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Crop residues burning problems, its mitigation and management strategies in rice-wheat cropping system

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Abstract
The major farming system in India is the rice-wheat system, however it is no longer sustainable due to issues with soil health and climate change. The irrigated rice-wheat system's high yields have resulted in the production of vast amounts of agricultural leftovers. The frequent burning of rice straw in north-western India results in nutritional losses and significant air pollution that is harmful to human health. Crop residue management innovations can aid in achieving sustainable productivity to prevent straw burning, enable farmers to use less fertiliser and water, and lower risks associated with climate change. Crop residues contain significant amounts of plant nutrients, and wise use of these nutrients would improve the management of nutrients in the rice-wheat system. Long-term residue recycling studies have shown changes in the soil's physical, chemical and biological health. Another option for the management of crop residues is to use some of the excess residue for the production of biochar, which can be used to improve soil health, increase nutrient use efficiency, and decrease air pollution. Other options include mushroom cultivation, which can turn unusable crop residues into valuable food, surface mulching for weed and moisture control, and the production of biofuel and compost. The decomposition of soil residues greatly increases organic carbon and other nutrients in the soil. This collected review literature addressed the potential for residues and possible options for the efficient management of crop residues in the rice wheat cropping system to improve crop water productivity and soil health.

Keywords: Rice-wheat system, residue burning, environment health, soil fertility, crop residues management

Introduction
The majority of emerging nations struggle with the issue of how to improve agricultural production without harming the environment. Producing enough food to sustain the expanding population in developing nations is one of the largest issues since it is a basic human necessity. As a result, there should be more environmental technologies used in the production of food. One of such intervention is adequate management of agro-waste, particularly as it concerns agricultural and food processing wastes. Agricultural wastes are defined as the residues from the growing and processing of raw agricultural products such as fruits, vegetables, meat, poultry, dairy products, and crops residues. It is necessary to perceive the problem at the intrinsic starting of waste generation. It is important to view ‘waste’ as a valuable ‘resource’ that can be converted into a variety of useful products. This process of turning garbage into a product that can be used for everyday purposes might be seen as a way to create riches. Hence the phrase says that ‘Waste to Wealth’. The idea of "waste-to-wealth" has been utilised to solve the environmental issue by challenging the conventional perception of garbage as a finished good that has to be disposed off. Farmers are diffident to invest in field cleaning with a chopper or others agriculture machineries since rice straw has no economic value and this will add to the cost. The majority of crop residues produced by the system are traditionally removed from the fields and burned in open fields, with the exception of rice and wheat straw that is used as dry fodder. However, these uses account for only a small portion of the total amount of crop residues produced every year by the rice wheat cropping system (Bhattacharyya *et al.*, 2016) [1]. The management of rice residue is a major problem in the Indian subcontinent due to the short time interval between the integration of rice residue management in the field and wheat sowing, low temperature, and the slow rate of breakdown of rice straw due to its high silica concentration.

The problem of crop residue management has become more critical with the use of combine harvester, which leaves 15-25 cm tall stubbles of crops and scatters the rest of the straw over the field. On-farm crop residue management is a serious concern. Because the turnover time between rice and wheat is so short that residue control is especially crucial during this period. The animal business uses wheat straw residue, however rice straw cannot be used in the dairy industry due to its higher silica content.

What is Agricultural Waste and its types?

Waste generated by various agricultural activities. It comprises waste from agriculture farms, slaughterhouses, and poultry houses as well as waste from harvesting operations, fertilizer runoff from fields, pesticides that end up in water, the atmosphere, or soils, and salt and silt that has been drained from fields.

What is Crop residue?

Crop residues are parts of the plants left in the field after crops have been harvested and threshed. The recycling of crop residues has the advantage of converting the farm waste into useful product for meeting nutrient requirement of succeeding crops. These are the best resources that adds to soil as a manure which results an improve the soil physical, chemical and biological property. Crop residues are a good source of organic matte for enhance the soil microorganisms and also contribute to plant nutrients (Singh and Kumar, 2018 [4]. Every year, India produces around 501 million tonnes (Mt) of crop residue (MNRE, 2009) [10]. Generation of cereal crop residues was highest in the states of Uttar Pradesh (72 Mt) followed by Punjab (45.6 Mt), West Bengal (37.3 Mt), Andhra Pradesh (33 Mt) and Haryana (24.7 Mt) (Jain *et al*., 2013) [6]. Cereal crops account for 70% of total crop residues (352 Mt), with rice accounting for 34% and wheat accounting for 22% (Saia *et al*., 2020) [15]. Rice (*Oryza sativa* L.)-wheat (*Triticum aestivum* L.) system (RWS), the world's largest agricultural production system is critically important for global food security. In South Asia, RWS produce more than 30% of the rice and 42% of the wheat consumed (RWC-CIMMYT, 2003) occupying nearly 15.8 M ha in the Indo-Gangetic plains of South Asian countries, India (12.3 m ha), Pakistan (2.2 m ha), Bangladesh (0.8 m ha) and Nepal (0.5 m ha) (Ladha *et al*., 2009) [7]. RWS generates 7-10 tonnes of residues every year on per hectare basis (Singh *et al*., 2019) [23] and withdraw 630 kg of NPK from the soil, added through inorganic fertilizers (Mandal *et al*., 2004) [9].

