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Prospective of Crop Residue Management for Sustainable Agriculture

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India is an agrarian country and generates a large quantity of crop residues. Crop residues are the biomass left in the field after harvesting of the economic components *i.e.*, grain. It is estimated that approximately 500-550 million tons of crop residues are produced per year in the country. The disposal of such a large amount of crop residues is a major challenge. Farmers now a days burn crop residue in a hurry to clear off the field for the next season, but this practice not only affects the soil microbes but also affects the soil fertility and productivity. Hence, better crop residue management strategies are essential to keep the soils healthy, protecting the soil from nutrient losses and soil erosion. However, these crop residues, which contain abundant organic carbon and mineral nutrients, are important sources of organic matter that can be returned to soil for nutrient recycling and for improving soil physical, chemical and biological properties. Some of them are eco-friendly, easy and economically viable alternatives include crop residue incorporation, crop residue retention in the field and compost preparation from crop residues.

Introduction

The rising global demand for food has greatly expanded agricultural production, making farming a key economic activity in both developed and developing nations. However, this intensification has also led to increased pollution and waste generation. Technological advancements such as modern irrigation systems, improved fertilizers and large-scale mechanization have turned vast wastelands into cultivable areas, putting additional pressure on natural resources **(Nagendran, 2011).** After harvest, a considerable quantity of crop residue remains in the fields. Proper recycling of these residues enriches the soil with organic carbon, supports microbial activity and enhances nutrient availability for the following crops.
India, being one of the world's largest agricultural economies, produces around 500–550 million tonnes (Mt) of crop residues every year, with nearly 92 Mt burned annually**.** Burning is most widespread in Punjab, Haryana, Uttar Pradesh, and West Bengal due to limited labor, high collection costs, and mechanized harvesting. While residues can be used for composting, biofuel, livestock feed or biogas, the poor palatability of rice straw owing to its high silica content makes its utilization difficult. Though field burning offers a quick and inexpensive way to prepare land and control pests, it causes serious losses of soil nutrients and organic matter and contributes about 0.05% to India's total greenhouse gas emissions**.** Continuous burning also damages soil structure and biodiversity. Retaining residues on the soil surface, however, can reduce erosion, minimize water loss and improve soil health**.** Sustainable crop residue management is therefore essential for maintaining soil productivity and ecological balance.

Sustainable agriculture

Sustainable Agriculture is farming in a way that allows for more effective use of natural resources, reduces the environmental impact of agriculture, and increases capacity for climate change and climatic variability adaptation without endangering the ability of present or future generations to meet their own needs. It is an integrated system of plant and animal production practices having a site-specific application that will, over the long term.

Sustainable Agriculture - Principles

1. **Environmental Sustainability:** Sustainable environmental practices include safeguarding, recycling, replacing and sustaining the natural resource base, which includes the land (soil), water and animals.
2. **Economic Sustainability:** Economic sustainability is achieved through enhancing crop rotation and soil management, which increases yields.
3. **Social Sustainability:** Maintaining social justice and cultural unity is essential for achieving social sustainability.

Crop residue

Crop residue is plant material remaining after harvesting, including leaves, stalks and roots.

Types crop residues

Field residues are those residues left in an agricultural field after the crop has been harvested. These residues include stalks and stubble, leaves and seed pods. The residue can be ploughed directly into the ground, or burned first. In contrast, no-till, strip-till or reduced tillage in agriculture practices carried out to maximize crop residue cover. Good management of field residues can increase the efficiency of irrigation and control of soil erosion.

Process residues are materials left after the crop have been processed into a usable resource. These residues include husks, seeds, bagasse, molasses and roots. They can be used as animal fodder and soil amendment, fertilizers and in manufacturing.

