RESEARCH ARTICLE

SAWAOS: Smart Agri-Waste Analysis and Optimization System

Barnali Gupta Banik[1,*], **Hari Priya Boddula**[1] and **Shreethu Chatiri**[1]

[1] Mahatma Gandhi Institute of Technology, Hyderabad, Telangana 500075, India

Abstract

The growing volume of agricultural residues poses significant environmental and economic challenges, while existing waste management practices remain inefficient and unsustainable. This paper presents SAWAOS (Smart Agri-Waste Analysis and Optimization System), an applied AI-based decision-support framework for intelligent agricultural waste utilization. SAWAOS integrates waste characteristics, location information, and domain knowledge to generate context-aware recommendations for composting, bioenergy conversion, and industrial reuse. The system employs an explainable, rule-enhanced AI decision logic suitable for low-data rural environments and incorporates a digital marketplace that directly connects farmers with industries and consumers, supporting circular economy principles. The framework is validated through a functional prototype and case-study-based evaluation using representative agricultural residues. A comparative analysis with existing waste management approaches highlights the advantages of SAWAOS in terms of decision support, stakeholder integration, and scalability. The SAWAOS demonstrates how applied AI can transform agricultural waste from a disposal challenge into a sustainable economic resource.

Keywords: agricultural waste management, applied AI, decision-support systems, circular economy, sustainable agriculture.

1 Introduction

Agriculture supports global economies by providing food, raw materials, and income for over two billion people. However, it also generates massive agricultural waste, including crop residues, livestock manure, and agro-industrial by-products as shown in Figure 1. Globally, about 5 billion tons of biomass residues are produced annually, with Asia contributing nearly 45–50%. Countries like India, China, the U.S., and Brazil are major producers. Traditional systems recycle some residues, but much remains unused or disposed of unsustainably. Rising food demand and population growth will further increase this waste. The FAO emphasizes that managing agricultural waste is critical yet underexplored for sustainable food systems [1].

India is the second-largest agricultural producer globally and generates massive crop residues each year. The Indian Council of Agricultural Research (ICAR) estimates 500–600 million tons of residues

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***Corresponding author:**
✉ Barnali Gupta Banik
barnaligupta_cse@mgit.ac.in

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Table 1. Types of Agricultural waste produced in different states of India.

Agricultural Waste Type	States
Apple pomace	Himachal Pradesh
Bamboo waste	Mizoram
Banana stems	Kerala
Buckwheat stalks	Sikkim
Cashew nut shells	Goa
Coconut shells	Goa, Karnataka, Kerala
Cotton stalks	Gujarat,Maharashtra, Rajasthan
Groundnut shells	Gujarat
Jute stalks	Assam, West Bengal
Maize husks	Himachal Pradesh,Sikkim
Maize stalks	Arunachal Pradesh, Bihar, Chhattisgarh, Jharkhand, Manipur, Meghalaya, Nagaland, Odisha, Telangana, Uttarakhand
Mustard stalks	Rajasthan
Pineapple leaves	Arunachal Pradesh, Tripura
Rice straw	Andhra Pradesh, Assam, Bihar, Chhattisgarh, Haryana, Jharkhand, Madhya Pradesh, Manipur, Meghalaya, Mizoram, Nagaland, Odisha, Punjab, Tamil Nadu, Telangana, Tripura, Uttar Pradesh, Uttarakhand, West Bengal
Soybean stalks	Madhya Pradesh, Maharashtra
Sugarcane bagasse	Andhra Pradesh, Karnataka, Maharashtra, Tamil Nadu, Uttar Pradesh
Wheat straw	Haryana, Punjab

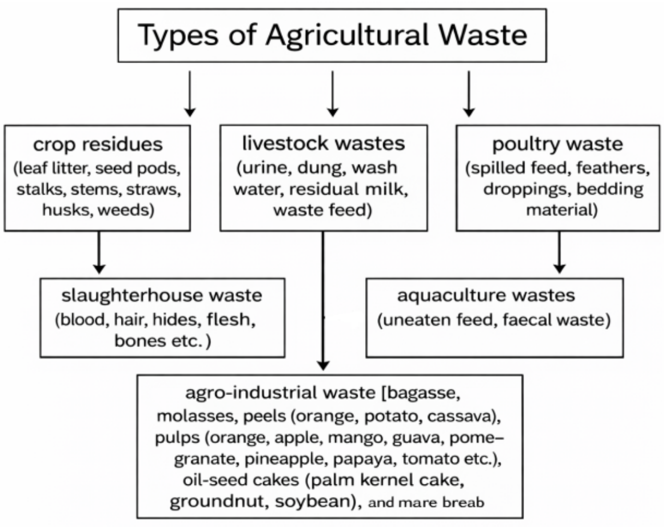

Figure 1. Different types of agricultural waste.