Key facts about rice residue generation

Global rice straw production was produced 800 -1000 Mt per year, which 60 percent alone produced in Asian country. While India produced 60 Mt rice straw and Haryana contribute about 28 Mt straw every year which are generally burned in farm field (Jain *et al*., 2014) [24].

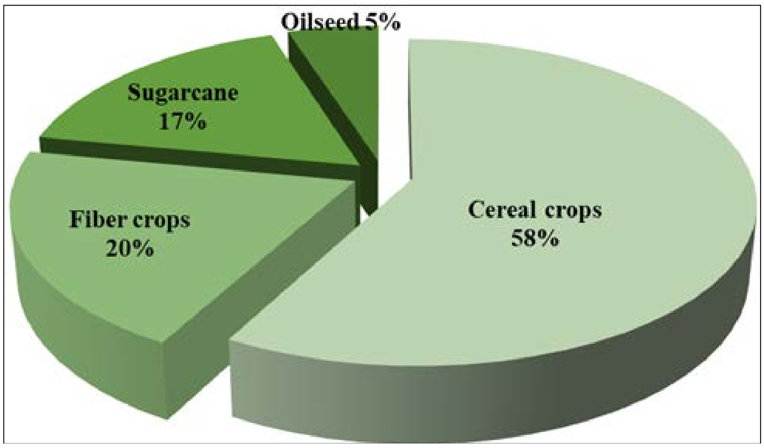

Fig 1: Contribution of different crops categories in residue generation

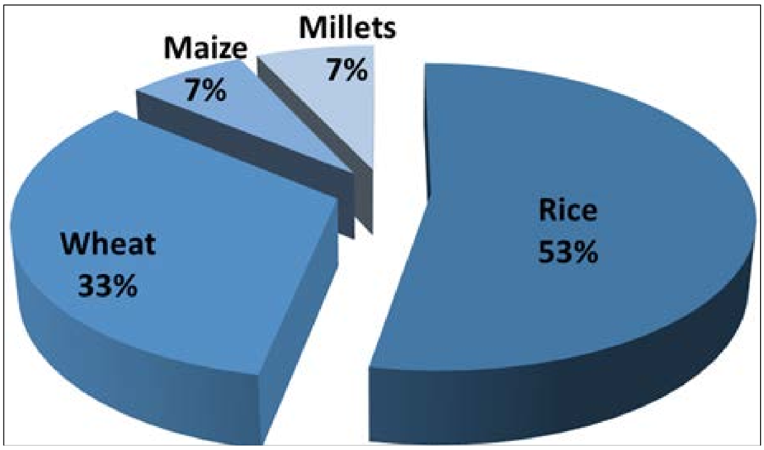

Fig 2: Contribution of different cereal crops in residue

Among the different crop categories 361.85 Mt of residue was generated by cereal crops followed by fibre crops (122.4 Mt) and sugarcane (107.5 Mt) (Table 2). The cereal crops generated 58% of residue while rice crop alone contributed 53% and wheat ranked second with 33% of cereal crop residues (Figs. 1(a) and (b)). Fibre crops contributed 20% of residues generated with cotton ranking first (90.86 Mt) with 74% of crop residues. Sugarcane residues generated 17% of the total crop residues. The oilseed crops generated 28.72 Mt of residue annually (Fig. 1(a)) (Jain *et al*., 2014) [24].

Why do farmer practice crop residue burn?

