The Journal of Agricultural Sciences - Sri Lanka
Vol. 19, No 3, September 2024. Pp 462-474
http://doi.org/10.4038/jas.v19i3.10831

Agriculture for Sustainable Development to Empower Smallholder Farming Communities

R. Abdullah[1], M.M.M. Najim[1], and M. Esham[2*]

Received: 04th February 2024 / Accepted: 22nd July 2024

ABSTRACT

Purpose: *Intensive actions implemented to alleviate poverty created many challenges. Millions of people face acute food insecurity; hence, food production needs to be increased to feed the existing and increasing population through sustainable agricultural practices. Sustainable agricultural development is the only way forward to assist humanity.*

Research Method: *TExisting literature on sustainable agriculture was reviewed, explored, understood, described, evaluated, and synthesized and their relationships to sustain smallholder farmers were analyzed.*

Findings: *Technological innovations in increasing resource use efficiency, modern breeding techniques, and renewable energy sources aid in achieving sustainability in agriculture. Technology enhances the adaption of agriculture to climate change and increases productivity and the quality of life of farming communities. Smallholder farms with limited information and transportation need government support to access markets with modern commercialization channels. Women need to be empowered to deliver multiple agricultural roles. Wise use of natural resources, optimum allocation, and utilization of resources are vital in enhancing farm productivity. Technical knowledge, availability of inputs, extension services, and financial support are paramount in maximizing productivity and income from agriculture. Agricultural investments need substantial increments to address food insecurity and adaptation to climate change. Dissemination of research findings and experience in sustainable agricultural production practices in informal and formal ways among all agricultural stakeholders is vital in achieving agricultural sustainability. Minimizing postharvest losses through technologies is essential in minimizing global food insecurity to enhance smallholder farmers' income. Policies related to social, economic, eco-friendly production strategies and environmental aspects directly and indirectly linked to agriculture are vital in these processes. Hence, an integral approach towards the agricultural development of smallholder and subsistence farmers can lead them to sustainability ensuring their food security.*

Keywords: *Farmers, Food Security, Innovation, Poverty, Productivity, Technology*

INTRODUCTION

The development that meets the present generation's needs without compromising the future generations was the concept of Sustainable Development (Butlin, 1989) proposed by the World Commission on Environment and Development in 1987. Millennium Development Goals (MDGs) were formulated by the United Nations in 2000 to implement the concept of sustainable development. In 2015, the United Nations transformed the MDGs into 17 Sustainable Development Goals (SDGs).

The SDGs are supposed to transform the world to end poverty and inequity in all aspects and ensure the world population enjoys health, prosperity, and justice, and as a whole those goals are expected to protect the planet.

[1]Faculty of Agriculture, Sultan Sharif Ali Islamic University, Sinaut Campus, Km 33, Jln Tutong, Kampong Sinaut, Tutong TB1741, Brunei Darussalam.
[2]Department of Agribusiness Management, Sabaragamuwa University of Sri Lanka, Belihuloya, Sri Lanka.

*esham@agri.sab.ac.lk

https://orcid.org/0000-0002-4498-9274

Open Access Article

In the process of alleviating poverty and achieving prosperity, intensive actions are being implemented which in turn has created many challenges such as rapid advances in industrialization, urbanization, and globalization. (Liu *et al.*, 2023) stated that these rapid changes have challenged sustainable development due to the increased vulnerability and instability of rural areas. Hence, concepts of sustainability and sustainable development are prominently linked now with policies on environmental management, and industrial and agricultural production (Ruggerio, 2021).

The world population reached 8 billion in mid-November 2022 and is estimated to increase to 9 billion in 2030, and to 10 billion (UNDESA, 2017) or 9.7 billion (UN, n.d.) in 2050. An increase in population also needs a significant increase in food production. According to (Serageldin, n.d.), over a billion people live below less than a dollar daily under extreme poverty. Every day, about 40,000 people die from hunger and related causes. Eighty percent of the world's population lives in developing countries. About 70 percent of the land and 80 percent of the water in these countries are used by agriculture exerting tremendous pressure on the resource base of those countries. Agriculture, in general, consumes considerable amounts of natural resources where increased consumption may challenge sustainability. Agriculture is also linked with many issues such as diminishing availability of non-renewable natural resources; degradation of soil; damage to the environment due to excessive and improper use of agricultural chemicals etc. which may lead to a reduction in quantity and quality of food (Calicioglu *et al.*, 2019 ; Singh *et al.*, 2019 ; Laurett *et al.*, 2021). Under these circumstances, a 50% increase in food production by 2030 (UN, 2012), 70% increase by 2050 (Dubois, 2011), and between 100% and 110% increase by 2050 (Tilman *et al.*, 2002) will be required to feed the increasing population.

Behnassi and Yaya (2011) reported that food consumption rose rapidly as the world population grew by 73 million annually between 1995 and 2020 which was a 32% rise. Food demand is rising faster than food supply. The food needs of developing countries will increase by 60% in 2030 and will be doubled by 2050 (Alexandratos and Bruinsma, 2012). This increment is mainly to feed the world's increasing population. Alexandratos and Bruinsma (2012) also reported that there is a need to increase world food production by 42% in 2030 and 70% in 2050. According to the Food Security Information Network and Global Network Against Food Crises (FSIN and GNAFC), around 258 million people in 2022 across 58 countries and territories faced acute food insecurity which is an increment of 193 million people compared to 2021 figures (Food Security Information Network, 2023). According to a report by the World Bank (2022), 943 million people will be facing severe food insecurity by 2025. A further population of 956 million people will be facing severe food insecurity by 2028 (World Bank, 2022). Food production needs to be increased to feed not only the existing population but also to cater to the projected population.

As such, agriculture faces multifaceted challenges such as overuse and degradation of natural resources, scarcity of water resources, pollution and contamination of water resources, lack of water or timely unavailability of water, land and soil degradation, encroachment into arable lands, urbanization, inadequate infrastructure, unavailability of human resources or quality of human resources, etc. To face these challenges, agricultural food production needs to be increased which can only be achieved through sustainable agricultural practices.

Agricultural practices can be sustainable if agriculture ensures profitability, environmental health, and social and economic equity. Sustainable agriculture also contributes to food security and ensures food availability, access, utilization, and stability. FAO's vision for sustainable agriculture includes the production of nutritious foods that are accessible to everyone by sustainably managing natural resources where current ecosystem functions are supported and maintained ensuring future human needs (FAO, n.d.). Sustainable Development Goals were proposed as a solution to address most of the above-mentioned issues.

