Air Pollution: Technologies for Solving Crop Residue Burning in South Asia[1]

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Abstract

With the development of modern technologies and an increase in agricultural products, crop straw yield has also been growing in South Asia. Furthermore, inadequate access to suitable technologies and machinery to sustainably utilize the straw or promote its recycled usage has led to its burning, causing air pollution, including through transboundary sources. Currently, crop residue burning is one of the primary sources of severe air pollution in many parts of this subregion. Aside from health issues for people and climate change impacts from the emission of greenhouse gases, there are adverse impacts on agricultural production and food security due to deteriorating soil health. While it is essential to adopt suitable technologies for efficient and effective crop residue management, it is crucial to remember that in order to create a sustainable solution, strategies addressing the residue burning should also focus on interventions that generate real economic and commercial value for crop residues so that their burning results in an economic loss to the farmers. Thus, this article, after a brief review of the connection between air pollution and crop residue burning, provides information on some of the available crop residue management technologies and the incentives behind using them.

JEL Codes(s): O13, Q16, Q53, Q55

Keywords: air pollution, crop residue management, straw burning, agriculture technology and machinery

Introduction

Air pollution is a major environmental issue that affects countries worldwide, and South Asia is no exception. Many countries in this subregion, such as Bangladesh, India, Nepal, Pakistan, and Sri Lanka, face significant air pollution challenges due to various factors. Rapid industrialization has led to an increase in emissions from industries such as power plants, refineries, cement factories, and steel mills. Increasing transport vehicles on roads contributes significantly to air pollution, especially in cities. Old and poorly maintained vehicles, coupled with traffic congestion, result in high levels of exhaust emissions containing harmful pollutants. The high rate of urbanization and construction activities in South Asia has caused the release of dust particles into the air, and inadequate waste management systems have resulted in the open burning of waste, releasing toxic fumes into the atmosphere. At the same time, in rural areas of South Asia, biomass burning for cooking and heating purposes is prevalent. Agricultural practices such as seasonal stubble burning after harvest are another contributing factor to air pollution. Burning crop residues releases large amounts of smoke and pollutants into the air.

Air pollution has severe health impacts. The high levels of PM2.5 (particulate matter with a diameter of less than 2.5 micrometers) can penetrate deep into the lungs, causing respiratory problems, cardiovascular diseases, and even premature death. Some studies find connections between air pollution and an increase in infertility rates for both men and women. (Kumar&Singh (2022), Conforti et al. (2018)). Children, the elderly, and individuals with pre-existing health conditions are particularly vulnerable. Air pollution contributes to environmental degradation by damaging vegetation, reducing agricultural productivity, and harming ecosystems. Some air pollutants, such as black carbon or soot, contribute to climate change by absorbing sunlight and warming the atmosphere. Air pollution imposes significant economic costs on South Asian countries. The damage to crops and ecosystems affects agricultural output and livelihoods.

Addressing air pollution requires a multi-faceted approach involving government

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policies, technological advancements, public awareness campaigns, and international cooperation. In border areas of Bangladesh, India, Nepal, and Pakistan, straw burning is widespread, leading to severe air pollution across borders, as they are beyond national boundaries. Every year, cities like Dhaka, Delhi, and Lahore reel under severe PM2.5 impact, which causes health hazards as well as a lack of visibility for driving vehicles, landing planes, and train arrivals.

This paper discusses one of the important causes of air pollution, biomass or crop residue burning, and how innovative and localized technologies can be effective in the comprehensive management of this problem. This paper is based on a series of recent studies by ESCAP on straw management in Bangladesh, India, Nepal, and Pakistan and a subregional overview of this topic.

Various existing literature has examined how crop residue burning has a direct link with air pollution as it leads to atmospheric emissions of various pollutants such as Particulate matter (PM10, PM2.5), Carbon monoxide (CO), Carbon dioxide (CO2), Sulphur dioxide (SO2), Oxides of nitrogen (NOx), Ammonia (NH3), Methane (CH4), Elemental Carbon (EC), Organic Carbon (OC), Volatile Organic Compounds (VOCs), Polycyclic Aromatic Hydrocarbons (PAHs). (Awasthi et al. (2011), Jain et al.(2014) and Oanh et al. (2018)). Many studies find crop burning to be a strong contributor to South and South-West Asia's seasonal air pollution. (Ghosh et al. (2019), Kübra et al. (2023) Abdurrahman et al. (2022)).

