

CIRCULAR ECONOMY IN ANIMAL AGRICULTURE: FROM WASTE TO RESOURCES ECONOMIE CIRCULARĂ ÎN AGRICULTURA ZOOTEHNICĂ: TRANSFORMAREA DEȘEURILOR ÎN RESURSE

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ABSTRACT | REZUMAT

This mini-review delves into the transformative potential of circular economy principles within the realm of animal agriculture, emphasizing the sustainable conversion of waste into valuable resources. It explores the multifaceted challenges that impede the adoption of these practices, including technological limitations, regulatory constraints, market acceptance issues, financial barriers, and the need for greater awareness and education among stakeholders. Despite these obstacles, the review underscores the significant benefits that circular economy practices offer to animal agriculture, such as enhanced resource efficiency, waste reduction, and environmental protection. By examining innovative solutions such as the conversion of agricultural waste into bioenergy and biofertilizers, the development of closed-loop systems, and the importance of stakeholder collaboration, this review highlights the critical role of circular economy principles in promoting sustainability within the agricultural sector. It concludes with a call to action for targeted research, policy support, and educational initiatives to overcome existing challenges and fully realize the potential of circular economy practices in transforming animal agriculture into a more sustainable, efficient, and environmentally friendly industry.

Keywords: circular economy, animal agriculture, sustainability, bioenergy, biofertilizers

Această recenzie sintetică se concentrează pe aplicarea principiilor economiei circulare în cadrul agriculturii zootehnice, accentuând conversia deșeurilor în resurse valoroase. Analizează provocările majore care stau în calea adoptării acestor principii, printre care se numără barierele tehnologice, constrângerile legislative, acceptarea pe piață, obstacolele financiare și necesitatea unei conștientizări și educații sporite în rândul părților interesate. Recenzia evidențiază beneficiile considerabile pe care practicile economiei circulare le aduc în agricultura zootehnică, inclusiv eficientizarea utilizării resurselor, minimizarea cantităților de deșeuri și protecția mediului înconjurător. Prin examinarea soluțiilor inovatoare cum ar fi transformarea deșeurilor agricole în bioenergie și biofertilizanți, implementarea sistemelor circulare și importanța colaborării dintre toate părțile interesate, lucrarea subliniază importanța vitală a economiei circulare în promovarea unui sector agricol sustenabil. În încheiere, recenzia propune o serie de acțiuni direcționate către cercetare, adaptări legislative și programe educaționale menite să depășească aceste provocări și să exploateze în totalitate potențialul economiei circulare pentru a transforma agricultura zootehnică într-o industrie mai verde, mai eficientă și mai prietenoasă cu mediul.

Cuvinte cheie: economie circulară, agricultură zootehnică, sustenabilitate, bioenergie, biofertilizanți

The circular economy has emerged as a sustainable model, integrating economic growth with environmental stewardship. This model advocates for a systemic shift towards resource optimization and waste minimization, aiming to replace the traditional linear economy with a more sustainable approach. This transition is crucial for mitigating environmental degrada-

tion and promoting long-term economic sustainability (23, 26). Recognized for its potential to advance sustainability, the circular economy proposes a reduction in material waste, addressing both environmental degradation and climate change impacts (29). It emphasizes the importance of efficient resource use and waste reduction in industrial processes to contribute significantly to environmental conservation (15, 24, 33, 42). Applying these principles to animal agriculture offers a pathway to enhance sector sustainability. Such application can reduce environmental impacts and improve resource use efficiency, demonstrating compatibility with sustainable agriculture goals (8, 49, 45, 46). Specifically, circular economy

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strategies can enrich soil fertility, increase crop production, and facilitate renewable energy production from agricultural by-products, exemplifying the model's emphasis on maximizing resource value and closing nutrient loops (4, 7, 34, 48).

This review article aims to critically examine how circular economy principles can be applied to animal agriculture to promote sustainability and environmental protection. It intends to outline the benefits of integrating circular economy practices, such as waste reduction and resource efficiency, into animal agriculture. Additionally, the review will explore the implications of these practices for enhancing soil health, increasing agricultural productivity, and generating renewable energy. The goal is to offer insights into the potential for circular economy strategies to contribute to more sustainable agricultural practices, providing recommendations for further research and practical implementation.

