Chapter

Improving the Sustainability of Agriculture: Challenges and Opportunities

Gebeyanesh Worku Zerssa, Marta Hailemariam and Kirubel Teshome Tadele

Abstract

The agricultural practice is a foundation for all global development. Increasing its production and productivity may affect the land capacity in the future if not managed sustainably. Sustainable agriculture could be one way to preserve land use potential. However, several obstacles impede its implementation, such as high reliance on external inputs to boost short-term output, lack of innovative technology in developing countries, and climate change impacts. Despite these obstacles, a variety of tackling options have been proposed, like decreasing the excessive usage of artificial fertilizer and relying on locally available organic materials as sources of plant nutrients. Improving small-scale irrigation practices by managing their negative environmental effects in small-scale agriculture could also enhance sustainable agriculture. This chapter briefly overviews sustainable agriculture, its components, and the potential and obstacles to achieving overall sustainability in both developed and developing countries.

Keywords: organic fertilizer, small-scale farms, sustainable agriculture, conventional agriculture, food security

1. Introduction

Agriculture, which supplies all of the world's food and occupies 40% of the available land, is both the largest industry in the world and a major land use [1]. The economic growth of the world is heavily dependent on the agricultural sector. Developing countries continue to face the most pressing difficulties due to the increasing population and related food security. In the twentieth century, enhancing food production was only possible by increasing agricultural output with outside inputs like mineral fertilizers and pesticides [2–4]. Modern agricultural techniques built on the green revolution have led to a significant increase in grain productivity at the expense of depleting natural resources. Soil fertility and environmental resilience suffered significantly because of agriculture's externalization. Thus, it calls for different strategies that should train farmers to use their traditional knowledge to produce more grains with fewer outside inputs. The method is referred to as sustainable agriculture, which is currently essential.

The integrated usage of a variety of soil, nutrients, and pest management techniques including manure, crop residue, mixed cropping, and crop rotations has been encouraged in sustainable agriculture systems [5–8]. By minimizing soil degradation, these approaches increased soil quality, nutrient pools, climatic resilience, and ecosystem restoration, increasing the socioeconomic status of farmers. However, switching to exclusively organic management of agroecosystems is difficult due to the relatively lower supply of organic fertilizers. In order to improve soil quality and nutrient pools, integrated nutrient management (INM), which combines increased organic inputs into the soil with a balanced application of inorganic fertilizers, is encouraged [1, 9]. Briefly said the fundamental strategy of sustainable agriculture is that we must produce more while using fewer natural resources. Many new alternative practices, such as conservation agriculture and organic farming for soil management, water-saving agronomic practices, INM, biofertilizers, and precision agriculture, have been proposed to achieve the fundamental goals of sustainable agriculture.

There is no debate that conventional agriculture (CA) has high productivity, but it simultaneously generates environmental and social impacts of global concern [5, 10]. CA has an impact on the environment through greenhouse gas emissions, water quality decline, soil erosion, livelihoods, and food security [5, 6]. Currently, CA practices are contributing to the degradation of important ecological processes that support life on Earth. These practices are responsible for climate change, the degradation of the biosphere, the destruction of the land system, and the eutrophication of the oceans as a result of mineral fertilizers application [8, 11]. This chapter explores the viability of using sustainable agriculture practices in order to achieve global food and nutritional security sustainably [7, 12, 13]. Furthermore, it addresses the obstacles and possibilities for improving the practice in developed and developing countries. Disseminating sustainable agriculture methods to the field level through academic curricula, seminars, symposiums, and research is essential to achieving a brighter future.

2. Major components of sustainable agriculture

Agriculture could become sustainable with careful management of its components. The major components of sustainable agriculture are building healthy soil and preventing erosion, managing water wisely, increasing carbon sequestration, increasing resilience to extreme weather, and promoting biodiversity (**Figure 1**). In this chapter, the components related to soil ecosystem have received the most attention because it substantially impacts all other components and sustainable agriculture. Application of organic fertilizers like compost, green manure, vermicomposting, and cover crops supported by a careful rotation of crops are used in sustainable agriculture to maintain and enhance soil fertility. Maintaining healthy soil, increasing carbon sequestration, and resilience to extreme weather are interconnected and could be attained through these methods [8, 14]. Besides, locally accessible organic wastes could be transformed into plant nutrients, reducing the negative impact of artificial fertilizers on sustainable soil management. Developing guidelines to reuse different wastes as plant nutrients is crucial to reducing the use of synthetic fertilizer. The primary issues with artificial fertilizer use in industrialized countries are excessive application. However, low-rate applications are a problem in developing countries. Land resources and agricultural production are strongly impacted in both excessive

