

Agricultural Waste Management: A Review of Sources, Classification, and Sustainable Strategies

Esra Nermin Ertekin^{1*} and Musa Türkmen²

¹Field Crops Department/Institute of Science, Hatay Mustafa Kemal University, Türkiye
²Field Crops Department/Faculty of Agriculture, Hatay Mustafa Kemal University, Türkiye

*(nermin.kucukors@hotmail.com) Email of the corresponding author

(Received: 16 October 2025, Accepted: 21 October 2025)

(5th International Conference on Trends in Advanced Research ICTAR 2025, October 16-17, 2025)

ATIF/REFERENCE: Ertekin, E. N. & Türkmen, M. (2025). Agricultural Waste Management: A Review of Sources, Classification, and Sustainable Strategies, *International Journal of Advanced Natural Sciences and Engineering Researches*, 9(10), 296-301.

Abstract – Agricultural waste (AW) represents one of the largest global waste streams, posing major challenges for environmental sustainability, economic efficiency, and public health. Generated from both crop and livestock production, AW includes diverse organic and inorganic fractions requiring different handling approaches. Improper disposal of AW leads to greenhouse gas (GHG) emissions, nutrient runoff, and resource depletion. However, the transition toward circular economy frameworks has redefined AW as a resource for bioenergy, biofertilizer, and other value-added products. This review comprehensively explores the sources, classification, and composition of agricultural waste, as well as traditional disposal and innovative valorization strategies. Organic wastes from livestock (manure, bedding, feed residues) and crops (straw, husks, leaves) are analyzed with respect to their nutrient potential, biogas generation, and composting efficiency. Inorganic wastes such as plastics, packaging materials, and agrochemical containers are discussed in terms of recycling feasibility and regulatory compliance. Emphasis is placed on advanced technologies such as anaerobic digestion, thermochemical conversion, and biorefinery systems that enable nutrient recovery, renewable energy production, and pollution reduction. The paper further outlines policy recommendations and sustainable management frameworks to promote integrated AW management in line with circular economy principles.

Keywords – Waste, Agriculture, Crop production, Animal production, Sustainable

I. INTRODUCTION

Agricultural waste (AW) represents one of the most voluminous and environmentally significant waste streams worldwide. Its generation is intrinsic to modern agricultural systems, encompassing crop cultivation, livestock husbandry, aquaculture, and post-harvest processing. With global agricultural intensification and the rising demand for food, feed, and bio-based materials, the quantity and complexity of agricultural residues have grown considerably. It is estimated that agricultural activities contribute between 20% and 30% of total global waste generation annually, amounting to billions of tons of biomass residues and inorganic by-products [1], [2].

The mismanagement of AW—through open dumping, uncontrolled burning, or excessive land application—poses major environmental and public health risks. Nutrient leaching, eutrophication of aquatic systems, greenhouse gas (GHG) emissions, and loss of soil fertility are among the most pressing

outcomes [3], [4]. Additionally, waste accumulation near animal farms or food processing sites can harbor pathogens and pests, thereby threatening food safety and ecosystem stability.

The concept of agricultural waste management has evolved beyond mere disposal toward resource recovery, circular economy, and environmental protection. A circular bioeconomy model views agricultural waste not as an end-product but as a renewable feedstock for energy, fertilizers, and bioproducts. Through this lens, waste management becomes a mechanism for closing nutrient loops, reducing fossil fuel dependence, and enhancing farm profitability [5].

This comprehensive review provides an in-depth examination of agricultural waste: its sources, classification, and environmental implications, alongside sustainable strategies for its recycling and valorization. It integrates technical, environmental, and policy dimensions to illustrate how agricultural waste can be effectively transformed from a liability into a resource within a sustainable food system.

II. SOURCES AND CLASSIFICATION OF AGRICULTURAL WASTE

Agricultural waste originates primarily from two production sectors: animal-based (livestock, poultry, aquaculture) and plant-based (crop production, horticulture). Each generates both organic (biodegradable) and inorganic (non-biodegradable) fractions. Understanding the composition and origin of these waste streams is crucial for designing effective management strategies.

