acres, which is equivalent to managing 2.4 MnT of straw in this year alone.

2) Crop Diversification

Based on our recent experiences in the IGP, it is evident that the rice - wheat cropping system is an unsuitable and unsustainable cropping for the area. Hence, crop diversification is a great alternative. Less water - intensive and more resistant crops such as millet, moong, potato, vegetables, etc provide a great variety of options to choose from. (Intensive Agriculture, Oct - Dec, 2021). It helps maintain soil fertility, moisture, and nutrition (**Batra, 2017**).

3) Use of short - duration paddy varieties

A major reason for stubble burning is the cropping of long - duration paddy varieties. As reported by **Reddy et al., (2020)** , harvesting of short - duration paddy varieties, such as Pusa

Basmati - 1509 developed by **ICAR, IARI**, and other short - duration paddy varieties such as PR - 121, PR - 122, PR - 124, PR - 126 and PR - 115 developed by **Punjab Agricultural University (PAU)** take 20 - 40 days less than long duration paddy varieties such as Peeli Pusa and Dogar Pusa.

4) Mushroom Farming

Residues of rice, wheat, and bagasse are excellent sources of substrate in mushroom production, as per **Gottipati et al. (2021).** High - nutrition value foods like Oyster Mushrooms grow well on stubble (**Intensive Agriculture, April - June, 2020**). However, despite its huge potential, only 0.03% of stubble is used in Mushroom production in Inda (**Gupta et al., 2017**).

5) Composting

Ramasanta et al. (2017) reported that agriculture stubble is rich in nutrients and improves the productivity of the soil. As per **Gummert et al., 2020**, composting is generally conducted in 2 stages - anaerobic and aerobic, each process lasting for 40 days. Windrow composting is another process that via the use of a windrow turner, enhances the aeration to speed up composting process. This type of compost was also found to be richer in nutrients and especially good for vegetables. Crop residues can also be composted with other organic materials, such as animal manure, by simply packing them into piles or pits for a long time (**Misra et al., 2003**).

There has been a reported improvement in crop yield by 4 - 9% when stubble is used as a compost (**Sood, 2013**). However, it does have a few drawbacks, such as the undesirable presence of immobilized residual nitrogen that can decrease yields. Besides, composting can also create conditions suitable for rodent and pest infestation.

6) Mulching

Soil can be covered with stubble to reduce evaporation, stop erosion, control unwanted weed growth, etc. This technique is specifically suitable for farmers who grow rice after rice, as placing straw from early rice as mulch ensures that the soil is moist enough to allow late rice transplantation (**Peeyush et al., 2011**) . With a reduced or no - tillage system, preserving the stubble as a mulch becomes easier, as by holding it onto the field, we don't have to remove or add it till tillage (**Poriccha et al., 2021**). Tillage mulching is a common method to reduce erosion on low - soil lands. Stubble can also be used as mucus non - flooded crops. However, mulching is not commonly adopted, because to do it, stubble has to be removed first and then returned after planting (**Unger et al., 1991**). Consequently, it is rarely carried out in conventional rice - wheat fields of IGP (**Zaman et al., 1995**).

7) Biochar Production

Biochar is a fine, carbon - rich, porous substance produced via thermo - chemical conversion of biomass at temperatures between 350 - 700 C with little or no oxygen (**Jyothsna, 2019**). Biochar can be generated from stubble via pyrolysis (**Ravindra et al., 2018**). It can be used for a range of purposes, including soil sequestration and conditioning (**Ravindra et al., 2018**), thus, improving nutrient and microbial carries, and improving overall soil health. It can also be used as an immobilizing agent for toxic metal remediation, a catalyst for industrial purposes, a food supplement to improve animal health, etc (**Huang et al., 2021**).

8) Energy Generation

Pellets - Stubble can be converted into pellets for power generation (**Batra, 2017**). It will not only reduce India's import bills but also has the potential to generate 500 jobs during pellet plants' construction, and thereafter generate 200, 000 permanent jobs across the whole process from collection of stubbles to generation of power (**Purohit and Chaturvedi, 2016**). But since it emits harmful gases, it is not an environmentally sustainable way (**Batra, 2017**).

