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A Systematic Review of Environmental and Health Impacts of Agricultural Stubble Burning and Sustainable Management Strategies in India

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Abstract: *Agricultural stubble burning in India is a prevalent practice that significantly contributes to air pollution, adversely affecting environmental quality and public health. This systematic review analyzes the extent of air pollution caused by stubble burning, its impact on human health, and the environmental consequences. The review also evaluates various sustainable strategies, including alternative residue management techniques, policy interventions, and community awareness. In India, the practice of burning agricultural biomass, including residues from crops such as wheat, rice, and sugarcane, has a notable negative impact on air quality. Farmers resort to burning crop residues primarily to rapidly clear fields for subsequent planting, due to the absence of adequate tools and technologies to manage leftover plant material. Burning of crop residues produces harmful pollutants like particulate matter, carbon monoxide, carbon monoxide, methane, sulfur compounds, nitrogen oxides, and greenhouse gases, resulting in environmental pollution and health issues. Exposure to smoke from stubble burning is associated with respiratory problems, cardiovascular diseases, and other health issues in affected populations. In India, residue burning presents a serious environmental issue by degrading air quality, public health, and soil health. To mitigate these impacts, sustainable practices such as composting, residue incorporation, nutrient management, biogas, bioenergy, and biochar production have been identified as effective alternatives. These methods enhance soil fertility, reduce pollution, and promote sustainable agricultural practices. This study highlights the critical importance of implementing sustainable agricultural practices through farmer awareness and participation. Therefore, curbing agricultural burning is essential to improve air and soil quality, thereby safeguarding environmental health and promoting long-term agricultural sustainability in India.*

Keywords: *Agriculture wastes, Bioenergy, Crop residue, Particulate matter, Sustainability*

Introduction

Stubble or crop residues are the remains of crops left in fields post-harvest. Crop residue burning, commonly practiced after harvesting and before planting, serves to remove leftover crop material, dispose of agro-waste, and eliminate pests and weeds (Gatkal et al., 2024). Despite its widespread traditional use in many regions, this practice significantly contributes to atmospheric pollution by releasing aerosols and trace gases, which have detrimental effects on human health, climate, and the environment (Huang et al., 2012; Shyamsundar et al., 2019). Proper management of these residues is vital for maintaining soil fertility and facilitating nutrient cycling, which influences subsequent agricultural practices. However, the common practice of burning these residues leads to significant air pollution, contributing to pollution from industrial and vehicular sources (Gurjar et al. 2016). Addressing residue management is therefore essential both for sustainable farming and environmental protection. Burning crop residues, like rice straw, is common in farming but negatively impacts soil health, reduces crop yield, and wastes water (Goswami et al. 2020). This practice leads to loss of important nutrients, with about 5.5 kg of nitrogen lost for every tonne of rice straw burned, and it also releases nitrous oxide, a harmful greenhouse gas (Kaur et al. 2021). In India, the practice of burning crop residues is widespread, especially for rice, wheat, and sugarcane, with rice accounting for 80% of the burned residues (Jain et al. 2014). This method of residue management can lead to a higher reliance on synthetic fertilizers, which may negatively impact soil health. Additionally, the burning process contributes to environmental pollution, raising concerns about sustainability and ecological balance (Cheng et al. 2014; Chivenge et al. 2020). The practice of burning crop residues in agricultural fields differs widely depending on the region and crop type. This uncontrolled burning emits a variety of harmful pollutants into the atmosphere, including particulate matter (PM10, PM2.5), methane, carbon compounds, carbon monoxide, carbon dioxide, sulfur dioxide, nitrogen oxides, ammonia, volatile organic compounds, and polycyclic aromatic hydrocarbons. These emissions contribute significantly to air pollution problems, particularly in countries such as India, China, and across Southeast Asia, where crop residue burning is prevalent. (Awasthi et al. 2011; Jain et al. 2014; Zhang et al. 2018; Kim Oanh et al. 2018). South Asian countries primarily cultivate rice, wheat, and maize, generating large amounts of crop residues annually after harvest (Gathala et al. 2017). This practice deteriorates soil structure, increases erosion, and contributes to greenhouse gas emissions and ground-level ozone formation, which harms crops and promotes pests and diseases (Sarkar et al. 2020). The resulting smoke degrades air quality, especially in winter, increasing respiratory infections among local populations, particularly children (Gupta 2019; Chakrabarti et al. 2019). Bhuvaneshwari et al. (2019) explore the persistent issue of crop residue burning in India, identifying that sustainable management practices supported by robust government policies are key to resolving the problem. The Indian Ministry of New and Renewable Energy (MNRE) reports that India produces approximately 500 million tons of crop residue each year (NPMCR 2014). These large volume of crop residue presents opportunities for renewable energy and sustainable waste management. Crops residue burning raises subsoil temperatures to 33.8–42.2 °C at 10 mm depth, and the long-term thermal impact of such burning extends deeper, affecting soil temperatures up to 15 cm (Gupta et al. 2004). Consequently, increased soil temperatures may affect soil properties and biological activity over time. Therefore, crop residue burning negatively impacts agriculture, the environment, and human health. Higher crop production results in more crop residue generation. Therefore, identifying sustainable ways to manage crop residue is essential as an alternative to burning.

