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Editorial

Innovative Approaches in Agricultural Sustainability and Environmental Impact Management: Challenges and Opportunities

Weiwei Chen [1,*], Qiuju Xie [2] and Li Guo [3]

[1] State Key Laboratory of Black Soils Conservation and Utilization, Northeast Institute of Geography and Agroecology, Chinese Academy of Sciences, Changchun 130102, China
[2] College of Electrical and Information, Northeast Agricultural University, Harbin 150030, China; qiujuxie@neau.edu.cn
[3] College of Biological and Agricultural Engineering, Jilin University, Changchun 130022, China; liguo2012@jlu.edu.cn
* Correspondence: chenweiwei@iga.ac.cn; Tel.: +86-137-568-66141

The importance of sustainable agricultural practices has gained global recognition over recent decades. With the world facing significant environmental challenges, such as climate change, biodiversity loss, and water scarcity, agriculture remains both a critical component of food security and a major contributor to environmental impacts. This Special Issue brings together research from diverse fields, highlighting innovative approaches to enhancing agricultural sustainability while minimizing environmental impacts. The collection of papers in this issue underscores the increasing relevance of bioeconomy, carbon footprint reduction, soil health, and the circular economy in reshaping the future of agriculture.

Agricultural sustainability is closely intertwined with the concept of a bioeconomy—a model promoting resource efficiency and the closed-loop use of biological resources. As global populations rise, so does the demand for food, fiber, and fuel, placing further strain on natural ecosystems. However, the bioeconomy offers solutions through alternative, renewable sources for bio-based products, reducing reliance on fossil fuels. In the agricultural sector, this approach has gained traction as researchers work to integrate biomass production, waste management, and energy conversion technologies into sustainable practices [1,2]. This issue includes papers that investigate how circular economy practices can help create more sustainable agricultural systems. For example, one study provides an overview of the bioeconomy's role in agricultural sector waste recycling, circular material flows, and biomass production. This study illustrates the growing need to understand and adopt bio-based systems that enhance resource efficiency while ensuring economic viability [2]. In another article, researchers examine soil management techniques, focusing on the transformation of residue chemistry and the critical role of microbial interactions in nutrient cycling [1]. Table 1 summarizes the key findings from studies on the role of the bioeconomy in waste recycling and circular material flows, offering practical pathways for farmers and policymakers. This study emphasizes the importance of understanding the complex soil microbiome and its influence on the degradation of plant residues, which can enhance soil fertility and carbon sequestration. As research delves into bioeconomy practices, the issue of carbon emissions stands out as another critical area where agricultural systems are exploring sustainable strategies.

Agriculture is responsible for a considerable portion of greenhouse gas (GHG) emissions, primarily from livestock, soil management, and fertilizer use. Developing methods to reduce agriculture's carbon footprint is essential for reaching global climate targets. The research in this Special Issue presents novel approaches to addressing these challenges, such as implementing carbon assessment models and integrating precision agriculture technologies. One featured paper examines the carbon footprint of a typical crop–livestock

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dairy farm in Northeast China, providing insights into GHG emissions from various farming activities, including enteric fermentation, manure management, and feed production [3]. This study also explores several emission reduction scenarios, highlighting the potential for seeding-integrated dairy farming systems to reduce emissions. Through a scenario analysis, the authors identify key areas where carbon emissions can be mitigated, such as improved manure management and optimized crop rotations. This research adds to a growing body of literature that aims to guide policymakers and agricultural practitioners toward practical, science-based strategies for emission reduction in the livestock sector. Just as reducing emissions is critical, so too is managing the soil in which agriculture is rooted. Biochar, in this context, offers potential solutions for soil health and pollution control, representing another promising field in sustainable agriculture.

Table 1. Bioeconomy practices in agriculture.

Practice	Description	Benefits
Biomass Production	Cultivation of renewable bio-based crops	Reduces reliance on fossil fuels
Waste Management	Recycling agricultural residues	Enhances resource efficiency, reduces waste
Energy Conversion Technologies	Bioenergy production from residues	Supports renewable energy initiatives

Biochar has emerged as a promising tool for enhancing soil properties, sequestering carbon, and immobilizing pollutants. Produced via the pyrolysis of organic material, biochar is increasingly recognized for its ability to improve soil fertility, reduce nutrient leaching, and retain water. However, as noted in one article in this issue, the effectiveness of biochar can be influenced by environmental factors over time—a process known as biochar ageing [4]. This study examines how ageing affects biochar's surface properties, including its pH, specific surface area, and nutrient retention capability. The authors also investigate how biochar ageing can alter the bioavailability of heavy metals, raising questions about the long-term stability and effectiveness of biochar as a soil amendment. In another study, the authors explore the potential of biochar to mitigate pollution in agricultural soils, focusing on the bioavailability of heavy metals like copper, cadmium, and lead. By identifying optimal biochar properties and application methods, this research provides valuable guidance for using biochar to enhance soil health and prevent the accumulation of toxic substances in agricultural lands. Together, these findings underscore the importance of ongoing research to understand biochar's long-term interactions with soil and its role in promoting sustainable agriculture. To achieve comprehensive environmental monitoring, research efforts have also turned to the precision assessment of emissions from agricultural activities. The next group of studies examines these advancements in real-time emission tracking and monitoring.