annually, mainly from rice, wheat, maize, sugarcane, cotton, and oilseeds. Paddy alone contributes about 150–160 million tons of straw, much of which remains unused. Table 1 shows the types of agricultural waste generated across different states of India. Agricultural waste is a global challenge, not just India-specific. Open burning of rice straw occurs widely in China, Thailand, Indonesia, and the Philippines. In the U.S. and Europe, large volumes of corn stover and wheat straw remain unused. Brazil faces similar issues with sugarcane bagasse. These trends show agricultural waste management is a worldwide concern with environmental, economic, and health impacts. Besides crop residues, waste includes livestock manure, agro-processing residues, and horticulture waste. India, with over 535 million livestock, generates huge amounts of manure, much of which is wasted, causing soil and water pollution. Agro-industrial units like sugar mills and rice mills add significantly to the waste stream. Open burning remains common in northern India due to its low cost and speed. It emits harmful pollutants and greenhouse gases, worsening air quality and contributing to climate change. Dumping residues in open spaces contaminates soil and water and spreads pathogens. These practices destroy ecosystems and deny farmers the chance to convert waste into compost, bioenergy, or organic manure [2].

Sustainable waste management is essential for environmental protection and economic opportunity. Proper utilization improves soil fertility, reduces chemical fertilizer use, and supports renewable energy and biomass-based industries. It aligns with national missions like Swachh Bharat and Bio-Energy Mission and global SDGs. Transitioning from "waste disposal" to "waste utilization" is key to building a circular economy [3]. SAWAOS was designed as a digital solution to enable this shift. It is an AI-powered platform where farmers can list waste, receive smart usage suggestions, and connect with buyers or processors. Based on waste type, quantity, and location, SAWAOS recommends composting, biofuel production, or raw material supply. With multilingual and voice features, it ensures accessibility for all farmers. By bridging producers and consumers, SAWAOS reduces burning, creates rural jobs, and promotes sustainable agriculture.

2 Review of Agricultural Waste Management Practices

India generates 500–600 million tons of crop residues annually, mainly from rice, wheat, sugarcane, maize, and cotton. Rice and wheat account for nearly 70%, with paddy straw alone contributing about 150 million tons. Some of the agricultural wastes are crop residues such as paddy and wheat straw, sugarcane bagasse, maize stalks, cotton stems, groundnut shells, and husks as shown in Figure 2. Other wastes include animal manure, fruit and vegetable peels, and agro-industrial by-products like rice husk and bagasse. While some residues are reused as compost, fuel, or feed, a large portion is improperly disposed of. The most common disposal methods are open burning, dumping, and limited composting. Burning is prevalent in states like Punjab and Haryana due to its speed and low cost, but it releases toxic gases and particulate matter, worsening air pollution and climate change. Dumping near fields or water bodies leads to methane emissions and soil and water contamination. Composting is sustainable but remains small-scale due to lack of infrastructure and technical know-how [4].

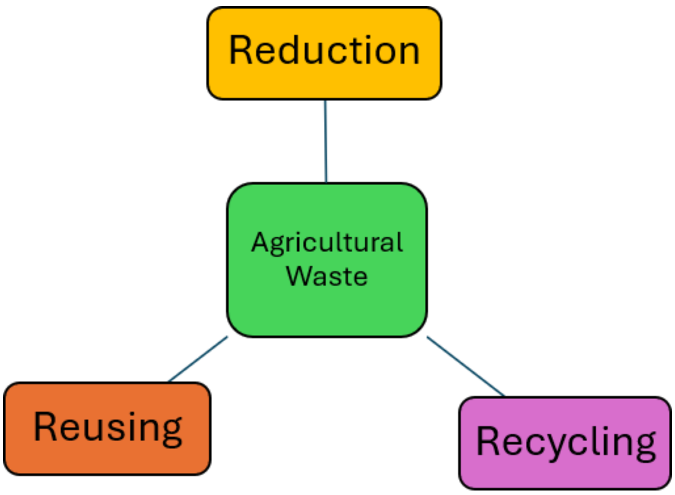

Figure 2. Ways to efficiently manage Agricultural waste.