Crop Residue Burning in South Asia

Agriculture is central to South Asian economies, lives, and livelihoods. For example, in Bangladesh, agriculture contributes nearly 13.02 % of Bangladesh's Gross Domestic Product (GDP) and employs 40.6 % of the country's workers. (BBS (2019), BBS (2020)). In India, it accounted for 16.6% of GDP in 2022[4] and 44 % of the employment (World Bank data, (2021, 2022)); in Pakistan, in recent years, it contributed to more than 19.2 % of Pakistan's aggregate GDP and employed 38.5 % of the labor force, and in Nepal, it accounts for 15.44 % of GDP (2019-20) covering 60.4 % of the employment in the country. (ESCAP.e (2023)). Air pollution caused by straw burning can also pose a transboundary issue, as smog may be easily picked up by the wind and carried over extended distances across countries and regions. (ESCAP(2020)).

Due to the development of modern technologies, the agricultural production rate has increased; however, this has caused a corresponding increase in crop residue yield as a by-product. These residues contain a considerable nutrient value. About 25 % of nitrogen (N) and phosphorus (P), 50 % of Sulphur (S), and 75 % of potassium (K) uptake by cereal crops are retained in crop residues. (ESCAP.e (2023)). However, optimizing the crop residue is a challenging task. With emerging outmigration patterns in the rural areas causing a shortage in agricultural labor and adding to the rise in the total amount of crop residue, short time spans between harvest and farming periods, and the high cost of available technologies and machinery, a sustainable crop residue management might not be manageable (or even economically reasonable) for farmers. In their study in Pakistan, Ahmed et al. (2013) estimated that the cost of collecting straw from the field was approximately US$140 per hectare, which is far more expensive than field burning. In addition, these straws might not be usable as a by-product for traditional use or with the available technologies. Despite the legal bans in place and as a result of these issues, many countries, especially in South Asia, have seen

