Vietnam Journal of Agricultural Sciences

ISSN 2588-1299

VJAS 2024; 7(2): 2173-2184
https://doi.org/10.31817/vjas.2024.7.2.07

Circular Agriculture: A General Review of Theories, Practices, and Policy Recommendations

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Abstract

The conventional agricultural sector is threatened by several factors that cause unsustainable development and serious environmental damage. Circular agriculture is regarded as an essential means and is being adopted globally by many countries. Through a narrative literature review, this article aims to discuss the concepts, theories, and practices of circular agriculture, and to draw recommendations for successful implementation. The findings reveal that circular agriculture focuses on promoting resource circularity in the agro-food value chain, minimizing external inputs, reducing resource requirements, regenerating bio-ecosystems, and reducing environmental impacts to meet increasing food demands and improve producers' livelihoods. Circular agriculture differs from conventional agriculture in terms of its principles, levels of circularity, evaluation criteria, and practices. Circular agriculture practices have been adopted globally due to their economic, social, and environmental benefits. However, circular agriculture still encounters obstacles to widespread adoption, such as vested interests and existing policies. Thus, a comprehensive strategy for circular agriculture development should include rethinking and repurposing the sector development strategy; enhancing changes in producer and consumer awareness and behaviors regarding circular agriculture and organic products; increasing investments in circular technology research and development; providing more incentives for producers to access credit and extension services, produce organic products, and to reuse and recycle agricultural resources; and strengthen farmers' organizations to adopt circular farming technologies.

Keywords

Circular agriculture, linear agriculture, conventional agriculture

Received: January 18, 2024
Accepted: June 8, 2024

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Introduction

The conventional agricultural sector is primarily based on a “linear production model” in which resources are used to produce food and fiber to meet human needs, followed by disposal and waste (Martínez, 2023). Linear agriculture is threatened by several factors leading to unsustainable development and serious environmental damage, including irrational waste, degradation, the scarcity of soil, water, energy, and biological resources, and climate change (Kharas, 2010). Circular agriculture is considered a crucial approach and has been adopted by many governments to achieve sustainable agricultural development (Michelini *et al*., 2017, Koppelmäki *et al*., 2021; Hars, 2022; Ninh *et al*., 2023). However, the concept of circular agriculture is still ambiguous (Jacqueline, 2020; Kristinn *et al*., 2021; Silvius *et al*., 2023). The conceptualized characteristics of circular agriculture are not sufficiently well-defined. A shift towards circular agriculture cannot be achieved by merely understanding the theories. Instead, realizing circular agriculture implies an ongoing process of fundamental changes in practices, organisations, markets, and institutions (Toop *et al*., 2017). Moreover, preceding studies have typically focused on specific case studies, but have not systemized the literature of circular agriculture in terms of broaden contexts. Thus, this paper focuses on reviewing the concept, principles, framework, assessment criteria, and practices of circular agriculture, and making policy recommendations for adapting and implementing circular agriculture.

To properly situate circular agriculture in the scholarly literature on agricultural science, we conducted a meta-study in which many academic case studies were selected based on a narrative literature review approach. This was conducted using the most recent and relevant articles on related themes indexed in Google Scholar, Science Direct, and the Web of Science. We set our timeframe from the 2010s, as this is the commonly accepted date for when the term “circular agriculture” began appearing frequently (Michelini *et al*., 2017). In analyzing how different academics have approached, investigated, and discussed circular agriculture, the keywords of concept, framework, principles, criteria, and practices of circular agriculture were defined first, and then the main content of each paper from the search was summarized. Among the 50 articles collected, those from researchers, practitioners, and institutions were selected for review. The review was conducted based on the methods of Pautasso (2019) in the following steps: (1) using keywords to search for titles; (2) studying abstracts and selecting relevant papers based on the search keywords; and (3) validating and synthesizing the research topics. This methodology enabled the capture of all research dimensions on circular agriculture, which are presented subsequently (Pautasso, 2019).

Circular Agriculture Theories

Why discuss circular agriculture?

