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Stubble burning in India: Evaluating the effectiveness of national green tribunal guidelines and legal challenges

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Abstract
Stubble burning in North-western India is a critical socio-environmental crisis, an unintended consequence of the post-Green Revolution agricultural paradigm. The dominant paddy-wheat monoculture, combined with mechanized harvesting, leaves farmers with vast crop residue and a narrow 10–15-day window for field preparation, making burning a widespread practice. This annual incineration releases hazardous pollutants, causing severe air quality degradation, public health emergencies, and environmental damage. This paper critically evaluates the effectiveness of judicial interventions, particularly the guidelines from the National Green Tribunal (NGT), in mitigating this issue. The analysis is framed within constitutional mandates, including the Right to Life under Article 21, and principles of environmental jurisprudence. Key findings reveal a significant gap between judicial mandates and on-ground implementation. While technological solutions like in-situ and ex-situ residue management have been promoted, leading to some reduction in fire incidents, their success is limited. This disparity is driven by deep-rooted economic constraints on farmers, systemic policy lock-ins favouring the paddy-wheat cycle, and acute logistical challenges. A purely punitive or technology-centric approach has proven insufficient. The paper concludes by advocating for an integrated strategy that combines enhanced financial support for farmers, policy incentives for crop diversification, strengthened enforcement, and proactive community engagement. Such a holistic framework is essential to foster a transition towards sustainable agriculture and achieve a lasting resolution.

Keywords: Stubble burning, National Green Tribunal (NGT), environmental jurisprudence, crop residue management, air pollution, Green Revolution, paddy-wheat monoculture, in-situ and ex-situ management, sustainable agriculture

Introduction

India, possessing a rich agricultural heritage, stands as the second most populous nation globally, generating substantial quantities of food grains such as wheat and rice, catering to both internal needs and international markets. Among the diverse array of cultivated crops, the primary contributors to crop residues are rice (43%), wheat (21%), sugarcane (19%), and oilseed crops (5%), with a significant portion of these residues being incinerated [1, 2, 3]. The task of identifying crops that yield minimal leftovers poses a significant challenge for farmers, particularly given the substantial returns on investment associated with these crops [4]. Parali, or stubble, refers to the residual lower segment of the rice crop that persists following the harvest of the upper portions, rendering it of little utility to farmers. Agriculturalists incinerate the residual crop, specifically the desiccated straw, as they must vacate the fields to cultivate the forthcoming crop.

In northern India, particularly in the regions of Punjab and Haryana, it is common practice for farmers to incinerate residual stubble or straw in their agricultural fields [5]. Nonetheless, it serves a multitude of functions, encompassing the production of mushrooms, mats, paper mash, alcoholic beverages, waste, and feed for ruminants, among others. A highly effective approach to managing agricultural stubble involves integrating it into the soil. This practice not only preserves the organic matter content but also enhances soil fertility. The incorporation of straw into the soil enhances its productivity and restores nutrients that would have otherwise been lost through combustion [6]. Generally, the incorporation of straw into soil enhances its fertility and promotes the sequestration of carbon. Nonetheless, numerous farmers, especially in developing countries, find themselves unable to bear the costs associated with the supplementary labour and/or mechanised equipment required for this method.

The Ministry of New and Renewable Energy reports that India produces approximately 500 million tonnes of agricultural residues each year. The resultant residue is predominantly employed as feed and energy source for a range of industrial and domestic applications. Nonetheless, there exists an excess of 140 million tonnes, with 92 million tonnes incinerated annually [7]. To reduce the interval between harvest and the subsequent sowing of crops, approximately 35 million tonnes of paddy crop residues are incinerated by farmers each year, predominantly in the regions of Punjab and Haryana. This represents an economical approach to disposal. The incineration of Parali, a prevalent practice in north-west India, has been acknowledged as a significant factor in the air pollution affecting Delhi [8, 9]. The act of burning stubble emits significant quantities of hazardous greenhouse gases, including carbon dioxide, methane, carbon monoxide, and nitrogen dioxide, which pose a considerable threat to human health [10]. Rice straw primarily consists of ash (18.67%), silica (74.67%), fixed carbon (15.86%), calcium oxide (3.01%), magnesium oxide (1.75%), nitrogen dioxide (0.96%), and potassium dioxide (6.30%).

