Chapter 2
Prospects, Challenges and Policies for Carbon-Negative Circular Agriculture

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Abstract Global conventional agricultural, livestock production and related land uses contribute a large proportion to the total global greenhouse gas (GHG) emissions. On the other hand, circular agriculture reduces carbon emissions and has the potential to be a carbon sink within the agricultural systems. However, the successful adoption of circular agricultural practices requires a national-level policy framework. The key challenges for adopting circular agriculture practices are: financial obstacles to acquiring technology, limited access to affordable credits and subsidies, technical incompetence of farmers and lack of institutional support, agribusiness objectives and environmental attitudes. This chapter identifies key prospects of circular agriculture, including climate change mitigation through carbon capture, utilisation and storage (CCUS) technologies, reducing atmospheric carbon dioxide (CO_2) levels by recycling carbon into valuable products, and enhancing carbon sequestration in forest soils and oceans. The integration of circular economy principles fosters economic opportunities, supports energy security and accelerates decarbonisation, ecosystem restoration and nature-based solutions. Policy challenges include fragmented governance, weak policy enforcement and limited institutional coordination. The policies to adopt circular agriculture by farmers need to focus on investment in circular agricultural research and development, institutional support, rewarding with carbon credits, incorporating circular agriculture models in regional development plans, development of technical standards and monitoring and evaluation capacity for the circular agriculture model, reforming agricultural subsidies and introducing innovative policy support, development of circular agricultural value chains, enhancement of private sector investment in circular agriculture, the establishment of more intersectoral circular bioeconomy models for sustainable and low-carbon rural development, and enhancement of international cooperation. The

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circular agriculture contributes to achieving maximum benefits from natural processes within the ecosystems through the application of environmentally friendly technologies with minimum input dependency, and efficient recycling of nutrients, energy and water. These processes transform waste into valuable food products with minimum costs and food losses by using the principles of reduce, reuse and recycle in the agri-food production and supply chain while contributing to tackling climate change.

Keywords GHG emissions · Reuse · Recycle · Ecosystems · Carbon sink · Circular economy

2.1 Introduction

The climate crisis is one of the most pressing issues of our time. Implementing long-term carbon sink measures is necessary to confront climate change and achieve the 1.5 °C target of the Conference of the Parties (COP 28) (Singh et al. 2024; Meena et al. 2025). As the Earth's system undergoes rapid transformation, fundamental life-supporting processes are undermined, which can lead to very serious consequences for society to tipping points that can irreversibly destabilise the Earth (Rockström et al. 2023). Global agricultural and related land use emissions in 2018 were 9.3 billion gigatonnes (Gt) of carbon dioxide (CO_2) equivalent (Gt CO_2eq.) (FAO 2020). About half (5.3 Gt CO_2eq.) of this total came from crop and livestock activities within the farm gate, whereas the land use and land use change activities are responsible for nearly 4 Gt CO_2eq. (Tubiello et al. 2014; Meena et al. 2024c).

Conventional agricultural practices, comprising crop cultivation, livestock management, fertiliser usage, waste disposal and energy consumption, significantly contribute to direct and indirect carbon emissions and impact climate change (Singh et al. 2024). Soil tillage and rice cultivation release CO_2 and methane (CH_4) (Fernández-Ortega et al. 2024), whereas livestock farming (ruminants) release CH_4 by ruminating and manure (Faizan 2024; Sikiru et al. 2024). Excessive usage of synthetic fertiliser and inappropriate application procedures increase emissions of ammonia (NH_3) and nitrous oxide (N_2O) (Sarkar et al. 2024; Thirunagari et al. 2024). Open burning of crop leftovers and organic waste, like poor waste management practices, increases CO_2 and CH_4 emissions (Khan et al. 2024; Kumar et al. 2024; Meena et al. 2024a), as well as carbon footprint from the use of fossil fuel in agricultural machinery and transportation (Qin et al. 2024; Wang et al. 2024). All these activities further deteriorate soil health (El-Ramady et al. 2024; Meena et al. 2024b), biodiversity (Selvakumar 2024) and ecosystem resilience while worsening climate change. In light of these emissions, an urgently needed sustainable and climate-resilient agricultural system is required. Circular agriculture is considered a sustainable solution to minimise carbon emissions.