- Mechanized harvesting of crops (Combine harvester: bottom 40 cm length remain)
- Short window (20 days) to manage residue
- shortage of human labour
- high cost of removing the crop residue
- Considered as most suitable and cost effective method
- In Indo Gangetic Plains, the wheat straw is preferred for dry fodder than Paddy straw
- Govt policy on cultivation of paddy
- Farmers consider it as a soil fertility enhancement and pest control measures.
- Lack of awareness among farmers about other economic use

Impacts of crop residue burning

In the present estimates, on farm burning of 98.4 Mt of crop residues led to the emission of 8.57 Mt of CO, 141.15 Mt of CO_2, 0.037 Mt of SOx, 0.23 Mt of NOx, 0.12 Mt of NH3 and 1.46 Mt NMVOC, 0.65 Mt of NMHC, 1.21 Mt of particulate matter for the year 2008-09. Burning of rice straw contributed the maximum (40%) to this emission followed by wheat (22%) and sugarcane (20%) (Fig. 3(b)). Highest emissions burning of rice straw contributed the maximum (40%) to this emission followed by wheat (22%) and sugarcane (20%). Burning of agricultural residues, resulted in 70, 7 and 0.66% of C present in rice straw as CO_2, CO and CH4, emission respectively, while 20, 2.1% of N in straw is emitted as NOx and N2O, respectively, and 17% as S in straw is emitted as SOx upon burning (Carlson *et al*., 1992) [25].

There are various strategies for efficient crop residue management

The rice wheat cropping method produces enormous amounts of crop residues in India. In North West India, the majority of rice and wheat is harvested by a combination harvester that leaves residues in the ground. As cattle feed, the residues of cereal crops are primarily used. Rice straw and husk for parboiling rice are used as domestic fuel or in boilers. Instead of wheat straw, rice straw management is a serious problem because there is very little processing time between rice harvesting and wheat sowing and because of the lack of adequate recycling technology and the higher content of silica than other crops. Livestock feed, mushroom planting, incorporation, surface retention and mulching, biochar and baling and removal of the straw are some management options available to farmers for the productive management of crop residues. As per the situation, farmers use various straw management methods (Bisen and Rahangdale, 2017) [2].

Crop residues as organic manure

Composting is a biological process in which microorganisms and earthworms use the organic matter of stubble to turn the dry waste into soil nutrients (Qian *et al*., 2013) [26]. Converting rice stubble to compost appears to be a viable option for avoiding open field burning. On a dry weight basis, 5-8 kg N, 0.7-1.2 kg P, 12-17 kg K and 0.5-1.0 kg S per tonne of rice straw are important nutrients at harvest (Dawe *et al*., 2000) [27]. Wastes are high in nutrients and enhances soil fertility. After five cycles of RWCS, organic C, total N, total K and accessible K were significantly greater in plots receiving crop residues compared to plots where residue was burned or removed in a study at Pant Nagar (Sharma *et al*., 2000) [28].

And jobs and reduced one gigaton of CO_2 equivalent per year. (www.unep.org).

Crop residues as animal fodder

Straws appear to be the best used for feeding livestock at the moment. In intensive rice growing areas such as India, all straw is still fed to livestock, despite the fact that they do not use it efficiently due to a lack of supplementary feeds. Rice straw has a higher silica content than lignin, hence it is not fully digested (Bhatt, 2017) [29]. Rice straw has a higher silica concentration (12-16 vs. 3-5 percent) and a lower lignin content (6-7 vs. 10–12 percent) than other straws. Rice straw stems are more digestible than leaves due to their reduced silica concentration; consequently, if the straw is to be fed to livestock, the paddy crop should be cut as close to the ground as possible (Talapatra *et al*., 1948) [30]. Over two-thirds of world's 1.3 billion impoverished people live in rural areas and rely on agriculture for a significant part of their livelihoods. Livestock are important assets of this group and play a critical role in both sustainability and intensification of agricultural productivity in most farming systems. Pastures (herbaceous plants, fodder trees/shrubs), crop residues, cultivated forages, concentrate feeds (agro-industrial by-products, grains, feed supplements, etc.) and household wastes are the main resources used as livestock feed. Crop residues are still the most important feed for ruminants in small-holder crop–livestock production systems of Asia and Africa.

Why necessary?

- Because increasing human population and changes in dietary habits associated with urbanisation and higher incomes are causing increased demands for food of animal origin.
- Availability of grazing land is decreasing due to expansion of cropping to meet the demands for food, urbanisation and land use for other activities such as industries.
- The adoption of introduced forages in tropical developing countries has been limited due to lack of evidence of economic profitability or inadequate technical support, such as seed availability.
- Small farmers in rural areas will increasingly depend on crop residues to feed livestock among other feed resources for some time to come (Mannetje, 1997) [31].
- Crop residues still contribute substantially to the supply of nutrients for animals in mixed farms in the tropical and sub-tropical developing countries.

