Can the practice of On-Field Surplus Crop Residue Burning be replaced with On-Field Composting in Punjab?

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Crop residue is used in various environmentally friendly ways: for mulching, rural house roofing, making packaging materials, and feed stock for bioethanol and biochar production. However, a large quantity of crop residue remains unused (Surplus) and is burnt in the fields by farmers in Punjab. Crop residue burning creates enormous environmental pollution that leads to detrimental effects on the health of humans, animals and plants in the region. The Indian government has declared it as an illegal activity and farmers who burn crop residue in their fields are fined to discourage this activity. However, the practice of burning crop residue in fields allows farmers to clear their land in a short time so that they can sow the next crop on time for better yield. Composting is another promising environmentally friendly method, known to farmers, but farmers do not adopt this method as it appears to be costly, inconvenient, and the composting process takes 4-5 months to convert crop residue into organic fertilizer. A recent study, using cost-benefit analysis of crop residue burning, and on-field crop residue composting, has shown that on-field composting makes more economic, social, and environmental sense as compared to crop residue burning in fields. This paper attempts to assess the environmental, social and economic impact of crop residue burning, and on-field composting to aid policymaking.

1. Introduction

Crop residues are the byproduct left in the field after the crop is harvested and threshed. Many farmers consider crop residue as waste and burn it in their fields causing various environmental, animal, and human health related issues. In Indian state of Punjab, burning of rice and wheat crop residues in fields has been common practice for the last few decades as it effectively helps farmers to manage the removal of crop residue and sowing of the next crop in short time window. More than half of the districts of Punjab undergo only rice-wheat crop rotation (Kaur & Kaur, 2018) and the time window between the harvesting of rice and sowing of the wheat crop in a rice-wheat crop sequence is short (15-20 days), which compels many farmers to burn crop residues on their farms to save time. Rice crops are grown in the summer season, while wheat is grown in the winter season. According to the National Bank for Agriculture and Rural Development's Punjab State Focus Paper 2021-22, Punjab state alone contributed more than 35% of wheat and 25% of rice to the central pool of India (website – State Focus Paper, n.d.).

Cropping Pattern, Cropping Diversity & Green Revolution

Agriculture in Punjab has undergone several significant changes over the last many decades and until the 1990s, the state was leading India with thriving agriculture. This success was attributed to the package program called "Green Revolution," which North America introduced with the help of the government of India. The main objective of the Green Revolution was the production of more food grains for feeding the growing population of India. This package included the Hybrid High Yielding Varieties (HYV) of crop seeds, chemical fertilizers, various pesticides and herbicides, and extensive use of farm machinery for agriculture production. During this time, Punjab's agriculture significantly changed its cropping pattern.

The initially introduced HYV seeds were wheat, the staple food of most Punjabis. Rice growing was familiar to farmers of Punjab, but it was a marginal crop. However, most of the population of India eats rice, therefore, HYV of rice was also introduced in Punjab. Therefore, the introduction of wheat and rice had a great impact on the selection of rice-wheat crop rotation by most of the farmers of Punjab. The cultivation of rice on a large scale was no longer an issue. The tube wells, a new source of irrigation, irrigated rice plantation and it also took care of the seepage problem from canals in some parts of the state (Shergill, 2005). Food Corporation of India (FCI) procured wheat and rice from farmers and wheat and rice production became viable commercial crops for farmers in short time. The average agricultural sector growth for the entire country from 1961 to 1986 was 2.6%, and for Punjab it was 6.4%, the highest of all states of the country (Singh & Kohli, 2005). Over time, rice and wheat emerged as the two main crops of Punjab, and the number of crops grown in the state dropped from 21 in 1960-61 to 9 by 1990-91. The proportion of area under rabi (winter) crops other than wheat declined to 17.12% in 2004-05 from 62.74% in 1960-61. The change was drastic for the rice crop, as the area under rice cultivation increased ten times from 6.05% in 1960-61 to 63.02% in 2004-05 (Toor et al., 2007). In 1980-81, Punjab contributed 2.52 million tons of rice and 4.3 million tons of wheat to the country's central food grain pool, and this contribution has increased to 9.3 million tons of rice and 10.7 million tons of wheat in 2009-10 (Website – Statistical Abstract Punjab (SAP) 2015, n.d.).

Crop residues are a byproduct of food grain production. A portion of crop residues get used by farmers themselves in different ways. For example, it is used as fodder for animals (Wheat straw is used as fodder for animals). Any surplus quantity of crop residue that has no use to farmers is burnt by them in their fields immediately after crop harvesting. Though surplus crop residue can be composted by farmers but not many farmers follow this practice, as the composting process takes 4-5 months to convert the crop residue into compost that can enrich farm soil for the next crop cycle. Therefore, in each season there is a large amount of surplus crop residue that gets burnt by farmers in fields. It was estimated in a study (Sidhu & Beri, 2005), that 81 percent of rice crop residue and 48 percent of wheat crop residue is burnt in fields of Punjab.

