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Review article

Green innovation to save water and energy for environmental sustainability in agricultural farming: A review

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Abstract

Importance of the work: As the world's population is growing at a fast rate, it is important to increase agricultural productivity by applying efficient crop management to feed the increasing population.

Objectives: To review: 1) the interdependencies among water, energy and agricultural farming; 2) green innovation in irrigation for agricultural farming, including sprinkler and drip irrigation, wastewater ferti-irrigation, precision agriculture with the internet of things (IoT) and wireless sensor networks (WSNs); and 3) solar energy for irrigation based on innovative solutions to save energy in agricultural farming for environmental sustainability.

Materials & Methods: A state-of-the-art literature review methodology was applied across various available sources, on the application of green innovation in agricultural farming to increase crop productivity with efficient use of water and energy.

Results: Some water, energy and fertilizer-saving green innovations include drip irrigation, sprinkler irrigation, ferti-irrigation and precision agriculture with the IoT and WSNs. The review provides insights, which may be beneficial to farmers and practitioners who need to adopt green innovation to improve agricultural sustainability by bringing efficiencies in irrigation, crop productivity and environmental sustainability.

Main findings: The challenges of water-energy-agricultural farming could be solved by adopting green innovation in agricultural water and energy management, thus leading to saving scarce water resources and fertilizers and reducing environmental problems.

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Introduction

Globally, the population is increasing at a rate that might result in approximately 9 billion people by 2050 (Food and Agriculture Organization of the United Nations, 2011). It has been estimated that about 70% of water resources are consumed in agricultural farming; consequently, sustainable agriculture with green innovation is needed in current agricultural practices (Doungmanee, 2016; Velasco-Munoz et al., 2018; Benyezza et al., 2021). To feed the increasing population and at the same time increase efficiencies in water, energy saving and productivity, it is essential to apply green innovation in agricultural crop cultivation (Joshi et al., 2020). Green innovation is essential to obtain a pollution-free environment by minimizing fossil fuel energy usage (Sun, 2023). Green innovation can be defined as a process that contributes to the creation of new production and technologies with the aim of reducing environmental risks, such as pollution, and the negative consequences of resource exploitation (Castellacci and Lie, 2017). There is worldwide freshwater scarcity due to the impact of climate change; consequently, about two-thirds of the planet experiences acute problems with water resource scarcity for crop irrigation (Mekonnen and Hoekstra, 2016). Thus, a major challenge for the 21st century is to increase global food production to feed an increasing world population, along with the challenges of climate change and the need for environmental sustainability (Neumann et al., 2011; Jagermeyr et al., 2015; Cameira and Pereira, 2019). Environmental sustainability implies using renewable resources or finding alternatives to non-renewables to reduce pollution in combination with sustainable land use (Aubert et al., 2012) and is based on three sectors: the environment, economy and social development (Boström, 2012). An inclusive way for environmental sustainability is to use innovative sustainable practices, including agricultural cultivation, by using renewable energy and innovation in irrigation design for precision agriculture that saves water with higher efficiency, while increasing the production from the existing farmland. Such innovation should aim for the sustainable use of water, fertilizer, energy and other resources for reducing emissions of greenhouse gases (GHGs) and creating a sustainable environment (Cameira and Pereira, 2019).

This article applied a state-of-the-art literature review methodology to review the stated objectives via prominent search engines available online by typing keywords, such as: interdependence of water, energy, and agricultural farming; green innovation in irrigation for agricultural farming, sprinkler and drip irrigation; wastewater irrigation, precision agriculture and solar energy for irrigation in agricultural farming for environmental sustainability. A review of the literature is essential to provide awareness of the interdependence of water-energy-agricultural farming for food production with a green economy to combat the challenges of climate change, increased population, globalization, economic growth and urbanization, which have caused increased demands for food, energy and water resources (Hoff, 2011). The contents of the reviewed articles were analyzed by focusing on the application of green innovation to save water and energy for environmental sustainability in agricultural farming. This review article is organized into several parts: Introduction; Water-energy-agricultural farming interdependence; Green innovation in irrigation for agricultural farming, including sprinkler and drip irrigation, wastewater irrigation and precision agriculture; Solar energy for irrigation; Conclusion and Recommendations. The review objectives were to investigate: 1) the interdependencies among water, energy and agricultural farming; 2) green innovation in irrigation for agricultural farming, including sprinkler and drip irrigation, wastewater irrigation and precision agriculture; and 3) solar energy for irrigation via innovative solutions to save energy in agricultural farming for environmental sustainability. The article is expected to be beneficial to both farmers as well as policy planners to promote and apply green innovation in agricultural farming for increasing crop productivity and environmental sustainability; for example, innovation in irrigation systems helps to achieve sustainable use of water, fertilizer, energy and other resources to increase environmental performance.