The role of volatile organic compounds (VOCs) in agricultural emissions has drawn increased attention, particularly in regions with high pesticide usage. VOCs are precursors to atmospheric ozone and particulate matter, both of which contribute to poor air quality and public health risks. This issue includes research focused on VOC emissions from pesticide spraying, using real-time monitoring to quantify emissions and assess environmental impacts [5]. This study provides valuable insights into emission factors for different pesticides, highlighting seasonal variations in emission rates that can inform targeted air quality interventions. An additional study evaluates CO_2 concentrations within greenhouse environments, proposing predictive models to optimize environmental control for enhanced crop yield and resource efficiency [6]. By using time-series analysis and predictive modeling techniques, the authors offer a framework for monitoring greenhouse gases, which can be adapted to various agricultural applications. The implications of this research extend beyond greenhouses, as effective emission monitoring is increasingly critical to reduce the environmental impact of agriculture and to support the transition to low-carbon systems. While each of these studies provides critical insights, there remains a need to build on these findings through interdisciplinary efforts. The final section of this issue explores future research directions in sustainable agriculture.

The research presented in this Special Issue provides a snapshot of current efforts to build a more sustainable agricultural sector. However, there is a continued need for interdisciplinary approaches that bring together insights from agronomy, ecology, chemistry, and data science. Table 2 highlights future research priorities, bridging knowledge gaps across agronomy, ecology, and data science. Future research should focus on optimizing resource use, minimizing waste, and enhancing the resilience of agricultural systems in the face of climate change. For instance, as digital and precision agriculture technologies evolve, there is tremendous potential to enhance the efficiency of resource use and reduce waste. Additionally, the development of climate-resilient crop varieties and soil management practices can help mitigate the impacts of extreme weather events, ensuring food security in an uncertain climate [7]. Furthermore, sustainable agriculture must be supported by effective policies that incentivize environmentally friendly practices. This includes subsidies for organic and regenerative farming, stricter regulations on agrochemical use, and support for the development of bio-based products. Researchers, practitioners, and policymakers alike must work together to address the multifaceted challenges facing agriculture and to unlock new opportunities for sustainable development.

Table 2. Future research priorities in sustainable agriculture.

Research Area	Key Objectives	Potential Impact
Climate-Resilient Crops	Develop varieties tolerant to stress	Enhanced food security
Precision Agriculture	Improve resource use efficiency	Reduced environmental footprint
Policy Incentives	Promote sustainable practices	Widespread adoption of innovations

In conclusion, the articles featured in this Special Issue reflect the dynamic and evolving nature of agricultural research. From biochar application and bioeconomy integration to emission monitoring and soil health, these studies underscore the need for innovative, evidence-based approaches to make agriculture more sustainable. By fostering collaboration and encouraging the adoption of sustainable practices, the research in this issue provides valuable contributions toward addressing the environmental challenges associated with agricultural production. Looking forward, it is our hope that these insights will inspire further research and guide practical actions that support a resilient, low-impact agricultural system for future generations.

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References

1. Zhang, Q.; Li, X.; Chen, G.; Luo, N.; Sun, J.; Ngozi, E.A.; Lu, X. The Residue Chemistry Transformation Linked to the Fungi Keystone Taxa during Different Residue Tissues Incorporation into Mollisols in Northeast China. *Agriculture* **2024**, *14*, 792. [CrossRef]
2. Toplicean, I.-M.; Datcu, A.-D. An Overview on Bioeconomy in Agricultural Sector, Biomass Production, Recycling Methods, and Circular Economy Considerations. *Agriculture* **2024**, *14*, 1143. [CrossRef]

3. Wang, Y.; Liu, S.; Xie, Q.; Ma, Z. Carbon Footprint of a Typical Crop–Livestock Dairy Farm in Northeast China. *Agriculture* **2024**, *14*, 1696. [CrossRef]
4. Cui, Z.; Wang, Y.; Wang, N.; Ma, F.; Yuan, Y. Effects of Ageing on Surface Properties of Biochar and Bioavailability of Heavy Metals in Soil. *Agriculture* **2024**, *14*, 1631. [CrossRef]
5. Li, R.; Xia, Z.; You, B.; Shi, B.; Fu, J. Volatile Organic Compound Emission Inventory for Pesticide Spraying in an Agricultural City of Northeast China: Real-Time Monitoring and Method Optimization. *Agriculture* **2024**, *14*, 1223. [CrossRef]
6. Shin, S.H.; Deb, N.C.; Arulmozhi, E.; Tamrakar, N.; Ogundele, O.M.; Kook, J.; Kim, D.H.; Kim, H.T. Prediction of Carbon Dioxide Concentrations in Strawberry Greenhouse by Using Time Series Models. *Agriculture* **2024**, *14*, 1895. [CrossRef]
7. Jiang, L.; Han, J.; Cui, H.; Chu, Z.; Li, S.; Zhang, Y.; Ji, Y.; Wang, Q.; Li, X.; Wang, P. Effect of Climate Change on Identification of Delayed Chilling Damage of Rice in China's Cold Region. *Agriculture* **2024**, *14*, 1456. [CrossRef]