SWITCH ON FOUNDATION

Waste to Wealth

Modern Agricultural Waste Management Strategies

SwitchON Foundation founded in 2008, also known as the Environment Conservation Society (ECS), has actively offered sustainable solutions for the vulnerable Indian population. With a commitment to clean energy, climate-resilient agriculture, and sustainable cities, ECS is working towards creating opportunities for 10 million people by 2030, promoting equitable growth through innovative business models and technologies.

Central to its efforts is the CRA-DRE (Integrating Climate Resilient Agriculture with Distributed Renewable Energy) program, where ECS integrates renewable energy solutions with **climate-resilient farming practices within a Farm-to-Fork ecosystem**. This program focuses on the collectivization of producers, enhancing their capabilities in value addition to primary produce, and establishing robust market linkages.

Through continuous action research and creation as well as dissemination of knowledge documents, ECS collaborates with government departments and civil society networks, sharing insights and evidence to inform policy. This dynamic approach not only advances the CRA-DRE program but also strengthens community engagement and capacity building, ensuring that farmers are key drivers of their economic development.

Project Team
Mr. Vinay Jaju, Executive Director
Mrs. Ekta Jaju, Executive Director

Research Team
Mr. Sourjya Narayan Chowdhury, Research Associate
Mr Apurba Kumar Guhathakurta, Research Assistant
Dr. Aditi Kundu, Research Manager

Communication Team
Mr. Debojyoti Das, Sr. Communication Manager and Video Lead
Mr. Sarthak Das, Creative Designer
Mr. Anirban Dey, Asst Manager - Graphic Design

Table of Contents

• Executive Summary

The report ‘Waste to Wealth: Modern Agricultural Waste Management Strategies’ delves into the pressing challenges and transformative opportunities in managing India’s agricultural waste, which amounts to **500 million tonnes annually**. Much of this waste remains unutilized, contributing to severe environmental issues, including air pollution, soil degradation, and water contamination. Mismanagement practices, such as stubble burning, are major contributors to **air pollution**, as seen in Delhi, where agricultural residue burning from Punjab leads to a 103-point rise in AQI during the post-monsoon season. This highlights the urgent need for sustainable solutions to address pollution caused by improper agricultural waste disposal.

India generates approximately 500 million tonnes of crop residues yearly, with **140 million tonnes** classified as **surplus**. Of this, 92 million tonnes are burned annually, significantly impacting air quality. Additionally, inorganic wastes such as pesticide residues and plastics exacerbate soil and water pollution, persisting in the environment for years and disrupting ecosystems. While these wastes represent environmental hazards, they also contain untapped potential for economic utilization through technologies like anaerobic digestion, composting, and biofuel production.

The report identifies key barriers to effective agricultural waste management, including inadequate infrastructure, economic constraints, limited public awareness, and insufficient access to modern technologies. Due to financial limitations and a lack of knowledge about alternatives, farmers often resort to low-cost and unsustainable practices. Addressing these challenges requires comprehensive strategies, including policy interventions, technological innovations, and capacity-building programs for farmers.

Proposed interventions focus on converting waste into valuable products such as bioenergy, organic fertilizers, and animal feed. Technologies like composting and biochar production reduce waste volumes and enhance soil health. Anaerobic digestion offers a dual benefit of producing biogas and nutrient-rich digestate. Recycling inorganic waste, such as plastics, and integrating IoT-driven systems for real-time waste monitoring are critical strategies for modernizing agricultural waste management.

The report underscores the importance of collaborative efforts between government agencies, research institutions, and farming communities to ensure the adoption of sustainable practices. By leveraging innovative technologies and promoting awareness, India can transform its agricultural waste into a resource-efficient and economically viable system. This approach aligns with global sustainability goals, ensuring environmental conservation while enhancing farm productivity and farmer livelihoods. Through these efforts, agrarian waste can become a cornerstone of India’s journey toward a cleaner, greener, and more sustainable future.