Methods

The present review studies conducted peer-reviewed scientific literature, annual institutional reports, and conference proceedings published within a specific timeframe. The methodology involved identifying relevant literature, screening for relevance, assessing eligibility, and conducting a qualitative synthesis. The study comprised 258 research articles, including annual reports, and conference publications within the defined period. The study involved systematic searches across prominent databases such as Google Scholar, Scopus, and Web of Science to gather relevant literature on crop residue burning in South Asia. Specific search terms included "biomass burning," "agriculture wastes," "crops left over," "stubble burning," and "air pollution from crop burning." To maintain scientific rigor and relevance, the study selected only peer-reviewed articles published in English within the last 12–18 years, including annual reports and conference proceedings with primary data. Excluded were articles without full text, studies lacking complete methodological details, duplicate publications, and papers unrelated to the review's focus. These inclusion and exclusion criteria ensured the reliability, consistency, and contemporary relevance of the data extracted for the study. A flow chart from PRIMSA illustrates the process (Figure 1).

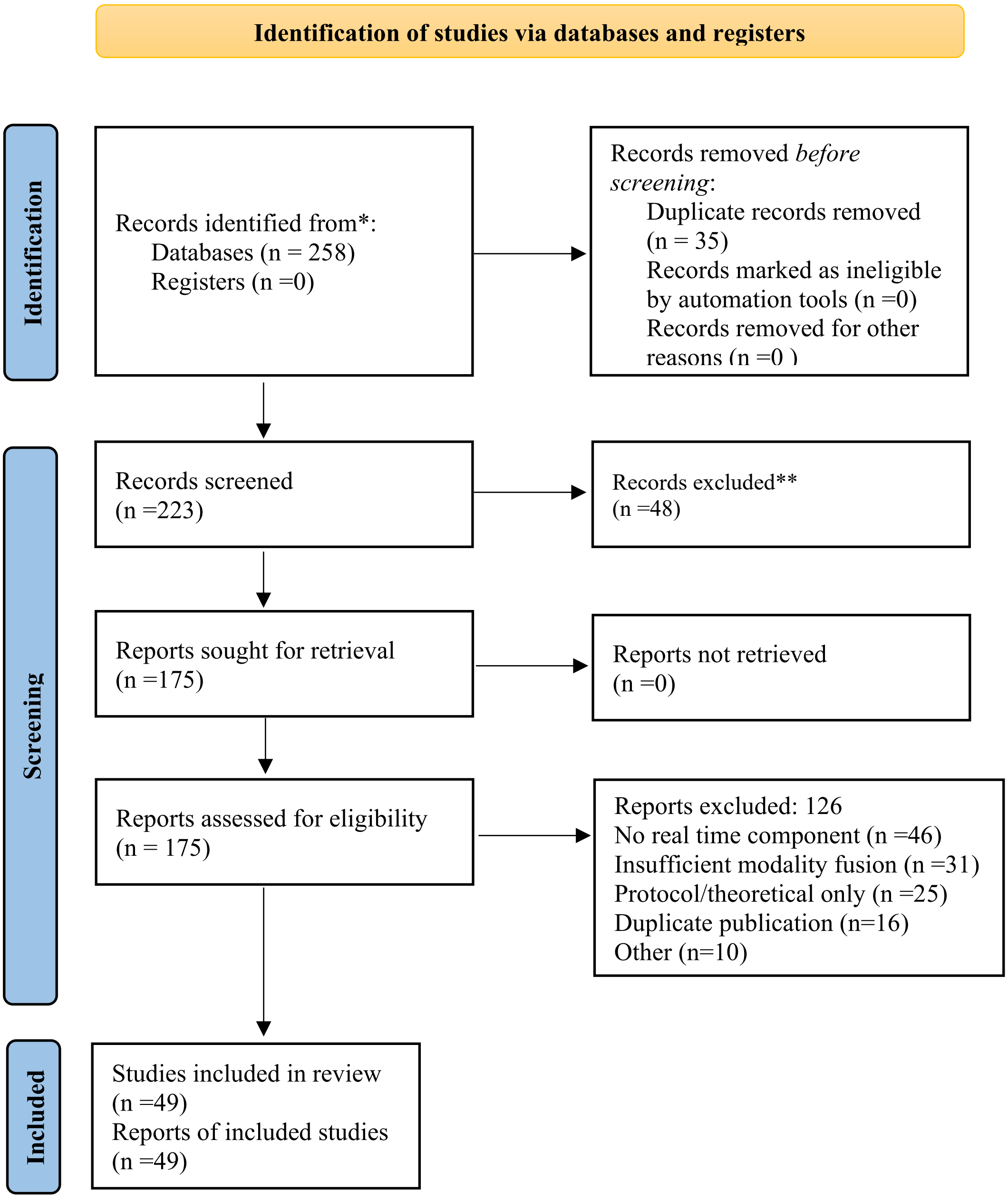

Fig. 1: PRISMA Flow Diagram of Study Selection (Page et al. 2020)