Conventional agriculture is threatened by several factors that have led to unsustainable development and serious environmental damage, including irrational waste, degradation, and the scarcity of soil, water, energy, and biological resources (Kharas, 2010; Ellen MacArthur Foundation, 2012; Michelini *et al*., 2017; Jorgensen & Pedersen, 2018; Chung & Le, 2023). The substantial increase in global food production, based on a linear approach in recent decades, has incurred high environmental costs. Half of the world's habitable land is now used for agriculture. One-third of the global forest cover has been lost in the last century, with 20 percent of the standing forests having been degraded between 1990 and 2015 (FAO, 2020). Approximately a quarter of the world's soils are estimated to have been degraded as a consequence of intensive linear agricultural practices (IPCC, 2019). In linear agriculture, the intensive use of chemical fertilizers, synthetic pesticides, other chemical inputs, and water resources over time leads to severe erosion of bio-resources and soils, degradation, and water scarcity. The global consumption of chemical fertilizers soared from approximately 12 million tons in 1961 to over 110 million tons in 2018, particularly in developing regions (Kristinn *et al*., 2021). Runoff from large volumes of fertilizers, pesticides, and other chemical inputs, coupled with the rising use of plastics in agriculture, are major contributors to water pollution. Over the last century, global freshwater use has increased nearly sixfold, more than double the rate of population growth from 1900 to 2010. Agriculture accounts for about 70% of global freshwater withdrawals. Certain crops are particularly water-intensive; for instance, rice, which is cultivated on 160 million hectares worldwide, uses about 40% of freshwater withdrawals and is responsible for 10% of the total global methane emissions (FAO, 2020). Many countries in the Middle East, North Africa, and South Asia face high levels of water stress due to resource-intensive water consumption (Climate Neutral Group, 2021). Conventional agricultural practices contribute to approximately 31% of global greenhouse gas emissions, marking the sector as a significant factor in climate change (Kristinn *et al*., 2021). Without modifications to the current unsustainable food systems and consumption patterns, food-related CO_2 emissions could double by 2050 (Climate Neutral Group, 2021).

The agriculture sector continues to play a vital role in the global economy, contributing 4% to the global GDP and over 25% in some developing economies. Sustainable agricultural development is essential to achieving the world's Sustainable Development Goals and is seen as one of the most effective means to alleviate extreme poverty, foster shared prosperity, and feed an estimated 10 billion people by 2050 (World Bank, 2023). However, agriculture-driven growth, poverty reduction, and food security in many countries are jeopardized by multiple shocks – from geopolitical events and global pandemic-related disruptions to environmental degradation – leading to increased food prices and rising hunger. Conventional agriculture practices, with their threats to biodiversity, the environment, and human health, are outdated for the 21st century. A transition to a new agricultural model, circular agriculture, is imperative. The adoption and effective implementation of circular agriculture are considered crucial in meeting food demands while addressing resource scarcity, degradation, and environmental challenges (Hars, 2022). Success hinges on policymakers' and stakeholders' understanding of the meanings, principles, practices, and strategies of circular agriculture.

What is circular agriculture?

As with other economic sectors, the concept of circular agriculture is gaining attention among scientists and practitioners amid the global shift from a conventional to a circular economy (Ellen MacArthur Foundation, 2012). The idea, influenced by the broader principles of a circular economy, has been applied to agricultural systems, resulting in a variety of perspectives on the concept. Posthumus (2019) noted the existence of a broad spectrum of definitions for circular agriculture. Hars (2022) articulated that circular agriculture entails maintaining agricultural biomass, along with waste and residues from food processing, as reusable resources within the food system, with an emphasis on recycling food waste, minimizing the use of external inputs, and reducing environmentally harmful waste within the cycle. The Ellen MacArthur Foundation (2016) emphasized the importance of minimizing external inputs, closing nutrient loops, reducing resource demands, regenerating soils, and lessening environmental impacts. Kristinn *et al*. (2021) advocated that circular agriculture represents a sustainable farming approach that leverages scientific progress, innovations, and emerging technologies. The perspectives of the scholars mentioned each focus on a specific professional area or component of the food system. Their principles do not necessarily conflict but are rather complementary. While there is a stronger focus on agricultural production, the entire agri-food value chain, as well as the social and economic aspects of sustainability, are often less emphasized. A holistic view that considers the entire food value chain and the economic, social, and environmental dimensions suggests that circular agriculture is an economic sector focused on minimizing the use of external inputs, closing nutrient loops, reducing resource requirements, regenerating bio-ecosystems, and minimizing negative environmental impacts. This approach aims to meet growing food demands and improve the livelihoods of producers. This definition highlights the fundamental differences between linear and circular agriculture, as illustrated in **Table 1**.