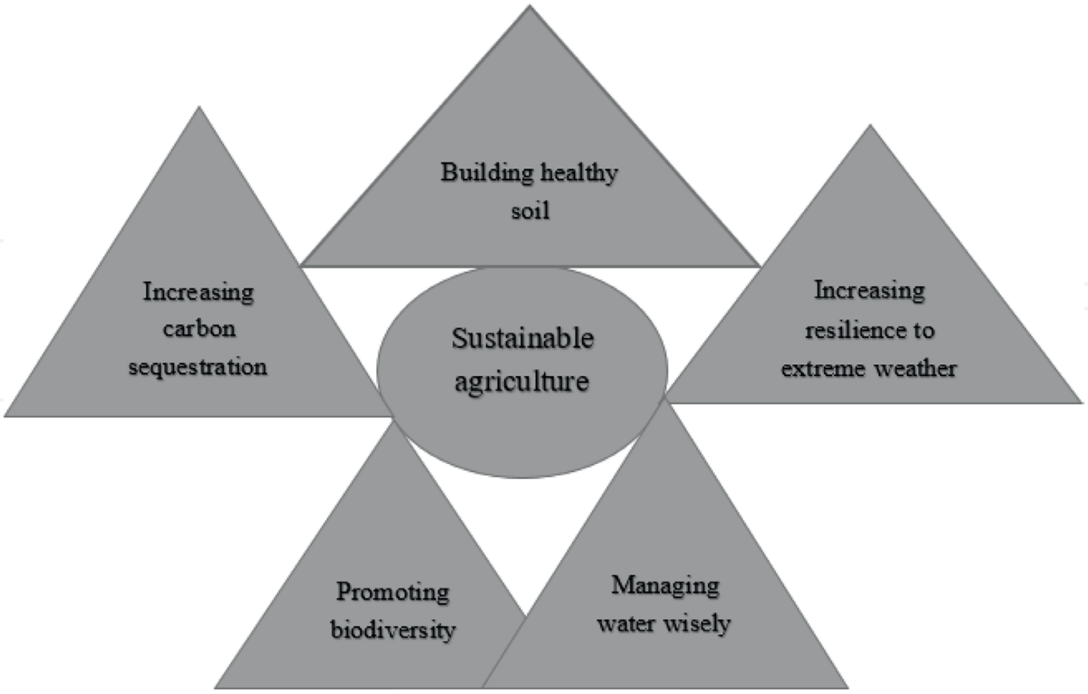

Figure 1.
Components of sustainable agriculture.

and low application scenarios. Supplementing with organic fertilizer made from waste materials through composting is essential to balancing the constraint caused by excessive and low application [9, 15]. Not only does building healthy soil boost productivity, but it also makes the soil more drought-resilient and increases carbon sequestration. As a result, it might be easier to adapt to a changing climate and reduce greenhouse gas emissions [16–18]. Increasing soil organic matter (SOM) content in the soils can increase water retention more at field capacity by improving bulk density and porosity and thus increase the plant available water capacity (PAWC) [19–21]. The availability of SOM material may affect how much PAWC increases. Thus, building up the SOM content of soils can make them as well as agroecosystems climate-resilient. Increasing soil resilience to drought could ensure optimum crop yield in dry seasons [20]; consequently, it improves sustained yield intensification.

3. Major challenges for achieving overall sustainability in agriculture

3.1 High use of mineral fertilizer and other chemical inputs

Due to the extensive use of synthetic chemical fertilizers and pesticides, the agricultural sector of developed countries is one of the most significant sources of environmental pollution [22–24]. To increase productivity per unit area, agricultural systems around the world use a lot of chemicals including fertilizers, insecticides, and herbicides [22]. These chemicals and fertilizers contribute to a number of issues, including soil, water, and air pollution, decreased input efficiency, decreased food quality, soil degradation, a lack of micronutrients in the soil, toxicity to various beneficial living organisms present above and below the soil surface, and decreased production. Additionally, overuse of synthetic nitrogen fertilizer may result in large atmospheric emissions of nitrous oxide [25].

