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Crop Residue for Nutrient Cycling: Unlocking the Potential of Nature's Leftovers

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Abstract

Crop residue recycling emerges as a sustainable and economically viable solution to the pressing challenges of soil nutrient depletion and environmental degradation in Indian agriculture. By harnessing the nutrient-supplying potential of surplus crop residues, farmers can reduce their reliance on chemical fertilizers, lower production costs, and enhance soil health. However, realizing this potential requires concerted efforts in policy support, technological innovation, and farmer education. As Indian agriculture continues to strive for agricultural sustainability and food security, integrating crop residue management into mainstream farming practices could serve as a cornerstone for achieving these goals. Embracing the wisdom of nature's leftovers not only preserves the environment but also ensures the long-term viability of Indian agriculture.

1. Introduction

Agricultural production is struggling to sustain crop productivity level of many parts of the world, and natural resources like soils, water and biodiversity are extended dangerously toward degradation. By 2050, the world will need to produce about 70% more food to meet the requirements of an estimated 9 billion people and this will be the most difficult challenge to face the food security (Kaur et al., 2022). Similarly agriculture forms the backbone of India's economy, engaging approximately 55% of the population. Over the past seven decades, the sector has witnessed unprecedented growth, with food grain production soaring from a modest 51 million tons (mt) in the 1950s to an impressive 310 mt in recent years (Naik et al., 2022). This surge can be largely attributed to the Green Revolution, which introduced high-yielding crop varieties, chemical fertilizers, pesticides, and improved irrigation facilities. While these advancements have significantly bolstered food security, they have also led to a heavy reliance on chemical fertilizers, resulting in soil nutrient depletion and environmental challenges. Amidst these

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concerns lies a promising solution: crop residue recycling for nutrient cycling.

2. Crop Residue Availability in India

Crop residues encompass the non-economic parts of plants left in the field post-harvest, including stalks, stems, leaves, and husks. In India, the annual gross crop residue potential stands at approximately 696.38 mt, with about 214.15 mt classified as surplus residue available for nutrient recycling (Singh et al., 2022). These residues are rich in essential nutrients such as nitrogen (N), phosphorus (P), potassium (K), and various micronutrients, making them invaluable for replenishing soil fertility.

3. Nutrient Composition of Crop Residues

Different crops contribute varying levels of essential nutrients through their residues, making them a valuable resource for nutrient cycling in agriculture. For example, rice residue supplies approximately 6 kg of nitrogen (N), 1.2 kg of phosphorus (P), and 14.5 kg of potassium (K) per ton, offering a balanced nutrient boost to soils. Lentil residue, on the other hand, is particularly high in nitrogen, providing around 19.6 kg of N and 11.4 kg of K per ton, which makes it an excellent choice for enhancing nitrogen-deficient soils. Banana residue is especially notable for its potassium content, contributing up to 57 kg of K per ton—ideal for potassium-depleted soils. Thus, *In-situ* incorporation of crop residue would enrich soil fertility, enhances crop productivity and conserves the environment (Ramanjaneyulu et al., 2021). This diversity in nutrient composition across different crop residues allows farmers to strategically use specific residues based on their soil's nutrient needs. Such targeted application not only supports soil health but also optimizes crop productivity by delivering essential nutrients in a natural, sustainable way.

4. Multifaceted Uses of Crop Residue

Multifaceted use of crop residue includes direct feeding to the animals, making compost for supplying nutrient to the crop plants, recycling of crop residue in the soil sustain fertility, crop residue waste utilization for bio-energy and industrial uses etc. (Figure 1).

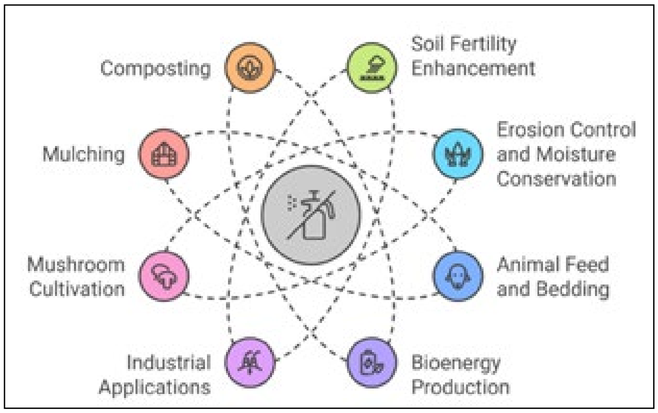

Figure 1: Multifaceted uses of crop residue

4.1. Addressing nutrient deficiencies

India's soils are grappling with multi-nutrient deficiencies, particularly in N, P, K, and essential micronutrients like zinc (Zn), boron (B), and iron (Fe) (Shukla et al., 2022). The overuse and imbalance of chemical fertilizers have exacerbated these deficiencies, leading to reduced soil fertility and declining crop yields. Crop residue incorporation offers a sustainable remedy by returning these nutrients to the soil organically. The nutrient-supplying potential of crop residues varies significantly across different crop types.