Table 1. The differences between linear and circular agriculture

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

Source: Synthesized from Ellen MacArthur Foundation (2016) and Kristinn et al. (2021)

Historically, circular agriculture was widely practised by pre-industrial societies (Kristinn *et al*., 2021) but it has been overshadowed by the advent of modern, linear agriculture characterized by large-scale, monoculture, and intensive practices driven by specialized agricultural firms prioritizing profit over environmental protection. In contrast, circular agriculture supports a diversity of production practices, is more labor-intensive, and better addresses health, nutrition, and the balance of social and environmental aspects compared to its linear counterpart. It also ensures a reduction in land use, chemical fertilizers, and waste, contributing to a decrease in global CO_2 emissions. In Europe, for instance, it is estimated that adopting a circular approach to food systems could cut the use of chemical fertilizers by up to 80% (Ellen MacArthur Foundation, 2016).

Principles of circular agriculture

The principles of circular agriculture shape the entirety of agricultural strategies and practices, and different experts offer various perspectives on this topic. Hars (2022) suggested that the principles of circular agriculture should include the optimal use of land and resources; production of priority food crops in suitable fields; the practice of planting successive crops for the best use of planted fields; increasing diversity by integrating mixed products into crop rotations; and utilizing crop residues as forage for livestock and biofertilizer for the soil.

Expanding on this, Kristinn *et al*. (2021) identified three phases in circular agriculture principles: sustainable production, sustainable use, and efficient recycling. The approach integrates the reuse and recycling of materials throughout the production and use phases, rather than treating them as a separate step. For instance, animal manure may serve as organic fertilizer, and wastewater can be repurposed for irrigation.

The Ellen MacArthur Foundation (2016) has proposed the most relevant principles of a circular economy for agriculture: designing out waste and pollution; maintaining the maximum utility of products, by-products, and materials throughout the food value chain; and regenerating natural ecosystems. However, Velasco-Munoz *et al*. (2021) noted that these principles are infrequently modified in practice.

Bianchi *et al*. (2020) proposed principles that stress the value of leveraging natural processes while limiting harmful inputs, focusing on resource-efficient processes to promote the cycling of nutrients, energy, and water, and minimizing food losses by transforming waste streams into valuable inputs for the food production chain.

The principles discussed predominantly focus on agricultural production and environmental sustainability, but there is a need to encompass technical, economic, social, and environmental aspects across the agri-food value chain to achieve a truly integrated circular agriculture system.

It is advised that circular agriculture incorporate the following principles:

First, eco-friendly technology application: Employ environmentally friendly technologies throughout the agro-food value chain to maximize benefits from natural processes while minimizing the use of external inputs, especially toxic chemicals and materials that are challenging to reuse or recycle (Toop *et al*., 2017). This involves developing resilient agroecosystems capable of maintaining soil functionality and balance in the ecosystem, managing pests, diseases, and weeds, and coping with adverse climatic conditions. Methods include organic farming, mixed farming with the introduction of beneficial species, and adopting less disruptive ecosystem management practices (Bianchi *et al*., 2020). In fields practising circular agriculture with fertile soils, diseases and pests are less prevalent. Strategies shift from using synthetic chemicals to natural bio-insecticides, biopesticides, integrated crop management, and cultivating plant varieties and animal breeds with higher resistance to pests and diseases. During processing and handling, the focus is on reducing food loss and utilizing non-toxic, renewable, and recyclable materials for processing, packaging, and storage (Vega-Quezada *et al*., 2017).