Achievement of Sustainable Development Goals is challenged as it tries to achieve optimum yield increasing farm income but minimizing the use of resources and environmental impacts (Peng *et al.*, 2022). In addition, environmental pollution and climate change are exerting tremendous pressure on agricultural production (Olesen and Bindi, 2002). By 2050, global warming is expected to impact the overall potential agricultural productivity and reduce it by 9 – 12% in developing countries (Le Mouël and Forslund, 2017). Global collective efforts are required to mitigate these impacts through different measures to ensure continued and sustained food production to secure livelihood (Rehman *et al.*, 2022). Collective actions can be taken at international conventions that collectively bind all stakeholders.

Many actions can be taken to attain sustainable

agricultural development increasing yields, producing more from a unit of land or increasing land productivity, minimizing post-harvest losses and food wastes, increasing distribution and access to food, etc. (Boix-Fayos and de Vente, 2023). According to Boix-Fayos and de Vente (2023), the above can be achieved through environmentally- friendly sustainable production systems. Transformation of the agricultural sector to sustainable agriculture can be achieved only if the agriculture sector is considered holistically which requires all the aspects of social, economic, cultural, technical, and environmental factors considered together. This transformation process needs adaptation of system changes by all the stakeholders as participants especially the agricultural producers (Boix-Fayos and de Vente, 2023). Hence, a holistic approach considering all the aspects of the agricultural sector together with all the stakeholders is vital in achieving agricultural sustainability. Sustainable agricultural development is the only way forward to assist humanity. Therefore, this study was conducted to review, synthesize, and advance the existing literature on sustainable agriculture and its impact on humanity.

In this research previous literature on agriculture for sustainable development was explored, understood, described, and evaluated and their relationships to sustain humanity were also analyzed. Online reliable databases were used in the bibliographic search with specific attention given to ScienceDirect. Other sources such as reports, communiques, and communications of official or relevant international organizations were also reviewed.

Increasing Agricultural Productivity

In the process of poverty alleviation and economic development, agricultural productivity plays an important role (Diao *et al.*, 2008). An increase in agricultural productivity is one of the key elements that can assist marginal and subsistence farmers in income generation and combat poverty. Productivity in agriculture needs to be improved and maintained to meet the food, feed, fiber, and raw material needs of the present and future generations. Technological innovations and adaptations play significant roles in achieving higher productivity (Liang *et al.*, 2017). Modern technological solutions can persuade productivity improvements to achieve higher yields from a smaller land area (Dimitrijević, 2023) or with less amount of unit inputs can achieve sustainability in agriculture. Input optimization in agriculture, introducing modern and appropriate technological innovations such as precision agriculture (Dimitrijević, 2023), and climate-smart agriculture can achieve sustainability. High-end agricultural technologies could reduce the use of inputs such as water, fertilizers, and other plant protection agrochemicals, agricultural equipment, etc. (Banu, 2015) while improving productivity through better management of farm inputs increasing profits (Tokekar *et al.*, 2016).

Ulvenblad *et al.* (2018) stated that world food production needs to be increased by around 70% by 2050. The major challenge faced by the agricultural sector is to utilize the available lands efficiently to increase productivity rather than opting for new lands for cultivation which could come with the expense of deforestation. Further, the increased production from these existing lands should be sustainable as such the continued sustained production would be able to feed the increasing population. The land, water, and other agricultural inputs need to be used with increased efficiency to enhance the sustainability of the agricultural sector. The increase in productivity needs the use of technological innovations.

Agriculture is one of the fields that has experienced rapid changes and improvements. The green revolution transformed agriculture with synthetic fertilizers and pesticides and high-yielding varieties that enabled to increase in yields and productivity of land and water. Chemical innovations such as the application of nanotechnology in agriculture can revolutionize the sector. The efficient use of fertilizers and agrochemicals can be improved by introducing nanomaterials. Efficient use of fertilizers and agrochemicals without reducing productivity (Fraceto *et al.*, 2016) and minimizing cost of production but with higher impacts. Investments in agricultural research enabled the agriculture sector to witness many changes. Morgan and Murdoch (2000) reported that the chemical revolution that occurred in the agricultural sector from the 1950s to 1980s enabled pest and disease control. Innovations in biotechnology and genetic engineering introduced hybrid varieties together with modern and efficient technologies from plant propagation up to post-harvest technology. Walter *et al.* (2017) reported that agriculture is in a new phase of development where the use of information technology is revolutionizing agriculture. As such, the application of technology is of paramount importance in achieving sustainable agriculture.

Agriculture uses considerable amounts of energy, mainly fossil fuel which is challenging sustainability. Renewable energy sources can replace fossil fuel usage making agricultural energy use more sustainable. Hydropower including power from mini hydro

projects, solar, wind, tidal and wave, biomass, and geothermal energy sources can be used in the agricultural sector. According to Chel and Kaushik (2011) and Majeed *et al.* (2023), renewable energy sources could lead to sustainable agriculture ensuring acceptable crop productivity and economic stability. Nowadays, many technologies are being used powered by renewable energy sources in irrigation, greenhouse management, monitoring and regulating systems, water pumping systems, drying, desalination, refrigeration, distillation, etc. powered through solar panels and solar photovoltaic cells, wind, geothermal, hybrid renewable energy water pumping systems, solar dryers, solar water heaters, etc. (Majeed *et al.*, 2023). Machinery powered by renewable energy sources can play a bigger role in sustainable agriculture. Such machinery can ensure ecological and environmental preservation ensuring sustainability in agricultural production.

One of the major challenges sustainable agriculture faces is climate change. Developing countries are mainly agriculture-dependent where a bigger portion of the GDP is coming from agriculture. Furthermore, most of the workforce in such countries are employed in the agriculture sector. Hence, a sustainable agriculture sector adapted to climate change is a must where technological innovations can impart important roles in adaptations in agriculture to climate change, and improve agricultural productivity leading to growth and development (Smithers and Blay-Palmer, 2001) in the sector.

Innovative methods and new approaches can enhance agricultural productivity and sustainability of farming systems, thereby increasing the quality of life of many farming families. The availability of high-yielding varieties, awareness building, education, and extension programs (Rozi *et al.*, 2023), and government sector involvement in facilitating the provision of inputs can facilitate sustainable agricultural production as a solution to the global food crisis. Not only the availability of food but also widespread malnutrition due to the nutritional imbalance of food material available to the poor also contribute to food insecurity. Bio-fortified cereals and pulses through new breeding techniques such as gene editing, gene overexpression, and gene transfer from wild relatives could produce food with optimal nutritional profiles providing balanced diets (Sandhu *et al.*, 2023). Hence, biofortification through high-tech breeding programs can facilitate sustainable production leading to sustainable production.