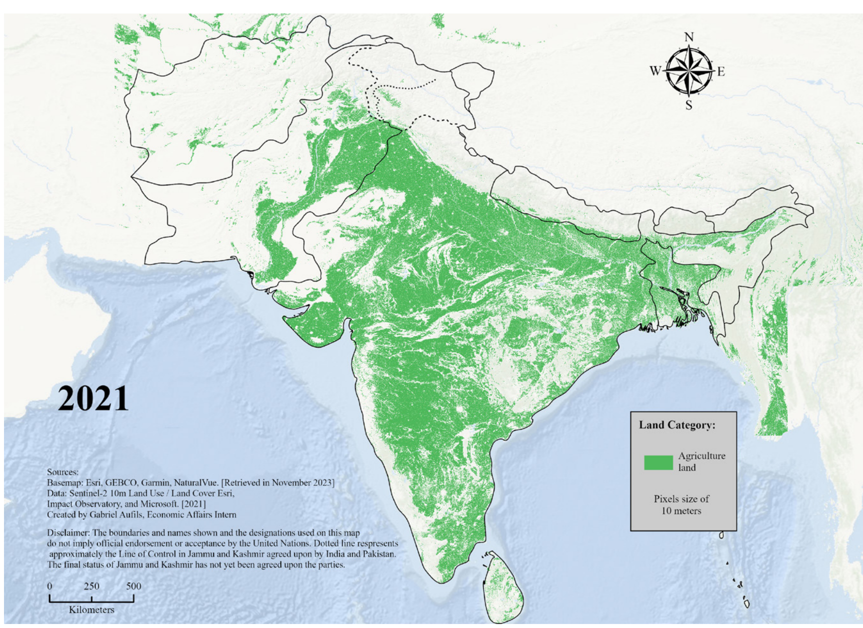


Figure 1. Map of Agricultural Area in South Asia
Source: ESCAP SSWA

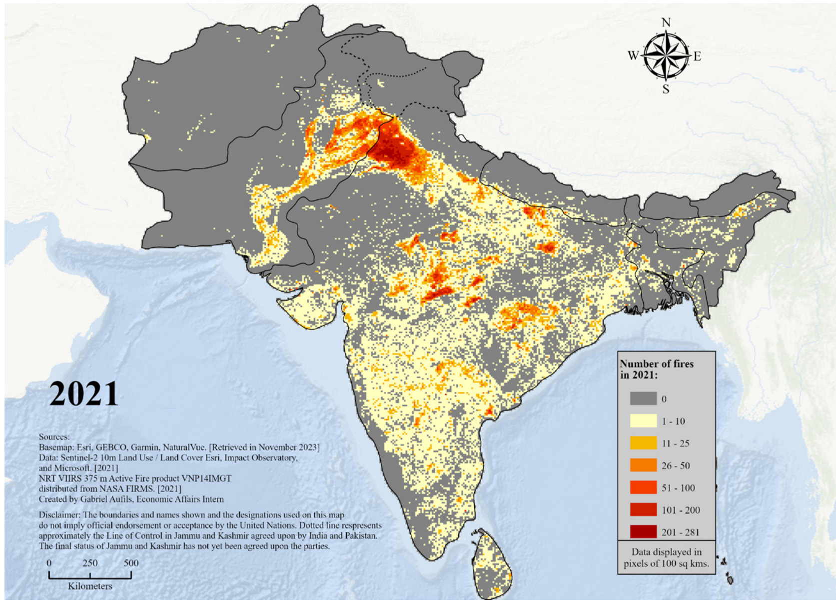


Figure 2. Pattern of Crop Fires in South Asia in 2021

Source: ESCAP SSWA

Note: This map shows the estimated number and concentration of fires in crop areas in South Asia over 2021. Identifying the crop and the calculations of fire in agricultural areas were based on the methodologies used by Kumar et al. (2019) and Kauchal & Leena (2022).

an increase in the burning of crop residue. Figure 1 presents the distribution of agricultural lands in South Asia, while Figure 2 shows the location and density of fire practice on agricultural lands in South Asia over one year in 2021.

The share of crop residue type differs by country based on their main agricultural products. For instance, in India, among the different crop residues, rice (43 %), wheat (21 %), and sugarcane (19 %) have had major contributions; however, residue burning is highly variable and dependent on usage patterns in each state. (ESCAP.e (2023)). For instance, residues subjected to burning could range from 8% to 80 % for rice crops across the states. (Jain et al. (2014)). Table 1, from ESCAP.e (2023),

Table 1. Biomass Burned and Emission Data for Major Crops in India

Crop	Year	Production* (Mt)	Straw production (Mt)	Biomass burned (dry matter) (Mt)	N_2O emission (kt)	CH_4 emission (kt)
Wheat	2016	92.29	161.51	12.17	0.85	32.85
	2017	98.51	172.39	12.31	0.86	33.24
	2018	99.87	174.77	11.86	0.83	32.02
	2019	103.6	181.30	11.72	0.82	31.66
Rice	2016	104.41	156.62	24.07	1.66	64.13
	2017	109.7	164.55	24.07	1.68	65.00
	2018	112.7	169.05	24.28	1.7	65.57
	2019	116.48	174.72	24.07	1.68	65.01
Maize	2016	22.57	33.86	9.9	0.693	26.73
	2017	25.9	38.85	9.63	0.67	26.00
	2018	28.75	43.13	9.38	0.66	25.32
	2019	27.72	41.58	9.02	0.63	24.37
Sugarcane	2016	348.44	139.38	3.22	0.22	8.68
	2017	306.07	122.42	2.88	0.20	7.78
	2018	379.90	151.96	3.07	0.21	8.31
	2019	405.11	162.04	3.289	0.23	8.88

*Source: *Ministry of Agriculture and Farmers Welfare (2021-22)* shows a sample of crop residues burned in India and the corresponding N2O and CH4 emissions produced between 2016 and 2019. At the same time, in recent years, Punjab (the state in Pakistan) has seen the burning of around 72% of rice straws due to difficult management techniques, limited resources of the farming community, and a short interval for seeding (ESCAP.d (2023)). Even though straw burning is not common across all South Asian countries, it is essential to pay attention to the projections and the potential rise in their occurrence due to the continuing structural changes.

Depending on the seasonal pattern of crop residue burning, the weather, and the temperature of the region, the resulting level of air pollution can vary. For example, seasonal crop residue burning (CRB) in the North-West (NW) agricultural states of Punjab and Haryana is a major source of PM2.5 air pollution in north India. (Kaskaoutis et al. (2014), Lohan et al. (2018)). Sembhi et al. (2020) found that during the 2016 air quality crisis, the NW Indian CRB timing shifts made a small contribution to worsening air quality (3% over Delhi) during the post-monsoon season.