• ***High nitrogen sources:*** Lentil and soybean residues are exceptionally high in nitrogen, making them ideal for nitrogen-deficient soils.

• ***Potassium-rich residues:*** Banana and sunflower residues stand out for their high potassium content, beneficial for crops requiring substantial K inputs.

• ***Balanced nutrient supply:*** Grains like rice and wheat provide a balanced supply of N, P, and K, supporting overall soil fertility.

The nutrient content and potential contribution of major crops in India were summarized in Table 1.

4.2. Enhancing soil structure and microbial activity

Incorporating crop residues into the soil increases organic matter content, which in turn improves soil structure, enhances water retention, and fosters beneficial microbial activity. These microorganisms play a crucial role in decomposing organic matter, releasing nutrients in forms accessible to plants, and suppressing soil-borne diseases.

4.3. Reducing soil erosion and improving water retention

Residues left on the soil surface act as a protective cover, minimizing soil erosion caused by wind and water (Figure 2). Additionally, the organic matter from decomposed residues enhances the soil's ability to retain moisture, making it available for crops during dry periods (Blanco and Lal, 2023).

Table 1: Nutrient supply potential of major crop residues (Singh et al., 2022)

Crop	Nitrogen (kg t^{-1})	Phosphorus (kg t^{-1})	Potassium (kg t^{-1})
Rice	6.00	1.20	14.50
Wheat	4.50	1.00	12.30
Maize	5.60	1.80	13.50
Sorghum	5.30	2.10	14.70
Pearlmillet	5.70	1.80	12.70
Gram	6.00	2.20	16.00
Redgram	7.40	2.80	8.90
Lentil	19.60	2.00	11.40
Sugarcane	4.00	1.80	12.80
Groundnut	16.00	2.30	13.70
Mustard	6.00	2.90	4.00
Linseed	8.00	2.10	9.30
Safflower	8.00	2.10	9.30
Soybean	11.20	1.40	16.50
Sunflower	5.70	2.00	17.50
Cotton	7.70	3.00	6.90
Banana	5.90	1.00	57.80

Figure 2: Crop residue cover protect soil from erosion

4.4. Animal feed and bedding

• ***Fodder:*** Residues from crops like maize, sorghum, and legumes serve as valuable feed resources for livestock, especially during forage shortages (Figure 3).

• ***Bedding Material:*** Straws and stalks provide comfortable bedding for animals, contributing to their well-being and farm hygiene.

4.5. Bioenergy production

• ***Biofuels*:** Crop residues can be converted into bioethanol

Figure 3: Baling of crop residue used as feed and bedding for animals

or biodiesel, offering renewable energy sources and reducing reliance on fossil fuels.

• ***Biogas:*** Anaerobic digestion of residues produces biogas, which can be used for cooking, heating, or electricity generation.

4.6. Industrial applications

• ***Biodegradable Products:*** Residues are utilized in manufacturing biodegradable packaging materials, reducing plastic waste.

• ***Construction Materials:*** Processed residues can be used to produce particle boards and other building materials, promoting sustainable construction practices.

4.7. Mushroom Cultivation

• ***Substrate:*** Certain crop residues, such as paddy straw and wheat straw, serve as substrates for mushroom farming, providing an additional income stream for farmers.

4.8. Mulching

• ***Weed Suppression:*** Applying residues as mulch suppresses weed growth, reducing the need for chemical herbicides.

• ***Soil Temperature Regulation:*** Mulching with residues helps maintain optimal soil temperatures, benefiting seed germination and root development (Figure 4).

4.9. Composting

• ***Soil Amendment:*** Composting crop residues produces nutrient-rich compost, enhancing soil fertility and structure when applied to fields (Figure 5).