Crop residue burning statistics in India

Burning of rice straw contributed the maximum (40 %) to this emission followed by wheat (22 %) and sugarcane (20 %) (Fig. 2(b)). Highest emissions were from the IGP states with Uttar Pradesh accounting for 23 % followed by Punjab (22 %) and Haryana (9 %) (**Jain *et al.*, 2014)**. The annual variability in emissions is dependent on generation of biomass and the quantity burnt (Fig. 2(b)). The CO_2 accounted for 91.6 % of the total emissions. Out of the rest (8.43 %) 66 % was CO, 2.2 % NO, 5 % NMHC and 11 % NMVOC (Fig. 1(a)).

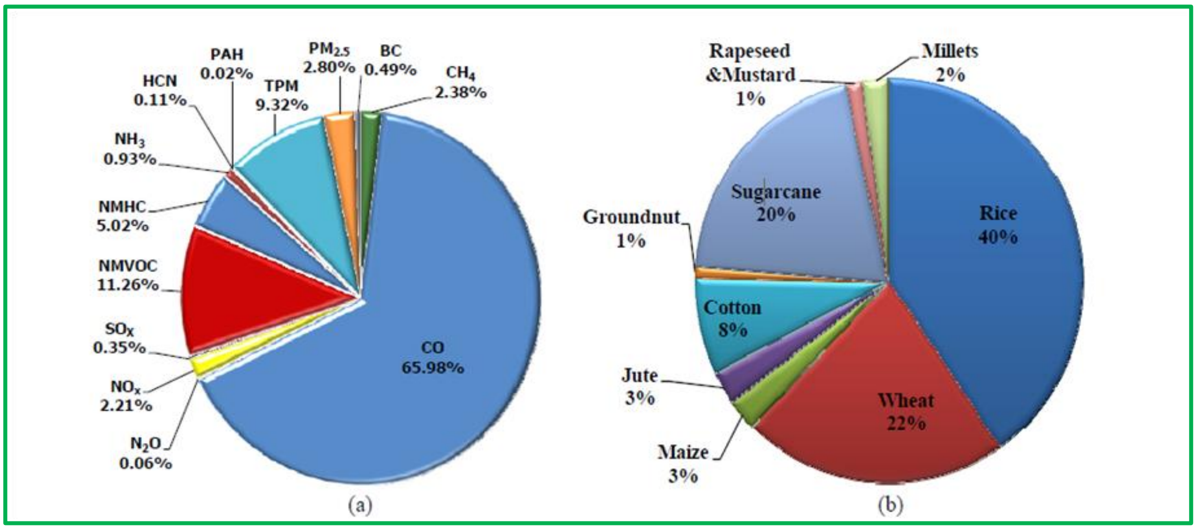

Fig. 1: (a) Emission of different pollutants and GHGs due to field burning of crop residues. (b) Contribution of different crops in burning.

Crop residue management

The use of crop residues in India differs across regions, depending on local practices and resource availability. Traditionally, these residues have served multiple purposes such as animal feed, fuel, roof thatching, composting and packaging materials. Cereal residues, particularly from rice and wheat, are largely utilized as cattle feed, while rice straw and husk often serve as domestic fuel or are used in boilers for rice parboiling. Farmers either use these residues on their farms or sell them to intermediaries and industries for further use. However, a significant portion remains unutilized and is burned directly in the fields. In Punjab and Haryana, where rice straw is unsuitable as cattle feed, large-scale on-farm burning is prevalent. Similarly, sugarcane tops are either fed to livestock or burned to clear land for the next crop. Residues from groundnut, cotton, chilli, pulses and oilseeds are frequently used as household fuel, while coconut shells and stalks of rapeseed, mustard, pigeon pea, jute, mesta and sunflower serve as domestic energy sources. The surplus residues, i.e., the portion left after all possible uses, are generally burned in the open, contributing to environmental pollution and resource loss.

