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IoT enabled soil moisture sensor based irrigation in banana

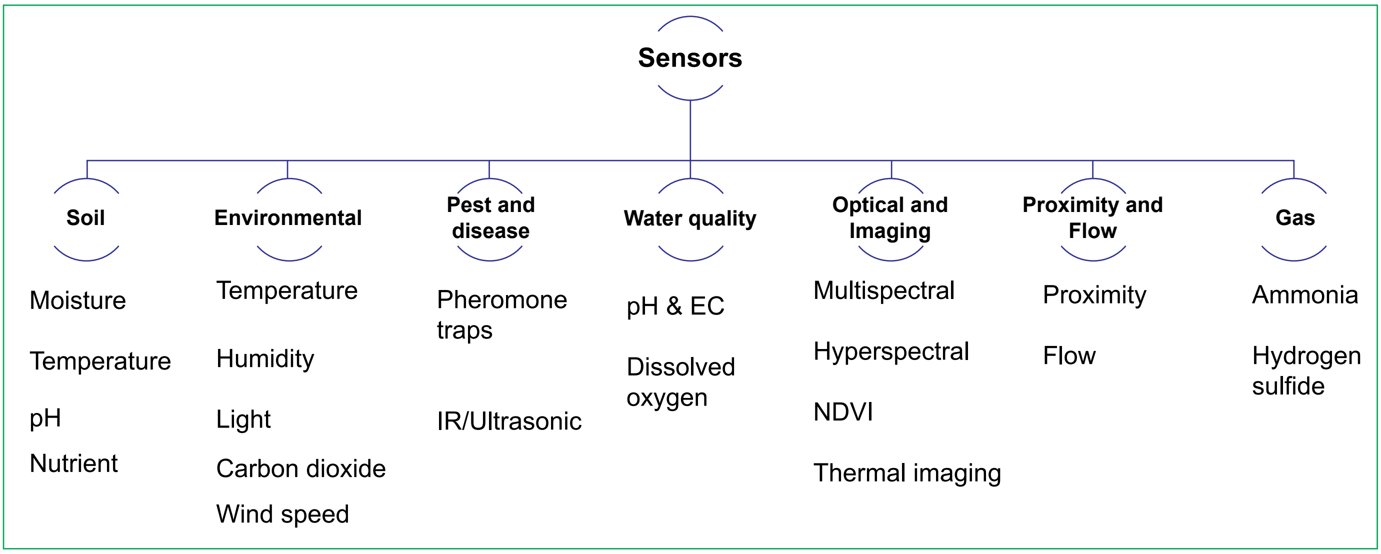
Bananas are a crucial staple crop worldwide, with India leading in global production but contributing only a small fraction to international exports due to a focus on domestic demand. Climate change poses significant challenges to banana cultivation, including increased storm frequency, drought, and temperature extremes, necessitating adaptive measures for sustainable production. This study explores the role of Internet of Things (IoT) technology in improving water and nutrient use efficiency in banana farming through automated, sensor-based smart irrigation systems. IoT-enabled moisture sensors were tested in a field experiment at ICAR-National Research Centre for Banana to automate irrigation in response to real-time soil moisture data, optimizing resource usage. Results showed a 25-30% reduction in water usage and a 15-20% decrease in nutrient application without compromising yield. The IoT system increased crop productivity, reduced operational costs, and enhanced nutrient uptake. While IoT-based smart irrigation demonstrates substantial potential, widespread adoption will require addressing challenges related to cost, rural infrastructure, data management, and user training. Future opportunities include scaling IoT solutions, developing cost-effective systems, and refining technology to adapt to diverse soil types and farming contexts. Implementing AI and ML in horticulture through IoT can support sustainable, efficient, and resilient banana cultivation in India, contributing to enhanced food security and resource conservation.