4.10. Biochar production

• ***Soil Improvement:*** Pyrolyzing residues to create biochar can improve soil health by increasing nutrient retention and microbial activity

Figure 4: Mulch for suppressing weeds and moisture conservation

Figure 5: Crop residue used for making compost

5. Current Challenges in Residue Management in Agriculture

5.1. Environmental pollution from residue burning

In regions like Punjab, Haryana, and Uttar Pradesh, farmers often burn crop residues to quickly clear fields for the next planting season. This practice releases significant amounts of particulate matter and greenhouse gases, contributing to air pollution and health issues. Despite efforts to curb this practice, it remains prevalent, leading to toxic smog in areas such as Delhi.

5.2. Economic constraints

The adoption of sustainable residue management practices often requires investment in specialized machinery and technologies. For many farmers, especially smallholders, the high costs associated with equipment like mulchers or seeders are prohibitive, limiting their ability to implement eco-friendly practices.

5.3. Lack of awareness and training

Many farmers are unaware of the benefits of sustainable residue management or lack the necessary training to implement such practices effectively. This knowledge gap leads to the continued use of traditional methods, such as burning, which are detrimental to the environment.

5.4. Competing uses for residues

Crop residues have multiple applications, including use as animal feed, bioenergy production, and industrial raw materials. Balancing these competing demands while ensuring sufficient residue retention for soil health poses a significant challenge.

5.5. Technological limitations

The lack of access to appropriate technologies for residue collection, processing, and utilization hampers sustainable management efforts. Inadequate infrastructure and limited availability of suitable machinery further exacerbate this issue.

6. Policy and regulatory challenges

While policies exist to promote sustainable residue management, enforcement is often weak, and incentives may be insufficient to drive widespread adoption. Additionally, the absence of stringent regulations against residue burning allows the practice to persist.

6.1. Policy interventions and support mechanisms

To overcome these barriers, comprehensive policy support and incentives are essential:

- *Awareness Campaigns:* Educating farmers about the long-term benefits of residue recycling can shift perceptions from viewing residues as waste to valuable resources.
- *Financial Incentives:* Subsidies for machinery like the Happy Seeder, which allows sowing seeds without removing residues, can encourage farmers to adopt sustainable practices.
- *Research and Development:* Investing in research to develop efficient residue management technologies and crop varieties that produce manageable residue volumes can facilitate adoption.
- *Integrated Nutrient Management (INM):* Promoting INM practices that combine chemical fertilizers with

organic inputs like crop residues can enhance soil fertility sustainably.

- ***Regulatory Measures:*** Implementing regulations that discourage residue burning through penalties and promoting eco-friendly practices through certifications can drive change.

7. Success Stories and Technological Innovations

Innovative technologies and successful pilot projects offer hope for scalable solutions:

• ***Happy Seeder:*** This machine enables direct seeding of crops without the need to remove residues, thus preserving soil structure and moisture (Figure 6).

Figure 6: Use of 'Happy Seeder' for direct sowing of seeds

• ***Composting Initiatives***: Community-based composting projects transform surplus residues into high-quality compost, providing an accessible nutrient source for local farmers.

8. The Economic and Environmental Impact of Using Crop Residues

8.1. Economic benefits

Cost Reduction: By recycling crop residues, farmers can reduce their dependency on expensive chemical fertilizers. This not only lowers input costs but also stabilizes production expenses against volatile fertilizer prices

Enhanced Yield Stability: Improved soil health through nutrient recycling leads to more consistent crop yields, providing economic stability for farmers.

Diversified Income Streams: Residues can be utilized for value-added products like compost and bioenergy, creating additional revenue opportunities for farmers and rural communities.

8.2. Environmental advantages

Reduction in Air Pollution: Eliminating residue burning significantly cuts down particulate matter and greenhouse gas emissions, contributing to better air quality.

Carbon Sequestration: Organic matter from decomposed residues enhances soil carbon stocks, aiding in climate change mitigation efforts.

Biodiversity Enhancement: Healthier soils support a diverse microbial ecosystem, which is crucial for nutrient cycling, pest control, and disease suppression.

Water Conservation: Improved soil structure from organic matter increases water infiltration and retention, reducing the need for irrigation and enhancing resilience against droughts.

9. Conclusion

Crop residue management is very important for achieving agricultural sustainability and climate resilient to combat global climate change and vulnerability in long run. Crop residue retention along with zero-tillage improves crop productivity, profitability, resource-use efficiencies, soil health (improved SOC, soil aggregation, micro-biological activity) and at the same time reduce environmental footprints in terms of reduction in greenhouse gas emission. Thus, utilize crop residue management is very crucial for maintaining ecosystem services and generating livelihood of the farmers which have to be scaled up.

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