Increase Employment and Value Addition – Empower the Farming Community and Increase Access to Markets

Agriculture determines the household dietary requirements of subsistence smallholder farmers. Smallholder farmers who are engaged in subsistence farming should be transformed into commercial farmers so that they can be empowered and uplifted from poverty. This transformation needs modern marketing and commercialization channels. (Duan *et al.*, 2024) stated that it is difficult for smallholder farmers to penetrate the market and generate income due to factors such as remote and information-poor locations, lower production scale, and higher costs of transportation and many other factors. A solution could be enabling them to generate profits, and integrating them into markets where the government should support the market access and promotion of agricultural products (Duan*et al.*, 2024). Farmer empowerment will facilitate the sustainability of agriculture among the smallholders.

Empowerment of the farming community to increase income through agriculture improves access to nutritional requirements of farmer family members, especially females (Jones *et al.*, 2019; Murugani and Thamaga-Chitja, 2019; Kassie *et al.*, 2020). Further, empowering farmers improves agricultural production (Diiro *et al.*, 2018). Empowering farmers, hence, facilitates desirable impacts such as improved food security, and better and more job opportunities, which lead to sustainable agriculture. Agricultural production and productivity in both the long- and short-term are influenced by the quantities of fertilizers and other agricultural inputs used, the amount of energy consumed, and the extent of lands allocated. When farmers are not in a position to maintain proper resource allocation, their production may not be sufficient or profitable hence they may shift their livelihoods away from agriculture. This may divert the agricultural labor force to off-farm employment options encouraging urban migration (Agbola and Fayiga, 2016), which will have a considerable impact on sustainable agriculture.

There is a growing demand for agricultural products worldwide. This demand increases the opportunities in a variety of jobs (Mathlouthi *et al.*, 2022). Agriculture is the major income source or the primary employment of many, especially, in agricultural economies. Agriculture also provides many related direct and indirect job opportunities. The sustainability of agriculture will ensure the sustenance of these employment opportunities. Peng *et al.* (2022) reported

that diversification of farming activities positively impacts farmers by increasing their profits, while diversified farms such as farms with multiple cropping, crop rotation, intercropping, animal-crop integration systems, fish and animal integration systems, fish and aquaponics integrated systems, etc. are more environmentally sustainable. Increasing cropping diversity, agricultural income can be improved which will enhance the dietary diversity and nutritional status of farmer families (Dillon *et al.*, 2015).

A significant proportion of the household income of the farmer families is received from agriculture. Further, agriculture allows the farmer families to earn a living (Dorosh and Thurlow, 2018; Abhilash *et al.*, 2021) and even in some instances to engage in different production and other entrepreneurial operations based on the agricultural produce (Dorosh and Thurlow, 2018; Abhilash *et al.*, 2021). However, many agricultural laborers work on off-farm income generation activities due to which the agricultural sector faces a shortage of labor. The labor shortage has impacted farms with poor management of the farms and land resources and in most cases underutilization of farmland (Ojha *et al.*, 2017). Labor shortages have led agriculture more feminized (Maharjan *et al.*, 2023). According to (FAO, 2002), 50 to 90% of rice cultivation-related fieldwork in Asia is performed by women. Urbanization and migration of men and youth to urban centers seeking off-farm employment have transformed roles and responsibilities in farming operations. Women are forced to engage in agricultural activities such as labor and capital management, input procurement, irrigation, land management, marketing, etc. Women play a bigger and a crucial role in agriculture (FAO, 2017). Hence, empowering women to deliver their roles in agriculture is important in sustaining agriculture. Maharjan *et al.* (2023) showed that environmental conservation agriculture can empower women, especially in decision-making in farm management.

Protect Natural Resources and Environment

Sustainable agriculture is required to increase agricultural productivity which can only be achieved by sustainably managing natural resources. A balance between environmental protection and sustainable agriculture is important and maintaining the quality of natural resources over the long term is of paramount importance in achieving sustainability. Natural resource planning and utilization hence play an essential role in sustainable agriculture. Sustainability can be achieved only through sustainable use of natural resources used in agriculture. Natural resources need to be conserved and used wisely and the environment needs to be protected to achieve the goals of sustainable agriculture.

More than 70% of the total available water is used by the agriculture sector (Yang *et al.*, 2015) and a considerable amount of irrigation water is derived from groundwater sources, some are non-renewable. Irrigated agriculture is vital in increasing the agricultural productivity. Sustainable agriculture is dependent on sustainable irrigation. In areas where uncertain or harsh climatic conditions prevail, supplying irrigation requirements sustainably is challenging where excessive pumping of groundwater could adversely affect the groundwater table dynamics (Mandal *et al.*, 2021), leading to drawdown, saltwater intrusion, etc. Mandal *et al.* (2021) suggested that the socioeconomic status of the farmers can be improved by optimum planning of cropping systems, irrigation scheduling, and allocation of resources along with water policies and groundwater legislations can facilitate improved socio-economic status for farmers. Hence, optimum cropping system planning and water resource allocation are essential to achieve sustainable agricultural development. Sustainable agriculture also requires an abundance of natural resources such as fertile lands with sufficient nutrients and favorable soil physical and chemical characteristics. Increase in cropped area, yields, and total productivity is dependent on healthy soils (Fischer *et al.*, 2022; Ye *et al.*, 2022). Overuse of natural resources and the destruction of ecosystems affect the sustainability of agriculture. Overuse and misuse of some natural resources accelerate climate change which could have adverse consequences on the food security and livelihoods of millions of farmers throughout the world (Aryal *et al.*, 2020).

Strategies, Technologies, and Approaches Towards Sustainability

The advancement of agriculture and maintaining sustainability in agriculture requires innovative approaches. Technological advancement through research can make farming more efficient leading to the best use of resources (Ren *et al.*, 2023). Precision agriculture is one such innovative approach where water, fertilizer, pesticides, and other inputs are used efficiently minimizing losses by employing satellite imaging, drones, and soil sensors making farmers financially stronger and agriculture more sustainable (Narinbaeva *et al.*, 2021). Provision of policy support is of utmost importance to explore the role of innovation, natural resources, and climate change toward sustainable growth in the agriculture sector (Ren *et al.*, 2023).