It is clear that the incineration of paddy straw, which harbours these hazardous compounds, disperses them into the atmosphere, thereby compromising the quality of the surrounding air [11]. It additionally generates perilous clouds that result in a state of emergency characterised by elevated AQI (Air Quality Index). The presence of these gases exerts

detrimental impacts, affecting both ecological systems and the well-being of humans and animals alike [12]. Moreover, air pollution has the potential to induce irritation in both the skin and eyes, alongside the risk of severe neurological, cardiovascular, and respiratory ailments, including asthma, chronic obstructive pulmonary disease, bronchitis, diminished lung capacity, emphysema, cancer, and various other health complications. Furthermore, it elevates mortality rates as a consequence of extended exposure to elevated pollution levels. Moreover, the practice of stubble burning exerts a detrimental influence on climate, soil fertility, and the economic advancement of the nation. The act of burning stubble also has an indirect effect on the increase in global temperatures, thereby compromising the integrity of the ozone layer [13].

The substantial crop waste generated in India necessitates international consideration for two primary reasons: firstly, the organic nature of the residue presents societal advantages; secondly, the considerable volume of this waste, if mismanaged, poses environmental risks that could reverberate well beyond India's borders**.**

Identifying the Causes of Stubble Burning

In India, the practice of stubble burning is characterized by its temporal and spatial specificity. The practice is extensively observed between the cropping seasons, particularly in summer and the onset of winter. However, its effects are predominantly experienced during the winter months, as the smoke dissipates rapidly in the warmer summer climate. There exist clear and pragmatic justifications for the practice of burning stubble. For the farmers, this method serves as a rapid and effective means to eliminate stubble, thus facilitating the preparation of the field for the upcoming crops in the next cropping season, given the brief interval of merely 10–15 days between the harvest of one crop and the sowing of another. Considering the practicality and cost-effectiveness of the exercise, it appears that farmers throughout India are likely to engage in the burning of stubble. Nevertheless, that is not the situation. The practice is confined to the north-western region of India, specifically within the states of Punjab, Haryana, and western Uttar Pradesh, and is rarely observed in other areas of the country. It is noteworthy that stubble-burning is not prevalent in the southern, eastern, and central regions of India, which are historically recognized as traditional rice-growing areas that cultivate rice during both primary cropping seasons. Consequently, to characterize stubble burning solely as an agricultural issue, attributed to the ‘stubborn, ignorant, unrelenting’ farmers seeking to enhance farm efficiency and reduce their costs, would merely scratch the surface of a far more complex situation. There exist profound historical and policy-oriented factors that contribute to the recurrent conflagrations in the agricultural regions of Punjab, Haryana, and western Uttar Pradesh with the arrival of each summer and winter season.

History imparts invaluable insights that empower us to shape a more enlightened present and future. However, it is frequently the case that particular events from history resurface to impact our current circumstances. The origins of stubble burning can be linked to the occurrence of the Green Revolution in India during the late 1960s. The agricultural scene of North-west India was significantly changed by the Green Revolution, which unintentionally fuelled stubble burning. A farm site could effectively grow both rice and wheat using a high-yielding variety (HYV) of rice appropriate for June–October cultivation, with only 10–15 days separating the two crops. Government policies supporting the Green Revolution helped to drive even more cropping practices harmful to the environment and marked by poor biomass management by complementing them. This included policies such as the guarantee of minimum price support only for rice and wheat in the stubble burning regions, which gave farmers a feeling of 'security' in the growing of these crops and hindered the diversification of agricultural practices. One important aspect of the Green Revolution was the improvement of large-scale mechanisation in the agricultural process. Since the onset of the Green Revolution, there has been a notable rise in the adoption of mechanized harvesting among farmers, aimed at enhancing efficiency and minimizing labour expenses, particularly accelerating in prevalence since the mid-1980s. Nonetheless, the use of mechanized harvesting present's challenges, as it tends to leave behind extended crop residues or stalks that remain anchored in the soil and are challenging to extract. The remnants or stubbles remaining after mechanized harvesting typically measure around 1 to 2 feet, in stark contrast to the mere 6 inches observed in manual harvesting. Given the presence of such residues and the limited time available for the disposal or removal of biomass between cropping seasons, it is understandable that farmers often turn to burning as a solution. In a nation like India, which faced a deficit in self-sufficiency regarding food grains during the 1960s, the origin or expense of the grains was of little consequence, provided that there was an enhancement in agricultural productivity. Although the behavioural and cost-reduction practices of farmers are significant factors contributing to stubble burning, it is essential to recognize that historical and policy-related influences have also played a crucial role in the continuation of this practice in North-west India.