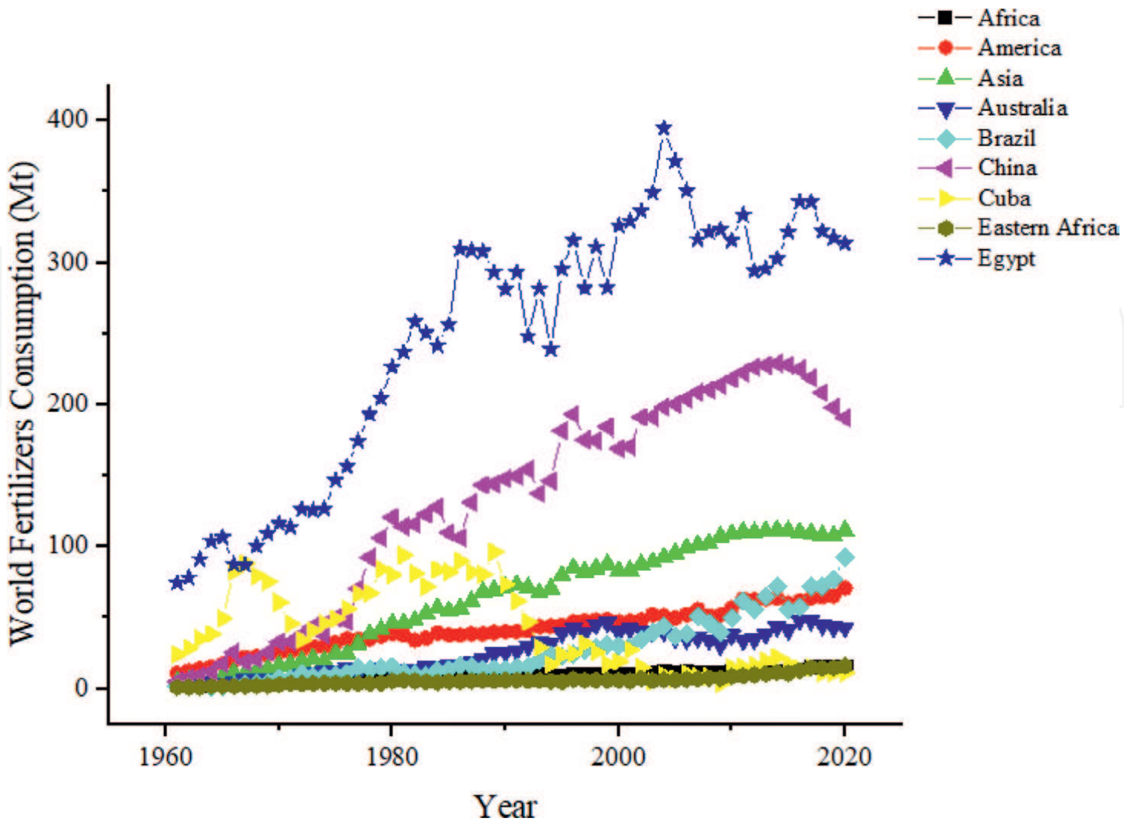

Figure 2.
World fertilizers consumption (Mt). Sources: IFA and FAOSTAT [26, 27].

The consumption of fertilizer worldwide has greatly increased since 1961 (**Figure 2**). Global research indicates that the production of synthetic N fertilizers that are added to crops has increased about sevenfold, whereas the yield production of crops has increased by almost 2.4 times [28, 29]. Furthermore, nearly 60% of all synthetic chemical fertilizer production was made up of nitrogen. The significant attention paid to this fertilizer significantly affects natural soil ecosystems, which in turn impacts sustainable agriculture. As a result, producing agricultural products that are chemical-free and high in nutrition is necessary for both human and animal use. To prevent the degradation of natural resources, the focus should be placed on producing high quality and quantity food [29]. Overall, using excess mineral fertilizer has a negative influence on sustainable agriculture.

3.2 Lack of advanced technology

Adoption of advanced technology by smallholder farmers can enhance their income and livelihood [30–32]. In most developing countries, agricultural practices are dominated by many traditional approaches. For instance, compared to other regions, the sub-Saharan African countries, which rely primarily on rain-fed agriculture, have been adversely affected by climate change and variability [33, 34]. Due to low adoption of advanced irrigation practices like drip irrigation and water harvesting, the region is highly susceptible to climate change and variability. Drip irrigation is a technology that conserves water and reduces water losses through drainage. This technology was developed in response to the incentives present in Israel, a country that suffers from a severe water scarcity problem and which made a concerted effort to develop water-conserving technologies [30]. It is critical to prioritize smallholders' needs in agricultural development programs in an area where they account for an estimated 80% of farms and generate the majority of the region's food [30].