Circular agriculture reduces carbon emissions and enhances the circulation of carbon while emphasising the reuse and recycling of resources in the agricultural ecosystem (Yang et al. 2022). It not only reduces carbon emissions but also supports carbon sequestration and retention within agricultural systems, functioning as a potential carbon sink (Singh et al. 2024). Though various circular agricultural practices exist and are implemented in different parts of the world, governmental policies are lacking in those countries to make circular agriculture a national need. The key prospects of circular agriculture include climate change mitigation through carbon capture, utilisation and storage (CCUS) technologies (Roy et al. 2023; Tebbiche et al. 2021; Meena et al. 2023), the restoration of degraded ecosystems (Priyadarshini and Abhilash 2020) and the integration of circular economy principles for economic gain and improved energy and food security (Selvan et al. 2023; Sharma et al. 2021; Kumar et al. 2025). These systems maximise resource efficiency and minimise environmental foodprints.

However, significant challenges remain in circular agriculture, such as high initial investment costs for technology adoption, lack of technical skills among farmers, limited access to credit and subsidies, inadequate policy support and fragmented institutional frameworks (Jaroenkietkajorn et al. 2024; Sharma et al. 2021; Meena and Pradhan 2023). To overcome these barriers, effective policy interventions are crucial. This chapter attempts to identify key aspects, such as challenges associated with traditional agriculture regarding carbon emissions, the prospects of various circular agricultural practices and their contribution to minimising carbon emissions, and policies to establish and regulate circular agricultural practices to make agricultural food production a sustainable and low-carbon emission system.

2.2 Global Carbon Emissions from Agriculture

The global distribution of agricultural emissions is not consistent and is influenced by resource availability, climate and farming practices in different regions of the world (Lakhouit et al. 2025; Li et al. 2025). In Asia, CH_4 emissions originating from rice paddies are predominant. Many countries like India, China and Indonesia mainly depend on the flooded rice culture, which accounts for roughly 20% of atmospheric CH_4 emissions (Darikandeh et al. 2025; Li et al. 2021; Pradhan and Meena 2023b). However, livestock farming is the most significant source of emissions in Europe and North America, with large amounts produced through dairy and beef farming (O'Mara 2011). These regions also depend on synthetic fertilisers, which produce N_2O. The manufacturing of synthetic nitrogen fertilisers constitutes around 2% of global energy consumption (Walling and Vaneeckhaute 2020). Africa contributes a relatively small proportion (2–3%) of global agriculture emissions (IPCC 2018). Predictions indicate that Africa's lowest anticipated proportion of world emissions will approach 10% by 2050 (Mostefaoui et al. 2024).

Because of continuous human-induced releases of CO_2 and other greenhouse gases (GHGs) into the atmosphere, the Earth's climate is changing quickly (IPCC 2018). Among various GHGs (e.g. N_2O and CH_4), CO_2 stands out as the primary driver of global climate change due to its substantial increase from pre-industrial times to the present (Table 2.1). Specifically, atmospheric CO_2 concentrations have

Table 2.1 Global warming potential of greenhouse gases

Greenhouse gas	Main source	Average lifetime in the atmosphere	100-year GWP
CO_2	Fossil fuels; land use change	Carbon lifetime cannot be represented with a single value	1
CH_4	Fossil fuels, rice and livestock	12	28
N_2O	Fertilisers	121	265
CHF_3	Refrigerants	222	12,400