Assessing the Impact of Crop Burning

1. **Environment:** While the Indian economy is significantly influenced by the agricultural sector, the processes of sowing and cultivation remain consistently stable. As a result, this culminates in the generation of substantial biomass waste or residue, which is annually incinerated, notwithstanding the numerous regulations promulgated by the Central Government to the State Governments. This practice of burning engenders environmental hazards, including global warming and pollution, thereby contributing to the elevated levels of particulate matter in the atmosphere. The production of particulate matter arises from the release of various gases, including Carbon Dioxide, Carbon Monoxide, Ammonia, Nitrogen Oxide, Sulphur Oxide, Methane, and aromatic hydrocarbons, along with other volatile and semi-volatile organic compounds that pose significant risks to the environment. The presence of particulate matter diminishes the essential nutrients retained in the soil, thereby hindering the enrichment of seeds sown subsequently with the necessary nutrients. Furthermore, it is noteworthy that the emission of particulate matter resulting from crop burning significantly exceeds the pollutants released by industrial activities or vehicular sources. Furthermore, particulate matter resulting from stubble burning disseminates to various states and cities with

remarkable agility, facilitated by the formation of smog, characterised by its brownish, cloudy appearance, which engenders severe pollution as it traverses the landscape.

2. **Ozone layer:** The presence of smog has a significant impact on the ozone layer, stemming from a complex interplay of causes and effects. Smog arises from the release of greenhouse gases produced through the combustion of stubble. Consequently, this results in a heightened concentration of deleterious gases in the atmosphere, including various compounds of carbon oxides, nitrogen, sulphur oxides, hydrogen, and other particular particulate matter released as a consequence of agricultural burning [14]. The gases consequently undermine soil fertility by depleting existing nutrients, while the detrimental impact of smog extends to human health and the environment, affecting surrounding vegetation and ultimately compromising the ozone layer that shields the Earth from ultraviolet radiation, as a significant portion of the ozone resides within a stratospheric layer relatively close to the Earth's surface. The practice of stubble burning alters the ratio of carbon to nitrogen, resulting in a rapid increase in soil temperature. This results in the resurgence of microbes even subsequent to combustion. Moreover, the essential nutrients such as carbon, nitrogen, phosphorus, sulphur, and potassium present in stubble are depleted as a result of combustion.

3. **Biodiversity:** The practice of crop residue burning is likely to result in a significant decline in the biodiversity of the specific state, which also presents a conflict with the Biodiversity Act, 2002 [15] ("the Act"). According to the Act, biodiversity encompasses the full spectrum of species inhabiting the ecosystem, which includes plants, animals, and the genetic materials originating from them, with the exception of human genetic materials. According to Section 18 of the Act, the National Biodiversity Authority is empowered to offer recommendations to both the Central Government and State Governments regarding matters related to the conservation of biodiversity, the sustainable utilisation of resources, and the fair distribution of benefits derived from biological resources. Section 36 of the Act holds significant relevance in the context of preventing crop burning, as it delineates two key responsibilities for the Central Government. Firstly, it is tasked with formulating policies and strategies aimed at conserving biological diversity and the resources derived from it for sustainable utilisation and equitable benefit-sharing. Concurrently, it must also engage in promoting, educating, and enhancing awareness among farmers and individuals within the respective state. Secondly, it is imperative to oversee and administer the areas of biological diversity and their resources, particularly when they are susceptible to or endangered by overexploitation, misuse, or detrimental activities impacting the environment and its context. It additionally bears the responsibility of scrutinising any risks linked to the advancement of projects concerning biological diversity and assessing their environmental impact. Should the situation prove detrimental and pose a threat to biological diversity, it is imperative that prompt measures are implemented to mitigate the associated risks. Therefore, the act of burning crop residue manifests the loss of biodiversity and its resources and further violates the provisions of the Biodiversity Act, 2002. The Central Government ought to implement advisory measures to deter states from engaging in the practice of burning residue, thereby preserving the harmony and equilibrium of biodiversity and its resources.