Second, resource efficiency: At all stages of the agri-food value chain, prioritize efficient resource use. Technologies for resource use should enhance the effective cycling of nutrients, energy, and water within ecosystems (Collivignarelli *et al*., 2019). This can be achieved through practices like organic farming, mixed farming, agroforestry, and circular aquaculture. A robust ecosystem can be fostered and maintained by species that occupy diverse niches, such as different soil layers or aquatic levels, and through beneficial species interactions, like enhanced nutrient uptake in plants through symbiosis with mycorrhizal fungi (Therond *et al*., 2017).

Third, waste valorization: Transform waste into valuable inputs for food production to minimize costs and food losses (Aznar-Sanchez *et al*., 2020). This involves reducing, reusing, and recycling resources at every stage of the agri-food value chain. Steps include separating waste into reusable and non-reusable streams, establishing reuse practices or processing facilities that can regenerate products, and developing markets for these regenerated products (Ellen MacArthur Foundation, 2016).

Implementing these principles helps to build a circular agriculture model that not only sustains production but also nurtures the environment and society.

Framework of circular agriculture

In line with the principles of a circular economy, circular agriculture also needs an underpinning framework. In the contemporary literature, several studies have focused on building a conceptual framework for circular agriculture. For example, Boon & Anuga (2020) proposed a circular model with a 6R framework: rethink, refuse, reduce, reuse, recover, and repair. This model was opted in the Ellen MacArthur Foundation's butterfly circular economy model, which is used in conjunction with the three dimensions of sustainable development (economic, social, and environmental). Jacqueline (2020) recommended a 9R framework showing the priority of each level of circularity. With the views of minimizing the consumption of natural resources and maximizing the use of waste materials, by combining the preceding frameworks, Chung & Le (2023) recommended a broad circularity that included a 10R framework: rethink, repurpose, refuse, reduce, reuse, repair, refurbish, remanufacture, recycle, and recover, as depicted in **Table 2**. The initial two Rs—rethink and repurpose—urge policymakers and practitioners to envision a form of agriculture that is transparent, responsible, and sustainable, serving multiple purposes beyond food provision, including environmental protection and cultural conservation. In reference to the third R, refuse, stakeholders in agriculture should reject the use of toxic inputs and non-renewable resources within the food value chain, as well as the consumption of unsafe food products. These initial three Rs, which are fundamental to policy, strategy, and practice in agricultural development, must be enacted to facilitate the realization of the subsequent 7Rs. These principles of circularity ought to be the central focus of any agricultural development strategy. However, the prioritization of these principles should form a trapezoid, as illustrated in **Table 2**, indicating a significant emphasis on resource recovery (land, water, climate, and biological resources).

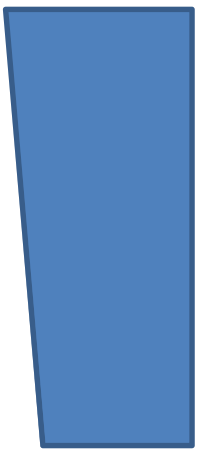
Criteria for evaluating circular agriculture

Velasco-Munoz *et al*. (2021) introduced 23 indicators for measuring the circularity of agricultural activities, which were derived from the circular economy framework. However, these indicators are heavily focused on technical aspects and do not comprehensively address the various specific aspects related to agriculture (Ninh *et al*., 2023). Posthumus (2019) suggested the following eight indicators: (1) the reuse and recycling of bio-based materials into new products; (2) material losses; (3) food waste; (4) the use of chemical pesticides and fertilizers; (5) plant and animal nutrient balances; (6) the use of renewable energy; (7) carbon emission outputs; and (8) financial benefits derived from the circular agri-business model. Nonetheless, these proposed indicators predominantly target environmental sustainability, while the social and economic dimensions are not explicitly addressed.

In advancing economic, social, and environmental sustainability, the criteria for evaluating circular agriculture should encompass the following integrated perspectives: (1) integration of environmentally friendly technologies across all stages of the agro-food value chain; (2) reductions in the use of chemicals, materials, and other inputs that are toxic or challenging to reuse or recycle; (3) reusing and recycling bio-based nutrients, energy, and water resources into new products; (4) enhancement of productivity and product quality; (5) promotion of welfare for both producers and consumers; (6) conservation and efficient utilization of land, water, and biological resources; (7) decreases in carbon emission outputs; (8) improvements in soil fertility and the biodiversity of ecosystems; (9) enhancement of the working and living conditions for producers, with particular attention to vulnerable groups; and (10) preservation of cultural heritage.

