



Crop Residue Management for Enhancing Soil Health and Sustainable Agricultural Productivity

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Crop residue management plays an important role in sustainable agriculture, especially in areas where large amounts of farm waste remain after harvesting. Farmers often burn these residues to clear fields quickly, but this practice causes serious air pollution, causes nutrient losses of up to 80% nitrogen and 25% phosphorus, and damages soil health. Crop residues contain nearly 40–45% carbon and serve as an important source of organic matter when managed properly. Instead of burning, residues can be utilized through in-situ and ex-situ techniques such as mulching, residue incorporation, composting, vermicomposting, and biochar production. These practices improve soil fertility by increasing soil organic carbon, available nitrogen, and microbial activity. Residue retention also improves soil physical properties by enhancing porosity, reducing bulk density, and increasing water-holding capacity. During decomposition, residues release carbon dioxide and organic acids, which may slightly influence soil pH and nutrient availability. Overall, proper crop residue management is a sustainable approach for maintaining soil health, reducing environmental pollution, and ensuring long-term agricultural productivity.

Introduction

The Indian economy depends heavily on agriculture which produces huge amount of crop leftovers in the field. This leftover material that includes straw, stubble, husk, and leaves is known as crop residue. India generates approximately 500 million tonnes of crop residues annually, of which a significant portion is burned. The most common practice to manage these residues is burning them to quickly prepare the fields for next crop as this seems the easiest way. The main reason behind this is the short time span left with farmers between the harvest of previous crop and sowing of next crop. While this practice saves time, it creates serious environmental and agricultural problems. Crop residue burning leads to serious air pollution, by releasing large amounts of carbon dioxide, carbon monoxide, methane, nitrous oxide, and particulate matter into the atmosphere. Burning also causes the loss of valuable plant nutrients such as nitrogen, phosphorus, potassium, and sulphur that could otherwise be returned to the soil. Repeated burning reduces soil organic matter, deteriorates soil physical properties such as aggregation, porosity, and water-holding capacity. As a result, soil fertility declines over time, leading to lower productivity and greater dependence on chemical fertilizers. However, what many people see as useless waste is actually a valuable resource. Instead of burning, crop residues can be naturally recycled with the help of microorganisms. Several sustainable residue management practices are



available, such as residue retention, mulching, residue incorporation, composting, vermicomposting, biochar production, and use of happy seeder technology. Recycling crop residues helps increase the amount of organic carbon stored in the soil, which is essential for maintaining good soil health.

Nutrient Composition and Decomposition of Crop Residues

Crop residues are rich in essential nutrients and play an important role in supporting crop growth. They typically contain about 40–45% carbon, 0.6–1% nitrogen, 0.45–2% phosphorus, 14–23% potassium, along with important micronutrients. Because of this, they help correct nutrient imbalances in the soil and reduce the limitations of relying only on inorganic fertilizers. The way nutrients are released from crop residues depends on several factors including environmental conditions like temperature and moisture, soil properties such as pH and water content. Another key factor is the C/N ratio. When the C/N ratio is higher than 25:1, microorganisms use available nitrogen for decomposition, temporarily reducing its availability to plants (**immobilization**). On the other hand, a lower C/N ratio leads to faster breakdown and release of nutrients (**mineralization**). Warm temperatures and adequate soil moisture further enhance the decomposition process and help in the release of nitrogen, making nutrients more readily available for plant uptake.

Crop residue management: Impact on soil health

Improves soil texture

Adding crop residue back into the soil improves its structure and quality. It helps the soil hold more water, makes it less compact (lower bulk density), and increases spaces between soil particles (porosity), which allows better air and water movement. Over time, this improves soil aggregation and structure, more fertile, and better for crop growth.

pH and cation exchange capacity

Adding crop residues to soil can help improve its pH, especially in acidic soils, making the soil more suitable for crop growth. It also increases the soil's cation exchange capacity (CEC), which means the soil can hold and supply more nutrients to plants. This happens because crop residues increase organic matter in the soil. Over time, fields with residue retention show better nutrient availability compared to fields where residues are removed or burned.

Organic carbon (OC) and NPK

When crop residues decompose in the soil, they add **organic carbon**, which improves soil structure and fertility. They also release important nutrients like **nitrogen (N)**, **phosphorus (P)**, and **potassium (K)**, making them available for plant growth. This helps reduce nutrient loss and improves overall soil productivity. However, since residues have a high carbon-to-nitrogen ratio, they may temporarily tie up nitrogen, so sometimes extra nitrogen fertilizer is needed.

Soil microbial and enzyme activity

Adding crop residues to the soil helps increase beneficial microorganisms like bacteria and fungi, which are important for nutrient cycling and soil health. These residues act as food for microbes, improving their growth and activity. As a result, soil enzyme activity also increases, which is a good indicator of better soil fertility. Overall, residue management creates a healthier soil environment that supports better crop growth.

Fig 1 shows how crop residues improve soil health and crop productivity through multiple pathways. When retained in the field, residues increase soil organic matter (SOM) and release organic binding agents, which improve soil aggregation and aggregate stability. Better soil structure reduces nutrient losses through leaching and erosion while improving nutrient and water use efficiency. Crop residues also act as mulch, reducing evaporation and modifying soil temperature, which enhances microbial and enzyme activity. Although nutrients may be temporarily immobilized at first, residues gradually release them over time, resulting in higher nutrient availability and increased crop productivity.