4. **Health:** The incineration of stubble generates a significant quantity of particulate matter along with gaseous pollutants such as sulphur oxides, nitrogen oxides, carbon monoxide, carbon dioxide, and methane, among others. The ozone layer experiences degradation due to the presence of carbon monoxide and carbon dioxide, which facilitates the transmission of ultraviolet light that poses significant risks to human skin. The presence of burning residue may result in various health hazards, including bronchial asthma, asthma, acute respiratory infections (ARI), and irritation of the eyes.

As a result of the heightened levels of smog, a significant 84.5% of individuals experienced heart-related complications, 76.8% reported eye irritation, 44.8% indicated discomfort in the nasal region, and 45.5% expressed concerns regarding throat irritation. Additionally, instances of wheezing rose by 18.0%, while cough-related issues saw an increase of 41.6%. Extended exposure to elevated levels of pollution likewise contributes to an increase in mortality rates. Various age demographics experience distinct impacts from the particulate matter produced through combustion. Children are at a heightened risk for Acute Respiratory Infections (ARIs) due to their elevated respiratory rates [16]. A study conducted by Gupta (2018) further substantiated the influence of particulate matter (PM) emitted during combustion on various physiological parameters in children. The combustion of paddy straw emits toxic gases such as carbon monoxide, which diminishes the blood's capacity to absorb oxygen, consequently resulting in respiratory complications. In a comparable manner, carbon dioxide emissions can cause irritation to the eyes, whereas nitrogen and sulphur oxides exert direct detrimental impacts on the blood, skin, lungs, and respiratory systems, potentially resulting in various diseases, including cancer [17].

1. **Aquatic Ecosystem:** The primary gas contributing to the greenhouse effect, among the myriad of gases released during stubble burning, is carbon dioxide, the concentration of which is steadily increasing over time. Given that carbon dioxide represents the most oxidised and thermodynamically stable state of the element, its conversion into alternative compounds poses significant challenges. The sole viable approach to eliminate it may involve gathering and preserving it. While the oceans serve as the primary reservoir for carbon dioxide emissions, the rising levels of carbon dioxide contribute to increased acidity in these waters, thereby impacting aquatic ecosystems.

NGT Guidelines and Measures

1. 2021: The Formulation of a Comprehensive Framework

In 2021, the Commission for Air Quality Management (CAQM), under the guidance of the NGT, initiated

discussions with various stakeholders, including the governments of Punjab, Haryana, Uttar Pradesh, and Rajasthan, along with knowledge institutions like ICAR, IARI, and ISRO. These deliberations culminated in a multi-pronged framework to manage stubble burning effectively [18].

The framework developed in 2021 revolved around six key pillars aimed at addressing the stubble burning crisis comprehensively. First, in-situ crop residue management focused on encouraging the use of bio-decomposers to convert crop residues into organic manure, alongside promoting the adoption of machinery like Happy Seeders and Super Straw Management Systems. These technologies facilitated direct sowing without the need for residue removal. Second, ex-situ crop residue management promoted the utilization of paddy straw as a resource in biomass power plants, ethanol production, and industrial boilers, providing an economic alternative to burning. Third, stringent enforcement of crop residue burning prohibitions was implemented, with strengthened mechanisms at state, district, and village levels to ensure compliance. Fourth, monitoring and enforcement were enhanced through the use of satellite-based tracking of fire incidents, utilizing protocols developed by ISRO to provide real-time data on stubble burning activities. Fifth, information, education, and communication (IEC) campaigns played a crucial role in raising awareness among farmers through print, electronic, and social media, as well as farmer workshops and demonstration camps. Lastly, efforts were made to reduce residue generation by advocating for crop diversification and the adoption of early-maturing paddy varieties, thus addressing the root causes of the issue.