• Introduction

Agricultural waste management is a critical yet often overlooked aspect of **sustainable farming**, with significant implications for environmental health, soil quality, and air pollution. Agriculture, while serving as the backbone of food and nutritional security, generates vast waste as a by-product of its processes. Improper management of this waste contributes to **soil and water contamination, air pollution,** and **greenhouse gas emissions**. However, with innovative technologies and sustainable practices, this waste can be transformed into valuable products that reduce pollution and create economic opportunities for farmers and industries. This approach aligns with resource efficiency and environmental conservation goals, contributing to a sustainable future. Unmanaged agricultural residues contribute to air, soil, and water pollution, with practices like burning leading to greenhouse gas emissions and health hazards.

This report delves into agricultural waste's classification and impact, focusing on organic and inorganic components, their generation patterns, and the associated environmental challenges. Focusing on key statistics and case studies from India highlights the pressing issues of improper waste management, such as **stubble burning, plastic pollution,** and **nitrate contamination**, while showcasing **crop-wise residue generation** and its potential uses.

This study aims to present actionable strategies for sustainable waste management, emphasizing **composting, bioenergy production, technological integration,** and **regulatory compliance.** By providing a comprehensive understanding of the challenges and opportunities in agricultural waste management, this report underscores the importance of adopting innovative and sustainable practices to balance productivity with environmental stewardship.

• Classification of Agricultural Waste

Organic Waste
Organic waste refers to materials derived from living organisms, including plant and animal residues. These are biodegradable and decompose naturally, often contributing to soil fertility if managed properly

Crop residues: These include the parts of plants left in the field after harvest, such as stalks, leaves, husks, and stems. They are a major source of farm waste, especially in large-scale grain production. Rich in cellulose and lignin, crop residues are an important carbon source, enhancing soil fertility (TANU, 2016). India generates approximately 500 million tonnes (Mt) of crop residues annually, with a significant portion used for feed, fuel, and other purposes. However, about **140 Mt** remains as **surplus** and 92 Mt of this surplus is burned each year, contributing to severe air pollution issues (ICAR, 2022).

Key Statistics on Crop Residue
India generates approximately 500 million tonnes (Mt) of crop residues annually, with a significant portion used for feed, fuel, and other purposes.
Cereals account for 54% (368 Mt) of India's crop residues
Sugarcane contributes 16% (111 Mt)
Rice generates the highest crop residue: 154 Mt, followed by wheat at 131 Mt.

Source: ICAR, 2022

Animal manure: Comprising primarily feces and urine, animal waste is a significant organic by-product, particularly in intensive livestock operations. Improper handling of manure can lead to environmental issues like water and air pollution.

Key Statistics on Animal Manure
In 2021, livestock animals produced an estimated 3.12 billion tons of manure annually. This includes about 127 million metric tons of nitrogen (N) contained within the manure.
In 2018, the world's total livestock manure reached 125 million tonnes of nitrogen (N). Of this, 88 million tonnes of N was left on pasture by grazing animals, 34 million tonnes of N were treated in manure management systems, and 27 million tonnes of N was applied to soils for crop production.
Livestock-related greenhouse gas (GHG) emissions resulted from manure processes and enteric fermentation, amounting globally to 3.5 billion tonnes of CO2eq in 2018, 15 percent higher than in 1990. These livestock emissions represented two-thirds of all emissions from agriculture.