THE CIRCULAR ECONOMY FRAMEWORK

The circular economy proposes a transformative approach to achieving a regenerative economic system, which endeavours to minimize waste and optimize resource value through the perpetual cycle of usage, reuse, and recycling of materials (9, 44). This sustainable framework is underpinned by several fundamental principles:

- **Resource Efficiency:** This principle underscores the importance of enhancing the efficiency with which resources are utilized, aiming to reduce waste generation and foster the effective use of materials (9, 35).
- **Closed-Loop Systems:** It advocates for the maintenance of material and energy flows within closed loops, extending the lifespan of resources and diminishing the dependence on virgin resource extraction (9).
- **Regeneration:** The circular economy aspires to rejuvenate natural systems by innovating products and processes that yield positive environmental and societal outcomes (25, 27).
- **Sustainability:** At its core, the circular economy embodies the ethos of sustainable development, striving to fulfil contemporary needs without jeopardizing the prospects of future generations (27, 41).
- **Waste Minimization:** This involves the implementation of strategies aimed at eradicating waste and pollution, enhancing the circulation of products and materials, and restoring natural ecosystems (5).
- **Value Creation:** By prioritizing resource optimization and waste reduction, the circular economy seeks to generate economic value concurrently with minimizing environmental impacts (9, 44).
- **Systemic Approach:** A holistic and systemic perspective is requisite for reconfiguring production

and consumption patterns, ensuring the enduring sustainability of economic systems (14).

By adopting circular economy practices, there is a significant opportunity to confront global environmental challenges head-on and enhance resource management strategies. Transitioning from linear to circular economic models enables societies to effectively address environmental concerns while improving resource efficiency (13, 26).

Within the broader context of environmental sustainability, the circular economy introduces a novel paradigm that emphasizes the redesign of processes and the cyclical utilization of materials, fostering sustainable business practices. By closing the loops of economic and ecological resource flows, the circular economy aims to diminish the intake of virgin materials and the generation of wastes, thus contributing to the preservation of resources and environmental conservation (16).

Furthermore, the circular economy is instrumental in promoting sustainable development by mitigating the adverse effects of resource consumption and waste production. Emphasizing resource efficiency, waste reduction, and the closure of material loops, it offers a viable route towards disentangling economic growth from resource utilization and curtailing environmental degradation (10, 50).

Additionally, the circular economy fosters sustainable practices across various sectors, including waste management, construction, and manufacturing. By championing reuse, recycling, and conservation of resources, it aids in alleviating environmental pollution, conserving natural resources, and endorsing sustainable production and consumption patterns (24, 36).

CURRENT PRACTICES IN ANIMAL AGRICULTURE

Historically, animal agriculture has prioritized the utilization of animal waste, primarily as organic fertilizer, to enhance soil fertility and crop productivity. This practice exemplifies the principles of circular sustainability, advocating for the recycling of residues to bolster soil health and agricultural productivity while minimizing waste (28, 21). Despite the benefits, the traditional application of animal manure presents environmental sustainability challenges, including soil nutrient overload, potential water source contamination, and greenhouse gas emissions (22, 47).

Addressing these challenges necessitates the adoption of modern waste management technologies such as composting, vermicomposting, and anaerobic digestion. These methods transform animal waste into valuable soil amendments, reducing environmental impact and promoting sustainable farming (2, 20).

Linear waste management strategies, character-

alized by inefficiencies, lead to excessive waste, inadequate recycling, and significant environmental degradation. Such inefficiencies manifest in municipal solid waste management through poor waste collection and disposal, contributing to environmental and health risks (29). Additionally, the linear approach limits resource recovery, exacerbating resource wastage and environmental challenges (39, 40). Inadequate policies further complicate waste management, resulting in illegal dumping and increased environmental damage (18).

Transitioning towards sustainable and circular waste management strategies is crucial. This shift involves enhancing resource recovery, implementing effective waste management technologies, and establishing robust policies to mitigate environmental impact and support sustainable development.

TRANSFORMING WASTE INTO RESOURCES

The conversion of crop residues and by-products into eco-friendly packaging materials, bio-based plastics, and compostable products offers a sustainable alternative to conventional fossil fuel-derived plastics, embodying the circular economy's ethos of minimizing waste and closing nutrient loops (31, 19).

This approach not only mitigates environmental impacts by reducing waste generation but also fosters the development of circular resource flows within the agricultural sector. The creation of biodegradable materials from agricultural waste exemplifies the potential to enhance sustainability, paving the way for new value chains and business models in the agricultural industry (6, 17).

Through innovative practices such as anaerobic digestion and pyrolysis, agricultural waste is transformed into renewable energy sources, including biogas, biochar, and bio-oil. Anaerobic digestion breaks down organic matter in oxygen-free environments to produce biogas, whereas pyrolysis converts biomass into biochar and bio-oil, useful as energy sources or soil amendments. These processes not only contribute to reducing greenhouse gas emissions but also to generating renewable energy and minimizing waste (11). Further emphasizing sustainability, the conversion of manure and agricultural by-products into bio-fertilizers via composting and vermicomposting showcases another application of circular principles in agriculture. These methods decompose organic materials to produce nutrient-rich soil amendments and high-quality fertilizer, enhancing soil fertility, improving crop yields, and decreasing dependency on synthetic fertilizers, thereby promoting sustainable agricultural practices (11). Additionally, these practices include the generation of biogas through anaerobic digestion of manure and agricultural residues, offering a sustain-

able energy solution. Similarly, the production of bio-char and bio-oil through pyrolysis provides alternative energy sources and soil amendments. Codigestion, hydrothermal carbonization, and bioethanol production from agricultural waste further illustrate the potential for creating renewable energy and enhancing waste management efficiency, thereby demonstrating the broad applicability and benefits of circular economy principles in animal agriculture (1, 3, 30, 37).