In 2015, India banned the burning of crop residue, but crop residue burning by farmers did not stop thus making the air quality worse during crop harvesting seasons. The practice of on-field crop residue burning is illegal, but farmers find it easiest to clear their fields in a short time. The massive crop residue burning in a short period of 15- 20 days, results in the deterioration of air quality through emissions of smog, haze, heat waves, and GHGs, contributing to global warming (Bhuvaneshwari et al., 2019).

Crop residues need to be managed to protect the environment, public health, and to make it more economical to food grain producers. Therefore, to discourage crop residue burning and to promote sustainable methods of crop residue management, it is important to assess the quantity of crop residue burnt for each district of the state. The assessment of the quantity of crop residue being burnt is useful to devise and implement a proper policy framework to promote environmentally friendly methods to manage surplus crop residue in the state. The review of literature related to the assessment of the surplus quantity of crop residue burnt in fields in each district is not available because there is no systematic method of reporting the crop residue burning incidents. Moreover, there is also a shortage of staff and other resources with government departments involved to check and report such incidents. Therefore, the data generation related to crop residue burning can be helpful in the assessment of the amount of greenhouse gases generated, as well as the assessment of the cost of on-field crop residue burning in comparison to other environmentally friendly methods of crop residue composting.

In this paper, the basic assumption is that surplus rice and wheat crop residue is burnt to clear the fields in a short time for sowing the next crop. Therefore, this the objectives of this paper are to find the various methods being used to manage crop residues and assess the environmental, social and economic impact of crop residue burning, and on-field composting. To meet these objectives, secondary information related to management of crop residue and surplus crop residue were collected using credible sources such as government departments, websites of government agencies and peer reviewed journals.

2. Rice -Wheat Crop Rotation - Literature Review

There are sufficient and sound reasons why the rice-wheat crop combination is more popular among farmers. It provides stable crop yield and sustains income of farmers. It contributes to the country's food security and has good export potential (Shergill, 2005). However, Punjab's agricultural growth slowed to 3% annually from 1985-86 to 2004-05, and it went down to 1.6% per annum after a few years (Gulati et al., 2021) due to the adverse effects of the Green Revolution, such as a reduction in genetic diversity and soil fertility, soil erosion, soil contamination, water shortages and greater vulnerability to pests.

Punjab produces around 13 million metric tons of rice annually and it is about 10% of the total rice produced in India (Website - https://www.statista.com/statistics/1019575/india-rice-production-volume-in-punjab/). According to the Package of Practices -2024, rice crops occupied 31.68

lakh hectares with an average yield of 64.79 quintals per hectare (26.22 quintals/acre).

Short Time Window between Harvesting of Rice and Sowing of Wheat Crop

Rice crops can be either sown or transplanted. In Punjab, sowing time for rice crops is 20 May–20 June, and harvested at the end of October, i.e., 130 days after sowing (Package of Practices for the crops of Punjab, 2024). In the case of transplanting, nursery seedlings are sown at the same sowing time (20 may-20 June), and 30 -35 days old seedlings are transplanted in the fields from 20 June-10 July. Farmers had to stick to the timely sowing of rice crop nursery (20 May – 20 June) and timely transplanting of the nursery (20 June–10 July) in fields for better grain quality, water saving and for low build-up of pests.

Wheat was a major cereal crop grown on 35.26 lakh hectares during 2021-22, with an average yield of 42.16 quintals/hectare (17.1 quintals per acre). The first fortnight of November is an optimal time for sowing and most wheat varieties harvested at the end of April (Package of practices for crops of Punjab, 2023-24). As per the package of practices, a delay of one week from optimum sowing time reduces wheat yield by about 150 kg per acre. As per the Package of Practices, the optimal time window between rice and wheat crops in Punjab is from the end of October to the first fortnight of November (15-20 days, after rice harvesting) and for rice crop it is the end of April to 20 May (20-25 days) after wheat harvesting. This short time window between crop harvesting and sowing of the next crop creates the challenge of crop residue management for farmers of Punjab.

3. Large Quantity of Crop Residue Generation

The agriculture sector produces multiple kinds of crop residue. Crop residues are in the form of leaves, rice straw, wheat straw, oats and barley straw, and seed pods (Koul et al., 2022). Crop residue management technology depends on the source, quantity, and type of agricultural waste generated. Crop residues are used to feed cattle, compost making, rural roofing, packaging materials, wood, paper, bioethanol, biochar, and put to many other uses (Kaur, 2017).