Agriculture Waste

Crop Residues

Examples
- Rice straw
- Wheat straw
- Corn stover
- Barley Straw
- Leaves

Industrial Processing Waste

Examples
- Sugarcane bagasse
- Rice bran
- Rice husk
- Barley straw Leaves
- Egg shells
- Orange peel
  Plantain peel
- Banana peel

Livestock Waste

Examples
- Cattle manure
- Pig manure
- Animal fat
- Birds feathers
- Broiler droppings

Fruit Wastes

Examples
- Cabbage
- Lettuce
- Tomato
- Mango

Different Types of Organic Agricultural Wastes

As per **figure 1**, agricultural waste can be classified into several categories based on its source and nature. These include offcuts, which are leftover parts from primary agricultural produce; crop residues, such as **rice straw, wheat straw,** and **maize cobs; industrial wastes generated** during **agro-industrial processing,** like **sugarcane bagasse** and **oil cakes; animal wastes,** including **manure** and other **byproducts** from **livestock farming;** and food-related wastes, such as banana peels and rice husks. Each type of waste presents unique challenges and opportunities for sustainable management and valorization (Rao & Rathod, 2019).

SWITCH ON FOUNDATION

Inorganic Waste

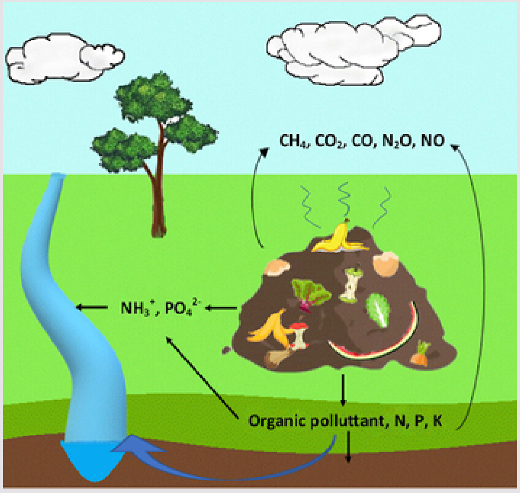
Inorganic waste consists of non-biodegradable materials, such as synthetic chemicals and plastics, that can persist in the environment for long periods. These wastes often contribute to pollution and require careful disposal to prevent harm to ecosystems.

Pesticides and chemicals: Herbicides and synthetic fertilizers, widely used to boost yields and control pests, often leave residues that persist in soil and water, posing risks to ecosystems. According to FAO (2022), **global herbicide use exceeds 4 million tons annually**, with many designed for environmental persistence, contributing to long-term contamination.

Plastics and packaging: Plastics are extensively utilized in agriculture for applications such as crop covers and packaging. However, they can take hundreds of years to decompose, and improper disposal results in significant environmental damage, wildlife harm, and an increase in global plastic pollution. Over the past 70 years, the use of plastics in agriculture has grown substantially, reaching an estimated **12.5 million tons annually** (Hofmann *et al.*, 2023). This extensive use has led to the accumulation of macroplastics, microplastics, and nanoplastics in soils and surrounding environments, posing long-term ecological challenges.

• Impact of Agricultural Waste on Soil Quality and Surrounding

Agricultural waste has a significant impact on soil health when not managed effectively. The accumulation of agricultural waste in soil can produce gases like **methane (CH_4)**, **carbon dioxide (CO_2)**, **ammonia (NH_3)**, **nitrous oxide (N_2O)**, and **hydrogen sulfide (H_2S)**, as well as ions such as **nitrate (NO_3^-)**, **ammonium (NH_4^+)**, and **sulfates (SO_4^{2-})**, which can lead to pollution, soil acidification, and nutrient imbalances.



Improper disposal of plastics **depletes soil fertility** by disrupting microbial activity, increasing acidity, and causing **nutrient imbalances**. Sustainable practices like converting waste into biochar or compost improve water retention, aeration, and nutrient availability, enhancing soil health and promoting sustainable agriculture.

Studies have shown that leachate from agricultural waste significantly increases soil salinity and sodicity indices, leading to reduced soil quality. For example, a study reported that **electrical conductivity (EC) levels increased by 78% to 114% in soils** affected by leachate compared to control soils (Yeilagi *et al.*, 2021).

