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Towards organic agriculture as a pathway to agricultural sustainability: A review

Majeed Kadhim Abbas*[1], Ali Sabah Al-Hassan[2]

[1]College of Agriculture Tecniques/Al-Mustaqbal Private University, Babylon, Iraq
[2]College of Agriculture/Al-Qadisiyah University, Al-Diwaniyah, Iraq

***Corresponding author:** Majeed.Kadhim.Abbas@uomus.edu.iq
ORCID: https://orcid.org/0000-0001-8212-6819

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Abstract: Organic farming is among the most rapidly expanding industries in agriculture. Organic agricultural strategy employs organic fertilizers, while prioritizing methods such as crop rotation and companion planting to ensure sustainable agriculture. To complete the output, we reviewed 50 studies that examined sustainable agriculture; its components and methods. Furthermore, we identified organic farming, its advantages, challenges and contribution to sustainable development. Sustainable development is characterized as progress that satisfies current demands without jeopardizing the capacity of future generations to fulfill their own requirements. This is achieved through resource utilization, investment direction, technological advancement, and institutional transformation. Human, economic, and social development are critical domains for attaining sustainable development. Agriculture is universally acknowledged as an essential element of sustainable development over the long run. Sustainable agriculture is characterized by the effective use of agricultural resources to fulfill evolving human requirements, while preserving or enhancing environmental quality and conserving natural resources. Organic farming gained prominence in the 1970s owing to the growing awareness of the harmful environmental effects of some synthetic pesticides and fertilizers. It denotes a system that predominantly avoids or eliminates synthetic inputs, including inorganic fertilizers, pesticides, hormones, and similar substances. Organic farming is a production system that preserves the integrity of soil, ecosystems, and human health. It depends on natural processes, biodiversity, and cycles adapted to local conditions, rather than on inputs having detrimental impacts. The principles of health, ecology, justice, and compassion serve as the foundational pillars of organic agriculture. We may draw the conclusion that organic farming is a successful strategy for preserving environmental equilibrium and protecting natural resources like soil, water, air, forests, biodiversity, and so forth. Agricultural productivity is increased by organic farming's creative and sustainable methods.

Key words: Crop rotation, Organic agriculture, Organic fertilizer, Soil management, Sustainability.

Introduction

Sustainability aims for the perpetuation of an activity or system, comprising various interconnected elements, components, or subsystems that collectively maintain the integrity of that activity (Menash, 2019). Sustainable development is characterized as a harmonious equilibrium of economic development, environmental conservation, and social well-being for all civilizations worldwide, operating within the planet's inherent limits (Laurett et al., 2021). Sustainability does not imply that a system possesses infinite longevity; instead, it is characterized by a lifespan that aligns with its temporal and geographical parameters.

The substantial global population imposes significant demand on resources, with consumption rates increasing. Extensive areas of forest and farmland are being compromized due to urban populations' demand for housing, sustenance, water, and energy for transportation, among other needs. Urbanization degrades agricultural land, forests, and wetlands, while also modifying soil fertility and disrupting wildlife habitats. Consequently, there is a significant necessity to rectify the situation to ensure that humans can experience a clean, safe, and sustainable environment (de Jong and Vijge, 2021). The substantial increase in food demand cannot be met using traditional agricultural methods. Therefore, modern agricultural methods must be employed to produce adequate food for the rapidly expanding global population.

Modern agriculture is an intricate system that incorporates advancements and practices utilizing high-yield crops, chemical fertilizers, pesticides, fungicides, and several other methods (Gamage et al., 2022). The excessive exploitation of resources has led to numerous adverse effects due to the lack of sustainable procedures. Agriculture affects all 17 Sustainable Development Goals, both directly or indirectly (Lu and Wu, 2022). The eradication of poverty, the foremost Sustainable Development Goal, is unattainable without ensuring food security. Achieving Sustainable Development Goal 2, which aims

for zero hunger, necessitates the provision of sufficient, safe, and cheap food for all individuals (Pânzaru et al., 2023). The third Sustainable Development Goal, optimal health, commences with adequate nutrition. Likewise, the achievement of Goal 4, which prioritizes quality education, depends on the availability of nutritious foods, as they are vital for optimal learning. Gender equality, identified as Goal 5, may improve agricultural productivity, as countries commonly facing economic crises are generally supported by gender dynamics (Arora-Jonsson, 2023). Consequently, Goal 5 is related to the other sustainability objectives.