Innovations in technology and approaches have a great potential in improving agricultural productivity even in changing environments which is important in achieving agricultural sustainability. Technology and innovations can also play an important role in the reduction of greenhouse gas emissions (Qayyum *et al.*, 2023). Information and Communications Technology (Janssen *et al.*, 2017), Artificial Intelligence (AI), and the Internet of Things (IoT) (Sahil *et al.*, 2023) have the potential to increase agricultural productivity. Through optimized resource allocation, improvements in technologies and innovations can increase agricultural productivity enhancing farmer income through better competitiveness in the markets (Qayyum *et al.*, 2023). Qayyum *et al.* (2023) reported that expansion in agricultural production is possible with the expansion of cropland but with the cost of deforestation, which is not sustainable. However, a balance between sustainable land development, increased productivity of the developed lands and environmental sustainability is important in supplying global food demand (Ahmad and Wu, 2022).

Food supply is dependent on many factors and challenges. Food supplies that are incapable of fulfilling the demands may lead to food insecurity as the communities will face a shortage of food commodities and hence a sharp increase in prices which will not be affordable to them. Local production of food is considered the most prominent factor that can ensure food security by overcoming food insufficiency. This can be achieved effectively by policy initiatives (Stein and Santini, 2021). Governments, through policy initiatives, should strengthen agri-food supply chains within their countries (Smith, 2007) to ensure efficient and effective food supplies. Hence, sustainable agriculture requires policies related to social, economic, and environmental aspects (Boix-Fayos and de Vente, 2023) that are directly and indirectly linked to agriculture. In the planning of agricultural strategies, it is needed to pay sufficient attention to climate change.

Dependency on agricultural imports is predicted to rise in the next decades, which will affect most of the regions in the world including Southeast Asian economies. The economies of such countries have to focus on enhancing agricultural productivity to minimize dependency on imports and face the challenges caused by changes in climate (Wang *et al.*, 2023). Climate Change impacts together with population expansion and urbanization tend to cause disequilibrium in food supply that challenges meeting increasing food demand (Wang *et al.*, 2023). The adverse effects of climate change on agricultural sustainability need to be addressed through a policy mix. Mitigating policy responses and adaptive policies towards ensuring sustainable agricultural production is required.

Improve Livelihood of Farming Communities – Improve Access to Resources, Technology and Finance

Increasing the income of poor farmers and sustaining or improving their family well-being depends on the extent of the nature of farming and this can be constrained by many factors (Leicht *et al.*, 2018). Sustainable agricultural development is affected by a decline in resource availability, low productivity, degradation of oil, water, and other resources, and declining per capita land availability (Gashu and Muchie, 2018; Wassie, 2020).

Resource scarcity leads to multiple challenges such as environmental degradation, inadequacy of infrastructure, inequality in resource and income distribution, poverty, and climate change (Feng *et al.*, 2023). These challenges in agriculture hinder achieving agricultural sustainability. Facing these challenges and improving agricultural production requires broadening agricultural activities. This could be achieved by directing agricultural development to increase efficiency and improve agricultural technology and human resource quality. It is of utmost importance to utilize agricultural land resources in a well-planned manner (Kamaludin *et al.*, 2017).

Haryanto *et al.* (2019) stated that economic development in rural areas is highly dependent upon agriculture on the utilization and use of agricultural land. Sustainable agriculture development hence is constrained by the availability of land and its utilization potential. According to Choudhary *et al.* (2018), farmers with limited land face challenges in achieving sufficient productivity. Limited agricultural land limits the availability of other resources or utilization of other resources. Most of the small holdings depend on rainwater. The right choice of commodities needs to be provided to achieve suitable production from such lands. To utilize the land, the farmers need to be empowered with sufficient technical knowledge and know-how. Many efforts should be taken to improve agricultural productivity from limited land so that farming will not only be sustainable but also will sustain the income of the farming community. The smallholder farmers should be provided with technology, planting resources, agricultural inputs,

extension services, and needed financial support to maximize productivity and increase the intensity of cultivation to achieve sustainability.

Gebru *et al.* (2018) highlighted that interventions such as risk reduction, increase in mobility, minimization of barriers to entry, and ensuring fairness and transparency in the operations of public agencies are important in alleviating poverty and improving livelihood. Identifying opportunities and facilitating to improvement of poor farmers' assets and income-generating capabilities is also important (Gebru *et al.*, 2018). By improving the livelihood of the farming communities, sustainability in agricultural production can be achieved. Many interventions such as access to resources, technology, and finance assist this process.

The amount of investment in agriculture by developing countries is high however this amount must be greatly increased to address food insecurity (Le Mouël and Forslund, 2017). Huang and Wang (2014) reported that agriculture is much under-invested in developing countries, and mitigation and adaptation to climate change need substantial investment. According to (Islam, 2011), current investment and commitment in agriculture fall far short of the requirements to meet the growing needs.

Smallholder farmers face challenges such as poor access to credit facilities, poor farming decisions due to unpredictable weather, poor access to market information, and poor transportation facilities for the products to the markets. Digital agricultural solutions could be used to address these challenges where they can provide greater access to credit and remunerative markets (Miine *et al.*, 2023). Digital agriculture would assist smallholder farmers to increase yields, reduce cost, and improve agricultural sustainability thereby increasing food security (Dibirov and Dibirova, 2022).

Knowledge Sharing and Sustainable Agriculture

Due to global population increase, urbanization, and climate change, agriculture faces tremendous pressure. Therefore, the needs of the people have to be produced with limited resources under challenging scenarios. This causes enormous environmental pressure hence sustainability in agricultural operations is becoming more vital. This requires the sharing of knowledge among all the stakeholders from the agriculture sector. The recent knowledge and skills based on research findings and long-term experience in achieving sustainable agricultural production practices need to be communicated efficiently and effectively.

Sustainable agricultural production practices have the potential to reduce farmers' reliance on agricultural inputs maintaining higher production (Piñeiro *et al.*, 2020). Farmer's knowledge of sustainable production practices is vital (Dessart *et al.*, 2019) which needs informal and formal ways of knowledge sharing. Eco-friendly agricultural production can be promoted by pro-environmental education. Pro-environmental education can promote eco-friendly agricultural production practices (Xie*et al.*, 2023). Persuading farmers to adopt more sustainable agricultural production practices needs economic policies such as subsidies and behavioral intervention policies such as facilitating peer-to-peer knowledge sharing (Slijper *et al.*, 2023). Agricultural enterprises also have to formulate sustainable eco-friendly production strategies (Shoaib *et al.*, 2022). To increase adoption rates, Tensi *et al.* (2022) recommended that policymakers, extension services, and farmers be active in knowledge sharing.

Protect Harvest – Minimize Losses

Postharvest losses of perishable agricultural products have been estimated at 40% in low- and middle-income countries (Spang *et al.*, 2019; Jarman *et al.*, 2023). Globally, the postharvest losses of fruits and vegetables were estimated at 22% (FAO, 2019). Smallholder farmers do not have access to technologies to minimize postharvest losses (Jarman *et al.*, 2023).

