A Comprehensive Review on Tackling the Problem of Stubble Burning - An Indian Perspective

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Abstract. Our Bharat is known as the 2nd biggest agro-economy-based country. India shines bright as ever, ranked as second in the world, holds more than 20 per cent of the complete production of rice. The northern belt of India, from Punjab to Haryana and allied regions face this the problem of burning the stubble or straws which are left over after the harvesting of grain is complete in the fields. Stubble Burning has always an issue of warning alarm in India due to increasing Air Quality Index (AQI). Every year during October and November, the situation of air pollution in Northern India becomes worst due to burning of Stubble after the rice harvesting rice, leads to bad results. The most depreciated situation is faced by the nourishing value of soil which gets adversely affected. Incorporating crop residues into the soil can enhance its physical, chemical, and biological properties in various ways. In this research, various effective methods for utilization of Stubble are studied and its effectiveness in India is stated. Stubble is converted into a valuable resource through several methods. Widespread awareness is required to educate farmers for the negative effects of burning stubble and availability of more economical viable alternatives.

1 Introduction

India, the second most popular country in the world with its deep agricultural history is able to produce vast quantities of rice and wheat, for both local and export markets. Rice-43 per cent, wheat-21 per cent, sugarcane-19 per cent, and oilseeds- 5 per cent are mainly responsible for residue of crop burning. [1,2] Stubble, or stubble, refers to the leftover part of the rice crop after the upper portion has been harvested, which is of no use to the farmers. To prepare the fields for the next crop, farmers burn the remaining dry stubble (straw). Among the farmers in North India, this practice of burning leftover stubble is very common. This especially so in the states Punjab and Haryana.[3] However, it can be utilized for various purposes, such as producing mats, mushrooms, liquor, paper-mache, manure, as well as fodder among others.[4] An effective approach to managing agricultural stubble is by incorporating it into the soil, which helps maintain the organic matter content and enhances soil fertility. Added with soil, the straw can boost its productivity as well as restore as

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nutrients that are lost through burning (Fig.1).[5] Overall, incorporating straw into the soil enhances fertility and boosts carbon sequestration. However, many farmers, especially in developing countries, are unable to deploy extra labour charges or use mechanized equipment that is required for this method. [5]

Fig. 1 In-Situ Stubble Burning [2]

It needs to be underlined that government agencies states that India generates around crop residues of 500 million tons annually. While most of this is used as animal fodder or fuel for domestic and industrial purposes, approximately 140 million tons remain unused, with 92 million tons being burned each year. To expedite the transition between harvesting and the next planting season, farmers - especially in the States of Punjab and Haryana - put to fire nearly 35 million tons of paddy crop waste annually. This cost-effective disposal method significantly contributes to air pollution, particularly in Delhi, where stubble burning in northwest India has been identified as a major pollutant.[6]
Burning crop residues releases large amounts of harmful greenhouse gases (GHGs) such as carbon dioxide (CO2), methane (CH4), carbon monoxide (CO), and nitrogen dioxide (N2O), posing serious health risks.[7] Rice straw mainly consists of ash (18.67 per cent), silica (74.67 per cent), fixed carbon (15.86 per cent), calcium oxide (3.01 per cent), magnesium oxide (1.75 per cent), nitrogen dioxide (0.96 per cent), and potassium dioxide (6.30 per cent). When burned, these substances are released into the atmosphere, severely degrading air quality.[8] The resulting toxic clouds lead to dangerously high Air Quality Index (AQI) levels, adversely affecting both the environment and the health of humans and animals.[9]
Air pollution can also cause skin and eye irritation, along with severe neurological, cardiovascular, and respiratory conditions such as asthma, chronic obstructive pulmonary disease (COPD), bronchitis, reduced lung capacity, emphysema, cancer, and other serious health issues. Prolonged exposure to high pollution levels further increases mortality rates. Beyond its health impacts, stubble burning also harms the climate, reduces soil fertility, and hinders the country's economic growth. Additionally, it indirectly contributes to rising global temperatures, which accelerates ozone layer depletion.[10]

Given India's substantial crop waste production, the issue of residue burning demands global attention for two key reasons: first, its organic composition makes it a valuable resource for society and second, improper disposal of such large quantities can lead to environmental repercussions that extend beyond India's borders.[3]
The major aim of the study is to present the current situation of stubble burning in India. Further, various measures to avoid the stubble burning are presented in the paper and also the various effective methods in which the stubble can be reused as a raw material are also stated. Moreover, the study also illustrates the various reasons due to which the stubble burning still exists even after various solutions/alternatives are proposed and prevalent. Various methodologies relevant to effective utilization of stubble/crop residue are elaborated and the effectiveness of each method is proposed.