Results

Challenges

Crop residues left in agricultural fields pose a significant challenge for farmers. Removing these residues manually requires considerable time and financial resources. To avoid these costs, many farmers opt to burn the residues directly in the fields (Kaushal and Prashar 2021). This practice helps them save both time and money, although it may have other environmental and agronomic implications. Moreover, farmers have only 7 to 10 days between harvesting and planting, leading them to burn crop residues to clear fields quickly (Kumar and Singh 2020). To manage weeds and pests, they believe the ash improves soil nutrients like potassium (Irfan et al. 2014). Rice straw is not good for animal feed due to low nutritional value, and there is no market for stalks and stubble, promoting burning (Kaur 2017; Kaushal 2020; Kaur et al. 2021). Farmers often don't know about the health and environmental risks of this practice. Larger farms produce more crop leftovers, but farmers who don't have animals or who are far from their fields usually do not gather these leftovers. This situation leads to more burning of crop residue (Ahmed et al. 2015; Rafiq et al. 2019; Bajracharya et al. 2021).

Present scenario

Crop residue burning is a prevalent agricultural practice in South Asia, producing substantial emissions of greenhouse gases and air pollutants. In 2009, India generated approximately 620,000 Gigagrams (Gg) of crop residue, with 16% burned on farms (Jain et al. 2014), while Pakistan produced 62,470 Gg in 2014, burning about 20,000 Gg (Azhar et al. 2019). Nepal's crop residue burning increased from 2,280 Gg in 2003/04 to 2,908 Gg in 2016/17, with 25% burned (Das et al. 2020). Bangladesh's rice residue, primarily from Aman rice, is frequently burned post-monsoon in the Indo-Gangetic Plains (IGP) (Haider 2013). In Nepal, over 80% of air pollutants, such as CO_2, CO, CH_4, SO_2 and $PM_{2.5}$, come from crop burning between February and May (Das et al. 2020). Indian states such as Punjab, Haryana, Maharashtra, and Uttar Pradesh report the highest incidence (Jain et al. 2014; Shyamsundar et al. 2019; Kaushal and Prashar 2021). In 2017, residue burning contributed notably to N_2O emissions, accounting for about 24%, and other emissions are projected to rise by 45% by 2050 without intervention (Ravindra et al. 2019).

The Intergovernmental Panel on Climate Change (IPCC) identifies Uttar Pradesh as the leading state in crop residue burning, followed by Punjab and Haryana. It estimates that more than 25% of total crop residues are burnt on farms nationwide. The proportion of paddy residue burned varies significantly across different states, ranging from 8% to 80% (Jain et al. 2014). Among crop types, rice residues account for the largest share of burning at 43%, followed by wheat at 21%, sugarcane at 19%, and oilseed crops at 5% (Sahai et al. 2011). These findings highlight the significant regional and crop-specific contributions to agricultural residue burning in India.

India's agricultural system generates substantial quantities of crop residues annually, including cereal straws, woody stalks, and other crop wastes (Kang et al. 2009). A significant portion of crop residues remains unused and is left in agricultural fields despite some being used for fodder, cooking, and fuel (Roy and Kaur 2015). Moreover, turnover period of rice residue in soil is prolonged primarily because of its poor nitrogen content with high carbon-to-nitrogen (C:N) ratio, resulting slows down microbial decomposition processes. Additionally, absence of adequate soil moisture at the end of the harvesting period further inhibits the breakdown of the residue (Goswami et al. 2020). Consequently, rice residue remains in the soil for an extended duration, affecting nutrient cycling and soil health.