Kader (2006) reported that research innovations-based technologies have reduced postharvest losses of perishables. Spang *et al.* (2019) pointed out that postharvest losses could be minimized through the application of technologies such as pre-cooling, cold storage and transportation, drying and dry storage, controlled atmosphere storage, improved packaging, regulated ripening, growth-regulating chemicals, etc. According to Jarman *et al.*(2023), cold chain and dry chain systems could be used to address postharvest losses of small-scale enterprises.

Reduction in postharvest losses is important in minimizing global food insecurity, enhancing smallholder farmers' income, and ensuring agricultural sustainability. Jarman *et al.* (2023) stated that changes in sustainable postharvest management could minimize food insecurity. Excessive postharvest losses reduce the household income of smallholder and subsistence farmers. This could force the farmers to either give up agriculture or shift to other off-farm income sources minimizing attention on agriculture which could impact the sustainability of agriculture.

CONCLUSION

Efficient use of inputs assisted with technology, information technology, new breeding techniques, and technologies powered by renewable energy sources are aiding sustainable agriculture. Technological innovations can play important roles in adaptations in agriculture to climate change, improve agricultural productivity, and increase the quality of life of many farming families. Smallholder farmers who are in remote and information-poor locations with lower production scale and higher costs of transportation face many challenges. Integrating them into markets is important where government should support the market access and promotion of agricultural products. Empowerment of framing community through modern marketing and commercialization channels could improve the nutritional requirements of farmers, food security, and better and more direct and indirect job opportunities. Women play a bigger and a crucial role in agriculture hence empowering women in delivering the roles in agriculture is important in sustaining agriculture.

The sustainability of agriculture will ensure the sustenance of employment opportunities and diversification of farming activities through which agricultural income could be improved. Sustainably managing natural resources and maintaining the quality of natural resources over the long term is of paramount importance in achieving sustainability. Natural resources need to be conserved and used wisely and the environment needs to be protected to achieve the goals of sustainable agriculture. The socioeconomic status of the farmers can be improved by optimum planning of cropping systems, irrigation scheduling, and allocation of resources along with water policies and groundwater legislations that can facilitate improved socio-economic status for farmers. Optimized resource allocation, improvements in technologies, and innovations can increase agricultural productivity enhancing farmer income. A balance between sustainable land development and increased productivity of the developed lands is important in the local production of food to ensure food security and strengthen agri-food supply chains. Policies related to social, economic, and environmental aspects directly and indirectly linked to agriculture are vital in these processes.

Farmers need to be empowered with sufficient technical knowledge and know-how. Smallholder farmers should be provided with technology, planting resources, agricultural inputs, extension services, and needed financial support to maximize productivity and increase the intensity of cultivation. Interventions such as risk reduction, increase in mobility, minimization of barriers to entry, and ensuring fairness and transparency in the operations of public agencies are important in alleviating poverty and improving livelihood. Opportunities in facilitating to improvement of poor farmers' assets and income-generating capabilities are also important.

Many interventions such as access to resources, technology, and finance assist in improving the livelihood of the farming communities and achieving sustainability in agricultural production. Investment in agriculture must be greatly increased to address food insecurity and adaptation to climate change. Digital agriculture would assist smallholder farmers in increasing yields, reducing costs, and improving agricultural sustainability thereby increasing food security. The sharing of knowledge among all the stakeholders from the agriculture sector, recent knowledge and skills based on research findings, and long-term experience in achieving sustainable agricultural production practices need to be communicated efficiently and effectively. Farmer's knowledge of sustainable production practices is vital hence informal and formal ways of knowledge sharing are needed. Economic policies such as subsidies, behavioral interventions, and peer-to-peer knowledge sharing are vital tools. Formulating sustainable eco-friendly production strategies can assist in this process. Postharvest losses could be minimized through the application of technologies, where reduction in postharvest losses is important in minimizing global food insecurity, enhancing smallholder farmers' income, and ensuring agricultural sustainability.

REFERENCES

Abhilash, P. C., Bastianoni, S., Chen, W., DeFries, R., Fraceto, L. F., Fuckar, N. S., Hashimoto, S., Hunter, D., Keesstra, S., Merah, O., O'Farrell, P., Pradhan, P., Singh, S., Smith, P., Stringer, L. C., & Turner, B. L. (2021). Introducing 'Anthropocene Science': A New International Journal for Addressing Human Impact on the Resilience of Planet Earth. *Anthropocene Science*, 1(1), 1–4. https://doi.org/10.1007/S44177-021-00001-1

Agbola, P., & Fayiga, A. O. (2016). Effects of climate change on agricultural production and rural livelihood in

Nigeria. *Journal of Agricultural Research and Development*, 15(1), 71–82. https://www.ajol.info/index.php/jard/article/view/152193

Ahmad, M., & Wu, Y. (2022). Combined role of green productivity growth, economic globalization, and eco-innovation in achieving ecological sustainability for OECD economies. *Journal of Environmental Management*, 302, 113980. https://doi.org/10.1016/J.JENVMAN.2021.113980

Alexandratos, N., & Bruinsma, J. (2012). World agriculture towards 2030/2050: the 2012 revision. https://doi.org/10.22004/AG.ECON.288998

Banu, S. (2015). Precision Agriculture: Tomorrow's Technology for Today's Farmer. *Journal of Food Processing and Technology*, 06(08). https://doi.org/10.4172/2157-7110.1000468

Behnassi, M., & Yaya, S. (2011). Food Crisis Mitigation: The Need for an Enhanced Global Food Governance. In *Global Food Insecurity*, 93–125. https://doi.org/10.1007/978-94-007-0890-7_8

Boix-Fayos, C., & de Vente, J. (2023). Challenges and potential pathways towards sustainable agriculture within the European Green Deal. *Agricultural Systems*, 207, 103634. https://doi.org/10.1016/J.AGSY.2023.103634

Butlin, J. (1989). Our common future. *Journal of International Development*, 1(2), 284–287. https://doi.org/10.1002/jid.3380010208

Chel, A., & Kaushik, G. (2011). Renewable energy for sustainable agriculture. *Agronomy for Sustainable Development*, 31(1), 91–118. https://doi.org/10.1051/AGRO/2010029

Choudhary, M., Datta, A., Jat, H. S., Yadav, A. K., Gathala, M. K., Sapkota, T. B., Das, A. K., Sharma, P. C., Jat, M. L., Singh, R., & Ladha, J. K. (2018). Changes in soil biology under conservation agriculture-based sustainable intensification of cereal systems in Indo-Gangetic Plains. *Geoderma*, *313*, 193–204. https://doi.org/10.1016/J.GEODERMA.2017.10.041

