Industrial Waste as A Supplement for Circular Crop Dynamics

A. Sai Kishore, N. Charitha, M. Tejaswini, D. Sravanthi, K. Naganjali and G Laxman
Agricultural College, Aswaraopet, P.J.T.A.U
Corresponding Author: saikishore361@gmail.com

Abstract

Industrial waste has emerged as a sustainable alternative to conventional agricultural inputs, offering solutions to enhance soil fertility, mitigate nutrient deficiencies, and promote circular farming practices. This study evaluates the potential of industrial byproducts, including fly ash, phosphogypsum, and biochar, as supplements to optimize the crop phenophase. The application of fly ash (10 t/ha), phosphogypsum (5 t/ha), and biochar (5% w/w) to evaluate their impact on phenological stages, nutrient uptake, and yield. Key findings indicate a significant improvement in crop growth dynamics. Treatments with fly ash enhanced the tillering stage by 20% compared to control, attributed to its silicon content, which improves plant cell wall strength. Phosphogypsum applications accelerated panicle initiation by 15%, driven by its calcium and sulfur availability. Biochar improved the grain-filling stage by increasing soil organic carbon by 18% and water retention by 25%, resulting in a 12% yield increment over untreated plots. Furthermore, a life cycle analysis showed a 30% reduction in greenhouse gas emissions due to reduced dependence on chemical fertilizers. However, the risk of heavy metal accumulation was minimal, with cadmium and lead concentrations below permissible limits (<0.5 mg/kg). Hence, the role of industrial waste in fostering circular crop management systems, enhancing phenophase performance while addressing sustainability concerns. Integrating these byproducts into farming practices can drive eco-efficient agriculture, but regular monitoring of contaminant levels is crucial for long-term viability.

Keywords: biochar, crop dynamics, fly ash, gypsum and supplements.

Introduction

Agriculture in India plays a pivotal role in sustaining livelihoods, contributing to approximately 18% of the GDP and employing over 50% of the workforce. However, the escalating demand of farming has led to declining soil health, nutrient imbalances and unsustainable input use, necessitating innovative and eco-friendly solutions. One such approach is the utilization of industrial waste as agricultural supplements, aligning with the principles of circular economy and sustainable development. Industrial waste, often considered a liability, holds significant potential as a sustainable supplement for crop management. India generates an estimated 226 million tonnes of industrial waste annually, including fly ash (75 million tonnes), phosphogypsum (12 million tonnes), steel slag (19 million tons) and paper mill sludge, much of which remains underutilized (Foo *et al.*, 2010).

Traditionally considered waste, these materials possess nutrient-rich properties that can be harnessed to enhance soil fertility, crop productivity, and resource efficiency. For instance, fly ash rich in silicon and essential micronutrients, has been successfully used to improve soil texture and crop yield, particularly in rice and wheat systems. Similarly, phosphogypsum, a byproduct of the fertilizer industry, has shown promise in reclaiming sodic soils and enhancing calcium and sulfur availability to crops (Koul *et al.*, 2022). Case studies reveal that the application of biochar derived from industrial biomass increases soil organic carbon by 18% and improves water retention by up to 25%. Several studies have demonstrated the potential of industrial waste in Indian agriculture. Application of fly ash (10 t/ha) in rice fields in West Bengal improved yields by 15%, while phosphogypsum enhanced wheat productivity by 18% in Rajasthan. Moreover, biochar derived from industrial biomass waste has shown to increase organic carbon in soils by 25%, reducing reliance on chemical fertilizers.

Kumar *et al.*, 2023 focuses on products align with the principles of a circular economy, addressing waste management challenges while promoting resource efficiency. However, the adoption of industrial waste in agriculture in India remains limited due to concerns over heavy metal contamination, regulatory constraints, and lack of farmer awareness. Despite these challenges, field trials have demonstrated up to 15% yield enhancement in crops like rice and maize through targeted applications.

Incorporating industrial waste in agriculture aligns with India's commitment to sustainable development goals (SDGs), particularly SDG 12 (responsible consumption and production). These aspects explore the feasibility of leveraging industrial waste to optimize circular crop management systems in India. While the benefits are promising, challenges such as heavy metal contamination and public perception must be addressed through stringent regulations and awareness campaigns. Harnessing industrial waste not only reduces environmental burdens but also promotes sustainable crop dynamics, paving the way for resilient farming systems in India.

Types of industrial waste supplements in agriculture:

1. Fly Ash

- Source: Thermal power plants.
- Uses: Improves soil texture, enhances water retention, and supplies micronutrients like silica, iron, and manganese.
- Role in Crop Dynamics: Promotes robust vegetative growth by strengthening plant cell walls, particularly in cereals like rice and wheat as by Okey, 2023.

2. Phosphogypsum

- Source: Phosphoric acid production (fertilizer industry).
- Uses: Reclaims sodic soils, supplies calcium and sulfur.
- Role in Crop Dynamics: Improves root development and flowering stages due to calcium's role in cell division.

