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REVIEW

Navigating the environmental, economic and social impacts of sustainable agriculture and food systems: a review

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KEYWORDS

Food security, agrisilviculture, agroecology, agroforestry, halal, crop production

HIGHLIGHTS

- Addresses global challenges like food insecurity, climate change and social inequality.
- Provides environmental preservation, economic viability and social equity.
- Strategies include agroforestry, ecosystem conservation, sustainable intensification and direct marketing.
- Emphasizes government support and policy, community-based approaches and participatory decision-making.
- Explores challenges and opportunities in transitioning to sustainable practices and rural-urban interactions.

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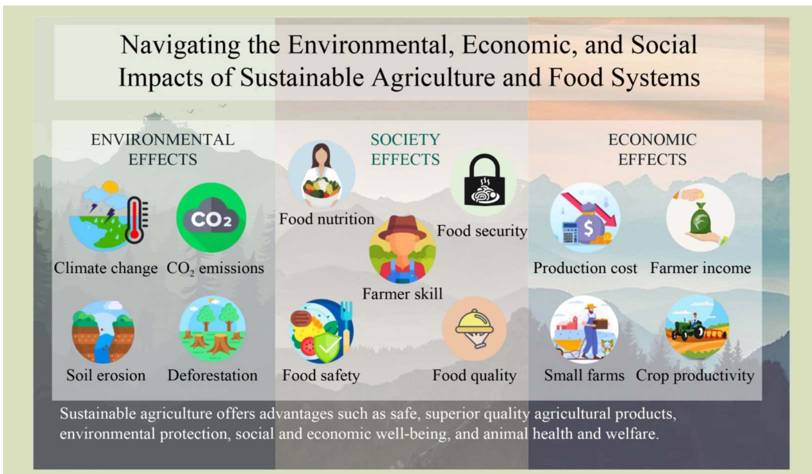
GRAPHICAL ABSTRACT



ABSTRACT

The escalating recognition of sustainable agriculture and food systems is a response to the multifaceted challenges of food insecurity, climate change, environmental deterioration and economic pressures. In this review, sustainable agriculture is characterized as an array of farming practices that effectively address immediate demands, while simultaneously safeguarding the potential of future generations to fulfill their needs. The primary objectives include sustained productivity, pollution reduction, and economic viability and sustainability. Sustainable food systems incorporate dimensions beyond production, including processing, distribution, consumption patterns, and waste management along the entire food supply chain. An abundance of research underscores the manifold benefits offered by sustainable agriculture and food systems to society at large. These advantages include fostering climate resilience, curbing greenhouse gas emissions, enhancing water quality, promoting biodiversity, enriching soil fertility, fortifying rural livelihoods and nurturing community well-being. Nevertheless, the path toward sustainability is strewn with significant challenges. These include substantial costs involved in transitioning, conflicts in policy objectives, and the pervasive influence of traditional methods. Achieving sustainability requires the execution of holistic strategies that traverse various sectors and scales. Accelerating this progress can be facilitated through the adoption of diverse strategies, including agroforestry, agroecology, urban agriculture, farmer knowledge exchange, ecosystem service payments and supply chain shortening. However, the success of these strategies hinges on the provision of appropriate policies and incentives. Further research is vital to ascertain the ideal conditions for implementing specific interventions and to assess the comprehensive expenses and benefits linked to them. This review emphasizes the assertion that widespread adoption of sustainable practices in agriculture and interconnected food systems has positive impacts in terms of community nutrition, conservation of natural resources and long-term economic progress.

1 Introduction

Establishing sustainable agriculture and food systems is instrumental in forging a prosperous society. Agriculture is the science, art, or practice of cultivating soil, producing crops and raising livestock for diverse purposes, including food, fiber, biofuel and medicinal plants. The World Health Organization (WHO) defines agriculture as the cultivation of animals, plants and fungi for a wide spectrum of products, while the Food and Agriculture Organization (FAO) defines it as the cultivation of animals, plants, and fungi for food, fiber, shelter, fuel, and recreation[1]. The term sustainable agriculture implies agricultural practices that ensure long-term environmental, social and economic sustainability[2,3]. Given global challenges such as climate change, food insecurity, social inequality and biodiversity loss, recognizing the importance of sustainable agriculture and food systems in addressing these issues becomes indispensable. This review explores the importance of sustainable agriculture and food systems, with an emphasis on their potential to propel the United Nations Sustainable Development Goals (SDGs) by 2030. Aligning sustainable agriculture and food systems with the SDGs enables a deeper understanding of their transformative capacity and favorable societal impacts[4,5].

Sustainable agriculture strives to safeguard the environment while endorsing the long-term prosperity of farmers and communities. It extends beyond cultivation to include the processing, distribution, marketing, consumption, and disposal of food within society. The food system impacts agricultural methods through infrastructure, policies, consumer demands, and waste patterns. Techniques like cover cropping, integrated pest management, and conservation tillage positively influence soil health, biodiversity, and ecosystem services. Similarly, embracing local and seasonal diets while also minimizing food waste serves to endorse and support sustainable agriculture practices[4,6,7].

Enhanced transparency and fair labor practices improve farm viability and worker well-being. Investments in sustainable agriculture and food systems present intertwined solutions that support rural livelihoods, ensure food security, protect environmental protection, and enhance public health. The complex connections between agriculture, the food system, and societal requirements underline the need for holistic transitions toward sustainability.

A sustainable society refers to a socioeconomic and ecological framework designed to meet present needs without compromising upon the future generations' ability to meet their own needs[8]. Resolving the global issues of climate change, social injustice, and environmental degradation requires envisioning a healthful society[9]. This involves reconfiguring current economic and social systems to foster a future that is fair, prosperous, and environmentally friendly. By prioritizing sustainability, individuals can fortify and build strong communities, safeguard natural resources, and enhance living conditions globally.

Sustainable agriculture and food systems are designed to meet current needs without compromising the future capacity of future generations to do the same. These systems prioritize environmental stewardship, economic health and societal well-being. These systems also ensure food availability, healthfulness and culturally suitable for everyone[10]. Establishing sustainable agriculture and food systems is vital for building a sustainable society and addressing global concerns such as climate change, food insecurity, and social inequality. Their implementation can foster resilient communities, preserve natural resources and improve human and environmental well-being.

The objectives of this review are to define sustainable agriculture and food systems, elucidate their interrelationship, and elaborate on their societal values and significance. With growing global populations and escalating environmental pressures, the shift toward sustainable food production and consumption models is imperative. This review underscores how practices like integrated pest management, food waste reduction, and equitable labor standards within agricultural and food systems can benefit the environment, food security, livelihoods and human health. The importance lies in shedding light on the systemic changes required in policies, institutions, infrastructure and mindset to feed the world equitably, while conserving natural resources for future generations. Additional research will further unravel the multifaceted challenges and solutions inherent in sustainable agricultural systems. Nonetheless, the value of sustainable agriculture and food systems is evident in their integrated approach toward the environmental, economic and social aspects of food production.

2 Benefits of sustainable agriculture

Sustainable agriculture has numerous advantages, spanning environmental, economic and social dimensions. This approach prioritizes the use of natural resources in a manner that does not lead to their exhaustion, while simultaneously producing nutritious food and enhancing the economic prosperity of farmers and rural communities. The concept of sustainable agriculture encapsulates three primary objectives: environmental health, economic viability and social equity (Fig. 1)[3]. The realization of these objectives has been facilitated by a diverse range of philosophical stances, policy

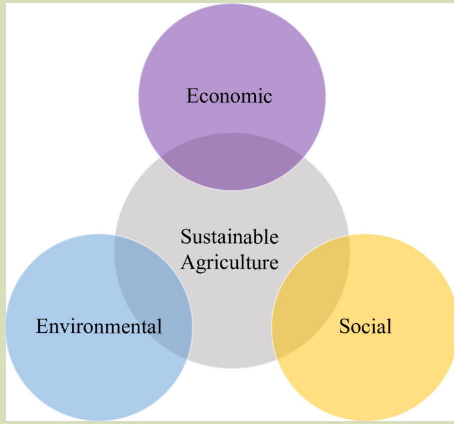


Fig. 1 Sustainable agriculture is a comprehensive approach, assigning equal importance to environmental, social and economic factors within the agricultural sector.

measures and practical strategies. Nevertheless, most definitions of sustainable agriculture identify several common themes and principles.

2.1 Environmental benefits

The implementation of sustainable agriculture practices yields significant environmental benefits, notably in preserving soil, water and other natural resources. The objective is realized through methods such as conservation tillage[11,12], crop rotation[13–15] and the utilization of cover crops[16,17]. Sustainable agriculture reduces water and air pollution[18,19] while conserving natural habitats by reducing the use of mineral fertilizers and synthetic pesticides[20]. Additionally, it fosters biodiversity. According to Altieri and Nicholls, sustainable agriculture practices promote environmental sustainability through implementing conservation tillage, cover crops and other sustainable farming practices, which mitigate soil erosion and maintain soil quality[21]. Reganold and Wachter[22] emphasize the reduction of mineral fertilizers and synthetic pesticides due to their contamination potentials in the soil, water and air. Also, fostering carbon sequestration and curtailing the use of fossil fuel have been recognized as effective strategies for diminishing greenhouse gas emissions[23]. As highlighted by the FAO[24], conserving biodiversity can be accomplished through endorsing habitat protection and restraining habitat destruction.

Sustainable agriculture employs a multitude of practices, such as conservation tillage, cover cropping and agroforestry[25,26]. These practices are instrumental in mitigating soil erosion[27] and preserving soil quality[21]. The application of conservation tillage practices decreases soil disturbance, preserves soil coverage, and reduces wind and water erosion[27,28]. Cover crops safeguard the soil against erosion, increase organic matter content, facilitate nutrient cycling and foster soil structure, thus enhancing soil fertility and preventing soil degradation over time[27]. By minimizing the use of mineral fertilizers and synthetic pesticides, sustainable agriculture reduces harmful environmental impacts. These chemicals substances can contaminate soil, water and air, triggering detrimental effects on ecological systems and human health[22].

Within the context of climate change, sustainable agriculture endorses the transition toward alternative techniques such as organic farming[29,30], integrated pest management and biological control methods[31]. These methods aim to decrease dependency on agrochemical inputs, emphasizing ecological balance and natural pest control processes[31]. Sustainable agriculture is pivotal in climate change mitigation, both through limiting greenhouse gas emissions and enhancing carbon sequestration. According to Lal, implementing techniques such as agroforestry, conservation agriculture, and organic farming can effectively increase the carbon sequestration process in soils and biomass, presenting a feasible strategy to offset emissions[32]. Also, sustainable agricultural practices aim to reduce reliance on nonrenewable energy sources, advocating for energy-efficient technologies, reducing mechanization dependency and integrating renewable energy sources. Such a strategy significantly curtails the carbon footprint associated with agricultural activities[33]. The preservation of biodiversity and natural resources is a fundamental aspect of sustainable agriculture as it facilitates habitat protection and reduces detrimental impacts of habitat destruction[34]. Evidence suggests that sustainable agriculture contributes to preserving and enhancing biodiversity on farmland through the adoption of agroecological practices, the establishment of wildlife corridors and the conservation of natural areas[35–37]. Various farming systems, such as crop diversification, agroforestry and heritage crop genotype conservation, create suitable and conducive environments. These systems, along with sustainable forest farming techniques like alley cropping, which benefits insects, birds and other fauna, thereby promoting ecological balance[38,39].