2. 2022: Updates and Reductions

Building on the experiences of 2021, the NGT directed states to refine their action plans further. Emphasis was placed on expanding CRM machinery distribution and adopting bio-decomposer technology. Punjab recorded 49,922 fire counts compared to 71,304 in 2021, showing a reduction of over 30%. Haryana's fire counts decreased significantly to 3,661 from 6,997 in the previous year, demonstrating nearly a 47% decline. Uttar Pradesh NCR also saw a drop to 198 incidents, marking consistent progress in curbing the problem [19]. Over 1 lakh CRM machines, including Happy Seeders and Super Straw Management Systems, were made available across Punjab and Haryana to support farmers in adopting sustainable practices [20]. Real-time tracking of fire incidents through ISRO's satellite-based protocols allowed for better enforcement and immediate intervention in areas with high fire counts. Extensive use of multimedia platforms, including radio jingles, TV spots, and social media, helped educate farmers about the consequences of stubble burning. Village-level demonstration events showcasing the effectiveness of bio-decomposer technology and machinery were also organized.

3. 2023: Strengthening the Efforts

Recognizing the need for sustained efforts, the CAQM began preparations for the 2023 season as early as February [21]. The focus shifted to district-specific action plans, ensuring localized solutions for a more targeted approach. Punjab aimed for zero incidents in six districts, with a 50% reduction in others [22]. Haryana and Uttar Pradesh NCR targeted near-complete elimination of stubble burning incidents. Punjab deployed 1,17,672 CRM machines by 2023, reflecting a significant increase from the previous year. Haryana's count increased to 80,071 machines, ensuring greater access for farmers [23]. The ex-situ management of paddy straw surged from 3.31 million tonnes in 2022 to 6.62 million tonnes in 2023, encompassing diverse industrial applications like biomass power generation, ethanol production, and compressed biogas plants. Collaborative events with stakeholders like TERI and IIT Tirupati promoted innovative and sustainable practices for residue management. Significant reductions in fire counts across Punjab, Haryana, and Uttar Pradesh NCR were reported, continuing the trend from 2022. Increased adoption of bio-decomposer technology and CRM machinery reflected the success of awareness campaigns and government subsidies.

4. Technological and Policy Interventions

ISRO's satellite imagery was employed to monitor and record fire incidents [24]. This real-time data enabled authorities to take swift action and track the effectiveness of mitigation measures [25]. The standard protocols provided precise data on the number and locations of fire events. Developed by IARI, the PUSA bio-decomposer converts crop residue into organic manure. Despite its potential, feedback indicated that it needed to be integrated with agricultural machinery for effective results. For the 2023 season, extensive application was promoted across several thousand acres in Punjab, Haryana, and Uttar Pradesh NCR. Under the Central Sector Scheme on Crop Residue Management, farmers were offered financial assistance to purchase CRM machinery [26]. Cooperative societies and Custom Hiring Centers (CHCs) received subsidies to facilitate machine rentals for small and marginal farmers, ensuring broader accessibility. Paddy straw was utilized in biomass co-firing in thermal power plants, production of ethanol in bio-refineries, compressed biogas plants, and other industrial applications, including packaging and cardboard manufacturing.

Judicial Approach in India towards Stubble Burning

The development of environmental law in India has progressed notably, especially through the interpretation of Article 21 [27] of the Constitution, which ensures the right to life. The judiciary has broadened the scope of Article 21 to encompass the right to a clean and healthy environment. This analysis has established a legal basis for tackling environmental concerns such as stubble burning [28].

The concept of sustainable development, which harmonises economic advancement with ecological preservation, has served as a fundamental element of environmental law in India. In the case of Vellore Citizens Welfare Forum v. Union of India [29], the Supreme Court acknowledged the significance of sustainable development within the framework of Indian law, highlighting the imperative to safeguard the environment for the benefit of future generations. Cited in stubble burning-related cases, this idea supports the adoption of sustainable farming methods [30].