These general criteria serve to assess the circularity of the agricultural sector holistically. For specific types of circular farming, such as rice, wheat, coffee production, livestock raising, aquaculture, etc., there should be distinct circularity criteria based on the nature and characteristics of the respective plants or animals.

Table 2. Recommended levels of circularity and priority - 10Rs in circular agriculture

Level of priority	Circularity
High	**1. Rethink** to develop transparent, responsible, and green agriculture
	**2. Repurpose** agriculture as a sector with multiple purposes: economic, social, cultural, and environmental aspects
	3. Refuse to use toxic materials/inputs and non-renewable resources in food production, processing, handling, and consumption
	4. Reduce land, water, bio-resources, and others in production and processing, generating value while decreasing environmental impact
	5. Reuse secondhand equipment and materials in production
	6. Repair products, tools, and equipment to avoid wasting
	7. Rotate crops by time and space that bring more value to enrich ecosystems, provide soil cover, and decrease soil erosion and other negative environmental impacts
	8. Re-plant to create plant cover on degraded soils and clear lands
	9. Recycle processed waste materials into products (animal manure, crop residue as organic composts, and other products) or reuse water in irrigation
Low	**10. Recover** energy and resources from waste, soil, eco-systems, and other resources

Source: Modified from Chung & Le (2023).

Circular Agricultural Practices

Based on the nature and degrees of circularity, circular agricultural practices can be divided into categories such as organic farming, mixed farming, agroforestry, and circular aquaculture. Each of these practices contributes to the overall sustainability of agriculture and supports the principles of a circular economy within the sector. The principles and primary characteristics of each practice are detailed as follows:

Organic farming

Organic farming is a circular agricultural system rooted in the utilization of natural processes and resources, eschewing chemicals or genetically modified organisms to produce healthier, more nutritious food. It aims to preserve soil fertility, prevent pest proliferation, and safeguard the environment. This approach replaces chemical agricultural inputs with organic methods tailored to each ecosystem, reducing reliance on chemical fertilizers, pesticides, insecticides, and plastics (Zikeli *et al*., 2014). Organic farming encompasses the crop, livestock, and aquatic sectors. Organic crop farming deploys ecologically based pest control and organic fertilizers derived from animal and plant waste, along with nitrogen-fixing cover crops. It fosters robust plant ecosystems through organic inputs, integrated pest and crop management, rotational farming, cover cropping, multi-cropping, and polyculture (Ponisio *et al*., 2015). Organic livestock farming boosts animal health, maintains soil fertility, encourages ecological equilibrium, ensures animal welfare, and protects biodiversity. Animal health is managed through natural bio-insecticides and by choosing breeds with greater pest and disease resistance (Zikeli *et al*., 2014). Organic aquaculture adheres to organic standards in fish farming, emphasizing natural ecosystem balance, and biodiversity, and minimizing environmental contamination. It also considers the welfare and dietary needs of aquatic organisms to ensure high-quality and safe environmental standards (Sethi *et al*., 2023).

The largest advantage of organic farming systems lies in their reduced impact on the environment compared to conventional agriculture. This is also the reason why many governments in industrialized countries subsidize organic farming (Meemken & Qaim, 2018). Although conventional agriculture typically yields more than organic farming, this gap has narrowed in recent years (Robertson *et al*., 2004; Reganold & Wachter, 2016). Organic farming is an economically viable option for many farmers today because the organic market is growing continuously on a global scale. Most developed countries in North America, Europe, Australia, and Japan have large and well-functioning organic sectors, and organic products are easily available to most consumers. As the consumption of sustainable and fairly produced goods has increased, so has interest in personal health and fitness (Zikeli *et al*., 2014). Yet, even in many emerging economies such as China, Brazil, Vietnam, and India, organic markets are developing (Kristinn *et al*., 2021). Certification and labeling systems such as the Internal Control System or Participatory Guarantee System allow organic farming to serve as a tool for small-scale farmers in the Global South to gain access to international markets to increase their income, reduce inputs and costs, and increase crop diversification and price premia for organic products. The land area devoted to organic farming increased from 11 million hectares in 1999 to 72.3 million hectares in 2019 (Kristinn *et al*., 2021). Some regions have ambitious organic agriculture goals. Bhutan aspires to become the first country globally to be 100% organic, while Sikkim in northeastern India achieved this status in 2016 by eliminating chemical fertilizers and pesticides and prohibiting the sale and use of chemical pesticides. Denmark, too, has embraced organic farming and has the highest market share of organic products globally at 10%, where almost 80% of Danes buy organic food (Kristinn *et al*., 2021).