Discussion

Impact on the environment

Burning of agricultural residues, especially stubble burning, is a major problem in many regions worldwide (Shyamsundar et al. 2019). Stubble burning is a common farming practice used around the world, especially in developing countries, to get rid of crop leftovers after harvest. This practice releases harmful gases and particulate matter, causing serious air pollution that harms both health and the environment (Anu Rani Sharma et al. 2010). These burning is a harmful agricultural practice that leads to various forms of environmental degradation. It deteriorates air quality by releasing pollutants, contaminates the upper soil surface, and reduces soil fertility. This degradation ultimately decreases land productivity, negatively impacting farmers' profitability (Lohan et al. 2018; Abdurrahman et al. 2020). It also disrupts the environment by contributing to climate change, reducing soil fertility, and affects economic development (Reddy et al. 2019. The environmental impacts include rising global temperatures and further damage to the ozone layer, which threatens ecological balance and human health (Reddy et al. 2019). Additionally, burning crop residues results in a significant loss of carbon, reducing the environment's ability to store carbon and worsening climate change issues (Singh et al. 2020). Moreover, rice cultivation accounts for more than 10% of global agricultural greenhouse gas emissions and approximately 1.3% to 1.8% of total anthropogenic greenhouse gas emissions worldwide (Maraseni et al. 2018). So, it is important to address stubble burning for sustainable farming and environmental protection. Overall impacts of crop residues (CR) burning in various sectors are depicted in Figure 2.

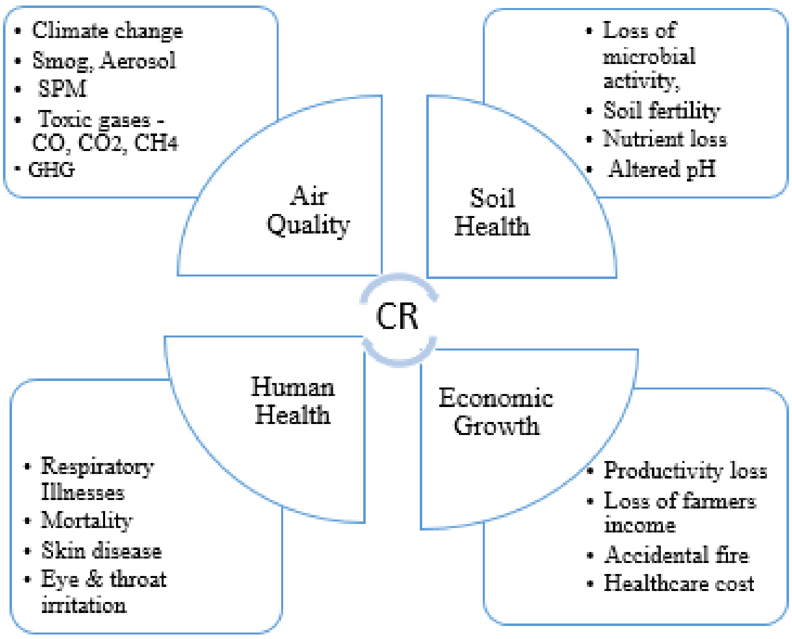

Fig. 2: Overall impacts of crop residues (CR) burning in various sectors

Air pollution

Crop residue burning is a major contributor to air pollution, releasing a wide range of harmful substances into the atmosphere. These pollutants include greenhouse gases like carbon dioxide (CO_2) and carbon monoxide (CO), as well as ammonia (NH_3), nitrogen oxides (NOX), sulfur oxides (SOX), non-methane hydrocarbons (NMHC), volatile organic compounds (VOCs), semi-volatile organic compounds (SVOCs), and black carbon, and particulate matter of PM2.5 and PM10 (Zhang et al. 2011). The increased presence of these pollutants contributes detrimental effects on air quality and negatively impact human health and the environment (Ravindra et al. 2019; Chanana et al. 2023). Emissions of particulate matter (PM) with various gaseous compounds from burning of major crop residue are presented in Figure 3