A major component of environmental law, the precautionary approach has also been applied in situations involving stubble burning. Confronted with environmental risks, the precautionary approach calls for proactive actions even without clear scientific proof. Emphasising the need to

foresee, prevent, and reduce environmental damage, the court restated this principle in A.P. Pollution Control Board v. Prof. M.V. Nayudu [31]. Under the concept of stubble burning, this idea has been used to advocate the execution of proactive measures meant to reduce air pollution.

Stubble burning in India can be linked to the introduction of mechanised agriculture and the Green Revolution during the 1960s and 1970s. Though it led to great agricultural residue generation, this time saw a significant increase in crop yields [32].. In states like Punjab and Haryana, the post-harvest burning of paddy straw became a common practice, fuelled by the lack of cost-effective alternatives for residue disposal. Over the decades, this practice has emerged as a major contributor to seasonal air pollution in northern India, particularly in the National Capital Region (NCR). The winter months exacerbate the situation, as cooler temperatures and low wind speeds trap pollutants closer to the ground, creating thick smog that severely impacts public health and daily life [33].

By the turn of the century, the issue had escalated to a pivotal point, capturing the focus of legislators, environmental advocates, and the legal system. Preliminary analyses concentrated on regulatory frameworks; however, the implementation of these measures was hindered by the economic limitations encountered by agricultural producers. Acknowledging the insufficiency of administrative measures, the judiciary assumed a proactive role in tackling the issue of stubble burning. The judiciary, notably the Supreme Court and the National Green Tribunal (NGT), commenced the interpretation of constitutional provisions, particularly Article 21 (Right to Life), to establish a connection between environmental protection and fundamental rights. The phenomenon of judicial activism was significantly propelled by pivotal cases such as M.C. Mehta v. Union of India [34] and Subhash Kumar v. State of Bihar [35], which established a foundational basis for categorising stubble burning as an infringement on the right to clean air.

Over the years, the interventions by the judiciary evolved to become increasingly focused and precise. The Supreme Court's suo motu cognisance in Aditya Dubey v. Union of India [36] represented a significant development, highlighting the responsibility of state governments and the importance of encouraging farmers to embrace sustainable alternatives. Concurrently, the NGT promulgated a series of directives designed to advance in-situ residue management technologies, impose penalties for infractions, and establish frameworks for public awareness initiatives. By 2024, judicial directives had prompted the establishment of satellite monitoring systems, financial support for residue management machinery, and cooperative initiatives between state and central governments.

This evolution of judicial oversight demonstrates the courts' increasing recognition of stubble burning as a multi-faceted issue requiring a blend of legal, technological, and socio-economic solutions. The following sections delve into the judiciary's approach, highlighting case laws, environmental jurisprudence, and the practical measures enforced to mitigate this environmental crisis [37].

By using several techniques that balance enforcement with motivation, the judiciary has taken a vital role in maintaining compliance with laws and policies meant to address stubble burning. Judicial institutions have consistently stressed the need of promoting sustainable practices through government-led projects in view of the economic difficulties experienced by farmers. Specifically, state governments have been told to fund technologies like Happy Seeders and Super Straw Management Systems, which enable in-situ residue management without using fire [38].

Aiming to strengthen enforcement systems, the judiciary has supported increased monitoring and harsher punishments for rule violators. The Supreme Court ordered the use of satellite pictures to track fire events and to impose penalties on districts showing notable infractions in Aditya Dubey v. Union of India (2020) [39]. Likewise, the National Green Tribunal (NGT) in Vikrant Tongad v. Environment Pollution (Prevention and Control) Authority [40] ordered local governments to create district-level task forces responsible for guaranteeing compliance and quickly handling infractions.

Judicial institutions have also underlined, therefore, the need of projects meant to raise public knowledge. Governments have been told to tell farmers about the environmental and health effects linked with stubble burning by means of mass media outlets including radio, television, and social media. These projects provide information on the paths agricultural workers might get technical and financial help and highlight even more the benefits of other approaches. Advancement of ex-situ residue management—including the use of paddy straw in biomass power generation and the manufacture of ethanol—has been a major goal. The National Green Tribunal ordered the creation of supply chain systems meant to encourage the use of crop residue in several industrial uses in Council for Environment, Education and Development v. State of Punjab (2021) [41] This strategy provides a different income source for farmers as well as addresses the disposal issue.