BANANAS are the fourth most important staple crop worldwide and are essential to maintaining food and nutritional security among 400 million people in producing countries. India is the largest producer of banana in the world, with a production of 35.38 million metric tonnes from an area of 0.94 million hectares in 2023. India's export of banana represents only 0.6% of the world exports since most of the bananas grown in India are for the domestic market. Banana producers will have to adapt to potential challenges brought on by changing climatic conditions, such as increased incidences of storm, drought, and extreme heat event, as well as disease, if they are to remain viable. Improved water management in the sector is an important climate adaptation to be a sustainable production system as precipitation trend has becomes less reliable. Improving resource efficiency (water, fertilizers, machinery, and labour) in agriculture is a pressing global issue. According to estimates, G20 developed countries had higher natural resource use efficiency (0.9528) than developing nations (0.506), indicating that technological changes are the primary predictor of natural resource use efficiency. Water is a key input in fruit crops, and its use efficiency varies substantially depending on crop type, irrigation method, and local climate. In a study, it is revealed that the average WUE of banana, lemon, and mango in a semi-arid climate was 2.19, 1.58, and 1.58 kg/m^3, respectively. Several researchers believed that instead of regular flooding the field and soil application of nutrients, deficit irrigation, micro-irrigation, sensor-based irrigation, and fertigation can be better alternatives to enhance both WUE and NUE in fruit crops.

All things considered, drip irrigation and fertigation performed better than traditional techniques for applying water and nutrients. Nonetheless, recent advancements in sensor-based irrigation and fertigation have produced encouraging outcomes for a variety of field crops. This technology has more potential in fruit crops because these are all wide-spaced and perennial crops. The utilization of IoT-based irrigation can be a future technology to save water and nutrients. The applications of digital interface in banana are discussed below.

IoT technology in horticulture

The Internet of Things (IoT) encompasses a system of interconnected physical devices embedded with sensors, software and other technologies that enable them to collect and exchange data over the internet. In IoT, these devices interact with each other and centralised



Different types of sensors used in horticulture

systems, often autonomously, to improve efficiency, enabling automation and decision-making across various applications without human intervention. In agriculture, IoT refers to the integration of smart devices, sensors, and other technologies to collect, transmit, and analyse data related to various agricultural processes like precision farming, smart irrigation, livestock monitoring, greenhouse automation, supply chain monitoring to drones and remote sensing.

Components of IoT

The key components of IoT include devices or things, connectivity, data processing, a user interface and supporting technologies.

Devices or Things: These are the physical objects equipped with sensors and actuators that gather and transmit the data. Sensors are essential components that collect environmental data, such as temperature, humidity, motion, light, *etc*.

Connectivity: This includes the network technologies that facilitate communication between devices, ensuring secure and efficient data transfer. Generally, Wi-Fi, Bluetooth, and cellular networks are used to transmit data.

Data processing: Data collected from devices must be processed to derive meaningful insights, which can be done on the device or in the cloud.

User interface: The user interface could be any mobile application, web dashboard, or control system allowing data monitoring, device control, and configuration settings. It allows end users to interact with IoT devices.

Cloud computing and analytics: The cloud provides storage and computing power for a large amount of data, and analytics tools help interpret that data.

Security: Security measures like data encryption, authentication, secure communication protocol and regular updates are essential to protect IoT systems.

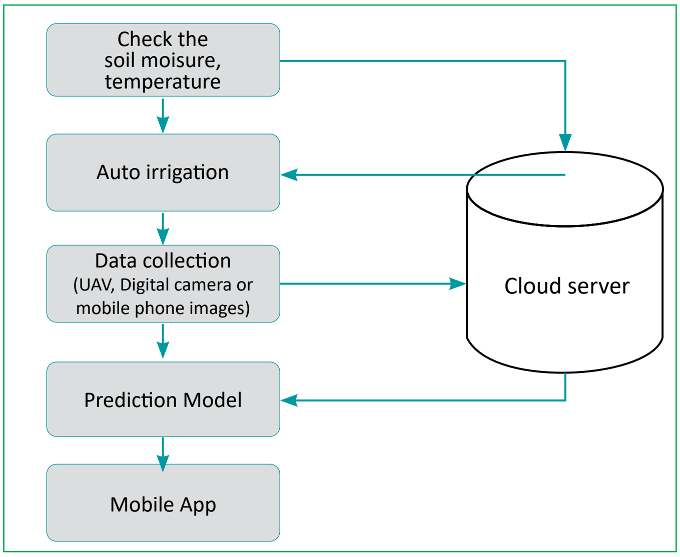
Types of sensors

In horticulture, various types of sensors are used to monitor and manage the environmental conditions that affect plant growth. These sensors help by providing real-time data on various parameters that can enhance crop management and ultimately increase efficiency.

