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Stubble Burning: Destroying Soil, Endangering the Future

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Agriculture sector provides the base for the growth of the Indian economy, with farmers being the backbone of this progress. To meet the increasing food demand of the country, farmers intensively cultivate soil, leading to the generation of substantial agricultural waste. However, there is limited discussion among the stakeholders regarding the management of this agricultural waste. This gap may be attributed to the fact that the agricultural industry is not as strictly regulated as municipal solid waste (MSW). Consequently, the responsibility for managing agricultural waste falls solely on farmers. While a portion of this waste is repurposed as food, fuel, and fodder, a significant quantity remains unutilized. The excess residue is often disposed of through burning called Stubble Burning —a prevalent agricultural practice in India—despite its well-documented environmental and soil health consequences.

Stubble burning is primarily driven by the need to quickly clear fields for the next cropping cycle, particularly in regions practicing intensive agriculture, such as Punjab, Haryana, Uttar Pradesh, West Bengal and Assam. The mechanization of farming, particularly the use of combine harvesters, leaves behind large amounts of stubble after harvesting the crop (mostly Paddy and Wheat), which farmers often find difficult to manage due to economic and time constraints. Instead of adopting sustainable residue management techniques, many farmers resort to burning as a quick and cost-effective solution. According to the Indian Ministry of New and Renewable Energy (MNRE), India produces approximately 500 million tons (Mt) of crop residue annually. A significant portion of this residue is utilized for various purposes, including fodder, domestic fuel, and industrial applications. However, despite these uses, an estimated surplus of 140 Mt remains unutilized, with around 92 Mt being burned each year (NPMCR, 2025) posing a severe risk to the environment and soil health and so the well – being.

Farmers often consider burning a quick, simple, and cost-effective method for clearing fields, as it efficiently eliminates unwanted plants, shrubs, and husks. Some believe that burning can enhance soil fertility by releasing nutrients back into the soil. However, scientific evidence suggests that burning agricultural residues can lead to the loss of essential nutrients, reducing soil productivity over time. The combustion process releases vital elements such as nitrogen, phosphorus, and sulfur into the atmosphere instead of retaining them in the soil, leading to nutrient depletion. Moreover, burning disrupts soil microbial communities, which play a crucial role in organic matter decomposition and nutrient cycling. Continuous burning of agricultural land has a harsh impact on soil physicochemical properties, which play a crucial role in crop production and maintaining soil quality over time. The long-term consequences of burning not only affect current agricultural productivity but also pose risks to soil sustainability for future generations. A closer look at how various physicochemical properties are impacted reveals significant concerns regarding soil degradation and reduced fertility and increases production cost for the farmers.

a) ***Rise of Soil Temperature****:* Burning paddy straw increases the soil temperature to a range of 33.8 to 42.2 degrees Celsius within the top one centimetre of the soil. Researchers identified that during the burning process, the fire in the litter layer increased upto a range of 415 to 469 degrees Celsius. This rise in temperature kills the essential microorganism required in nutrient cycle and leading to reduction of yield. Therefore, to increase microbial activity farmers go for input to the field leading to rise the cost of production (Arunrat *et al*., 2020).

b) ***Soil Structure Degradation:*** The heat from burning alters soil structure by breaking down its aggregates, leading to compaction. Burning reduces pore space volume by about 11.5% and lowering aggregate stability. These physical changes may impair water retention. Compacted soil reduces root penetration and water infiltration, ultimately affecting plant growth. This degradation makes it difficult for the next crop to establish a healthy root system, thereby reducing yield potential (Pradhan *et al*., 2024)

c) ***Loss of Soil Nutrient:*** Stubble burning results in the immediate loss of essential nutrients such as nitrogen, phosphorus, and potassium (Pradhan *et al*., 2024). Research has shown that burning one ton of rice straw leads to the loss of approximately 5.5 kg of N, 2.3 kg of P and 1.2 kg of S. If we calculate, then it is found that about 12 kg of Urea, 36 kg of SSP fertilizer is required to match the loss. This means, loss not only affects the next crop cycle but also necessitates the increased use of synthetic fertilizers, which further deteriorate soil health over time.

d) ***Increase in Soil Acidity***: Continuous burning of stubble contributes to soil acidification. The heat alters the pH balance, making the soil more acidic. Acidic soils hinder nutrient availability, leading to deficiencies that negatively impact plant growth. Over time, farmers may have to apply lime or other amendments to restore soil pH, increasing their input costs.