Judicial orders have advanced to address stubble burning as a multifaceted problem by including technological developments, financial support, and strict enforcement to create a comprehensive framework for compliance. These actions underline the active attitude of the court in tackling one of India's most pressing environmental concerns.

Challenges in Judicial Intervention

Notwithstanding the active engagement of the judiciary, numerous obstacles persist in the effort to tackle the issue of stubble burning. The obstacles presented include economic, administrative, and social factors that impede successful execution and adherence [42].

1. **Economic Constraints:** Numerous agricultural producers in regions such as Punjab and Haryana, where the practice of stubble burning is particularly widespread, face significant financial constraints that hinder their ability to adopt sustainable technologies like Happy Seeders or bio-decomposers, despite the availability of subsidies. The initial financial burdens linked to these technologies present significant challenges for small and marginal farmers. Moreover, the procrastination in the allocation of financial assistance intensifies the issue, compelling farmers to turn to burning as a rapid and cost-effective remedy.

2. **Implementation Gaps:** There is a notable disparity between the mandates issued by the judiciary and their practical implementation in reality. Local authorities

frequently encounter limitations in resources and personnel, which hampers their ability to effectively oversee and ensure adherence to regulations. For example, while the implementation of satellite-based monitoring for fire incidents has been required, the execution of ground-level measures to rectify violations continues to be uneven. The absence of effective enforcement undermines the efficacy of judicial mandates, permitting ongoing non-compliance to endure.

3. **Awareness Deficits:** A significant number of farmers lack awareness regarding the enduring advantages of sustainable agricultural methods and the existence of governmental programs that facilitate residue management. The insufficient distribution of information via focused campaigns intensifies this problem. Furthermore, the entrenched nature of traditional residue disposal methods introduces a further dimension of complexity, as there exists a cultural resistance to the adoption of new practices.

4. **Coordination Issues:** Effectively tackling the issue of stubble burning necessitates a harmonious collaboration among a diverse array of stakeholders, encompassing both central and state governments, local authorities, agricultural producers, and non-governmental organisations. Nevertheless, discordant priorities and a lack of effective collaboration frequently hinder the development and implementation of unified action strategies. For example, variations in the timelines for policy implementation among different states lead to disjointed efforts, thereby diminishing their overall effectiveness.

5. **Short Windows:** The short time between paddy harvest and wheat planting creates a major logistical challenge. Farmers often have only two to three weeks to prepare their fields, which greatly limits the viability of using time-consuming options like in-situ residue management. This urgent need often drives farmers to burn their fields as the quickest way to clear them.

6. **Penalty and Support Imbalance:** The small window of time between paddy harvest and wheat planting presents a significant logistical difficulty. Farmers usually have just two to three weeks to get their fields ready, which severely reduces the feasibility of using labour-intensive techniques such in-situ residue management. Often, this pressing demand pushes farmers to set fire to their fields in the fastest means of clearing them.

These difficulties' continuous character emphasises the complex character of handling stubble burning. Dealing with these issues calls for a thorough approach combining judicial oversight, policy development, technical innovation, and community participation. By means of the investigation of these issues, India could move closer to achieving permanent solutions for one of its most pressing environmental concerns.

Suggestions

1. **Financial Support:** Reducing the economic strain on farmers and encouraging the incorporation of sustainable practices depends on a good financial system. Particularly for small and marginal farmers who struggle economically, it is absolutely necessary to increase financial assistance for residue management tools such Happy Seeders and bio-decomposers. These subsidies could significantly lower the financial barriers, therefore enabling access to advanced technologies for a larger portion of the agricultural sector. Moreover, the application of a carefully planned rental system for machinery through Custom Hiring Centres (CHCs) in every district can ensure that even the humblest farmers have access to these necessary tools. Monetary incentives tied to sustainable practices, such as financial rewards for abstaining from stubble burning, can serve as quick motivators during the evolution of more lasting solutions.