Sustainable agriculture involves altering many agricultural methods to guarantee environmental protection while offering innovative and economically viable solutions for farmers, labourers, consumers, and other stakeholders in the food supply chain. It has the potential to improve water security. Individuals who partake in nutritious diets regard clean water and sanitation as the sixth objective (Linderhof et al., 2021).

Sustainable agriculture

Definitions of sustainable agriculture

Sustainable agriculture refers to the effective management of agricultural resources to address evolving human demands while preserving or enhancing environmental quality and safeguarding natural resources. In 1989, the American Society of Agronomy articulated a comprehensive definition of sustainable agriculture: "Sustainable agriculture is that which, in the long term, enhances the environmental quality and resource base on which agriculture depends; provides basic human needs for food and fiber; is economically viable; and enhances the quality of life for farmers and society as a whole" (ASA, 1989). Sustainable agriculture functions within the constraints of physical and biological resources, with socio-economic capacity and quality.

Douglas (1984) posited that sustainability should be regarded as lasting food adequacy, requiring agricultural systems to increasingly depend on environmental variables and refrain from exhausting their natural resources. Sustainability as care denotes that agricultural systems are founded on a deliberate ethical framework concerning the interrelations among humans, future generations, and other species within the natural environment. Sustainability in society requires that agricultural systems are just**.** Agricultural systems are unsustainable when land, income, and power are distributed unequally and inequitably. Social conflicts and unrest in diverse locations worldwide often stem from the exploitation of these disparities.

A definition of sustainability must acknowledge its several dimensions: physical, economic, environmental, cultural, social and ethical. Sustainability may only be delineated within a systemic framework, particularly after determining what requires preservation. Establishing borders is challenging because of the multi-tiered structure of agricultural systems, encompassing the soil system, cropping or farming system, agroecosystem, and extending to broader regional, national, and global levels (Lynam, 1994). Sustainable agriculture seeks to generate adequate food to meet population demands while maintaining soil fertility and reducing environmental impact. Sustainable agricultural systems are defined by decreased toxicity and energy consumption while maintaining productivity and profitability. It is, thus, enables lucrative output. Also, preserves environmental quality, optimizes natural resource utilization, provides consumers with high-quality and economical products, reduces dependence on non-renewable resources, enhances the quality of life for farmers and rural communities, and guarantees sustainability for future generations (Zakirova et al., 2020).

Components of sustainable agriculture

Economic, human, and social development are essential elements for achieving sustainable development (Moallmi et al., 2020). Food security is critical for human growth, including various dimensions, including health, education, housing, longevity, and vital services. The declining per capita availability of cultivable land and water, together with the imperative for augmented agricultural production to meet rising human needs, resulted in the unrestrained use of the following components that are essential to sustainability (Gamage et al., 2023):

Production: An augmentation in agricultural output is inevitable owing to the continuous decline in per capita arable land. Ensuring productivity per unit area within the land's productive capacity is essential for the sustainability of an agricultural production system.

Economic viability: Although economic viability is inherently linked to production, it is neither constant nor stable. The demand for agricultural products varies according to the dynamics and specific needs of the human population, alongside the agricultural and non-agricultural policies enacted. Economic viability for the farmer is crucial for the sustainability of agriculture.

Environmental Viability: It is essential to maintain and improve the quality of natural resources including; land, water, air, and biodiversity to maintain biological production and ecosystem services for sustainable agriculture. Preserving the environmental integrity of agricultural production systems is more intricate than that of natural ecosystems, as agroecosystems are human-modified systems with significant goals.

Social Acceptance: The fourth element of sustainability, social justice and equality, is more intricate. This phenomenon is external to the farm and natural resources; it pertains to the human values that affect agricultural practices and the degree of acceptance of technology aligned with the social norms of the agricultural community.

Sustainable agriculture methods

Organic farming exemplifies sustainability in global agriculture, serving as an efficient method for mitigating the environmental impact of sustainable development. The enhanced utilization of organic resources in agriculture might

mitigate adverse environmental effects by maintaining natural cycles and promoting ecological recovery. Organic farming can substantially diminish the reliance on chemical fertilizers, pesticides, growth hormones, and feed additives in livestock operations (Gamage et al., 2023). Sustainable farming, in contrast to intensive agriculture provides significant potential for environmental enhancement and the conservation of natural resources. Numerous solutions share overlapping concepts that are sustainable in the long term and may be entirely organic or predominantly so. The following few sustainable farming strategies and practices exemplify the several approaches to attaining significantly more sustainable agriculture.