Dessart, F. J., Barreiro-Hurlé, J., & Van Bavel, R. (2019). Behavioral factors affecting the adoption of sustainable farming practices: a policy-oriented review. *European Review of Agricultural Economics*, 46(3), 417–471. https://doi.org/10.1093/erae/jbz019

Diao, X., Headey, D., & Johnson, M. (2008). Toward a green revolution in Africa: what would it achieve, and what would it require? *Agricultural Economics*, 39(SUPPL. 1), 539–550. https://doi.org/10.1111/J.1574-0862.2008.00358.X

Dibirov, A., & Dibirova, K. (2022). Prospects and Problems of Digitalization of the Agricultural Economy. *Smart Innovation, Systems and Technologies*, 245, 207–218. https://doi.org/10.1007/978-981-16-3349-2_18/COVER

Diiro, G. M., Seymour, G., Kassie, M., Muricho, G., & Muriithi, B. W. (2018). Women's empowerment in agriculture and agricultural productivity: Evidence from rural maize farmer households in western Kenya. *PLOS ONE*, 13(5), e0197995. https://doi.org/10.1371/JOURNAL.PONE.0197995

Dillon, A., McGee, K., & Oseni, G. (2015). Agricultural Production, Dietary Diversity, and Climate Variability. *The Journal of Development Studies*, 51(8), 976–995. https://doi.org/10.1080/00220388.2015.1018902

Dimitrijević, M. S. (2023). Technological progress in the function of productivity and sustainability of agriculture: The case of innovative countries and the Republic of Serbia. *Journal of Agriculture and Food Research*, 14, 100856. https://doi.org/10.1016/J.JAFR.2023.100856

Dorosh, P., & Thurlow, J. (2018). Beyond Agriculture Versus Non-Agriculture: Decomposing Sectoral Growth–Poverty Linkages in Five African Countries. *World Development*, 109, 440–451. https://doi.org/10.1016/J.WORLDDEV.2016.08.014

Duan, W., Jiang, M., & Qi, J. (2024). Agricultural certification, market access, and rural economic growth: Evidence from poverty-stricken counties in China. *Economic Analysis and Policy*, 81, 99–114. https://doi.org/10.1016/J.EAP.2023.11.028

FAO. (n.d.). Background | Sustainable Food and Agriculture | Food and Agriculture Organization of the United Nations. Retrieved February 3, 2024, from https://www.fao.org/sustainability/background/en/

FAO. (2002). *Gender and Access to Land*. FAO.

FAO. (2017). *The future of food and agriculture: trends and challenges*. FAO, Rome.

FAO. (2019). *The state of food and agriculture: Moving forward on food loss and waste reduction*. FAO, Rome.

Feng, Y., Hu, J., Afshan, S., Irfan, M., Hu, M., & Abbas, S. (2023). Bridging resource disparities for sustainable development: A comparative analysis of resource-rich and resource-scarce countries. *Resources Policy*, 85, 103981. https://doi.org/10.1016/J.RESOURPOL.2023.103981

Fischer, C., Aubron, C., Trouvé, A., Sekhar, M., & Ruiz, L. (2022). Groundwater irrigation reduces overall poverty but increases socioeconomic vulnerability in a semiarid region of southern India. *Scientific Reports*, 12(1), 1–16. https://doi.org/10.1038/s41598-022-12814-0

Food Security Information Network. (2023). *Global report on food crises: Joint analysis for better decisions*. https://www.ifpri.org/publication/2023-global-report-food-crises-joint-analysis-better-decisions

Fraceto, L. F., Grillo, R., de Medeiros, G. A., Scognamiglio, V., Rea, G., & Bartolucci, C. (2016). Nanotechnology in agriculture: Which innovation potential does it have? *Frontiers in Environmental Science*, 4(MAR), 186737. https://doi.org/10.3389/FENVS.2016.00020/BIBTEX

Gashu, K., & Muchie, Y. (2018). Rethink the interlink between land degradation and livelihood of rural communities in Chilga district, Northwest Ethiopia. *Journal of Ecology and Environment*, 42(1), 1–11. https://doi.org/10.1186/S41610-018-0077-0/FIGURES/2

Gebru, G. W., Ichoku, H. E., & Phil-Eze, P. O. (2018). Determinants of livelihood diversification strategies in Eastern Tigray Region of Ethiopia. *Agriculture and Food Security*, 7(1), 1–9. https://doi.org/10.1186/S40066-018-0214-0/TABLES/3

Haryanto, L. I., Masyhuri, M., & Irham, I. (2019). The Policy Analysis Matrix in Measuring Competitiveness of Maize Farming System in Marginal Areas. *Agro Ekonomi*, 29(2), 244–260. https://doi.org/10.22146/AE.35964

Huang, J. kun, & Wang, Y. jie. (2014). Financing Sustainable Agriculture Under Climate Change. *Journal of Integrative Agriculture*, 13(4), 698–712. https://doi.org/10.1016/S2095-3119(13)60698-X

Janssen, S. J. C., Porter, C. H., Moore, A. D., Athanasiadis, I. N., Foster, I., Jones, J. W., & Antle, J. M. (2017). Towards a new generation of agricultural system data, models and knowledge products: Information and communication technology. *Agricultural Systems*, 155, 200–212. https://doi.org/10.1016/J.AGSY.2016.09.017

Jarman, A., Thompson, J., McGuire, E., Reid, M., Rubsam, S., Becker, K., & Mitcham, E. (2023). Postharvest technologies for small-scale farmers in low- and middle-income countries: A call to action. *Postharvest Biology and Technology*, 206, 112491. https://doi.org/10.1016/J.POSTHARVBIO.2023.112491

Jones, E., Qadir, M., van Vliet, M. T. H., Smakhtin, V., & Kang, S. mu. (2019). The state of desalination and brine production: A global outlook. *Science of The Total Environment*,657, 1343–1356. https://doi.org/10.1016/J.SCITOTENV.2018.12.076

Kader, A. A. (2006). The return on investment in postharvest technology for assuring the quality and safety of horticultural crops. *Journal of Agricultural Investments*, 4, 45–52.