Nevertheless, and particularly for certified organic farming, this is in most cases not a solution for those who are the most strongly affected by food insecurity, as these population groups in many cases lack the degrees of organization and education that are necessary to enter the organic market, at least not without the help of NGOs. Moreover, organic agriculture tends to be dominated by transnational agricultural corporations in the global market, thus making the transition to organic farming extremely challenging for small-scale farmers because of low awareness, technology, and lack of market accessibility (Reganold & Wachter, 2016; Meemken & Qaim, 2018). Besides, organic agriculture standards have become a major barrier in international agricultural trade, especially from developing to developed countries (Zikeli *et al*., 2014).

Mixed farming

Mixed farming is a practice within circular agriculture where a single farm serves multiple purposes, often cultivating various crops while raising animals, based on the synergistic relationships of crops, livestock, and aquatic systems. This approach encompasses practices like multiple cropping, crop-livestock integration, and crop-livestock-fish farming (Shanmugam *et al*., 2024).

Multiple Cropping involves transitioning from a monoculture to cultivating interdependent crops such as legumes, soybeans, and cereals, which mutually benefit one another, on the same land. This method reduces reliance on off-farm inputs, manages soil fertility, and bolsters resilience through the strategic arrangement of crops to optimize the use of land, water, and biological resources (Reganold & Wachter, 2016). For example, the Chinese government promulgated the National Sustainable Agriculture Development Plan (2015-2030) in 2015. It proposed to promote the “rice–fish symbiosis”, “pig and biogas fruit”, and forest economies, as well as other ecological circular agricultural models according to local conditions (Li *et al*., 2021). In Vietnam, the Goverment has also promoted "rice-shrimp" farming in the Mekong River Delta since 2016 to adapt to climate change (Chung & Loan, 2022).

Integrated Crop-Livestock Farming combines crop cultivation with animal husbandry, deepening circular agriculture practices and reducing emissions through the use of locally produced feeds and manure instead of imported feeds and chemical fertilizers (Shanmugam *et al*., 2024). Livestock consume crop residues and natural forage from land unsuitable for crop production, while their manure improves soil fertility, increases crop yields, and enhances soil ecosystems. With environmental and economic benefits, such as reduced costs and decreased sensitivity to market fluctuations, this practice is widely adopted across Asia—including countries like India, Malaysia, Indonesia, Afghanistan, China, and South Africa—as well as in Central Europe, Canada, and Russia (Ryschawy *et al*., 2012; Kristinn *et al*., 2021).

Integrated Crop-Livestock-Fish Farming is a mixed farming system where crop, livestock, and fish components may operate independently, yet their outputs synergistically contribute to the overall productivity (Ninh *et al*., 2023). By-products from one subsystem, which may otherwise be wasted, are repurposed as inputs for another, enhancing the efficiency and productivity of the land and water under the farmer's management (Nayak *et al*., 2018). This system is noted for by-product recycling and improved space utilization, where two subsystems can share the same area, increasing productivity. This method of farming enhances biodiversity and sustainability, and reduces risks. It is commonly practiced in Southeast Asia, including in China, Vietnam, Thailand, Bangladesh, India, and the Philippines (Cao *et al*., 2011; Qiu, 2016; Tran *et al*., 2016; Nayak *et al*., 2018; John, 2020; Chung & Loan, 2022; Ninh *et al*., 2023).