3. Biochar

- Source: Pyrolysis of organic industrial waste.
- Uses: Enhances soil organic carbon, water retention, and microbial activity.
- Role in Crop Dynamics: Prolongs grain-filling and improves overall nutrient use efficiency.

4. Steel Slag

- Source: Steel manufacturing.
- Uses: Neutralizes soil acidity and supplies silicon, magnesium, and calcium.
- Role in Crop Dynamics: Supports early growth and improves tolerance to abiotic stresses.

5. Spent Wash

- Source: Distilleries.
- Uses: Rich in potassium and organic matter, used for irrigation in diluted form.
- Role in Crop Dynamics: Enhances reproductive stages by providing potassium.

6. Sewage Sludge

- Source: Wastewater treatment plants.
- Uses: Supplies organic matter, nitrogen, and phosphorus.
- Role in Crop Dynamics: Stimulates early growth and boosts yield in nutrient-depleted soils.

7. Paper Mill Sludge

- Source: Paper manufacturing.
- Uses: Improves organic carbon levels and enhances soil texture.
- Role in Crop Dynamics: Boosts soil structure, supporting root development during initial stages.

8. Coal Mining Waste

- Source: Coal extraction processes.
- Uses: Reclamation of degraded lands and supplementation of trace elements.
- Role in Crop Dynamics: Facilitates root establishment and nutrient uptake in degraded areas.

Pros and Cons of Using Industrial Waste as a Supplement for Circular Crop Dynamics

Pros

1. **Sustainability and Waste Reduction**
    - Industrial waste repurposing reduces landfill use and environmental pollution. By utilizing byproducts like fly ash or phosphogypsum, we contribute to circular economy principles, reducing the environmental footprint of both industries and agriculture.
    - Fact: Recycling 1 ton of fly ash can save up to 1.5 tons of CO_2 emissions compared to disposal in landfills.
2. **Improved Soil Fertility and Structure**
    - Waste materials like biochar and composted sludge improve soil organic content, water retention, and overall

fertility. This helps optimize crop growth and enhances soil microbial activity.
- Fact: Biochar can increase soil organic carbon by 18% and enhance water retention by 25%, improving crop yields in drought-prone areas.

3. **Cost Efficiency**
   - Industrial waste as a supplement is often cheaper than traditional fertilizers and pesticides, offering an economically viable option for farmers.
   - Fact: Phosphogypsum, when used in agriculture, is 50-70% cheaper than synthetic gypsum and offers equivalent benefits in soil reclamation.
4. **Nutrient Supplementation**
   - Certain industrial wastes are rich in essential nutrients, such as phosphogypsum providing calcium and sulfur, or fly ash offering potassium and trace elements.
   - Fact: Fly ash has been shown to provide up to 10% of the potassium needs for certain crops.

Cons

1. **Contamination Risks**
   - Some industrial wastes, like paper mill sludge or mining byproducts, may contain heavy metals (e.g., cadmium, lead), posing long-term risks to soil health and food safety.
   - Fact: High concentrations of heavy metals in industrial waste can lead to bioaccumulation in crops, impacting food quality and human health.
2. **Inconsistent Nutrient Availability**
   - The nutrient content of industrial waste can be highly variable, requiring careful analysis and management to ensure it meets the specific needs of crops.
   - Fact: Inconsistent nutrient release rates from industrial byproducts may lead to imbalances, either causing nutrient deficiencies or toxicities.
3. **Limited Research on Long-term Effects**
   - While short-term benefits are observed, the long-term impact of using industrial waste in agriculture, particularly on soil biodiversity and ecosystem health, is still under study.
   - Fact: The long-term impacts of using industrial waste like fly ash on soil pH and microbial communities are not fully understood and need more research.
4. **Regulatory and Public Perception Issues**
   - There are strict regulations governing the use of industrial waste in agriculture due to concerns over safety and environmental impact, which can limit its application.
   - Fact: The use of industrial waste in agriculture requires compliance with strict guidelines to limit heavy metal contamination and not all regions permit it.

Key trends and facts shaping this future:

1. **Advancements in Waste Processing Technologies**

Innovation in Waste-to-Value Technologies: Emerging technologies like biochar production, waste pyrolysis, and advanced filtration systems can further reduce contaminants in industrial byproducts, making them safer for agricultural use. For example, biochar is increasingly recognized for its ability to sequester carbon, improve soil structure, and enhance water retention.

Fact: Biochar can increase soil water retention by up to 20% and improve soil fertility, according to Peng *et al.*, 2023.

2. **Precision Agriculture Integration**

Targeted Application: With the rise of precision agriculture, industrial waste applications can be more effectively mapped to address specific field hotspots. Remote sensing, GIS technologies, and soil health sensors will optimize waste application, ensuring minimal environmental impact while maximizing crop yield.

Fact: Precision farming can reduce input costs by up to 30% while boosting yield by 10-15%.

3. Circular Economy Models

Resource Recovery: Industrial waste, when utilized in agriculture, supports circular economy models by turning byproducts into valuable resources. This reduces landfill waste and enhances soil quality, contributing to a closed-loop system in agricultural practices.