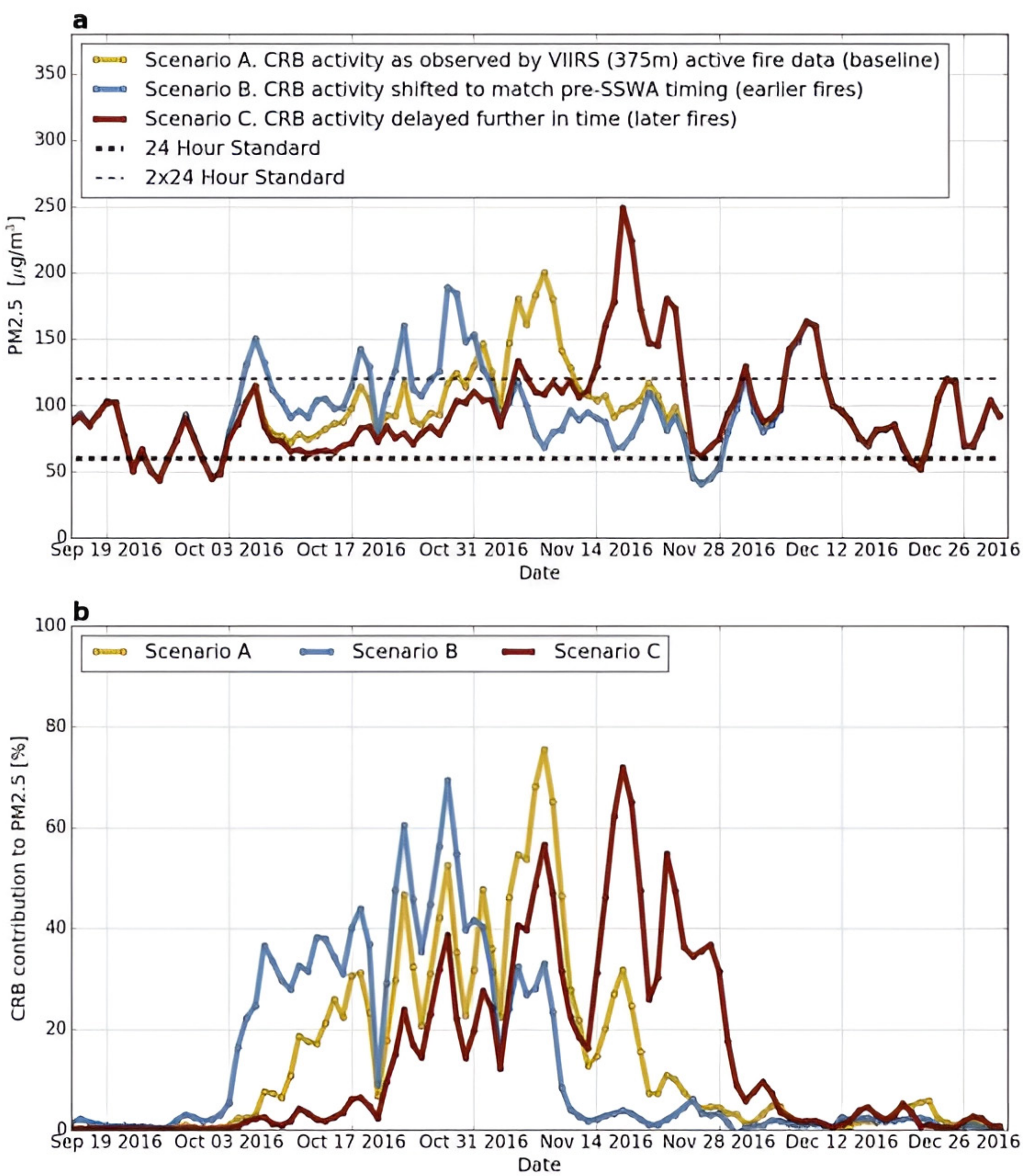
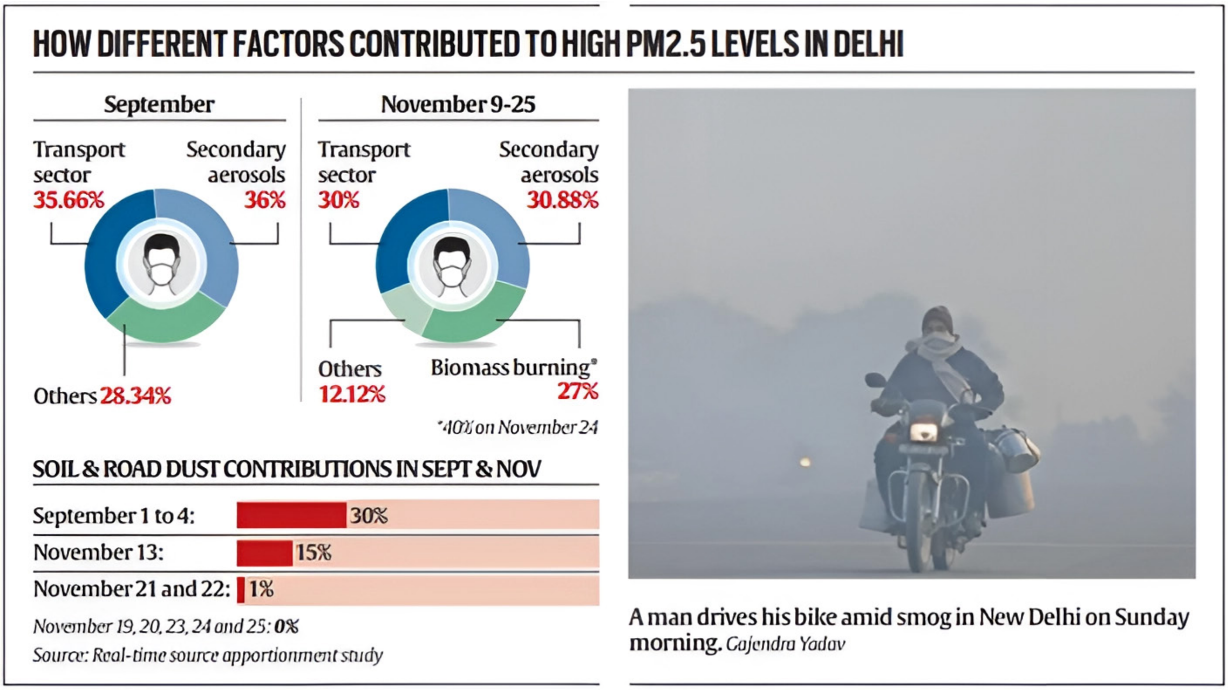