2 Reason of Burning Stubble

There are two primary reasons for burning crop residues. First, there is a very narrow time frame between harvesting paddy and sowing wheat at the end of the Kharif season. Second, removing the remaining paddy stalks from the field is a labour-intensive task. Due to the lack of available labour and the limited time window, burning the residue directly in the field becomes the easiest option for farmers. For them, burning is more cost-effective and requires less effort.[11]

2.1 Rice-Wheat Cropping System: Constraints of Limited Time Gap Between Successive Crops

In agriculture, determining the appropriate sowing time is the most fundamental and crucial agronomic practices. For paddy cultivation, the recommended sowing period falls in the second half of May, with transplanting occurring between the second half of June and a maximum of July 5th. The crop reaches maturity in November. However, wheat is typically sown in the first half of November in the rice-wheat cropping system leaving farmers with little to no time for proper rice straw management. Although late-sown wheat varieties have been introduced, allowing sowing to extend until the first week of December, the gap between two successive crops remains limited to a maximum of 20 days.[11]

2.2 Limited Awareness of Stubble Management Practices

Farmers often lack awareness of proper residue management within a short timeframe. To dispose crop remains, burning comes as the easiest way. The Government of India, however, is actively working for educating and informing farmers about the alternative management practices.[12]

2.3 Mechanical Harvesting Systems

Rice, as a major cereal crop grown over extensive areas, renders manual harvesting highly inefficient. To address this, mechanical harvesters - most notably, combine harvesters - were introduced. However, these machines are not designed to cut the rice at ground level and incorporate the straw into the soil, leaving a significant amount of residue in the field.[13]

2.4 Irresponsibility in Residue Management

Even though many are aware of proper residue management and its environmental implications, some still resort to burning stubble in the fields. As a result, lawmakers have introduced new regulations to curb these negligent practices among a minority of farmers.[14]

2.5 Unsuitable for Cattle Feed

From the most cereal and forage crops, residues are commonly used for feeding the dairy cattle. However, due to its high silica and lignocellulose content in Northern regions, rice straw is typically avoided as cattle feed. Coupled with low protein levels (2-7 per cent), it becomes an unsuitable option. In contrast, cattle tend to favour basmati rice fodder because of its enhanced palatability.[15]

2.6 Labour Scarcity and Rising Costs in Intensive Agriculture

The shift toward intensive agriculture has led to a gradual decline in the use of manual labour, with mechanization increasingly taking over. The share of agricultural and overall labour from 62.67 per cent in 1970-71 to 35.96 per cent in 2012-13 in Punjab. Farmers now often burn their crop residue - a cost-free method - to reduce expenses as labour wages have surged.[14]

3 Issues Caused by Stubble Burning

3.1 Air Pollution and Greenhouse Gas Emissions

Crop residue burning leads to release of greenhouse gases, along with other aerosols and trace gases that are chemically and radioactively impactful. These harmful gases can go beyond the emission levels that the Central Pollution Control Board has recommended.[12] It is estimated that burning rice straw releases 70 per cent of the carbon in the straw as CO_2, 7 per cent as CO, and 0.66 per cent as CH_4. Additionally, 2.09 per cent of the nitrogen that is released in the straw as N_2O into the atmosphere, contributing to global warming.[16]

Fig. 2 High Smoke in the air due to Stubble Burning [4]

3.2 Lack of Nutrients

About 90 per cent of the nitrogen, 50 per cent of the sulphur, 25 per cent of the phosphorus, and 20 per cent of the potassium, along with other essential nutrients, are released into the atmosphere as gases and particulates when crop residues are burned.[17]

3.3 Decline in Soil Fertility

Most farmers consider burning to be a fast, easy, and cost-effective method as it eliminates unwanted shrubs, plants and husks. It is believed that fire helps in replenishing the nutrients of soil. But on the ground husk burning actually reduces the productivity of soil by destroying its nutrients.15 Burning stubble transfers heat to the soil, leading to a loss of moisture and beneficial bacteria, which negatively impacts the soil. Burning paddy straw can increase the soil temperature to between 33.8 and 42.2 degrees Celsius at a depth of up to one centimeter.[18]

3.4 Fumes and Soot Particles

The smoke produced by burning husks pollutes the air, forming a dense layer of pollutants that contributes to Delhi's "toxic atmosphere." Studies on crop residue burning reveal that it emits around 0.25 million tons of sulphur oxides, 9 million tons of carbon monoxide, 149 million tons of carbon dioxide, and 1.28 million tons of particulate matter.[19]

3.5 Health Impacts

Stubble burning releases large amounts of particulate matter and harmful gases, including sulphur oxides, nitrogen oxides, carbon monoxide, carbon dioxide, and methane. Carbon monoxide and carbon dioxide contribute to ozone layer depletion, increasing the penetration of harmful UV rays, which can pose serious risks to skin health.[4]

3.6 Impact on Aquatic Ecosystems

The main greenhouse gas released during stubble burning is carbon dioxide, which continues to accumulate in the atmosphere over time. Since carbon dioxide is the most oxidized and thermodynamically stable form of carbon, converting it into other compounds is difficult. The most effective approach to managing its impact is through carbon capture and storage.[20]

4 Handling of Crop Residues

There are many different ways to use crop residue, provided one has the basic knowledge and awareness required.