Punjab has high biomass availability in the form of crop residues. According to Sangeet & Rajkumar (2016), the total crop residue generated in Punjab is 48.2 million tons. Rice-Wheat rotation produces about 23 and 17 million tons of paddy and wheat straw respectively, per year (Kumar et al., 2015). Various crop residue management options are available in Punjab for rice and wheat crop residues (Kumar et al., 2022).

Crop Residue – Source of Energy

The study conducted by Gross et al. (2021) indicated that cattle and buffalo manure and crop residues could be used together as feedstock to produce biogas by anaerobic digestion and producing organic fertilizer as a byproduct. Many researchers have shown that bioenergy can also be generated from rice crop residues via anaerobic digestion to produce biogas (mainly Methane) which can be collected and combusted to generate electricity (Singh et al., 2020). According to Lohan et al. (2018), many countries such as China, Indonesia, Nepal, Thailand, Japan, Philippines, Malaysia, and Nigeria generate compost and bioenergy from crop residues. It was estimated that total surplus crop residues generated in Punjab have a high annual bioenergy potential of 77.3 MW (Mega Watt) and the contribution of wheat and rice crop residues could be maximum due to the higher area under production of these crops (Sangeet & Rajkumar, 2016).

Mulching (Soil Protective Cover)

Crop residue is used to provide a protective covering of the soil to reduce evaporation, prevent erosion, control weeds, and enrich soil (mulching). Some researchers have focused on residue incorporation in soil for further decomposition that improves soil's organic composition and properties (Singh Y. et al., 2004).

Fodder for Animals

A significant proportion (47%) of the wheat stubble is used as animal fodder in seven districts: Amritsar, Bathinda, Faridkot, Gurdaspur, Kapurthala, Ludhiana, and Sangrur. Gurdaspur district was the only district in which wheat residue (2.4%) was incorporated into the soil. So, most of the residues burnt belong to rice and wheat crops, and a small amount is incorporated back into the soil. Rice straw has a high amount of silica content (Mirmohamadsadeghi & Karimi, 2020) which contributes to poor nutrient digestibility (< 50%) and thus is unfit for ruminant consumption.

Biochar Production

Biochar is another product that is produced from straw through the pyrolysis process. In this process, straw or crop waste is burnt under low-oxygen conditions, which prevents the complete combustion of the material, resulting in the formation of biochar that can be used to improve soil fertility by increasing nutrient availability and soil structure of soil (Jiang et al., 2020). Pyrolysis also reduces carbon emissions by sequestration of carbon into soil for long periods (Zhang, et al., 2017). While biochar offers various benefits, the pyrolysis process requires high initial costs for the setting up of biochar production facilities and it is an expensive process, especially for small-scale farmers. Additionally, if biochar is not produced under the right conditions, it may introduce harmful compounds into the soil such as heavy metals or toxic substances that could harm plants and soil organisms (Kuppusamy et al., 2016). Farmers in general, lack the technical expertise to produce or apply biochar effectively.

In Situ Incorporation in Soil

According to the Department of Agriculture of Punjab, less than 1% of farmers in Punjab adopted in situ incorporation of crop stubble, because it reduces the yield of wheat crops. This is due to incomplete decomposition of residues which leads to nitrogen deficiency in soil due to inorganic nitrogen immobilization (Singh Y. et al., 2004). However, if crop residues are given the required time for decomposition after incorporation of crop residues in the field, there would be no N immobilization issue and there would be considerable increase in soil organic matter and potassium supply. This can be done by complete composting of crop residues, which takes a period of 4-5 months.

4. Surplus Crop Residue Burning

As per a recent study of Punjab, farmers face various problems regarding rice straw management, including technical, managerial, financial, and domestic usage problems (Singh & Ranguwal, 2023). The study by Singh & Ranguwal stated that 100% of surveyed farmers agreed that no other suitable rice straw management technology exists except burning. Other alternatives delay wheat sowing and there is a high cost of removing residue from fields. Using crop residues for large-scale bioenergy production is a challenge too. A high alkaline ash content present in crop residues pose an operating issue for electricity generation machinery (Porichha et al., 2021). Economically, feedstock transportation costs from fields to centralized large-scale power plants are high due to bulkiness of crop residue and therefore it makes large bioenergy plants unprofitable to use crop residue as fuel. For this reason, biomass power plants in Punjab consume only 1 million tons of rice straw annually, that is, only 5% of the total residue generated (Porichha. et al., 2021). According to Sidhu et al. (1998), in many districts, farmers managed their rice and wheat straws by on-field burning. Only 0.5 to 0.6 percent of rice straw was used as fuel in Gurdaspur and Jalandhar districts. In contrast, no farmer prepared compost from rice and wheat crop residues, and very few farmers incorporated crop residues into the soil directly (Kumar et al., 2015).