Figure 3. Time Series of Post-Monsoon CRB Smoke Emissions Impacts over Delhi under Different CRB Timing Scenarios for 2016

Source: Sembhi et al. (2020)

Note: (a) shows the absolute daily mean ambient PM2.5 concentration, and figure 3(b) shows the CRB contribution (in %). Simulated. PM2.5 data from the baseline Scenario A (mustard line), along with that of Scenario B (earlier fires than currently experienced, blue line) and C (later fires than currently experienced, maroon line), are shown.



A man drives his bike amid smog in New Delhi on Sunday morning. *Gajendra Yadav*

Figure 4. Airpollution Contributors in Delhi

Source:https://indianexpress.com/article/cities/delhi/real-time-source-apportionment-study-delhi-air-quality-transport-sector-delhi-vehicles-9043660

However, their estimations predicted that further delayed CRB would cause a much more severe situation in the source region (i.e., Ludhiana) and for Delhi by deteriorating the air quality by 30% and 4.4%, respectively. Figure 1 presents the pattern of the PM2.5 level in 2016 and the estimated contribution of crop residue burning during the same period.

A recent report on Delhi in November 2023 indicated that vehicles and secondary aerosols are the largest contributors to Delhi's PM2.5 level during September, which is pre-harvest, as shown in Figure 4. The average percentage contribution from vehicles was around 35.66% in September, while the contribution of secondary aerosols was 36%. Biomass burning emerged as an addition to these sources in November 2023 and is now one of the top three, with a contribution of around 27% to the overall causes.

Technological Solutions for Crop Residue Management

Innovative and localized technologies can help manage the in-situ and ex-situ crop residue. Retaining or mulching and incorporating the crop residues in the field and decomposing them using a consortium of microbes are methods of in-situ crop residue management, which can be easily managed with local technologies. Baling and transporting straw outside the field for alternative uses is known as the ex-situ management method. Various methods, technologies, and machinery are used in crop residue management for both methods.

