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Crop Residue Burning: Cheaper Than Any Other Option

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Crop residue burning is a recurring environmental issue in northern India, particularly in the rice–wheat cropping system. Large volumes of paddy and wheat residues are generated after harvest, and farmers often resort to open burning due to labour shortages, high costs of mechanical removal, limited storage space, and a short window between successive crops. Mechanized harvesting further aggravates the problem by leaving large amounts of loose straw in the fields. Although burning is a quick and inexpensive solution, it releases harmful pollutants such as particulate matter, greenhouse gases, and toxic gases, leading to severe air pollution episodes that affect both rural and urban populations. The practice also depletes soil organic carbon, disrupts nutrient cycling, and reduces microbial activity, negatively impacting soil health and crop productivity. Beyond environmental damage, crop residue burning poses significant economic and health costs, including increased disease burden and productivity losses. The article discusses various in-situ and ex-situ management options, existing policy frameworks, and technological interventions aimed at reducing residue burning and promoting sustainable agricultural practices.

Key Words: Crop residue burning, Stubble burning, Rice-wheat system, Air pollution, Soil health, In-situ and ex-situ management, Sustainable agriculture, India

Introduction

Every winter, northern India experiences severe air pollution largely driven by crop residue burning, which adds to emissions from traffic and industry. Intensified rice–wheat cultivation generates large volumes of post-harvest residue that are costly and time-consuming to manage mechanically, making open burning the fastest and cheapest option for farmers. This practice is driven not by negligence but by economic constraints and acute time pressure, as the interval between rice harvesting and wheat sowing is often less than three weeks, further reduced by groundwater conservation policies such as the Subsoil Water Acts of 2009. Smoke from these fires spreads far beyond agricultural fields, degrading urban air quality and posing serious public health risks. A United Nations report presented at COP30 in November 2025 identified India as a major hotspot for methane emissions from crop residue burning, estimating that nearly 100 million tonnes of residue are burned annually, with about 70% of these fires concentrated in Delhi, Punjab, Haryana, Uttar Pradesh, and Rajasthan, particularly in Punjab and Haryana.

Crop residue or stubble burning?

The leftover material that remains in the field after a crop is harvested is referred as stubble or crop residue. In simple terms, it includes all parts of the plant other than the thing that is sold and consumed. Figure 1 shows how different crops contribute to total crop residue generation in India. Together, rice and wheat account for more than half of all crop residues, highlighting their importance in any targeted crop residue management strategy.

Crop residue burning refers to a practice in which farmers deliberately set fire to leftover straw, stalks, and stubble to quickly clear fields for the next cropping cycle. This practice releases harmful pollutants into the atmosphere, including carbon dioxide (CO_2), carbon monoxide (CO), nitrous oxide (N_2O), volatile organic compounds (VOCs), and fine particulate matter such as PM2.5 and PM10. Modern satellite systems like VIIRS and Sentinel-2 are now used to monitor and track these agricultural fires.

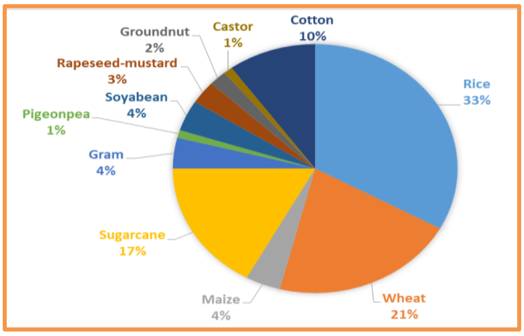

Fig 1: Percentage (%) of dry biomass share from different crop residue in India (Jain *et al.*, 2018)

Why do farmers burn crop residue or stubble?

