14 Application of SMART Technologies in Organic Farming: Recent Advances and Future Directions

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Abstract

Smart farming is the use of information technology and sensors to collect and analyze data about crops, soil and weather conditions to make informed decisions about crop management, such as when to irrigate, apply fertilizer or control pests and diseases. The application of SMART technologies in organic farming is a relatively new field, but there have been some recent advances that have the potential to improve the sustainability and efficiency of organic production. The future of SMART technologies in organic farming is promising. As these technologies continue to develop, they will provide organic farmers with new tools to improve their yields, reduce their environmental impact, and make their operations more sustainable. This chapter reports current developments and application of SMART technologies such as sensor technology, biotechnology, nanotechnology and information communication technology, etc. in organic agriculture and blooming technologies for scientists and students who are working in the field to use this chapter as reference material.

Keywords: nano-biotechnology, organic farming, plant protection, sensors, SMART technologies

Introduction

Organic farming is a holistic system of agriculture that strives to optimize the productivity and fitness of diverse communities within the agro-ecosystem, including soil organisms, plants, livestock and people with the expectation of economic, environmental and social sustainability (Stockdale *et al.*, 2001). There are many different approaches like crop rotation, cover cropping, composting, integrated pest management (IPM) and animal welfare that are critically considered to optimize farm production while minimizing costs. Therefore, organic farming is a complex system that requires a deep understanding of the principles of ecology and sustainable agriculture (Altieri, 2004; Francis and Porter, 2011). However, the rewards of organic farming can be improved soil health, reduced environmental impact, secure nutritious food and better animal welfare.

Apart from the benefits, there are uncertainities in organic farming such as lower yields, higher costs, more labour-intensive, more difficult to scale, less predictable yields due to unpredictable weather changes and pests outbreaks (Malhi *et al.*, 2021). SMART technologies are a set of technologies that use sensors for precision irrigation, fertilization and weed control, biotechnology to improve agricultural productivity, nanotechnology to improve the effectiveness of biopesticides, and artificial intelligence (AI)-based pest monitoring, which are really indispensable to overcome the bottlenecks in organic agriculture (Javaid *et al.*, 2022; Ali *et al.*, 2023). Smart technologies can be

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used in a variety of ways in organic farming, as detailed below.

Sensors for Precision Irrigation, Fertilization and Weed Control

There are a number of sensors that can be used for precision irrigation, fertilization and weed control. Some of the most common sensors include:

- soil moisture sensors: these sensors measure the amount of water in the soil, which can be used to determine how much water is needed to irrigate each field;
- leaf wetness sensors: these sensors measure the amount of water on the leaves of plants, which can be used to determine if the plants need to be irrigated (Millán *et al*., 2019; Sánchez Millán *et al*., 2023);
- Nitrogen sensors: these sensors measure the amount of nitrogen in the soil, which can be used to determine how much fertilizer to apply to each field (Liu *et al*., 2023);
- weed sensors: these sensors detect the presence of weeds, which can be used to determine if herbicides need to be applied (Andújar *et al*., 2012).

These sensors can be used to collect data using a variety of methods such as coupled plasma (ICP) spectroscopy, near-infrared spectroscopy (NIRS), X-ray fluorescence (XRF), capacitance, resistance, optical sensors, infrared sensors, and thermal sensors (Kandpal *et al*., 2022). These data can then be used to create a management plan for each field. For example, if the soil moisture sensor indicates that a field is dry, the irrigation system can be activated. If the leaf wetness sensor indicates that the plants are not getting enough water, the irrigation system can be adjusted to provide more water. If the nitrogen sensor indicates that the soil is low in nitrogen, fertilizer can be applied. If the weed sensor indicates that there are weeds present, herbicides can be applied (Javadi *et al*., 2021; Greenberg *et al*., 2023).