Technologies for In-Situ Management

Farmers usually do not prefer in-situ incorporation because the stubble takes a long time to break down into the soil (particularly paddy crops). However, the in-situ incorporation of straw has benefits for soil properties. Ploughing back or surface retention of farm waste yields many benefits to soil's physical, chemical, and biological properties. (ESCAP.e (2023)). Selecting the appropriate type of technology depends on many factors, such as the type and size of land, crop, and temperature. In addition, the direct and indirect cost of using these types of machinery is a significant factor for the farmers. Some of the examples of in-situ machinery, as well as some challenges in using them, are presented in Table 2. Overall, the machinery cost seems to be a major issue that can especially affect small farmers. Localizing the available machinery is also needed based on the land, soil, and crop type.

In-situ and Mechanization Solutions

On-farm use of crop residues is the easiest way to prevent burning, as it requires minimum effort, and the cost incurred is also low in comparison to any other ex-situ management techniques. With the following three core interlinked principles, conservation agriculture is a viable option for sustainable agriculture and an effective solution to check land degradation. (Friedrich et al. (2009)). First, it is important to minimize mechanical disturbance in the soil and seed directly into untilled soil to improve its organic matter content and health. The next step is enhancing the organic matter cover on the soil using cover crops and/or crop residues. This protects the soil surface, conserves water and nutrients, promotes biological activity, and contributes to integrated pest management. Finally, it is important to diversify crops in associations, sequences, and rotations to enhance system resilience.

An impact assessment of in-situ residue management machinery was conducted by the Ministry of Agriculture and Farmers Welfare, Government of India. (MAFW (2019)). The committee recommended that the best and the most environmentally sustainable use of paddy straw is its incorporation into the soil. However, a series of challenges in using crop residue management machinery to sow seeds and apply fertilizer and pesticides need to be considered; some of them are shared in Table 2. Some of the limiting factors in the adoption of crop residue management (CRM) machinery for farmers include additional management skill requirements, apprehension of lower crop yields and/or economic returns, negative attitudes or perceptions, and institutional constraints. These need to be addressed through large-scale demonstrations and training. It is essential to support on-farm adaptation of CRM machinery in both large and scattered small fields and develop focused institutional and policy support, including appropriate incentives for its widespread dissemination and adoption. (ESCAP.e(2023)).

Technologies for Ex-Situ Management

Various existing and emerging technologies such as pyrolysis (biochar), bio-methanation (biogas), and conversion

Table 2. Machinery for In-situ Management of Crop Residue

	**Happy Seeder** Punjab Agricultural University (PAU), Ludhiana, India, has developed a Happy Seeder for sowing wheat directly into the combined harvested paddy fields without any other operation. Happy Seeder cuts straw in front of furrow openers and throws it over the sown crop in a single operation, which simultaneously acts as a mulch while drilling the seed and fertilizer. This mulch helps conserve soil moisture, prevent erosion, and suppress weed growth. Mulch helps to reduce irrigation requirements by about 15-20 % and weed emergence by about 50 %. Happy seeders cannot be used on unlevelled fields. However, in suitable locations, sowing with the help of Happy Seeders reduces labor requirements by 80 %, saves up to 10 % of fertilizers, and increases yield by up to 5 %. It also prevents the machine from choking under a heavy straw load. It can cover about 2.4 - 3.2 ha in one day. Happy Seeders are commercially available in 10, 11, and 13-row models. (Manes *et al*., (2017)). In Pakistan, the Rocket Seeder (eight-row), suitable for removing loose straws without cutting stubbles in front of each tine, was modified and named the Pak Seeder. This ten-row machine can undertake direct seeding of wheat into heavy rice residue and can be used immediately after combined harvesting on the same day. The results indicated that the average yield in heavy rice residue increased up to 600 kg/ha. Around 40 Happy Seeders are being used in the far-west, mid-west, and central parts of Nepal by commercial farmers and in research stations. Happy Seeders are not commonly used among marginal farmers as the capital investment required is high, and they need technical support.
	**Super Straw Management System (SMS)** The combine harvester throws straw residues from straw walkers in the center of the harvested area. The width of straw walkers is usually one-third the width of the combined cutter bar. This forms heaps of loose residues (as wide as the straw walker width) in lines, hindering Happy Seeders' operation. PAU developed a super straw management system as an attachment for the self-propelled combine harvester. Super SMS chops and uniformly spreads loose straw coming out of straw walkers of the harvester. It facilitates the working of Happy Seeders and increases its capacity. However, sometimes there is additional fuel consumption. In Pakistan, efforts were made to integrate a fine straw mechanism with combined harvesters, but this mechanism has not gained popularity among farmers. It was due to a decrease in operational capacity from 10 to 4 hectares per day and a high cost of operation. It is vital to spread loose straw uniformly before seeding to ensure a better yield utilizing the Pak Seeder/Happy Seeder. A simple, low-cost straw-spreading kit was developed in Pakistan to fix onto a combine. Owners/rental companies remove the chopping and spreading mechanism since it requires more power. Farmers who do not want to pay the additional cost of spreading straw also do not see any benefit in spreading out the straw in the field.
	**Mulcher** The Mulcher, with a vertical axis of rotation, is a rotation mower. Rotary mulchers cut standing stubble and leftover straw into small pieces and lay them over the field's surface. Small pieces of straw are then pressed by a roller attached to the rear side, creating a mulch layer over the topsoil. A Happy Seeder or reversible MB plow can then be used to sow wheat or invert straw into the soil, respectively. (Chaudhary et al. (2019)). To use this machine effectively, the straw needs to be dry.