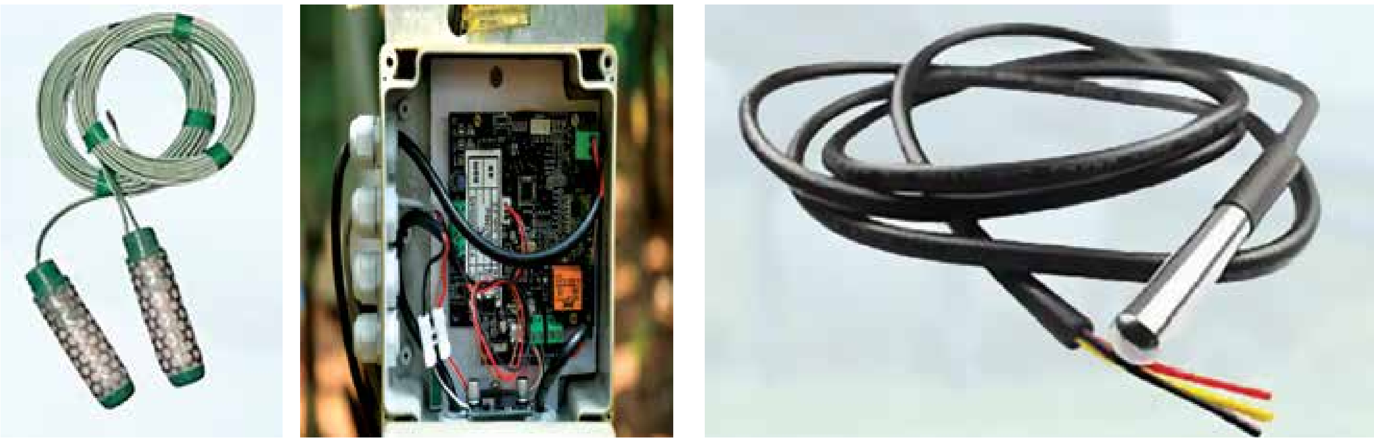
Technical challenges

The implementation of IoT in horticulture presents several technical challenges that need to be addressed. A major challenge is the lack of communication infrastructure in rural areas, where many regions remain unconnected to the Internet. Additionally, the cost of components, such as sensors, automated machinery, farm management software, and cloud services, can be expensive, making them difficult to afford. Maintaining IoT devices also incurs extra costs, and regular maintenance and repairs require technical expertise that is not always readily available, especially in rural areas. Moreover, existing agricultural systems, such as irrigation and climate control, may not be compatible with new IoT technologies, creating operational bottlenecks. Devices manufactured by different companies often use various communication protocols, leading to interoperability issues.

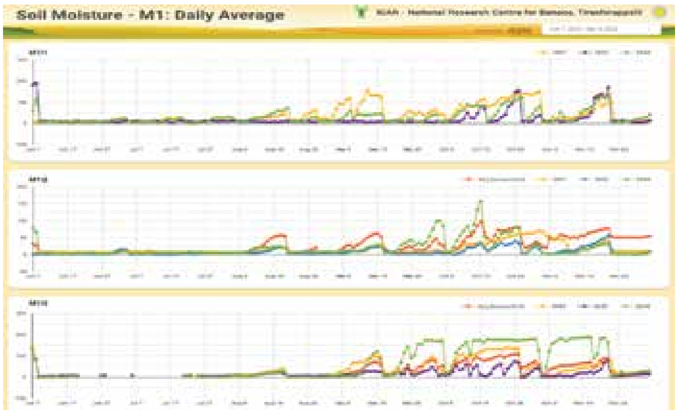
Data management is another significant challenge, as IoT sensors generate vast amounts of data. Environmental changes can affect sensor performance, so sensors must be robust enough to withstand rapid fluctuations in