2.2 Economic benefits

Sustainable agriculture practices can result in economic advantages for farmers and rural communities[38]. This approach to agriculture can eventually enhance profitability over time by minimizing dependence on expensive inputs such as mineral fertilizers and synthetic pesticides, and sustainable farming helps to reduce production costs[39]. Adopting agroforestry practices has been instrumental in realizing significant economic benefits for farmers and rural communities. Through the integration of trees and the use of organic materials such as litter and manure, agroforestry significantly reduces the necessity for expensive mineral fertilizers. Also, this reduction in input costs has a direct and positive impact on production expenditures, ultimately enhancing the long-term profitability of farming operations[40]. In addition, agroforestry has facilitated access to new markets for sustainably produced foods, contributing to economic growth and expansion. It also reinforces small-scale and family farming, which is essential for strengthening local economies and ensuring their resilience and sustainability[41,42].

The economic advantages of sustainable agriculture are anchored by the strategic application of natural and organic methods. These methods not only enhance soil fertility and control pests and diseases, but also support financially efficient agricultural practices. This reduces the need for expensive inputs like mineral fertilizers and synthetic pesticides, effectively delivering economic benefits to those engaged in agriculture[22]. The deployment of agricultural techniques such as crop rotation, integrated pest management and the use of organic fertilizers can further reduce farmer dependence on agrochemical inputs, which can ultimately increase profitability[41,43,44].

The economic benefits of sustainable agriculture predominantly focus on the enhancement of soil vitality, the optimization of nutrient cycles and the augmentation of ecosystem services. These efforts are designed to ensure a consistent increase in productivity and crop yields over a prolonged period. As suggested by Altieri and Nicholls[21], adopting of these strategies significantly contributes to improved soil health and fertility, leading to higher crop yields and overall agricultural productivity[21]. Leveraging sustainable practices such as agroforestry[45,46], conservation tillage, precision agriculture[47] and other conservation-focused agricultural methods like organic farming, enables farmers to improve crop yields. This is accomplished without an excessive dependency on agrochemical inputs, which can ultimately facilitate an enhance in overall economic profitability[48].

A sustainable agricultural system and the use of litter and manure to reduce the need for mineral fertilizers is a major advantage of agroforestry, which has numerous other advantages. The main economic benefits of agroforestry such as its impact on reducing input costs, improved soil fertility, improved water management, increased crop yield and quality, diversified income sources, pest and disease management, and biodiversity conservation[6,25,49]. This makes it an attractive and environmentally-friendly approach to farming for many regions and communities.

A noteworthy advantage of sustainable agriculture is the potential creation of new markets for sustainably produced food items. The rise in consumer awareness and preference for ecologically responsible food production provides an opportunity for farmers to venture into specialized markets and secure higher returns for their goods. According to the FAO[35], implementing sustainable agricultural methods, such as organic farming, regenerative agriculture and fair-trade certifications, can provide access to these expanding markets for farmers. By adopting sustainable production techniques and securing relevant certifications, agricultural producers can distinguish their products, attract environmentally conscious consumers and secure elevated market values.

Promoting small-scale and family farming systems can also serve to strengthen local economies, as these are typically prioritized by sustainable agriculture. As pointed out by Pretty et al.[50], sustainable agriculture contributes in preserving vibrant rural communities and preventing the monopolization of agricultural production by large corporations through the promotion of diversified and resilient farming systems. Sustainable practices offer advantages to small-scale and family farmers, including facilitating access to local markets, establishing direct relationships with consumers and allowing for the retention of a larger proportion of the value generated along the supply chain.

2.3 Social benefits

The adoption of sustainable agriculture practices can result in several social advantages, including improving food security, strengthening rural livelihoods and encouraging cultural diversity[51]. There is potential within sustainable agriculture to combat malnutrition and hunger by providing access to wholesome and nutritious foods. It also can promote employment and income generation in rural regions while simultaneously safeguarding traditional agricultural methods and indigenous food networks.

One key aspect of sustainable agriculture is its role in enhancing food security through the provision of diverse, healthy and nutritious food options. This approach emphasizes diversifying crop cultivation by including a range of essential produce such as fruits, vegetables, grains and legumes, which are essential for a balanced and healthy diet[52,53]. Sustainable agriculture endeavors to strengthen food supply resilience and increase access to a diverse range of nutritious foods for local communities. Integrating functional food crop integration with agroforestry techniques is crucial for nurturing agricultural diversity and reducing dependence on monocultures. This comprehensive approach enhances food security, mitigates risks of hunger, and addresses health issues associated with unhealthy eating habits. It furthers the overarching goals of strengthening food system resilience and promoting sustainable agriculture[3,54,55].

Sustainable agriculture also aims to improve the economic conditions of rural communities by expanding livelihood opportunities. By enhancing productivity measures and broadening market access, sustainable agriculture can alleviate poverty in these areas. According to the FAO[35], implementing sustainable agricultural techniques, such as agroecology and organic farming, can potentially improve smallholder productivity and financial returns. By reducing costs and improving product quality, agricultural producers can access premium markets, earn fair compensation for their produce, and establish sustainable income sources. Consequently, this strategy aids in reducing poverty, improving living standards and strengthening rural economies.

Advocating for preserving local food systems and traditional farming practices to promote cultural diversity is another facet of sustainable agriculture[51]. This approach recognizes the importance of safeguarding traditional farming techniques and indigenous knowledge. According to Altieri and Nicholls[21], sustainable agriculture contributes to the preservation of cultural diversity in agriculture by advocating for diversified farming systems and agroecological methods. This effort encourages the growth of traditional and ancestral plant species, preserves regional ecological diversity and upholds gastronomic staples of culinary traditions[56]. Preserving cultural heritage is a protective measure and makes a significant contribution to the promotion of dietary diversity and local food traditions.

Sustainable agriculture fosters community involvement and empowerment through active participatory decision-making mechanisms. As highlighted by Pretty et al.[50], participatory approaches, such as farmer field schools and agroecology networks, facilitate knowledge sharing among farmers, promoting the exchange of experiences, and enabling collaborative problem-solving. By involving farmers in the development and implementation of agricultural practices, sustainable agriculture fosters ownership, social cohesion and capacity building at the local level[53].

The application of sustainable agriculture practices can foster a range of social benefits, including the strengthening of food security, improvement of rural livelihoods, preservation of cultural diversity, and facilitation of community engagement. Prioritizing social sustainability within the scope of sustainable agriculture promotes healthier, more resilient communities, empowers farmers and fortifies local food systems.

3 Challenges to sustainable agriculture and food system

Sustainable agriculture is crucial for addressing global food security concerns, promoting environmental sustainability and enhancing societal well-being. Nonetheless, this practice confronts several barriers that hinders its broad acceptance and execution. These obstacles arise from many factors, which include industrial agricultural practices, climate change and issues related to food loss and waste. Overcoming these hurdles is vital to ensuring the long-term viability and success of sustainable agricultural systems.

3.1 Industrial agriculture practices

The dominance of industrial agriculture represents a significant obstacle to the adoption of sustainable agriculture. Industrial agriculture relies heavily on agrochemical inputs, large-scale monocultures and intensive utilization of water and energy resources[57]. Such practices have the potential to detrimentally impact soil health, deplete water resources, generate greenhouse gas emissions and trigger a decrease in biodiversity. Transitioning from industrial agriculture toward sustainable agriculture practices requires overcoming barriers such as policy support, access to resources and shifting consumer preferences[22].

Environmental degradation is a significant consequence of industrial agriculture and poses a primary challenge. A study conducted by Gomiero et al.[58] investigated the environmental implications of diverse agricultural management techniques, including conventional and organic farming, revealed that industrial agricultural practices contribute to soil degradation, water resource contamination, and reduction of biodiversity. Foley et al.[59], argue that sustainable intensification is crucial for minimizing the environmental impacts of industrial agriculture, such as land transformation, emission of greenhouse gases, and water pollution.

Soil degradation is common in industrial agriculture, reducing soil fertility and productivity. The research by Lal[60] emphasizes the adverse effects of intensive tillage, agrochemical inputs and monoculture practices on soil quality. As Reganold and Wachter[22] suggest organic agriculture presents a viable and sustainable option that fosters soil conservation, organic matter accumulation and improved soil biodiversity.

Water pollution is a significant issue associated with industrial agriculture. The study conducted by Carpenter et al.[61] investigated nonpoint pollution in surface waters caused by phosphorus and nitrogen. Their research demonstrates a correlation between water pollution, increased use of chemical fertilizers and insufficient waste management practices in industrial agriculture[61]. The importance of sustainable intensification in reducing water pollution and guaranteeing water quality is emphasized[62].

Industrial agriculture practices often lead to a reduction in biodiversity, impacting ecosystems balance and services they provide. Research highlights the significance of employing multifunctional shade-tree management within tropical agroforestry landscapes as a vital approach to nurturing and conserving biodiversity[63]. Kremen and Miles[64] conducted a comparative analysis of the advantages, spillover effects and trade-offs associated with biologically diverse farming systems compared to traditional industrial agriculture. Their finding underscores the critical role of biodiversity conservation in the framework of sustainable agricultural practices[64].

Greenhouse gas emissions, a significant outcome of industrial agriculture, contribute greatly to exacerbating climate change. The Intergovernmental Panel on Climate Change[65] highlight the role of agriculture in mitigating climate change, emphasizing the need to decrease emissions derived from agricultural practices. West et al.[52] have identified specific leverage points to enhance global food security and environmental sustainability. Their research emphasized the significance of transitioning toward sustainable agricultural systems that contribute less to greenhouse gas emissions[52].

3.2 Climate change

The climate change phenomenon presents a substantial challenge to achieving sustainable agriculture. Agricultural productivity and stability are influenced by various factors such as rising temperatures, shifting precipitation patterns, increasing frequency of extreme weather events and altering pest and disease dynamics[66]. Addressing the impact of climate change requires the integration of adaptive and mitigative strategies into sustainable agricultural practices, such as conservation agriculture, agroforestry[6,25,49], crop diversification[30,67,68] and water management improvement[69]. The successful execution of these strategies requires a comprehensive understanding, adequate resources and supportive policies.

The impacts of climate change on agriculture are extensive, influencing diverse aspects of agricultural systems, such as crop productivity, water availability and food security. The subsequent references provide insights into the challenges that climate change presents with regard to sustainable agriculture. The effect of climate change on crop productivity and food security forms a significant concern. Changes in temperature and precipitation patterns can negatively impact crop growth, development and yield. Lobell et al.[66] have highlighted the adverse impacts of climate patterns on global crop yield, thereby presenting potential obstacles to maintaining food security. Similarly, Rosenzweig et al.[70] underscores the importance of evaluating and managing agricultural risks and hazards associated with climate change to secure future food production.

The issues of sustainable agriculture are compounded by changing rainfall patterns, prolonged droughts, and increasing water scarcity, which affect water availability and irrigation. Wheeler and von Braun[69] examined the potential impacts of climate change on global food security, focusing on the risks and hazards related to diminishing water resources for irrigation purposes. Their research highlights the significance of improved water management practices and efficient irrigation systems in mitigating the consequences of climate change.