Wheat occupies the highest acreage in the world followed by rice, maize, barley, sorghum and millets (includes pearl millet and several minor millets). Maize is prominently grown in Africa, while rice predominates in India.

Use of new generation machines

With conservation agriculture and agricultural residue management, ensuring adequate seed germination and crop residue management are the key difficulties. Tarbo happy seeder, rotary disc driller and double disc opener drill are now available for post-rice residue treatment in wheat planting up to 10 t/ha. The Happy Seeder is the ideal solution since it sows seed while also removing the straw, dispersing it uniformly around the field, mulching it and helping it retain moisture while also boosting seed germination. Over time, the straw decomposes organically, enriching the soil. Tips for getting the most benefit out of Happy Seeder.

- Happy Seeder operation should be avoided in the early morning hours because of excessive moisture content in residue and dew can clog the Happy Seeder.
- Before operating the machine, the operator should familiarise himself with all of the machine's mechanisms
- Before sowing the previous crop, the fields should be laser levelled (rice in this case)
- To ensure uniform crop establishment, ensure that the soil moisture content is ideal at the time of sowing.

Use of PUSA decomposer

The burning of rice/wheat residue is a serious issue not only at the state level but also at the national level. IARI scientists Dr. Livleen Shukhar and her team of senior research fellows and technical personnel created the one of the most potent residue mitigator PUSA bio-decomposer. Within 20-30 days, crop residue can be converted to manure, preventing stubble burning. To speed up the breakdown of stubble, four PUSA capsules must be dissolved in water and spray on one hectare of land. The pill contains crop-friendly fungus and has the advantage of having no negative effects. The crop remnants take about 20-30 days to degrade after being sprayed with the solution, which comes in the form of capsules that cost Rs 5-20. The fields retain some moisture as agricultural waste decomposes and the soil is nourished, reducing fertiliser need. This year, the Delhi government announced that the PUSA decomposer spray would be sprayed on 800 hectares of farmland across the city (Usha Rai, 2020) [32]. Some of the benefits include- as the stubble acts as manure and compost for the crops, the decomposer improves soil fertility and productivity, reducing fertilizer requirement. Stubble burning depletes the soil fertility and eliminates beneficial soil bacteria and fungi, in addition to harming the environment. It is a cost-effective, achievable and practical method for preventing stubble burning. It is an ecologically sound and beneficial technology that will aid in the achievement of a clean environment

Mechanization for in situ incorporation of crop residues

As a physical buffer, crop residues protect soil from the direct impacts of rain, wind and sunlight leading to improved soil structure, reduced soil temperature and evaporation, increased infiltration, and reduced runoff and erosion. While some studies suggest that plant roots contribute more carbon to soil than surface residues (Gale and Cambardella, 2000) [33], crop residue contributes to soil organic matter and nutrient increases, water retention, and microbial and macroinvertebrate activity. These effects typically lead to improved plant growth and increased soil productivity and crop yield.

Crop residue is managed using conservation tillage systems

Such as notill, strip till, ridge till, mulch till, and other reduced tillage methods. Power *et al.* (1986) [34] found increased crop yields for corn and soybean when residues were left on the soil surface compared with yields under residue removal in Nebraska. This yield effect was most pronounced in drier years, leading them to attribute yield increases to residue induced water conservation. Rate of residue decomposition varies by climate and crop, leading to varying amounts of erosion protection and organic matter additions to the soil. Due to these and other site-specific effects of residue on soil function, residue removal recommendations need to consider soil type, climate, cropping system, and management in order to protect soil quality while allowing for residue harvest for biofuel production.

Beneficial effect of in-situ incorporation of crop residues in the field

Crop Water Productivity

Mulching using rice straw not only keeps the soil moist, but also helps to moderate the soil temperature, check the weed emergence, and, most importantly, increase the yield of wheat (Rahman *et al*., 2005) [12]. It has been reported that 84% of the residues are wasted from rice–wheat systems (Singh and Panigrahy, 2011) [19]. They also reported that rice straw improves the wheat root length by 40% as a consequence of better soil moisture storage. The 13 years of the experiment reported that continuous rice residue incorporation enhanced the wheat yield by 34.89% as compared to residue burning due to the better resource use efficiency and soil health (Mandal *et al*., 2004) [9].