A. Wastes from Animal Production

The livestock sector contributes substantial organic waste, including manure, urine, feed residues, and mortalities, as well as inorganic components like plastics and veterinary disposables [4], [6]. The type and volume of waste depend on animal species, production intensity, and management practices.

Organic wastes: Manure is the dominant waste from livestock operations, comprising a mixture of feces, urine, and bedding material. It is rich in nutrients, particularly nitrogen (N), phosphorus (P), and potassium (K), as well as organic matter that can improve soil health. However, direct land application of untreated manure in excessive quantities can lead to nutrient runoff, groundwater contamination, and GHG emissions [7].

Composting and vermicomposting have emerged as effective biological stabilization techniques. Composting involves the aerobic decomposition of organic matter under controlled conditions, reducing moisture, pathogens, and odors while producing a stable humus-like material [8]. Vermicomposting uses earthworms (e.g., *Eisenia fetida*) to accelerate decomposition and enhance nutrient availability. Both products serve as valuable biofertilizers that improve soil structure, microbial activity, and water-holding capacity.

Anaerobic digestion (AD) represents another cornerstone of manure management. In oxygen-free conditions, microorganisms convert organic matter into biogas (a mixture of methane and carbon dioxide) and a nutrient-rich digestate [9]. Biogas can be used for heat, electricity, or upgraded to biomethane for vehicle fuel. Digestate serves as a biofertilizer, completing the nutrient cycle. Large-scale AD systems contribute to renewable energy goals while mitigating methane emissions from open manure storage.

Other organic wastes, such as animal carcasses and unconsumed feed, require strict handling to prevent pathogen proliferation. Rendering, composting, or thermal treatment (e.g., incineration) are the main disposal options, with rendering being the most resource-efficient as it recovers fats and proteins for industrial uses [10].

Inorganic wastes: Inorganic wastes from livestock operations include discarded plastics (silage films, feed sacks, fencing materials), metal tools, and veterinary pharmaceutical containers [11]. These are non-biodegradable and may contain hazardous residues. Proper segregation and cleaning are essential for safe recycling.

Plastics used in animal husbandry, especially polyethylene (PE) and polypropylene (PP), can be reprocessed into secondary products like plastic lumber, fencing, or drainage pipes [12]. Veterinary medicine packaging and sharps (e.g., syringes) must be treated as hazardous waste, collected separately, and disposed of via licensed contractors to avoid environmental contamination [13].

B. Wastes from Crop Production

Crop production generates vast amounts of biomass residues such as straw, husks, stalks, roots, and leaves. These residues represent significant carbon and nutrient stocks that can be harnessed for energy and soil improvement [14].

Organic wastes: Globally, crop residues account for more than 4 billion tons of organic waste per year [2]. Traditionally, many farmers have resorted to open-field burning to clear residues quickly, especially in cereal systems like rice and wheat. This practice emits particulate matter (PM_{2.5} and PM₁₀), carbon dioxide, methane, and nitrous oxide—major contributors to air pollution and climate change [15].

Sustainable alternatives emphasize residue retention and valorization.

- Soil incorporation and mulching increase soil organic matter and enhance microbial biodiversity. Retained residues act as mulch, reducing erosion and improving moisture retention [16].
- Composting transforms crop residues into organic fertilizer, enriching soils with nutrients and beneficial microorganisms.
- Animal feed utilization is another viable pathway, particularly for cereal straws and legume haulms.

Recent advancements in bioenergy and biorefinery technologies have opened new opportunities for residue utilization. Lignocellulosic biomass can be converted through biochemical routes (fermentation to bioethanol, enzymatic hydrolysis) or thermochemical processes (pyrolysis, gasification, torrefaction) into high-value products such as biochar, bio-oil, and syngas [17]. Biochar not only serves as a soil amendment but also sequesters carbon, contributing to climate change mitigation.