Water-energy-agricultural farming interdependence

As the world's population is increasing rapidly, there is an increasing demand for water and energy to increase food production. By 2050, global food production needs to be increased by up to 70%, with the agricultural consumption of crop water increasing by more than 40% from 6,400km^3 in 2000 to 9,060km^3 (Zheng et al., 2018), resulting in about 29% greater greenhouse gas emissions (Bennetzen et al., 2016). Therefore, it is essential to find innovative solutions in agricultural cultivation to underpin environmental sustainability (Qadir et al., 2007), taking into account the water-energy-food interdependence around the globe. Environmental scientists have initiated innovative issues in agricultural water and energy management to solve the problem associated with water scarcity and environmental problems and for uplifting rural society. The agricultural process consumes a large amount of energy and water (58%) and this consumption varies according to the location of the water resources and the type of irrigation system; for example, extracting water from underground consumes more energy than surface water, water in a drip irrigation system consumes more energy than in a sprinkler irrigation system. However, due to the introduction of green innovation, such as drip irrigation for saving energy and water in agriculture, the amount of water consumed in the agriculture process has diminished gradually from 5,158 m^3/ha in 2002 to 4,824 m^3/ha in 2007, while the efficiency of water usage for irrigation has increased gradually (Hardy et al., 2016).

Recent studies have reported the need for policy regarding adopting innovative solutions, including drip irrigation, wastewater treatment and other green innovation in the process of cultivation. Such research aimed to use precision agriculture to minimize water and energy consumption in all regions, including, arid and semi-arid regions where water is scarce and there is excessive dependent on groundwater for irrigation (Koech and Langat, 2018; Neupane and Guo, 2019; Scardigno, 2020; Stafford, 2000; Zhang et al., 2021). Tsakmakis et al. (2018) evaluated the impact of different irrigation technologies on the water footprint of cotton plant cultivation. Their results found that the application of drip irrigation technology saved 5% more water than sprinkler irrigation. Similarly, the use of drip irrigation could save about 45–50% of water use compared to surface or sprinkler irrigation, resulting in better yields for the application of the full amount of water to the cultivated crops or vegetables, thereby increasing the farmers' net income (Rashidi and Keshavarzpour, 2011).

Al-Said et al. (2012) further investigated maximizing profits to the farmers using appropriate combinations of vegetable crops grown in a region of Oman under drip irrigation by minimizing water usage while increasing productivity. Their results showed that drip irrigation had performance in terms of crop water productivity. However, other studies have reported that drip irrigation alone was not sufficient, with the need to consider the issue of precision agriculture using information and communication technology (ICT) for sustainable agriculture (Lindblom et al., 2017; Kolady et al., 2021). Agricultural farmers can also apply drip fertigation with plastic compost to get higher and better-quality yields, while saving wastage of fertilizers, thus resulting in more efficient usage of water and nutrients in crop cultivation. Precision agriculture enhances profitability and water savings and reduces environmental impact through the effective application of the irrigation management system by observing differences in soil and crop growth (Neupane and Guo, 2019; Pandya et al., 2021). Another study in Spain on the association of water-energy-crop cultivation found three management levels of performance: basin, irrigation district and farm, with the basin level consuming the highest amount of energy and its consumption increased due to different water source factors, such as surface water, recycled water and groundwater (Soto-García et al., 2013).

Nouri et al. (2019) assessed the possibility of reducing the water scarcity crisis by reducing the water footprint in the agricultural crop production process through the application of innovative drip irrigation with soil mulching and quantifying the consumption of water in crop cultivation.

Endo et al. (2017) reported on the future research direction of the water-energy-food interdependence by focusing on the need to develop a common framework for agricultural food production to analyze the complex relationship between systems of water-energy-food. The above literature review can be represented by the interdependence of water, energy and agricultural farms, as shown in Fig. 1.

