International Journal of Environment and Climate Change

Volume 14, Issue 3, Page 274-297, 2024; Article no.IJECC.114189
ISSN: 2581-8627
(Past name: British Journal of Environment & Climate Change, Past ISSN: 2231–4784)

Challenges and Opportunities in Sustainable Stubble Management in Punjab: A Review

Shubham Anand [a*] and Harleen Kaur [a]

[a] *Department of Climate Change and Agricultural Meteorology, Punjab Agricultural University, Ludhiana-141004, India.*

Authors' contributions

This work was carried out in collaboration between both authors. Both authors read and approved the final manuscript.

Article Information

DOI: 10.9734/IJECC/2024/v14i34040

Open Peer Review History:
This journal follows the Advanced Open Peer Review policy. Identity of the Reviewers, Editor(s) and additional Reviewers, peer review comments, different versions of the manuscript, comments of the editors, etc are available here: https://www.sdiarticle5.com/review-history/114189

Review Article

Received: 24/10/2023
Accepted: 29/12/2023
Published: 07/03/2024

ABSTRACT

The review highlights the situation of paddy stubble farming in Punjab, where farmers aim to prevent environmental harm by avoiding crop residue burning. Despite this intent, challenges such as insufficient machinery and lack of crop insurance hinder their transition to sustainable practices. Punjab, a key agricultural region in India, faces issues like air pollution and environmental degradation due to stubble burning. Farmers increasingly recognize these problems and are willing to explore alternatives. Farmers in Punjab are committed to adopting sustainable practices to minimize stubble burning's adverse effects on soil health and pollution. However, they face obstacles, notably the high cost and limited availability of necessary machinery such as happy seeders and mulchers, particularly affecting small-scale farmers. Additionally, inadequate crop insurance exacerbates the situation by failing to cover risks associated with stubble management, dissuading farmers from transitioning. To address these challenges, promoting accessible and affordable environmentally friendly machinery is crucial. Collaborative efforts between the government and private sector can facilitate this. Moreover, revising crop insurance policies to include stubble management risks will provide farmers with the confidence and financial security

**Corresponding author: E-mail: shubhanand0001@gmail.com;*

needed to adopt sustainable practices. Stakeholder collaboration is essential to create a supportive environment for farmers, enabling Punjab to lead in sustainable agriculture and environmental stewardship.

Keywords: Crop residue burning; stubble burning; soil health; pollution.

1. INTRODUCTION

As the world braces itself for the approaching smog season, a grave concern looms large—the alarming consequences of stubble burning. This destructive practice, employed by numerous regions to clear fields for succeeding crops, unleashes toxic plumes of smoke into the atmosphere. Shockingly, the World Health Organization (WHO) estimates that air pollution, including the detrimental effects of such burning, claims the lives of 7 million people annually, with 6,50,000 of them being innocent children [1]. Despite being glaringly evident, these issues often go unnoticed, as if hidden beneath a mask of silence. It is incumbent upon us to acknowledge that these concerns are not unspoken but rather persistently present, demanding our immediate attention.

Recently a distressing incident occurred in New Delhi where the smog becomes so dense that drivers are left disoriented, leading to multiple collisions on Yamuna Expressway [2]. Such conditions recur every year, exacerbating air pollution levels in the city. Are we inadvertently inhaling poison in Delhi? While Delhi has long been plagued by pollution, something is making it even worse.

1.1 What is Stubble Burning?

Crop residues or stubble are by-products from harvesting left on cultivated land. Many farmers consider agricultural burning the most effective and cost-efficient way to clear land, fertilize soil and prepare it for new plantation. However, these blazes that spread from them are the world’s largest source of black carbon, a threat both to human and environmental health. Moreover, a rapidly growing demand for food translates into a constant ramping up of yield production, which increasingly forces farmers to burn fields after harvest. However, these blazes that spread from them are the world’s largest source of black carbon, a threat both to human and environmental health.

1.2 Stubble Burning in Punjab

India is ranked as the second-highest crop residue burning (CRB) contributor (84 Tg/year) in the world [3]. The total amount of agricultural waste generated annually in India is much greater than that in other countries. According to the Ministry of New and Renewable Energy (MNRE) estimates, an average of 500 Mt of crop residue is generated in India each year, a majority portion of which is used as fuel for industrial and domestic purposes [4]. Concurrently, [5] identify Punjab (~20 Mt), Haryana (~10 Mt) and Uttar Pradesh (~11 Mt) as the Indian states with the largest crop residue burning volume. Approximately 85-90% of paddy straw is burned in the fields, and to some extent, wheat straw is also burned during the rabi harvesting season as shown in Fig. 1. Although the problem of straw burning exists in multiple states, it is particularly prevalent and extensive in Punjab and Haryana. Kaskaoutis [6] estimate that paddy residue generated in India is ~97 Tg/year, of which ~24% is commonly burnt in fields as surplus. However, Punjab and Haryana alone contribute about half of the paddy straw surplus generated per year [7]. Lohan [8] note that in Haryana, *rabi* CRB was nearly thrice as compared to *kharif* CRB. Unlike Punjab, in Haryana *rabi* CRB poses a much serious issue than *kharif* CRB. Whereas in Punjab, the occurrences of fire incidents are as shown in Fig. 2 on a district-wise basis. During the *Kharif* season of 2022, Sangrur and Barnala recorded the highest number of fire events, while Moga and Gurdaspur took the lead during the *Rabi* season of 2023. Every year during October and November, an estimated 35 million tonnes of paddy straw are set ablaze in the state over a period of two to three weeks. Figs. 3 and 4 illustrates the occurrence of fire incidents during the rice harvesting period in Punjab (Crop Residue Burning (CRB) Information and Management System).

1.3 Whose Fire is it Anyway?

Each year, during the months of October and November, the accumulated stubble burning results in a significant smoke cloud that drifts towards Delhi. Fig. 5, based on real-time air quality data from the Central Pollution Control Board (CPCB), obtained through VIIRS (Visible Infrared Imaging Radiometer Suite) and FIRMS

(Fire Information for Resource Management System), demonstrates a direct relationship between the increase in stubble burning incidents in Punjab and Haryana and the rise in $PM_{2.5}$ pollutant concentration in Delhi. This period also coincides with the Diwali festival [10]. Delhi faces exacerbated air pollution due to two factors.

Firstly, the geographical location of the Himalayan mountains acts as a barrier, directing smoke towards Delhi. Secondly, the winter weather conditions contribute to the issue. Cold winds from the mountains descend towards Delhi, creating a dome-like effect where the warm air traps pollution on the ground. When the smoke from stubble burning reaches Delhi, it mixes with urban pollution, forming a hazardous smog that blankets the city (Fig. 6). The study conducted by Prabhjyot-Kaur [11] indicated that temperature inversion, calm surface winds, and a low ventilation coefficient are favourable meteorological conditions for smog formation. Analysis of smog occurrences from 2012 to 2019 revealed that calm wind conditions (less than 2 km/h) sustained the smog, while its dissipation occurred when wind speeds increased (above 4-5 km/h) or rainfall was experienced (Fig. 7). It is unlikely that the air quality in neighboring states such as Haryana and New Delhi would be significantly affected by winds blowing from the southeast direction.

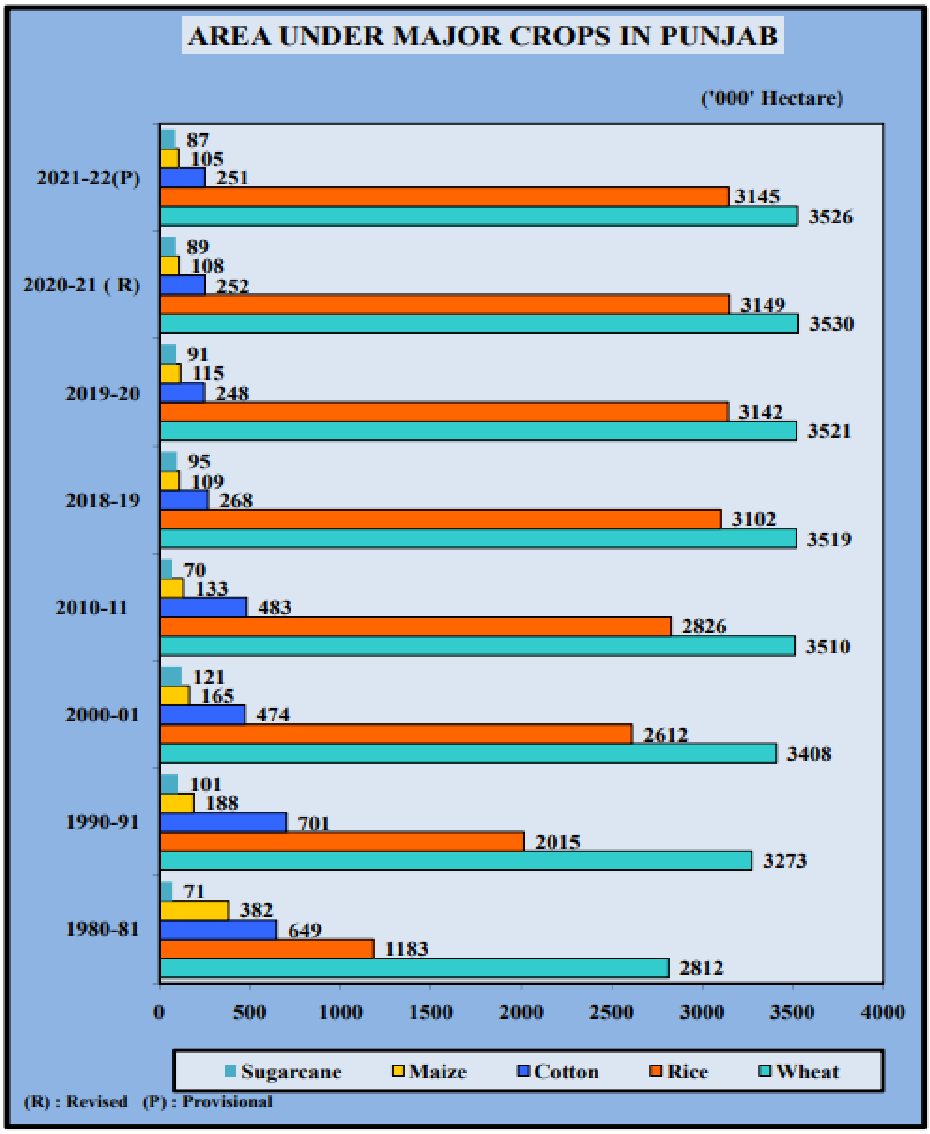


Fig. 1. Area under major crops in Punjab
(Source: ESOP [9])