Inorganic wastes: Inorganic wastes from crop production primarily include agrochemical containers, fertilizer packaging, and agricultural plastics such as mulch films, irrigation tubes, and greenhouse covers [18]. Improper disposal of pesticide containers can result in the release of toxic residues, contaminating soils and water bodies.

The triple-rinsing or pressure-rinsing method, recommended by the FAO and the European Commission, ensures containers are safely decontaminated before recycling [13]. Agricultural plastics, once cleaned and segregated, can be processed into secondary raw materials. Some countries have implemented take-back programs in collaboration with plastic manufacturers to encourage recycling and prevent illegal burning [19].

III. ENVIRONMENTAL AND SOCIOECONOMIC IMPACTS OF MISMANAGEMENT

Improper management of agricultural waste leads to widespread ecological degradation and economic losses. Key impacts include:

C. Soil Degradation

Excessive manure or sludge application causes soil salinization and nutrient imbalance, impairing plant growth. Conversely, burning residues depletes soil organic carbon and destroys beneficial soil biota [20].

D. Water Pollution

Nutrient leaching (especially nitrate and phosphate) from manure and fertilizers contaminates groundwater, while surface runoff contributes to eutrophication of rivers and lakes, leading to algal blooms and hypoxia [6], [21].

E. Air Pollution and Greenhouse Gas Emissions

Open burning releases CO₂, CH₄, and N₂O—potent greenhouse gases. Manure storage emits ammonia and hydrogen sulfide, contributing to odor nuisance and atmospheric nitrogen deposition [22].

F. Public Health Concerns

Pathogens from animal wastes (e.g., *E. coli*, *Salmonella*, *Cryptosporidium*) can spread through water and food chains. Residues of antibiotics and pesticides further exacerbate antimicrobial resistance and chemical contamination [23].

G. Economic Implications

Farmers lose potential income when valuable nutrients and energy resources contained in waste are not recovered. The economic burden also includes environmental cleanup costs and declining soil productivity [24].

IV. RECYCLING AND VALORIZATION TECHNOLOGIES

H. Composting and Vermicomposting

These are cost-effective biological treatments suitable for mixed organic waste. Optimized conditions (C:N ratio 25–30:1, 50–60% moisture, adequate aeration) yield mature compost within 6–8 weeks [8]. Vermicomposting shortens the process and produces a nutrient-rich product with higher microbial activity.

I. Anaerobic Digestion (AD)

AD systems are widely adopted in Europe and Asia. Feedstocks include manure, crop residues, and food waste. Modern digesters integrate co-digestion, combining wastes of complementary characteristics to enhance biogas yield [25]. Biogas utilization reduces fossil fuel demand, while digestate recycling promotes nutrient circularity.

J. Thermochemical Conversions

Pyrolysis (300–600°C in oxygen-limited conditions) produces biochar, bio-oil, and syngas. Gasification (800–1000°C) generates syngas for power generation, while torrefaction enhances fuel properties of biomass [26].

Biochar, due to its high surface area and stability, improves soil cation exchange capacity and water retention and sequesters carbon for centuries [27].

K. Integrated Biorefineries

Biorefineries transform agricultural residues into multiple products—biofuels, biochemicals, bioplastics, and animal feed. This integrated approach maximizes resource efficiency and economic returns. The use of lignocellulosic feedstocks for producing second-generation bioethanol is gaining momentum [28].

V. INORGANIC WASTE MANAGEMENT AND RECYCLING SYSTEMS

Inorganic agricultural wastes require tailored solutions:

Plastics: PE, PP, and PVC used in mulching and irrigation should be collected and recycled through mechanical or chemical methods [12].

Pesticide Containers: Must be decontaminated and processed through certified hazardous waste facilities [13].

Metals and Glass: From machinery and storage facilities, these can be re-melted and reused with minimal environmental impact.

Advanced recycling systems use AI-based sorting and chemical depolymerization to recover pure polymers from mixed agricultural plastics. Extended Producer Responsibility (EPR) schemes ensure that manufacturers participate in post-consumer waste management [29].

