

Transitions Toward a Circular Economy in Protected Agriculture Across the Americas: A Bibliometric Analysis of Trends, Approaches, and Research Gaps.

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INTRODUCTION & AIM

Protected agriculture is a strategic component for ensuring food security, improving production efficiency, and reducing vulnerability to climate change. These systems enable higher yields, better quality, and greater control over environmental conditions compared to open-field production. However, they also rely heavily on external inputs such as water, energy, fertilizers, and plastic materials, which generate significant environmental impacts and increase the ecological footprint of intensive food production. This situation highlights the urgent need to transition toward more sustainable and resource-efficient production models [1].

In this context, the circular economy has emerged as an innovative framework aimed at closing material and energy cycles, promoting resource reuse, waste valorization, nutrient recovery, and emission reduction within protected cropping systems [2]. Circular strategies such as water recirculation, substrate recycling, organic waste conversion, and renewable energy integration offer promising pathways to enhance sustainability and resilience in greenhouse and nursery production. Despite its growing importance, the scientific development and regional adoption of circular economy principles in protected agriculture across the Americas remain fragmented and insufficiently characterized.

The objective of this study was to analyze the evolution, trends, and research gaps related to the application of circular economy principles in protected agriculture across the Americas through a bibliometric analysis of scientific production indexed in the Scopus database, providing insights to support the transition toward more sustainable, low-carbon, and climate-resilient agricultural systems.

METHOD

A bibliometric analysis was conducted using the Scopus database, covering the period from 1994 to 2025. A total of 34 scientific documents related to circular economy and protected agriculture in the Americas were identified and analyzed. Bibliometric indicators such as annual scientific production, country contribution, and keyword co-occurrence were evaluated using Bibliometrix (R) and VOSviewer to identify research trends and conceptual structure.

RESULTS & DISCUSSION

Bibliometric Overview of Circular Economy Research in Protected Agriculture

The bibliometric indicators reveal that circular economy research in protected agriculture across the Americas remains an emerging but increasingly relevant field. Although the total number of publications is relatively limited, the high average number of citations per document indicates that existing studies have generated significant scientific impact and serve as key references for subsequent research. The steady annual growth rate reflects a gradual consolidation of this topic, particularly in response to global challenges related to resource efficiency, climate change mitigation, and sustainable food production. The high number of authors and co-authors per document, along with the substantial proportion of international collaboration, highlights the multidisciplinary and cooperative nature of this research area. This pattern suggests that addressing circularity in greenhouse systems requires the integration of expertise in agronomy, environmental engineering, energy systems, and sustainability assessment. Furthermore, the diversity of keywords confirms that circular economy approaches in protected agriculture are primarily associated with waste management, nutrient recycling, bioenergy, and sustainable production strategies.

Bibliometric Summary

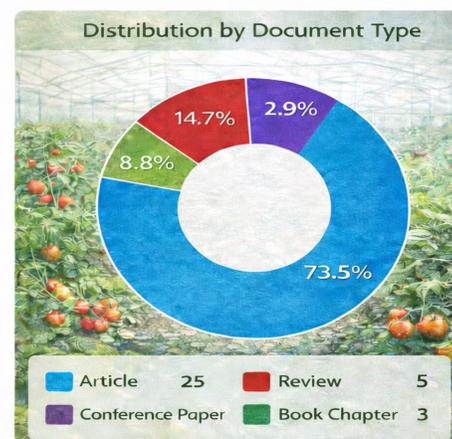
Circular Economy in Greenhouse and Protected Agriculture



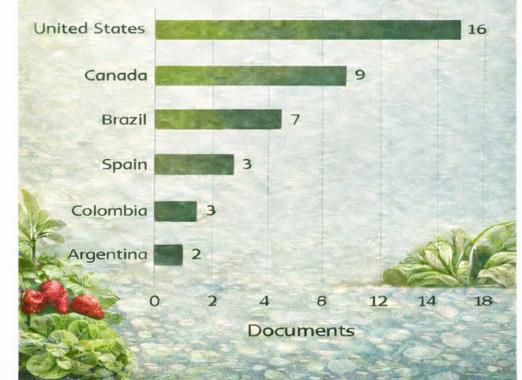
Document Types, Country Contribution, and Temporal Evolution of Circular Economy Research in Protected Agriculture (1994–2025)