Environmental impacts are severe: burning emits greenhouse gases, reduces soil fertility, and harms biodiversity. Dumping pollutes groundwater and spreads pests. Economically, farmers lose potential revenue from residues that could be sold to bioenergy or compost industries. Socially, stubble burning causes respiratory and cardiac illnesses, especially among vulnerable groups, increasing healthcare burdens. India's current waste management practices are inefficient and outdated, causing environmental damage, economic loss, and health risks. There is an urgent need for organized, technology-driven solutions like SAWAOS that promote recycling, reuse, and reduction, turning waste into value and supporting sustainable agriculture. India's agricultural waste management remains inefficient, causing environmental harm, financial loss, and health risks. There is an urgent need for organized systems that enable farmers to manage waste profitably and sustainably. SAWAOS addresses this by linking farmers with industries, promoting recycling, reuse, and reduction, as shown in Figure 3, and driving a shift from harmful disposal practices to sustainable solutions [5].

Figure 2 illustrates the strategies for managing agricultural waste, emphasizing three key approaches: reduction, reusing, and recycling. These methods aim to minimize environmental impact while promoting sustainable waste management practices.

3 Existing Government Policies and Initiatives

The Indian government has launched several programs to tackle agricultural waste and promote sustainable management. These initiatives aim to reduce open burning, improve cleanliness, and encourage renewable energy use. Together, they create a strong foundation for platforms like SAWAOS, which connects farmers, industries, and policymakers through technology. Started in 2014, SBM focuses on cleanliness and waste management. Initially aimed at sanitation, it now promotes waste segregation and recycling. Though centered on municipal waste, its principles of community involvement and clean environments align with agricultural waste management [6]. SAWAOS complements SBM by enabling systematic digital monitoring and eco-friendly disposal in rural areas. NBEM promotes converting crop residues into renewable energy like biogas and biomass power. India has huge potential for biomass energy, but collection and coordination remain challenges. SAWAOS supports NBEM by linking farmers with bioenergy plants, ensuring steady raw material supply and extra income for rural communities. To curb stubble burning, the government offers subsidies for machines like Happy

Seeders and Straw Balers. These schemes encourage in-situ residue management and biomass utilization. However, adoption is slow due to high costs and poor market linkages. SAWAOS bridges this gap by providing a virtual marketplace for selling residues, making collection efficient and profitable. Despite policies, rural areas lack infrastructure for waste collection and transport. Farmers often remain unaware of schemes or struggle to access subsidies. Weak market linkages further hinder progress. SAWAOS addresses these gaps by offering information, AI-based suggestions, and direct connections between farmers and buyers, turning policy goals into practical outcomes.

4 SAWAOS: System Overview

SAWAOS (Smart Agricultural Waste Analytics and Optimization System) is an internet-based platform for sustainable agricultural waste management. It addresses issues of residue burning and resource loss by converting waste into economic and environmental opportunities. The system connects farmers, industries, and policymakers through a digital marketplace for listing, trading, and optimizing waste utilization. SAWAOS uses AI and data analytics to recommend profitable and eco-friendly waste applications such as composting, recycling, or sale to biomass plants. Core features include waste listing, marketplace integration, real-time alerts, and dashboards for farmers and buyers. The platform supports multilingual access, voice input, and lightweight mobile and web versions for inclusivity. Geospatial integration optimizes logistics by linking farmers with nearby buyers, reducing transport costs and carbon footprint. Data security is ensured through compliance with India's DPDP Act, end-to-end encryption, role-based access, and anonymized location data. Regular audits and monitoring maintain system integrity. SAWAOS combines sustainability, profitability, and accessibility, creating a data-driven, secure, and farmer-centric solution for agricultural waste management.

4.1 Proposed Methodology

4.1.1 *AI-Based Decision-Support Logic*

The intelligent component of SAWAOS is formulated as an applied decision-support framework rather than a black-box predictive model. This design choice reflects the characteristics of agricultural waste management, where labeled datasets are limited and explainability is essential for user trust and policy alignment [7]. Accordingly, SAWAOS adopts a rule-enhanced, knowledge-driven AI approach that combines domain expertise with contextual data processing. The decision-support logic operates on structured inputs including waste type, quantity estimates, geographic location, seasonal context, and proximity to processing facilities. These inputs are mapped to a predefined recommendation space comprising composting, bioenergy conversion, industrial reuse, and direct marketplace exchange. Domain rules derived from agricultural best practices and policy guidelines are applied to eliminate infeasible options and ensure regulatory compliance. To prioritize feasible alternatives, lightweight data-driven heuristics based on historical demand patterns and contextual constraints are employed. The system outputs a ranked set of utilization recommendations, enabling transparent and informed decision-making. This hybrid, explainable AI design ensures scalability and suitability for deployment in low-resource agricultural environments.