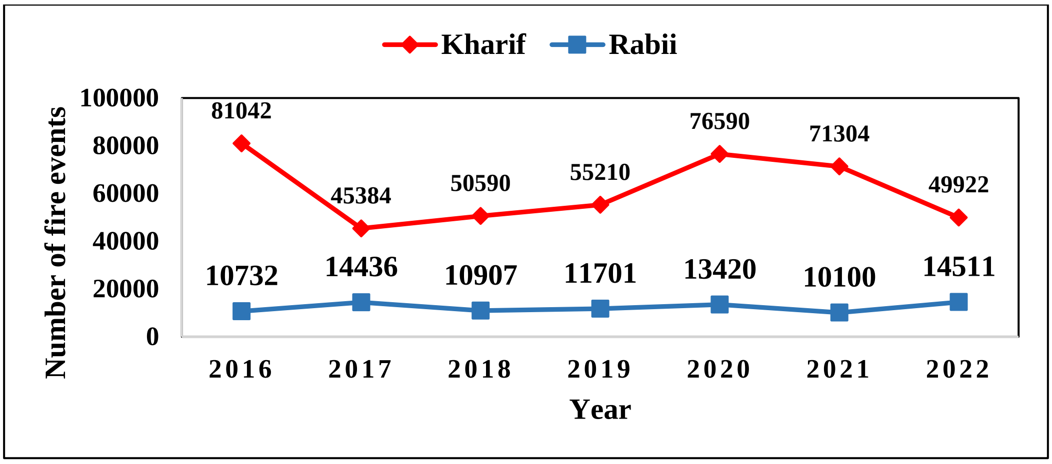


Fig. 2. Number of fire events during *Kharif* and *Rabi* season in Punjab

2. GREEN REVOLUTION AND TRANSFORMATION IN PUNJAB

While this crisis of smog and its devastating impact on human health pervades various regions, it is important to shed light on the significant role played by Punjab, a key food-producing state in India. Punjab's agricultural growth is closely intertwined with the renowned 'Green Revolution,' a transformative period marked by the introduction and widespread adoption of high-yielding crop varieties, particularly wheat and rice. Spearheaded by the visionary leadership of Prime Minister Indira Gandhi and Agriculture Minister C. Subramaniam, this movement heralded a series of bold decisions aimed at addressing agricultural crises [12].

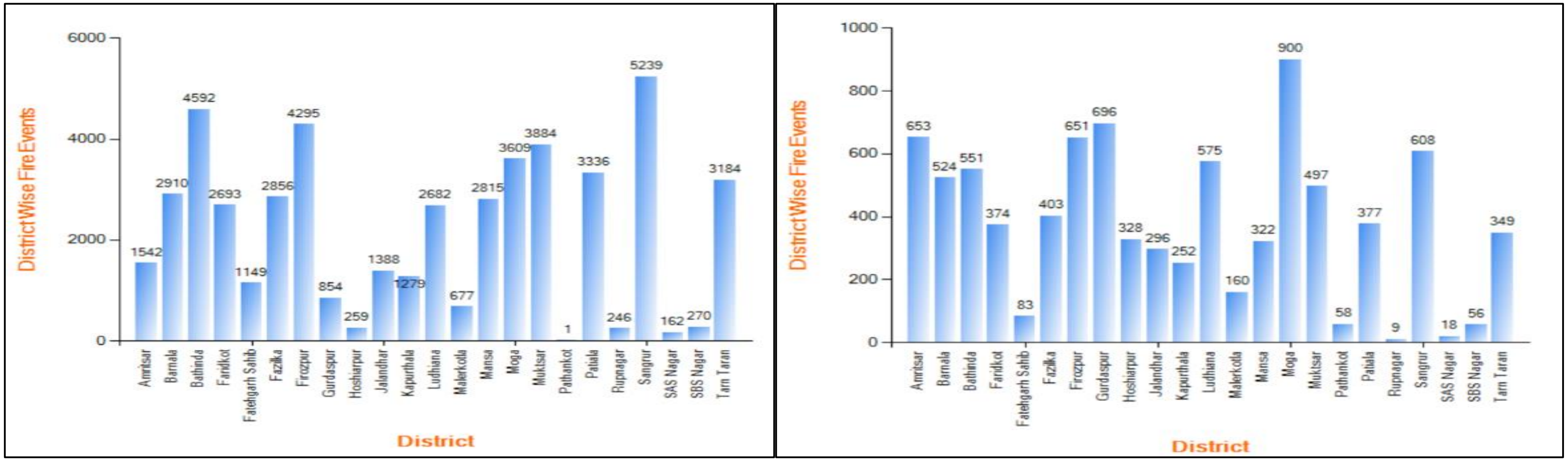
The Green Revolution in Punjab led to a shift towards a rice-wheat rotation, resulting in a decline in the cultivation of other crops. The area dedicated to crops like maize, millets, jowar, sugarcane, groundnut, pulses, gram, barley, and mustard decreased as a consequence. Statistical data shows that the production of pulses witnessed a decline over time, leading to a significant decrease in per capita annual consumption. In 1958-59, per capita annual consumption of pulses was 27 kg, but by 2010, it had decreased to 13 kg, representing a 53% decrease. The National Food Security Mission, during this period, did not prioritize enhancing pulse production, leading to limited emphasis on increasing their cultivation and production [13]. The production of wheat and rice, two of India's primary food crops, has grown as a result of the adoption of green revolution (GR) technologies. These developments not only helped to significantly increase agricultural output but also significantly aided India's economic development [14]. Punjab in the northwest was the first to experience and benefit from these technologies [15,16]. Cereal yield in this region has increased as a result of the legislative initiatives designed to encourage the adoption of GR technology, including as water and energy subsidies, minimum support prices (MSP), and procurement [17,18,19]. The area under major crops in Punjab 1980 onwards is as shown in Fig. 1.

A detailed examination was conducted by the Committee of Secretaries (CoS) in nine major states, including the three main rice-wheat cropping systems states of Punjab, Haryana, and Uttar Pradesh, as well as West Bengal, Bihar, Andhra Pradesh, Karnataka, Maharashtra, and Rajasthan and concluded that original Green Revolution states were grappling with the issues of yield stagnancy and overexploitation of groundwater resources. As a result, urgent action was needed to diversify crops and promote technological innovations that would enable farmers to choose suitable alternatives [20]. Currently, Punjab faces a paradoxical situation to fulfil the country's food security requirements, while simultaneously grappling with a growing issue of straw disposal.

3. UNVEILING THE FACTORS BEHIND STUBBLE BURNING

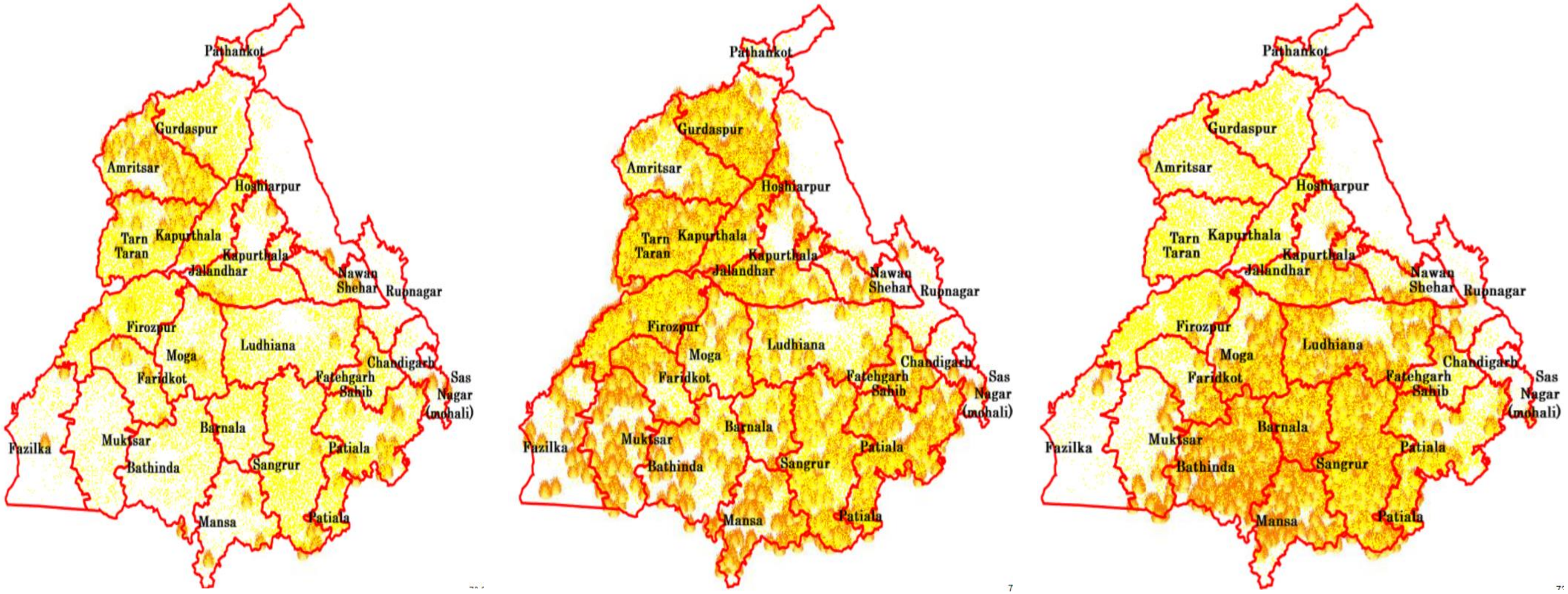
3.1 Policies Shaping Water and Electricity Management in Punjab

The cultivation area dedicated to rice and wheat in Punjab has witnessed a significant increase, rising from 47% of the total cropped area in the



***a) Kharif* (2022)** **b) *Rabi* (2023)**

Fig. 3. District wise fire events in Punjab during
(Source: Crop Residue Burning (CRB) Information and Management System)



