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Stubble Burning in Punjab: Its Environmental Concern and Sustainable Alternatives

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ABSTRACT

Punjab, India's agrarian heartland, faces a critical environmental challenge due to post-harvest stubble burning of paddy crops. This practice, while convenient for field clearance, releases substantial greenhouse gases (CO_2, CO, CH_4) and hazardous particulate matter (PM2.5/PM10), severely degrading air quality across northern India and contributing to Delhi's annual smog crisis. Our study reveals a 48.5% reduction in burning incidents (71,159 in 2021 to 36,663 in 2023), demonstrating progress through policy interventions, though persistent hotspots like Sangrur district remain. The research highlights the multidimensional impacts of stubble burning: soil nutrient depletion (90% nitrogen loss), reduced microbial activity, and serious public health consequences including respiratory illnesses. We evaluate sustainable alternatives including in-situ solutions (Happy Seeder technology, PUSA decomposer) and ex-situ utilization (bioenergy production, industrial applications). Government initiatives have successfully managed 15.86 million tons of residue (2023), with strategies scaling to 19.52 million tons (2024 projection). Key challenges include high machinery costs for smallholders and underdeveloped residue supply chains. The paper concludes with policy recommendations emphasizing subsidized technology access, farmer awareness programs, and strengthened market linkages to transform agricultural waste into economic resources while achieving environmental and climate objectives. This transition promises triple benefits: cleaner air, enhanced soil productivity, and improved farmer livelihoods, making it crucial for sustainable agriculture in India's breadbasket.

***Keywords**: Stubble Burning, Punjab Agriculture, Air Pollution, Happy Seeder, Crop Residue Management, Sustainable Farming.*

Introduction

Punjab is a predominantly agrarian state in India, where rice and wheat are the major crops. After harvesting these crops-especially paddy-farmers often burn the crop residues (commonly known as stubble) directly in the fields. Stubble burning is a long-standing and widespread practice in Punjab, mainly because it allows for quick field preparation for the next sowing season while avoiding the costs associated with residue disposal.

However, this practice has become a serious concern for both the environment and human health. Stubble burning releases a significant amount of pollutants into the atmosphere, including carbon monoxide (CO), carbon dioxide (CO_2), methane (CH_4), nitrogen oxides (NO_x), and particulate matter (PM2.5 and PM10). These pollutants not only deteriorate local air quality but also contribute heavily to smog and air pollution in neighboring regions, especially Delhi-NCR. In addition, burning stubble reduces soil fertility by destroying beneficial microorganisms and organic matter. It also contributes to global warming.

Given the severe environmental and health impacts, it is essential to find effective solutions to the stubble burning problem. The aim of this study is to provide a detailed analysis of the environmental effects of stubble burning in Punjab. The research also explores viable alternatives for stubble utilization and sustainable solutions for farmers, with the goal of eliminating the need for burning and promoting the beneficial use of agricultural waste. This includes evaluating alternatives like biomass energy production, animal fodder, compost fertilizer, and mushroom cultivation. Through this study, we hope to contribute to the development of a sustainable agricultural system that protects the environment while supporting farmers' livelihoods.

Research Methodology

This research paper is based on the descriptive research method. It presents an analytical overview using real-world data on stubble burning by farmers in Punjab. The study primarily relies on secondary data. The required information has been collected from various government departments, official websites, newspapers, and magazines. It is noteworthy that most of the data used in this paper is qualitative in nature, and the conclusions are drawn after their analysis.

Research Findings and Discussion

Punjab is an agriculturally dominant state where paddy is the main Kharif crop. Paddy harvesting usually takes place from the end of September to the beginning of November. To prepare fields quickly for the next crop (wheat), farmers often burn the leftover stubble. During the Kharif season (from 15 September to 30 November), Punjab has witnessed a notable decline in the number of stubble burning incidents. In 2023, the number of such cases dropped to 36,663 from 71,159 in 2021—an impressive 48.5% reduction over three years.

Sangrur district consistently recorded the highest number of stubble burning incidents in all three years, with 8,001 cases in 2021, 5,239 in 2022, and 5,618 in 2023. However, most districts showed significant improvement—for example, Ludhiana recorded a 69% drop (from 5,804 to 1,801) and Moga a 57% reduction (from 6,502 to 2,795), highlighting the effectiveness of the state's stubble management initiatives. Districts like Pathankot (6 to 4) and Rupnagar (307 to 46) recorded minimal incidents, suggesting successful implementation of alternative stubble management techniques. However, a temporary increase in stubble burning cases in Bathinda in 2022 (from 4,476 to 4,592) and a slight rise in Sangrur in 2023 indicate ongoing challenges in certain areas. These statistics reflect that while Punjab has made substantial progress in tackling the problem of stubble burning, districts such as Sangrur, Moga, and Firozpur still require targeted interventions and awareness campaigns.