3.3 Climate change impacts

Climate change and variability are the greatest challenging factors to sustainable agriculture (SA) in the world [16, 21]. Climate change and variability affect the cereal production system through irregular rainfall distribution, flooding, and increasing mean temperature [35]. Most developing countries are highly vulnerable to climate variability due to extremely high dependence on rain-fed agriculture, low development of irrigation schemes [16, 36, 37]. Vulnerability to climate variability is also exacerbated due to a lack of improved technologies, lack of effective early warning systems, and small and fragmented land size [35]. For instance, in Ethiopia, it is anticipated that agricultural production will decrease by 6–33% between 2030 and 2050 due to the effects of climate change and variability [14, 38]. This will cause food and nutrition insecurity and increases the loss of life in the country. The effects of climate change on agriculture will depend on the rate and severity of the change and how successfully farmers can adapt. The impact of climate change and variability is very evident in developing countries as compared to developed countries. In order to guarantee sustainable agriculture and food security, developing countries need to receive a lot more attention.

4. Opportunities to enhance sustainable agriculture

There are numerous potentials to expand sustainable agriculture worldwide. Some of the opportunities are region-specific, while others can be applied everywhere [11, 13, 30]. To feed the world's growing population without depleting the land's capacity and transfer for future generations, SA must be adopted. Some of them include focusing on INM, expanding the use of small-scale irrigation, and promoting the adoption of locally accessible organic nutrients like compost, vermicompost, biofertilizer, and biochar application.

4.1 Focusing on locally available organic resources

4.1.1 Compost application

Compost is a plant- and animal-derived organic material aerobically digested by mesophilic and thermophilic bacteria [15, 22]. Compost application in agriculture can enhance nutrients and organic matter in the soil. The improvement of SOM, soil humus, soil microbial biomass, enzyme activity, and resistance to pests and diseases are among the outstanding benefits of compost application [8, 39, 40]. Applying compost to the ground can boost the soil's capacity to store carbon, which in turn reduces the impact of global warming. Additionally, adding compost to soil can increase the cation exchange capacity of the soil and improve the availability of both macro and micronutrients for plant uptake. It can enhance the soil bulk density, porosity, and water-holding capacity, increasing plants' tolerance to water shortages. Due to a number of positive impacts, compost application may be suggested as a practical tool in sustainable agriculture. For instance, farmers could obtain compost more easily than inorganic fertilizer because they could make it by themselves from locally available waste resources; it could enhance all soil properties (i.e., physical, chemical, and biological) and could provide all essential plant nutrients for plants [8, 9, 22]. Compost has numerous advantages; therefore, farmers should combine it with other soil-management techniques to ensure sustainable crop production.

4.1.2 Vermicompost application

Earthworms are employed in the vermicomposting process to turn organic waste into a humus-like substance known as vermicompost. It is a mesophilic technique that makes use of bacteria and earthworms that are active between 10°C and 32°C. The process is faster than composting; because the material goes through the earthworm gut, thereby leading to the creation of earthworm castings [41, 42]. Vermicomposting, or worm composting, produces a rich organic soil amendment containing a diversity of plant nutrients and beneficial microorganisms. Vermicompost improves soil physicochemical properties of the soil and hence increases crop yields to improve the livelihood of the community. In recent years, various research studies have reported the significant role of vermicompost in crop production in different agroecological conditions. Economically, it is affordable for poor farmers, and it is environmentally suitable, making it efficient for sustainable crop intensification. Studies have shown that applying vermicompost leads to enhanced nutrient availability and positive effects on soil properties, productivity, profitability, and resilience [41, 43, 44].