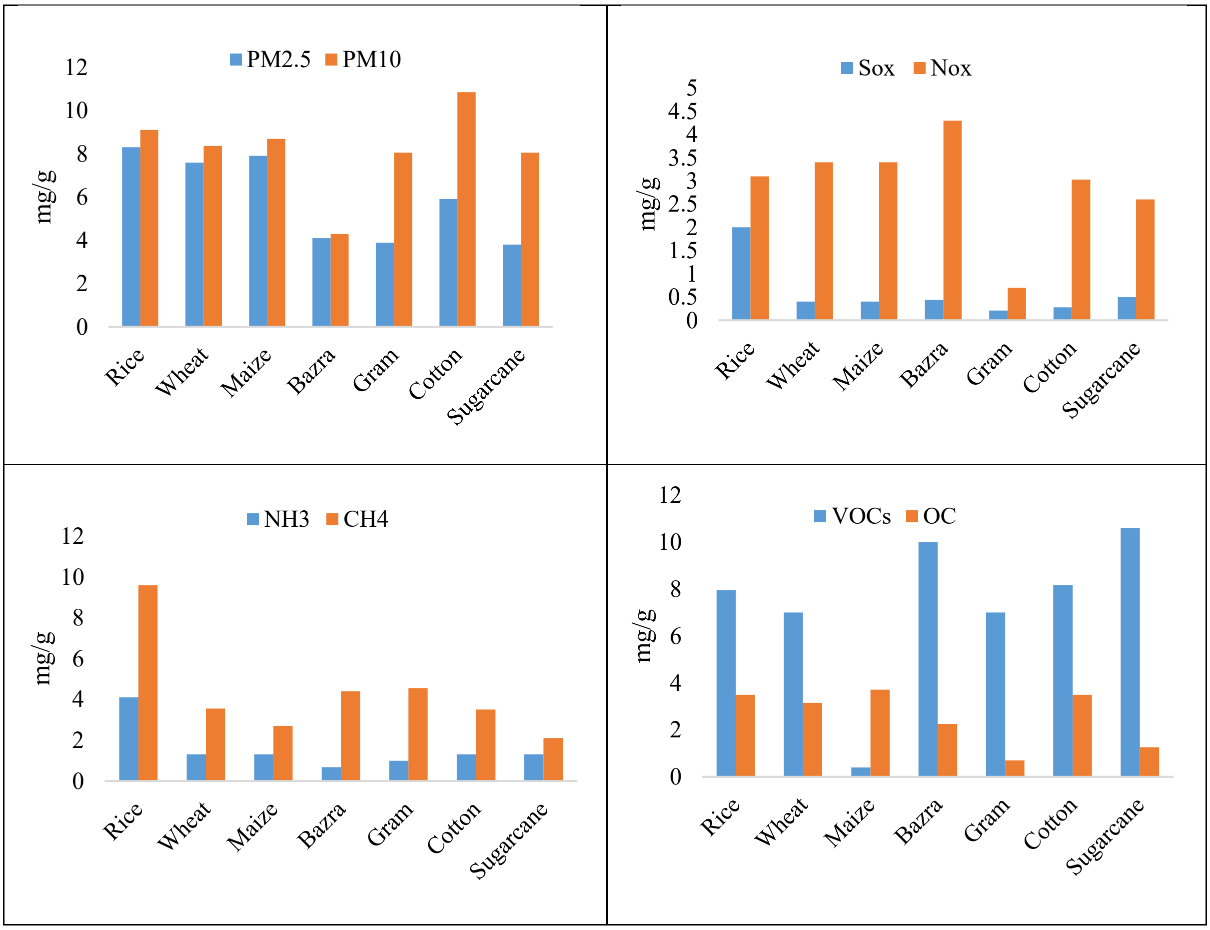

Fig. 3: Emissions of particulate matter (PM) with various gaseous compounds from burning of major crop residue (Sahu et al. 2021; Ravindra et al. 2019).

Agricultural productivity

Particulate pollution from staple burning disrupts agricultural productivity. Plants exposed to this pollution can suffer from problems like chlorosis and bifacial necrosis, affecting their growth and yield (Ghosh et al., 2019). Crop residue burning has detrimental effects on agricultural ecosystems. It reduces soil microbial diversity, which is crucial for maintaining soil health and fertility. Additionally, burning crop residues leads to an increase in pest populations within agricultural fields, posing challenges for crop protection. Furthermore, this practice depletes essential soil nutrients, thereby threatening the sustainability and productivity of crops over the long term (Parambil-Peedika et al. 2025). Hence, the risks of ongoing air pollution from biomass burning require sustainable practices to protect crop health.

Impact on soil

Stubble burning, often used in farming, damages the environment and soil health. It worsens air quality by releasing harmful pollutants and decreases soil fertility because burning destroys essential minerals needed for productive soil. This causes a double problem: increased air pollution and reduced soil nutrients, which can harm crop yields and long-term farming sustainability (Singh et al., 2018). Burning also significantly affects soil enzymes such as β-glucosidase, urease, acid phosphatase and protease, mainly due to thermal damage and changes in microbial communities (Sun et al. 2021). Fungi are more impacted by burning than bacteria, but these effects are temporary, allowing microbial communities to recover over time. Mesothermic microbes, which prefer moderate temperatures, experience the most severe effects (Dutta et al. 2022).

Human health

Stubble burning produces harmful fine particulate matter (PM2.5) that can enter the lungs and bloodstream, causing eye and lung problems and raising healthcare costs (Anu Rani Sharma et al. 2010). This pollution is a major health issue in South Asia, particularly in India, where it increases the risk of respiratory infections (Krishna et al. 2017). Wind spreads these pollutants to neighbouring countries like Pakistan, Nepal, and Bangladesh, worsening air quality and health effects in those areas (Sarkar et al. 2018; Bikkina et al. 2019). Overall, burning crop residue leads to more cardiac and respiratory illnesses and deaths both indoors and outdoors (Chen et al. 2017).