Climate change also influences pests and disease dynamics, resulting in further obstacles to maintaining sustainable agriculture[71]. The rise in temperature and changes in precipitation patterns can create environments suitable for the spread of pests and disease transmission, potentially leading to increased crop damage and reduced yield. To effectively address the challenges brought on by pests and the impacts of climate change impacts, it is fundamental to incorporate species diversification in agroforestry practices. Purposeful diversification of plant species within agroforestry systems allows farmers to foster agricultural landscapes that are more resilient and adaptable. This tactical methodology includes the integration of a diverse array of trees, shrubs, crops and occasionally livestock species, enriching biodiversity and bringing about numerous benefits. Diverse agroforestry systems have the capability to diminish vulnerability to pest invasions, enhance natural pest control mechanisms and improve overall ecosystem vitality. Also, growing climate-resilient crop cultivars within these diversified systems contribute to sustainable agriculture by mitigating risks and promoting long-term food security[72].

Adaptation strategies are vital for achieving sustainable agriculture in the face of climate change-induced challenges, underscoring the significance of resilience in agricultural systems. These strategies include the development and implementation of climate-resilient crop cultivars, the enhancement of water management practices, and the promotion of agroforestry systems. The effective implementation of these adaptive strategies can strengthen the resilience of agricultural systems, empowering farmers to manage and adapt to changing climatic conditions effectively[73].

3.3 Food loss and waste

Food loss and waste refers to the reduction or discard of consumable food throughout the entire food distribution process, which includes production, processing, distribution and consumption stages. Food loss is the unintentional loss of food due to spoilage, damage or inadequacies in the distribution network and food waste is the intentional disposal of edible food[9].

The issue of food loss and waste significantly impedes the pursuit of sustainable agriculture across the supply chain. There are significant food loss or waste stems from insufficient storage, transportation, and inefficient distribution systems, as reported by the Food and Agriculture Organization[35]. Food waste is a major contributor to inefficiencies in resource utilization, environmental degradation, and economic losses. Therefore, the integration of sustainable agriculture practices with initiatives to mitigate food waste, enhance postharvest management and optimize supply chains is crucial for ensuring the fair distribution of food resources[74,75].

Food loss and waste permeate the entire supply chain, from production and postharvest handling[75], processing[76,77], distribution[78] and consumption[78,79]. The magnitude of food loss and waste is significant, with a substantial amount of food being lost or discarded globally[76]. The ensuing discourse delves into the obstacles presented by food loss and waste within sustainable agriculture.

The issue of food loss and waste has substantial implications for environmental sustainability. Food production, processing and distribution require substantial resources, including land, water, energy and inputs. The squandering of food results in the waste of these resources, intensifying the process of environmental degradation. In addition, the decomposition of discarded food in landfills emits greenhouse gases, exacerbating climate change[77,79]. The minimization of food loss and waste is a crucial aspect of promoting environmental sustainability and minimizing the ecological footprint of agriculture[80,81].

The economic viability of various stakeholders, such as farmers, food producers and consumers, is affected by food loss and waste. The loss or waste of food signifies a depletion of investments, labor, and income for the farmers and enterprises engaged in the food supply chain. Minimizing food loss and waste can enhance economic sustainability, increase profitability, and generate prospects for value-added products, conferring advantages to the agricultural industry.

Numerous strategies can be implemented across the food supply chain to minimization food loss and waste. These strategies include improved postharvest handling methodologies, resource allocation toward better storage and transportation infrastructure, increased collaboration among stakeholders, implementation of consumer education and awareness initiatives, and the advocacy of innovative technologies for food preservation and processing. The effective minimization of food loss and waste requires the collaborative efforts of governments, businesses and consumers[82].

4 Sustainable food systems

Sustainable food systems are holistic approaches to food production, distribution and consumption that promote environmental stewardship, social equity[83] and economic viability. They include sustainable agriculture practices, efficient food processing and distribution, waste reduction and equitable access to nutritious food[84]. Sustainable food systems aim to reduce environmental impacts, improve food security, strengthen regional economies, and safeguard the welfare of current and future generations. The SDGs implemented in 2015 call for significant changes in agriculture and food systems to eradicate hunger, achieve food security and improve nutritional outcomes by 2030[3]. The establishment and maintenance of sustainable food systems are of utmost importance in developing and preserving a sustainable society. They facilitate environmental conservation, promote social equity and fair access to food, and foster economic sustainability. This section examines the diverse roles of sustainable food systems in accomplishing sustainability objectives.

Environmental sustainability is closely linked to sustainable food systems, which prioritize the responsible management of natural resources. This is achieved by adopting practices that minimize resource depletion, reduce greenhouse gas emissions, protect biodiversity and preserve ecosystems. Garnett[56] suggested that sustainable food systems include regenerative agriculture, organic farming, and sustainable fishing practices, which mitigate the environmental impacts of food production. Implementation of sustainable land use practices, water conservation measures and reduction of chemical inputs are significant contributors to the long-term preservation and well-being of the natural environment[85,86].

Social equity and food justice are integral to sustainable food systems, prioritizing the provision of safe, nutritious, and culturally appropriate food to all individuals[86]. Mishra et al.[87] discuss concerns pertaining to equitable access to food by endorsing regional food systems, advancing equitable trade policies and championing the concept of food sovereignty. De Schutter88] highlighted that sustainable food systems prioritize the requirements and welfare of underprivileged communities, promoting equity in food access and reducing disparities in nutritional outcomes in the annual report submitted to the Human Rights Council Sixteenth session by the United Nation[88]. Sustainable food systems enhance social well-being and mitigate disparities in food distribution by promoting community engagement, empowering small-scale farmers and endorsing local food initiatives.

Economic resilience can be fostered through sustainable food systems, which have the potential to strengthen local economies, generate employment prospects and enhance the viability and sustainability of small-scale farmers and food producers. According to the report of the High-Level Panel of Experts on Food Security and Nutrition[89], sustainable food systems decrease reliance on external inputs and markets, thereby increasing the resilience of local communities. Promoting local sourcing, shortening supply chains and encouraging diverse agricultural practices are effective measures for fostering strong local economies, improving food security and reducing vulnerability to global economic shocks.

There are several examples of sustainable food systems practices, including various initiatives and models. These examples illustrate the application of sustainable farming practices, sourcing of locally produced food, minimizing waste and involving the communities. Table 1 presents an overview of the diverse methodologies employed in establishing sustainable food systems.

The preceding examples demonstrate the diversity of sustainable food systems and the multitude of methodologies employed to achieve sustainability objectives. By adopting such measures, both communities and organizations can significantly contribute to the evolution of a food system that exhibits enhanced sustainability and resilience. Also, these

Table 1 Sustainable food systems in practice

Practice	Description key information	Advantages	Disadvantages	Reference
Agroforestry	Agroforestry is the integration of trees and shrubs into agricultural systems involving crops and animals. By merging agricultural and forestry technologies, agroforestry cultivates land-use systems that are diverse, productive, profitable, healthy and sustainable land use systems	· Improves soil fertility and structure · Enhances nutrient cycling · Increases crop yields · Provides timber, fuel, food · Prevents soil erosion · Sequesters carbon dioxide · Provides wildlife habitat · Diversifies farm income	· High investment and establishment costs · Complex planning and design · Increased competition for sunlight, water and nutrients · Potential harbor for pest species · Unfamiliarity among farmers · Delayed returns on investment · Requires long-term land tenure	[6,25,49]
Community supported agriculture	Involves consumers purchasing a share or subscription to a local farm's harvest in advance of the growing season. The customers then receive a weekly portion of produce, meat, dairy or other farm products throughout the season as they are harvested	· Supports small local farms · Provides fresh produce to community · Promotes farmer-consumer relationships · Encourages seasonal/local eating · Lowers farmer marketing costs · Shares production risks · Contributes to local food security/sustainability · Reduces long supply chains and food miles · Offers organic/sustainable options	· Can be costly for consumers · Requires coordination for share pick-up · Leads to some food waste · Provides less choice and consistency · Limited to seasonal availability · Can be logistically challenging for farmers · Delivers raw produce requiring prep · Shares must be purchased upfront · Not as convenient as grocery shopping	[90–93]
Farm-to-school programs	Programs connect schools with local farms to serve healthy, local foods in school cafeterias. This include activities such as purchasing and featuring local farm products in school meals, offering food, agriculture, nutrition education and establishing school gardens	· Provides fresh, nutritious meals to students · Supports local farmers and the food economy · Reduces carbon footprint through local sourcing · Connects children to where food comes from · Promotes agricultural literacy and healthier eating habits · Creates markets and income for small to mid-sized farms	· Can be logistically challenging. · Schools have strict budgets local food may cost more · Requires coordination between schools, farms, distributors · Limited by seasonality of local crops · Food safety and procurement regulations can be hurdles · Needs teachers willing to take on education roles · School gardens require long-term maintenance	[83,94,95]
Urban agriculture	Urban agriculture involves growing, processing, and distributing food and other agricultural products in and around cities. This include backyard, rooftop and community gardens, vertical farming, livestock grazing in urban spaces, aquaculture and hydroponics	· Improves food security and access in cities · Provides income opportunities · Productive use of vacant urban land · Reduces transport needs and food miles · Creates green spaces and urban forestry · Manages stormwater runoff · Fosters community and connections	· Space constraints in dense urban areas · Urban soils may be contaminated · High startup costs for some technologies · Growing conditions can be less ideal · May require special zoning allowances · Could increase urban-wildlife conflicts · Risk of producing unsafe foods · Requires urban gardening knowledge	[96,97]

(Continued)

Practice	Description key information	Advantages	Disadvantages	Reference
Food recovery and redistribution	Food recovery and redistribution involves collecting unsold, unused fresh food from sources like restaurants, grocers, farmers markets and gardens, and distributing it to those in need through food banks, shelters and community programs	· Reduces food waste and landfill methane emissions · Makes nutritious food more available to food insecure populations · Supports emergency food providers · Can lower costs for food businesses through tax incentives · Allows for use of imperfect yet edible produce	· Requires coordination between many entities · Cold storage and transportation needs · Food safety regulations create challenges · Labor intensive to safely handle and redistribute foods · Does not address root causes of hunger/food waste · Need to educate consumers on use of recovered items · Cannot completely replace need for purchased fresh foods	[54,55]
Halal certification	Verification that food adheres to Islamic dietary laws include Sourcing of ingredients and products with minimal environmental impact and minimizing food waste at all stages of production and consumption	· Ensures food is prepared, processed and labeled according to Halal standards · Focus on reducing carbon footprint, conserving resources · Ethical treatment of animals and fair trade · Promotes small-scale, sustainable farming · Reduces chemical use and transportation emissions	· Access to Muslim markets · Enhances consumer trust · Promotes ethical and humane treatment of animals · Supports local economies · Reduces the carbon footprint · Healthier, more natural ingredients	[98,99]
Organic farming	Organic farming uses cultural, biological and mechanical practices that promote ecological balance and conserve biodiversity. It excludes mineral fertilizers, synthetic pesticides, genetic engineering and ionizing radiation. Organic crops are grown without agrochemicals or genetically modified organisms, and livestock are raised free of antibiotics or hormones	· Protects the environment from chemicals · Preserves biodiversity · Improves soil fertility over time · Conserves water · Avoids health risks of pesticides · Meets consumer demand for organic products · Commands premium organic market prices	· Typically lower yields than conventional farming · Organic inputs like compost can be expensive · More labor intensive weed and pest control · Transition period from conventional is difficult · Specific organic certifications required · Knowledge-intensive farming methods · Consumer fraud risks if standards not met	[85,86]
Crop rotation and cover crops	Crop rotation involves growing different crops sequentially on the same fields year to year. Cover crops are plants sown between harvests to cover and protect soil rather than for harvest	· Improves soil fertility and structure · Reduces soil erosion and nutrient loss · Suppresses weeds, pests and diseases · Reduces the need for agrochemical inputs · It helps manage soil moisture content · It may increase crop yields · Provides livestock feed options · Promotes on-farm biodiversity	· Can be labor and management intensive · Requires advanced planning and record keeping · Cover crops compete for moisture · Added time, costs and labor for planting cover crops · Potential reduction in main cash crop outputs · Specific equipment or collaborations needed · Transition period for soil balancing	[30,67,68,]
Precision agriculture	Involves using technology such as GPS, remote sensing and sensor data to precisely manage inputs and farming practices at a very localized, site-specific level	· Optimizes yields and profitability · Reduces environmental impacts · Targets inputs to reduce costs · Saves time and labor · Early disease/pest detection · Improves record keeping and decision-making	· High upfront technology costs · Steep learning curve for farmers · Reliance on technical specialists · Data security and privacy risks · Not feasible for small farms · Promotes larger industrial farming model · Raises barriers to entry for new farmers	[100–102]