4.1 Crop Residue as Animal Feed

Crop residues are a key source of animal feed in India. For northern regions, wheat and maize straws serve as the primary feed for livestock. Conversely, rice straw is predominantly used in southern regions, despite its high silica content, likely due to limited alternative feed options. Additionally, husk of rice is processed as fine powder and primarily given cattle in the south. Supplementing dry straw with urea further enhances its nutritional value, benefiting livestock health.[14]

4.2 Crop Residue Bedding for Cattle: Enhancing Livestock Health and Productivity

In many southern Indian states, cattle shed use paddy straw traditionally use as bedding. More recently, this practice has been adopted in northern regions during the colder months based on government recommendations. A study by the College of Agriculture, PAU, found that employing crop residue as bedding in winter significantly improved both the quantity and quality of milk production, largely due to enhanced comfort and better leg and udder health. Winter bedding helps cattle stay warm by regulating heat loss and creates a safe, non-slip, hygienic and dry environment that minimizes the danger of lameness and injury. This improved leg and hoof health contributes to increased milk yield and better reproductive performance in livestock.[21]

4.3 Biogas Production from Crop Residues

Biogas plants offer a renewable alternative to fossil fuels by converting agricultural waste into energy. Crop residues - especially rice straw, which is rich in lignocelluloses - play a crucial role in biogas production. These residues can also yield biochar. The process involves using grinders to break the stubbles into small pieces before mixing them with other materials in anaerobic digesters. This completely oxygen-free process produces both biogas and solid and liquid organic fertilizers. [11,22]

4.4 Bio-Thermal Power from Paddy Residues

Rice residues has a crucial role in the generation of electricity at bio-thermal plants. Currently, a number of institutions as well as power plants are promoting rice residue as useful inputs for power production, enabling farmers to avoid stubble burning and earn extra income from their waste. Additionally, agricultural residues can be converted into energy through processes such as extraction, methanation, or gasification.[23]

4.5 Sustainable Mushroom Production and Leveraging Crop Residues

Residues from wheat, rice, and sugarcane bagasse serve as excellent substrates for cultivating mushrooms. Among these, paddy straw is particularly favoured because it is economical and rich in lignocellulose, making it an ideal choice to offset the rising costs of mushroom production. In India, popular edible mushrooms include Agaricus bisporus (button mushroom), Volvariella spp. (paddy straw mushroom), Calocybe indica (milky mushroom), and Pleurotus ostreatus (oyster mushroom). These mushrooms largely depend on the quality of the compost used for their growth, which is influenced by the substrate selected during bagging. This selection affects how efficiently the mushroom spawn can utilize the compost's nutrients, with various physiochemical factors during composting playing a critical role. Despite the significant potential for using crop residues in mushroom cultivation, only about 0.03 per cent of the agricultural crop residues in India are currently utilized for this purpose.[24]

4.6 Utilizing Crop Residues in Compost Production

Composting is a time-honoured method for creating nutrient-rich organic material. It relies on natural processes in which microorganisms break down organic matter - such as crop residues, animal manure, vegetable waste, and also some of municipal wastes - into a valuable fertilizer. This organic fertilizer, produced once the decomposition process is complete, enhances the soil's chemical, biological and physical properties of soils. Crop leftovers like stubble, straw, stover, and haulms, along with remnants from thrashing sheds and crop processing, are ideal candidates for composting. These residues hold significant potential to be transformed into manure, offering an eco-friendly organic fertilization option for agriculture.[23]

4.7 Crop Residues in Paper Industries: Sustainable Raw Materials and Energy Production

In the paper sector, paddy straw is blended with wheat straw in a 40:60 ratio to produce paper. Moreover, the sludge left over from the papermaking process can be converted into energy via biomethanization—a method already adopted by some paper mills to supply about 60 per cent of their energy needs. Additionally, paddy straw is a common raw material for manufacturing paper and pulp board.[25]

4.8 Crop Residue Management at Farm Level

The method of managing stubble directly in the field is a cost-effective practice that farmers employ. This provides significant benefits at minimal expense. Stubble incorporation and stubble mulching are two primary methods for achieving the efficient use of crop residues on-site.[26]