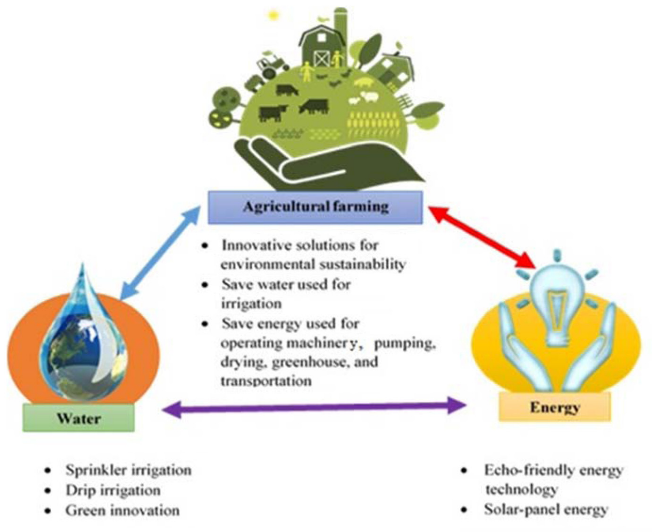


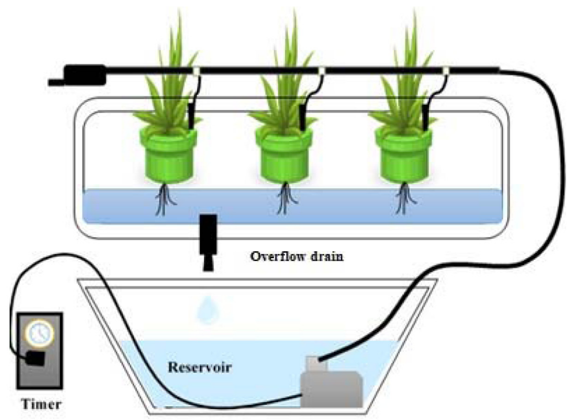
Fig. 1 Water-energy-agricultural farm interdependence

Green innovation in agricultural farm irrigation

The concept of green innovation has been gaining importance in recent decades regarding irrigation in agricultural farming, as it is the only factor that facilitates success in sustainable agricultural practices (Oliveira et al., 2019). Since climate change affects agriculture with scarce rainfall and increase in temperature, it is essential to adopt green innovation or climate smart agriculture (CSA) practices to increase crop productivity, income, and reduce emissions of GHGs from agricultural activities (Khamkhunmuang et al., 2022). In agricultural farming, green innovation is defined as the innovative process of producing green agricultural products in order to reduce pollution, produce energy-savings, promote waste-recycling and to protect the environment (Chi, 2022). Green innovation aims to combine the efficiency of water utilization with renewable energy usage in agricultural farming (Kumar et al., 2012), along with improvement in designing, promoting and delivering training programs to farmers to create awareness and provide incentives for purchasing innovative types of machinery based on a microfinance funding model. Such initiatives are considered to be essential, because of the high consumption of energy and water for irrigation in agricultural production and wastewater treatment (Endo et al., 2017). Irrigation is the lifeblood of agriculture, especially in hot, arid regions without adequate rainfall, because without irrigation, the world's food production would decrease by 20% (Falloon and Betts, 2010). In response, global irrigated areas have almost doubled in size over the past 50 year, with further expansions being forecast (especially in developing countries) to about 40 million ha by 2030, to meet the food supply requirements of the growing population. A study conducted by Neumann et al. (2011) reported expansion of the global pattern of irrigated croplands. Their findings suggested the necessity of considering topographic, socio-economic and management information to identify the need for irrigated agricultural land, because irrigation is the largest consumer of global water resources, (70–90%) of global water consumption. Conventionally, 60% of the world's crop cultivation relies on rainwater. However, in past decades, there has been irregular rainfall, caused by climate and environmental changes, which has affected the number of cultivated crops (Food and Agriculture Organization of the United Nations, 2011). This makes it crucial to adopt an efficient water-saving irrigation technique with the ability to supply water in all seasons and all regions to sustainable agricultural production (Garcia et al., 2017). Due to irrigation, agricultural land produces more than 40% of the global cereals (Portmann et al., 2010). Thus, it is very important to switch to a smart agricultural crop production process, by using green innovation irrigation technology that offers water-saving and water efficiency, such as drip irrigation, sprinkler irrigation, wastewater ferti-irrigation and precision agriculture to reduce the water scarcity impact on human life (Jagermeyr et al., 2015).