By using sensors to collect data and create management plans, farmers can improve the efficiency of their irrigation, fertilization, and weed control practices. This can lead to increased crop yields, reduced input costs and improved environmental sustainability (Millán *et al*., 2019; Sánchez Millán *et al*., 2023; Liu *et al*., 2023).

Biotechnology to Improve Agricultural Productivity

Biotechnology has been applied to breeding resistance cultivars to improve the agricultural productivity in a number of ways particularly important to organic agriculture.

Gene transfer

Genes from other organisms can be transferred into crop plants to confer resistance to diseases. For example, in the early 2000s, a group of scientists at Syngenta developed a transgenic corn by transferring genes from the bacterium *Bacillus thuringiensis* (*Bt*) into corn and cotton to provide resistance to insects, such as European corn borers, and help to protect the corn from insect damage. This technology has helped to reduce use of synthetic pesticides several-fold (Buiatti *et al*., 2013; Romeis *et al*., 2019).

RNA interference (RNAi)

RNAi is a natural process by which cells silence genes that are essential for the pathogen's survival. This can be used to develop crops that are resistant to diseases by silencing genes. There are a number of examples of how RNAi has been used to protect crops from disease (Halder *et al*., 2022). For example, tomato yellow leaf curl virus (TYLCV) is a serious disease that can cause significant yield losses in tomato crops. RNAi-resistant tomato plants are produced by introducing a gene into the plant that encodes for a short interfering RNA (siRNA) that targets the TYLCV genome. When the siRNA binds to the TYLCV genome, it triggers the RNAi pathway, which leads to the destruction of the TYLCV RNA and the prevention of virus replication (Koeppe *et al*., 2023).

The same principles used to develop many disease-resistant crops like resistant rice plants to the rice tungro virus (RTV), tobacco plants to the tobacco mosaic virus (TMV), potato plants to the potato virus Y (PVY) and soybean to the soybean cyst nematode (Koeppe *et al*., 2023).

RNAi is a powerful new tool that has the potential to revolutionize the way that we protect crops from disease. As our understanding of RNAi improves, we can expect to see even more innovative and effective ways to use RNAi to protect crops from disease (Liu *et al*., 2020; Koeppe *et al*., 2023).

Genetic engineering and genome editing

Genetic engineering techniques can be used to modify the genes of crop plants to make them more resistant to diseases. For example, in the 1990s, a group of scientists at Monsanto developed a transgenic soybean plant that was resistant to the herbicide Roundup. This technology, known as Roundup Ready soybeans, has revolutionized soybean production and has helped to reduce the use of chemical herbicides (Homrich *et al.*, 2012).

In recent years, there has been a growing interest in using targeted genome editing using transcription activator-like effector nucleases (TALENs), zinc finger nucleases (ZFNs) and CRISPR/Cas9, to develop plants that are resistant to diseases. Genome editing allows scientists to make precise changes to the DNA of plants, which can be used to alter genes that are involved in disease resistance. CRISPR/Cas9 technique applied to tomato plants resistant to the tomato yellow leaf curl virus (TYLCV), potato plants resistant to the potato virus Y (PVY) and leaf hoppers, rice plants resistant to the rice tungro virus (RTV), salt-tolerant, brownplant hoppers have been successfully developed and are widely being used. As the technology continues to develop, we can expect to see even more innovative and effective ways to use genome editing to protect crops from diseases (Li *et al.*, 2020; Pramanik *et al.*, 2021).

These technologies have the potential to reduce the use of pesticides and herbicides in organic agriculture. However, there are also concerns about the safety of genetically modified crops and the potential for these crops to harm the environment (Bawa and Anilakumar, 2013).

Image processing for pest and disease detection

Image processing techniques can be utilized for the early detection of crop pests and diseases. By analyzing images of crops, it becomes possible to identify visual signs and symptoms associated with specific pests or diseases (Ngugi *et al.*, 2020).

This model is applied to unseen images to detect potential pests or diseases. The model will classify each image based on the learned patterns and provide a diagnosis. When a potential pest or disease is detected, the detection system with an alert mechanism notifies farmers or agricultural experts. The alerts can be sent through mobile applications, email notifications, or other communication channels (Li *et al.*, 2021).