(Continued)

Practice	Description key information	Advantages	Disadvantages	Reference
Aquaponics	Aquaponics is a food production system that combines aquaculture (fish farming) with hydroponics (soilless plant growth). It is a symbiotic recirculating system where fish waste provides nutrients for plants and plants naturally filter water for fish	· It uses 90% less water than soil-based agriculture · No chemical fertilizers are needed · Grows food year-round in any climate · Higher yields compared to hydroponics or aquaculture alone · Dual harvest of fish and plants · Scalable systems work in small and large spaces	· High startup costs for system infrastructure · Ongoing electricity costs for pumps and lights · Careful system monitoring required · Balancing nutrients can be challenging · Requires technical expertise to operate well · Disease transmission risks between fish and plants	[97,103]
Permaculture	Permaculture is an agricultural philosophy and system design approach aimed at developing productive, sustainable human habitats by integrating land, resources, people and the environment. It uses ethics of earth care, people care and fair share to guide holistic solutions	· Works with natural ecosystems and cycles · Regenerative, practices promoting biodiversity · Ethical and resource-efficient approach · Multi-functional landscape design · Drought and climate-resilient · Empowers self-reliant communities	· Knowledge-intensive, steep learning curve · Needs long-term planning and observation · Labor intensive establishment · Lower yields than conventional agriculture · Difficult to implement on large scale · Restricted by land tenures and policies · Lack of adequate certification systems	[72,104,105]

practices can help to mitigate the environmental impact of agriculture, enhance economic viability for farmers, and foster food security and societal well-being. A strategic combination of these approaches can pave the way to a food system that harmoniously integrates environmental responsibility, economic feasibility and societal needs.

5 Promoting sustainable agriculture and food systems

The promotion of sustainable agriculture and food systems is critical in achieving global sustainability objectives, ensuring food security, and conserving the environment. Promoting sustainable agriculture and food systems involves a range of strategies, the roles of governmental policies and regulations, and community-based approaches that facilitate the progression of sustainable agriculture and food systems.

5.1 Strategies for promoting sustainable agriculture and food systems

Numerous strategies have been devised and implemented to attain sustainability in agriculture. These strategies prioritize optimizing resource use, advocating for ecological principles and providing support for local food systems. Through the implementation of these measures, it is possible to establish resilient and ecologically sustainable agricultural systems. This facilitates the provision of nutritious foods while mitigating adverse effects on the environment. Table 2 presents examples of strategies for promoting sustainable agriculture and food systems.

5.2 The role of government support, policy and regulation

The implementation of effective governmental policies and regulations is key to nurturing and advancing sustainable agriculture and food systems[108]. Governments can establish a conducive framework that encourages sustainable practices, foster equitable resource distribution, and protects environmental and social interests through the formulation and enforcement of appropriate policies. Implementing effective policies and regulations can bring significant and comprehensive changes across the food system, including all production and consumption stages[116]. This policy-based approach is crucial for achieving sustainable development objectives[117]. Such interventions should not only target the reduction of harmful practices but also incentivize positive shifts in both agricultural production and consumption behavior. Table 3 presents the role of government support, policy and regulation.

Through effective policies and regulations, governments can

Table 2 Strategies for promoting sustainable agriculture and food systems

Strategies	Description	Advantages	Disadvantages	Reference
Agroforestry	Agroforestry is a deliberate practice that involves the intentional integration of trees and shrubs into agricultural systems that include crop cultivation and animal husbandry. This integration is designed to yield a spectrum of advantages that include environmental, economic and social aspects. Prominent practices include silvopasture, forest farming, riparian buffers, alley cropping, windbreaks, and more innovative techniques	· Sequesters carbon in soils and biomass · Improves soil health and fertility · Reduces nutrient leaching and runoff · Provides habitat for beneficial insects and wildlife · Can increase crop yields when combined properly · Offers farm diversification and extra income sources	· High start-up costs for tree planting and establishment · Increased management complexity · Potential for competition between trees and crops · Risk of hosting pest species · Delayed benefit realization until trees mature · Lack of farmer familiarity with practices · Needs long-term planning and design	[6,7,25,42,49]
Conservation and restoration of ecosystems	Agricultural conservation and ecosystem restoration involve protecting and renewing ecosystem functions and services through practices including the installation of buffer strips, the establishment of wildlife habitats, watershed management, agroforestry, cover cropping and regenerative grazing techniques	· Enhances biodiversity · Improves soil health and filters water and nutrient flows · Sequesters carbon in soils · Connects fragmented habitats · Supports pollinators and pest predators · Can increase yields over time · Flood control and climate adaptation	· Land taken out of production · Establishment costs for plantings · Ongoing maintenance requirements · Delayed or lower returns on investment · Knowledge-intensive planning and design · Dependent on farmer participation · Benefits are not always quantifiable · Requires long-term commitment	[53,106]
Agroecology	Ecological approach to agriculture that aims to sustainably produce food by optimizing interactions between plants, animals, humans and the environment. It focuses on on-farm solutions rather than external inputs	· Environmentally sustainable · Supports biodiversity · Builds climate resilience · Reduces the need for external inputs · Appropriate for small farmers · Maintains yields over the long-term · Deepens food sovereignty	· Knowledge-intensive · Context-specific so requires local innovation · Needs farmer participation and exchange · Can have high labor requirements · Hard to scale up and certify · Yield gaps may persist in the transition period · Needs supportive policies and incentives	[107,108]
Sustainable intensification	Sustainable intensification aims to increase agricultural productivity and yields per unit area while also reducing the negative environmental impacts of food production systems	· Increases food production on existing farmland · Avoids expansion into forests and grasslands · Optimizes inputs to reduce costs and waste · Can incorporate high-tech solutions · Maintains ecosystem services through agriculture · Preserves biodiversity in the landscape · Helps meet rising food demand	· Improving sustainability is very complex · Risk of focusing too narrowly on yields · Could still promote monocultures · Requires well-targeted technologies and practices · High management skills are needed · Success context is specific to each farm · Does not fundamentally transform larger food systems	[56,109,110]
Direct marketing and local food systems	Direct marketing provides consumers access to foods directly from farmers through venues like farmers markets, farm stands, community supported agricultures and online sales. Local food systems focus on production and consumption within a small geographic region	· Allows farmers to retain more value · Provides consumers fresh, seasonal produce · Supports local economic development · Reduces transport miles and emissions · Connects consumers directly to food sources · Circulates money within local economy	· Weather events can drastically impact the supply · Seasonal availability limits options · Distribution infrastructure needs development · Requires consumer participation and tourism · Price competitiveness challenges · Food safety compliance can be difficult · Requires marketing skills from farmers	[111,112]

(Continued)

Strategies	Description	Advantages	Disadvantages	Reference
Farmer training and knowledge exchange	Farmer training involves education programs and knowledge sharing opportunities to teach farmers new skills and techniques. Knowledge exchange facilitates collaborations for farmers to learn from one another	· Accelerates adoption of new practices · Provides hands-on, field-based learning · Allows farmers to network and exchange ideas · Makes research more accessible to farmers · Enhances technology transfer · Builds capacity and empowers farmers	· Context-specific and locally relevant · Requires extensive time commitment · Can be costly to deliver quality programs · Language and educational barriers · Needs clear incentives for participation · Hard to reach all farmers, including women · Knowledge exchange needs facilitation · Outdated practices may persist · Tracking impact and outcomes is difficult	[113]
Collaboration and partnerships	Agricultural collaborations and partnerships involve farmers, researchers, businesses, non-profits, government agencies and other entities working together toward shared goals through joint projects, resource sharing, coordinated initiatives and multidirectional learning	· Shared costs, resources, knowledge · Expands reach and adoption · Fosters innovation through diverse perspectives · Improves research relevance · Tackles complex system challenges · Clarifies roles of different stakeholders · Builds social capital and trust	· Extensive time investment · Managing varied interests is challenging · Unequal power dynamics possible · Requires careful planning and communication · Defining shared goals can be difficult · Accountability and credit issues · Sustaining momentum long-term · Assessing collaborative impacts	[114]
Access to finance and support	Access to finance and support in agriculture involves the ability of farmers to obtain lending, credit, insurance, grants, subsidies, and other financial services and mechanisms to help manage costs, risks and investments in their farm businesses	· Helps farms start-up and expand · Allows investment in improvements · Manages the risk of crop/animal losses · Levels playing field with subsidies · Bridges timing gaps and seasonality · Encourages sustainable transitions · Builds climate resilience · Tax incentives support practices	· Debt risks for farmers if loans mismanaged · Application hurdles limit eligibility · Corruption in subsidy allocation · Public expense of support programs · Record-keeping burdens · Admin costs reduce farmer profit · Gaps persist for small farms · Hard to target and track impact	[115]

drive transformative change in the agricultural sector, foster sustainable practices and create an enabling environment for developing resilient and inclusive food systems.

5.3 Community-based approaches

Building sustainable agriculture and food systems demands a holistic approach, which includees an array of tactics, governmental regulations and community-driven endeavors. Adopting agroecological practices, sustainable intensification, direct marketing and local food systems can contribute to developing more resilient and environmentally sustainable agricultural systems. Governments are pivotal for implementing subsidy reform, setting regulations and investing in research and development. In contrast, community-based methodologies facilitate knowledge transfer, promote social equity and empower individuals to engage in sustainable agriculture[133]. By adopting these strategies and engaging stakeholders at all levels, a food system that is both sustainable and equitable can be fostered.