Alternate practices

Crop residue management is essential for sustainable agriculture, offering benefits like improved soil health, reduced greenhouse gas emissions, and renewable energy generation. By implementing good management practices, farmers can protect natural resources and support their local economy. It is important to understand the value of crop residues and handle them properly to maximize their use (Jain et al. 2014). These residues play a key role in various applications, enhancing agricultural sustainability and environmental health (Keenan et al. 2015). Sustainable farming practices fosters environmental protection and a resilient agricultural future, and supporting farmers is crucial for achieving these goals. Crop residues like maize stover and wheat straw can be used in several ways, including biofuel production, livestock feed, and paper industry, promoting economic growth and reducing waste. Overall, the utilization of crop leftovers supports environmental sustainability and circular economy. Alternative initiatives of based practice for management of crop residues are depicted in Figure: 4.

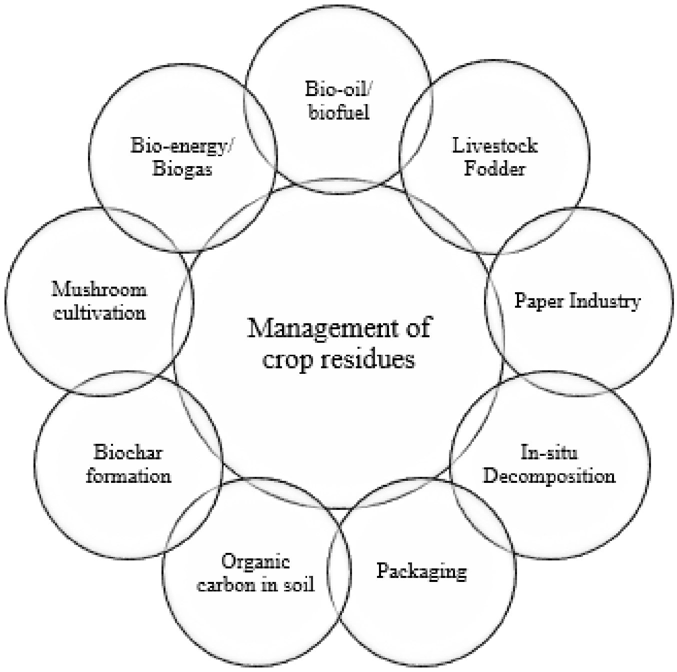

Fig. 4: Sustainable initiatives of based practice for management of crop residues

Nutrient Management

The practice of incorporating crop residues into agricultural fields is encouraged as a means to maintain soil organic matter and improve soil fertility (Ravindra et al. 2018). Incorporating crop leftovers back into the soil helps recycle nutrients and reduces the need for chemical fertilizers. This natural process maintains soil health and leads to more sustainable farming by minimizing the use of external fertilizers. Crop straw naturally contains important nutrients like nitrogen, phosphorus, and potassium. Adding straw to the soil recycles these nutrients, making the soil more fertile (Yin et al. 2017). This method promotes sustainable farming and leads to better crop growth by improving nutrient availability and soil quality. Crop residues serve as a natural organic fertilizer rich in nutrients, improving soil quality and potentially replacing chemical fertilizers and pesticides (Gottipati et al. 2021; Singh et al. 2021).

Composting

Composting is an effective way to utilize crop leftovers by combining them with other organic waste materials. This process results in nutrient-rich compost that enhances soil fertility. Crop residues contain high concentrations of nutrients that plants can easily absorb. The compost typically contains vital nutrients such as nitrogen (2%), phosphorus (1.5%), and potassium (1.4-1.6%), which are essential for plant growth (Abdurrahman et al 2020). This method not only recycles agricultural waste but also contributes to sustainable farming practices by improving soil health and reducing the need for chemical fertilizers. Composting of crop residues with organic amendments and microbial inoculants facilitates rapid decomposition, producing nutrient-rich compost that enriches soil organic matter and nutrient cycling. These practices support sustainable agricultural productivity by enriching soil fertility.

Biogas generation

Biogas production utilizing biomass such as rice straw represents a highly attractive renewable energy option. It is energy-efficient, non-toxic, and environmentally sustainable, contributing to reduced carbon emissions (Satpathy and Pradhan 2023). The biomass from rice leftovers can be converted into biogas through methods like anaerobic digestion, gasification, and pyrolysis. These processes convert rice residues into biogas, helping reduce atmospheric carbon dioxide levels. One tonne of rice residue can produce about 300 cubic meters of biogas through anaerobic digestion (Venkatramanan et al. 2021). This is an efficient and eco-friendly alternative energy source from agricultural waste. Rice straw is a source for biofuel production, which generates biogas, a mixture of gases including methane (CH_4), carbon dioxide (CO_2), hydrogen sulphide (H_2S), oxygen, nitrogen, and trace gases. Among these, methane is the most valuable component due to its high energy density (Ngan et al. 2020).