Agroforestry

Agroforestry, a circular agricultural practice, harmoniously blends crops or pastures, livestock, and forestry. This method not only helps restore biodiversity in agricultural landscapes but also increases soil fertility through the accumulation of organic matter from decaying natural materials. It is a practice that integrates trees, shrubs, crops, and animals into a cohesive system, extending across more than 1 billion hectares globally (Giovanni, 2017). Historically utilized by indigenous peoples, agroforestry has gained popularity among farmers due to its numerous benefits, including increased circularity through reduced reliance on chemical fertilizers and pesticides, and fostering the empowerment of women (Kristinn *et al*., 2021).

Agroforestry presents opportunities to lessen negative ecological impacts, such as using crop residue biomass as animal fodder and trees to provide shade, and biomass for livestock, and maintain soil cover. It reduces the need for plastic mulch by using leaves and other plant materials as organic matter. Additionally, it contributes to climate change mitigation through carbon sequestration and supports biodiversity, water cycling, and food security (Giovanni, 2017). Agroforestry is extensively practiced across Europe, Asia, and Africa. For instance, in West Africa's drylands, agroforestry initiatives in Burkina Faso, Ghana, Niger, and Senegal have led to regenerated tree growth and diversified production (Reij *et al*., 2009). In South East Asia, Tenneson *et al*. (2021) found that agroforestry using herbaceous crops was generally the most expansive. Agroforestry involving shrub crops, such as coffee and tea, was most common in Indonesia and Vietnam, reaching a total area of 719,000 ha and 137,000 ha, respectively. The main palm crops were oil palm in Indonesia and coconut in the Philippines and Thailand. Tree crops included in agroforestry were fruit or nut tree species or tree species commonly used in forest plantations, such as rubber, or pulpwood species, such as acacia or eucalyptus. Across the sampled countries, large areas of tree crops were found in Cambodia and Indonesia (Tenneson *et al*., 2021).

Circular Aquaculture

Circular aquaculture is a sustainable farming practice that adopts the principles of a circular economy, transforming waste into raw materials for new products. There are two common forms: polyculture and recirculating aquaculture systems (RAS). *Polyculture* is a method where multiple aquatic species are co-cultivated, leveraging their biological and ecological interactions to enhance efficiency, reduce waste, and offer ecosystem services like bioremediation. Lower trophic species utilize waste products from higher trophic species as nutrients, creating a synergistic environment where both can thrive and be harvested, potentially increasing the farmer's revenue. This practice is known as integrated multi-trophic aquaculture (IMTA), with well-known combinations including grass carps and tilapia, or mud carps and silver carps, which are popular in Europe, Asia, and the US (Marta *et al*., 2020). *Recirculating aquaculture systems* (RAS) represent another circular approach, where water is purified and reused through biofiltration to manage ammonia levels. Biofiltration and stringent environmental controls are essential to maintain water quality and provide a conducive habitat for fish. RAS allows for high stocking densities with reduced land and water use but comes with high energy demands and associated production costs. Technology is typically beneficial for cultivating high-value species that can offset the increased costs (Marta *et al*., 2020). Circular aquaculture's focus is on enhancing the circularity of water and feed resources and valorizing aquaculture waste. This approach promises reduced waste, improved efficiency, and more sustainable operations, providing greater value for operators by doing more with less. It is gaining popularity in Asia, Europe, and the US, where farming components are integrated to recycle and reuse nutrients effectively (John, 2020).

Recommendations for Circular Agriculture Development

Circular agriculture offers significant economic, social, and environmental benefits over conventional methods. Despite these advantages, it is often supplanted by large-scale, specialized agricultural systems in many regions. The broader adoption of circular farming faces hurdles including vested interests, existing policies, a lack of information on the production and consumption of safe agro-foods, insufficient infrastructure, cultural biases, and misconceptions. Furthermore, circular agricultural practices receive less public and private research and fewer investments than conventional methods, particularly in developing countries (Kristinn *et al*., 2021). Producers often lack the necessary knowledge, skills, and financial resources to adopt circular farming methods (FAO, 2020). Additionally, incentives for producers to utilize organic inputs, renewable resources, and technologies that conserve resources, along with the support for farmers' organizations to reuse and recycle resources, are typically inadequate.