Source: Alsarhan et al. (2021), GWP - Global Warming Potential

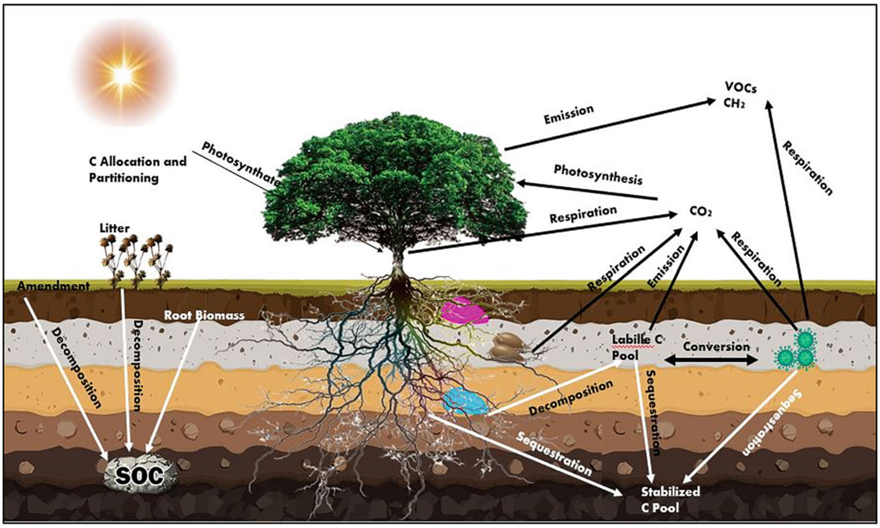

Fig. 2.1 Carbon circulation in the environment

surged from approximately 300 ppm before 1850 to 420 ppm in 2023 (NOAA 2022; Richardson et al. 2023; WMO 2021). Predictions estimate that if existing trends continue, CO_2 levels may attain 550 ppm by 2050 and 731 ppm by 2130 (Pacheco-Torgal 2024). Most of this overall rise in atmospheric CO_2 is attributed to the burning of fossil fuels, accounting for about two-thirds of the increase (IPCC 2018). The remaining portion of the increase is linked to the loss of soil organic carbon (SOC) due to changes in land use (Singh et al. 2024), such as deforestation (Amoakwah et al. 2022) and crop cultivation (Fig. 2.1) (Nazir et al. 2024). Soil contains a significant portion of the Earth's terrestrial carbon, with a total carbon content of approximately 3170 Gt (Jansson et al. 2021). Precisely, 2500 Gt of carbon are in the top 3 m of soil. Of this, 1550 Gt are SOC and 950 Gt are soil-inorganic carbon (Singh et al. 2024; Friedlingstein et al. 2023). This soil carbon reservoir is 3.3 times greater than the air carbon reservoir, which holds 760 Gt (Lal 2004). The conversion of natural ecosystems into farmland has resulted in a decline in SOC levels. This alteration has led to the emission of 50–100 Gt of carbon from the soil into the atmosphere since the onset of the Industrial Revolution in 1950 (IPCC 2018).

2.3 Carbon Emissions by Various Traditional Agriculture

2.3.1 Crop Farming

Traditional crop farming systems, which rely heavily on monocultures and synthetic fertilisers, play a major role in GHG emissions (Basheer et al. 2024; Xing and Wang 2024; Pradhan and Meena 2023a). Fertilisation with nitrogen-based fertilisers also releases N_2O, a very potent GHG with a global warming potential of 300 times that of CO_2 (Caillol 2011; Punia et al. 2020). Inefficient irrigation practices aggravate this problem, as wet fields produce anaerobic conditions that allow CH_4 emissions, mainly from rice cultivation (Darikandeh et al. 2025; Li et al. 2021; Jangir et al. 2024). Burning crop residues, particularly in countries like India and China, also emits millions of tonnes of CO_2 each year, helping to cause air pollution and harming public health (Li et al. 2021). Most crop farming systems using linear production tend to maximise productivity in the short term at the cost of soil health and biodiversity (Kumar et al. 2022; Chung et al. 2024), where the comparisons between linear and circular agriculture are listed in Table 2.2. Intensive tillage methods change soil structure and promote microbial degradation of soil organic matter,

Table 2.2 The comparisons between linear and circular agriculture

Criteria	Linear agriculture	Circular agriculture
Development history	Widely practised by industrial societies	Widely practised in pre-industrial society
Business model	Large-scale, specialised agricultural firms	Small-scale, integrated agriculture smallholders
Farming practices	Modern farming, large-scale, monoculture and inorganic practices	Indigenous, small-scale, polyculture, bio-organic practices
Input use	More capital-intensive with off-farm inputs	More labour-intensive with on-farm inputs
Focus	Maximising profit over the protection of the environment	Balancing economic, environmental and social aspects
Reuse	Downcycling; low-grade recycling	Upcycling, cascading and high-grade recycling
Products that have reached the end of their life	Invaluable and waste	Valuable next-use resources
Impacts	Increased resource requirements and waste; less sustainable	Reduced resource requirements and waste; more sustainable

Source: Chung at al. (2024)

resulting in soil CO_2 release (Nunes et al. 2020). In turn, they deplete the soil's organic carbon and reduce its ability to sequester carbon, aggravating climate change. Monocultures reduce ecosystem richness, destabilise these systems' resilience and increase their vulnerability to pests, diseases and climatic variability (Khatri et al. 2024; Huss et al. 2022).