Bio-oil generation

Bio-oil is a dense liquid made from organic waste materials such as bagasse, wheat residue, and rice hull through pyrolysis at over 500°C (Dutta et al. 2022). This process transforms biomass into a valuable energy resource. Studies have explored the extraction of bio-oil from rice residue under varying temperature and gaseous environments (Balagurumurthy et al. 2015). Bio-oils serve multiple purposes, including use in boilers, heat generation systems, gas turbines, and transportation fuels (Kumar et al. 2015). The renewable origin makes them a promising alternative to conventional oil, contributing to sustainable oil production.

Energy production

This approach supports sustainable waste management and enhances renewable energy and soil fertility. Researchers have explored various lignocellulosic biomass pre-treatment methods to enhance biofuel production (Kumar et al. 2009). Utilizing crop residues can fulfill approximately 17% of India's total energy requirements. India's total bioenergy generation potential is 16,700 MT per year, with Uttar Pradesh having the highest, followed by Maharashtra, Gujarat, and Punjab. This distribution highlights the regional variation in bioenergy resources across the country (Hiloidhari et al. 2014).

Paper industry

Paddy straw, a by-product of rice cultivation, is used in making paper, pulp board, packaging padding, and floor tiles (Saini et al. 2023). Using straw in paper production helps reduce environmental harm from burning agricultural residues. In Punjab, straw makes up about 50% of the paper industry's raw materials (Manikandan et al. 2023). Moreover, combining rice and wheat straw provides a sustainable source for paper, using established chemical methods (Dutta et al. 2022). This sustainable practice lowers straw burning and aids both industry and environmental protection. According to Kumar and Singh (2020), approximately 50% of the paper industry in Punjab uses straw as a raw material, resulting reducing the practice of crop residue burning and environmental disruption.

Mushroom cultivation

Mushroom cultivation helps farmers financially and reduces agricultural waste by using paddy straw. It is a profitable and eco-friendly business that employs rice and wheat straw as growing materials. Clean, dry, and mould-free straw is needed, preferably collected right before harvesting (Le VinhThuc et al., 2020). The paddy straw mushroom is highly popular, making up 50-60% of global production (Ahlawat et al. 2011). Rice straw serves as a substrate, producing 5-10% mushroom yield. The oyster mushroom is also commonly grown on rice straw, turning low-quality straw into nutritious food and promoting sustainable farming practices (Naresh et al., 2021). This approach promotes sustainable practices by adding value to agricultural residues.

Industrial uses

Crop residues are generated from major crops like rice, which leaves husk and bran; wheat, which leaves bran and straw; maize, which produces stover, husk, and skins; millet, which yields stover and sugarcane, which results in tops, bagasse, and molasses (Arvanitoyannis and Tserkezou 2008). These residues are by-products of harvesting and processing crops and can be used for different agricultural and industrial purposes. Additionally, agricultural waste can be treated using anaerobic and aerobic methods, including composting, biogas production, vermicomposting, bio-methanation, and bio-pile farming (Garg 2017).

Household use

Rice residue, particularly rice stubble and paddy straw, serves multiple domestic purposes in India. In northern states such as Uttarakhand, Himachal Pradesh, and Jammu & Kashmir, rice stubble is commonly used as fuel wood alongside cow dung cakes (Jain et al. 2014). In other regions like Tamil Nadu, Gujarat, Maharashtra, West Bengal, and Assam, paddy straw is utilized for thatching roofs, domestic fuel, mulching, paddy parboiling combustion, and as fodder (Singh et al. 2011). These traditional uses highlight the resourcefulness in managing agricultural by-products for various household and agricultural needs. Furthermore, rice straw plays a vital role as an alternative feed source for livestock, especially when green fodder availability is limited (Dutta et al. 2022). This practice shows how agricultural by-products are effectively used, supporting sustainable livestock feeding strategies.

Technology of Crop Residue Management

Using technology to manage crop residues offers many benefits for agriculture and industry, including improved soil and water conservation and higher productivity. However, how well these methods work can differ based on farming practices, how residues are used, the resources available, and farmers' economic situations. Advances in machinery, especially for harvesting, are important for reducing soil damage and lowering carbon and water loss. It is crucial to adapt these technological solutions to fit local circumstances for effective and sustainable crop residue management. Lohan et al. (2018) emphasize the importance of in-situ paddy residue management using conservation agriculture machinery to promote sustainable farming and reduce environmental hazards in North-West India. Tools like the Happy Seeder enable effective in-situ residue management, promoting soil health and reducing pollution. Innovative equipment use for in-situ management of crop residues is presented in Figure 5.