Kamaludin, M., Shandy Narmaditya, B., Wibowo, A., & Febrianto, I. (2017). Agricultural land resource allocation to develop food crop commodities: a lesson from Indonesia. *Heliyon*, *e07520*. https://doi.org/10.1016/j.heliyon.2021.e07520

Kassie, M., Fisher, M., Muricho, G., & Diiro, G. (2020). Women's empowerment boosts the gains in dietary diversity from agricultural technology adoption in rural Kenya. *Food Policy*, 95, 101957. https://doi.org/10.1016/J.FOODPOL.2020.101957

Kunwedomo Miine, L., Dziedzom Akorsu, A., Boampong, O., & Bukari, S. (2023). Drivers and intensity of adoption of digital agricultural services by smallholder farmers in Ghana. *Heliyon*, 9, e23023. https://doi.org/10.1016/j.heliyon.2023.e23023

Laurett, R., Paço, A., & Mainardes, E. W. (2021). Sustainable Development in Agriculture and its Antecedents, Barriers and Consequences – An Exploratory Study. *Sustainable Production and Consumption*, 27, 298–311. https://doi.org/10.1016/J.SPC.2020.10.032

Le Mouël, C., & Forslund, A. (2017). How can we feed the world in 2050? A review of the responses from global scenario studies. *European Review of Agricultural Economics*, 44(4), 541–591. https://doi.org/10.1093/ERAE/JBX006

Leicht, A., Heiss, J., & Byun, W. J. (2018). *Issues and trends in education for sustainable development*. UNESCO Publishing.

Liang, X. Z., Wu, Y., Chambers, R. G., Schmoldt, D. L., Gao, W., Liu, C., Liu, Y. A., Sun, C., & Kennedy, J. A. (2017). Determining climate effects on US total agricultural productivity. *Proceedings of the National Academy of Sciences of the United States of America*, 114(12), E2285–E2292. https://doi.org/10.1073/PNAS.1615922114/SUPPL_FILE/PNAS.201615922SI.PDF

Liu, B., Zhang, X., Tian, J., Cao, R., Sun, X., and Xue, B. (2023). Rural sustainable development: A case study of the Zaozhuang Innovation Demonstration Zone in China. *Regional Sustainability*, 4(4), 390–404. https://doi.org/10.1016/J.REGSUS.2023.11.004.

Maharjan, K. L., Singh, M., and Gonzalvo, C. M. (2023). Drivers of environmental conservation agriculture and women farmer empowerment in Namobuddha municipality, Nepal. *Journal of Agriculture and Food Research*, 13, 100631. https://doi.org/10.1016/J.JAFR.2023.100631.

Majeed, Y., Khan, M. U., Waseem, M., Zahid, U., Mahmood, F., Majeed, F., Sultan, M., and Raza, A. (2023). Renewable energy as an alternative source for energy management in agriculture. *Energy Reports*, 10, 344–359. https://doi.org/10.1016/J.EGYR.2023.06.032.

Mandal, U., Dhar, A., and Panda, S. N. (2021). Enhancement of sustainable agricultural production system by integrated natural resources management framework under climatic and operational uncertainty. *Agricultural Water Management*, 252, 106903. https://doi.org/10.1016/J.AGWAT.2021.106903.

Mathlouthi, F., Ruggeri, R., and Rossini, F. (2022). Alternative Solution to Synthetic Fertilizers for the Starter Fertilization of Bread Wheat under Mediterranean Climatic Conditions. *Agronomy*, 12(2), 511. https://doi.org/10.3390/AGRONOMY12020511.

Morgan, K., and Murdoch, J. (2000). Organic vs. conventional agriculture: knowledge, power and innovation in the food chain. *Geoforum*, 31(2), 159–173. https://doi.org/10.1016/S0016-7185(99)00029-9.

Murugani, V. G., and Thamaga-Chitja, J. M. (2019). How does women's empowerment in agriculture affect household food security and dietary diversity? The case of rural irrigation schemes in Limpopo Province, South Africa. *Agrekon*, 58(3), 308–323. https://doi.org/10.1080/03031853.2019.1610976.

Islam, N. (2011). Foreign aid to agriculture: review of facts and analysis. *IFPRI-Discussion Papers*, (1053).

Narinbaeva, G., Menglikulov, B., Siddikov, Z., Bustonov, K., and Davlatov, S. (2021). Application of innovative technologies in agriculture of Uzbekistan. *E3S Web of Conferences*, 284, 02009. https://doi.org/10.1051/E3SCONF/202128402009.

Dubois, O. (2011). The state of the world's land and water resources for food and agriculture: managing systems at risk. FAO, Rome, Italy.

Ojha, H. R., Shrestha, K. K., Subedi, Y. R., Shah, R., Nuberg, I., Heyojoo, B., Cedamon, E., Rigg, J., Tamang, S., Paudel, K. P., Malla, Y., and McManus, P. (2017). Agricultural land underutilization in the hills of Nepal: Investigating socio-environmental pathways of change. *Journal of Rural Studies*, 53, 156–172. https://doi.org/10.1016/J.JRURSTUD.2017.05.012.

Olesen, J. E., and Bindi, M. (2002). Consequences of climate change for European agricultural productivity, land use, and policy. *European Journal of Agronomy*, 16(4), 239–262. https://doi.org/10.1016/S1161-0301(02)00004-7.

Peng, W., Zheng, H., Robinson, B. E., Li, C., and Li, R. (2022). Comparing the importance of farming resource endowments and agricultural livelihood diversification for agricultural sustainability from the perspective of the food-energy-water nexus. *Journal of Cleaner Production*, 380, 135193. https://doi.org/10.1016/J.JCLEPRO.2022.135193.

Piñeiro, V., Arias, J., Dürr, J., Elverdin, P., Ibáñez, A. M., Kinengyere, A., Opazo, C. M., Owoo, N., Page, J. R., Prager, S. D., and Torero, M. (2020). A scoping review on incentives for adoption of sustainable agricultural practices and their outcomes. *Nature Sustainability*, 3(10), 809–820. https://doi.org/10.1038/s41893-020-00617-y.

Qayyum, M., Zhang, Y., Wang, M., Yu, Y., Li, S., Ahmad, W., Maodaa, S. N., Sayed, S. R. M., and Gan, J. (2023). Advancements in technology and innovation for sustainable agriculture: Understanding and mitigating greenhouse gas emissions from agricultural soils. *Journal of Environmental Management*, 347, 119147. https://doi.org/10.1016/J.JENVMAN.2023.119147.

Rehman, A., Farooq, M., Lee, D. J., and Siddique, K. H. M. (2022). Sustainable agricultural practices for food security and ecosystem services. *Environmental Science and Pollution Research*, 29(56), 84076–84095. https://doi.org/10.1007/S11356-022-23635-Z.

Ren, X., He, J., and Huang, Z. (2023). Innovation, natural resources abundance, climate change, and green growth in agriculture. *Resources Policy*, 85, 103970. https://doi.org/10.1016/J.RESOURPOL.2023.103970.