Transitioning to circular farming systems is a way to reduce emissions and promote sustainability. The approach is recycling the nutrients within the agricultural ecosystem (Valve et al. 2020). Moreover, organic substitutes for synthetic inputs (compost and animal manure) promote soil health, mitigate N_2O emissions (Lazcano et al. 2021; Adegbeye et al. 2020) and decrease energy consumption in synthetic fertiliser production (Vaneeckhaute et al. 2013; Tuomisto et al. 2012; Pradhan et al. 2023). Rotational practices and intercropping practices also help to diversify root systems, maintain continual ground cover, and help soil fertility for carbon sequestration (Eddy and Yang 2022). Global Positioning System (GPS) guided equipment and soil sensors are used to optimise the usage of water, fertiliser and pesticides to reduce waste and emissions (Vellingiri et al. 2025; Gautam et al. 2023). Such tactics can help balance production and environmental responsibility on farms.

2.3.2 Livestock Farming

In ruminants (cattle, sheep and goats), enteric fermentation produces 90 million tonnes of CH_4 per year, approximately 40% of all agricultural GHG emissions (FAO 2013). This makes livestock responsible for about 14.5% of total global GHG emissions, with CH_4 being accountable for the majority of these (FAO 2013). CH_4 is a GHG that has the potential to cause 25–30 times more global warming than CO_2 over 100 years (Arif 2024; Jackson et al. 2024; Sobanaa et al. 2024). Beef and milk production from cattle make about 3.8 Gt of CO_2 equivalent every year, which is 62% of all the emissions from animals. Fourteen percent of the emissions come from pigs, 9% from chickens, 8% from buffaloes, and 7% from small ruminants (Džermeikaitė et al. 2024). Manure management techniques also impact climate change, especially in large-scale operations that emit CH_4 and N_2O (Ouatahar et al. 2024; Yan et al. 2024). Traditional livestock systems rarely operate efficiently enough to minimise emissions. Poor-quality feed causes animals to need more feed to meet energy needs, increasing the amount of CH_4 emitted per unit of meat or milk produced (Nedelkov et al. 2024; Waghorn and Hegarty 2011). Using a balanced ration feeding routine, Garg et al. (2013) observed a significant increase in animal productivity in lactating cows and buffaloes in India. Integrating livestock into the agricultural system modifies interactions among soil, vegetation and the atmosphere. Animals increase biodiversity and nutrient and water flow channels, improving nutrient recycling, food production efficiency and fertiliser and resource use (Fig. 2.2) (Bhagat et al. 2024; Paramesh et al. 2020).