e) ***Destruction of Soil Microorganisms:*** The elevation of the soil temperature and acidity impacts soil microbial communities by destroying beneficial microbes that play a vital role in soil renewal and nutrient cycling. The loss of these essential microorganisms leads to reduced soil fertility and disrupts natural biological processes. As a consequence, crops become more susceptible to diseases due to the depletion of "friendly" pests that naturally control harmful pathogens. The decline in beneficial insect populations, such as predatory beetles and parasitoid wasps, further exacerbates pest infestations, allowing "enemy" pests to thrive unchecked (Pradhan *et al*., 2024)

f) ***Loss of Soil Organic Matter***: Organic matter content, the most affected among the others. Burning crop residues leads to the immediate loss of organic materials that would otherwise decompose and enrich the soil. Instead of burning, retaining stubble would increase Microbial biomass C 22% with N fertilizers 30%. Studies reported that this practice reduces bacterial population by 51.8%, fungal population decreased by 18.8%, Actinomycetes decreased by 32.8%. This practice results in the rapid oxidation of organic carbon, releasing it into the atmosphere as CO_2 and reducing the SOM content. Studies have also shown that continuous residue burning can lead to a substantial decline in soil organic carbon levels, adversely affecting soil fertility and structure (Abdurrahman *et al*., 2020).

g) ***Other effects***: Stubble burning significantly contributes to air pollution and greenhouse gas (GHG) emissions, posing serious environmental and health hazards. The burning of crop residues releases pollutants such as Carbon Monoxide, Nitrogen oxides (NO_2), sulfur dioxide (SO_2), and particulate matter (PM2.5 and PM10), which degrade air quality and cause respiratory diseases. Additionally, it emits greenhouse gases like carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O), accelerating climate change. The resulting smog reduces visibility and disrupts transportation. Moreover, black carbon from burning settles on glaciers, hastening their melting. Adopting sustainable residue management practices is crucial to mitigating these adverse effects (TERI, 2019).

Alternatives to Stubble Burning

There are several alternative ways to stubble burning, though they may take more time; however, considering the future of soil health and the well-being of the next generation, adopting sustainable residue management practices is crucial. In-situ management techniques, such as the Happy Seeder, enable direct sowing without removing stubble, while rotavators and mulchers incorporate crop residues into the soil, enhancing organic matter and moisture retention. Zero tillage farming further promotes soil conservation by leaving residues undisturbed. Ex-situ management techniques involve converting residues into biochar, compost, or vermicompost, enriching soil fertility, while processing paddy straw into fodder supports livestock farming. Industrial applications utilize residues for bioenergy production, bioethanol, and biogas generation, as well as in manufacturing paper and biodegradable packaging. Microbial decomposition techniques, such as the Pusa Decomposer developed by IARI, accelerate straw breakdown, replenishing soil nutrients without burning. Beneficial microbes like Trichoderma and cellulolytic fungi further enhance decomposition efficiency (Bhuvaneshwari *et al*., 2019). Policy interventions, including subsidies for residue management machinery, farmer training, and carbon credit programs, encourage sustainable practices. Shifting to these alternatives is essential to preserving soil fertility, reducing air pollution, and ensuring long-term agricultural sustainability. Governments, researchers, and farmers must collaborate to promote eco-friendly residue management strategies (Abdurrahman *et al*., 2020).

Conclusion

Effective crop residue management requires a holistic, community-driven approach rather than isolated interventions. Establishing self-sustaining mechanisms is crucial to ensure long-term solutions rather than temporary fixes. Empowering farmers and stakeholders through education, technical support, and economic incentives can help shift traditional mindsets, encouraging sustainable waste management practices. Additionally, the issue of stubble burning should not be confined to just the agricultural and energy sectors. Instead, it should be addressed through a multi-sectoral approach that integrates environmental, economic, and social perspectives. By fostering collaborative efforts among local governments, municipalities, and farmer associations, sustainable solutions such as compost utilization, waste-to-energy initiatives, and equipment-sharing programs can be implemented effectively. Ultimately, a nexus-thinking approach that promotes cross-sectoral cooperation will be key to overcoming the long-standing challenges of crop residue burning, leading to enhanced soil health, reduced agrochemical dependency, and improved environmental sustainability.

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