Burnt area 10 oct 2019 Burnt area 25 oct 2019 Burnt area 9 Nov 2019

Fig. 4. Burnt during rice harvesting period in Punjab

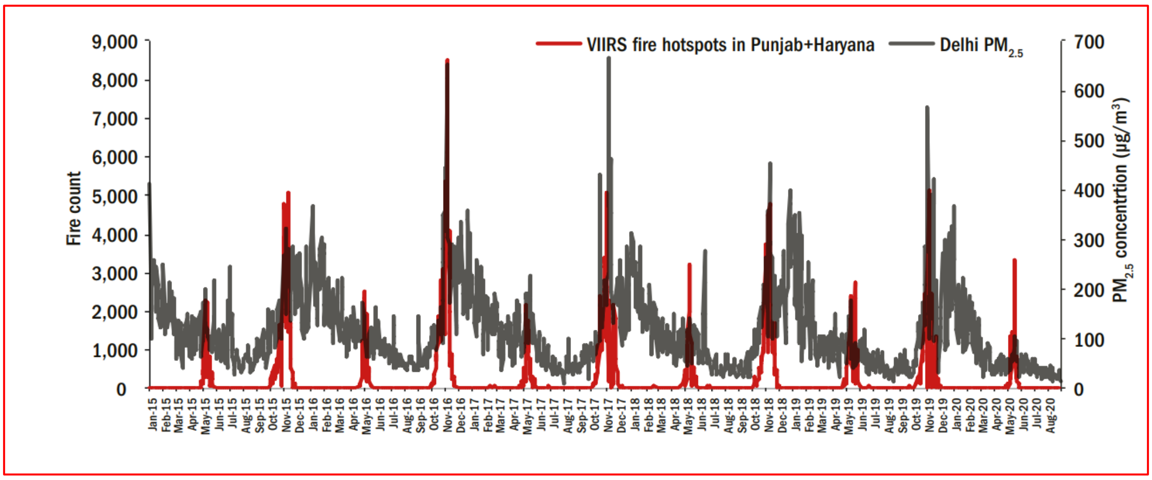


Fig. 5. Trend in stubble fire hotspot data and Delhi's $PM_{2.5}$ concentration as per CPCB real time air quality data [10]

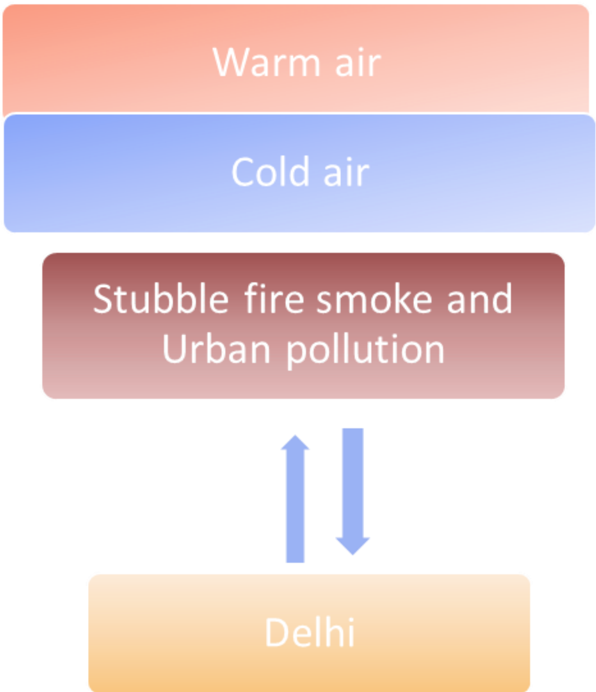


Fig. 6. Dome like effect in Delhi

1970s to over 80% in 2019. This substantial shift in agricultural practices has had adverse consequences, as it has led to the displacement of traditional crops like oilseeds, pulses, maize, and cotton. In an attempt to address this issue, the Government of Punjab introduced 'The Punjab Preservation of Subsoil Water Act, 2009,' which mandates delaying the transplantation of paddy beyond June 10th, after the most critical evapotranspiration phase. However, the effectiveness of this measure in curbing the depletion of groundwater resources has limited supporting evidence [21].

3.2 Constraints of Sowing Window

Due to the implementation of the Punjab Preservation of Subsoil Water Act in 2009, farmers encountered a restricted timeframe for field preparation before the next crop, which consequently compelled them to resort to residue burning as a method of field clearance [22].

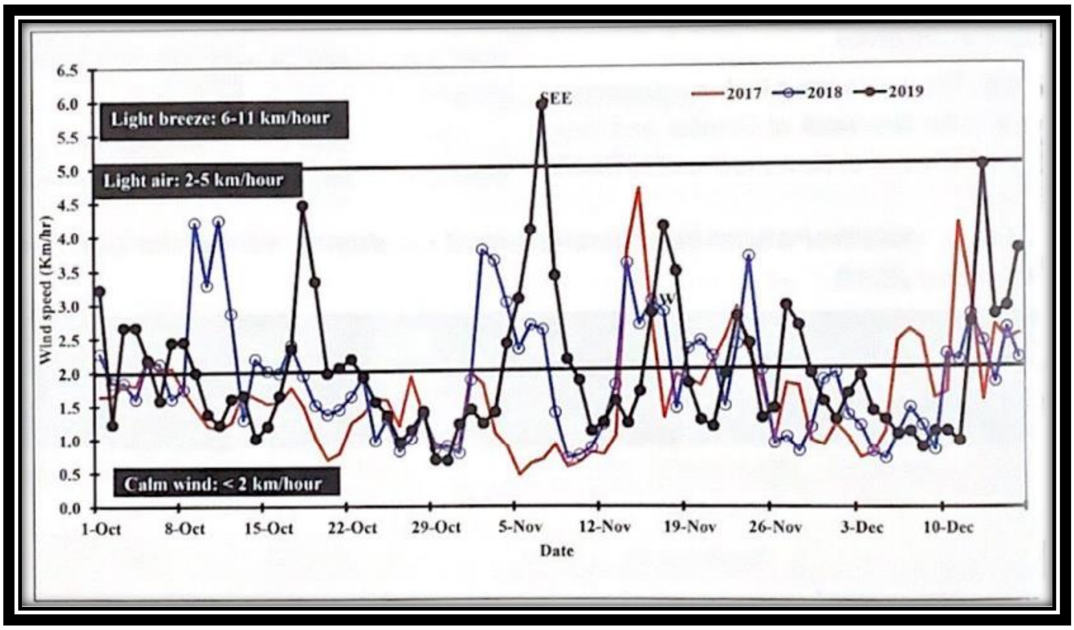


Fig. 7 Average wind speed (km/hour) in Punjab during 2017, 2018 and 2019 (October 1 to December 16) (*Source:* [11])

3.3 Challenges in Managing Rice Straw for Cattle Fodder: Costs, Decomposition and Labor Shortage

The need for dry fodder for cattle is primarily fulfilled by the availability of wheat straw, supplemented by basmati straw if necessary. Due to lack of sufficient nutrient required to maintain high milk production levels, farmers do not feed their dairy animals with rice straw preferably. Additionally, fodder crops are cultivated in ample areas within the state. However, the equipment and processes involved in cutting, ploughing back, or collecting and transporting straw incur significant costs that are often beyond the means of small and marginal farmers. The high silicon dioxide (SiO_2) content in straw makes it resistant to decomposition when it is incorporated or retained in the soil for the subsequent crop. Additionally, the acute shortage of labor for collecting and storing rice straw pushes farmers towards resorting to straw burning as an alternative solution [22].

3.4 Pest Control and Economic Implications

In addition to the reasons mentioned, farmers argue that burning crop residues also helps eliminate harmful pests that hibernate within the remnants. They further assert that the undecomposed straw from the previous season can float on water surfaces and disrupt newly planted wheat seedlings when exposed to strong winds. Punjab and Haryana state agriculture departments recommend incorporating the residues into the soil using machinery, but farmers are concerned about the increased cultivation costs associated with this approach. They also mention that frequent deep ploughing leads to the loss of investment made in laser land levelling. Typically, farmers opt for laser land leveling and deep ploughing every 3-4 years, as deep ploughing annually would be economically impractical [23].

4. CROP RESIDUE MANAGEMENT STRATEGIES

4.1 On Farm Crop Residue Management Strategies

4.1.1 Residue removal

Residue removal practices, including bailing, briquetting, and utilization for cattle fodder, cooking fuel, animal bedding, or industrial processes, are common [24]. However, removing residues can have detrimental effects on soil quality in certain cases. Therefore, it is essential to estimate sustainable residue removal rates to ensure the maintenance of good soil quality [25].

The removal of crop residues can result in a decrease in the input of biomass carbon, leading to a decline in nutrient and elemental cycling in the soil [24]. Additionally, there may be logistical challenges in transporting the removed crop residues over longer distances, which can incur additional costs [4]. Machinery for Ex- situ management is as shown in Table 1.

4.1.2 Residue retention

Surface retention of some or all of the residues may be the best option in many situations. It suppresses the weed growth [26]. Residues decompose slowly on the soil surface, increasing the organic carbon and total nitrogen in the top 5-15 cm of the soil, while protecting the surface soil from erosion [27].

The use of zero till drills in the presence of surface-retained residue can lead to reduced seed sowing efficiency and poor seed germination due to the accumulation of straw in the seed furrows. Additionally, zero till drills, such as the happy seeder, require high power consumption (> 33.6 kW) and may experience issues with machine clogging when dealing with large amounts of straw (> 7-8 Mg ha^{-1}). These factors can contribute to poor crop establishment [28].

4.1.3 Residue incorporation

Residue incorporation refers to the practice of using tillage equipment to bury crop residues into the soil, with the primary purpose being the return of organic matter to the soil. This form of tillage involves burying all surface-level crop residues in the soil [29]. The process of residue incorporation typically begins with primary tillage, which can involve ploughing with a mouldboard plough, followed by secondary tillage techniques such as disking, harrowing, or field cultivating. Another approach to incorporating residues is by using zero till drill machines or roto-till drills during the sowing of wheat crops in fields with rice straw and stubble. However, it should be noted that zero tillage machines, which combine seed and fertilizer drilling, may experience reduced effectiveness when straw accumulates in the furrow openers, leading to decreased seed sowing efficiency and poor seed germination [28].

Short-term methane (CH_4) emissions can be stimulated as a result of residue management practices [15]. The presence of crop residues can lead to nitrogen (N) deficiency in crops due to microbial immobilization of soil and fertilizer N. The decomposition of crop residues takes time, necessitating a significant fallow period between two successive crops [30]. If proper machinery is not available to every farmer, residue management can be labour-intensive [31]. The high carbon-to-nitrogen (C: N) ratio of residues needs to be addressed by applying additional fertilizer N during residue incorporation [32].

4.1.4 Residue burning

Burning residue on the farm is the most common and preferred management option for many farmers due to its cost and time effectiveness, mechanization, pest control benefits, and the unsuitability of rice straw as cattle feed [8].

A sudden increase in soil temperature (33.8-42°C) can lead to the death of beneficial microbes [33]. Burning crop residues degrades air quality and indirectly affects human health [8]. When paddy straw is burned, approximately 70% of the carbon is released as CO_2, 7% as CO, and 0.66% as CH_4, while around 2.09% of the nitrogen in the straw is emitted as N_2O. This practice contributes to heavy smog problems in neighboring regions during the winter season.