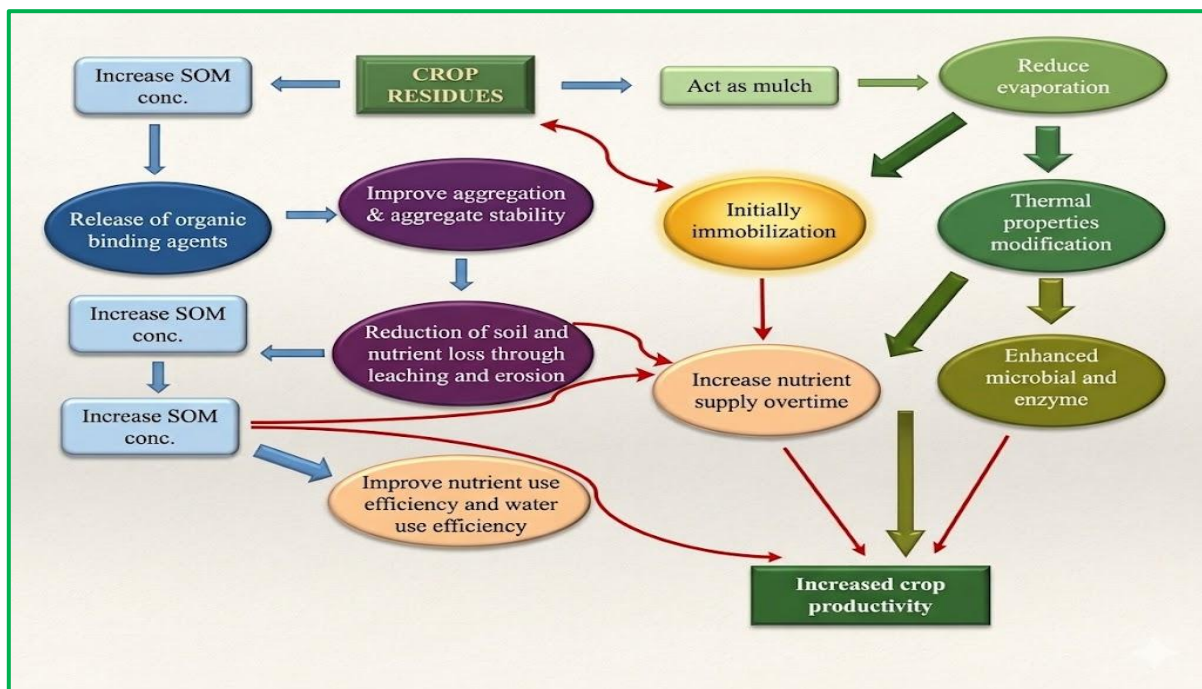


Fig 1: Mechanism on how crop residue enhances soil health and crop production

Source: (Ramteke et al., 2022)

Methods of Crop Residue Management for Improving Soil Health

In-situ Residue Management

This method focuses on using crop residue directly in the field to improve soil health.

Mulching: Mulching means spreading crop residues on the soil surface, which helps conserve moisture and improve the use of water and nutrients. It also controls weeds, reduces soil erosion, and maintains a better soil temperature. As the residues decompose, they release nutrients and improve soil fertility.

Residue Incorporation: Incorporating crop residues into the soil is a simple and effective way to improve soil health. As the residues decompose, they add organic matter and release nutrients that help the next crop grow better. This also increases microbial activity and improves soil structure, leading to higher yields.

Happy Seeder Technology: This technique allows farmers to sow the next crop directly into crop residues without burning them. It saves time, fuel, and labour while giving similar or even higher crop yields, especially in wheat. The retained residue acts as mulch, improving soil moisture and fertility.

Ex-situ Residue Management

Composting: Crop residues are decomposed under controlled conditions to form compost. It improves soil organic matter, enhances nutrient availability (N, P, K) and promotes beneficial microorganisms. This method converts waste into nutrient-rich organic fertilizer.

Vermicomposting: Earthworms are used to convert crop residues into nutrient-rich organic manure. The earthworms feed on crop waste like straw and leaves and break it down into a fine, dark compost called vermicompost. This compost is rich in nutrients like nitrogen, phosphorus, and potassium, and it improves soil fertility, structure, and microbial activity. It also enhances water retention and promotes better plant growth.

Biochar: Biochar is produced by heating crop residues in a low-oxygen environment (a process called pyrolysis). Instead of burning residues openly, they are converted into a carbon-rich material that can be added to the soil. It improves soil by increasing water holding capacity, enhancing nutrient retention, and supporting beneficial microorganisms. It also helps in long-term carbon storage, reducing environmental pollution.

Conclusion

Crop residues play a vital role in maintaining soil health and supporting sustainable agriculture. Instead of treating them as waste, they should be properly managed and recycled

to improve soil fertility, organic carbon, and nutrient availability. Effective residue management enhances soil moisture, promotes microbial activity, and improves soil structure, leading to better crop productivity. It also helps reduce soil erosion and supports efficient nutrient cycling. Avoiding residue burning is essential, as it harms the environment, soil quality, and human health. Scientific management practices like mulching, incorporation, and composting can convert residues into valuable resources. Additionally, crop residues offer opportunities for renewable energy production, reducing dependence on fossil fuels. Overall, proper crop residue management is a cost-effective and eco-friendly approach to ensure long-term soil sustainability, environmental protection, and food security.

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