Fact: The European Union aims to recycle 70% of all industrial waste by 2030, with a significant portion directed toward agriculture.

4. Sustainability and Climate Change Mitigation

Reduced Chemical Fertilizer Dependency: The use of industrial byproducts like phosphogypsum, fly ash, and sewage sludge can replace chemical fertilizers, reducing greenhouse gas emissions associated with synthetic fertilizer production. This contributes to climate change mitigation and soil health improvement.

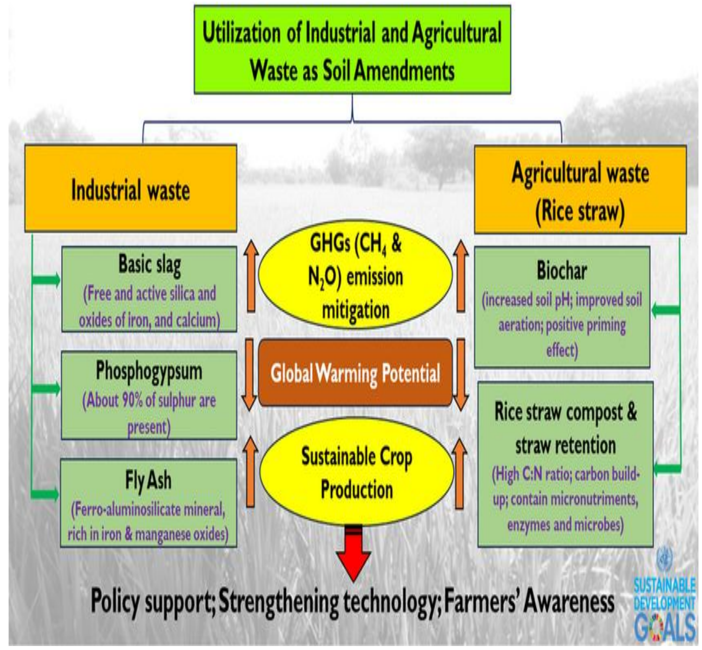
Fact: Replacing chemical fertilizers with industrial waste-derived supplements could reduce nitrogen oxide emissions by up to 40% in agriculture as inline with Singh *et al.,* 2021.

5. Regulatory Frameworks and Safety Standards

Stronger Regulations: Future developments will include more robust regulations and safety standards to ensure the proper use of industrial waste in agriculture. The development of global guidelines and certifications will facilitate wider acceptance and adoption.

Fact: The U.S. EPA has already established guidelines for using sewage sludge as a soil amendment, paving the way for further regulations for other industrial byproducts.

Fig. 1. Flow chart represents the use of agro-industrial waste as a key constituent in crop lands



Conclusions

In context to SDG's, use of residual industrial waste greatly improved in crop phenophases in agriculture, highlighting fly ash improves tillering by 20%, phosphogypsum speeds up panicle initiation by 15%, and biochar increases yield by 12%. These byproducts contribute to a 30% reduction in greenhouse gas emissions, so encouraging sustainable behaviours. Furthermore, biochar application enhanced soil organic carbon by 18%, highlighting the potential of waste-based treatments to improve soil health. Regular monitoring of pollutants is critical for long-term sustainable development.

References

Foo, K.Y. and Hameed, B.H., 2010. Insight into the applications of palm oil mill effluent: a renewable utilization of the industrial agricultural waste. *Renewable and Sustainable Energy Reviews*, *14*(5), pp.1445-1452.

Koul, B., Yakoob, M. and Shah, M.P., 2022. Agricultural waste management strategies for environmental sustainability. *Environmental Research*, *206*, p.112285.

Kumar Sarangi, P., Subudhi, S., Bhatia, L., Saha, K., Mudgil, D., Prasad Shadangi, K., Srivastava, R.K., Pattnaik, B. and Arya, R.K., 2023. Utilization of agricultural waste biomass and recycling toward circular bioeconomy. *Environmental Science and Pollution Research*, *30*(4), pp.8526-8539.

Okey, S.N., 2023. The Use of Agricultural Wastes as Renewable Energy Resources: A Review. *Nigerian Journal of Animal Science and Technology (NJAST)*, *6*(2), pp.23-34.

Peng, X., Jiang, Y., Chen, Z., Osman, A.I., Farghali, M., Rooney, D.W. and Yap, P.S., 2023. Recycling municipal, agricultural and industrial waste into energy, fertilizers, food and construction materials, and economic feasibility: a review. *Environmental Chemistry Letters*, *21*(2), pp.765-801.

Singh, R., Das, R., Sangwan, S., Rohatgi, B., Khanam, R., Peera, S.P.G., Das, S., Lyngdoh, Y.A., Langyan, S., Shukla, A. and Shrivastava, M., 2021. Utilisation of agro-industrial waste for sustainable green production: a review. *Environmental Sustainability*, *4*(4), pp.619-636.

* * * * * * * * *