(1) Mixed cropping or diversified cropping cultivation: This is an age-old practice wherein two or more crops are cultivated concurrently inside the same field. Intercropping is a well-known and beneficial agricultural strategy for achieving success in organic farming (Yu et al., 2022).

(2) Crop rotation: It refers to the systematic cultivation of various crops in successive seasons on the same agricultural area. This method regulates pests and pathogens, enhances soil fertility, and mitigates soil erosion. Soil typically cannot sustain its viability under the incessant cultivation of a single, high-yield crop, as certain nutrients essential for the crop are entirely exhausted while others remain unused, resulting in a significant nutritional imbalance in the soil (Li et al., 2019).

(3) Soil Management: Soil is a finite resource, and sustainable agriculture aims to safeguard and preserve soil health. Healthy soil is a crucial element of sustainable agriculture, since it conserves water and nutrients while fostering robust crop plants that exhibit reduced vulnerability to pests and diseases. Consequently, soil must be safeguarded and cultivated to guarantee sustained productivity and stability. Protection strategies encompass the implementation of cover crops, compost, reduced tillage, and soil moisture conservation to enhance the soil's water retention capacity (Titirmare et al., 2023).

Organic farming

What is organic farming?

The United States Department of Agriculture (USDA) characterizes organic farming as a method that eschews and substantially diminishes the use of synthetic inputs, such as inorganic fertilizers, pesticides, and hormones. Organic farming relies on crop rotation and the use of plant residues, animal dung, mineral rock supplements, and biological nutrient transport mechanisms to ensure optimal plant protection. It is an agricultural approach that preserves soil health, ecosystems, and human welfare. It depends on biological processes, biodiversity, and cycles tailored to local conditions, instead of utilizing inputs with detrimental effects.

Organic farming is defined as an environmentally sustainable and efficient agricultural system that maximizes the use of natural resources, prioritizing internal farm resources while minimizing external inputs. It also eliminates the use of synthetic chemical fertilizers, pesticides, genetically modified organisms, growth regulators, and concentrated feed additives. It depends on crop rotations and organic fertilizers. It additionally relies on preventative and biological pest management (Mohan et al., 2022).

Organic agriculture amalgamates traditional and innovative methods to improve the communal environment, promoting equitable connections and a superior quality of life for all stakeholders. It enhances resilience to the detrimental impacts of climate change by bolstering agroecosystem robustness. It produces resilient, environmentally viable agricultural systems that endure temperature fluctuations and drought while mitigating soil erosion. It additionally promotes sustainability, environmentally responsible management, conservation strategies, and bioregeneration efforts. Thus, organic agriculture promotes a sustainable lifestyle for future generations. The International Federation of Organic Agriculture Movements (IFOAM) has delineated four principles of organic agriculture to enhance environmental management for secure agricultural production (Milovanov, 2019):

1. The Health Principle: Organic agriculture must enhance and sustain the health of humans, earth, plants, and animals as an interconnected entity.
2. The Environmental Principle: Organic agriculture must uphold agricultural cycles and living ecosystems, operate in harmony with them, and enhance their sustainability.
3. Principle of Justice: Organic agriculture must establish partnerships that guarantee equity within the communal environment and opportunities for life.
4. The Principle of Care mandates that organic agriculture be conducted responsibly and preventatively to safeguard the health and welfare of current and future generations, together with the environment.

Advantages of organic agriculture

Organic agriculture is an effective approach for reducing environmental and ecological impacts on sustainable development. It represents the notion of worldwide agricultural sustainability. Integrating supplementary organic materials into agricultural practices alleviates adverse environmental impacts by preserving natural recovery processes. Organic agriculture possesses the capacity to improve food quality. Moreover, organic farming predominantly prohibits the utilization of synthetic fertilizers, pesticides, growth hormones, and feed additives in livestock management. It is important for preserving soil fertility, providing plant nutrients, managing pests naturally, and controlling weeds, insects, and other disturbances. The financial costs of organic farming are somewhat lower than those of conventional farming. Furthermore, organic agriculture aids farmers and local communities in adjusting to the subtle impacts of climate change. Furthermore, it meets certain requirements for effective adaptation strategies (Gamage et al., 2023) (Figure 1).