Drip irrigation

Drip irrigation is one innovative technology with the ability to maximize the distribution efficiency of irrigation water (Postel et al., 2001; Wang et al., 2021). It is important to provide poor farmers with the incentive to own low-cost affordable drip irrigation (Postel et al., 2001) that can apply water in small amounts directly to the root of the cultivated plant with high efficiency in saving water, fertilizer and crop productivity. Drip irrigation with fertilizer is another innovative technique of fertilizer application commonly known as "fertigation". Through this technique, soluble fertilizers and water for irrigation are blended in a tank and then sprayed in the root zone of the cultivated plant using small pipes or drippers. The main advantages of this technique are its ability to increase nutrients received by the cultivated plants, to achieve higher yields and quality and to avoid wastage of water, energy and fertilizer (Selim et al., 2009; Sureshkumar et al., 2017). Fig. 2 shows the application of drip irrigation with fertilizer.



(Adapted from https://www.pinterest.dk/pin/452330356294552634/)
Fig. 2 Drip irrigation with fertilizer

Sprinkler irrigation

A sprinkler irrigation system is shown in Fig. 3. Sprinkler irrigation is the equivalent of human-made rainfall to distribute water to cultivated crops. It has 80–85% water-saving efficiency by applying innovative green irrigation technology with the ability to spray water intelligently to the cultivated crops, in a similar manner as rainwater. It can be used to sprinkle crops of different kinds. The components of sprinkler irrigation are a water pump, water pipe, source of water, tubing, head of the sprinkler, the nozzle and other accessories. Water is sprinkled as tiny drops, like rainfall, on the cultivated crops through the nozzle at the end of the pipe using medium-to-high pressure. However, the efficiency of the sprinkler irrigation system depends on the efficiency of the system components and the applied pressure (Food and Agriculture Organization of the United Nations, 2020). This method of irrigation is commonly used in areas of scant rainfall, which is inadequate for

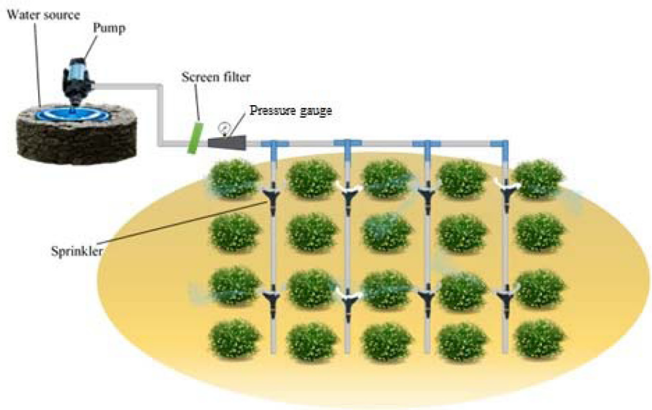


Fig. 3 Sprinkler irrigation

the optimal growth of an agricultural crop. One disadvantage of sprinkler irrigation is that it is unsuitable for areas with high temperatures, intense wind velocity, low humidity, and arid regions (Rasheed and Al-Adili, 2016).

Ferti-irrigation using wastewater

Wastewater irrigation is a sustainable agricultural approach, which not only can save the limited quantity of freshwater resources, but also the expenses for crop fertilizer. The process of adding supplements to the water used for irrigation in agriculture is called 'ferti-irrigation' and involves either adding supplements, such as carbon, nitrogen, phosphorus and potassium to irrigation water or by using wastewater as it may minerals and other nutrients essential for the growth of crops. However, the wastewater requires proper treatment before application as there is a risk of contamination from heavy metals. If properly treated, ferti-irrigation has many benefits, including the ability to recycle the water along with the nutrients. In addition, it is a low-expense option in areas with less rainfall, where it can help to address the demands for agricultural irrigation and increased crop yields (Khouri et al., 1994; Scott et al., 2000; Toze, 2006; Salakinkop and Hunshal, 2014).

Precision agriculture technology

Precision agriculture (PA) is agricultural cultivation management that is applied automatically with the aid of information technology to optimize the yield, minimize the environmental impact and reduce costs and human power requirements (Paek et al., 2014). PA with the IoT and WSNs can transform current agricultural practices into smart agricultural farming methods by automating the entire process of agricultural crop cultivation management including the environmental conditions, water irrigation and soil conditioning using real-time monitoring and assistance in insect, pest and disease management (Pandya et al., 2021; Ali et al., 2023).