Source: ESCAP.a(2023), ESCAP.b (2023), ESCAP.c (2023), ESCAP.d (2023), ESCAP.e (2023).
Pictures are Courtesy of ICAR/PAU

to biofuels (such as briquettes, pellets, bio-compressed natural gas [CNG], and bio-diesel) have been recommended for ex-situ use of paddy crop residue. (CII and NITI Aayog, (2018)). These newer options have been added to other existing practices, such as using straws for animal feed, mushroom cultivation, paper production, building materials, and handicrafts. (ESCAP.e (2023)).

The supply chain of crop residue and using it as fodder for animals, for electricity generation, or other ex-situ options requires various on-farm and off-farm operations, including collection, packing, handling, transportation, storage, and pre-feed processing. Any types of gaps and challenges within this process can interrupt the economic use of the residues. For example, a reliable supply of biomass to the end user requires a dense network of collection centers and supply chain management (SCM) facilities. However, the high cost of collection and transportation of residues from the field to the end-user has proven to be the prime impediment for scaling up ex-situ management practices. (Singh et al. (2010)). Therefore, entrepreneurs in the supply chain find the economics of handling crop residue unattractive. A sample of the supply chain of ex-situ management of crop residues has been presented in Figure 5.

Other Factors for Crop Residue Management

Concrete action plans and short- and long-term strategies built on collaboration among all the relevant stakeholders need to be developed to provide a sustainable solution. Some of the main guiding factors to achieve this goal are as follows:

Data Support

Significant amounts of crop residues are generated from agricultural crop production. The amount of extra residues depends on in-situ use to maintain soil fertility and the residue's competitive use for agricultural or industrial purposes. The use of agricultural crop residues for ex-situ purposes, such as bioenergy production (as straw or stover – stalks, ears, leaves, or cobs), requires accurate data on the availability of the crop residue by type as well as their local and annual variability. Estimating the residues available for bio-energy production provides information on the best locations for a bio-energy plant and plant size.

Therefore, the first and foremost action required is collecting accurate data about different residue production and use stages. For example, assessing the available amount of crop for ex-situ use and properly estimating the amount of potential biomass that can be generated from different crops is important. The availability of data is essential for the formation of an action plan for effective crop residue management. Using modern technologies such as Artificial intelligence (AI) can assist in data preparation, collection, and management; however, this needs to be explored further.

Increasing the direct value of the crops, Biomass Products, and Energy Generation

Ex-situ management can be a viable solution for using crop residues in a circular economy in an economically acceptable or attractive way for the farmer. To do so, good supply chain management is needed. This can include a strong network of biomass depots, providing a minimum support price for crop residue and its products, and creating accessible markets for the residues as well as their products.