4.9 Enhancing Soil Health and Crop Productivity through Stubble Incorporation

In this technique, straw is mixed into the soil after harvest either by manual labour or with the help of heavy machinery such as rotavators and choppers. Straw is cut and blended into the ground. For example, the rice straw can be effectively handled on the farm by allowing a 20-25 day interval between its incorporation and the sowing of the wheat crop, which helps prevent nitrogen deficiency caused by nitrogen immobilization. Applying nitrogen along with the straw, either separately or together, improves soil biomass carbon, respiratory activity, and phosphate levels. The highest levels of microbial biomass carbon and phosphate were observed 30 days after straw decomposition began. Field experiments indicated that incorporating paddy straw 21 days before wheat sowing significantly improved wheat yield in clay loam soil in Sonipat district. However, no notable benefits were recorded in sandy loam soil in Hissar district.[26]

4.10 Stubble Mulching: Enhancing Soil Conservation and Crop Performance

For preventing erosion caused by wind and water, conserve soil moisture, and suppress weed growth stubble mulching involves even distribution of crop residues over the soil surface. Research has shown that this practice helps retain moisture in deeper soil layers, resulting in roughly 40 per cent longer root growth compared to areas without mulch. Moreover, using rice straw as mulch has been found to reduce water usage by 3–11 per cent, increase yields of wheat, and for improving water use efficiency by 25 per cent relative fields that are non-mulched.[26]

4.10.1 Happy Seeder: Revolutionizing Zero-Till Residue Management and Wheat Sowing

The Happy Seeder is a tractor-mounted, zero-tillage device that cuts standing rice straw while simultaneously planting wheat seeds, leaving the residue as mulch, see Fig.3. This mulch helps retain soil moisture, minimize erosion, and suppress weeds. Additionally, using the Happy Seeder reduces labour for residue collection and sowing by 80 per cent, cuts herbicide use by up to 50 per cent, and decreases irrigation needs by 20–25 per cent. When combined with a basic straw-spreading mechanism—the "Super Straw Management System"—and attached to a combine harvester for even residue distribution, it greatly improves efficiency and stabilizes crop yields. [26]

Fig. 3 Implementation of Happy Seeder [8]

Stubble burning is still a common sight in India, owing to a range of social, economic, and systemic problems, even when multiple solutions are provided and existing in the society. Alternative methods for clearing fields are simply not feasible for farmers in Punjab, Haryana, and Uttar Pradesh who face an extremely tight turnaround time of a month between harvesting paddy for wheat sowing. Small and marginal farmers, who comprise a substantial part of the agriculture economy, possess limited mechanized options, particularly the expensive Happy Seeder. Even though there are government awareness initiatives and subsidies, they are seldom implemented properly and consistently. Furthermore, the new policies and technologies don't garner support from farmers as there is no immediate visible benefit to the farmer's wallet.

Apart from the above, ineffective residue management stubble systems pose a more put forth problem. Stubble is a valuable resource but without adequate and economical means of collection, farmers have no alternative but to burn it. Concerning the policies and penalties put forth for burning stubble, they prove to be extremely hard to enforce with unanimity.

Adding on to all of this is the unsteady monsoon season along with worsening climate change, which puts additional strain on farming work.

5 Conclusions

- **Severe Environmental Impact:** Stubble burning significantly contributes to air pollution, releasing harmful greenhouse gases (CO_2, CH_4, CO, and N_2O), leading to deteriorating air quality and increasing health risks.
- **Health Hazards:** The toxic emissions from stubble burning cause severe respiratory illnesses, cardiovascular diseases, skin and eye irritation, and contribute to high mortality rates.
- **Decline in Soil Fertility:** Burning crop residues depletes essential soil nutrients, destroys beneficial microorganisms, and reduces soil moisture, ultimately lowering agricultural productivity.
- **Climate Change Concerns:** The rising levels of greenhouse gases from stubble burning contribute to global warming, ozone layer depletion, and unpredictable climate patterns.
- **Lack of Awareness & Labor Constraints:** Farmers burn stubble due to the limited time gap between crop cycles, high labour costs, lack of awareness about alternative methods, and the inefficiency of mechanical harvesting systems.
- **Sustainable Stubble Management Alternatives:**

  On-Farm Management: Techniques such as stubble incorporation, mulching, and Happy Seeder technology help retain soil nutrients and reduce environmental impact.
  Industrial Utilization: Crop residues can be used in paper industries, biogas production, bio-thermal power generation, and composting.
  Livestock & Agriculture: Stubble can serve as animal fodder, cattle bedding, and a substrate for mushroom cultivation.
- **Policy & Awareness Initiatives:** The government must implement stricter regulations, provide financial incentives, and run awareness campaigns to educate farmers about eco-friendly residue management techniques.
- **Way Forward:** A collaborative approach involving farmers, policymakers, researchers, and industries is essential to eliminate stubble burning, promote sustainable agriculture, and safeguard environmental and human health.

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