4.1.5 Crop residue as compost

On-farm composting is a cost-effective method that can be utilized as organic fertilizer [4]. While composting does require labor input, it is not capital-intensive and does not necessitate sophisticated infrastructure or machinery [30]. Researchers have conducted successful trials using specific microbes, such as *Aspergillus terreus* MTCC 11778 and Trichoderma hargianum MTCC 8230, to assist in on-site composting of paddy residues, providing an alternative to the common practice of residue burning. Other trials have shown that a bacterial isolate (Pseudomonas) obtained from naturally degrading paddy straw can decompose the straw within 45 days by applying only 5% urea after shortening the straw using a happy seeder machine. Another group of researchers has developed microbial consortium-based decomposing capsules called PUSA decomposer, which consists of crop-friendly fungi. These capsules can decompose one hectare of farm waste into usable compost. Each capsule costs around Rs 5-10 [34].

The presence of crop residues creates a favorable habitat for rodent pests and can lead to the immobilization of residual nitrogen, which is undesirable [35]. It may necessitate the use of additional chemicals and controlled conditions.

The decomposition of residues is a time-consuming process, requiring a longer gap between successive crops [30].

4.2 Off Farm Crop Residue Management Strategies

There are several off-farm or ex-situ options available for managing crop residues. However, these options often face common limitations, such as the high costs associated with collection and transportation.

4.2.1 Livestock feed

Rice straw is actually not suitable for livestock feeding due to its high silica content (6-12%) and low nutritional value (protein 2-7%) [8]. To encourage the use of rice residues as animal fodder, a pilot project was initiated, focusing on the natural fermentation of rice straw to produce protein-enriched livestock feed. Cattle fed with this feed showed significant improvements in health and milk production [36]. Rice straw, in particular, requires extra pre-treatment due to its high silica content, which makes it less digestible and less palatable [37].

4.2.2 Biofuel and bio-oil

Rice straw is an abundant lignocellulosic biomass having the potential for use as a feedstock for the production of bioethanol. Bioethanol, derived from lignocellulosic biomass, is particularly significant as it can be blended with petrol and diesel, reducing harmful emissions in the transport sector. Rice straw, in addition to sugarcane molasses, can be an ideal feedstock for biofuel production by converting it into sugary slurries [38]. Bio-oil can also be produced from a variety of crop residues through a process called fast pyrolysis, which involves rapidly raising the temperature of biomass to around 400-500°C within seconds [33]. Although this technology is still evolving in India, it faces certain limitations due to energy and cost-intensive conversion steps. Rice straw, in particular, is resistant to microbial attacks during the conversion processes due to the presence of phenolic monomers in its structure [39].

4.2.3 Biomass pellets from crop residues as a fuel supplement in thermal power plants

Biomass pellets derived from crop residues are utilized as a supplementary fuel source in thermal power plants. These pellets readily burn alongside coal, the conventional fuel used in power plants. With the addition of crop residue-based biomass pellets, the cost of production will increase by Rs. 0.20 per unit (kWh) of power [40].

4.2.4 Biogas generation

Crop residues can be utilized for biogas generation through the process of gasification. This thermo-chemical process involves partial combustion of the residues, resulting in the formation of gas known as "Producer Gas." The gas is then cleaned using bio-filters and fed into specially designed engines coupled with alternators to produce electricity. Approximately 1 tonne of crop biomass has the capacity to generate 300 kWh of electricity [8].The PAU, Ludhiana centre of the AICRP on Energy in Agriculture and Agro-Industries has developed a biogas plant considering the alternate use of paddy straw for bio-gas production. This is a very simple and efficient technology for extraction of biogas from paddy straw. The estimated cost of the biogas plant for handling about 1.6 tonne paddy straw is Rs. 1.2 lakhs which is about four times costly as compared to conventional animal dung-based biogas plant of same capacity (biogas production). One biogas plant can manage 4.5-5.0 tonne of paddy straw per year. Several such biogas plants have been installed in Punjab and all the plants are working very well producing 482.58 CBG t/day and consuming 2 lakh metric ton of paddy straw per annum [41].

Some studies have presented contradictory findings regarding the production of air pollutants during incomplete combustion of biogas, including the release of pollutants such as carbon monoxide (CO), nitrogen oxides (NO), and methane (CH_4). Therefore, it is crucial to accurately assess these emissions to ensure social acceptance of this technology [42].

4.2.5 Mushroom cultivation

Crop residues, including rice straw, can also be used for mushroom cultivation. In Punjab, rice straw is commonly used for mushroom culture, although wheat straw is also utilized by farmers. Various mushroom species such as *Agaricus bisporus*, *Pleurotus spp*., Volvariella, and Volvacea can be cultivated using crop residues. For every 1 kg of paddy straw, approximately 300 g, 600 g, and 120-150 g of mushrooms can be produced for *Agaricus bisporus*, *Pleurotus spp*., and Volvariella/Volvacea, respectively (Kumar, 2015).

4.2.6 Paper production

Rice and wheat straw are commonly used together, in a ratio of 40:60 respectively, for the production of paper. The resulting sludge from the paper production process can undergo bio-methanization to generate energy. Additionally, paddy residue alone can serve as an ideal raw material for manufacturing paper and pulp boards. More than 50% of pulp board mills and paper industries utilize paddy residues as their raw material [36].

4.2.7 Biochar production

Crop residues can also be used for the production of biochar. Biochar is a carbon-rich substance with fine-grained and porous characteristics, created through thermo-chemical conversion reactions known as pyrolysis. When biochar produced from crop biomass is applied to the soil, it enhances soil fertility, reduces nutrient leaching, increases soil carbon content, improves fertilizer use efficiency, mitigates greenhouse gas emissions from the soil, and ultimately enhances overall agricultural productivity. The production of biochar has been found to have detrimental impacts on certain vital soil properties, such as soil available water content, soil salinity, and soil erosion [43]. However, the biochar production technology is not economically feasible due to the high costs associated with the products and co-products involved, such as heat energy, bio-oil, and H_2 gas. Therefore, there is a need to develop affordable pyrolysis kilns to make the process more cost-effective [44].

5. INITIATIVES AND POLICIES TRANSFORMING PIONEERING CROP RESIDUE MANAGEMENT IN PUNJAB

5.1 Project for Promotion of Technologies to stop Burning of Straw under RKVY (2009-2010)

During 2009-210, the ‘Project for promotion of technologies to stop burning of straw’ was introduced under Rashtriya Krishi Vikas Yojna (RKVY) (2009-2010). This initiative aimed to discourage the burning of straw by providing a 50% subsidy to farmers for straw management equipment such as Rake, Baler and Happy seeder [45].

5.2 New and Renewable sources of Energy Policy (2012)

The policy aims at setting up small high pressure biomass plants with higher efficiency in rice mills [46]. By 2022, the goal is to achieve a target of generating 600 MW of power from biomass and agricultural residue. Currently, there are a total of 11 biomass power projects operating in Punjab with a combined capacity of 97.50 MW. These projects utilize 8.8 Lac Metric tons of paddy straw annually. Two biomass power projects with a capacity of 14 MW became operational by June 2021. These projects utilize 1.26 Lacs Metric tons of paddy straw per year. The Punjab government has proposed the allocation of 100 MW standalone biomass power projects and 25 MW biomass solar hybrid power projects [47].

5.3 Agriculture policy for Punjab (2013)

The policy aimed at enhancing mechanisation in agriculture to achieve precision in farm operations. To ensure cost-effective repair and maintenance, upgradation and standardisation of available equipment [48].

5.4 Crop Diversification programme in Punjab, Haryana and UP (2013)

In 2013-14, the Finance Minister allocated Rs 500 crores for Crop Diversification in Punjab, Haryana, and Western Uttar Pradesh to reduce reliance on water-intensive paddy cultivation. The objectives were to promote improved production technologies for alternate crops, restore soil fertility through leguminous crops, and divert at least 5% of paddy-growing blocks to other crops. A varying allocation of funds for the program over the years, with some years receiving higher amounts while others experiencing a decrease in funding.

- 2013-14: An amount of 24,950.00 lakhs was allocated for the program during this fiscal year.
- 2014-15: A total of 25,000.00 lakhs was allocated for the program in this fiscal year.
- 2015-16: The allocated funds for the program decreased to 7,500.00 lakhs during this fiscal year.
- 2016-17: A total of 7,947.00 lakhs was allocated for the program in this fiscal year.
- 2017-18: The allocated funds decreased further to 1,766.00 lakhs during this fiscal year.
- 2018-19: The allocation for the program significantly reduced to 706.66 lakhs during this fiscal year [49].

5.5 National Policy for Management of Crop Residue (NPMCR) (2014)

The "National Policy for Management of Crop Residue (NPMCR)" aims to address the environmental degradation caused by burning crop residue and promote its efficient utilization. The major objectives of the policy are to prevent burning through in-situ management techniques, diversify the use of crop residue for various purposes, raise awareness about the harmful effects of burning, and implement suitable legislation to control the practice. Financial resources are mobilized through various ministries and schemes, with the involvement of state governments. Monitoring mechanisms involve state-level implementation and regular national-level monitoring to ensure effective implementation of measures to curb residue burning [20].

The central government introduced several initiatives in 2018 to encourage the broader utilization of crop residue. These programs include the Promotion of Agricultural Mechanization for In-Situ Management of Crop Residue and the National Biofuel Policy. These policies aimed to support the adoption of remote sensing techniques and aerial surveillance to identify areas where crop burning is taking place.

5.6 Management and Utilisation of Paddy Straw in Punjab (2014)

The document, known as the White Paper, tooks a holistic approach to paddy-straw management and promotes the concept of 'Earn, Don't Burn' by advocating for an integrated approach to prevent resource loss from burning paddy straw. It emphasized the need to reduce the area under paddy cultivation and proposed an in-situ management strategy of incorporating paddy straw into fields. The desired outcome was to utilize 5.73 million tonnes of paddy straw in 2016-17, with industries using it as a raw material eligible for incentives under the 'Fiscal Incentives for Industrial Promotion - 2013' scheme in Punjab.

5.7 Scheme for Promotion of Straw Management Equipment under Sub-mission ON Agricultural Mechanisation (SMAM) (2016)

The Department of Agriculture, Ministry of Agriculture, Cooperation, and Farmer Welfare initiated the "Scheme for promotion of Straw Management Equipment" in 2016. This scheme aimed at encouraging and offering financial incentives for the acquisition of equipment related to the management of straw in the states of Punjab, Haryana, and Uttar Pradesh under the SMAM (Straw Management Awareness and Application Model).