4.1.2 *System Architecture and Data Flow*

SAWAOS follows a modular decision-support architecture that separates data input, inference, and recommendation generation, as shown in Figure 3. Structured inputs related to agricultural waste characteristics, location, and seasonal context are first validated and normalized. The processed data is then evaluated by the AI decision-support module, where domain rules and contextual constraints are applied to identify feasible utilization options. Contextual factors such as proximity to processing facilities and policy-aligned practices are incorporated to prioritize suitable recommendations. The system outputs a ranked set of utilization suggestions, enabling transparent and informed decision-making [8]. This modular design improves scalability and interpretability while ensuring practical applicability in resource-constrained agricultural environments.

4.2 Case Study / Prototype Demonstration (with outcomes)

To demonstrate the feasibility of the proposed framework, a functional prototype of SAWAOS was developed and evaluated using representative agricultural waste scenarios. The case study considers common residue types such as rice straw, maize stalks, and sugarcane bagasse, reflecting typical waste generation patterns in agricultural regions. For each scenario, structured inputs including waste type, estimated quantity, location, and seasonal

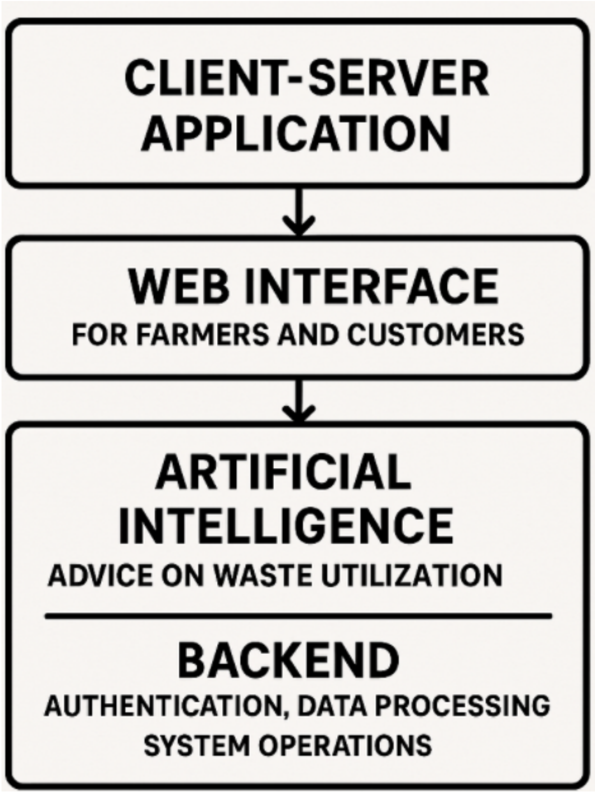

Figure 3. Architecture of SAWAOS platform: Client-Server model with AI integration.

context were provided to the system. The AI-based decision-support module processed these inputs to generate ranked utilization recommendations, including composting, bioenergy conversion, industrial reuse, and marketplace-based exchange [9]. The generated recommendations were assessed against expert-validated best practices and existing policy guidelines to evaluate their practical relevance and consistency. Table 2 summarizes the evaluation results across selected waste categories. The system demonstrated consistent recommendation accuracy and low response latency, indicating suitability for real-time decision support. These results validate the applicability of the proposed framework as an intelligent support tool for agricultural waste management rather than as a purely theoretical model.

Table 2. Prototype evaluation using sample scenarios.

Waste Type	Recommendation Accuracy	Response Time (ms)
Rice Straw	92%	210
Maize Stalks	89%	195
Sugarcane Bagasse	94%	225

The prototype was evaluated using representative sample datasets reflecting common agricultural residues. Recommendation accuracy was measured by comparing system outputs with expert-validated best practices. The results demonstrate consistent decision accuracy across waste categories, validating the feasibility of the proposed intelligent framework.

4.3 Expected Outcomes and Benefits

The proposed SAWAOS framework is expected to support more efficient and sustainable agricultural waste management by enabling informed, context-aware decision-making. By providing ranked utilization recommendations aligned with domain knowledge and policy guidelines, the system helps reduce environmentally harmful practices such as open-field burning while promoting value-oriented waste utilization pathways. From an economic perspective, the framework facilitates improved connectivity between farmers and relevant stakeholders, including processors and industries, thereby enhancing opportunities for income generation from agricultural residues. The decision-support approach also reduces reliance on ad hoc disposal methods by offering structured guidance tailored to local conditions. At a broader level, the adoption of such an applied AI-based system can contribute to improved resource efficiency, reduced environmental impact, and better alignment with circular economy objectives. These outcomes highlight the potential of decision-support technologies to complement existing agricultural practices and policy initiatives in real-world settings.