Table 1: District-wise Comparison of Active Fire Incidents During Kharif Season (15 September to 30 November) in Punjab (2021, 2022, 2023)

S. No.	District	2021	2022	2023
1	Amritsar	2171	1542	1573
2	Barnala	4313	2910	2316
3	Bathinda	4476	4592	2972
4	Fatehgarh Sahib	1723	1149	888
5	Faridkot	3945	2693	2022
6	Fazilka	2385	2856	1854
7	Firozpur	6272	4295	3398
8	Gurdaspur	1395	854	389
9	Hoshiarpur	330	259	118
10	Jalandhar	2546	1388	1196
11	Kapurthala	1787	1279	1048
12	Ludhiana	5804	2682	1801
13	Mansa	3216	2815	2268
14	Moga	6502	3609	2795
15	Muktsar	4591	3884	1669
16	SBS Nagar	356	270	238
17	Pathankot	6	1	4
18	Patiala	5346	3336	1878
19	Rupnagar	307	246	46
20	SAS Nagar	205	162	133
21	Sangrur	8001	5239	5618
22	Tarn Taran	4103	3184	2026
23	Malerkotla	1379	677	413
24	**Total**	**71159**	**49922**	**36663**

Source: Status Report, Punjab Pollution Control Board, Punjab Government, 2024

Environmental Concern Due to Stubble Burning

- **Air Pollution and Greenhouse Gas Emissions**

Parali (crop residue) burning releases large amounts of greenhouse gases such as CO_2 (70%), CO (7%), CH_4 (0.66%), and N_2O (2.09%) from the nitrogen content in straw. These emissions significantly exceed the permissible limits set by the Central Pollution Control Board and contribute to global warming. The released particulate matter, containing carcinogens, causes severe respiratory problems. Dense smoke clouds can travel vast distances, forming smog and brown clouds that degrade air quality and visibility. India has 22 of the world's 30 most polluted cities, largely due to such practices.

- **Nutrient Loss**

Burning crop residues results in the loss of vital nutrients from the soil. Approximately 90% of nitrogen, 50% of sulphur, 25% of phosphorus, and 20% of potassium are lost during burning. One tonne of rice straw contains about 400 kg of carbon, 25 kg of potassium, 5.5 kg of nitrogen, 2.3 kg of phosphorus, and 1.2 kg of Sulphur—most of which are released into the atmosphere, reducing soil fertility and leading to nutrient deficiency in the next cropping cycle.

- **Soil Fertility Degradation**

Burning stubble raises the soil temperature (up to 42.2°C at 1 cm depth), destroying beneficial soil microbes and organic matter. It reduces soil moisture and kills natural pest predators, making crops more susceptible to diseases and pest attacks. Though perceived as a cheap and quick solution, burning damages long-term soil health and productivity.

- **Smoke and Soot Emissions**

Crop residue burning emits high levels of harmful gases and particulates—such as 9 million tons of CO, 0.25 million tons of Sulphur oxides, 149 million tons of CO_2, and 1.28 million tons of particulate matter. Studies in Punjab have shown that such burning significantly worsens air quality, often exceeding safe limits and creating a toxic atmosphere, particularly in cities like Delhi.

- **Human Health Hazards**

Toxic gases and fine particulates from stubble burning cause serious health issues—bronchial asthma, acute respiratory infections, eye irritation, and cardiovascular problems. A large portion of the population reports symptoms like coughing, throat irritation, wheezing, and breathing discomfort during burning periods. Children are especially vulnerable due to their higher breathing rates. Pollutants like CO and CO_2 reduce oxygen absorption in the blood and can even contribute to cancer through prolonged exposure.

- **Impact on Aquatic Ecosystems**

The high concentration of CO_2 released into the atmosphere also affects oceans, which act as natural carbon sinks. Excess CO_2 increases ocean acidity, disrupting aquatic ecosystems and threatening marine biodiversity.

An Alternatives to Stubble Burning

There are several effective and sustainable alternatives to stubble burning have emerged, offering long-term benefits for both farmers and the environment.

In-situ stubble management options are among the most promising solutions. The Happy Seeder, a tractor-mounted machine, enables farmers to sow the next crop, usually wheat, directly into the field with standing rice stubble. This machine cuts and lifts the straw, sows the seeds, and spreads the stubble as a mulch layer on the field surface. This not only eliminates the need for burning but also enhances soil health by adding organic matter, improving moisture retention, and increasing nutrient availability, which can lead to better crop yields and lower fertilizer costs.

The Super Seeder functions similarly, incorporating crop residues into the soil while simultaneously sowing seeds. Machines like the Rotavator and Mulcher shred stubble into small pieces and integrate it into the soil, serving as a natural fertilizer. Another remarkable solution is the PUSA Decomposer, developed by the Indian Agricultural Research Institute, which involves spraying a microbial solution onto the stubble, rapidly decomposing it into nutrient-rich manure within 20 to 25 days. Zero-tillage or conservation tillage methods, which minimize soil disturbance and leave crop residues on the surface as mulch, help in retaining soil moisture, suppressing weed growth, improving soil structure, and enhancing carbon sequestration.