5.8 Biomass Utilisation for Power Generation Through co-firing in Pulverised Coal-fired Boilers (2017)

The Central Electrical Authority (CEA) has formulated a policy to promote the use of biomass pellets in coal-based thermal power plants. The policy advises all public and private power-generating utilities with fluidized bed and pulverized coal units to blend 5-10% of biomass pellets, primarily made from agro residues, along with coal. The desired outcome of this policy was to utilize approximately 53.5 million tonnes (mt) of crop residues annually, which accounts for about 30% of the total annual surplus crop residue in the country. This would have required an estimated daily biomass pellets requirement of around 146,498 tonnes, assuming 275,000 tonnes of biomass pellets for 7% blending in a thermal power plant with a capacity of 1000 MW [50]. Additionally, the government planned to establish a 60 MW biomass-based power plant specifically for the production of biomass pellets [51].

5.9 National Biofuel Policy (2018)

The biofuels policy in India aims to promote and integrate biofuels into the country's energy and transportation sectors. It proposes an indicative target of 20% blending of biofuels (bio-diesel and bio-ethanol) by 2017. Bio-ethanol blending is already mandatory, while bio-diesel blending is currently recommended. Minimum Support Price (MSP) is provided for non-edible oilseeds used in bio-diesel production. Financial and fiscal measures are considered to create a level playing field for biofuels in the energy sector. The MSP mechanism ensures fair prices for oilseed farmers, and employment opportunities in biofuel plantations can be covered under the National Rural Employment Guarantee Programme (NREGP).

The state is currently implementing eight Bio-CNG projects, with the majority of them were scheduled to be commissioned in 2021 and 2022. These projects are expected to require approximately 3 lakh metric tonnes of paddy stubble annually [52]. The Punjab government has entered into a Memorandum of Understanding (MoU) with Hindustan Petroleum Corporation Limited, Indian Oil Corporation, Verbio India Private Limited, and Rika Biofuel Development Limited. This MoU aims to establish Bio-gas and Bio-CNG plants within the state [53,54].

5.10 Energy from agricultural waste/residue in form of biogas-bio-CNG by MNRE (2018)

The objective of the Programme is to promote the establishment of projects that recover energy in the form of Biogas/BioCNG/Enriched Biogas/Power from urban, industrial, and agricultural wastes. The scope of the scheme includes providing Central Financial Assistance in the form of capital subsidy and Grants-in-Aid for various activities. These activities include biogas production from industrial waste, sewage treatment plants, urban and agricultural waste/residue through biomethanation. It also covers power generation or the production of Bio-CNG/enriched biogas from the biogas produced from the mentioned sources.

5.11 Promotion of Agricultural Mechanisation for in-situ Management of Crop Residue in State of Punjab, Haryana, Uttar Pradesh & NCT of Delhi (2018)

The Scheme aims to achieve several objectives, including protecting the environment from air pollution and preserving soil health by preventing the burning of crop residue. To facilitate effective residue management, the Scheme supports the establishment of Farm Machinery Banks, which allow farmers to access necessary machinery through custom hiring. This helps overcome the economic challenges faced by small landholder [55].

The availability of machines caused a decline in the number of machines delivered in 2019-20, dropping from 28,609 in 2018-19 to 14,625 [56]. The Punjab government asserts that they have established 7,378 custom hiring centers (CHCs) within a span of two years. They have further announced plans to set up an additional 5,200 CHCs in 2020 to ensure that each village has access to at least one CHC [57]. As part of the scheme, farmers in Punjab have received a subsidy of approximately Rs. 460 Crore on 50,815 farm machines. The Government of India has identified around 180 manufacturers from Punjab to ensure a steady supply of farm equipment/machinery [58]. In Punjab, during the year 2018-19, the area managed by various in-situ crop residue management machinery was 1,602,822 hectares. Notably, the happy seeders specifically managed an area of 449,529 hectares [59]. Machine wise status of subsidies applied and received by the farmers are as shown in Table 2.

5.12 National Clean Air Programme (NCAP)

The National Clean Air Programme (NCAP) has the following objectives:

- Implement stringent measures to prevent, control, and reduce air pollution.
- Establish a reliable and comprehensive ambient air quality monitoring network.
- Enhance public awareness and capacity-building for effective air pollution management.

The NCAP is a mid-term, five-year action plan, with the possibility of extension based on outcomes. It aims to coordinate efforts among central ministries, state governments, and local bodies.

Table. 1. Machinery for Ex- situ management

S.no.	Machines	Description	Cost of machines	Total no. of machines in Punjab
1.	Baler	For collecting the paddy straw and compressing and making bales (Round/Rectangular)	Approx. cost: Rs. 3,75,000/- (Round baler) and Rs. 12,00,000/- (Square baler)	In Punjab total 648 Baler are running till 2021
2.	Straw combine	Used for making paddy straw it cuts and chop the straw and throw it	Approx. cost: Rs. 2,30,000/-	

Table 2. Machine wise status of subsidies applied and received by the farmers [60]

Machine	Adopter		Non- adopter		Subsidy amount	Ceiling on prices	Government approved prices
	Applied (%)	Received (%)	Applied (%)	Received (%)	Rs in 000	Rs in Lakh	Rs in Lakh
Happy seeder	10.5	4.1	0.2	0	39-105	0.8	1.4-1.8
Super seeder	12.2	9.0	1.2	0.5	50-157	1.1	2.1
MB plough	8.2	3.4	0.2	0	143	1.3	1.2-2.5
Rotavator	8.5	2.7	2.0	0.7	25-50	NA	0.9-1.3
Baler	5.4	0.8	0.1	0	NA	9	10
Super SMS	6.4	2.4	0	0	88-100	0.6	1.2
Zero drill	0.3	0.2	0	0	22-35		
Mulcher	0.1	0.1	0	0	80-85		

To address the issue of stubble burning, the central government has allocated over Rs 1,600 crore under two schemes. One scheme focuses on tackling pollution in Delhi-NCR, while the other aims to discourage stubble burning. An amount of Rs 1,178.47 crore has been disbursed for the "Promotion of Agricultural Mechanisation for In-Situ Management of Crop Residue" in Punjab, Haryana, Uttar Pradesh, and Delhi. Additionally, around Rs 460.96 crore was released for a separate program called "Control of Pollution" in 2019-20. This program supports state pollution control boards, committees, and the implementation of the National Clean Air Programme [61]. Furthermore, an ordinance was issued to establish a comprehensive Commission for Air Quality Management in NCR and surrounding areas. This commission is aimed at fostering a coordinated approach to combat air pollution [62].

5.13 CII Crop Residue Management (2019)

One of the task forces formed by NITI Aayog focused on biomass management and specifically aimed to address the issue of stubble burning in north-western states like Punjab. The task force collaborated with key stakeholders, including Punjab Agriculture University (PAU) and farmers' communities, to identify actionable solutions.

The outcomes of the project showed significant progress, with a large percentage of farmland becoming free of crop residue burning, substantial amounts of rice straw being recycled or avoided from burning, improved air quality, reduced greenhouse gas emissions, water conservation, cost-effectiveness for farmers, and increased crop yields. Overall, the initiative demonstrated the effectiveness of collaborative efforts involving stakeholders and implementing holistic approaches to tackle biomass burning and improve environmental conditions.

5.14 The Nature Conservancy (TNC) (2019)

The Nature Conservancy (TNC), the largest conservation non-profit in the world, launched a project in 2019 to promote sustainable in situ CRM in the states of Punjab and Haryana to complement the efforts of the government.

5.15 Agro Machinery Service Centres (AMSC)

The Government of Punjab initiated the Agro Machinery Service Centres (AMSC) project with the aim of addressing the expensive nature of agricultural machinery and ensuring its availability for farmers on a rental basis. Initially, individual farmers, cooperative societies, and entrepreneurs were encouraged to establish AMSCs with government subsidies. The requirement for these centres included the mandatory provision of a Happy Seeder and Laser land leveller.

6. POLICY DISCUSSION

The battle for preserving the precious sub-soil water, somehow curbed the ominous practice of stubble burning. The protagonist of this tale was 'Punjab Preservation of Sub-Soil Water Act,' a legislative measure designed to protect state's dwindling groundwater resources. However, as with any story, this act had its own set of important features and limitations. One key feature of the act that cannot be overlooked was the narrow window between rice harvesting and the sowing of wheat. This window, as highlighted by the scholarly work of Pandey [56], became the main factor contributing to the menacing issue of stubble burning within the rice-wheat cropping cycle. The act unintentionally altered the agricultural landscape, disrupting the well-established rhythm of the farming calendar. Intriguingly, a recent study conducted by Singh [63] shed light on an unforeseen consequence of shifting paddy cultivation dates. Before the water conservation law was enacted, a staggering 86% of paddy was planted on or before June 28. However, this percentage dramatically plummeted to 40% after the inception of the law. Consequently, the harvest was delayed, with only 14% of the crop being collected before June. This shift in the planting and harvesting timeline left farmers with an arduous challenge. The shortened time frame between rice harvesting and wheat sowing left the soil beds ill-prepared for the new crop. Farmers found themselves trapped in a predicament, desperately seeking a quick-fix solution. And so, in their desperation, they turned to the unfortunate practice of burning paddy residue in their fields. What was intended to be a temporary solution to a pressing problem ultimately exacerbated the issue at hand. Thus, the tale of Punjab's struggle with water conservation, pollution, and the unintended consequences of a well-intentioned act unfolded. It served as a reminder that every decision, even those made with the noblest of intentions, can have far-reaching implications. As the people of Punjab navigated through this beleaguered state, they yearned for sustainable solutions that would strike a balance between preserving the environment, safeguarding public health, and securing the livelihoods of the farming community.

Mechanization, advanced irrigation systems, and the availability of hybrid varieties paved the way for a new era of monoculture, with rice and wheat taking centre stage. Before the act, farmers in Punjab practiced multiple cropping, planting a variety of crops and relying on alternative options for sustenance if one crop failed. However, the law drastically changed this pattern, leaving farmers with no choice but to continue with the risky monoculture of rice and wheat. The government, with provisions such as subsidized inputs and assured market outputs, further incentivized this shift, reinforcing the new cropping pattern [64].

Yet, over time, the over-reliance on paddy and wheat began to take its toll. Punjab faced various socio-economic and environmental concerns, including the depletion of groundwater, declining soil fertility, increased water pollution from excessive chemical usage, and soil erosion. The consequences of this narrow focus on two crops became increasingly apparent. To address these issues, the government introduced programs like 'Crop Diversification' in 2013. The objective was to encourage farmers to shift away from monoculture and explore alternative crops. However, despite the provisions and efforts made, the majority of farmers found it financially unviable to diversify from paddy cultivation. Rice and wheat continued to dominate the agricultural landscape, occupying much more land than other crops. The issue of stubble burning, a major concern in Punjab, also demanded immediate attention. While the adoption of new rice varieties that mature within 125 days could reduce burning incidents, promoting their adoption could hinder the desired outcomes of the diversification program. The program also overlooked issues related to storage and transportation of alternate crops, failing to address the need for agro-processing units and cold storage facilities. Additionally, the honorarium provided under the scheme was insufficient to convince farmers to sustain diversification, as incentives for rice and wheat cultivation far outweighed those for alternate crops. Despite the government's promotion of crop diversification, the allocation of funds for the program experienced a significant decline. Lack of sufficient funds and inadequate support from the government deterred farmers, especially small and marginal ones, from participating in the program. The financial burden of the program, shared between the central and state governments, often hindered its implementation, with the state struggling to provide its share of funds [52].