Kumar et al. (2015) listed the end use of crop residues in different districts of Punjab. The rice straw was burnt and had no other end-use in the Bathinda district of Punjab. In the Amritsar district, rice crop residue was used for other uses (apart from burning), with maximum use as fodder (18.2%). Furthermore, 19.6 percent of the total residue produced was sold in the market, and 9.4 percent was given to poor, landless families. Almost 20.6 % of the rice crop residue is provided to poor landless families in Gurdaspur district, 12.9 % is used as fodder, and the rest of rice residue is burnt. In the Patiala district, 81.5 % of the rice residue produced was burnt; of the rest, 11.7 % was used as fodder for animals, and 5.9 % was sold in the market. Except for the Ferozepur district, rice stubble is hardly incorporated in the soil (8.8 %). In this district, 18.8 % of the rice straw is provided to poor landless families, and 68.1 % is burnt.

Effects of Crop Residue Burning - On Environment

The main reason for crop residue burning in the field is the higher cost of removing crop residues from fields and time-consuming process of other alternatives, such as bioenergy production, converting it into cushioning materials, and mulching, and farmers believe that it is more expensive, and it also needs more time to complete the process. Moreover, Haider (2012) indicated that crop residue burning in the field generates some benefits, that include land clearing in a short time and weed/pest management. Burning the residues within the field kills residue-borne pathogens and damages weed plants and their seeds in the soil.

Crop residue burning leads to quick release of nutrients such as nitrogen, phosphorus and potassium into the soil due to the breakdown of complex organic compounds from the heat of the fire (Biederbeck et al., 1980). The Nitrogen in organic matter is particularly sensitive to burning due to its low temperature of volatilization (200 degree Celsius. However, it causes an increase in inorganic N in soil leading to an increase in the availability of Nitrogen in soil (Sharma & Mishra, 2001), but the negative effect of burning on soil last longer.

Soil Health

With open field burning, nutrients such as nitrogen, sulfur, and organic carbon decline, ultimately reducing the microbial population of soil as soil nutrients are required for their survival (Sharma & Mishra, 2001). Heat produced by crop residue burning harms the soil's microbes, which further leads to decreased soil fertility and crop yields. As per the study conducted by the Department of Soils, PAU, Ludhiana (2010), one ton of soil loses 6-7 kg Nitrogen, 1-1.7 kg phosphorus, 14-25 kg potassium, and 1.2-1.5 kg sulfur because of crop residue burning. This leads to an additional yearly expenditure of Rs. 150 crore/year to replenish the soil (Kaur, 2017).

Public & Animal Health

Burning crop residues release soot particles and smoke, causing human and animal health issues. Researchers have suggested that the burning of crop residue leads to Polycyclic Aromatic Hydrocarbons (PAH) emissions (Zhang et al., 2011). In a study it is mentioned that rice residue burning in Punjab, led to an increase of 50-75% in PM2.5 (Particulate Matter that measures less than 2.5 micrometers), 40-45% in PM10 (Particulate Matter that measures less than 10 micrometers) concentration in the air of the capital city of India (Khan et al., 2023). According to (Godde et al., 2009), open burning of crop residues results in the emissions of harmful chemicals that have toxicological properties and are potential carcinogens like polychlorinated dibenzo-p-dioxins (PCDDs), Polycyclic Aromatic Hydrocarbons (PAH) and Polychlorinated dibenzofurans (PCDFs) referred to as dioxins.

The dioxins released from burning crop residue have toxicological properties and are potential carcinogens. Burning crop residues have adverse impacts, especially for those people who are already suffering from a respiratory disease or cardiovascular disease. Inhaling delicate particulate matter triggers asthma and can even aggravate bronchial attack symptoms. More than half (60%) of the population in Punjab live in rice-growing areas and are exposed to air pollution due to the burning of rice residues (Singh et al., 2008). Irritation in the eyes and congestion in the chest are two main health issues faced by people due to crop residue burning. Even the medical records of the civil hospital of Zira city (Ferozepur district), in the rice-wheat belt, depicted a 10 percent increase in the patients' number within 20–25 days of the crop residue burning period every season (Singh et al., 2008).

Air Quality

Ravindra et al. (2019) described that crop residue burning could increase emissions by 45% by 2050, considering 2017 as the base year. In addition, crop residue burning leads to accidents on roads due to decreased visibility caused by smoke during the peak periods of stubble burning, that is, in the months of October and November. Air pollution also affects animals' health. Inhaling carbon monoxide and carbon dioxide from polluted air can cause hemoglobin to convert to deadly hemoglobin. There can also be a potential decrease in the yield of milk from milk-producing animals.