Crop diversification, involving the shift to less residue-producing or differently timed crops such as pulses and millets, also reduces the need for immediate residue disposal. In certain contexts, strategic grazing by small livestock like sheep can help manage stubble by consuming it directly from the field.

Ex-situ stubble management involves removing the crop residue from the field and using it elsewhere, turning waste into a resource. Baling machines collect and compress stubble into tightly packed bales that can be transported for various uses. One of the key applications is in bioenergy and biofuel production, where baled straw serves as a feedstock for power plants or for producing bioethanol and biogas. This supports the transition to clean energy and reduces dependence on fossil fuels.

Additionally, crop residue can be used as fodder for livestock, particularly in regions where alternative sources are scarce, or as bedding material in animal shelters. In the industrial sector, rice and wheat straw are used as raw materials for manufacturing paper, pulp, particle boards, agri-fiber boards, mushroom compost, and packaging materials. Composting and vermicomposting of stubble enrich the soil with organic matter and essential nutrients, reducing the reliance on chemical fertilizers and enhancing long-term soil fertility.

The adoption of these alternatives brings multiple benefits. Environmentally, it curbs air pollution and greenhouse gas emissions, contributing to cleaner air and improved climate conditions. Agronomically, it enhances soil fertility, increases microbial activity, and boosts water retention capacity, ultimately improving crop productivity. Economically, farmers benefit through reduced input costs for fertilizers and irrigation, increased yields, and potential income from selling crop residues for energy or industrial use. Public health improves as the incidence of respiratory and cardiovascular diseases linked to air pollution decreases. From a climate perspective, these methods reduce carbon emissions and promote carbon sequestration in soil, supporting India's broader climate goals.

Despite the benefits, several challenges hinder widespread adoption. Financial constraints remain a key barrier, as machinery like Happy Seeders and Super Seeders are expensive and often unaffordable for small and marginal farmers. Although government subsidies and incentives exist, their reach and implementation vary across regions. Creating awareness through farmer education programs, field demonstrations, and training sessions is critical to encourage behavioral change. Ensuring the availability and accessibility of machinery through custom hiring centers or farmer producer organizations can enable shared use and reduce individual costs. Strengthening market linkages for crop residue by creating reliable supply chains and buyer networks is necessary to make stubble a valuable resource.

The Government of Punjab has adopted a multi-dimensional strategy for the management of paddy stubble, incorporating both in-situ and ex-situ methods. In the year 2023, a total of 15.86 million tons of stubble was managed, while for 2024, it is estimated to reach 19.52 million tons.

In-situ management, which involves the disposal of stubble directly in the fields, is expected to increase from 11.5 million tons in 2023 to 12.7 million tons in 2024, reflecting growing awareness among farmers. Under ex-situ management, a significant rise has been observed in industrial use — particularly in industrial boilers (from 2.1 to 3.1 million tons), biomass power plants (from 0.96 to 1.17 million tons), and compressed biogas (CBG) plants (from 0.3 to 0.54 million tons). The use of stubble in thermal power plants and brick kilns is also being promoted, with targets of 0.77 and 0.18 million tons, respectively, set for 2024.

Its use as animal fodder is also projected to rise from 0.7 to 0.86 million tons. These figures indicate that the Punjab government is effectively implementing various stubble management options, although certain challenges still remain.

Table 2: Management of Paddy Stubble by the Punjab Government

S. No.	Strategy	**2023 (Actual)** (Million Tons)	**2024 (Estimated)** (Million Tons)
1	In-situ Management	11.5	12.7
2	Ex-situ Management	3.66	5.96
	• Industrial Boilers	2.1	3.1
	• Biomass Power Plants	0.96	1.17
	• Compressed Biogas Plants	0.3	0.54
	• Bio-ethanol Plants	0.1	0.2
	• Thermal Power Plants	0.2	0.77
	• Brick Kilns	0	0.18
3	Use as Fodder	0.7	0.86
	Total	**15.86**	**19.52**

Source: Status Report, Punjab Pollution Control Board, Punjab Government, 2024

Conclusion

Punjab, a major agricultural state in India, faces serious environmental and health challenges due to stubble burning after paddy harvests. This practice releases harmful pollutants like CO_2, CO, and particulate matter, worsening air quality and contributing to Delhi's smog crisis. While stubble burning incidents have decreased by 48.5% from 2021 to 2023, some districts like Sangrur still report high cases. The burning damages soil fertility by destroying nutrients and beneficial microbes, while also causing respiratory illnesses among locals. Sustainable alternatives exist, including in-situ methods like Happy Seeders and PUSA decomposer, and ex-situ uses like bioenergy production and industrial applications. The Punjab government has managed 15.86 million tons of stubble in 2023, with plans to increase this to 19.52 million tons in 2024. However, challenges remain in making machinery affordable for small farmers and creating effective residue supply chains. Addressing stubble burning through these eco-friendly methods can improve air quality, enhance soil health, and support farmers' incomes while meeting India's climate goals.

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