• Crop Residue Produced by Major Crops in India

Crop residues from major crops such as rice, maize, millet, and sugarcane are valuable by-products that play a critical role in sustainable agriculture. These residues, traditionally used for soil enrichment and erosion control, are now gaining attention for their potential in **renewable energy** and **biofuel production.**

Crop	Residue Composition	Estimated Residue Generation	Alternative Outcomes (post-treatment)	Products and Uses
Rice	Husk, Bran	368 mt	Rice Bran Oil, Bioethanol, Animal Fodder, Rice Husk Ash (RHA)	Edible Oil, Renewable Fuel, Silica Production, Essential roughage for livestock
Wheat	Bran, Straw		Biochar, Biogas, processed straws,	Bioenergy, packing material, Fodder
Maize	Stover, Husk, Skins		Microbial protein, Mud Cups	Dietary Supplements
Millet	Stover		Bioethanol, Biogas, Pellets, Compost, Biochar	Bioenergy, Animal feed, Biochar, Paper Pulp
Sugarcane	Sugarcane tops, Bagasse, Molasses	111 mt	Compost material	Reduce soil and water contamination

Source: ICAR, 2022

Crop residues from major crops like rice, maize, millet, and sugarcane include field leftovers such as stalks, straw, husks, and other non-food plant components collectively known as lignocellulosic biomass (ICAR, 2022). These residues are traditionally used to enhance soil fertility and stability through direct plowing or composting, supporting irrigation efficiency and erosion control. However, large-scale crop production has reduced reliance on these sustainable practices, with burning becoming common, particularly in Asia, despite its environmental consequences. Lignocellulosic biomass, comprising cellulose, hemicellulose, and lignin, is now recognized as a valuable raw material for biofuel production due to its abundance, though lignin's resistance to fermentation poses challenges.