Bioenergy - As per **Shaffie (2016)** energy can be generated from stubble via combustion, gasification, methanation, etc. Energy can be generated by either cofiring it with another furl or direct combustion of straw (**Jenkins et al., 1998**). Its by - products are fly ash and bottom ash which can be trapped and used as blends to manufacture construction materials (**Kumar et al., 2015**). Direct combustion can also be done via gasification, in which straw is gasified by steam to generate a gas - fuel mix of N_2, H_2, CO_2, and CO which is further combusted to generate electricity (**Poriccha et al., 2021**).

Biogas **-** Using anaerobic digestion, we can produce biogas from stubble (**Sun et al., 2016**). Besides biogas, it also produces solid and liquid organic manure, which can be used as organic fertilizer for plants (**Sun et al., 2016**). While the U. P., Maharashtra, and Punjab report the highest biomass generation, Punjab generates the highest amount of biomass energy in India (**Moonmoon et al., 2014**). As per the Ministry of New and Renewable Energy (MNRE), 2018, biomass contributes about 11.5% of total renewable energy generation.

Biofuel - Lately, biofuel generation using crop residues has been gaining traction (**Singh et al., 2018**). Straw is simply heated at high temperatures to produce gas, from which we extract gases like CH_4, CO_2, etc to produce oil. This oil can then be used in vehicles (**Batra, 2017**). Cellulose - based ethanol is one commonly used biofuel that can be prepared via enzymatic breakdown of polysaccharides of agricultural residues, followed by fermentation (**Priya and Bisaria, 1998; Kishore et al., 2004**).

Considering that first - generation biofuels such as wood and grains can lead to food crisis (**Abdurahman et al., 2020**), stubble is a better alternative as it has high lingo - cellulosic mass, enough abundance and much lesser usage (**Hiloidhari et al., 2014**). Biofuels have the potential to fulfill 17% of India's energy demands (**Hiloidhari et al., 2014**).

9) Other uses

Fodder - While wheat stubble has been traditionally used as fodder, owing to its high nutritious value and digestibility, rice stubbles are unsuitable for the same because of their high silica content and lower nutritious value (**Binod et al., 2010; Na et al., 2014**).

Application of residue pulp - Stubble can be pulped chemically or mechanically to produce various products such as papers, cardboard, etc. It solves the problem of the felling of trees, while simultaneously utilizing the stubble. However, mechanical pulping is better suited as chemical pumping gives a lower yield and produces a black liquor that can pollute water bodies (**Singh et al., 2018**). It can also be used to produce disposable utensils equivalent to grade III craft papers specified in IS 1397: 1990 (**Sain et al., 2021**). However, technical and financial limitations in countries like India are the reason why this can't be realized on a large scale.

Bioplastics and Bio packaging materials - Waste rice straw contains a high amount of cellulose (32 - 47%), hemicellulose (19 - 27%), and lignin (5 - 24%) (**Saha, 2003**). These components can be used to produce bioplastics and biodegradable packaging materials, which will help solve the twin problems of plastic and stubble burning.

As per **Zhang et al. (2017),** stubble can be used in the production of *bio lubricants and nano - silica*. This nano - silica can then be used to produce solar cells, cosmetics, nanomedicines, etc (**Zhang et al., 2016**). Stubble can even produce various types *of concrete and bricks* (**Liu et al., 2018**). A study reported that concrete produced from stubble has better compressive and bending strength, besides being more durable (**Bories et al., 2015**).

Institutional interventions

In India, **MoEFCC** is the central ministry, under which **CPCB** and its state subsidiaries, form the core regulating body for air pollution management in India. In 2000, the Delhi government mandated that public vehicles should only use CNG as a fuel (**Foster and Kumar, 2011**). A remediation plan initiated in 2006 by CPCB, reported that half of the industrialized cities are critically polluted (**Ghosh et al., 2019**).

In 2009, following the reports of unprecedented decline in groundwater levels, the Punjab government was compelled to roll out the **Punjab Preservation of Subsoil Water Act (PPSW), 2009**. But because of this law, farmers began to burn way more residues than ever owing to the very small time window available between paddy harvest and wheat cropping in November (**Kant et al., 2022**).