There is also an emission of greenhouse gases, namely carbon dioxide, methane, and nitrous oxide, which causes global warming. India-wide, agricultural fire emissions from the northwest states (Punjab. Haryana, Rajasthan, Uttar Pradesh, Himachal Pradesh) contribute more than 90% of the fire-related exposure, with 64% from Punjab (Lan et al., 2022). Crop residue burning has an adverse negative impact on the environment of neighboring states and countries as well. A recent study by Huang et al. (2022) has shown that PM2.5 (Particulate Matter that measures less than 2.5 micrometers) and other harmful gases (CO2, CH4, NO2, etc.) emitted in crop residue burning affect air quality not only in Punjab or India but is also being transported by the predominantly north-westerly winds to neighboring countries; Pakistan, Nepal, and Bangladesh.

5. Role of Government Laws in Stopping Crop Residue Burning

Section 188 of the Indian Penal Code (IPC) makes stubble (crop residue) burning a crime. Additionally, under the Air (Prevention and Control of Pollution) Act, 1981, it was notified as an offence. National Green Tribunal (NGT) is a specialized body with expertise in handling environmental disputes involving multi-disciplinary issues, and it has directed every district administration of Punjab to fine farmers found burning crop residues. The NGT fines farmers for burning crop residues in fields (Singh & Zaffar, 2017). Despite being banned or penalized, the practice of crop residue continues, as farmers do not find viable alternatives to clear their fields in a short time window. The Punjab Agriculture and Farmers' Welfare Department has taken significant steps, such as an 80% subsidy on Crop Residue Management (CRM) Machines if rented through Custom Hiring Services and 50% if purchased. The state has allocated Rs. 350 crores to curb crop residue burning during harvest (Bajwa, 2023). Even the Agricultural Department has launched an Extension drive to educate and train farmers regarding the usage of this farm machinery. It is advertised in local newspapers to inform people about the adverse impacts of crop residue burning on the environment and the health of humans and animals. The District Commissioners direct gram panchayats to help stop the practice of crop residue burning in Punjab.

6. Can On-field Composting be a Substitute for Crop Residue Burning in Punjab

Crop residue burning wastes valuable resources, as it could be a good source of carbon, bio-active compounds, feed, and energy for small industries and rural households. Instead of being burnt in the field, it can be composted. On-field composting is one of the strategic technologies for the sustainability of farming activities, which could solve the critical issue of the disposal of crop residues (Pergola et al., 2018).

Composting is a biological process in which organic waste is recycled into value-added products, i.e., compost under aerobic conditions, and this product can be utilized for crop cultivation (Kim Ho et al., 2022). Compost limits the transport properties of soil, prevents the erosion of pesticides, and retain the porosity of soil (Woignier et al., 2016), thus enhancing soil health. Besides agricultural lands, urban soil such as gardening soil can also benefit from this compost, as it would provide soil nutrients and contribute to Soil Organic Carbon (SOC), etc. (Kranz et al., 2020), so it can be a good source of income for farmers.

There was a steep decline in using crop residue as household fuel for bedding and composting. The crop residues have been traditionally used as organic waste to prepare compost. Straw from crops, especially rice and wheat, along with cow dung and kitchen waste, are used in compost preparation. This compost serves as an organic manure for the soil. In the composting process, microorganisms release biochemicals to break down these raw materials (feedstock) by undergoing several biochemical processes, including oxidation. Carbon and nitrogen are the most essential elements required for microbial decomposition. The composting process has four phases: mesophilic, thermophilic, cooling, and maturation. The mesophilic phase is characterized by the explosive growth of mesophilic bacteria and fungi; during the thermophilic phase, more complex compounds such as proteins, fats, and cellulose get broken down by heat-tolerant microbes. In the cooling phase, temperature drops, and in the maturation phase, a series of secondary reactions take place, which cause condensation and polymerization of the compost. Crop residue acts as a carbon energy source for microbial growth in soils for decomposition and biological nutrient cycling

(Singh Y. et al., 2004). Various factors affect the length of the composting process, such as pH, C: N ratio of raw material, moisture, composting technology, oxygen availability, etc. The ideal C: N ratio for the composting process from the northwest states of India is generally considered to be around 30:1, and the C: N ratio of crop residue, such as straw, is 75-80:1. Moreover, adequate phosphorus, potassium, and trace minerals (calcium, iron, boron, copper, etc.) are essential to microbial metabolism, and these are present in ample concentration in the crop residues. In addition, compost positively affects soil's physical and chemical properties (Becker et al., 2010). So, crop residues can be used as a good source of compost (Lentz et al., 2016-17; Ferraz et al., 2020).

On Field Composting as Crop Residue Management Strategy

To replace 'On-field crop residue burning strategy', farmers need help find a suitable and sustainable crop residue management strategy. However, farmers are aware of the composting method but very few farmers in Punjab have implemented it in their fields (on-field composting). The composting strategy of crop residue management can allow farmers to adopt organic farming, Bioremediation, Biocontrol, and composted product can be a bioinoculant carrier too (Koul et al., 2022). A high-quality product can be produced to overcome the cost of composting (Bernal et al.,2009).