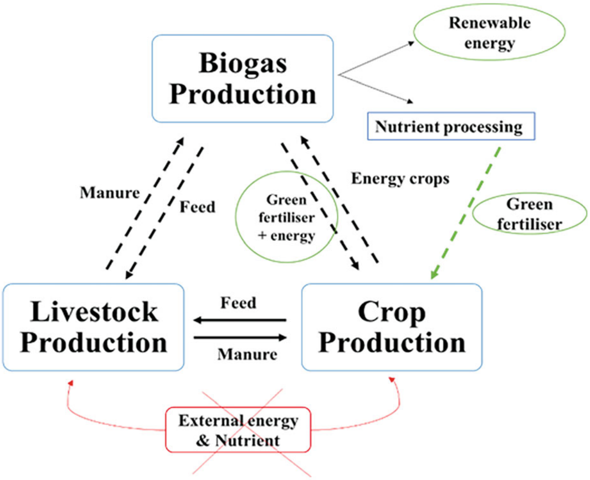

Fig. 2.2 Livestock and crop integration

2.3.3 Agricultural Land Use and Land Use Change

Changes in agricultural land use, such as deforestation and wetland conversion, are primary sources of GHG emissions (Hergoualc'h and Verchot 2014; Kreileman and Bouwman 1994). Significant deforestation is documented in tropical countries, particularly in South America and Southeast Asia, for palm oil production (Chiriacò et al. 2024; Vijay et al. 2016; Ravindranath et al. 2009). However, these land use changes release substantial quantities of carbon formerly sequestered deep into the atmosphere, accounting for around 12.5% in 2010 (Houghton et al. 2012) to 25% in 2017 (Hong et al. 2021) of anthropogenic GHG emissions. Additionally, they reduce ecosystems' capacity to absorb CO_2, which is the primary cause of climate issues. Conventional agricultural systems often fail to overlook the long-term environmental impacts of land use changes. Wetland conversion to agriculture causes CO_2 emissions (Tan et al. 2020) and loss of important ecosystem services such as water filtration and animal habitat (Kingsford et al. 2016; Verhoeven and Setter 2010). These changes make the ecosystems less resilient and less varied. That makes them more susceptible to climate change and extreme weather.

Circular agriculture is a mechanism to achieve economic productivity while conserving the environment. Agroforestry is an important technique for enhancing carbon sequestration and generating economic benefits from timber, crop, animal shade and fruit production (Keprate et al. 2024; Montagnini 2024; Jhariya et al. 2022). Soil organic carbon (SOC) stores can be restored through the use of organic amendments (compost, biochar) to restore water retention and increase microbial activity levels (Fahad et al. 2022). In addition, these techniques help make farming systems more resilient and effective and also lower emissions.

2.4 Circular Agriculture as a Key to Sustainable and Low-Carbon Food Production

2.4.1 Circular Agricultural Practices

Circular agriculture is based on recycling resources within the agricultural environment, which turns waste into useful inputs (Hoogstra et al. 2024; Chung et al. 2024; Rodino et al. 2023). Another way to include them is to turn food waste into animal feed and animal dung into biofertilisers. By closing the nutrient cycle and eliminating reliance on artificial inputs, this method keeps waste in the system to a minimum and maximises resource usage (Pal et al. 2024). Circular agriculture exemplifies agroforestry and integrated farming systems. Agroforestry integrates trees with agricultural and livestock cultivation to provide advantages such as carbon sequestration, enhanced soil fertility and increased revenue via timber and crop production (Keprate et al. 2024; Montagnini 2024). Integrated farming systems integrate crop and animal production, facilitating nutrient recycling and minimising waste (Kumar et al. 2023a; Bhagat et al. 2024). Manure that fertilises crops and agricultural wastes that nourish animals result in a symbiotic connection that enhances production and environmental health.

Precision agriculture technologies enhance the circularity of the agricultural system (Sanyaolu and Sadowski 2024). Utilising sensors and GPS-guided equipment, farmers may accurately administer water, fertilisers and pesticides at the appropriate times and locations (Vellingiri et al. 2025; Gautam et al. 2023). This not only conserves resources but also reduces emissions with minimal impact on yields or maybe enhances them. In addition, circular practices, such as composting and applying biochar, turn organic waste into fertiliser (Gunasekara et al. 2024). Biochar is a carbon-rich substance derived from biomass, which enhance soil structure and fertility while sequestering carbon, contributing to climate change mitigation (Gyawali 2024).

Circular agriculture approaches are not limited to farms but extend to the post-harvest process. Cold storage facilities driven by renewable energy mitigate food loss and decrease the carbon footprint of storage activities. Farmers may utilise solar-powered refrigeration units in remote locations to keep perishables for extended periods, reducing spoiling and improving marketing availability (Rami and Allouhi 2024). Adopting these comprehensive methods will enable the farms to become sustainable systems that satisfy food security, economic resilience and global climate goals.