Ever since stubble burning became one important driver of air pollution, it came into the focus of these bodies, along with other institutions such as courts. Consequently, in **2014 central** government had to draft a **National Policy for Management of Crop Residues (NPMCR, 2014).** The policy besides talking about awareness programs and policy formulation, aims to control stubble burning using stubble management practices such as in - situ corporation, crop diversification, bioenergy, pulp usage, mushroom cultivation, etc.

In **2015** to combat the menace of stubble burning, **NGT (National Green Tribunal)** banned the practice and it was declared a criminal offence under the **Air Act, 1981**. However, it had to be decriminalized following the 2021 farmers' protests. In **2016,** the Delhi High Court ordered the states of U. P., Punjab, and Haryana to formulate effective policies to curb this practice. This resulted in the enactment of stringent laws including heavy fines to combat the burning.

In **2018,** a **central scheme for the promotion of agricultural mechanization** was initiated, in which machinery is provided to the farmers at up to 80% subsidies. In **2019, the** government launched the **National Clean Air Programme (NCAP)** which was to be implemented in 5 years, however, its final version is yet to be published (**Poriccha et al., 2021**). Also in **2019, the Supreme Court** asked the government to provide an incentive of Rs.2400 per acre to farmers for stubble management.

In **August 2021,** a statutory **Commission for Air Quality Management (CAQM)** For NCR and adjoining areas was launched. CAQM came up with an action plan for stubble management using management practices, monitoring, an effective plan to reduce stubble generation and even banning stubble burning (**PIB, 09th Dec.2021**).

Way forward

It is obvious that this has been due to the unsustainable rice - wheat cropping system that stubble burning became such a big problem. Hence, there's a need **to diversify the staple diet of the Indian population**, which besides solving the stubble problem will also prove more nutritive. This also necessitates **crop diversification in agriculture**. Also, there's a need to **adopt short - duration paddy varieties** that can be harvested earlier, thus providing more time window for farmers to manage stubble.

At the institutional level, there's a need to generate **more awareness** and **educate farmers** about various stubble management practices. There is a need **to take stubble management to grassroots levels and** invest more in **capacity building and research**. A **marketplace for stubble** needs to be established, **and industries** that can utilize stubble should be **legislatively compelled** to use crop residues as a priority. There's a need for **effective implementation** of laws and policies. Also, **accessibility to good healthcare facilities** needs to be ensured so that mortality can be controlled. In the end, **international collaboration and coordination** are also required, given that stubble - burning impacts don't know national boundaries.

3. Conclusion

Undoubtedly, the rice - wheat cropping system in the heydays of the green revolution was the need of a country struggling to feed its population, but as evidenced with passing time, this cropping system has only proved unsustainable for India. The massive amount of crop residues that they generate is still so high that because of their burning, the entire IGP is forced to heave its lungs with extremely polluted air. Stubble burning besides polluting the air, is also known to decrease the soil and agricultural productivity, which in turn impacts overall food production causing price hikes, thus impacting the overall economic development of the nation. Stubble burning is also known to negatively impact human health and cause large - scale mortality. It compels people to spend on healthcare facilities, thus increasing poverty.

Stubble burning appears more chaotic when we consider that it can be utilized in so many ways, including in situ incorporation, composting and mulching, production of papers and cardboard, packaging materials, energy generation, etc. Institutions have tried to curb this practice by legislating various laws and promoting sustainable agricultural practices and mechanization. However poor implementation of laws, inefficient and unsystematic awareness programs, and high prices of other stubble management practices have so far resulted in very low effectiveness of these interventions.

In so many ways can stubble be used to increase farmers' income, meet energy demands, and in the economic development of a country, besides helping save the environment with its applications. But by burning the stubble, we are missing out on all these opportunities and are only harming ourselves. Hence there's a need to take stubble management practices to grassroots levels by conducting efficient awareness programmes and investing in more research and capacity building. This is important because stubble management will ultimately benefit the whole country, and improve India's reputation on the global stage.

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