Conducting Research and Development to identify more ways of using crop residue is also essential. Some of the new technologies that use crop residue as input include Gasification and Biofuel Production. Gasification is a process that converts biomass (wood, agriculture residues, briquettes, etc.) or fossil fuel-based carbonaceous materials into gases. India is one of the few countries in the world with an active research and demonstration program on small-scale biomass gasification

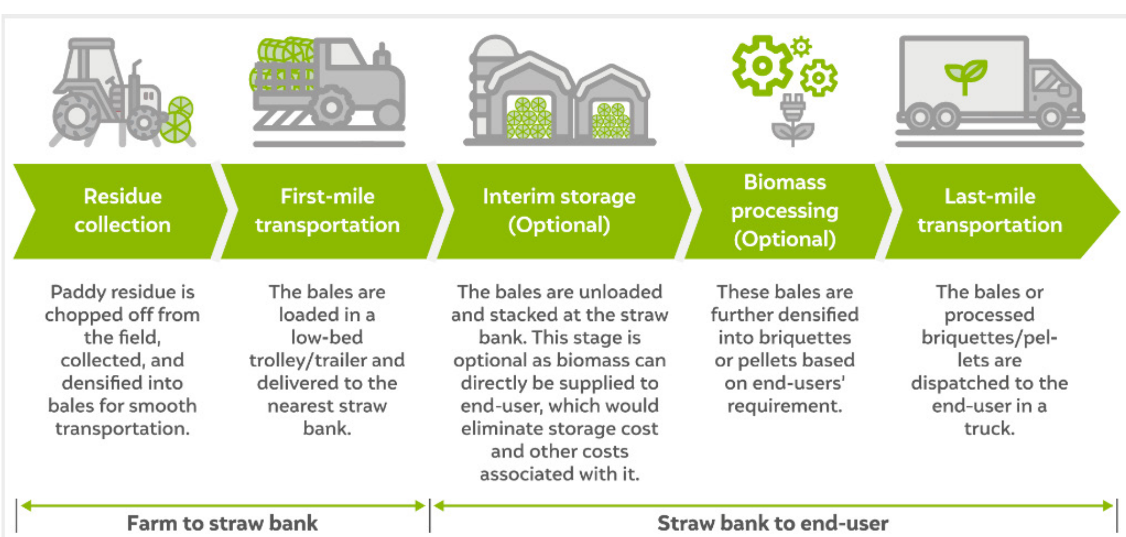


Figure 5. Supply chain of crop residue for ex-situ management
Source: Kurinji&Sankalp (2021).

technologies. About 1.2-1.4 kg of biomass is required to produce 1 kWh of electricity (using a 100 % producer gas engine). Crop residues can be utilized as fuel for running a biomass gasifier for multiple applications, including electricity, agro-processing, and running decentralized cold storage at the village level. This can also provide farmers with an alternate option to shift to horticulture crops for which farmers currently are reluctant, owing to limited cold storage capacity at the local level. A 250-kW capacity biomass gasifier plant can utilize about 2,000 tons of paddy straw annually and support a 50-tonnage refrigeration (TR) cold storage facility besides producing electricity. (Datta et al. (2020)).

There is a huge potential to offset fossil fuels by generating ethanol from bulk crop residues with efficient commercial technologies. Potentially, 250–350 l of ethanol can be produced from each metric ton of dry crop residues. Considering that only 20 % of the world's rice straw is used for this purpose, this would lead to an annual ethanol production of 40 billion liters, which would be able to replace about 25 billion liters of fossil fuel-based gasoline (Bhattacharyya and Barman, (2018)). For instance, in India, the potential of annual bio-ethanol production from surplus crop residue (178 Mt) has been estimated at 51.12 billion liters (Bl) out of the total annual bio-ethanol potential, ranging between 13.08 Bl and 38.04 Bl, depending on the season. Sugarcane biomass has the maximum bio-ethanol potential, followed by rice, cotton, and wheat crops.

Conclusion

This paper discussed the relationship between air pollution and crop residue burning, the leading causes of crop residue burning, and existing technologies for in-situ and ex-situ management methods. The alarming level of contribution from crop residue burning to air pollution in the northern areas of India and other countries in the subregion, observed in recent years, suggests that addressing this issue is an urgent task.

To overcome crop residue burning, an inexpensive and labor-efficient way of removing unwanted crop residues, technological solutions need to be explored, localized, and promoted by the government and the private sector.

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