To overcome these obstacles, the adoption of circular agriculture aims to work in harmony with nature. Implementing the following recommendations is essential to address the challenges highlighted above:

Rethink and Repurpose in Agricultural Development Strategy: Policymakers and practitioners must fully grasp the circular agriculture framework, particularly the initial Rs of rethink and repurpose. The existing top-down approaches to agriculture and national development should be replaced by appropriate bottom-up strategies to create awareness across the entire agricultural value chain. Moreover, agricultural strategies should be designed to be transparent, responsible, and sustainable with multiple objectives beyond just food production. Strategies should be responsive to global changes in diets, market demands, climate, and environmental challenges.

Enhancing Producer and Consumer Awareness: Development strategies should focus on encouraging producers to use non-toxic inputs and materials throughout food production, processing, and handling. Concurrently, it is important to raise public awareness and willingness to pay for clean, organic agro-foods, thereby driving a market shift towards more sustainable products.

Invest in Circular Agricultural Research and Development: Transitioning to circular agriculture requires embracing scientific progress, innovation, and new technologies tailored for crops, livestock, aquatic production, forestry, and food processing. Public investment is crucial in the research and development of new technologies that close the resource cycle and promote resource recycling at net zero energy costs. Research should focus on creating resilient agroecosystems equipped to manage pests, diseases, and climatic challenges through diverse farming practices suited to various ecological conditions.

Institutional Reinforcement: Engaging small-scale farmers in the adoption of new technologies is essential for the effective and efficient practice of circular farming. Strengthening farmers' associations will empower smallholders to effectively manage cooperatives, water user associations, and farmer interest groups. Improvement areas for farmers' organizations should include economies of scale for new technologies, access to financial and water resources, and partnerships within the value chain.

These recommendations aim to create a cohesive support system for circular agriculture, fostering an environment where sustainable practices are not only viable but also thriving.

Conclusions

The conventional agricultural sector faces various challenges leading to unsustainable development and environmental degradation. Circular agriculture has emerged as a vital alternative, and has been adopted by governments worldwide to promote sustainable agricultural development. This approach differs from linear agriculture in several key aspects, including its development history, business model, farming practices, input usage, emphasis on reusing, and its overall impact. The core principles of circular agriculture involve: (1) the rational application of environmentally friendly technologies to maximize benefits from natural processes while minimizing reliance on external inputs; (2) focusing on the efficient cycling of nutrients, energy, and water within ecosystems; and (3) transforming waste into valuable inputs for food production, thereby minimizing costs and food losses through the principles of reduce, reuse, and recycle across the agri-food value chain.

A comprehensive framework for circular agriculture includes ten principles: rethink, repurpose, refuse, reduce, reuse, repair, rotation, replanting, recycle, and recover. These form the basis for evaluating circular agriculture, which covers technical-economic, social, and environmental aspects. Circular agricultural practices are varied, ranging from organic farming and mixed farming to agroforestry and circular aquaculture, each adapted to the specific nature and degree of circularity within farm systems.

Despite its advantages, circular agriculture confronts several challenges: it's often overshadowed by large-scale, specialized agricultural systems; it faces barriers to widespread adoption due to existing policies and vested interests; there is a lack of public awareness and a lack of both public and private investments in research; and producers often lack the necessary knowledge and incentives to adopt circular farming technologies.

To foster the development of circular agriculture, comprehensive policy recommendations are proposed: (1) rethink and repurpose the formulation of a sector development strategy that encourages responsible and sustainable agriculture with multiple objectives; (2) enhance the awareness and behaviors of producers and consumers regarding circular agriculture and organic products; (3) allocate more funds for research and development of circular agricultural technology; (4) offer greater incentives to producers to enable access to credit and extension services, and support the production of organic products, as well as the reuse and recycling of agricultural resources; and (5) strengthen institutions such as farmers' organizations to facilitate the adoption of circular farming technologies. These measures aim to address the existing challenges, leveraging circular agriculture's full potential to create a more sustainable, resilient, and equitable food system.

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