Brar (2024) assessed the cost of crop residue burning and compared it with the cost of on-field composting on a per acre basis. According to Brar, a compost pit assumed to be dug out in the corner of the field where crop residue collected from the field will be composted, and the field would be ready for sowing the next crop in a short time interval without removing the residue away from the field. A valuable organic compost product would be formed in the next 4-5 months, waiting to be broadcast back into the field for the next crop. The process takes 4-5 months to get the compost product ready to be broadcast in the field as an organic fertilizer. Using this strategy, residues of rice and wheat crops can be managed by an eco-friendly method (on-field composting) and it can help stop the practice of crop residue burning.

Brar, P. (2024) assessed on-field composting costs (labor and farm machinery costs) for four on-field models: one acre, four-acre, eight-acre, and sixteen-acre farm model to manage the rice and wheat crop residues. The assessed cost of burning surplus crop residue (with and without the inclusion of government-imposed penalty) compared with the cost of composting per acre basis. The assessed burning costs of crop residues with penalty charges included (in cost assessment) found to be higher than the total cost of on-field composting for most districts of Punjab. However, the cost savings for on-field composting of rice crop residues was found to be relatively less than on-field composting of wheat crop residues.

In the second scenario where the penalty cost due to crop residue is not included in the cost estimation, the cost of surplus crop residue burning is assessed to be significantly less than the on-field composting costs for rice and wheat crops, in most of the districts of Punjab. Perhaps, this is one of the main reasons that farmers tend to go for 'on-field crop residue' burning. Also, it is common knowledge that government agencies do not have enough resources to go out and check crop residue burning everywhere. Moreover, government officials cannot reach every village in a very short crop residue burning season. Therefore, farmers find crop residue burning as the cheapest and easiest way to clear their fields before sowing the next crop.

However, on-field composting method can be an excellent alternative to crop residue burning, as it does not require the removal of residue from the field and can be managed within a short time window without delaying the sowing of the next crop. The on-field composting method of crop residue management would have a positive impact on the environment, animals, human health, and financial health of farmers.

7. Conclusions, Limitations of the Study, and Future Research Directions

Crop residue burning method to clear fields in a short time allows farmers to sow the next crop on time to get higher yield. Higher yield leads to the increase in the revenue of farmers as well as their contribution of food grains to the India's national pool of food grains thus increasing the capacity of the Government of India to meet its social responsibility related goals of serving economically weaker sections of population in terms of distribution of food and other necessary items at lower prices. However, crop residue burning increases air pollution through increase in the air particulate matter in air that creates health issues for the human and animal population in the region. In addition, crop residue burning also causes global warming by emitting a large quantity of greenhouse gases in a short time period. On the other hand, composting process converts organic matter of crop residues into organic fertilizer that enriches soil thus saving significant quantity of inorganic fertilizers. It also reduces the quantity of greenhouse gases emissions into the air as a large quantity of organic matter in crop residues gets converted into organic fertilizer during composting process. Therefore, for future research, it is important to assess surplus crop residue for each crop to assess the amount of fertilizer savings in terms of Nitrogen, Phosphorus, and Potash (NPK) through composting the surplus crop residue. Composting process also generates some amount of greenhouse gases, but it is much less than the crop residue burning process as some portion of carbon and nitrogen changes into natural fertilizer for the next crop. In addition, the issue of crop residue penalty for burning and its cost to farmers as well as to government agencies involved in stopping crop residue burning practice also needs researchers' attention.

We have argued in this paper that despite all the possible limitations related to data and information collection, the composting method appears to be better than the practice of crop residue burning as it reduces pollution, reduces the incidence of sickness among the population and reduces the cost related to the fertilizer input for farmers of Punjab. In the paper we have also tried to make a case for more research related to on-field composting, its benefits to farmers, society and the environment as compared to the practice of crop residue burning. The objective was to encourage farmers and government agencies to work on this issue together to help farmers to adopt environmentally friendly methods of crop residue management and shun the practice of crop residue burning in their fields.

References

Bajwa, H. (2023). Punjab to provide over 24,000 machines to curb stubble burning. *The New Indian Express.* Retrieved from https://www.newindianexpress.com/nation/2023/sep/21/punjab-to-provide-over-24000-machines-to-curb-stubble-burning-2616877.html

Becker, S., Ebrahimzadeh, A., Herrada, B. P., & Lao, M. (2010). Characterization of Compost Based on Crop Residues: Changes in Some Chemical and Physical Properties of the Soil after Applying Compost as Organic Amendment. *Communications in Soil Science and Plant Analysis*. doi:10.1080/00103620903563931

Bernal, M. P., Alburquerque, J. A., & Moral, R. (2009, November). Composting of animal manures and chemical criteria for compost maturity assessment. A review. *Bioresource Technology*. doi:10.1016/j.biortech.2008.11.027

Bhuvaneshwari, S., Hettiarachchi, H., & Meegoda, J. (2019). Crop Residue Burning in India: Policy Challenges and Potential Challenges. *International Journal of Environmental Research and Public Health,* p. 832.