Organic agriculture offers solutions to various modern challenges in agriculture and food production. The ideals of health, environment, justice, and compassion form the essential pillars of organic agriculture. It is abundant in nutrients and predominantly devoid of pesticide residues and chemicals (Hammed et al., 2019; Pandiselvi et al., 2017). Organic livestock

enterprises produce animal products free from antibiotics and other medications. They alleviate the growing health crisis caused by the dangerous spread of antibiotic-resistant pathogens.

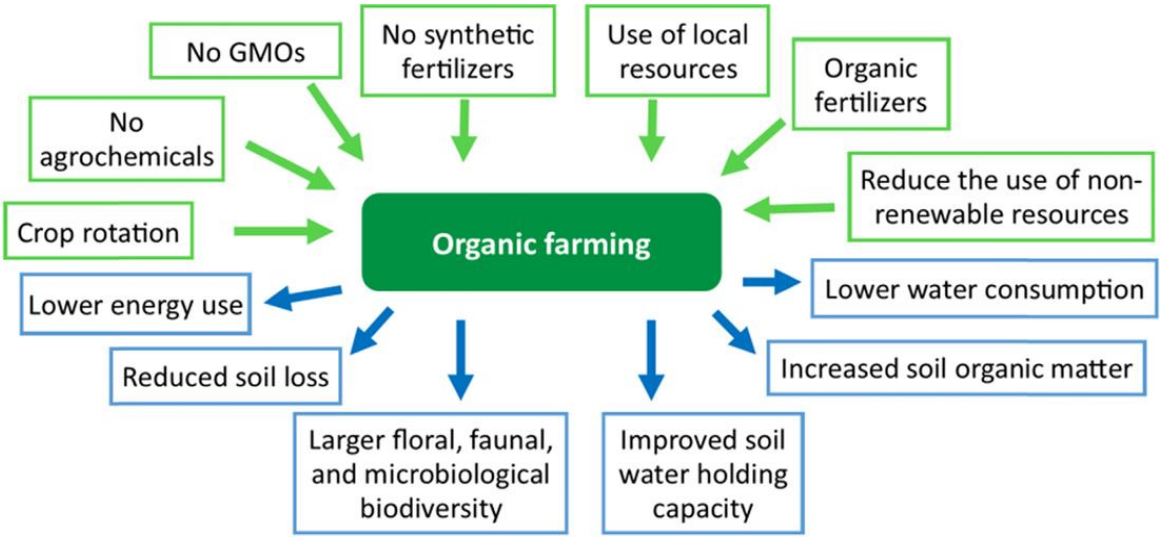

Figure 1. Key Practices and impacts of organic agriculture (Gamage et al., 2023).

Organic farming enhances natural resources, including water, air, and wildlife, which are vital for sustaining a healthy ecosystem and generating nutritious food, especially when organic produce contains lower amounts of pesticides and nitrates (Maharjan et al., 2021). Studies demonstrate that adopting organic farming allows a conventional farmer to reduce production costs by more than 25% compared to traditional practices. This obviates the necessity for costly synthetic fertilizers and pesticides, diminishes soil erosion by up to 50%, and enhances crop yields by as much as fivefold. Organic farms can significantly increase animal populations, especially in lowland regions (Willer et al., 2020, 2021). Organically farmed foods provide health benefits since they lack synthetic chemicals and genetically modified organisms (GMOs), corresponding with the rising customer preference for natural, unadulterated products. Research indicates that organic crops typically have higher levels of antioxidants, lower concentrations of cadmium (Cd), and fewer pesticide residues than conventionally grown crops (Bara´nski et al., 2014). On average, organic tomatoes contain higher quantities of vitamin C than ordinary tomatoes (Mitchell et al., 2007). Organic farming alleviates any health risks linked to pesticide residues by reducing the use of synthetic pesticides. This approach may reduce the incidence of some diseases and chronic conditions (Forman and Silverstein, 2012).

Contribution of organic agriculture to sustainable development

The First Green Revolution arose due to declining agricultural productivity and rising malnutrition, which promoted the widespread implementation of industrial agricultural techniques, such as pesticides and mineral fertilizers, in developing countries (Nelson et al., 2019). During this period, nascent sustainable agriculture practices were implemented, albeit on a limited scale.