Rozi, F., Santoso, A. B., Ayu, G., Mahendri, P., Timbul, R., Hutapea, P., Wamaer, D., Siagian, V., Anggraeni Elisabeth, D. A., Sugiono, S., Handoko, H., Subagio, H., and Syam, A. (2023). Indonesian market demand patterns for food commodity sources of carbohydrates in facing the global food crisis. *Heliyon*, 9, e16809. https://doi.org/10.1016/j.heliyon.2023.e16809.

Ruggerio, C. A. (2021). Sustainability and sustainable development: A review of principles and definitions. *Science of The Total Environment*, 786, 147481. https://doi.org/10.1016/J.SCITOTENV.2021.147481.

Sahil, K., Mehta, P., Kumar Bhardwaj, S., and Dhaliwal, L. K. (2023). Development of mitigation strategies for climate change using artificial intelligence to attain sustainability. *Visualization Techniques for Climate Change with Machine Learning and Artificial Intelligence*, 421–448. https://doi.org/10.1016/B978-0-323-99714-0.00021-2.

Sandhu, R., Chaudhary, N., Bindia, Shams, R., Singh, K., and Pandey, V. K. (2023). A critical review on integrating biofortification in crops for sustainable agricultural development and nutritional security. *Journal of Agriculture and Food Research*, 14, 100830. https://doi.org/10.1016/J.JAFR.2023.100830.

Serageldin, I. (n.d.). Agriculture's Role in Sustainable Human Development: An Action Agenda for the New Millennium. Retrieved February 4, 2024, from http://www.serageldin.com/Speech/Details.aspx?ID=45.

Shoaib, M., Nawal, A., Zámečník, R., Korsakienė, R., and Rehman, A. U. (2022). Go green! Measuring the factors that influence sustainable performance. *Journal of Cleaner Production*, 366, 132959. https://doi.org/10.1016/J.JCLEPRO.2022.132959.

Singh, R., Singh, H., and Raghubanshi, A. S. (2019). Challenges and opportunities for agricultural sustainability in changing climate scenarios: a perspective on Indian agriculture. *Tropical Ecology*, 60(2), 167–185. https://doi.org/10.1007/S42965-019-00029-W/METRICS.

Slijper, T., Tensi, A. F., Ang, F., Ali, B. M., and van der Fels-Klerx, H. J. (2023). Investigating the relationship between knowledge and the adoption of sustainable agricultural practices: The case of Dutch arable farmers. *Journal of Cleaner Production*, 417, 138011. https://doi.org/10.1016/J.JCLEPRO.2023.138011.

Smith, B. G. (2007). Developing sustainable food supply chains. *Philosophical Transactions of the Royal Society B: Biological Sciences*, 363(1492), 849–861. https://doi.org/10.1098/RSTB.2007.2187.

Smithers, J., and Blay-Palmer, A. (2001). Technology innovation as a strategy for climate adaptation in agriculture. *Applied Geography*, 21(2), 175–197. https://doi.org/10.1016/S0143-6228(01)00004-2.

Spang, E. S., Moreno, L. C., Pace, S. A., Achmon, Y., Donis-Gonzalez, I., Gosliner, W. A., Jablonski-Sheffield, M. P., Abdul Momin, M., Quested, T. E., Winans, K. S., and Tomich, T. P. (2019). Food Loss and Waste: Measurement, Drivers, and Solutions. *Annual Reviews*, 44, 117–156. https://doi.org/10.1146/ANNUREV-ENVIRON-101718-033228.

Tensi, A. F., Ang, F., and van der Fels-Klerx, H. J. (2022). Behavioral drivers and barriers for adopting microbial applications in arable farms: Evidence from the Netherlands and Germany. *Technological Forecasting and Social Change*, 182, 121825. https://doi.org/10.1016/J.TECHFORE.2022.121825.

Tensi, A. F., Ang, F., and van der Fels-Klerx, H. J. (2022). Behavioral drivers and barriers for adopting microbial applications in arable farms: Evidence from the Netherlands and Germany. *Technological Forecasting and Social Change*, 182, 121825. https://doi.org/10.1016/J.TECHFORE.2022.121825.

Tilman, D., Cassman, K. G., Matson, P. A., Naylor, R., and Polasky, S. (2002). Agricultural sustainability and intensive production practices. *Nature*, 418(6898), 671–677. https://doi.org/10.1038/nature01014.

Tokekar, P., Hook, J. Vander, Mulla, D., and Isler, V. (2016). Sensor Planning for a Symbiotic UAV and UGV System for Precision Agriculture. *IEEE Transactions on Robotics*, 32(6), 1498–1511. https://doi.org/10.1109/TRO.2016.2603528.

Ulvenblad, P., Barth, H., Björklund, J. C., Hoveskog, M., Ulvenblad, P. O., and Jenny Ståhl. (2018). Barriers to business model innovation in the agri-food industry: A systematic literature review. *Outlook on Agriculture*, 47(4), 308–314. https://doi.org/10.1177/0030727018811785.

UN. (n.d.). Population | United Nations. United Nations. Retrieved February 4, 2024, from https://www.un.org/en/global-issues/population.

UN. (2012). Resilient People, Resilient Planet: A future worth choosing, United Nations Secretary General's High-Level Panel on Global Sustainability.

UNDESA. (2017). Probabilistic population projections based on the world population prospects: The 2017 revision.

Walter, A., Finger, R., Huber, R., and Buchmann, N. (2017). Smart farming is key to developing sustainable agriculture. *Proceedings of the National Academy of Sciences of the United States of America*, 114(24), 6148–6150. https://doi.org/10.1073/PNAS.1707462114/ASSET/46D243E5-C255-467E-A465-3EA021385443/ASSETS/GRAPHIC/PNAS.1707462114FIG02.JPEG.

Wang, T., Sun, C., and Yang, Z. (2023). Climate change and sustainable agricultural growth in the Sahel region: Mitigating or resilient policy response? *Heliyon*, 9(9), e19839. https://doi.org/10.1016/j.heliyon.2023.e19839.

World Bank. (2022). Food Security Update. International Bank for Reconstruction and Development, Washington DC 20433.

Xie, Y., Chen, Z., Tang, H., Boadu, F., and Yang, Y. (2023). Effects of executives' pro-environmental education and knowledge sharing activities on eco-friendly agricultural production: Evidence from China. *Journal of Cleaner Production*, 395, 136469. https://doi.org/10.1016/J.JCLEPRO.2023.136469.

Yang, G., Guo, P., Huo, L., and Ren, C. (2015). Optimization of the irrigation water resources for the Shijin irrigation district in north China. *Agricultural Water Management*, 158, 82–98. https://doi.org/10.1016/J.AGWAT.2015.04.006.