Applying PA needs hardware components, such as wireless sensors, that can collect real-time data (obtained from observations tools, including satellites, drones and sensors (Khanna and Kaur, 2019), a geographic information system, remote and proximal sensing, and a global navigation satellite system to monitor the growth and to optimize agricultural productivity (Neupane and Guo, 2019). The application of PA can increase the yield while minimizing water and energy usage (Zhang et al., 2021). In brief, PA is an information-based agricultural management system and IoT technology aids in its operation in terms of collecting and processing crop cultivation data, environmental information and the appropriate time for planting, fertilizing and harvesting crops to maximize their quantity, quality and the cost-effectiveness of agricultural cultivation. IoT-based smart agricultural technology offers a wide scope for water utilization in agricultural farming with maximum yield, by improving irrigation site management and the efficient monitoring of soil temperature, soil moisture and humidity, from a convenient place that may even be sitting in a comfortable room (Podder et al., 2021). Thus, PA with WSNs can be reliable for collecting, analyzing and reporting data for agricultural crop management (Fountas et al., 2015). Through WSNs, the farmer can remotely monitor and optimize the output of irrigation water in a pump or field using a mobile phone connection, for example when the water level is beyond the optimum (Ojha et al., 2015) and to calculate all kinds of agricultural farming parameters, including water for irrigation, fertilizer quantity, pesticides, soil moisture and air temperature. Many scholars have designed and developed PA systems using WSNs. Le and Tan (2015) monitored and controlled environmental parameters, including soil, humidity, air, light and temperature. Tagarakis et al. (2021) developed low-cost, low-power consumption WSNs, applicable in small-to-medium-sized fields located anywhere within cellular network coverage, even in an isolated village. The convenience of this system is that it can be operated even by a mobile phone, with low energy consumption and increased network reliability, while bringing efficiencies in monitoring environmental, soil and crop conditions. Hamouda and Msallam (2020) developed a fuzzy logic control sensor to estimate the soil temperature and moisture content needed for a farm site, which also showed significant improvement in energy consumption while enhancing crop production. Benyezza et al. (2021) developed and tested a new zoning-irrigation-system technology based on WSNs installed in the different zones of a greenhouse. The system was controlled by a fuzzy logic controller that enables the farmer to monitor and make intelligent and optimal adjustments at any time and from anywhere.

Solar energy for irrigation

Using conventional agricultural machinery powered by fossil fuel energy is disapproved of by most environmental scientists because such machinery harms the environment through excessive greenhouse gases emissions (Aroonsrimorakot et al., 2018). Solar energy, as shown in Fig. 4, can be considered as a viable option for renewable energy which can be utilized to solve global energy requirements, as it is free and abundantly available, with the Earth receiving approximately 1.8×10^{14} kW out of the total sun energy emitted at a rate of 3.8x1023 kW per second (World Energy Council, 2013; Kumar, 2020). Consequently, it can replace fossil fuels to power all types of equipment used in agricultural crop cultivation. For a long time, environmental researchers have been looking for an alternative renewable energy which produces no harmful impact on the environment (Kannan and Vakeesan, 2016). Using solar energy has many advantages, as it is economical, clean, easy to operate, produces no noise, has low-cost maintenance and does not emit greenhouse gases, unlike fossil fuel energy (Aroonsrimorakot and Laiphrakpam, 2019; Aroonsrimorakot et al., 2020; Kumar, 2020).