Farmers often burn stubble not out of choice, but out of compulsion. The major reasons includes:

- **Labour scarcity:** With fewer workers available, wages rise sharply and manual removal of crop residue has become too expensive. Burning, by contrast, costs almost nothing.
- **Shift to mechanization:** Combine harvesters, although, allow timely harvesting, leave behind 20-30 cm tall stubble and up to 9 tons of loose straw per hectare, making field preparation difficult (Dutta *et al.*, 2022).
- **Short window between two successive crops:** After harvesting rice, they have only a short window i.e., only 7-10 days for basmati and 15-20 days for traditional high yielding rice, to prepare fields and sow wheat (Sahai *et al.*, 2011).
- **Management of weed and pest:** Many farmers believe burning helps control weeds, pests, and diseases, improving soil conditions by trimming the weed and pathogen load for the next crop.
- **Problem in decomposition:** Rice residue decomposes slowly due to its low nitrogen content, i.e. high carbon-to-nitrogen ratio, and dry soil conditions after harvest. (Goswami *et al.*, 2020)
- **Decline of use in domestic sector:** Traditional uses of paddy straw, such as animal feed or thatching mud houses, have declined because of high silica content (8% on dry matter basis) and expansion of public housing projects (Bhattacharyya *et al.*, 2021).
- **Storage problem:** The bulky and fluffy nature of rice residue makes storage difficult, the space most farmers do not have (Sidhu *et al.*, 2015).

Impacts of crop residue or stubble burning

Environmental impacts:

- **Air pollution:** When crop residue is burned, dense smoke is released, degrading air quality and turning a farming solution into a serious public health concern. Air quality is assessed using the Air Quality Index (AQI), which indicates how safe the air is to breathe. The EPA calculates the AQI based on five major pollutants: ground-level ozone, particulate matter (PM2.5 and PM10), carbon monoxide, sulfur dioxide, and nitrogen dioxide. The AQI is classified into six categories ranging from Good (0–50) to Severe (401–500) (Machado, 2017).
- **Impact on carbon stock and nutrient dynamics of soil:** Repeated residue burning disrupts the soil's carbon-to-nitrogen (C:N) ratio, causing significant nitrogen loss from the top 15 cm of soil (Gupta et al., 2004). It also releases about 3.86 MT of soil organic carbon annually, weakening soil structure, reducing nutrient and moisture retention, and increasing vulnerability to degradation (Jat et al., 2016).
- **Impact on soil health and productivity:** The intense heat generated during residue burning raises soil temperatures to 33.8–43°C, severely affecting the top 2.5–3.5 cm of soil. This heat can reduce beneficial bacteria and fungi by up to 50%, leading to lower soil fertility and reduced future crop yields (Gupta et al., 2004).

Economic impacts

- **Health costs:** Long-term exposure can lead to severe diseases including tuberculosis, strokes, lung cancer, cardiac issues, and chronic respiratory diseases such as asthma, Chronic Obstructive Pulmonary Disease (COPD), emphysema, and bronchitis (Ghosh *et al.*, 2019).
- **Productivity loss:** Declining soil fertility leads to reduced crop yields, affecting farmers' incomes and the agricultural economy. These productivity losses ripple through the economy, costing India around INR 5000 million each year (Bimbraw, 2019).
- **Mortality rates:** Pandey et al. (2021) revealed that 1·67 million (95% uncertainty interval 1·42-1·92) deaths were attributable to air pollution in India in 2019, accounting for 17·8% (15·8-19·5) of the total deaths in the country.
- **Economic development:** The cumulative impact of air pollution cost India's economy around 4.5 to 7.7% of its GDP in 2018, with projections indicating a potential rise to about 15% by 2060 (The Energy and Resources Institute [TERI], 2019).

Management options

In-situ residue management

- In-situ crop residue management focuses on managing crop leftovers directly on the farm. Instead of burning residue, farmers either spread it on the soil surface as mulch or mix it into the soil, allowing it to decompose naturally.

✓ 'Straw incorporation': residue is kept in the field and let it decompose chemically

✓ 'Straw mulching': residue is mixed and sowing can be done simultaneously

- A range of machinery has made in-situ management more feasible, including paddy straw choppers/ mulchers, rotavators, reversible mould board plough, Happy Seeders, Combine harvesters with Super SMS for incorporation of paddy straw into the soil.