As we know, image processing is a smart technology for early detection of crop pests and diseases. It can be used to identify and classify pests and diseases based on their visual characteristics, such as colour, shape and texture. This can be done by using a variety of image processing techniques, such as image segmentation, feature extraction and classification (Shahoveisi *et al.*, 2023).

Image processing for crop pest and disease detection has a number of advantages over traditional methods, such as visual inspection and laboratory testing. These advantages include: (i) speed: image processing can be used to quickly scan large areas of crops for signs of pests and diseases. This can help to identify problems early, when they are easier to control; (ii) accuracy: image processing can be very accurate in identifying pests and diseases. This is because it can be used to extract features that are not visible to the naked eye; (iii) cost-effectiveness: image processing is a relatively inexpensive method of pest and disease detection. This is because it does not require the use of specialized equipment or trained personnel. As a result of these advantages, image processing is becoming increasingly popular for crop pest and disease detection. It is being used by farmers, agricultural researchers and government agencies around the world (Shoaib *et al.*, 2023; Ngugi *et al.*, 2021; Shahoveisi *et al.*, 2023).

Here are some examples of how image processing is being used to detect crop pests and diseases:

1. The PlantVillage project is a collaborative effort between the University of Florida and Google. The project has developed an image processing system that can identify 26 different plant diseases. The system has been used by farmers in over 100 countries to help them detect and control plant diseases.
2. The Cornell University Plant Disease Detection System is another image processing system that is used to detect plant diseases. The system has been used to identify over 100 different plant diseases.
3. The European Union's e-Phyto system is a web-based system that uses image processing to detect plant pests and diseases. The system is used by EU member states to inspect imported plant material.

As the technology continues to develop, it is likely that image processing will become even more widely used in agriculture.

It is important to note that the effectiveness of image processing for early pest and disease detection depends on the availability of high-quality training data, accurate labelling, and continuous refinement of the detection model based on real-world observations. Regular updates to the model using newly acquired data can improve its accuracy over time and combining image processing with other data sources, such as weather information or soil analysis, can further enhance the detection capabilities and provide more comprehensive insights for crop management (Ngugi *et al*., 2020; Shoaib *et al*., 2023).

Overall, image processing is a promising SMART technology to protect crops and ensure food security by early detection of crop pests and diseases in organic agriculture (Dhanaraju *et al*., 2022).

Nanotechnology in organic agriculture

Nanotechnology has the potential to revolutionize various industries, including agriculture. In the field of organic agriculture, nanotechnology can offer innovative solutions for plant protection (Deshpande, 2019). Here are a few potential applications of nanobiotechnology in plant protection in organic agriculture:

Nano-botanical-pesticides. Nanoparticles can be utilized to develop targeted and controlled release formulations of pesticides. By encapsulating active ingredients in nanoparticles, their delivery and efficacy can be enhanced while minimizing their negative impacts on the environment. These nanopesticides can be designed to release the pesticide gradually, providing long-lasting protection against pests and diseases (Chaud *et al*., 2021).