VI. POLICY, LEGISLATION, AND STAKEHOLDER ENGAGEMENT

Effective waste management requires coherent policy frameworks, regulatory enforcement, and stakeholder cooperation.

L. Global and Regional Policies

The European Union's Waste Framework Directive (2008/98/EC) and Circular Economy Action Plan mandate waste prevention, reuse, and recycling hierarchies [13]. Similarly, the FAO promotes the Sustainable Food and Agriculture (SFA) framework to integrate waste valorization into agricultural practices [30].

M. National Implementation

Countries such as Germany, Denmark, and China have adopted incentives for biogas and composting facilities, offering feed-in tariffs for renewable energy and subsidies for organic fertilizer production. Developing countries are encouraged to adapt similar models with context-specific adjustments [31].

N. Role of Farmers and Communities

Awareness and training are essential. Farmers must be educated on waste segregation, composting techniques, and proper handling of hazardous materials. Community-based recycling programs have proven successful in rural areas by combining economic incentives with environmental stewardship [32].

VII. FUTURE DIRECTIONS AND TECHNOLOGICAL INNOVATIONS

The next generation of agricultural waste management will integrate digital technologies, biotechnology, and smart monitoring systems.

O. Smart Waste Tracking

IoT-based systems can monitor waste generation, collection, and recycling efficiency, allowing for data-driven optimization of management strategies [33].

P. Biotechnological Advances

Genetically engineered microbes are being developed for enhanced biodegradation of lignocellulosic residues and conversion of organic wastes into biopolymers or biohydrogen [34].

Q. Policy and Market Integration

Carbon credit markets and green certification schemes will increasingly reward farms adopting low-emission waste management systems. The integration of waste valorization with national climate commitments (NDCs) can further accelerate sustainability goals [35].

VIII. CONCLUSION

Agricultural waste management is a cornerstone of sustainable development, bridging environmental protection, food security, and renewable energy generation. The transition from linear disposal models to circular resource recovery systems represents a paradigm shift in agricultural sustainability.

By adopting technologies such as composting, anaerobic digestion, and biochar production, alongside efficient recycling of plastics and hazardous materials, agricultural systems can significantly reduce pollution while enhancing soil fertility and energy self-sufficiency.

A multi-dimensional approach—combining policy support, technological innovation, and stakeholder participation—is vital for the widespread implementation of sustainable waste management practices. Such integration will not only mitigate environmental impacts but also create new economic opportunities, paving the way for resilient and climate-smart agricultural systems aligned with the United Nations Sustainable Development Goals (SDGs).

REFERENCES

- [1] S. Das, S. H. Lee, P. Kumar, K. H. Kim, S. S. Lee, and S. S. Bhattacharya, "Solid waste management: Scope and the challenge of sustainability," *J. Clean. Prod.*, vol. 228, pp. 658–678, 2019.
- [2] Food and Agriculture Organization (FAO), *Global food loss and waste – Extent, causes and prevention*. Rome: FAO, 2021.
- [3] L. Zhang, C. C. Xu, and P. Champagne, "Overview of recent advances in thermo-chemical conversion of biomass," *Energy Convers. Manag.*, vol. 51, no. 5, pp. 969–982, 2010.
- [4] C. H. Burton and C. Turner, *Manure Management: Treatment Strategies for Sustainable Agriculture*. Paris: Editions Quae, 2003.
- [5] European Commission, *Circular Economy Action Plan*. Brussels, 2020.
- [6] R. W. McDowell and P. M. Haygarth, "Reducing phosphorus losses from agricultural land to surface water," *Curr. Opin. Biotechnol.*, vol. 89, p. 103181, 2024.
- [7] J. R. Bicudo and S. M. Goyal, "Pathogens and manure management systems: A review," *Environ. Technol.*, vol. 24, no. 1, pp. 115–130, 2003.