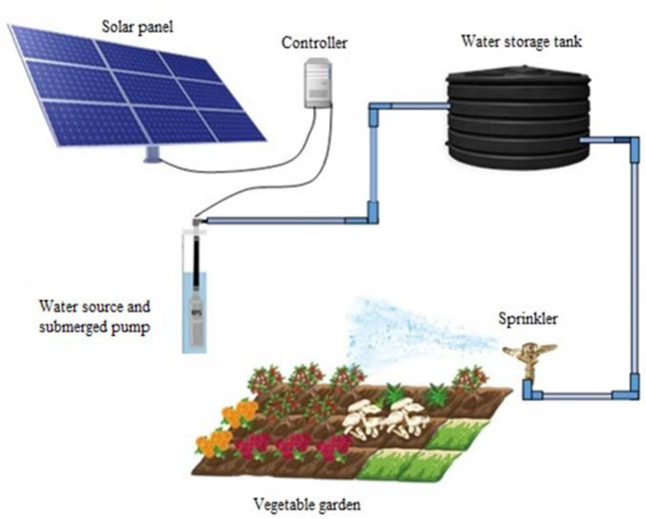


Fig. 4 Using solar energy for agricultural farm irrigation

Even though the cost of buying a solar PV system is a little high for most farmers, it provides unending resources and saves on farming area and provides low-cost green energy, even for farms located in far-away rural areas. The system can take the form of water pumps used for crop irrigation, both sprinkler or drip (Eker, 2005; World Energy Council, 2013). Using innovative solar energy is considered a boon to farmers, especially rural farmers in remote areas, as it is affordable, reliable, efficient and also has no impact on the environment in the agricultural food production process. As a result, in recent decades, most countries have opted to replace fossil fuel energy with green solar energy technology. Solar energy can be used for various applications in the crop cultivation process including solar panel water pumps for crop irrigation, space heating, drying, ventilation and greenhouse cultivation (Global Network on Energy for Sustainable Development, 2004). Solar energy can be converted into electrical energy using a solar photovoltaic PV system, in which semiconductors convert direct sunlight into electrical energy that can be used in the agricultural production process. PV energy provides natural, green and sustainable electricity for agriculture (Xue, 2017). The operating process of solar PV utilizes a solar panel mounted 2 m above ground level to avoid shading by the cultivated crop (Weselek et al., 2019). The application of solar panels in agricultural cultivation is considered to be a reliable green innovation because it can meet the demand of energy requirement for cultivation effectively and smoothly at a reduced cost and with no harmful impacts from greenhouse gas emissions into the environment, unlike fossil energy (Torshizi and Mighani, 2017). The design of solar panel energy for irrigation must consider the nature or type of irrigation, along with the various ways of usage, such as a solar water pump for irrigation, which relies on the level of water and the demand of the irrigated area (Frenjo et al., 2017). In brief, PV energy offers the best solution for remote agriculture with numerous applications, including water pumps used to irrigate farms, green energy for sprinkler and drip irrigation, transportation, storage, wastewater purification, disposal and greenhouse heating (Eker, 2005).

Conclusion and Recommendations

To address the challenges to food security raised through water scarcity and the depletion of fossil fuel energy, it is essential to use green innovation in agriculture, to utilize available resources and to increase food production for the increasing global population. The article used content analysis by describing the contents of the reviewed articles, focusing on the application of green innovation to save water and energy for environmental sustainability in agricultural farming. Innovation in an irrigation system design aims for the sustainable use of water, fertilizer, energy and other resources to reduce greenhouse gas emissions. With the application of green innovation, there have been improvements in the irrigation water and fertilizer distributions, through increased efficiency and performance, and also have economic benefits as it saves water and energy with higher yields. Finally, the paper concludes that the application of green innovation technologies would solve many challenges of energy and water scarcity and greenhouse gas emission in the agricultural cultivation process. With the application and adoption of green energy and water-saving irrigation technology, such as solar energy, drip and sprinkler irrigation, wastewater ferti-irrigation, precision agriculture using IoT and WSNs in agricultural crop cultivation, the problem of greenhouse gas emissions, climate change and the water scarcity issue can be solved for environmental sustainability.

Some recommendations from the current study are: 1) provide more incentives and increase the awareness of farmers in PA, drip irrigation, waste water treatment and other innovative solutions; 2) implement policies for adopting green innovations to solve the problems associated with the water and energy crisis and to save on resource usage in agricultural activities; 3) identify the economic status of farmers in different regions and then implement appropriate policy support to farmers at low economic development levels to invigorate green innovation in agricultural technology (Sun, 2023); 4) integrate different research fields to solve the challenges associated with using PA for sustainability (Mackrell et al., 2009); 5) reduce the problems with using ICT by offering training so that the farmers can adapt more readily to new techniques (Rossi et al., 2014); 6) conduct more research on intervention methods to improve farming methods (Brauman et al., 2013); 7) conduct more research on the agricultural factors of a region, such as topography, soil, and climatic conditions, which are essential inputs in determining the best irrigation method to adopt; and 8) adopt IoT technologies to address the challenges in the application of green innovation technology (Rayhana et al., 2020).

Conflict of Interest

The authors declare that there are no conflicts of interest.

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The Mahidol University Library and Knowledge Center provided access to all the journals and other literature available on the internet and also checked for inadvertent plagiarism in the draft manuscript.

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