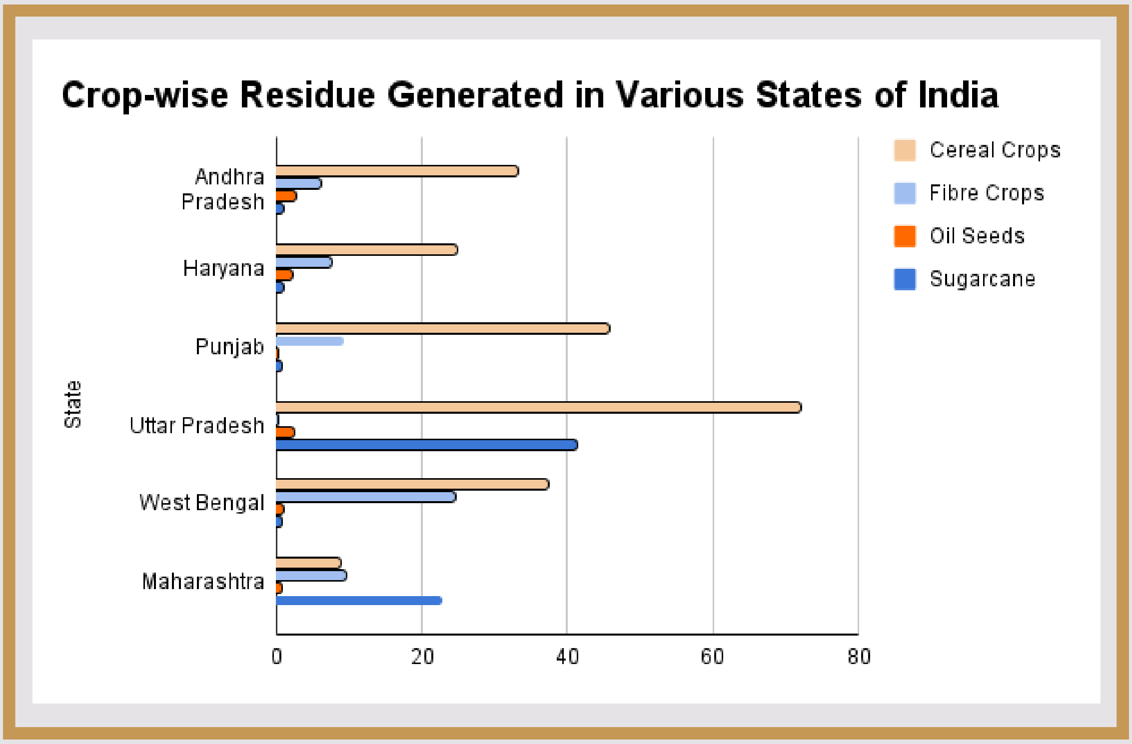


Figure 2: Crop-wise Residue Generated in Various States of India
Source: ICAR, 2022

Crop residues from major crops like rice, maize, millet, and sugarcane include field leftovers such as stalks, straw, husks, and other non-food plant components collectively known as lignocellulosic biomass (ICAR, 2022). These residues are traditionally used to enhance soil fertility and stability through direct plowing or composting, supporting irrigation efficiency and erosion control. However, large-scale crop production has reduced reliance on these sustainable practices, with burning becoming common, particularly in Asia, despite its environmental consequences. Lignocellulosic biomass, comprising cellulose, hemicellulose, and lignin, is now recognized as a valuable raw material for biofuel production due to its abundance, though lignin's resistance to fermentation poses challenges.

Figure 2 shows that crop residue production varies significantly across regions in India, with Uttar Pradesh leading in **cereal crop residues (72 Mt)** and **sugarcane residues (44.2 Mt)**. In Punjab and Haryana, rice and wheat residues are prominent, with a substantial portion— approximately **80% of rice straw**—burned on fields, contributing to environmental challenges. West Bengal contributes significantly to **cereal residues (39.6 Mt) and fiber crop residues (24.4 Mt)**. Maharashtra also plays a key role, generating **19.5 Mt** of fiber crop residues. Andhra Pradesh contributes to the country's overall crop residue through its diverse agricultural outputs, although specific figures are not highlighted. These regions collectively demonstrate the need for effective residue management strategies to balance agricultural productivity and environmental sustainability.

• Cases of Large-Scale Improper Agricultural Waste Management in India

Example from Indo-Gangetic Region (IGR)

Groundwater in the Indo-Gangetic Plains shows nitrate contamination exceeding **45 mg/L** due to residues from leguminous crops, cereal crops, and maize. Poor residue management poses risks to health, crop productivity, and ecosystems. Subsequently, this has increased the dependency on chemical fertilizers and created nutrient imbalances in the region. There is a trend of massive nitrate leaching rates and contamination of open water sources after groundwater sources are exposed to them.

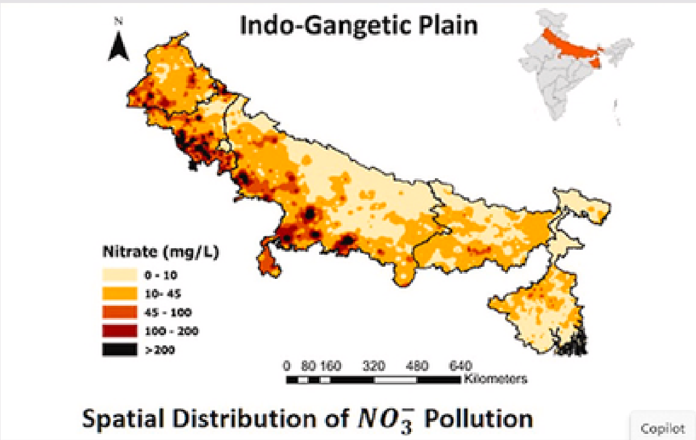


Figure 3: Spatial distribution of NO3 pollution
Source: Verma, *et al.*, 2023

Example from Haryana:

From 2019 to 2023, Haryana recorded 14,122 fire incidents in 2019 and 7,959 in 2023, with districts such as Karnal and Kaithal reporting figures reflecting 86% and 78% lower activity, respectively. However, certain districts like Gurgaon, Mewat, and Jhajjar experienced increases in fire incidents. These fires, primarily from stubble burning during the post-monsoon season, significantly contributed to Delhi's air quality issues by adding particulate matter and pollutants to the atmosphere. Stubble burning in Haryana is a major seasonal source of pollution, contributing to a 103-unit rise in Delhi's AQI. The transboundary movement of pollutants exacerbates the already vulnerable air conditions in Delhi, highlighting the urgent need for strengthened fire management strategies, sustainable agricultural practices, and collaborative efforts between Haryana and Delhi to address this recurring environmental challenge.

The transboundary movement of pollutants exacerbates the already vulnerable air conditions in Delhi, highlighting the urgent need for strengthened fire management strategies, sustainable agricultural practices, and collaborative efforts between Haryana and Delhi to address this recurring environmental challenge.

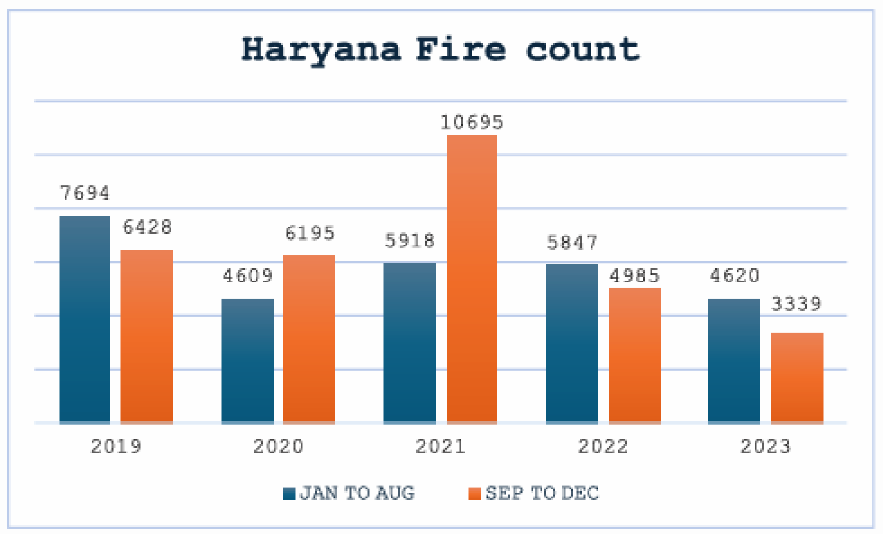


Figure 4: Fire count caused by stubble burning in Haryana: 2019-2023
Source: Carbon copy, 2024

Example from Punjab

From 2019 to 2023, **Punjab recorded 95,048 fire incidents in 2020 and 52,722 in 2023**, with districts such as Gurdaspur and Muktsar showing significant **reductions of up to 71%**. However, some districts like Sahibzada Ajit Singh Nagar experienced slight increases in fire counts. These fires, primarily from stubble burning during the post-monsoon season, were a major contributor to Delhi's deteriorating air quality. The pollutants released from these incidents led to a **103-unit rise in Delhi's AQI**, significantly affecting the city's air health.

The transboundary movement of pollutants from Punjab's fields added to Delhi's already high levels of particulate matter, exacerbating seasonal spikes in pollution. This underscores the pressing need for collaborative efforts between Punjab and Delhi, including improved fire management practices, adoption of sustainable agricultural methods, and stricter enforcement of measures to mitigate the environmental impact of stubble burning.