2.4.2 Circular Carbon Economy

The economic model proposed to find the balance between the economy and the environment is termed the Circular Carbon Economy (Fig. 2.3) (Marku et al. 2024;

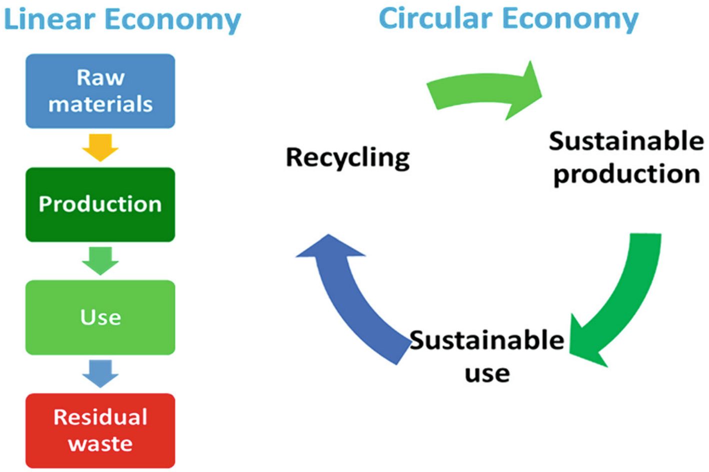

Fig. 2.3 Linear economy versus circular economy

Minh Khue et al. 2024; Yang et al. 2023), which is based on the 3Rs concept: reduce, reuse and recycle (Zoboli et al. 2016). From this perspective, circular agriculture emerged, focusing on preserving agroecosystems, reducing waste and optimising resource use and energy use (Rauw et al. 2023; Silvius et al. 2023). One of the main goals of circular agriculture is to reduce the reliance on external inputs by applying a closed nutrient loop system within the agricultural models (Minh Khue et al. 2024).

The organic carbon levels increase when soil is enriched by cover cropping (keeping ground cover year-round) and reduced tillage (less soil disturbance). They also improve soil fertility, prevent erosion and provide water retention (Koushika et al. 2024; Leharwan et al. 2023). The other key element of the circular carbon economy is converting agricultural waste into bioenergy (Yrjälä et al. 2022). Biogas facilities convert manure and agricultural byproducts into renewable energy and nutrient-rich digestate. These organic fertilisers are crucial for decreasing dependence on synthetic fertilisers and promoting nutrient recycling (Islam et al. 2021). Renewable energy is integrated into agricultural processes to advance the circular carbon economy further. A solar-powered irrigation system is a cost-effective, emission-efficient substitute for diesel pumps. Wind turbines and small hydropower systems empower farms to generate their clean energy. These renewable sources enable farms to minimise their carbon footprint while preserving their resources (Velasco-Muñoz et al. 2021).

2.4.3 *Challenges for Carbon-Negative Circular Agriculture*

Circular agriculture offers many benefits, but there are also significant barriers to broader adoption. Financial obstacles are the most important. Anaerobic digesters, precision farming equipment and renewable energy technology all have prohibitive upfront costs for most smallholders. Moreover, the limited access to affordable credits and subsidies further complicates the challenge by restricting farmers from adopting sustainable practices (Singh et al. 2024; Chung et al. 2024).

Furthermore, there are several technological limitations. Farmers in developing countries may encounter challenges using advanced technologies such as composting units, biogas plants and digital monitoring systems. Although these technologies are available, farmers do not use them due to a lack of technical skills or training. For example, smallholder farmers lack the tools to perform precision agriculture. Such tools may be unaffordable to them, or they may have trouble maintaining them, which will have little impact on their agricultural practices (Velasco-Muñoz et al. 2021).

Implementing collaborative strategies or capacity-building initiatives is essential to tackling these challenges. Multi-stakeholder partnerships bridge resources and expertise, guiding farmers to adopt circular practices. Circular agriculture has the potential to become a reality and contribute to the maintenance of global food systems.

2.5 Guiding Policies for Carbon-Negative Circular Agriculture

2.5.1 Enhancing Producer and Consumer Awareness

Raising awareness among farmers and consumers about the benefits of transitioning to circular agriculture is essential. Farmers generally neglect the long-term sustainability and cost-saving potential of circular processes. Implementing successful educational campaigns can boost trust and demonstrate the economic advantages of circular systems. Customers also play a significant role in creating demand for food produced through sustainable practices. Eco-labelling and public awareness initiatives might educate customers about the environmental effects of the foods they choose. Labelling such as carbon footprints or circular production processes can influence purchase decisions and create market incentives for farmers to use sustainable practices (Velasco-Muñoz et al. 2021).