Nano-organic-fertilizers. Nanotechnology can also contribute to the development of nano-fertilizers that improve nutrient uptake and utilization by plants. Nanostructured organic fertilizers can be designed to release nutrients slowly, preventing nutrient leaching and optimizing plant nutrition. Additionally, nanoscale nutrient carriers can enhance the efficiency of nutrient delivery to plants, reducing the amount of fertilizer needed (Beig *et al*., 2022). Research on nano-organic fertilizers is an emerging field that explores the potential benefits of nanotechnology in improving the efficiency and effectiveness of organic fertilizers (Vasseghian *et al*., 2022). Recent researches focus on (i) nanoencapsulation of organic nutrients: nanoencapsulation involves the encapsulation of organic nutrients within nanoscale materials to protect them from degradation, improve their solubility, and enhance their controlled release (Ayyaril *et al*., 2023). Researchers are investigating the use of biocompatible nanomaterials, such as polymers or lipids, to encapsulate organic nutrients like compost, manure or plant extracts. This approach aims to improve nutrient availability and reduce nutrient losses in organic farming systems; (ii) nanostructured delivery systems: nanostructured delivery systems provide a platform for the controlled release of organic nutrients. Nanoemulsions, nanogels or nanoparticles can be designed to encapsulate and slowly release organic fertilizers, ensuring a sustained nutrient supply to plants (Jíménez-Arias *et al*., 2022). These delivery systems can improve nutrient uptake efficiency, reduce nutrient leaching, and minimize the risk of nutrient loss to the environment (Ayyaril *et al*., 2023); (iii) nutrient uptake enhancement: nanotechnology offers the potential to enhance nutrient uptake by plants. Researchers are exploring the use of nanoparticles to improve the solubility and mobility of organic nutrients in the soil, making them more available for plant uptake. Nanoparticles can also interact with plant roots to enhance nutrient absorption processes, leading to improved nutrient use efficiency (Yadav *et al*., 2023).

Nano-organic fertilizers are being investigated for their impact on soil health and fertility. Nanomaterials can modify soil properties, such as water holding capacity, nutrient retention and microbial activity. Researchers are studying the effects of nano-organic fertilizers on soil microbial communities, nutrient cycling processes and overall soil fertility to assess their long-term impact on soil health in organic farming systems. Further, it is crucial to assess the potential environmental impacts of nano-organic fertilizers. Advanced researches are being conducted to evaluate the fate and behaviour of nanoparticles in the environment, their potential toxicity to soil organisms, and the risk of nanoparticle accumulation in plants and ecosystems (Ahmed *et al*., 2023). Understanding the environmental implications is essential for the safe and sustainable use of nano-organic fertilizers. It is important to note that research in this area is still in its early stages, and more studies are needed to fully understand the benefits, risks and practical applications of nano-organic fertilizers in organic agriculture. Regulatory frameworks and guidelines are also required to ensure the safe and responsible use of these technologies (Basavegowda and Baek, 2021).

Nanosensors. Nanotechnology-based sensors can be employed for early detection of pests, diseases and environmental stresses. These sensors can monitor various parameters such as moisture levels, nutrient status and the presence of pathogens. By providing real-time data on plant health, nanosensors enable farmers to take timely and precise actions to prevent crop damage (Shaw and Honeychurch, 2022).

Nanobiosensors. Nanotechnology can be utilized to develop biosensors that can detect specific pathogens or pests. These biosensors can identify the presence of harmful organisms in plants or the surrounding environment, enabling farmers to implement targeted control measures. Nanobiosensors offer high sensitivity, specificity and speed, allowing for rapid and accurate disease diagnosis (Mondal *et al*., 2022).

Nanocarriers for biocontrol agents. Beneficial microorganisms, such as biocontrol agents, can be encapsulated within nanoparticles to enhance their stability and efficacy. Nanocarriers protect these agents from degradation, improve their adhesion to plant surfaces and promote controlled release. This approach ensures the targeted delivery of biocontrol agents, enhancing their ability to suppress pests and diseases (Saberi Riseh *et al*., 2022).

Regulations and guidelines should be established to evaluate and manage the potential risks associated with the use of nanomaterials in organic agricultural practices.

Conclusions

The use of SMART technologies in organic farming is a novel strategy and a promising area of research and development. These technologies have the potential to improve the sustainability, profitability and efficiency of organic farms. As these technologies continue to develop, it is likely that we will see even more widespread adoption of SMART technologies in organic farming in future. Technologies are costly and may be difficult to handle in real field scenarios with unpredicatable climate changes; therefore, appropriate choices of amenable sustainable technology when predicting future technology would have the potential to significantly improve the sustainability and efficiency of organic production.

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