ROLE OF SENSORS, IOT DEVICES, AND WIRELESS COMMUNICATION FOR SUSTAINABLE AGRICULTURE

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Abstract:
To address the needs of a growing global population, it is crucial to enhance the sustainability and self-reliance of our world food network. A key objective in achieving the goal of global sustainability and food security is the digitalization of agricultural processes, resources, and outcomes of agriculture and food processes. The eventual outputs of this digitization is aimed to strike a symbiotic balance among social, cultural, economic, and environmental fabric within these digitalized agriculture and food systems. Digitalization is already showing promising results. The agricultural sector is undergoing a transition towards becoming more resilient and data-driven with and increasing demand for precision and advanced technologies to enhance the performance of traditional farming methods. In this technical transformation, the key technologies (such as sensors, robotics, and wireless communication platforms) are playing a significant role in propelling this evolution. The rapid adoption of these internet of things (IoT) technologies is reshaping agriculture and other manufacturing and service industries. This transformative shift is positively disrupting existing farming practices while presenting new opportunities and challenges. This review discusses the global sustainability needed for food security of the future, the push towards digitization, and the advent of new IoT technologies for improved performance and efficiency.

Introduction

Crop yields in developed countries have witnessed dramatic increases since World War II, primarily through revolutionary agricultural policy changes and global food security initiatives [1-3]. Challenging external environments not only hamper crop productivity but also degrade soil structure [2-7]. Additionally, the excessive and indiscriminate use of chemical fertilizers and pesticides by farmers pose growing concerns for environmental safety within modern agriculture. For example, factors like temperature, terrain, and soil quality constrain the availability of arable land, further exacerbated by economic, political, and urbanization pressures [5-14]. The role of external environment plays a critical role on certain crops that play pivotal roles in supporting the economies of different countries.

Therefore, establishing a sustainable, environmentally friendly agricultural system and enhancing crop production are pivotal in maintaining environmental stability. The crop health and yield are influenced by weather, land profiles, and soil characteristics, necessitating plans tuned to the local economy and precision farming tools to optimize yields [5-18]. Sustainable agricultural systems require a nuanced and planned approach, incorporating various techniques judiciously such as crop rotations, robotic machinery inputs, and organic matter utilization to reduce reliance on chemical fertilizers and pesticides [14-20]. Additionally, understanding the interplay between different critical components in agricultural systems is crucial for sustainability and food security.

Agricultural Sensors and Internet-of-Things Devices

To address the challenges in agriculture at local and regional levels, farmers and growers require access to advanced sensor technologies and service-based solutions to maximize food production with limited farming resources (e.g., personnel, water, field machinery). Smart agriculture which is facilitated by ubiquitous sensing technologies can help minimize the impact of climatic and environmental factors on crop yield [21-28]. For example, wireless sensors can help in continuous crop monitoring and detecting crop health issues early in the growth stages so that timely remedial steps can be taken. Advanced technologies like IoT enhance agricultural operations, from harvesting to transportation and storage, making farm processes more efficient for growers. Different sensors and internet of things (IoT) devices can be tailored for specific agricultural tasks for near real-time sensing and actuation [22-30]. The integration of appropriate techniques and IoT devices can be used for field sowing, planting, fertilizing, disease detection, harvesting, packaging, and food transportation [30-38].

Academic Institutions in Agricultural Transformation

Several academic institutions and agricultural companies are currently researching new technologies to facilitate efficient farm practices and management schemes. These technologies help in achieving optimal results and enhancements in various sectors while minimizing associated inefficiencies in seed application, growing stages, and harvesting [21-27]. These innovative technologies offer substantial improvements in essential farming infrastructures, while leveraging wireless devices through internet technology and a wide array of field services. These field services encompass cloud-based sensor information, automation of diverse farming operations, and facilitating effective decision-making. In addition, farmers view economic viability is a crucial component of sustainability in agriculture which is largely driven by profitability and net household income. The net profitability is a key metric influencing many farming decisions of farmers and is often a driving force behind enforcing new agricultural policies by government agencies [15-19].

Soil Health Monitoring for Agricultural Sustainability

One important component in agriculture is soil health. Soil plays a pivotal role in plant growth, necessitating field-scale monitoring to make informed decisions at different plant developmental stages. Routine soil analysis aims to measure nutrient content, moisture content, and resistance to pests which helps to guide treatments to fulfill the desired nutrient requirements [20-24]. Soil health factors, including soil types and moisture, inform fertilizer and irrigation needs and provide insights into physical, chemical, and biological properties. New agricultural practices like organic fertilization, crop rotation, and minimal soil disturbance contribute to improving soil health, essential for agricultural productivity and environmental resilience.

Soil microbes significantly contribute to crop growth and development by combating soil-borne pathogens [18-26]. Understanding the role of soil microbes is crucial for sustainable agriculture. However, prolonged and excessive use of chemical fertilizers can negatively impact soil health and crop productivity. Advanced technologies like IoT offer alternatives to reduce chemical use in farms, enhance disease management, and improve crop yields and productivity. Monitoring and managing crop diseases and pests are vital for maintaining crop health and productivity. Remote sensing technology enables cost-effective analysis of large agricultural areas, providing insights into crop health, disease, and environmental factors. These technologies offer effective strategies for disease management, minimizing reliance on harmful chemicals.

Furthermore, efficient management of soil and water is essential for enhancing crop quality and yield. Precision nutrient application methods enhance nutrient uptake by crops, reducing environmental impacts. Techniques such as vertical farming and hydroponics offer sustainable solutions to land and water constraints, maximizing resource efficiency.

Discussion

The discussed smart methods show great promise in advancing agriculture, having been effectively employed to cultivate various crops in favorable conditions. Among these, phenotyping approaches [19-23], advanced genetic engineering techniques, and biotechnology stand out, correlating crop genetic sequences with agronomical and physiological aspects [29-38]. Various challenges hinder the achievement of agricultural sustainability goals by 2050, including declining agricultural manpower, diminishing arable land, water scarcity, and the impacts of climate change. Urbanization trends further exacerbate these challenges, leading to not only a decline in rural population but also an aging rural workforce, necessitating the involvement of young farmers. Moreover, climate change is already affecting crop production worldwide, exacerbating long-term ecological challenges like droughts, floods, soil degradation, and groundwater depletion [4-8].

Conclusion

As the world population increases, there is added pressure on arable land available for agriculture. With arable land for farming is becoming limited, there is need for efficient, innovative farm technologies to achieve food security. Currently, there is increased focus on innovative approaches to improve crop yields and optimize farm processes. However, we need to address the communication gap among stakeholders. Addressing this communication gap requires the thrust for innovative solutions, such as IoTs and ubiquitous sensors, and their integration with edge computing and wireless communication platforms. Adopting advanced technologies such as IoT devices and sensors is critical for advancing agriculture in a sustainable manner. These advanced technologies offer valuable insights into soil and crop health, optimizing resource usage and enhancing productivity while minimizing environmental impacts. By leveraging these innovations, farmers can meet the challenges of feeding a growing population while preserving natural resources for future generations.

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