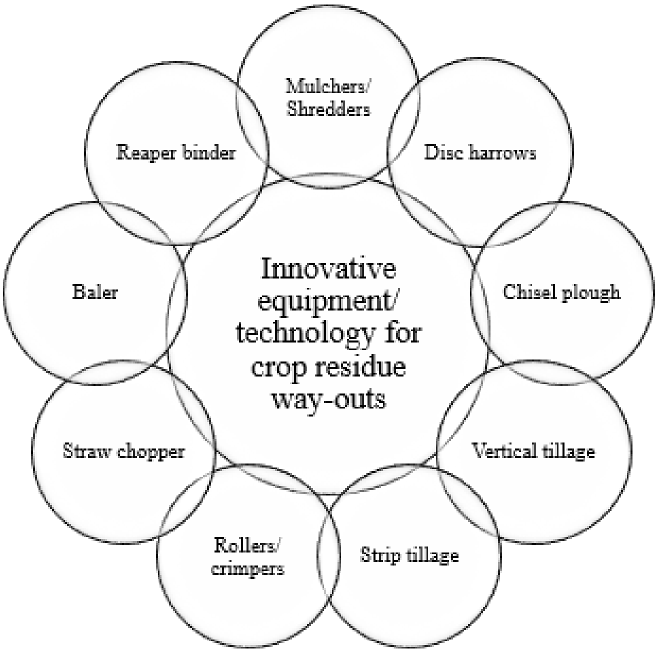

Fig. 5: Innovative equipment used for in-situ management of crop residues

Policy implications

National schemes and policies have been created to manage and reduce crop residue burning. These policies provide farmers with incentives, machinery support, and awareness programs to minimize open burning while aiming to keep agricultural productivity and protect the environment. The National Policy for Management of Crop Residue (NPMCR 2014) in India focuses on reducing environmental damage from burning. It promotes in-situ management techniques like direct soil incorporation and mulching, and encourages the use of farming equipment and remote sensing technologies to monitor burning. To monitor crop residue management in collaboration with the National Remote Sensing Agency (NRSA) and the Central Pollution Control Board (CPCB). This approach aims to reduce air pollution and promote sustainable farming practices by minimizing the negative impacts of traditional residue burning.

The Central Electrical Authority (CEA 2017) proposed a policy that requires coal-based power plants to blend 5-10% biomass pellets with coal to encourage biomass use and utilize crop residues.

The National Biofuel Policy (NBP 2018) aims to increase biofuel production from crop leftovers and surplus grains unfit for eating, helping meet energy needs and reduce climate change effects. Using rice residue to create bio-gas and bio-CNG offers a sustainable way to deal with agricultural waste, addressing pollution from burning and supporting renewable energy. This approach boosts energy security, lowers greenhouse gas emissions, and encourages cleaner farming practices, aligning with the goals of the Ministry of New and Renewable Energy (MNRE, 2018).

The National Clean Air Programme (NCAP 2019) is designed to lower air pollution in India by managing pollutants and addressing stubble burning, with a significant budget aimed at improving air quality in Delhi and its surrounding areas.

The National Green Tribunal Act (2010) requires states to take tough actions against crop burning, promoting recycling and public awareness about its environmental dangers (Bhuvaneshwari et al. 2019). On December 10, 2015, the National Green Tribunal issued an order prohibiting the burning of agricultural residue across multiple National Capital Territory (NCT) of Delhi regions in India including, Delhi, Rajasthan, Punjab, Uttar Pradesh, and Haryana (Jitendra et al. 2017). The order reflects a judicial effort to enforce environmental protection measures and promote sustainable agricultural practices in the affected regions. Ob the other hand, National Green Tribunal (NGT) issued directives in 2015 to curb crop waste burning by farmers, imposing environmental compensation fines based on farm size. Small farmers owning less than 2 acres are fined INR 2,500 per incident, those with 2 to 5 acres pay INR 5,000, and farmers with more than 5 acres face a fine of INR 15,000 per incident. These measures aim to reduce environmental pollution caused by crop residue burning and encourage sustainable agricultural practices.

Conclusion

Stubble burning in India significantly increases the concentration of greenhouse gases and toxic compounds, which elevate health risks for farmers and nearby villagers. These burning releases large amounts of particulate matter, carbon dioxide, methane, and other greenhouse gases, contributing to air pollution and climate change. Conversely, the sustainable use of crop residues is crucial not only for promoting sustainable agriculture but also for maintaining societal equilibrium. Utilizing crop residues as soil amendments enhances soil fertility and supports ecological balance, offering an environmentally friendly alternative to burning practices. Moreover, it helps improve irrigation and keeps moisture in the soil. By providing organic material, it supports soil bacteria and boosts soil fertility. Good management of leftovers reduces soil erosion and enhances soil health. As the demand for food increases with a growing population, more crop residues are produced due to increasing farming practices, creating chances to use these resources for both environmental and agricultural benefits. Techniques include leaving residue on the field, using it as animal feed, or turning it into compost. Effective mitigation requires government policies, farmer education, and incentives to encourage sustainable practices and reduce reliance on stubble burning. Overall, it is concluded that crop residue management is important for sustainable farming.

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