In Punjab, the cropping system has been shaped by factors such as price, yield, and subsidized access to groundwater, leading to a significant increase in the area under rice cultivation. The marketing infrastructure and government food grain management heavily favor cereal crops, particularly paddy and wheat. The minimum support price (MSP) and procurement policies for these crops have created a well-developed market ecosystem, while alternate crops face uncertainties and challenges in the supply chain.

The lack of a successful procurement model for alternate crops, coupled with the financial viability of paddy and wheat, has deterred farmers from adopting diversification. Over time, Punjab's agriculture has become resource-centric, with large farmers benefiting more from MSP and subsidies, leaving small and marginal farmers struggling with low incomes, debt traps, and even suicides. The food procurement policy in Punjab, once a catalyst for agricultural growth, has become detrimental to sustainability and the livelihood of small farmers [65].

In Punjab, several policies and programmes recognize the potential of utilizing paddy straw for power generation and biofuels to control crop residue burning and reduce greenhouse gas emissions. However, challenges hinder the smooth utilization of straw. The introduction of combine harvesters has made straw collection a major challenge, requiring efficient collection methods like balers [66]. There is a conflict between the state and central government regarding the environmentally friendly treatment of paddy straw, with the state supporting incorporation into the soil while the central government favors ex-situ treatments. This creates confusion for farmers. The lack of storage facilities and high transportation costs further burden farmers and biomass power plants. The surplus supply of wheat and rice leads to post-harvest wastage, highlighting the need for improved storage and management systems. The economic viability of alternative options for biomass utilization is also a concern due to high processing and transportation costs [59].

In response to the need for effective crop residue management, a Central Sector Scheme was introduced in Punjab, Haryana, Uttar Pradesh, and Delhi, promoting the in-situ management of crop residue through mechanization. The scheme provided subsidies to farmers and collectives for purchasing machinery for crop residue management. However, farmers are facing challenges with the implementation of these machines. The distribution of machines decreased in 2019-20, with the popular Happy Seeder seeing a significant decline. One reason for this decline is that most tractors in Punjab have insufficient horsepower to operate the Happy Seeder, placing an additional burden on farmers to hire suitable tractors. Moreover, the limited usage period of the Happy Seeder makes it a less attractive investment for farmers. Issues such as machine malfunctions, lack of after-sales support, and low productivity also contribute to farmers resorting to traditional methods of sowing and crop burning. The gap in the supply and demand chain for these machines further exacerbates the problem. Additionally, farmers have raised concerns about increased costs and a lack of proper training. The high cost of hiring machines and the absence of standardized rental rates make it more economically viable for small farmers to pay fines for crop burning instead. These challenges highlight the need for addressing technical issues, improving availability and affordability, and providing comprehensive support to farmers to ensure the successful implementation of in-situ crop residue management machinery.

In Punjab, the agricultural practices were carefully planned to avoid labor shortages during crucial farming activities. However, the enactment of the 'Punjab Preservation of Subsoil Water Act' changed the dynamics. The act pushed the harvesting of rice and the sowing of Rabi crops to the months of October and November, coinciding with the festive season in North India. During this festive period of Dussehra, Deepawali, and Chatth, the availability of labor, which plays a vital role in managing rice straw and preparing fields for the next crop, became a challenge [56]. In Punjab, migrant workers from Uttar Pradesh and Bihar are the primary source of labor. However, the mechanization of paddy harvesting, driven by the Green Revolution, reduced the need for manual labor. Moreover, the implementation of the Mahatma Gandhi National Rural Employment Guarantee Act (MGNREGA) across India provided alternative employment opportunities closer to their hometowns. This resulted in a decline in seasonal migration to Punjab, further exacerbating the labor shortage issue. With labor becoming scarce and expensive, farmers relied more on mechanized harvesting and showed less interest in crop diversification programs. The transition to mechanization and the decrease in manual labor availability had significant implications for managing crop residue, as the labor-intensive process of removing paddy straw became more challenging. In this changing landscape, farmers faced difficulties in adopting alternative practices and coping with the demands of sustainable agriculture. The need for innovative solutions to address labor shortages, promote crop diversification, and ensure effective residue management became more pressing than ever in Punjab's agricultural story [14].

In the land of Punjab, agricultural subsidies were meant to alleviate the burdens of farmers. However, these very subsidies have inadvertently contributed to a host of problems, including the intensification of stubble burning and environmental degradation. The subsidies provided for power have had a significant impact on groundwater exploitation. Free and unmetered electricity supply to farmers has led to unsustainable utilization of resources and imperiled the groundwater table. The increasing cost of power subsidies has burdened the state's budget and has been a prime cause of bankruptcy for state boards. Punjab, under its 'free power scheme,' supplies free electricity to a vast number of agriculture sector tubewells [67]. The power subsidy bill has reached staggering amounts, putting a strain on the state's finances. If the power subsidy were to be withdrawn, the profitability of crops like rice, which require frequent irrigation, would be adversely affected and could potentially promote diversification to other crops. The government's policy on chemical fertilizer subsidies has also had unintended consequences. Indiscriminate use of chemical fertilizers has led to environmental deterioration, contamination of natural resources, and a threat to human health. Punjab's high consumption of fertilizers for crops like paddy, coupled with significant subsidies on urea, has resulted in excessive and inefficient use of fertilizers, causing nitrogen losses to the environment and impacting air and water quality [68]. The costs of these subsidies now outweigh the benefits. Punjab is experiencing declining fertilizer response ratios, stagnation in yield levels, and declining soil fertility for major cereal crops. If the current rate of environmental abuse continues, the state is heading towards agricultural distress [69]. This tale of subsidies highlights the unintended consequences that can arise when well-intentioned policies do not consider the long-term sustainability and environmental impacts. It serves as a reminder that balancing economic support for farmers with responsible agricultural practices is crucial for the well-being of both the agricultural sector and the environment.

6.1 Agencies and Institutions Supporting the Creation of the Initiatives and Policies around Agricultural Residue Management in Punjab

1. **Ministry of Agriculture & Farmer’s Welfare:** The Ministry of Agriculture & Farmers Welfare has introduced a Central Sector Scheme, fully funded by the central government, for the years 2018-2019 and 2019-2020. This scheme has been extended to cover the year 2020-2021 as well. Its purpose is to assist the governments of Uttar Pradesh, Punjab, Haryana, and the National Capital Territory of Delhi in their efforts to combat air pollution and provide subsidies for machinery needed to manage crop residues in the field.
2. **National Thermal Power Corporation (NTPC)**: The Indian Government has issued a directive to the National Thermal Power Corporation (NTPC) to blend crop residue pellets, comprising approximately 10% of the total, with coal for power generation purposes [70].
3. **Custom Hiring Centers (CHS)/Agriculture Service Centers (ASC):** In addition, the National Project on Management of Crop Residues (NPMCR) has implemented interventions by extending subsidies to farmers. These subsidies enable farmers to hire resource conservation machineries from various Custom Hiring Centres (CHS) and Agriculture Service Centers (ASC). Furthermore, NPMCR is actively promoting the establishment of new CHS/ASC to ensure the availability of different machines to farmers during crop harvesting [71].
4. **Punjab State Council for Science and Technology (PSCST):** The Punjab government is actively promoting the establishment of a 100% rice straw-based power plant. The objective is to set a target of utilizing 1 million tonnes of rice straw with a capacity of 200 MW in the near future, as outlined by the Punjab State Council for Science and Technology (PSCST) in 2013. This initiative aims to effectively utilize rice straw as a renewable energy source and reduce its environmental impact.
5. **National Academy of Agricultural Sciences (NAAS):** The National Academy of Agricultural Sciences has proposed an innovative solution to address the issue of air pollution caused by rice crop residue burning in the rice-wheat cropping system of North-West India. The solution involves the concurrent use of Super Straw Management System (SMS)-fitted combines and Turbo Happy Seeder. To promote the widespread adoption of this

technology, several business models can be implemented. Implementing these business models has the potential to achieve large-scale adoption of the technology. For instance, if 50% of the available combines in North-West India (approximately 6,500) are fitted with SMS and each owner acquires two Turbo Happy Seeders for dedicated use, it could result in a successful business model with a potential coverage of 1 million hectares within one year. This model not only reduces air pollution and fossil fuel usage but also generates employment opportunities for youth in the agricultural sector. The technology of concurrent use of combines and Turbo Happy Seeder is economically viable, environmentally friendly, and attractive to farmers. Encouraging its adoption through mechanisms such as payment for environmental services and carbon credits can further incentivize farmers [72].

6. **Krishi Vigyan Kendras (KVKs):** Over the past five years, the Krishi Vigyan Kendras (KVKs) in Punjab have been actively creating awareness about the issue of crop residue burning and promoting scientific management of residues. With the implementation of the Central Sector Scheme on "Promotion of Agricultural Mechanization for In-situ Management of Residue," funded by the Department of Agriculture, Cooperation & Farmers Welfare (DAC&FW) in New Delhi, the KVKs have received increased support to effectively address the issue and encourage people to take action [63].
7. **Indian Council of Agricultural Research (ICAR):** The Indian Council of Agricultural Research (ICAR), in collaboration with Krishi Vigyan Kendras (KVKs) and other stakeholders, implemented a project funded by the Department of Agriculture, Cooperation & Farmers' Welfare. The project aimed to address the issue of residue burning in Punjab, Haryana, Delhi, and Uttar Pradesh. The key efforts included:

- Information, Education, and Communication (IEC) Activities:
- Environment Building for In-situ Residue Management:
- Involving Young Minds
- Collaboration with Religious Leaders
- Promoting Zero Burning [63]

8. SAU’s and Government Institutes

Collaboratively with the government, agricultural universities (SAUs), and government institutes, various initiatives are being undertaken to address the issue of crop residue burning. These efforts aim to find effective solutions and alternatives. Some notable developments include:

Pusa Decomposer: The Indian Agricultural Research Institute (IARI) has introduced a promising method known as Pusa Decomposer, which allows for the decomposition of paddy stubble in the field itself. This low-cost capsule technology enables the conversion of stubble into bio-manure.

Microbial Decomposition: The Department of Microbiology at PAU conducted an experiment focused on microbial-assisted in-situ degradation of surface-retained paddy straw. The research involved spraying these microbial formulations onto the surface-retained straw, with subsequent evaluation of straw samples after 30 days to determine changes in lignin content and C/N ratio [73].