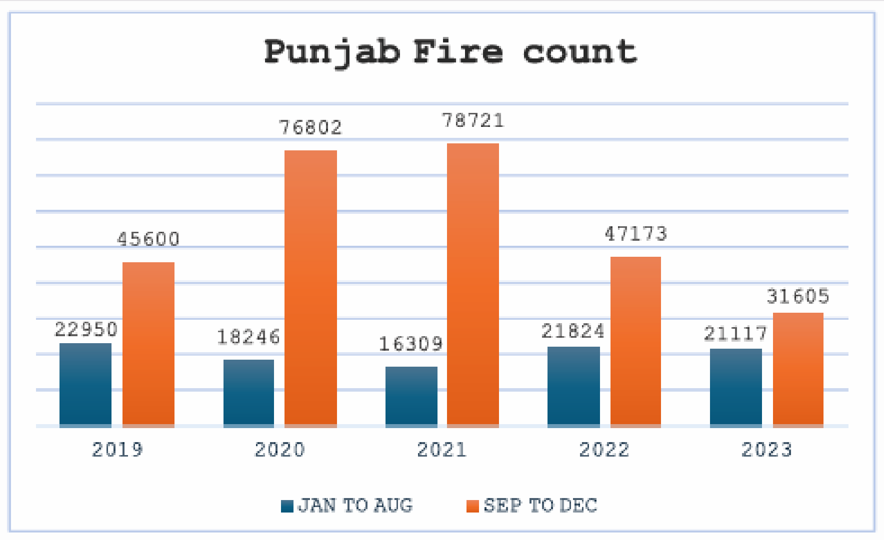


Figure 5: Fire count caused by stubble burning in Punjab: 2019-2023
Source: Carbon copy, 2024

• Challenges of Agricultural Waste Management in India

Infrastructure Deficiencies: A key challenge in agricultural waste management is the lack of infrastructure for proper collection, processing, and disposal. This leads to practices like open dumping and burning, worsening pollution in rural areas.

Economic Constraints: Financial barriers often hinder farmers from adopting sustainable waste management, as the costs of handling residues often exceed potential revenue. This economic challenge drives many to opt for burning as a quick and inexpensive solution.

Lack of Public Awareness and Participation: Limited public awareness about sustainable agricultural waste management leaves many farmers unaware of alternatives like composting or bioenergy production. This knowledge gap hampers community participation in adopting effective practices.

Technological Barriers: Although innovative technologies such as anaerobic digestion and composting exist, their adoption remains limited due to a lack of access and training for farmers. **Integrating modern technology** with traditional farming practices is essential for improving waste management but requires investment in education and resources

• Strategies and Interventions for Better Waste Management

Effective agricultural waste management is essential for sustainability. Here are key strategies:

1. **Composting:** Convert organic waste into nutrient-rich compost to enhance soil fertility and reduce waste volume.

2. **Anaerobic Digestion:** Use anaerobic digestion to produce biogas and nutrient-rich digestate, reducing waste while generating renewable energy.

3. **Wastewater Irrigation:** Utilize liquid manure or digestate for irrigation, efficiently distributing nutrients to crops.

4. **On-Farm Utilization:** Implement practices like mulching and using crop residues for livestock bedding to minimize waste.

5. **Waste Segregation and Recycling:** Sort agricultural wastes for recycling, particularly plastics and packaging, to reduce environmental impact.

6. **Technology Integration:** Use IoT sensors and waste management software for real-time monitoring and data analysis to optimize waste processes.

7. **Education and Training:** Provide training for farm workers on effective waste management practices to foster engagement and compliance.

8. **Regulatory Compliance:** Stay updated on local regulations regarding waste disposal to ensure sustainable practices.

9. **Continuous Improvement:** Regularly assess waste management practices, setting targets for reduction and improvement.

Conclusion

Agricultural waste in India, totaling around 500 million tonnes annually, presents a major environmental and economic challenge. The improper disposal of crop residues, especially through practices like burning, leads to severe air pollution, soil degradation, and greenhouse gas emissions. Despite this, agricultural waste offers an opportunity for sustainable resource utilization, with potential benefits such as bioenergy, organic fertilizers, and animal feed. Addressing these challenges requires the adoption of effective waste management strategies that can reduce pollution and transform waste into valuable resources.