Biederbeck, V., Campbell, C., Bowren, K., Schnitzer, M., & Mclver, R. (1980). Effect of Burning Cereal Straw on Soil Properties and Grain Yields in Saskatchewan. *Journal of the Indian Society of Soil Science*. doi:10.2136/SSSAJ1980.03615995004400010022X

Brar, P., (2024). Economic and Environmental effects of practicing Crop Residue on-field Composting as a Substitute for Burning- A Case Study of Punjab (India). M.Sc. Thesis Submitted in Partial fulfillment of the Requirements for the Degree of Master of Science in natural Resources and Environmental studies, UNBC.

Ferraz, P. F., Ferraz, G. A., Leso, L., Klopcic, M., Barbari, M., & Rossi, G. (2020). Properties of conventional and alternative bedding materials for dairy cattle. *Journal of Dairy Science*, 103.

Godde, B., Menke, C., & Wassmann, R. (2009). Rice Straw as a renewable energy source in India, Thailand, and the Philippines: Overall potential and limitations for energy contribution and greenhouse gas mitigation. *Biomass and Bioenergy*, 1532-1546.

Gross, T., Kumar, S., Breitenmoser, L., Ehrensperger, A., Wintgens, T., & Hugi, C. (2021). Anaerobic digestion of biowaste in India municipalities: Effects on energy, fertilizers, water and the local environment. *Resources, Conservation and Recycling*, 170.

Gulati, A., Roy, R., & Hussain, S. (2021). Performance of Agriculture in Punjab. In *Studies in Business and Economics.* Singapore: Springer.

Haider, M. Z. (2012). Options and Determinants of Rice Residue Management Practices in south-west Region of Bangladesh. PO Box 8975, EPC 1056,

Kathmandu, Nepal.: *South Asian Network for Development and Environmental Economics* (SANDEE).

Huang, T., Ma, J., Song, S., Ling, Z., Macdonald, R., Gao, H., . . . Mao, X. (2022). Health and environmental consequences of crop residue burning correlated with increasing crop yields in the midst of India's Green Revolution. *Climate and Atmospheric Science*. doi:https://doi.org/10.1038/s41612-022-00306-x

Jiang, Z., Lian, F., Wang, Z., & Xing, B. (2020). The role of biochars in sustainable crop production and soil resiliency. *Journal of Experimental Botany*, 71(2), 520-542. doi:https://doi.org/10.1093/jxb/erz301

Kaur, A. (2017). Crop Residue in Punjab Agriculture - Status and Constraints. *Journal of Krishi Vigyan*, 22.

Kaur, M., & Kaur, P. (2018). Diversification and Specialization of Punjab in Growing Various Crops: A District Level Approach. *Economic Affairs*, 963-972.

Khan, A. A., Garsa, K., Jindal, P., & Devara, P. (2023). Effects of stubble burning and firecrackers on the air quality of Delhi. *Environmental Monitoring and Assessment*, 195. doi:https://doi.org/10.1007/s10661-023-11635-6

Kim Ho, T. T., Tra, V. T., Le, T. H., Nguyen, N.-K.-Q., Tran, C.-S., Nguyen, P.-T., . . . Bui, X.-T. (2022). Compost to improve sustainable soil cultivation and crop productivity. *Case Studies in Chemical and Environmental Engineering*.

Koul, B., Yakoob, M., & Shah, M. (2022). Agricultural waste management strategies for environmental sustainability. *Environmental Research*, 206. doi:https://doi.org/10.1016/j.envres.2021.112285Li

Kumar, N., Chhokar, R., Meena, R., Kharub, A., Gill, S., Tripathi, S., . . . Singh, G. (2022). Challenges and opportunities in productivity and sustainability of rice cultivation system: a critical review in Indian perspective. *Cereal Research Communications*, 573-601.

Kumar, P., Kumar, S., & Laxmi Joshi. (2015). The extent and Management of Crop Stubble. *Socioeconomic and Environmental Implications of Agricultural Residue Burning* (pp. 13–34).

Kuppusamy, S., Thavamani, P., Megharaj, M., Venkateswarlu, K., & Naidu, R. (2016). Agronomic and remedial benefits and risks of applying biochar to soil: Current knowledge and future research directions. *Environment International*, 1-12.

Lan, R., Eastham, S., Liu, T., Norford, L., & Barett, S. (2022). Air quality impacts of crop residue burning in India and mitigation alternatives. *Nature Communications*.

Lentz, E., CCA, & Lindsey, L. (2016 -17). Nutrient value of Wheat straw. *Agronomic Crops Network*. https://agcrops.osu.edu/newsletter/corn-newsletter/nutrient-value-wheat-straw. Retrieved on March 11, 2025.