7. RECOMMENDATIONS AND POLICY GAPS IN PADDY STRAW MANAGEMENT IN PUNJAB

7.1 Recommendations

1. Encourage and provide incentives for the adoption of machinery: An expert from government should offer financial support, subsidies, and accessible loans to farmers to acquire machinery for managing paddy straw. Collaborations with private sector entities can ensure the availability and affordability of specialized equipment like happy seeders, straw balers, and mulchers. This would enable farmers to manage crop residue effectively without resorting to burning.

2. Strengthen agricultural extension services and farmer training: Enhance the reach and effectiveness of extension services to educate farmers about the advantages of sustainable paddy straw management practices. Organize training programs, workshops, and demonstrations to improve farmers' skills in operating machinery, implementing conservation agriculture techniques, and adopting alternative stubble management methods.

3. Promote research and development: Invest in research and development to explore innovative solutions for paddy straw management. Collaborate with agricultural universities, research institutions, and technology providers to develop cost-effective and efficient machinery, biofuel conversion technologies, and value-added products utilizing paddy straw. This would create additional income sources for farmers while reducing the need for burning. The heavy reliance on cereal crops has resulted in increased application of chemical fertilizers and pesticides, while the utilization of farm compost and recycling of crop residue has decreased. Consequently, the soil lacks essential nutrients. This situation offers an opportunity for the research community to develop hypotheses, gain insights, and provide recommendations to farmers on transitioning from a monoculture cereal system to a sustainable crop rotation approach. Such an approach should consider the specific conditions of the site, including soil quality, water resources, labour availability, and optimal planting dates, while also ensuring favourable economic outcomes.

4. Develop comprehensive crop insurance policies: Revise crop insurance policies to include specific provisions for paddy straw management. Address risks associated with stubble management practices, such as pest attacks, diseases, and adverse weather conditions. Ensure that farmers have access to affordable and comprehensive insurance coverage, providing them with financial security and encouraging the adoption of sustainable farming practices.

5. Strengthen market connections: Facilitate the establishment of robust market connections for paddy straw-based products like biomass pellets, biochar, and animal feed. Foster collaborations among farmers, industry players, and government agencies to create a sustainable market ecosystem that promotes the utilization of paddy straw residues. This would reduce economic burdens on farmers and incentivize proper paddy straw management. Several research studies and reports propose that in order to incentivize farmers, the government should enhance the infrastructure and establish a well-functioning network for procuring agricultural produce. To ensure that farmers receive the intended price security and benefit from support prices, the Minimum Support Price (MSP) should be supported either by efficient procurement methods or a deficiency payment system. This viewpoint is supported by [64].

6. Enhance coordination and collaboration: Foster greater coordination and collaboration among government departments, agricultural institutions, research organizations, farmer associations, and other stakeholders. Facilitate knowledge-sharing platforms, workshops, and forums to exchange best practices, address challenges, and collectively work towards effective paddy straw management solutions. This would create a supportive ecosystem and streamline efforts towards sustainable agricultural practices.

7. Irrigation water policies: Direct and tangible incentives are necessary to encourage the diversification of the state's crop patterns. Unless there is a system in place that provides incentives, the tendency to use water indiscriminately will persist. To promote efficient usage of surface water, it is important to adopt a pricing mechanism that is based on the volume of water consumed. However, careful planning is crucial for the successful implementation of such a policy. The introduction of a volumetric irrigation water pricing system can be done gradually, starting with areas that are irrigated by wells and tube wells, as measuring water usage in these areas is relatively.

8. Availability of machinery: It is essential to enhance the level of mechanization in order to improve the efficiency of paddy straw management. By employing advanced machinery and equipment, farmers can efficiently collect, process, and utilize paddy straw, thereby reducing the negative environmental impacts associated with its disposal [60].

7.2 Policy Gaps

1. Insufficient financial support: Existing policies do not adequately address the financial obstacles faced by farmers in acquiring paddy straw management machinery. More financial assistance, subsidies, and loan facilities are needed to make the necessary equipment affordable and accessible.

2. Limited focus on research and development: Current policies lack emphasis on research and development related to paddy straw management. Allocating resources and establishing dedicated research programs would drive innovation and the development of cost-effective technologies and practices.

3. Inadequate insurance coverage: Current crop insurance policies do not comprehensively cover the risks associated with paddy straw management. Policies should be revised to include specific provisions and coverage for these risks, instilling confidence in farmers to adopt sustainable practices.

4. Weak market connections: Insufficient attention is given to creating market linkages for paddy straw-based products. Policies should prioritize promoting the utilization of paddy straw residues in various industries, incentivizing investments, and establishing strong market ecosystems.

5. Fragmented approach and lack of coordination: There is a need for better coordination and collaboration among stakeholders involved in paddy straw management. Policies should encourage partnerships, knowledge-sharing platforms, and effective coordination mechanisms to ensure a holistic approach towards sustainable agricultural practices.

8. CONCLUSIONS

In conclusion, Punjab's agricultural saga embodies the intricate balance between noble intentions and unintended consequences. While policies like the Punjab Preservation of Sub-Soil Water Act aimed to safeguard vital resources, they inadvertently triggered challenges like stubble burning. Moving forward, addressing promoting crop diversification, enhancing crop residue management and re-evaluating subsidy structures are essential steps towards fostering a more resilient and sustainable agricultural ecosystem in Punjab. It's crucial for policymakers to think about the environment when they make rules for farming. This way, farming helps both the farmers and the environment. By balancing these things, future generations will have healthy farms and a healthy environment to enjoy.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

1. UNEP; 2021.
   Available: https://www.unep.org/explore-topics/air/about-air.
2. Anonymous; 2017.
   Available:https://www.indiatoday.in/india/video/smog-accident-highway-yamuna-expressway-cars-crash-1081738-2017-11-08.
3. Grover D, Chaudhry S. Ambient air quality changes after stubble burning in rice–wheat system in an agricultural state of India. Environ. Sci. Pollut. Control Ser. 2019;26(20):20550–20559.
4. Bhuvaneshwari S, Hettiarachchi H, Meegoda JN. Crop residue burning in India: policy challenges and potential solutions. Int. J. Environ. Res. Publ. Health. 2019;16(5):832.
5. Streets DG, Bond TC, Carmichael GR, Fernandes SD, Fu Q, He D, Klimont Z, Nelson SM, Tsai NY, Wang MQ, Woo JH. An inventory of gaseous and primary aerosol emissions in Asia in the year 2000. J. Geophys. Res.: Atmospheres 108 (D21); 2003.
6. Kaskaoutis DG, Kumar S, Sharma D, Singh RP, Kharol SK, Sharma M, Singh AK, Singh S, Singh A, Singh D. Effects of crop residue burning on aerosol properties, plume characteristics, and long-range transport over northern India. J. Geophys. Res.: Atmospheres. 2014;119(9):5424–5444.
7. Gadde B, Bonnet S, Menke C, Garivait S. Air pollutant emissions from rice straw open field burning in India, Thailand and the Philippines. Environ. Pollut. 2009;157(5):1554–1558.
8. Lohan SK, Jat HS, Yadav AK, Sidhu HS, Jat ML, Choudhary M, Peter JK. Sharma PC. Burning issues of paddy residue management in north-west states of India. Renew. Sustain. Energy Rev. 2018;81:693–706.
9. ESOP. Statistical Abstract of Punjab. 2022;784.
   Available: www.esopb.gov.in
10. Roychowdhury A. Pandemic and mobility: Lessons from covid-19 crisis for building solutions. Centre for Science and Environment; 2020.
   Available: Accessed at https://www.cseindia.org/pandemic-and-mobility-10274 on 15 January 2021
11. Prabhjyot-Kaur, Kaur S, Singh SS. Does smog in punjab affect neighbouring states? progressive farming, Punjab Agricultural University, Ludhiana; 2020;14-6

12. Singh BK, Sinha R. Crop Diversification: Transforming lives, one farmer at a time; 2022.
Available:https://www.bkcaggregators.com/2022/03/diversifying-agriculture-in-punjab-by.html?m=1 retrieved on 15-12-2022).
13. Kang MS. Achieving crop diversification in Punjab. The Tribune; 2013.
Available:https://www.academia.edu/26065277/Achieving_crop_diversification_in_Punjab retrieved on 20-12-2022.
14. Mukherjee P. Crop burning: Punjab and haryana's killer fields. [Down to Earth]; 2016, October 12. Available: https://www.downtoearth.org.in/news/air/crop-burning-punjab-haryana-s-killer fields-55960.
15. Singh Y, HS Sidhu. Management of cereal crop residues for sustainable rice-wheat production system in the Indo-Gangetic plains of India. Proceedings of the Indian National Science Academy. 2014;80(1):95-114.
16. Pingali P, Aiyar A, Abraham M, Rahman A. Transforming food systems for a rising India. Springer Nature; 2019;368.
17. John DA, Babu GR. Lessons from the aftermaths of green revolution on food system and health. Front. Sustain. Food Syst. 2021;5:644559;
Available:https://doi.org/10.3389/fsufs.2021.644559.
18. Roul C, Chand P, Pal S, Naik K. Assessment of agrobiodi- versity in the intensive agriculture: A case study of the Indo-Gangetic Plains of India. Biodivers. Conserv. 2022;31:397–412;
Available: https://doi. org/10.1007/s10531-021-02336-y.
19. Rasul G. Managing the food, water, and energy nexus for achieving the Sustainable Development Goals in South Asia. Environ. Dev. 2016;18:14–25.
Available:https://doi.org/10.1016/j.envdev.2015.12.001.
20. MoA. Crop diversification program in Haryana, Punjab & Western Uttar Pradesh. Ministry of Agriculture, Government of India; 2014.
Available:http://agricoop.nic.in/sites/default/files/CDPGuidelines_0.pdf on 16-12-2022.
21. Tripathi A, Mishra AK, Verma G. Impact of preservation of subsoil water act on groundwater depletion: The case of Punjab, India. Environmental management. 2016;58(1):48–59.
Available: https://doi.org/10.1007/s00267-016-0693-3.
22. Government of Punjab. Management and utilisation of paddy straw in punjab: Earn, don't burn initiative, draft white paper, department of science, technology and environment, Chandigarh; 2014.
23. Mandal KG, Misra AK, Hati KM, Bandyopadhyay Ghosh PK, Mohanty M. Rice residue-management options and effects on soil properties and crop productivity. J of sci techno. 2004;2:224-31.
24. Lal R. Residue management, conservation tillage and soil restoration for mitigating greenhouse effect by CO2-enrichment. Soil and tillage research. 1997;43(1-2):81-107.
25. Andrews SS. Crop residue removal for biomass energy production: Effects on soils and recommendations; 2006.
26. Bilalis D, Sidiras N, Economou G, Vakali C. Effect of different levels of wheat straw soil surface coverage on weed flora in Viciafaba crops. J. Agron. Crop. 2003;89:233–241.
27. Lenka NK, Dass A, Sudhishri S, Patnaik US. Soil carbon sequestration and erosion control potential of hedgerows and grass filter strips in sloping agricultural lands of eastern India. Agriculture, Ecosystems and Environment. 2012;158:31–40.
28. Sidhu HS, Singh M, Singh Y, Blackwell J, Lohan SK, Humphreys E, Jat ML, Singh V, Singh S. Development and evaluation of the Turbo Happy Seeder for sowing wheat into heavy rice residues in NW India. Field Crops Research. 2015;184:201-212.
Available:
https://doi.org/10.1016/j.fcr.2015.07.025. December 2015.
29. Tisdale SL, WL Nelson, Beaton JD. Soil fertility and fertilizers. Collier Macmillan Publishers; 1985.
30. Goswami SB, Mondal R, Mandi SK. Crop residue management options in rice–rice system: A review. Archives of Agronomy and Soil Science. 2020;66(9):1218-1234.
31. Dobermann ATHF, Fairhurst TH. Rice straw management. Better Crops International. 2002;16(1):7-11.
32. Singh J, BS Panesar, Sharma SK. Energy potential through agricultural biomass using geographical information system—A case study of Punjab. Biomass and Bioenergy. 2008;32(4): pp.301-307.