Key strategies for improving agricultural waste management include composting, anaerobic digestion, and bioenergy production. Composting can turn organic waste into nutrient-rich soil additives, while anaerobic digestion offers a way to produce biogas and reduce waste volumes. Encouraging on-farm utilization, such as using crop residues for animal bedding or mulching, can also reduce waste accumulation. Furthermore, integrating technology, like IoT sensors for waste monitoring, and promoting public awareness and farmer education are essential steps toward more sustainable practices. To support these efforts, investments in infrastructure, financial incentives for farmers, and stronger enforcement of regulations are necessary. These strategies will help mitigate environmental impacts, boost resource efficiency, and foster a more sustainable agricultural system in India.

References

TNAU Agritech Portal, Organic Farming. (2016). Organic farming compost. Link: https://agritech.tnau.ac.in/org_farm/orgfarm_composting_coir.html

Creating wealth from agricultural waste, Indian Council of Agricultural Research, New Delhi. (2020). Link: https://icar.org.in/sites/default/files/Circulars/Creating-Wealth-From-Agricultural-Waste.pdf

Ufitikirezi, J. d. D. M., Filip, M., Ghorbani, M., Zoubek, T., Olšan, P., Bumbálek, R., Strob, M., Bartoš, P., Umurungi, S. N., Murindangabo, Y. T., Heřmánek, A., Tupý, O., Havelka, Z., Stehlík, R., Černý, P., & Smutný, L. (2024). Agricultural Waste Valorization: Exploring Environmentally Friendly Approaches to Bioenergy Conversion. Sustainability, 16(9), 3617. Link: https://doi.org/10.3390/su16093617

Food and Agriculture Organization of the United Nations. (2018). Livestock and environment statistics: manure and greenhouse gas emissions Global, regional and country trends 1990–2018. Link: https://openknowledge.fao.org/server

Hofmann, T., Ghoshal, S., Tufenkji, N. et al. Plastics can be used more sustainably in agriculture. Commun Earth Environ 4, 332 (2023). Link: https://doi.org/10.1038/s43247-023-00982-4
Yeilagi, S., Rezapour, S. & Asadzadeh, F. Degradation of soil quality by the waste leachate in a Mediterranean semi-arid ecosystem. Sci Rep 11, 11390 (2021). Link: https://doi.org/10.1038/s41598-021-90699-1

Skip Shapiro Enterprises. (2023). Agricultural Waste Disposal: The Ultimate Guide. Link: https://shapiroe.com/blog/agricultural-waste-disposal-guide/

Turning Waste into Wealth: Exploring Strategies for Effective Agricultural Waste Management. (2024). Vigyan Varta, 5(5), 323. https://www.researchgate.net/publication/381008204_Turning_Waste_into_Wealth_Exploring_Strategies_for_Effective_Agricultural_Waste_Management. Link: https://www.researchgate.net/publication/381008204_Turning_Waste_into_Wealth_

Verma, A., Sharma, A., Kumar, R., & Sharma, P. (2023). Nitrate contamination in groundwater an associated health risk assessment for Indo-Gangetic Plain, India. Groundwater for Sustainable Development, 23, 100978. Link: https://doi.org/10.1016/j.gsd.2023.100978

Rao, M.M., Botsa, S.M., Rao, T.P. et al. A comprehensive review on agricultural waste production and onsite management with circular economy opportunities. Discov Sustain 5, 288 (2024). Link: https://doi.org/10.1007/s43621-024-00492-z

CarbonCopy. (2024, October 25). Stubble burning declining in Punjab and Haryana, still impacting Delhi's air: Report. Carbon Copy. Link: https://carboncopy.info/stubble-burning-declining-in-punjab-and-haryana-

Rao, P., & Rathod, V. (2019). Valorization of food and agricultural waste: a step towards greener future. The Chemical Record, 19(9), 1858-1871. Link- https://doi.org/10.1002/tcr.201800094


SWITCH ON
FOUNDATION