4.4 Comparative Discussion with Existing Methods

Conventional agricultural waste management relies on burning, dumping, or basic composting. These methods are cheap and quick but cause air pollution, soil degradation, and resource loss. Farmers continue these practices despite bans because alternatives are costly or complex. SAWAOS changes this by making waste management profitable and sustainable. SAWAOS integrates education, buyer connections, and convenience on one platform. It is simpler than fragmented systems and tailored for small farmers, unlike global biomass projects that require large infrastructure. The platform links all stakeholders, creating a closed-loop system for collection, utilization, and reward. Unlike other digital agriculture tools focused on crop growth or weather alerts, SAWAOS targets waste management—a neglected area. It is multilingual, intuitive, and designed for users with low digital literacy. SAWAOS promotes proactive planning, enabling circular value chains

Table 3. Comparison with existing approaches.

Feature	Traditional Methods	Existing Digital Tools	SAWAOS
AI-based decision support	No	Limited	Yes
Waste-specific recommendations	No	Partial	Yes
Marketplace integration	No	No	Yes
Policy alignment	No	Partial	Yes

where residues are reused or sold. This approach combines sustainability with economic benefits, making SAWAOS scalable and durable. Table 3 demonstrates the comparison of SAWAOS with existing approaches. The prototype was evaluated using representative sample datasets reflecting common agricultural residues. Recommendation accuracy was measured by comparing system outputs with expert-validated best practices. The results demonstrate consistent decision accuracy across waste categories, validating the feasibility of the proposed intelligent framework [10].

4.5 Challenges and Limitations

Despite its potential benefits, the proposed SAWAOS framework faces several challenges related to practical deployment and adoption. Data availability and quality remain key limitations, as accurate waste characterization and location-specific information are not always readily accessible in rural agricultural settings. In addition, effective adoption depends on user awareness, digital literacy, and access to basic technological infrastructure, which may vary significantly across regions. These factors can influence the reliability and reach of the decision-support recommendations. Market-related uncertainties also present challenges for large-scale implementation. Fluctuations in demand for agricultural residues, price volatility, and inconsistencies in supply chains can affect the economic viability of recommended utilization pathways. While SAWAOS provides decision support based on available contextual information, external market dynamics remain beyond the system's control. Addressing these limitations will require complementary policy measures, stakeholder engagement, and continuous system refinement.

5 Conclusion and Prospects

This paper presented SAWAOS, an applied AI-based decision-support framework for sustainable agricultural waste management. By integrating domain knowledge, contextual data, and explainable recommendation logic, the system enables informed waste utilization decisions aligned with environmental and economic objectives. Unlike conventional approaches that focus primarily on disposal, SAWAOS emphasizes value recovery through composting, bioenergy conversion, industrial reuse, and marketplace-driven exchange. A functional prototype and case-study-based evaluation demonstrate the feasibility of the proposed framework in real-world agricultural settings. The comparative analysis highlights the advantages of SAWAOS in terms of decision support, stakeholder integration, and scalability, particularly in resource-constrained rural environments. Future work will focus on expanding the recommendation logic using larger datasets, integrating additional waste categories, and evaluating system performance through extended field deployments. SAWAOS illustrates how applied, explainable AI can support practical and scalable solutions for agricultural waste management.

Data Availability Statement

Data will be made available on request.

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Conflicts of Interest

The authors declare no conflicts of interest.

AI Use Statement

The authors declare that no generative AI was used in the preparation of this manuscript.

Ethical Approval and Consent to Participate

Not applicable.

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Barnali Gupta Banik is Senior IEEE member and Associate Professor at Mahatma Gandhi Institute of Technology, Hyderabad. Her research interest includes AI, Expert System and Cyber Security. (Email: barnaligupta_cse@mgit.ac.in)

Boddula Hari Priya is a Data Science student at Mahatma Gandhi Institute of Technology. Interested in Data Analysis, Machine Learning, and app development. (Email: boddulaharipriya@gmail.com)

Chatiri Shreethu is a Data Science student at Mahatma Gandhi Institute of Technology. Interested in Data - driven systems, building practical solutions that address real-world challenges. (Email: shreethuch@gmail.com)