Scientific production is dominated by research articles, which represent 73.5% of the total documents, while reviews and conference papers account for a smaller proportion. The United States leads scientific output with 16 publications, followed by Canada (9) and Brazil (7), with emerging contributions from Colombia and Argentina. Additionally, the annual production remained very low until 2015, followed by a clear increase, reaching its highest values between 2021 and 2023 with up to five publications per year, reflecting the recent growth and consolidation of circular economy research in protected

Distribution by Document Type



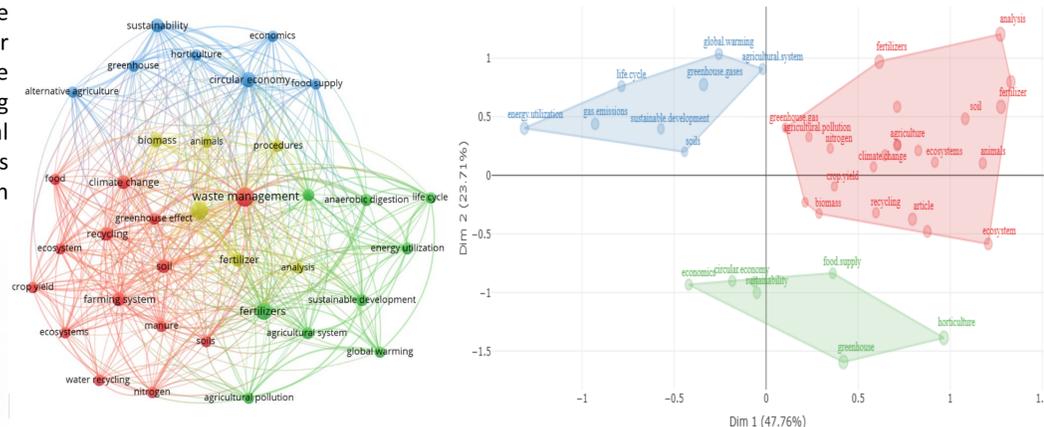
Scientific Production by Country



Keyword Co-Occurrence Network in Circular Economy Research in Protected Agriculture

The keyword co-occurrence network reveals that circular economy research in protected agriculture across the Americas is structured around three main thematic clusters. The first cluster is associated with waste management, recycling, soil, and fertilizers, highlighting the importance of nutrient recovery and organic residue valorization as core circular strategies. The second cluster is linked to bioenergy and resource efficiency, including terms such as anaerobic digestion, energy utilization, and life cycle, reflecting the growing interest in transforming agricultural waste into energy and reducing environmental impacts. The third cluster connects circular economy with greenhouse production, sustainability, and food systems, confirming the integration of circular principles into intensive horticultural systems. Overall, this structure demonstrates that circular protected agriculture in the Americas is evolving toward integrated approaches that combine waste valorization, energy recovery, and sustainable greenhouse production.

The thematic map confirms the consolidation of circular economy as a central research axis, closely linked to sustainability, greenhouse production, and resource efficiency. Motor themes such as bioenergy and waste valorization show high relevance and development, while emerging themes related to circular agriculture and resource management reflect a transition toward more integrated and sustainable greenhouse production systems. These results reinforce the shift toward circular models focused on optimizing resource use and reducing environmental impact in protected agriculture.



CONCLUSION

Circular economy research in protected agriculture across the Americas remains limited but shows clear growth and consolidation in recent years. Scientific production is dominated by the United States and Canada, with emerging contributions from Latin America. The main research focus is on waste valorization, nutrient recycling, and bioenergy integration, confirming the transition toward more sustainable and resource-efficient greenhouse systems. Strengthening regional research and implementing circular strategies will be essential to improve sustainability and resilience in protected agriculture.

FUTURE WORK / REFERENCES

Future research should prioritize life cycle assessment, redesign of greenhouse resource flows, and digitalization of circular systems. Strengthening inter-American research networks will be essential to consolidate resource-efficient, low-carbon, and climate-resilient protected agriculture in the region.

1. Salinas-Velanda, D.A.; Romero-Perdomo, F.; Numa-Vergel, S.; Villagrán, E.; Donado-Godoy, P.; Galindo-Pacheco, J.R. Insights into Circular Horticulture: Knowledge Diffusion, Resource Circulation, One Health Approach, and Greenhouse Technologies. *Int. J. Environ. Res. Public Health* 2022, 19, 2. Martínez-Moreno, M.M.; Buitrago, E.M.; Yñiguez, R.; Puig-Cabrera, M. Circular Economy and Agriculture: Mapping Circular Practices, Drivers, and Barriers for Traditional Table-Olive Groves. *Sustain. Prod. Consum.* 2024, 46, 430–441.