Soil Health

Rice and wheat are also exhaustive nutrient feeders and one of the major causes of poor soil health under the ricewheat system is due to this excessive nutrient mining of soils. The quantity of nutrients derived from rice and wheat is greater than the quantity added and recycled by fertilisers. The preservation of residues increases the physical (i.e. structure, penetration rate, water ability available to plants), chemical (i.e. nutrient cycling, cation exchange capacity, soil reaction) and biological (i.e. SOC sequestration, microbial biomass C, soil biota activity and species diversity) quality of the soil (Singh *et al.* 2008, Bisen and Rahangdale, 2017) [18, 2]. One of the safer crop production alternatives is the introduction of sustainable crop residue management activities (Raza *et al*., 2019) [13]. Indiscriminate combustion of crop residues has a significant effect on soil quality, the content of organic matter, plant micro- and macronutrients, and the microbial community (Raza *et al*., 2019, Nyanga *et al*., 2020) [13, 11]. Numbers of possible crop residue management technologies such as conservation tillage, nutrient cycling, soil conversation methods, zerotillage and residue mulching, use in animal feed, and vermicompost preparation are used in realistic field conditions in various parts of the world. Proper management of crop residue has a positive effect on improving efficiencies in input usage by controlling various biochemical properties of the soil (Sarkar *et al*., 2020) [16].

Impact on physical health of soil

In modern input-intensive agriculture, the use of heavy machinery and farm implements such as planters, zero-tillage implements, reapers, and combine harvesters is very common, and indiscriminate use of these heavy machinery pieces often leads to compacting the soil and hampering physical properties of the soil, such as infiltration rate, airflow, and water holding capacity (Smitha *et al*., 2019) [21].

Carlesso *et al*. (2019) [3] stated that the use of crop residues from ryegrass and straw residues as well as mixed litter can significantly increase the porosity of the soil and the capacity to retain water, and can eventually make the soil more efficient. In order to boost soil aggregate and carbon storage in rice-based cropping systems, the application of crop residues along with conservation tillage has been documented (wang *et al*., 2019) [22].

Impact on chemical health of soil

A strong correlation with the application of crop residue is observed in the soil carbon pool (both complete and labile pool). The application of 10 Mg ha^{-1} wheat residue mulching along with the application of 75 kg N ha^{-1} is stated to significantly increase the total and labile carbon pool of an irrigated maize production system (Chatterjee *et al*., 2018) [4]. In order to improve system productivity, K usage efficiency and obvious K balance, adoption of conservation tillage in a rice-maize cropping system with residue management may be effective (Singh *et al*., 2018) [4]. Residue incorporation is also beneficial for the recycling of up to 15 percent of usable K soil, as well as the need for K external supply (Singh *et al*., 2018) [4].

Impact on biological health of soil

The activity of soil enzymes responsible for the conversion of inaccessible to usable nutrient type also increases due to the increase in soil microbial population. Proper preservation of crop residues has been reported to have a major effect on soil microbial biomass control. Samui *et al*. (2020) [16] recorded improved microbial activity in the top layer of soil through the application of crop residue mulching, which may be attributable to plant-soil microclimate modification, increased availability of water and nutrients, and soil temperature control.

Impact on soil fertility and productivity of soil

For the maintenance of soil fertility and the recycling of soil nutrients, judicious crop residue management is very beneficial. Rusinamhodzi *et al*. (2016) [14] stated that good crop residue management not only helps improve soil productivity and nutritional status, but also helps improve the overall health status of farm animals. To increase soil productivity, C-pool and earthworm population productivity, long-term use of crop residues along with conservation tillage has been stated (Frazao *et al*., 2019) [5]. In global agriculture, crop residue is becoming increasingly important and is considered to be an excellent source of organic matter that helps to boost soil C stock, water conservation, nutrient recycling, and soil characteristics, and reduces residue burning patterns and the consequent environmental hazards upon retention (Liang *et al*., 2016) [8].

Conclusion

The most intensive method of production in the country is the rice-wheat cropping system. It occupies a commanding proportion of India's total cultivable land. The recycling of its residues has the great ability to get back to the soil a large amount of plant nutrients. The yield stagnation resulting from the decreasing organic carbon of the soil is a major threat to this system in particular. It is therefore a great challenge for farmers to effectively and efficiently manage rice – wheat residues in order to increase carbon sequestration and preserve the sustainability of production. It depends on a given set of conditions for soil, environment and crop management, consistent with the machinery available and socially and economically appropriate. It is important to evaluate and update the mechanised harvester technology for sustainable residue use in order to avoid residue burning in the rice wheat cropping system. Relevant conservation tillage methodology can be adopted for place and soil quality. If rice - wheat residues are properly handled, changes in soil physical, chemical and biological properties can be justified and rice-wheat cropping system productivity can be sustained.

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