Another prominent application of circular economy concepts within animal agriculture is manifested in the transformation of food waste into animal feed. This approach repurposes food waste, which would otherwise contribute to landfill accumulation, as a viable feed source for livestock, thereby enhancing waste management and resource utilization (12, 38).

The recycling of food waste for animal feed simultaneously tackles the critical challenges of waste mitigation and the provision of a sustainable nutrition source for livestock. This innovative practice not only diverts food waste from landfills, enhancing environmental sustainability, but also integrates such waste into the agricultural resource cycle. Countries like Japan and South Korea exemplify the successful implementation of this strategy, where a significant portion of food waste is recycled as animal feed, underscoring its efficacy in improving resource efficiency and minimizing waste (38).

Furthermore, this practice embodies the essence of the circular economy by effectively closing the nutrient loop and generating value from materials that would traditionally be deemed waste. Converting food waste into animal feed allows for a reduction in dependency on conventional feed, fostering more sustainable farming methods, and advancing a more circular, resource-efficient agricultural model (12).

CHALLENGES AND OPPORTUNITIES

Implementing circular economy practices within animal agriculture encounters numerous challenges, including technological barriers, regulatory constraints, and market acceptance, which collectively impede the full integration of these sustainable principles into the sector. The accessibility and implementation of advanced technologies necessary for converting agricultural waste into bioenergy or biofertilizers represent significant hurdles. Such technologies often require considerable investments, specialized equipment, and a high level of technical expertise. Furthermore, the availability of these technologies is limited, posing challenges to the efficient recycling of waste materials and the creation of value-added products.

The regulatory environment also plays a critical role in the adoption of circular economy practices within animal agriculture. Ambiguities or inconsistencies

in regulations related to waste management, bioenergy production, and the use of recycled materials create barriers for stakeholders looking to implement sustainable initiatives. Navigating through environmental standards, waste disposal regulations, and quality control requirements adds layers of complexity for those in the agricultural sector aiming to adhere to circular economy principles.

Market acceptance of products derived from recycled agricultural waste, such as biofertilizers or bio-based materials, is another significant challenge. Consumer perceptions, preferences, and willingness to pay for sustainable products can greatly influence the demand for solutions based on circular economy principles. Building consumer trust, educating the market about the benefits of these products, and ensuring their quality and safety are essential steps towards gaining widespread market acceptance.

Additionally, the initial financial outlay required for transitioning to circular economy practices, including setting up biogas plants or composting facilities, presents a barrier, particularly for small-scale farmers or businesses. The economic feasibility of these initiatives, encompassing the costs of technology adoption, operational expenses, and the potential return on investment, can affect the willingness of stakeholders to adopt sustainable practices. The progression towards embracing circular economy principles in animal agriculture is also slowed by limited awareness and understanding of these concepts.

Educating stakeholders, including farmers, industry participants, policymakers, and consumers, about the benefits of circular economy approaches, along with offering training and capacity-building programmes, is critical for overcoming these obstacles and fostering a culture of sustainability within agriculture.

Future research and development efforts are needed to address these challenges. Innovating cost-efficient and scalable technologies for converting agricultural waste into bioenergy, biofertilizers, and other value-added products is essential. Investigating the regulatory landscape to facilitate the integration of circular economy practices, understanding consumer attitudes towards recycled products, and enhancing supply chain collaboration are crucial areas of focus. Additionally, educational initiatives to increase awareness and knowledge about circular economy practices among agricultural professionals will be key in empowering stakeholders to adopt sustainable practices and advance towards a more circular agricultural ecosystem.

CONCLUSION

In conclusion, the integration of circular economy principles into animal agriculture represents a promising pathway towards achieving sustainability, re-

source efficiency, and environmental protection within the sector. While the transition faces challenges such as technological barriers, regulatory hurdles, market acceptance, cost considerations, and the need for enhanced awareness and education, these obstacles are not insurmountable. Addressing these challenges through targeted research, the development of innovative technologies, the clarification and harmonization of regulatory frameworks, market education, and awareness campaigns can facilitate the widespread adoption of circular economy practices in animal agriculture. By converting agricultural waste into valuable resources like bioenergy and biofertilizers, and by implementing closed-loop systems, the agricultural sector can significantly reduce its environmental footprint, enhance productivity, and contribute to the global sustainability agenda. The journey towards a circular agricultural economy requires concerted efforts from all stakeholders, including farmers, industry professionals, policymakers, and consumers, to realize the full potential of these sustainable practices. With commitment and collaboration, the principles of the circular economy can transform animal agriculture into a more sustainable, efficient, and environmentally friendly sector, ensuring its viability and resilience for future generations.

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