The demand for organic farming has increased due to concerns regarding the impact of chemicals on the environment and human health. Organic farming rose to prominence in the 1970s, as awareness of the harmful environmental impacts of certain synthetic pesticides and fertilizers grew. A compelling study was undertaken to investigate weight fluctuations over time in relation to organic food consumption, involving 62,000 participants from the NutriNet-Santé project. The rise in body mass index (BMI) over time was less significant in those with high organic food consumption compared to those with low consumption. A 31% decrease in the risk of obesity was noted in individuals with high consumption of organic food compared to those with low consumption (Kesse-Guyot et al., 2017). Agriculture is considered a fundamental component of sustainable development (FAO, 2018), since goal 2 of the 2030 Agenda for Sustainable Development aims to end hunger, and agriculture is a key part of that goal. Nevertheless, the agriculture sector contributes to all other Sustainable Development Goals to varying degrees.

A key advantage of organic farming is its capacity to reduce greenhouse gas emissions, such as methane and nitrous oxide, emitted into the atmosphere (Twarog, 2023). Bocean (2025) forecasts significant reductions in greenhouse gas emissions, projecting a decrease of over 14 percent from 2008 levels, as organic farming is anticipated to encompass over 23 percent of agricultural land by 2035 in the European Union (EU).

Organic agriculture also ensures the availability of nutritious food alternatives. Numerous individuals are concerned about the pesticides and chemicals employed that may taint their food; therefore, organic food production could alleviate consumer anxieties and increase consumption. Researchers at the University of California, Davis, discovered that organically cultivated foods contain up to 58% more antioxidant polyphenols than conventionally cultivated foods. Other researchers have established that increased levels of polyphenols function as a natural defence mechanism for plants against numerous pests, hence reducing the necessity for pest management costs. The synthetic fertilizers employed by numerous farmers need significant fuel consumption during manufacture; therefore, reducing dependence on synthetic

fertilizers leads to decreased fuel combustion. Organic farming significantly reduces these hazards by avoiding synthetic inputs, although proper management is essential to prevent problems such as nutrient leaching (Ramasamy et al., 2024).
Moreover, the utilization of non-renewable energy sources serves as the principal driver of climate change, while conventional food production constitutes the foremost source of greenhouse gas emissions. Sustainable farmers endeavour to utilize their resources judiciously, aligning with their objective of environmental conservation (Malik et al., 2020).
The principal aim of organic farming is to protect and maintain soil health. Nutrient-rich compost fertilizer made only from organic matter is employed, augmented with minerals such as rock phosphate, and crop rotation is practiced. Water pollution has become a critical global concern. The exclusion of pesticides in organic agriculture markedly diminishes the likelihood of groundwater contamination. Organic farms markedly diminish the risk of groundwater contamination by eschewing synthetic fertilizers and pesticides (Santos et al., 2023). Comprehensive studies in Europe indicated that places with more organic matter exhibited 40% lower nitrate concentrations in groundwater relative to conventionally farmed areas.