4.1.3 Biofertilizer application

Biofertilizers are types of fertilizer that contain different microorganisms, which can enhance microbial activity in soil [45, 46]. They can convert the organic nitrogen into available forms for plant use such as nitrate and ammonia, improve soil porosity and improve the resistance of plants against pathogens. Biofertilizers are one of the methods used in organic agriculture practices. They are the most important biotechnology needed to enhance the expansion of organic farming, sustainable agricultural development, and alternative clean agriculture [46–48]. Biofertilizers are natural and organic fertilizers that help to maintain soil with all nutrients and living microorganisms needed for crop health [46, 49, 50]. Biofertilizers are energy-efficient, free pollution and rely on exploiting the ability of some microorganisms such as bacteria, algae, and fungi. Biofertilizers fix atmospheric nitrogen in the soil, root nodules of legume crops, and make it available into the plant [46, 47]. Biofertilizers are low-cost plant nutrient source, eco-friendly and has a complementary role with synthetic fertilizers. They are Rhizobium, Azotobacter, Azospirillum, Blue Algae Green, and Azola. They improve physical and chemical properties of soil such as water-holding capacity, and buffer capacity. Biofertilizers can improve the yield by 10–25% and minimize the use of inorganic N by 25–50 kg ha^{-1} without adversely affecting the soil and environment [45, 47, 51]. It ensures sustainable agriculture by boosting soil resilience, plant productivity, and soil quality.

4.1.4 Biochar application

Biochar is the carbon-rich organic matter that is obtained after heating biomass (corn, rice or wheat waste) in little or no oxygen through a process called pyrolysis [15, 52, 53]. The chemical, biological, and physical features of the soil are changed when biochar is applied as a soil amendment, which substantially impacts soil fertility.

Its effects as a soil amendment improve soil fertility and plant growth, which increases crop output [52–54]. The potential for biochar to increase soil fertility and health could lead to sustainable yield intensification. Many reports stated that biochar application to soils significantly affected crop productivity taking into account soil health and increasing water availability [53–55]. Biochar as soil conditioner reduces nutrient loss by decreasing leaching through increasing cation exchange capacity [54]. It increases water-holding capacity due to its porous structure. It can increase soil fertility of acidic soils, protects plants from diseases, promotes growth of soil microbes, and increase the soil carbon content. Biochar can be used for long-term storage of carbon in the soil, thus decreasing the amount of CO_2 released in the atmosphere [54, 56].

4.2 Integrated nutrient management

INM, which is a comprehensive strategy, including maintaining and continuously adjusting soil fertility and plant nutrient delivery to an optimum level [14, 57, 58]. In order to achieve and sustain maximum production without threatening the soil ecology, adopting INM is a must. It is based on the integration of biological, inorganic, and organic nutrient sources in a specific cropping system while considering regional variables. In addition to having a good impact on the soil nutrient condition, INM can improve SOM and improve water retention and storage. As a result, it can strengthen agricultural systems and enhances soil carbon sequestration. Using INM instead of applying mineral fertilizer in Nitisol increased maize production by up to 18% [9]. Thus, it strongly supports the concept of sustainable agriculture anywhere. Combining applications could boost a farm's economic resilience, particularly for poor farmers in developing countries who cannot afford enough mineral fertilizer. Due to their limited economic capacity, they are unable to afford the significantly rising price of mineral fertilizer. Therefore, due to its substantial benefits for sustainable agriculture, various researchers recommended the adoption of INM rather than sole application [9, 45, 59, 60].

4.3 Adopting small-scale irrigation

The adoption of small-scale irrigation farming as a sustainable agricultural practice could significantly influence ensuring food security [33, 34]. Adopting small-scale irrigated farming as a SA practice is crucial for dry-land farming systems because it guarantees crop production during the dry season. The production of various crops twice or three times a year and boosting the income of rural farm-households are two significant goals that can be achieved by small-scale irrigation. However, the use of small-scale irrigation farming is significantly influenced by the availability of irrigation equipment, access to quality water sources, and awareness of water-saving techniques like rainwater harvesting [31, 33, 34]. Practices that will facilitate the implementation of small-scale irrigation farming are essential since this will substantially impact agricultural income and enable smallholder farmers to adjust quickly to climate change and variability.

5. Conclusion

Food and nutrition security could result from sustainable agriculture without harming the environment for future generations. The goal of sustainable development may be achieved by comprehending its components and managing them appropriately. However, significant reliance on mineral fertilizers, a lack of innovative technologies, and climate change and variability are likely to have an impact on sustainable agriculture. Both developed and developing countries are impacted by the same variables. However, the intensity of the impact is high in developing countries due to low adaptation capacity. Focusing on locally available organic resources, INM, and increasing the use of small-scale irrigation can help to enhance the SA everywhere. These could increase agriculture productivity and ecosystem sustainability due to their high input use efficiencies, reduced use of synthetic fertilizers and pesticides, and improved soil resilience and quality in a changing climate. Effective agricultural policies based on locally developed sustainable agricultural practices, a review of extension services for better information dissemination, and farmer training are required to increase the adoption of sustainable agricultural practices in both developed and developing countries.

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