Participatory decision-making is a crucial aspect of community-based approaches to sustainable agriculture and food systems. This involves the engagement of local communities in the decision-making process, ensuring their opinions are considered, and their knowledge and experiences are acknowledged. Stringer et al.[53] proposed the use of participatory approaches that can engender the establishment of ownership, promote social equity and facilitate the progression of sustainable agriculture and food systems customized to a particular context. Participatory approaches provide mechanisms for dialog, collaboration and collective problem-solving by engaging local communities in decision-making processes. Governmental and community efforts can cultivate more equitable and sustainable agricultural systems by addressing power imbalances, promoting social justice and fostering the evolution of sustainable agriculture and food systems, which are designed for unique contexts and the needs

Table 3 Role of government support, policy and regulation

Support, policy and regulation	Description	Reference
Regulations and standards	· It is within the purview of governmental bodies to institute regulatory frameworks and benchmarks aimed at promoting agricultural practices that are sustainable · The aforementioned may include directives pertaining to the application of pesticides, attainment of organic certification and implementation of sustainable land management techniques · Regulations of this nature establish a structured system for farmers to implement sustainable methodologies	[118–120]
Environmental regulations	· It is within the purview of governments to institute and enforce regulatory measures aimed at protecting natural resources and mitigating the adverse environmental externalities that may arise from agricultural practices · The aforementioned measures may include policies pertaining to the management of water resources, preservation of soil quality, application of pesticides and safeguarding of biodiversity	[121–123]
Food safety and quality standards	· The establishment and enforcement of food safety regulations and quality standards are critical functions performed by governments · The implementation of these standards serves to safeguard consumers against deleterious contaminants and guarantee the safe, nourishing and superior quality production and dissemination of food	[124,125]
Market support and access	· It is within the purview of governmental bodies to establish policies that strengthen the development of local and regional food systems, advance equitable trade practices and augment the market entry opportunities for smallholder farmers · The implementation of various measures, such as farmer markets, farm-to-school programs and public procurement policies that prioritize locally sourced and sustainably produced food, can be considered as potential initiatives	[111,112]
Subsidy reform	· It is possible for governments to implement reforms in agricultural subsidies as a means of promoting sustainable practices · The reallocation of subsidies from conventional agriculture, which frequently depends on agrochemical inputs, to sustainable agriculture has the potential to foster ecological stewardship and augment sustainability	[78,126–128]
Research and development funding	· It is within the purview of governmental bodies to allocate financial resources toward research and development endeavors that are geared toward promoting sustainable agricultural practices · This initiative facilitates the advancement and distribution of novel technologies, methodologies and information that augment agricultural output, optimize resource utilization and promote ecological sustainability	[114,129]
Sustainable farming incentives	· It is within the purview of governments to provide economic inducements such as financial incentives, subsidies or tax exemptions to farmers who choose to implement sustainable agricultural practices · The provision of incentives has the potential to promote the adoption of sustainable agricultural practices such as crop rotation, agroforestry and the use of organic fertilizers · These practices are aimed at reducing the dependence on agrochemical inputs and mitigating the adverse environmental effects associated with conventional farming methods	[130–132]

of the community. This approach applies a grassroots perspective, appropriately considering the distinct ecological, cultural and socioeconomic elements of communities. The involvement of stakeholders in the decision-making process is an essential element of community-based strategies aimed at promoting sustainable agriculture and food systems. These participatory approaches effectively promote ownership, foster social equity and facilitate the development of context-specific and sustainable solutions by actively engaging local communities in the decision-making process. This methodology acknowledges that communities possess significant knowledge and comprehension of their immediate surroundings, which can be crucial for formulating efficient and situation-specific remedies. Participatory approaches offer dialog, collaboration and collective problem-solving mechanisms by engaging local communities in decision-making[53].

Incorporating diverse viewpoints ensures that the needs, aspirations and concerns of all parties involved are considered, resulting in more equitable and comprehensive outcomes. The process of involving community members in decision-making processes regarding agricultural policies, land use planning and food system development instills a sense of ownership and empowerment. It also contributes to advancing social equity by facilitating the involvement of underrepresented groups, such as small-scale farmers, women, indigenous communities and youth. Participatory approaches potentially foster more equitable and sustainable agricultural systems by mitigating power imbalances and promoting social justice. These approaches also enable the development of sustainable agriculture and food systems designed for particular circumstances and requirements of a community. By embracing diverse perspectives and knowledge, participatory decision-making empowers communities to actively shape their agricultural systems and contribute to a more sustainable and equitable future.

Community-based initiatives, such as the creation of communal gardens, promote the development of resilient and environmentally conscious food systems by engaging farmers in sustainable practices. According to Okvat and Zautra[26], communal gardens serve the dual purposes of fostering social cohesion and providing opportunities for individuals to access locally grown produce while also gaining knowledge on environmentally sustainable horticultural practices. These gardens offer urban dwellers, who may have limited access to cultivable land, the chance to grow their own foods and experience the satisfaction of self-sufficiency. They serve as catalysts for social interaction and cohesion, facilitating the integration of heterogeneous community constituents and fostering a feeling of inclusivity and collective direction. Community gardens provide an opportunity to obtain locally cultivated produce that is fresher and more nourishing than commercial produce. Additionally, they provide education on environmentally sustainable horticultural practices, which enable individuals to incorporate environmentally sustainable practices in their gardening activities. Community gardens are pivotal in promoting sustainable food systems, as they promote communal cohesion, provide entry to regionally cultivated crops and convey expertise on environmentally conscious horticultural methodologies. By engaging individuals in sustainable practices, community gardens promote the establishment of robust and environmentally aware food systems[26].

Participatory decision-making is essential in community-based approaches to sustainable agriculture and food systems. It involves local communities in the decision-making process, which ensures their opinions are considered and their knowledge and experiences are given due recognition. Stringer et al.[53] posit that participatory approaches can create the establishment of ownership, promote social equity and facilitate the progression of sustainable agriculture and food systems customized to the context. Participatory approaches offer dialog, collaboration and collective problem-solving mechanisms by engaging local communities in decision-making processes. The act of involving community members in decision-making processes promotes a feeling of ownership and empowerment and can contribute to the advancement of social equity through the facilitation of the involvement of historically marginalized groups. Participatory decision-making is a process that enables groups to express their apprehensions and ambitions, granting them the agency to engage in decision-making procedures that have a direct bearing on their sustenance. It has the potential to foster more equitable and sustainable agricultural systems by mitigating power imbalances and promoting social justice. It is characterized by a bottom-up perspective that considers the distinctive ecological, cultural and socioeconomic factors of communities. Participatory approaches effectively promote ownership, foster social equity and facilitate the development of context-specific and sustainable solutions by actively engaging local communities in the decision-making process. By incorporating a range of viewpoints and expertise, participatory decision-making enables communities to take an active role in shaping their agricultural systems and promoting a more sustainable and just future[56].

Using community-based strategies in sustainable agriculture and food systems have many advantages, such as improving social unity, increasing availability of nutritious food, safeguarding cultural legacy and amplifying local capacity to withstand environmental and socioeconomic adversities. Through the involvement of communities in the decision-making process and the promotion of sustainable practices, these strategies facilitate the development of food systems that are more sustainable, equitable and resilient.

Figure 2 illustrates the Food System Mapping[134–136]. which can also be conveyed through verbal descriptions methodologies, commonly utilized in climate modeling and land use analysis[135,136]. Researchers have employed various methodologies to simulate the functioning of systems aiming to enhance the precision in describing systems accurately. These methodologies also strengthen the predictive capacity regarding changes and outcomes resulting from various interventions. Nourish Food System Mapping examines the material flows within the food system, covering aspects like transportation, waste, food and financial exchanges. Significantly, the representation of people in the artwork highlights the impactful role of individual and societal decisions in shaping various dynamics, as opposed to being governed only by impersonal principles or natural laws[137]. The portrayal explicitly includes the political system as a pivotal component, aligning it with health, biological, economic and social systems, emphasizing its significance within the agriculture and agroforestry food system[136–138]. Focusing solely on economic flows in the analysis of the food system overlooks the integration of other crucial driving elements that significantly influence its functionality and sustainability.

6 Conclusions

Sustainable agriculture and food systems are crucial for

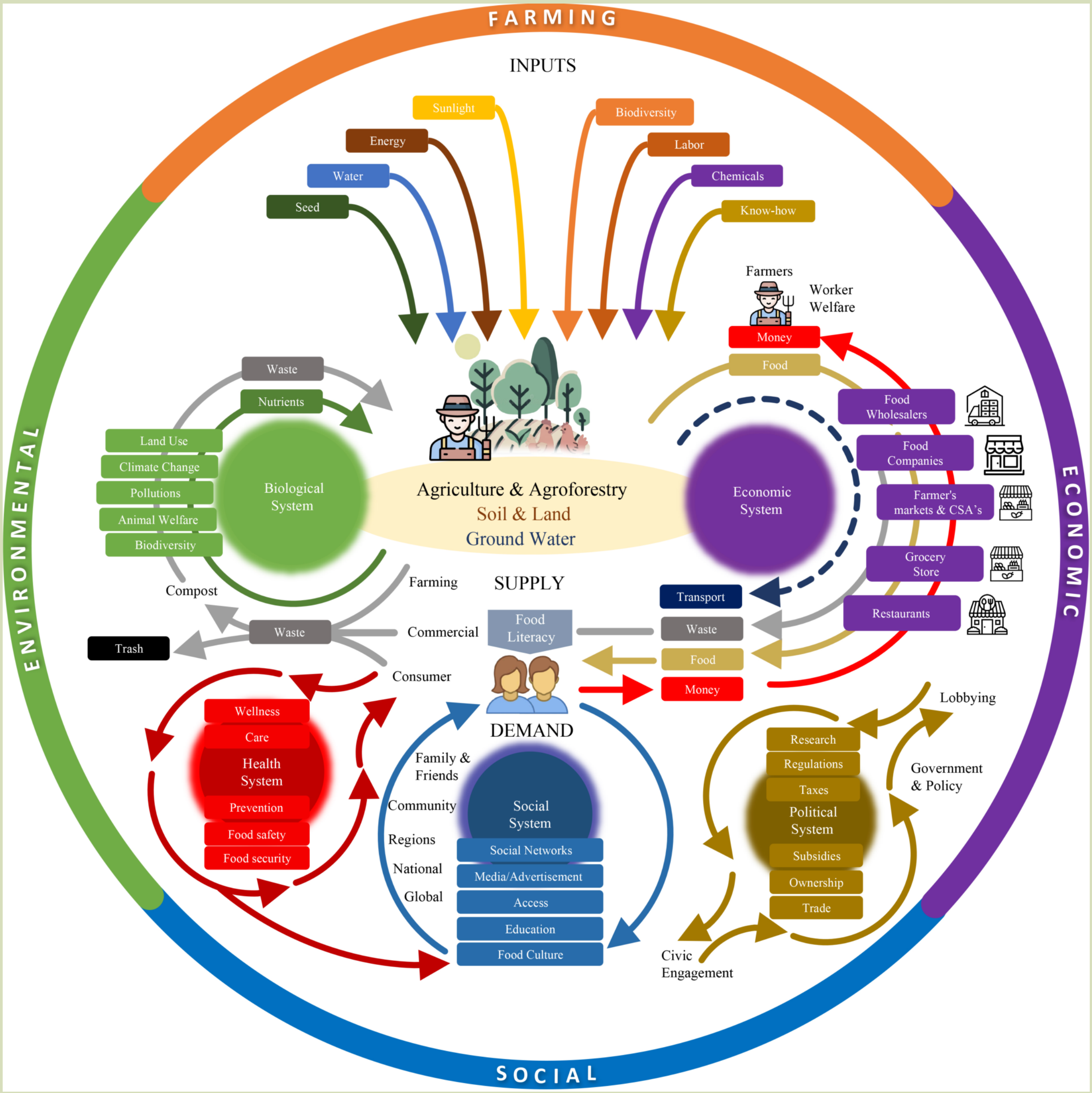


Fig. 2 Food System Mapping shows how multiple subsystems interact.

constructing a sustainable society. They contribute to environmental preservation, economic prosperity and social well-being. By adopting sustainable practices, it should be possible to mitigate environmental degradation, conserve natural resources and reduce greenhouse gas emissions by adopting sustainable practices. Sustainable agriculture also promotes economic benefits by reducing input costs, increasing productivity and creating new markets for sustainably produced foods. Also, it enhances food security, improves rural livelihoods and supports cultural diversity and community empowerment. To advance the sustainable agriculture and food systems, a united effort must be made by governmental bodies, policymakers, agriculturalists, consumers and local communities. Governments can enact supportive policies and regulations that incentivize sustainable practices, provide funding for research and development and support local food systems. Farmers can integrate agroforestry, conservation measures, precision agriculture and organic farming techniques. By also embracing agroecological approaches and minimizing agrochemical inputs, they can holistically advance sustainable agriculture and food systems. Consumers can support local and sustainably produced food by choosing products with certifications and labels, participating in community-supported agriculture programs and reducing food waste.