Governmental and non-governmental organisations (NGOs) can collaborate to establish knowledge-sharing platforms, develop digital tools and conduct workshops. However, these platforms must solve the practical challenges of circular practices like composting, renewable energy integration and waste recycling to materialise them. Empowering farmers and consumers with some information makes switching to a sustainable food system more feasible.

2.5.2 Investment in Circular Agricultural Research and Development

Advances in the technology and practical framework of circular agriculture require research and development (R&D). Investment is needed to fund innovative solutions such as bio-based fertilisers, carbon capture technology and precision farming instruments. Scaling this up will require both private and public agencies to join forces and give smallholder farmers access to these technologies (Haque et al. 2023; Kucher et al. 2022). Furthermore, public–private partnerships can hasten research and development. Universities and agribusiness joint ventures are a perfect example of how they could work together to develop climate-smart solutions for their region. Such a collaboration fills the gap between theory and real application and makes the ideas reach farmers (Osumba et al. 2021). Field-based studies also replicate findings. The demonstration farms are real-life examples of the benefits of circular practice. These farms can be used as demonstration farms so that farmers can learn about and get comfortable with alternative approaches.

2.5.3 Institutional Reinforcement

Strong institutional support is essential for the successful implementation of circular agriculture. However, extension services must be improved to enable farmers to access resources, training and technical support. Customised solutions are needed to address region-specific concerns, such as water shortages and soil degradation (Velasco-Muñoz et al. 2021). Another important factor is policy consistency. Frequent revisions of policies create confusion and slow implementation (Zarb and Taylor 2023). Moreover, this requires collaboration among stakeholders. Multi-stakeholder platforms can be used to share ideas and resources with farmers, researchers and policymakers. They can help to reduce systemic hurdles and enable an easier transition to circular agriculture (Seifu et al. 2022).

2.5.4 Rewarding with Carbon Credits

Carbon credit programmes compensate farmers for lowering emissions and increasing their carbon sequestration. In contrast, farmers practising agroforestry or no-till enter crediting for the carbon stored in their soils or trees (Raina et al. 2024; Singh et al. 2024; Tamba et al. 2021). Governments and international organisations can create specific access to carbon markets for small-scale farmers. It is easier to sign up for and accumulate points, so even resource-poor people can join (Tamba et al. 2021). Moreover, associations with financial institutions can enable the farmers to borrow or invest in their agricultural infrastructure using credit. They can be made more attractive through co-benefits like the protection of biodiversity or the water cycle. These systems provide incentives for reduction in emissions, as well as other environmental and social benefits (Raina et al. 2024).

2.5.5 Incorporate Circular Agriculture Models in Regional Development Plans

Integrating circular agriculture within regional development plans brings its principles into the social and economic strategies. Agroforestry and rainwater collection should be part of the plans for areas that are prone to soil erosion or a lack of water. Regional planning should also orient towards the growth of the value chain (Velasco-Muñoz et al. 2021). This can lead to job opportunities by setting up processing facilities for biogas or biofertilisers and implementing circularity. These actions align with supporting rural development goals by building economic resilience and environmental sustainability. This allows governments to push municipalities, agricultural institutions and local communities to work on circular objectives together. However, joint approaches can potentially optimise resource use and group work among stakeholders (Chung et al. 2024; Velasco-Muñoz et al. 2021).

2.5.6 Develop Technical Standards and Monitoring and Evaluation Capacity for the Circular Agriculture Model

Measures that can standardise the assessment of circular agriculture performance will be necessary to ensure consistency and the potential for scaling (Soto et al. 2021). These metrics need to account for carbon sequestration, nutrient recycling efficiency and optimisation of water usage. Monitoring frameworks must have rigour and be friendly to the farmer. Apps and satellite images can allow farmers to provide information on the health of their soil, their emissions, and their resource use. Farmers can use these tools to receive real-time feedback and adapt their practices to optimise their sustainability and efficiency. Circular agricultural initiatives must be reported and audited annually for accountability and transparency. These requirements will be facilitated by government and non-governmental organisations (NGOs) to support farmers and institutions in effectively meeting these challenges. This also allows for capacity building (Velasco-Muñoz et al. 2021).