Ex-situ residue management

- **Utilisation as livestock fodder:** Rice straw can be used as livestock fodder during periods of green fodder scarcity. Although its low nutritional value and high silica content limit digestibility, physical, chemical, and biological pre-treatments improve palatability and nutrient availability, making it a more sustainable feed option.
- **Paper Production:** Utilisation of crop residues such as rice and wheat straw by agro-based industries, including the pulp and paper sector, has been identified as an important mitigation pathway to reduce open-field residue burning and its associated environmental impacts (The Energy and Resources Institute ([TERI], 2019).
- **Bedding Material for Livestock:** Paddy straw is widely used as bedding material in cattle sheds, particularly during winter, a practice common in southern India and increasingly adopted in northern regions.
- **Compost Preparation:** On a per-hectare basis, paddy straw can be converted into approximately 3-4 tonnes of compost or farmyard manure equivalent through on-farm decomposition (ICAR, 2012).
- **Energy generation:** Surplus rice straw can be used alone or co-fired with coal in power plants to produce electricity.
- **Mushroom cultivation:** Mushroom cultivation offers additional income opportunities; from just one kilogram of paddy straw, farmers can harvest approximately 120–150 grams of mushrooms (Kumar *et al.*, 2015).

Environment laws, policy frameworks by Government of India

- The Indian Constitution provides the foundation for environmental protection through Articles 48A and 51A(g), which underpin several environmental legislations aimed at controlling anthropogenic pollution. Legal instruments such as the Air (Prevention and Control of Pollution) Act, 1981 and the Environment (Protection) Act, 1986, along with administrative measures like the imposition of Section 144 of the Civil Procedure Code, have been used to restrict the burning of paddy straw (Datta, 2020).

- Strict bans on crop residue burning have been enforced by the National Green Tribunal in states such as Punjab, Haryana, and Rajasthan, with fines up to Rs. 15,000 on violators.
- The Department of Agriculture, Cooperation & Farmers' Welfare (DAC&FW) allocated Rs. 21.29 Crores for a project to ICAR in 2018-19. This project is executed by ICAR-ATARIs through 60 KVKs across Punjab, Haryana, Delhi, and UP. Conducted awareness Campaigns and Mobilization, Capacity Building and Training for farmers about alternative residue management technologies and motivate them to celebrate Baisakhi as "No Crop Residue Burning Day" (Singh *et al.*, 2019).

Future thrust/Recommendations

- Wider adoption of resource-conservation technologies such as zero tillage, residue retention, integrated input management, high-tech seeding, and SMS technology is essential.
- Training and demonstration campaigns by public and private institutions should continue to build confidence in these technologies in rural areas.
- Promoting schemes to encourage farmers to grow basmati rice and start breeding programme to develop variety low in Si content.
- Custom hiring centres and rental-based machinery use can make advanced equipment accessible to small farmers.
- Regulated access to water and electricity in agriculture and setting up air-quality monitoring labs.
- Weekend and holiday periods should be targeted for intensified residue management efforts, particularly during peak burning seasons i.e. 25 October to 15 November.
- Engaging college students through the "Each One, Teach Ten" approach and empowering Panchayati Raj institutions to monitor residue burning can further strengthen community-driven change.
- Future research should prioritize in-situ field measurements across diverse agroclimatic zones and crop types.
- India's Panchayati Raj system may offer a cost-effective avenue for improving data collection. Gram Pradhans, elected village heads, could be tasked with reporting seasonal CRB, creating a localized, systematic mechanism.

Conclusion

Crop residue burning in northern India is not a result of farmer negligence but is a consequence of economic pressure, labour shortages, mechanized harvesting, and a short window between rice harvesting and wheat sowing. While burning provides a quick and low-cost solution, it leads to serious environmental, health, and economic consequences. There are many better alternatives to burning, including in-situ methods like mulching and straw incorporation, and ex-situ uses such as composting, livestock bedding, paper making, energy generation, and mushroom cultivation. Government policies, laws, and awareness programs have helped, but stronger implementation and farmer-friendly support systems like providing affordable machinery, training, and community-level monitoring can improve adoption. A combined efforts of farmers, government institutions, and local bodies is essential to reduce stubble burning and promote sustainable and environment-friendly agriculture in India.

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