In conclusion, the significance of sustainable agriculture and food systems is key to achieving a sustainable society. Recognizing the interrelatedness among food production, ecological sustainability and societal welfare is imperative. By embracing sustainable agriculture practices and promoting resilient and inclusive food systems, it should be possible to ensure a healthy and prosperous future for the current and future generations.

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Compliance with ethics guidelines

Rosli Muhammad Naim, Maisarah Abdul Mutalib, Aida Soraya Shamsuddin, Mohd Nizam Lani, Indang Ariati Ariffin, and Shirley Gee Hoon Tang declare that they have no conflicts of interest or financial conflicts to disclose. This article does not contain any studies with human or animal subjects performed by any of the authors.

REFERENCES

1. Food and Agriculture Organization of the United Nations (FAO). The State of Food and Agriculture 2021: Making Agrifood Systems More Resilient to Shocks and Stresses. Rome: *FAO*, 2021. Available at FAO website on January 30, 2024
2. United States House of Representatives. Congress. 7 U.S.C. 3103. *U.S. Government Information*, 2010. Available at U.S. Government Information website on January 30, 2024
3. United Nations (UN). Transforming Our World: The 2030 Agenda for Sustainable Development.*United Nations*, 2015. Available at UN website May 20, 2023
4. Hinrichsen D. Report of the World Commission on Environment and Development: Our Common Future. Oxford & New York: *Oxford University Press*, 1987
5. van Noordwijk M, Duguma L A, Dewi S, Leimona B, Catacutan D C, Lusiana B, Öborn I, Hairiah K, Minang P A. SDG synergy between agriculture and forestry in the food, energy, water and income nexus: reinventing agroforestry. *Current Opinion in Environmental Sustainability*, 2018, **34**: 33–42
6. Octavia D, Suharti S, Murniati, Dharmawan I W S, Nugroho H Y S H, Supriyanto B, Rohadi D, Njurumana G N, Yeny I, Hani A, Mindawati N, Suratman, Adalina Y, Prameswari D, Hadi E E W, Ekawati S. Mainstreaming smart agroforestry for social forestry implementation to support sustainable development goals in Indonesia: a review. *Sustainability*, 2022, **14**(15): 9313
7. Bazzana D, Foltz J, Zhang Y. Impact of climate smart agriculture on food security: an agent-based analysis. *Food Policy*, 2022, **111**: 102304
8. Trimble L. Accessibility at JSTOR: From box-checking to a more inclusive and sustainable future. *Learned Publishing*, 2018, **31**(1): 21–24
9. Food and Agriculture Organization of the United Nations (FAO). Building a Common Vision for Sustainable Food and Agriculture. Rome: *FAO*, 2014. Available at FAO website on January 30, 2024
10. Brodt S, Six J, Feenstra G, Ingels C, Campbell D. Sustainable agriculture. *Nature Education Knowledge*, 2011, **3**(10): 1
11. Chen L, Hao Z, Li K, Sha Y, Wang E, Sui X, Mi G, Tian C, Chen W. Effectsof growth-promoting rhizobacteria on maize growth and rhizosphere microbial community under conservation tillage in Northeast China. *Microbial Biotechnology*, 2021, **14**(2): 535–550
12. Liu C, Li L, Xie J, Coulter J A, Zhang R, Luo Z, Cai L, Wang L, Gopalakrishnan S. Soil bacterial diversity and potential functions are regulated by long-term conservation tillage and straw mulching. *Microorganisms*, 2020, **8**(6): 836
13. Yu T, Mahe L, Li Y, Wei X, Deng X, Zhang D. Benefits of crop rotation on climate resilience and its prospects in China. *Agronomy*, 2022, **12**(2): 436
14. Shah K K, Modi B, Pandey H P, Subedi A, Aryal G, Pandey M, Shrestha J. Diversified crop rotation: an approach for sustainable agriculture production. *Advances in Agriculture*, 2021, **2021**: 8924087
15. Boyabatlı O, Nasiry J, Zhou Y. (H). Crop planning in sustainable agriculture: dynamic farmland allocation in the presence of crop rotation benefits. *Management Science*, 2019, **65**(5): 2060–2076
16. Smit E H, Strauss J A, Swanepoel P A. Utilisation of cover

crops: implications for conservation agriculture systems in a mediterranean climate region of South Africa. *Plant and Soil*, 2021, **462**(1–2): 207–218

17. Mueller J P, Pezo D A, Benites J, Schlaepfer N P. Conflicts between conservation agriculture and livestock over the utilisation of crop residues. In: García-Torres L, Benites J, Martínez-Vilela A, Holgado-Cabrera A, eds. Conservation Agriculture. Dordrecht: *Springer*, 2003, 221–234
18. Ryan B E K, Shrum T, Zia A. Assessing farmer incentives for transitioning toward sustainable agriculture and provisioning of clean water. *Frontiers in Water*, 2022, **4**: 918035
19. Qureshi M I, Awan U, Arshad Z, Rasli A M, Zaman K, Khan F. Dynamic linkages among energy consumption, air pollution, greenhouse gas emissions and agricultural production in Pakistan: sustainable agriculture key to policy success. *Natural Hazards*, 2016, **84**(1): 367–381
20. Khan M R, Raja W, Bhat T A, Mir M S, Naikoo N B, Amin Z, Nazir A, Mir S A, Mohammad I, Wani A A, Patyal D. Zero budget natural farming: a way forward towards sustainable agriculture. *Current Journal of Applied Science and Technology*, 2022, **41**(13): 31–43
21. Altieri M A, Nicholls C I. Agroecología urbana: diseño de granjas urbanas ricas en biodiversidad, productivas y resilientes. *Agro Sur*, 2018, **46**(2): 49–60 (in Spanish)
22. Reganold J P, Wachter J M. Organic agriculture in the twenty-first century. *Nature Plants*, 2016, **2**(2): 15221
23. Wijerathna-Yapa A, Pathirana R. Sustainable agro-food systems for addressing climate change and food security. *Agriculture*, 2022, **12**(10): 1554
24. Food and Agriculture Organization of The United Nations (FAO). Transforming Food and Agriculture to Achieve the SDGs. 20 Interconnected Actions to Guide Decision-Makers. Rome: *FAO*, 2018, Available at FAO website on January 30, 2024
25. Schaffer C, Eksvärd K, Björklund J. Can agroforestry grow beyond its niche and contribute to a transition towards sustainable agriculture in Sweden. *Sustainability*, 2019, **11**(13): 3522
26. Okvat H A, Zautra A J. Community gardening: a parsimonious path to individual, community, and environmental resilience. *American Journal of Community Psychology*, 2011, **47**(3–4): 374–387
27. Dev P, Khandelwal S, Yadav S C, Arya V, Mali H R, Poonam, Yadav K K. Conservation agriculture for sustainable agriculture. *International Journal of Plant and Soil Science*, 2023, **35**(5): 1–11
28. Ghosh T, Maity P P, Das T K, Krishnan P, Bhatia A, Bhattacharya P, Sharma D K. Variation of porosity, pore size distribution and soil physical properties under conservation agriculture. *Indian Journal of Agricultural Sciences*, 2020, **90**(11): 2051–2058
29. Sapbamrer R, Thammachai A. A systematic review of factors influencing farmers' adoption of organic farming. *Sustainability*, 2021, **13**(7): 3842
30. Eremeev V, Talgre L, Kuht J, Mäeorg E, Esmaeilzadeh-Salestani K, Alaru M, Loit E, Runno-Paurson E, Luik A. The soil microbial hydrolytic activity, content of nitrogen and organic carbon were enhanced by organic farming management using cover crops and composts in potato cultivation. *Acta Agriculturæ Scandinavica. Section B: Soil and Plant Science*, 2020, **70**(1): 87–94
31. Jomanga K E, Lucas S S, Mgenzi A R, Simba R F, Kiurugo M G, Biseko E. Review on the mutual effects of conservation agriculture and integrated pest management on pest and disease control in agriculture. *International Journal of Current Science Research and Review*, 2022, **5**(10): 3928–3938
32. Lal R. Managing soils for negative feedback to climate change and positive impact on food and nutritional security. *Soil Science and Plant Nutrition*, 2020, **66**(1): 1–9
33. Wang L, Mehmood U, Agyekum E B, Uhunamure S E, Shale K. Associating renewable energy, globalization, agriculture, and ecological footprints: implications for sustainable environment in South Asian countries. *International Journal of Environmental Research and Public Health*, 2022, **19**(16): 10162
34. Miftari A. Sustainable agriculture and farmers choices among short term efficiency and preserving the future. *Academicus International Scientific Journal*, 2020, **21**: 89–100
35. Food and Agriculture Organization of the United Nations (FAO). Sustainable Food and Agriculture. *FAO*, 2024. Available at FAO website on January 30, 2024
36. Thrupp L A. Linking agricultural biodiversity and food security: the valuable role of agrobiodiversity for sustainable agriculture. *International Affairs*, 2000, **76**(2): 265–281
37. Sharma H R, Sharma E. Mountain Agricultural Transformation Processes and Sustainability in the Sikkim Himalayas, India. Mountain Farming Systems' Discussion Paper 97/2. Kathmandu, Nepal: *International Centre for Integrated Mountain Development*, 1997
38. Sharma R, Xu J, Sharma G. Traditional agroforestry in the eastern Himalayan region: land management system supporting ecosystem services. *Tropical Ecology*, 2007, **48**(2): 1–12
39. Schreinemachers P, Simmons E B, Wopereis M C S. Tapping the economic and nutritional power of vegetables. *Global Food Security*, 2018, **16**: 36–45
40. Wu Q, Guan X, Zhang J, Xu Y. The role of rural infrastructure in reducing production costs and promoting resource-conserving agriculture. *International Journal of Environmental Research and Public Health*, 2019, **16**(18): 3493
41. Yarzábal L A, Chica E J. Microbial-based technologies for improving smallholder agriculture in the ecuadorian andes: current situation, challenges, and prospects. *Frontiers in Sustainable Food Systems*, 2021, **5**: 617444
42. Octavia D, Murniati, Suharti S, Hani A, Mindawati N, Suratman, Swestiani D, Junaedi A, Undaharta N K E, Santosa P B, Wahyuningtyas R S, Faubiany V. Smart agroforestry for sustaining soil fertility and community livelihood. *Forest*