33. Gupta HS, Dadlani M. Crop residues management with conservation agriculture: Potential, constraints and policy needs. New Delhi: Indian Agricultural Research Institute; 2012.
34. Zaidi ST. Rice Crop Residue burning and alternative measures by India: A Review. Journal of Scientific Research. 2021;75:132-37.
35. Porichha GK, Y Hu, Rao KTV, Xu CC. Crop residue management in India: Stubble burning vs. other utilizations including bioenergy. Energies. 2021;14(14):4281.
36. Kumar P. The Extent and management of crop stubble. Socioeconomic and environmental implications of agricultural residue burning, Springer Briefs in Environmental Science; 2015.
37. Biswas PK, Goswami A, Biswas BK, Chand BK, Biswas A. Studies on improvement of poor-quality paddy straw through urea-molasses mineral mixture treatment on intake and milk production in cows. Journal of Interacademicia (India); 2002.
38. Anand S, Kaur J, Sarao LK, Singh A. Agricultural residues and manures into bioenergy. Agroindustrial waste for green fuel application, Clean Energy Production Technologies; 2023.
Available: https://doi.org/10.1007/978-981-19-6230-1_3.
39. Sharma S, Nandal P, Arora A. Ethanol production from NaOH pretreated rice straw: a cost effective option to manage rice crop residue. Waste and Biomass Valorization. 2019;10(11):3427-3434.
40. Motghare VS, Cham RK. Generation cost calculation for 660 MW thermal power plants. Int J Innov Sci Eng & Technol. 2014;1:660-64.
41. Anonymous. waste to energy projects; 2022.
Available: https://www.peda.gov.in/waste-to-energy-projects on 21.05.2023.
42. Paolini V, Petracchini F, Segreto M, Tomassetti L, Naja N, Cecinato A. Environmental impact of biogas: A short review of current knowledge. Journal of Environmental Science and Health, Part A. 2018;53(10):899-906.
43. Brtnicky M, Datta R, Holatko J, Bielska L, Gusiatin ZM, Kucerik J, Hammerschmiedt T, Danish S, Radziemska M, Mravcova L, Fahad S. A critical review of the possible adverse effects of biochar in the soil environment. Science of the Total Environment. 2021;796:148756.
44. Bhagawati R, Paul S, Dambale AS. Chapter-5 Farm waste management. AGRONOMY. 2020;77.
45. Meena HN, Singh SK, Meena MS, Narayan R, Bheem Sen. Crop residue: waste or wealth? technical bulletin 2022, published by ICAR- agricultural technology application research institute, Zone-II, Jodhpur. 2022;1-30.
46. NRSE Policy. Department of science and technology and non-conventional energy, government of Punjab; 2012.
47. PEDA. Biomass power projects. Retrieved from Punjab Energy Development Agency. [online]. Available at: https://www.peda.gov.in/biomass-power-projects.
48. Committee for Formulation of Agriculture Policy for Punjab State. Agriculture Policy 2013, Government of Punjab; 2013.
49. NFSM. Brief Note on CDP; 2018.
Available: https://nfsm.gov.in/ReadyReckoner/CU2/CUII_ Brief.pdf.
50. CEA. Technical specification for agro residue based bio-mass pallets (non-torrefied/ torrefied) for co- firing in coal based thermal power plants. Retrieved from; 2018.
Available: https://cea.nic.in/wp-content/uploads/2020/04/final_spec_biomass.pdf
51. CEA. All India installed capacity of power Stations; 2019.
Available online: http://www.cea.nic.in/reports/monthly/installedcapacity/2019/installed_capacity-03.pdf
52. Chaba A. Centre should support crop diversification in Punjab like it did during Green Revolution: Experts [Indian Express]; 2020.
Available:https://indianexpress.com/article/cities/chandigarh/centre-should-support-crop-diversification-punjab-experts-6919312/
53. Diprpunjab. Punjab govt signs MoU with IOC for setting up Bio-gas & Bio-CNG plants; 2018. Available: http://diprpunjab.gov.in/?q=content/punjab-govt-signs-mou-ioc-setting-bio-gas-bio-cng-plants.
54. Business Standard. BioCNG to be manufactured from paddy straw: Minister; 2018, June 11.
55. Government of India. On promotion of agricultural mechanization for in-situ

management of crop residue in the states of punjab, haryana, uttar pradesh and nct of delhi government of india Revised in 2020; 2020.
56. Pandey R, Kedia S, Malhotra A. Addressing air quality spurts due to crop stubble burning during covid19 pandemic: A case of Punjab; 2020. Available:https://www.nipfp.org.in/media/medialibrary/2020/06/WP_308_2020.pdf
57. Ramachandran A. Delhi: Crores allocated, but winter smog from stubble burning likely this year too. [Citizen Matters]; 2020. Available: https://citizenmatters.in/delhi-punjab-haryana-stubbleburning-winter-smog-and-covid-21241
58. The National Graph. Punjab Cm Orders social pre-audit of stubble management scheme for kharif season 2020; 2020. Available:http://www.thenationalgraph.com/eng/news/354.
59. MoAFW. Review of the scheme “Promotion of Agricultural Mechanisation for In-Situ Management of Crop Residue in states of Punjab, Haryana, Uttar Pradesh and NCT Of Delhi”; 2019.
60. Kumar S, Vatta K, Singh JM, Guleria A, Priscilla L, Kanwal V, Saini R, Singh G, Bansal S. Impact assessment study of central sector scheme for promotion of agricultural mechanisation for in-situ Paddy stubble management in Punjab. Department of economics and sociology, Punjab agricultural university, Ludhiana-141004; 2022.
61. Money control. Over Rs 1,600 cr central funds to combat pollution, stubble burning: RTI; 2019. Available: https://www.moneycontrol.com/news/india/over-rs-1600-cr-central-funds-tocombat-pollution-stubble-burning-rti-4728881.htm
62. Vibhaw N, Jain S. Ordinance passed to constitute a commission to control air pollution in the national capital region (ncr) and adjoining states; 2020. [Mondaq]. Available:https://www.mondaq.com/india/clean-air pollution/1003864/ordinance-passed-to-constitute-a-commission-tocontrol-air-pollution-in-the-national-capital-region-ncr-and-adjoining-states.
63. Singh J. Opinion of farmers regarding Crop diversification in Punjab. M.Sc Thesis. Punjab Agricultural University, Ludhiana, India; 2019.
64. Chhatre A, Devalkar S, Seshadri S. Crop diversification and risk management in Indian agriculture. Decision. 2016;43:167–179. Available: https://doi.org/10.1007/s40622-016-0129-1.
65. Ali S, Sidhu RS, Vattac K. Effectiveness of minimum support price policy for paddy in India with a case study of punjab. Agricultural Economics Research Review. 2012;Vol.25(2):231-242.
66. Balingbing C, Hung NV, Nghi NT, Hieu NV, Roxas AP, Tado CJ, Bautista E, Gummert M. Mechanized collection and densification of rice straw sustainable rice straw management springer, Cham; 2020. Available: https://doi.org/10.1007/978-3-030-32373-8_2.
67. Gulati M, Pahuja S. Direct delivery of power subsidy to agriculture in India; 2015. Available:https://www.esmap.org/sites/esmap.org/files/DocumentLibrary/SE4All-%20Direct%20Delivery%20of%20Power%20Subsidy%20to%20Agriculture%20in%20India_Optimized.pdf
68. Mansharamani A, Shrivastava A. Hazards of using fertilisers in Punjab. [Down to Earth]; 2020, March 02. Available:https://www.downtoearth.org.in/blog/agriculture/hazards-of-using- fertilisers-in-punjab-69548
69. IFPRI. Withering punjab agriculture: Can it regain its leadership?; 2007. Available:https://pdf. usaid.gov/pdf_docs/Pnadk223.pdf
70. Patial M, Pramanick KK, Shukla AK, Thakur A, Chauhan R. Crop residue: Type, alternative use and national policies for its management. 10, July. Crop residue: Type, alternative use and National Policies for its management (ropanonline.com); (Accessed on 18 Dec 2021). 2020
71. NPMCR. National policy for management of crop residues (NPMCR). Department of agriculture and cooperation, ministry of agriculture, government of India. 2014;1–11. Available:http://agricoop.nic.in/sites/default/files/NPMCR_1.pdf
72. Abarca RM. Innovative Viable Solution to Rice Residue Burning in Rice-Wheat Cropping System through Concurrent Use of Super Straw Management System-fitted Combines and Turbo Happy Seeder. National Academy of Agricultural Sciences. 2021;2:2013–2015. Available:http://naas.org.in/documents/CropBurning.pdf

73. Katyal P, Bhardwaj R, Sharma S, Sekhon J K, Pathania N, Vyas P, Kapoor S, Kocher G S. Microbial decomposer assisted in situ degradation of surface retained paddy straw. Int J Recycl Org Waste Agric. 2022;2:1-9.

© Copyright (2024): Author(s). The licensee is the journal publisher. This is an Open Access article distributed under the terms of the Creative Commons Attribution License (http://creativecommons.org/licenses/by/4.0), which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

Peer-review history:
The peer review history for this paper can be accessed here:
https://www.sdiarticle5.com/review-history/114189