2.5.7 Reform Agricultural Subsidies and Introduce Innovative Policy Support

Agricultural subsidies frequently support resource-exhausting methods under a linear, extractive model of agriculture. Reforming these subsidies for embedded sustainable and circular economies could accelerate the transition (Sreekumar et al. 2024). Subsidies for the use of synthetic fertilisers could support precision farming technology or the development of biofertiliser. Financial uncertainty with circular agriculture can be mitigated by innovative policies, including risk-sharing arrangements and insurance plans. New tax incentives for businesses that invest in circular technology may also help governments ensure the involvement of the private sector (Glauber et al. 2021). Future policy frameworks may also be furthered through public–private collaborations. The collaboration of both sectors for common goals might drive investment and promote innovation (Yin et al. 2024).

2.5.8 Develop Circular Agricultural Value Chains

Circular value chains begin and end with recycling and reuse across manufacturing, processing and distribution. Waste generated from food processing can be converted into bioenergy or animal feed, which both minimises waste and elevates the value of byproducts. Collaboration along the value chain is critical to maximise the effort to produce the product (Santiago et al. 2024). Closing the material loop requires farmers, processors, distributors and retailers to align their processes. Farmers can sign contracts with biogas plants to deliver a constant flow of organic waste and get renewable energy in return. Conversely, circular value chains create opportunities for development in rural areas. Moreover, it reduces transportation emissions and creates jobs.

2.5.9 Enhance Private Sector Investment in Circular Agriculture

Expanding circular agriculture necessitates the involvement of the private sector. Investing in technologies like anaerobic digesters and green energy systems can help ensure that these trends continue to spread broadly. These expensive technologies can be adopted in resource-constrained places and have a lower risk in public–private partnerships. Co-financing solutions enable smallholder farmers to access innovative technologies and infrastructure (Velasco-Muñoz et al. 2021). Circular agriculture may potentially get advantages from corporate social responsibility (CSR) initiatives (Santiago et al. 2024). Companies may assist with sustainable packaging and integrating renewable energy into farming. These initiatives simultaneously fulfil the goals of companies and the environment.

2.5.10 Establish More Intersectoral Circular Bioeconomy Models for Sustainable and Low-Carbon Rural Development

Intersectoral bioeconomy models integrate agriculture, energy, waste management and forestry sectors to enhance resource utilisation (Taron and Gebrezgabher 2024). Agricultural waste can be converted into bioplastics or bioenergy, allowing us to move away from fossil fuels. These approaches require strong collaboration among stakeholders. Policies and incentives can nurture synergies across sectors, enabling governments to work together more successfully. Support for renewable energy programmes that use agricultural waste serves both the energy sector and agriculture itself (Kumar et al. 2023b). Bioeconomy models also offer income diversification and job opportunities besides enhancing rural development. These models must be prioritised in national development strategies to optimise their potential.

2.5.11 Enhance International Cooperation

Climate change and food security are the current global concerns that require a collective response. Knowledge-sharing platforms facilitate the dissemination of best practices and technology to promote circular agriculture. Circular agricultural initiatives in underdeveloped countries will receive money from international sources like the Green Climate Fund. The allocated funds may be utilised for the development of infrastructure, as well as for training and capacity-building initiatives. Research programmes can be expedited by coordinated efforts across multiple nations (Velasco-Muñoz et al. 2021).

2.6 Conclusion

The conventional agricultural sector is facing several challenges, leading to unsustainable development and environmental degradation. Circular agriculture is a potential alternative, and governments around the world may integrate it into their agriculture and food security policy objectives to foster sustainable agricultural development. Sustainable agricultural practices include agroforestry, cover cropping, rotational grazing, reduced chemical fertiliser use and minimal tillage. The application of environmentally friendly technologies in a rational way can achieve maximum benefits from natural processes with minimum input dependency, efficient recycling of nutrients, energy and water within ecosystems and transforming waste into valuable food production inputs, minimising costs and food losses using the principles of reduce, reuse and recycle in the agri-food value chain. Implementing circular agriculture practices requires national-level policies and institutional mechanisms to deliver relevant extension, and technological and financial services to farmers in a timely and efficient manner.

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