- [8] D. J. Walker and M. P. Bernal, "The effects of olive mill waste compost and poultry manure on the availability and plant uptake of nutrients in a highly saline soil," *Bioresour. Technol.*, vol. 99, no. 2, pp. 396–403, 2008.
- [9] J. B. Holm-Nielsen, T. Al Seadi, and P. Oleskowicz-Popiel, "The future of anaerobic digestion and biogas utilization," *Bioresour. Technol.*, vol. 100, no. 22, pp. 5478–5484, 2009.
- [10] T. Mekonnen, P. Mussone, and D. Bressler, "Valorization of rendering industry wastes and co-products for industrial chemicals, materials and energy," *Crit. Rev. Biotechnol.*, vol. 36, no. 1, pp. 120–131, 2016.
- [11] S. Kasirajan and M. Ngouajio, "Polyethylene and biodegradable mulches for agricultural applications: A review," *Agron. Sustain. Dev.*, vol. 32, no. 2, pp. 501–529, 2012.
- [12] B. Madrid et al., "End-of-life management options for agricultural mulch films in the United States—a review," *Front. Sustain. Food Syst.*, vol. 6, p. 921496, 2022.
- [13] European Commission, *Waste Framework Directive 2008/98/EC*. Brussels, 2020.
- [14] S. Searle and K. Bitnere, "Review of the impact of crop residue management on soil organic carbon in Europe," *Int. Council on Clean Transp., Working Paper 15*, 2017.
- [15] B. Gadde, S. Bonnet, C. Menke, and S. Garivait, "Air pollutant emissions from rice straw open field burning in India, Thailand and the Philippines," *Environ. Pollut.*, vol. 157, no. 5, pp. 1554–1558, 2009.
- [16] M. L. Jat et al., "Conservation agriculture for sustainable intensification in South Asia," *Nat. Sustain.*, vol. 3, no. 4, pp. 336–343, 2020.
- [17] J. Lehmann and S. Joseph, Eds., *Biochar for Environmental Management: Science and Technology*. London: Routledge, 2012.
- [18] [18] G. Vox, R. V. Loisi, I. Blanco, G. S. Mugnozza, and E. Schettini, "Mapping of agriculture plastic waste," *Agric. Agric. Sci. Procedia*, vol. 8, pp. 583–591, 2016.
- [19] WRAP, *Agricultural Plastics Recycling Scheme*. United Kingdom, 2022.
- [20] N. C. Brady and R. R. Weil, *The Nature and Properties of Soils*. 13th ed. Upper Saddle River, NJ: Prentice Hall, 2008, pp. 662–710.
- [21] D. J. Conley et al., "Controlling eutrophication: Nitrogen and phosphorus," *Science*, vol. 323, no. 5917, pp. 1014–1015, 2009.
- [22] IPCC, *Climate Change 2021: Mitigation of Climate Change*. Cambridge: Cambridge Univ. Press, 2021.
- [23] J. Wu et al., "Antibiotics and antibiotic resistance genes in agricultural soils: A systematic analysis," *Crit. Rev. Environ. Sci. Technol.*, vol. 53, no. 7, pp. 847–864, 2023.
- [24] N. Gaurav, S. Sivasankari, G. S. Kiran, A. Ninawe, and J. Selvin, "Utilization of bioresources for sustainable biofuels: A review," *Renew. Sustain. Energy Rev.*, vol. 73, pp. 205–214, 2017.
- [25] L. André, A. Pauss, and T. Ribeiro, "Solid anaerobic digestion: State-of-art, scientific and technological hurdles," *Bioresour. Technol.*, vol. 247, pp. 1027–1037, 2018.
- [26] A. V. Bridgwater, "Review of fast pyrolysis of biomass and product upgrading," *Biomass Bioenergy*, vol. 38, pp. 68–94, 2012.
- [27] S. Jeffery, F. G. Verheijen, M. van der Velde, and A. C. Bastos, "A quantitative review of the effects of biochar application to soils on crop productivity using meta-analysis," *Agric. Ecosyst. Environ.*, vol. 144, no. 1, pp. 175–187, 2011.
- [28] F. Cherubini, "The biorefinery concept: Using biomass instead of oil for producing energy and chemicals," *Energy Convers. Manag.*, vol. 51, no. 7, pp. 1412–1421, 2010.