Lohan, S. K., Jat, H., Yadav, A. K., Sidhu, H. S., Jat, M. L., Choudhary, M., . . . Sharma, P. C. (2018). Burning issues of Rice residue management in north-west states of India. *Renewable and Sustainable Energy Reviews*, 81, 693–706.

Mirmohamadsadeghi, S., & Karimi, K. (2020). Recovery of silica from rice straw and husk. *Resource Recovery from Wastes*, 411-433.

Pergola, M., Persiani, A., Palese, A., Meo, V., Pastore, V., D'Adamo, C., & Celano, G. (2018). Composting: The way for sustainable agriculture. *Applied Soil Ecology*, 744-750.

Porichha, G. K., Hu, Y., Rao, K. T., & Xu, C. C. (2021). Crop Residue Management in India: Stubble Burning vs. Other Utilizations including Bioenergy. *Energies*, 14.

Ravindra, K., Singh, T., & Mor, S. (2019). Emissions of air pollutants from primary crop residue burning in India and their mitigation strategies for cleaner emissions. *Journal of cleaner production*, pp. 261–273.

Sangeet, & Rajkumar. (2016). Crop Residue Generation and Management in Punjab State. *Indian Journal of Economics and Development*, pp. 477–483.

Sharma, P. K., & Mishra, B. (2001). Effect of burning Rice and wheat crop residues: Loss of N, P, K, and S from soil and changes in the nutrient availability. *Journal of the Indian Society of Soil Sciences*, pp. 425–429.

Shergill, H. (2005). Wheat and Rice Cultivation and the Question of Optimal Cropping Pattern for Punjab. *Journal of Punjab Studies*, pp. 239–250.

Sidhu, B., & Beri, V. (2005). Experience with managing rice residues in an intensive rice-wheat cropping system in Punjab. *Conservation agriculture: Status and prospects*, 55-63.

Sidhu, B., Rupela, O., Beri, V., & Joshi, P. (1998). Sustainability Implications of Burning Rice and Wheat Straw in Punjab.

Singh, A., & Zaffar, H. (2017, November 8). Why Do Farmers Burn the Crop Residue in Punjab? *THE CITIZEN*. Retrieved from https://www.thecitizen.in/index.php/en/NewsDetail/index/2/12192/Why-Do-Farmers-Burn-the-Crop-Residue-in-Punjab?infinitescroll=1. Retrieved on March 11, 2025.

Singh, N., & Kohli, D. S. (2005). The Green Revolution in Punjab, India: The Economics of Technological Change. *Journal of Punjab Studies*, pp. 285–306.

Singh, R. P., Dhaliwal, H., Humphreys, E., Sidhu, H., Singh, M., Singh, Y., & Blackwell, J. (2008). Economic assessment of the Happy Seeder for rice-wheat systems in Punjab, India. In 52nd Annual Conference of the Australian Agricultural and Resource Economics (AARES 2008).

Singh, S., & Ranguwal, S. (2023). Generation and management of crop residues in Punjab. *Journal of Agricultural Development and Policy*, 267-276.

Singh, T., Biswal, A., Mor, S., Ravindra, K., Singh, V., & Mor, S. (2020). A high-resolution emission inventory of air pollutants from primary crop residue burning over Northern India based on VIIRS thermal anomalies. *Environmental Pollution*.

Singh, Y., Singh, B., Ladha, J., Khind, C., Khera, T., & Bueno, C. (2004). Effects of Residue Decomposition on Productivity and Soil Fertility in Rice-Wheat Rotation. *Soil Science Society of America Journal*, pp. 854–864.

Toor, M., Bhullar, A., & Kaur, I. (2007). Agriculture-Led Diversification and Labor Use in Punjab: Potentials and Constraints. *Indian Journal of Labor Economics, 2007.*

Woignier, T., Clastre, F., Fernandes, P., Rangon, L., Soler, A., & Lesueur - jannoyer, M. (2016). Compost addition reduces porosity and chlordecone transfer in soil microstructure. *Environmental Science and Pollution Research International*, 98-108.

Zhang, A., Cheng, G., Hussain, Q., Zhang, M., Feng, H., Dyck, M., . . . Wang, X. (2017). Contrasting effects of straw and straw–derived biochar application on net global warming potential in the Loess Plateau of China. *Field Crops Research*, 205, 45-54. doi:https://doi.org/10.1016/j.fcr.2017.02.006.

Zhang, H., Dawei, H., Jianmin, C., Xingam, Y., Shu, X., Ji, M., . . . Zhisheng, A. (2011). Particle size distribution and polycyclic aromatic hydrocarbons emissions from agricultural crop residue burning. *Environmental science & technology*, 5477-5482.