Challenges of organic farming

Organic farming faces challenges including the availability of organic nutrients, low productivity, efficient pest and disease management. Other challenges such as soil fertility maintenance, yield inconsistencies, economic and logistical obstacles are also counteracting organic farming. Obtaining appropriate organic crop certifications and market access, as well as promoting awareness of the importance of organic farming and providing training are also some obstacles (Panday et al., 2024). Combining organic agriculture with advanced technology is crucial for overcoming the challenges and constraints facing organic farming.
One notable drawback of organic farming is its high expenses and labour-intensive techniques, which may become unsustainable or unprofitable. The expenses are transferred to the consumer, resulting in organically farmed food being more expensive than conventionally produced food.
Identifying the sources and application methods of organic nutrients is a significant challenge in organic agriculture. In contrast to conventional agriculture, which utilizes various synthetic fertilizers to fulfil plant nutritional needs, organic farmers possess a more restricted selection of alternatives. Organic inputs, including compost, animal manure, and other organic materials like composted bone fragments, can vary greatly in their nutrient content. This feature means that they need to be carefully managed to keep the soil's fertility balanced (Gosling and Shepherd, 2005). Furthermore, the availability of organic fertilizers in the market is an additional concern. Due to their reduced nutritional value compared to synthetic fertilizers, they require significant quantities; hence, they create transportation and handling challenges (Muluneh et al., 2022).
In organic farming, controlling soil fertility can be very difficult, especially with organic fertilizer. Unlike inorganic fertilizers, organic fertilizers have a reduced nutritional concentration and do not provide a distinct nutrient supply. They contain several nutrients in organic forms, requiring mineralization to release the components vital for plant uptake. However, many factors influencing mineralization encompass soil attributes such as pH, moisture, temperature, and organic matter content. Thus, regulating the essential and recommended nutrient levels can be difficult, especially for crops with high nutrient demands (Mamatha et al., 2024).
Despite its advantages for the environment and human health, organic farming occasionally faces the challenge of declining yields in comparison to conventional farming, known as the "yield gap." Generally, organic yields are usually inferior to conventional yields. From 5% lower organic yields in rain-fed legumes and perennials on weak-acidic to weak-alkaline soils to 13% lower yields when optimal organic practices are used to 34% lower yields when conventional and organic systems are most comparable, the yield disparities are highly contextual and influenced by system and site characteristics (Seufert et al., 2012). This is because organic farming depends on the natural breakdown of organic fertilizers, such compost, to release nutrients (Gosling and Shepherd, 2005). Unlike conventional agriculture, which uses synthetic fertilizers, organic farming lacks the flexibility to adjust nutrient availability based on crop needs, resulting in reduced yields. The reliance on synthetic pesticides and herbicides in conventional agriculture poses challenges for controlling insect pests, weeds, and pathogens in organic farming. Because organic farming does not use synthetic pesticides, machine weeding is used, which may not adequately control the aggressiveness of certain weed species, resulting in increased costs (Melander et al., 2013).

Effects of organic fertilizers on soil

Organic fertilizers are a diverse assortment of materials employed in agriculture to improve soil properties and provide nutrients. Their attributes and benefits depend on their origin, processing techniques, and the context of their application to the soil (Jain et al., 2020). Organic fertilizers primarily share the characteristic of offering a sustainable alternative to alleviate the detrimental effects of chemical fertilizers on long-term soil fertility (Shi et al., 2021). They reduce susceptibility to climatic stresses and weather variability while minimizing agricultural environmental impacts (Smith et al., 2019).
Organic fertilizer is acknowledged for improving soil's physical properties, despite its relatively low nutrient content. While inorganic fertilizers provide nutrients directly and quickly, but they can harm the soil and the environment if used excessively (Aziz et al., 2019; Bergstrand, 2022). The only use of inorganic fertilizers leads to the decline of soil organic matter, modification of soil pH, degradation of soil structure, and environmental pollution. Thus, a comprehensive strategy that merges inorganic and organic nutrient management represents a sustainable and economically feasible solution for soil management, improving soil characteristics and fertility while reducing environmental effects (Gamage et al., 2023).

The effectiveness of organic fertilizer application depends on various factors, including the compatibility of fertilizers with soil characteristics, crop varieties, climatic and topographical conditions, irrigation and tillage methods, as well as the timing and technique of application, along with details concerning the source and production method of the fertilizer. Deficient fertilizer production can result in detrimental effects, with the contamination of source materials by metals and other pollutants being a major concern (Mahjoory et al., 2011).

The application of organic matter to improve soil relates not only to donate fertility but also to better modify physical, chemical, and biological properties, such as aeration, permeability, water retention, and nutrient retention capacity. The benefits depend on the specific organic fertilizers used and the characteristics of the soil. Organically maintained soils exhibit improved water retention and higher infiltration rates due to their increased organic matter content (Bhatt et al., 2017). Parameters like bulk density, aggregate stability, mean weight diameter, soil strength, hydraulic conductivity and infiltration rate are essential in governing soil functions.

Furthermore, by prioritizing soil health and using techniques such as crop rotation and green manure, organic farming enhances soil fertility and fosters biodiversity. It can significantly improve climate resilience and diminish the vulnerability of agricultural cropping systems (Yu et al., 2022).

These activities are essential for mitigating soil erosion, with estimates suggesting that organic approaches can reduce erosion potential by more than 61% (Seitz et al., 2018).

The application of organic compost in land management improves soil organic matter. Agriculture has a substantial role in climate change, responsible for around 22% of worldwide anthropogenic greenhouse gas emissions; organic treatment has shown a decrease in total GHG emissions per unit area (Thomas and Gurshaminder, 2024).

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