Crop residue incorporation

Crop residues can be added to the soil either fully or partially, depending on the tillage or cultivation practices adopted. Among various methods, ploughing is regarded as one of the most effective techniques for residue incorporation. Incorporation of rice straw prior to wheat sowing poses greater difficulty than that of wheat straw before rice, primarily due to lower temperatures after rice harvest and the limited interval between harvest and sowing (**Singh *et al*., 2008**). Unlike burning or removing residues, incorporating straw into the soil helps increase soil organic matter (SOM) and enhances the availability of essential nutrients such as nitrogen, phosphorus and potassium. In the early years, wheat yield may decline slightly owing to nitrogen immobilization from residues with a high carbon-to-nitrogen (C:N) ratio. However, with continued incorporation, soil fertility improves, leading to stable or even higher yields. For example, incorporation of rice straw has been found to increase wheat yield to about 3.5 t ha^{-1} compared to 2.91 t ha^{-1} when residues were removed.

A major drawback of straw incorporation is the short-term immobilization of inorganic nitrogen, which can restrict nutrient uptake and reduce crop productivity. This issue can be addressed through integrated nutrient management practices that combine organic residues with chemical fertilizers. Effective approaches include placing nitrogen fertilizer below the carbon-rich surface layer, applying slightly higher nitrogen doses, or adding a starter dose of 15–20 kg N ha^{-1} at the time of straw incorporation (**Singh *et al*., 2008**). These strategies help minimize nitrogen immobilization and sustain higher productivity in rice–wheat cropping systems.

Crop residue as a source of compost

Composting is one of the most effective recycling processes for organic waste, helping to close the natural nutrient cycle. Crop residues are rich in nutrients, containing about 25% nitrogen, 25% phosphorus, 50% sulphur and 75% potassium absorbed by cereal crops, making them valuable raw materials for compost preparation **(Singh *et al*., 2008)**. Through composting, these nutrients are returned to the soil, improving fertility and soil structure while reducing dependency on chemical fertilizers.

Over the years, several composting techniques have been developed and refined to enhance efficiency and overcome limitations of traditional methods. The most commonly practiced methods include the Bangalore method, Coimbatore method, Indore method, Japanese-vat method, NADEP method, Heap and Windrow composting, Vermicomposting, Artificial composting, and Coir pith composting. Each method varies in its approach, materials, and management practices but shares the common goal of converting organic residues into nutrient-rich compost for sustainable agriculture.

Residue retention

Direct drilling in surface-mulched residues involves sowing seeds into soil covered with straw or crop residues from the previous harvest without incorporating them into the soil. This method, commonly practiced under no-till or conservation tillage systems, helps protect the fertile topsoil from wind and water erosion. The surface retention of residues improves soil structure and moisture conservation while reducing temperature fluctuations. However, the accumulation of large amounts of residues can sometimes hinder machinery operation and affect seed placement. Despite these challenges, retaining part or all of the residues on the soil surface is often the most beneficial approach, as it enhances organic carbon and nitrogen content in the upper soil layers (5–15 cm) through slow decomposition and contributes to long-term soil health and sustainability **(Singh *et al*., 2008).**

Mushroom cultivation

The use of crop residues in mushroom cultivation provides an efficient means of converting otherwise inedible biomass into highly nutritious food. Mushrooms possess two to three times more protein than most vegetables and have an amino acid composition comparable to milk or meat. Residues such as wheat and rice straw serve as excellent substrates for the cultivation of *Agaricus bisporus* (white button mushroom) and *Volvariella volvacea* (straw mushroom). For *Agaricus* cultivation, straw is commonly mixed with horse manure and hay, resulting in a high conversion efficiency of the substrate into fungal biomass**.** Thus, mushroom production not only adds value to crop residues but also supports sustainable waste recycling in agriculture.

Conclusion

Huge amount of crop residues being generated globally can be effectively recycled and utilized in agriculture by adopting recent approaches like residue incorporation in soil by using mechanization, composting and creating awareness about burning of crop residue in farming community. Moreover, by adopting recent approaches of crop residue management may accelerate the recycling and utilization of crop residues in agriculture, which on the other hand improves soil physical, chemical, biological properties, enriches soil health and soil fertility. It helps in protecting the soil surface from nutrient loss and also to sustain the yield.

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