Science and Technology, 2023, **19**(4): 315–328
43. Romeh A A. Integrated pest management for sustainable agriculture. In: Negm, A., Abu-hashim, M, eds. Sustainability of Agricultural Environment in Egypt: Part II. The Handbook of Environmental Chemistry, vol 77. Cham: *Springer International Publishing*, 2018, 215–234
44. Martinrueda I, Muñoz-Guerra L M, Yunta F, Esteban E, Tenorio J L, Lucena J J. Tillage and crop rotation effects on barley yield and soil nutrients on a Calciortidic Haploxeralf. *Soil & Tillage Research*, 2007, **92**(1–2): 1–9
45. Shidiki A A, Ambebe T F, Awazi N P. Agroforestry for sustainable agriculture in the Western Highlands of Cameroon. *Haya: The Saudi Journal of Life Sciences*, 2020, **5**(9): 160–164
46. Yirga S A. Agroforestry for sustainable agriculture and climate change: a review. *International Journal of Environmental Sciences & Natural Resources*, 2019, **19**(5): 556022
47. Ali B, Dahlhaus P. Roles of selective agriculture practices in sustainable agricultural performance: a systematic review. *Sustainability*, 2022, **14**(6): 3185
48. Jat R S, Choudhary R L, Singh H V, Meena M K, Singh V V, Rai P K. Sustainability, productivity, profitability and soil health with conservation agriculture based sustainable intensification of oilseed brassica production system. *Scientific Reports*, 2021, **11**(1): 13366
49. Nair P K R. Agroforestry systems and environmental quality: introduction. *Journal of Environmental Quality*, 2011, **40**(3): 784–790
50. Pretty J, Benton T G, Bharucha Z P, Dicks L V, Flora C B, Godfray H C J, Goulson D, Hartley S, Lampkin N, Morris C, Pierzynski G, Prasad P V V, Reganold J, Rockström J, Smith P, Thorne P, Wratten S. Global assessment of agricultural system redesign for sustainable intensification. *Nature Sustainability*, 2018, **1**(8): 441–446
51. Shafieisabet N, Mirvahedi N. Benefits of rural-urban interactions for sustainable food security in Iran. *Human Geographies—Journal of Studies and Research in Human Geography*, 2022, **16**(1): 19–31
52. West P C, Gerber J S, Engstrom P M, Mueller N D, Brauman K A, Carlson K M, Cassidy E S, Johnston M, MacDonald G K, Ray D K, Siebert S. Leverage points for improving global food security and the environment. *Science*, 2014, **345**(6194): 325–328
53. Stringer L C, Dougill A J, Fraser E, Hubacek K, Prell C, Reed M S. Unpacking “participation” in the adaptive management of social-ecological systems: a critical review. *Ecology and Society*, 2006, **11**(2): art39
54. Frigo A, Lucchini M. Working Together towards Circular Economy: Recovery and Redistribution of Surplus Food for Social Purposes. In Proceedings of the 6th International Conference on Sustainable Solid Waste Management, Naxos Island, Greece. 2018
55. Grant F, Rossi L. The Italian observatory on food surplus, recovery, and waste: the development process and future achievements. *Frontiers in Nutrition*, 2022, **8**: 787982
56. Garnett T, Appleby M C, Balmford A, Bateman I J, Benton T G, Bloomer P, Burlingame B, Dawkins M, Dolan L, Fraser D, Herrero M, Hoffmann I, Smith P, Thornton P K, Toulmin C, Vermeulen S J, Godfray H C J. Agriculture. Sustainable intensification in agriculture: premises and policies. *Science*, 2013, **341**(6141): 33–34
57. Holt-Giménez E, Altieri M A. Agroecology, food sovereignty and the new green revolution. *Agroecology and Sustainable Food Systems*, 2012, **37**(1): 90–102
58. Gomiero T, Pimentel D, Paoletti M G. Environmental impact of different agricultural management practices: conventional vs. organic agriculture. *Critical Reviews in Plant Sciences*, 2011, **30**(1–2): 95–124
59. Foley J A, Ramankutty N, Brauman K A, Cassidy E S, Gerber J S, Johnston M, Mueller N D, O’Connell C, Ray D K, West P C, Balzer C, Bennett E M, Carpenter S R, Hill J, Monfreda C, Polasky S, Rockström J, Sheehan J, Siebert S, Tilman D, Zaks D P M. Solutions for a cultivated planet. *Nature*, 2011, **478**(7369): 337–342
60. Lal R. Challenges and opportunities in soil organic matter research. *European Journal of Soil Science*, 2009, **60**(2): 158–169
61. Carpenter S R, Caraco N F, Correll D L, Howarth R W, Sharpley A N, Smith V H. Nonpoint pollution of surface waters with phosphorus and nitrogen. *Ecological Applications*, 1998, **8**(3): 559–568
62. Pretty J, Bharucha Z P. Sustainable intensification in agricultural systems. *Annals of Botany*, 2014, **114**(8): 1571–1596
63. Tscharntke T, Clough Y, Bhagwat S A, Buchori D, Faust H, Hertel D, Hölscher D, Juhrbandt J, Kessler M, Perfecto I, Scherber C, Schroth G, Veldkamp E, Wanger T C. Multifunctional shade-tree management in tropical agroforestry landscapes—A review. *Journal of Applied Ecology*, 2011, **48**(3): 619–629
64. Kremen C, Miles A. Ecosystem services in biologically diversified versus conventional farming systems: benefits, externalities, and trade-offs. *Ecology and Society*, 2012, **17**(4): art40
65. Smith P, Martino D, Cai Z, Gwary D, Janzen H, Kumar P, McCarl B, Ogle S, O’Mara F, Rice C, Scholes B, Sirotenko O. Agriculture. In: Contribution of Working Group III to the Fourth Assessment Report of theIntergovernmental Panel on Climate Change, Metz B, Davidson O R, Bosch P R, Dave R, Meyer L A, eds. Climate Change 2007: Mitigation. Cambridge: *Cambridge UniversityPress*, 2007
66. Lobell D B, Schlenker W, Costa-Roberts J. Climate trends and global crop production since 1980. *Science*, 2011, **333**(6042): 616–620
67. Tosi M, Drummelsmith J, Obregón D, Chahal I, Van Eerd L L, Dunfield K E. Cover crop-driven shifts in soil microbial communities could modulate early tomato biomass via

plant–soil feedbacks. *Scientific Reports*, 2022, **12**(1): 9140

68. Drinkwater L E, Wagoner P, Sarrantonio M. Legume-based cropping systems have reduced carbon and nitrogen losses. *Nature*, 1998, **396**(6708): 262–265
69. Wheeler T, von Braun J. Climate change impacts on global food security. *Science*, 2013, **341**(6145): 508–513
70. Rosenzweig C, Elliott J, Deryng D, Ruane A C, Müller C, Arneth A, Boote K J, Folberth C, Glotter M, Khabarov N, Neumann K, Piontek F, Pugh T A M, Schmid E, Stehfest E, Yang H, Jones J W. Assessing agricultural risks of climate change in the 21st century in a global gridded crop model intercomparison. *Proceedings of the National Academy of Sciences of the United States of America*, 2014, **111**(9): 3268–3273
71. Belmain S R, Tembo Y, Mkindi A G J, Arnold S E, Stevenson P C. Elements of agroecological pest and disease management. *Elementa*, 2022, **10**(1): 00099
72. Mollison B C. Permaculture: a practical guide for a sustainable future. Washington, DC: *Island Press*, 1990
73. Scholes R J, Biggs R. A biodiversity intactness index. *Nature*, 2005, **434**(7029): 45–49
74. Food and Agriculture Organization of the United Nations (FAO). Global Food Losses and Food Waste Extent, Causes and Prevention. Rome: *FAO*, 2011. Available at FAO website on January 30, 2024
75. Lundqvist J, de Fraiture C, Molden D. Saving Water: from Field to Fork—Curbing Losses and Wastage in the Food Chain. Stockholm International Water Institute (SIWI) Policy Brief. *SIWI*, 2008
76. Krzywoszynska A. Waste: uncovering the global food scandal. *Geography*, 2011, **96**(2): 101–104
77. Parfitt J, Barthel M, Macnaughton S. Food waste within food supply chains: quantification and potential for change to 2050. *Philosophical Transactions of the Royal Society of London. Series B, Biological Sciences*, 2010, **365**(1554): 3065–3081
78. Grolleaud M. Post-harvest losses: discovering the full story. Overview of the phenomenon of losses during the post-harvest system. *Agro Industries and Post-Harvest Management Service*. Rome, Italy: *FAO*, 2001. Available at FAO website on January 30, 2024
79. Food and Agriculture Organization of the United Nations (FAO). Food loss prevention in perishable crops FAO. Agricultural Services Bulletin No. 43, Rome: *FAO*, 1981. Available at FAO website on January 30, 2024
80. Hiç C, Pradhan P, Rybski D, Kropp J P. Food surplus and its climate burdens. *Environmental Science & Technology*, 2016, **50**(8): 4269–4277
81. Ali N E H, Hamdan N A H, Talmizi N M, Mohamad M R, Leng P C, Teck G L H. Assessment of Food Waste and its Causes In Universiti Teknologi Mara Perak Branch, Seri Iskandar Campus, Malaysia. *International Journal of Academic Research in Business & Social Sciences*, 2022, **12**(8): 1147–1159
82. Food Loss and Waste Protocol (FLW). The food loss and waste accounting and reporting standard. Washington, DC: *FLW*, 2016
83. Mishra S K, Khanal A R, Collins W J. Farm-to-School programmes, benefits, health outcomes and barriers: A structured literature review. *Health Education Journal*, 2022, **81**(7): 781–792
84. Kneafsey M, Venn L, Schmutz U, Balázs B, Trenchard L, Eyden-Wood P, Blackett M. Short food supply chains and local food systems in the EU: a state of play of their socio-economic characteristics. Luxembourg: *Publications Office of the EU*, 2013
85. Gugalia G. A sustainable agriculture: organic farming: a review. *Bhartiya Krishi Anusandhan Patrika*, 2021, **36**(3): 204–207
86. Tiraieyari N, Hamzah A, Abu Samah B. Organic Farming and Sustainable Agriculture in Malaysia: Organic Farmers' Challenges towards Adoption. *Asian Social Science*, 2014, **10**(4): 1–7
87. Mishra A K, Kumar A, Joshi P K, D'Souza A. Production risks, risk preference and contract farming: impact on food security in India. *Applied Economic Perspectives and Policy*, 2018, **40**(3): 353–378
88. United Nations (UN). Agroecology and the Right to Food, Report presented at the 16th Session of the United Nations Human Rights Council [A/HRC/16/49]. *UN*, 2011
89. High-Level Panel of Experts (HLPE) on Food Security and Nutrition. Nutrition and food systems. A report by the High-Level Panel of Experts on Food Security and Nutrition of the Committee on World Food Security. Rome: *HLPE*, 2017
90. Mert-Cakal T, Miele M. 'Workable utopias' for social change through inclusion and empowerment? Community supported agriculture (CSA) in Wales as social innovation *Agriculture and Human Values*, 2020, **37**(4): 1241–1260
91. Galt R E, Bradley K, Christensen L, Fake C, Munden-Dixon K, Simpson N, Surls R, Van Soelen Kim J. What difference does income make for Community Supported Agriculture (CSA) members in California? Comparing lower-income and higher-income households *Agriculture and Human Values*, 2017, **34**(2): 435–452
92. Tang H, Liu Y, Huang G. Current status and development strategy for community-supported agriculture (CSA) in China. *Sustainability*, 2019, **11**(11): 3008
93. Jilcott Pitts S B, Volpe L C, Sitaker M, Belarmino E H, Sealey A, Wang W, Becot F, McGuirt J T, Ammerman A S, Hanson K L, Kolodinsky J, Seguin-Fowler R. Offsetting the cost of community-supported agriculture (CSA) for low-income families: perceptions and experiences of CSA farmers and members. *Renewable Agriculture and Food Systems*, 2022, **37**(3): 206–216
94. Kane M. The Feasibility of Implementing Farm-to-School Programs In Bloomington-Normal Public Schools. *Outstanding Senior Seminar Papers*, 2008
95. Dinis I, Guilherme R. Farm-to-School Programs in