2. **Crop Diversification:** Increasing cropping patterns is essential to reduce dependence on the paddy-wheat monoculture, a key contributor to the stubble burning problem. Farmers should think about switching to other crops, such maize, millets, or pulses, which produce less waste. The government must set higher Minimum Support Prices (MSPs) and consistent procurement systems for these alternative crops if this change is to be implemented successfully. By reducing residue and enhancing soil health, crop diversification helps to promote sustainable agricultural practices by supporting biodiversity as well. Demonstrations of pilot projects highlighting the economic viability and environmental benefits of crop diversification could help to convince farmers to accept these changes.

3. **Implementation and Monitoring:** Successful implementation of anti-burning rules depends on local governments having adequate resources and suitably qualified staff members. Operational level staff members must have the necessary tools and power to supervise and handle violations properly. Real-time monitoring and early intervention plans are made possible by the implementation of advanced technologies including artificial intelligence and predictive analytics. Combining mobile apps for on-the-ground reporting with satellite-based monitoring of fire incidents could greatly enhance both accountability and responsiveness in handling such events. Systematic evaluations and unambiguous reporting systems must be developed to gauge the effectiveness of implementation projects and enable necessary changes.

4. **Research and Development:** Research and development (R&D) are critical components of identifying innovative and lasting remedies to the stubble burning problem. It is imperative that additional financial resources be directed towards the advancement of economically viable and agriculturally beneficial technologies for the management of agricultural residues. Partnerships among educational establishments, research entities, and private industry can expedite the advancement of sophisticated machinery and bio-decomposition methodologies. For

example, advancements such as the PUSA bio-decomposer have demonstrated potential in expediting the natural decomposition of agricultural residues. Implementing these technologies necessitates comprehensive field trials and strategic dissemination approaches to facilitate broad acceptance.

5. **Industrial Utilization of Residues:** Using crop leftovers in industrial processes offers a sustainable substitute for burning, therefore transforming waste into precious resources. Improving the capacity of compressed bio-gas projects, ethanol production plants, and biomass power plants will significantly help to reduce the load of leftover waste. Connecting inside the supply chain will help to move excess leftovers to these businesses. Regulations mandating the inclusion of crop residues in industrial uses, such biofuel production or as feedstock for thermal energy plants, may promote their adoption and use. Financial incentives and government support for industries adopting residue-derived inputs will encourage more participation and capital injection.

6. **Awareness and Community Engagement:** Changing ingrained habits like stubble burning calls for constant awareness campaigns and community involvement. Comprehensive programs should tell farmers about the environmental and health effects of burning crop leftovers as well as the economic benefits of other approaches. Outreach projects might effectively communicate information using mass media, digital social networks, and localised community ties. Finding and rewarding farmers who use sustainable methods will help to create role models and inspire change by means of peer influence. Working with local organisations like educational institutions, women's groups, and agricultural cooperatives helps to foster a group commitment in the community to eradicate stubble burning.

Implementing these suggestions calls for a joint effort among several stakeholders including government agencies, the courts, business leaders, and local communities. By means of a thorough analysis of the economic, technological, and behavioural dimensions of the problem, India could create a sustainable agricultural system stressing environmental integrity and the welfare of its people. By means of constant focus and collaborative endeavours, these projects could help to build a future free of the environmental and health problems connected to stubble burning. Stubble burning in India highlights the larger struggle to balance agricultural efficiency with environmental preservation. Notwithstanding significant progress made through judicial interventions, policy changes, and technical breakthroughs, much remains to be done. A thorough approach that combines economic incentives, robust enforcement mechanisms, and community involvement-driven solutions will help to address this problem effectively. The results of this study underline how important cooperation among many different players is in the campaign to eradicate stubble burning. Government agencies, the courts, business interests, and civil society must work together to create a sustainable agricultural system that benefits farmers and protects environmental integrity and public health at the same time. India can solve the problem of stubble burning efficiently by means of unrelenting efforts and a commitment to progressive solutions, therefore promoting a cleaner and better future.

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