Portuguese Low-Density Rural Areas: How to Engage Farmers? *European Countryside*, 2023, **15**(1): 18–33

96. Smit J. Urban Agriculture Yesterday and Today. In: Nasr J, Ratta A, eds. Urban agriculture: food, jobs, and sustainable cities. 2001 ed. *The Urban Agriculture Network,* 2001, 35–37
97. Skar S L G, Pineda-Martos R, Timpe A, Pölling B, Bohn K, Külvik M, Delgado C, Pedras C M G, Paço T A, Ćujić M, Tzortzakis N, Chrysargyris A, Peticila A, Alencikiene G, Monsees H, Junge R. Urban agriculture as a keystone contribution towards securing sustainable and healthy development for cities in the future. *Blue-Green Systems*, 2020, **2**(1): 1–27
98. Alzeer J, Rieder U, Hadeed K A. Good agricultural practices and its compatibility with Halal standards. *Trends in Food Science & Technology*, 2020, **102**: 237–241
99. Rajagopal S, Ramanan S, Visvanathan R, Satapathy S. Halal certification: implication for marketers in UAE. *Journal of Islamic Marketing*, 2011, **2**(2): 138–153
100. Zhang P, Guo Z, Ullah S, Melagraki G, Afantitis A, Lynch I. Nanotechnology and artificial intelligence to enable sustainable and precision agriculture. *Nature Plants*, 2021, **7**(7): 864–876
101. Linaza M T, Posada J, Bund J, Eisert P, Quartulli M, Döllner J, Pagani A, Olaizola I G, Barriguinha A, Moysiadis T, Lucat L. Data-driven artificial intelligence applications for sustainable precision agriculture. *Agronomy*, 2021, **11**(6): 1227
102. Tomchek M. Sustainable Technology Impact on Agricultural Production. In: Leal Filho W, Azul A M, Brandli L, Lange Salvia A, Wall T, eds. Decent Work and Economic Growth. Encyclopedia of the UN Sustainable Development Goals. *SpringerLink*, 2021
103. Love D C, Fry J P, Genello L, Hill E S, Frederick J A, Li X, Semmens K. An international survey of aquaponics practitioners. *PLoS One*, 2014, **9**(7): e102662
104. McLennon E, Dari B, Jha G, Sihi D, Kankarla V. Regenerative agriculture and integrative permaculture for sustainable and technology driven global food production and security. *Agronomy Journal*, 2021, **113**(6): 4541–4559
105. Bhandari D, Bista B. Permaculture: A Key Driver for Sustainable Agriculture in Nepal. *International Journal of Applied Sciences and Biotechnology*, 2019, **7**(2): 167–173
106. Felipe-Lucia M R, de Frutos A, Comín F A. Modelling landscape management scenarios for equitable and sustainable futures in rural areas based on ecosystem services. *Ecosystems and People*, 2022, **18**(1): 76–94
107. Gliessman S R. Agroecology: The Ecology of Sustainable Food Systems. 3rd ed. Boca Raton: *CRC Press*, 2014
108. Francis C, Lieblein G, Gliessman S, Breland T A, Creamer N, Harwood R, Salomonsson L, Helenius J, Rickerl D, Salvador R, Wiedenhoeft M, Simmons S, Allen P, Altieri M, Flora C, Poincelot R. Agroecology: The Ecology of Food Systems. *Journal of Sustainable Agriculture*, 2003, **22**(3): 99–118
109. Jhariya M K. Ecological Intensification of Natural Resources for Sustainable Agriculture. In: Meena R S, Banerjee A, eds. Ecological Intensification of Natural Resources for Sustainable Agriculture. Singapore: *Springer Nature*, 2021, 1–28
110. Chidawanyika F, Muriithi B, Niassy S, Ouya F O, Pittchar J O, Kassie M, Khan Z R. Sustainable intensification of vegetable production using the cereal ‘push-pull technology’: benefits and one health implications. *Environmental Sustainability*, 2023, **6**(1): 25–34
111. Hinrichs C C, Lyson T A. Remaking the North American food system: strategies for sustainability. London: *University of Nebraska Press*, 2007
112. Schmidt M. Sustainable Global Value Chains. In: Giovannucci D, Palekhov D, Hansmann B, eds. Natural Resource Management in Transition. Cham: *Springer*, 2019
113. Franzel S, Carsan S, Lukuyu B, Sinja J, Wambugu C. Fodder trees for improving livestock productivity and smallholder livelihoods in Africa. *Current Opinion in Environmental Sustainability*, 2014, **6**: 98–103
114. McGuire S, Sperling L. Seed systems smallholder farmers use. *Food Security*, 2016, **8**(1): 179–195
115. Lowder S K, Skoet J, Raney T. The Number, Size, and Distribution of Farms, Smallholder Farms, and Family Farms Worldwide. *World Development*, 2016, **87**: 16–29
116. Abdullah D M F, Noor A M, Enh A M. Hydrological legacies of colonialism: examining water systems in Perlis, Malaya (1909–1950). *Journal of International Students*, 2023, **19**(2): 215–243
117. Lencucha R, Pal N E, Appau A, Thow A M, Drope J. Government policy and agricultural production: a scoping review to inform research and policy on healthy agricultural commodities. *Globalization and Health*, 2020, **16**(1): 11
118. DuPuis E M, Goodman D. Should we go “home” to eat?: toward a reflexive politics of localism *Journal of Rural Studies*, 2005, **21**(3): 359–371
119. Gan J, Stupak I, Smith C T. Integrating policy, market, and technology for sustainability governance of agriculture-based biofuel and bioeconomic development in the US. *Energy, Sustainability and Society*, 2019, **9**(1): 43
120. Tleuken A, Tokazhanov G, Jemal K M, Shaimakhanov R, Sovetbek M, Karaca F. Legislative, Institutional, Industrial and Governmental Involvement in Circular Economy in Central Asia: A Systematic Review. *Sustainability*, 2022, **14**(13): 8064
121. Liu Y, Wang A, Wu Y. Environmental regulation and green innovation: Evidence from China’s new environmental protection law. *Journal of Cleaner Production*, 2021, **297**: 126698
122. Baylis K, Heckelei T, Hertel T W. Agricultural Trade and Environmental Sustainability. *Annual Review of Resource Economics*, 2021, **13**(1): 379–401
123. Ahmed N, Hamid Z, Rehman K U, Senkus P, Khan N A, Wysokińska-Senkus A, Hadryjańska B. Environmental regulation, fiscal decentralization, and agricultural carbon intensity: a challenge to ecological sustainability policies in

the United States. *Sustainability*, 2023, **15**(6): 5145

124. Caswell J A, Mojduszka E M. Using informational labeling to influence the market for quality in food products. *American Journal of Agricultural Economics*, 1996, **78**(5): 1248–1253
125. GarridoGamarro E, Svanevik C S, Lundebye A K, Sanden M, D'Agostino E, Kjellevold M, Pincus L, Pucher J. Challenges in the implementation of food safety and quality assurance systems in small-scale fisheries. *Food Quality and Safety*, 2023, **7**: fyad007
126. Phalan B, Green R, Balmford A. Closing yield gaps: perils and possibilities for biodiversity conservation. *Philosophical Transactions of the Royal Society of London. Series B, Biological Sciences*, 2014, **369**(1639): 20120285
127. Chen K, Wang Z. Evaluation of financial subsidy for agriculture based on combined algorithm. *Computational Intelligence and Neuroscience*, 2022, **2022**: 6587460
128. Alkon M, Urpelainen J. Trust in government and subsidy reform: evidence from a survey of Indian farmers. *Studies in Comparative International Development*, 2018, **53**(4): 449–476
129. Whitfield S, Marshall A. Defining and delivering 'sustainable' agriculture in the UK after Brexit: interdisciplinary lessons from experiences of agricultural reform. *International Journal of Agricultural Sustainability*, 2017, **15**(5): 501–513
130. Gunningham N, Sinclair D. Leaders and laggards: next-generation environmental regulation. *Management of Environmental Quality*, 2003, **14**(1): 160–161
131. Picas S, Reis P, Pinto A, Abrantes J L. Does tax, financial, and government incentives impact long-term Portuguese SMEs' sustainable company performance. *Sustainability*, 2021, **13**(21): 11866
132. Benalywa Z A, Ismail M M, Shamsudin M N, Yusop Z. Financial Assessment and The Impact of Government Incentives on Contract Broiler Farming in Peninsular Malaysia. Proceedings of the International Conference on Science and Technology (ICOSAT 2017), Indonesia. *Atlantis Press,* 2018
133. Rashid N K A, Lani M N, Ariffin E H, Mohamad Z, Ismail I R. Community engagement and social innovation through knowledge transfer: micro evidence from Setiu Fishermen in Terengganu, Malaysia. *Journal of the Knowledge Economy*, 2023 [Published Online] doi:10.1007/s13132-023-01102-5
134. van Noordwijk M, Catacutan D C, Duguma L A, Pham T T, Leimona B, Dewi S, Bayala J, Minang P A. Agroforestry matches the evolving climate change mitigation and adaptation agenda in Asia and Africa. In: Dagar J C, Gupta S R, Sileshi G W, eds. Agroforestry for Sustainable Intensification of Agriculture in Asia and Africa. Sustainability Sciences in Asia and Africa. Singapore: *Springer*, 2023, 21–52
135. Zhang W, Gowdy J, Bassi A M, Santamaria M, DeClerck F, Adegboyega A, Andersson G K S, Augustyn A M, Bawden R, Bell A, Darknhofer I, Dearing J, Dyke J, Failler P, Galetto L, Hernández C C, Johnson P, Jones S K, Kleppel G, Komarek A M, Latawiec A, Mateus R, McVittie A, Ortega E, Phelps D, Ringler C, Sangha K K, Schaafsma M, Scherr S, Hossain M S, Thorn J P R, Tyack N, Vaessen T, Viglizzo E, Walker D, Willemen L, Wood S L R. Systems thinking: an approach for understanding'eco-agri-food systems. In: The Economics of Ecosystems and Biodiversity. TEEB for Agriculture & Food: Scientific and Economic Foundations. Geneva: *UN Environment*, 2018, 17–55
136. Nourish Initiative. Nourish Food System Map. *Nourish*, 2020. Available at nourish website on January 30, 2024
137. Cahyono E D, Pradesti E, Prayogo C, Suhartini R I. Exploring the relative advantages of local innovation in agroforestry. *Frontiers of Agricultural Science and Engineering*, 2023, **10**(1): 61–72
138. Argumedo A, Song Y, Khoury C K, Hunter D, Dempewolf H, Guarino L, de Haan S. Biocultural diversity for food system transformation under global environmental change. *Frontiers in Sustainable Food Systems*, 2021, **5**: 685299