Precision farming flow diagram



Moisture sensor and Rasberry pi board



Monitoring soil moisture in the banana installed with IoT enabled soil moisture sensors for smart irrigation

Banana experimental field installed with soil moisture sensors

Banana at maturity in the experimental field irrigated with IoT enabled soil moisture sensors

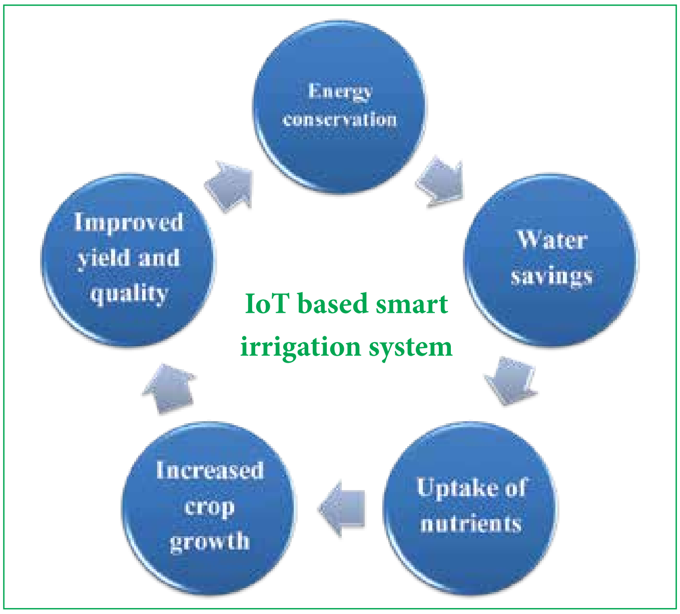
conditions. The need for real-time data analytics for immediate decision-making in horticulture is critical. Finally, user adoption and skill development represent major practical challenges. Training and support are essential to help users develop technical knowledge and utilise IoT systems efficiently. By tackling these technical challenges, stakeholders in horticulture can facilitate the adoption of IoT technologies, resulting in increased productivity, sustainability, and resilience in agricultural practices.

Development in big data analytics (AI/ML/DL), computer vision helps in timely image/data analysis for information. Crop simulation models and decision support systems in GIS environment helps in making decision rules in irrigation, e-agri advisory services to stakeholders for efficient crop management of pest and diseases, grading of bananas for export and distant markets, tracking the quality of banana through sensors.

Precision agriculture (PA) needs to go from a technology-push to application-driven approach. As no single agency can take on the entire PA process, it is essential that various agencies join and give a participatory approach for effective implementation of PA technologies. Small farm size will not be a major constraint, if the technologies are available through consulting, custom and rental services. Some of the scopes of Intelligent Indian Agriculture may be building digital nervous system for precision farming by small scale farmers with virtual joint management for order-made/market in production for customer, optimizing inputs /resources and accelerated breeding for smart crop with recent technologies of sensing and data analytics. Keeping in view above scenario, a project on precision farming in banana with IoT enabled moisture sensor-based irrigation is implemented.

Field experiment with IoT enabled soil moisture sensors

A field experiment was carried out at the ICAR-National Research Centre for Banana, Tiruchirappalli, Tamil Nadu to optimize the moisture level to irrigate the banana cv. Grand Nain based on the IoT enabled moisture sensors to automate the irrigation through AI/ ML. The moisture sensor-based irrigation system was installed and the root zone moisture was set at -33, -50, and -75 KPa. The data was collected at an interval of one hour and



Impact of IoT based irrigation system

sent to the cloud for processing and decision taken to switch on / off the irrigation pump through the AI. The microclimate is characterized throughout the experimental period. Precise irrigation in banana cultivation have been monitored in the experimental field on an area of 1.25 acres. The post-harvest quality and grading study also done in the lab.

The experimental results indicated that by implementing IoT- based automation of smart irrigation, image-based N management, 25-30% water over and above the existing drip irrigation system and 15-20% of nutrients of recommended dose of fertilizers in banana cultivation can be saved.

Major outcomes

Implementing advanced ICT tools like ML and AI can facilitate better management in banana cultivation through optimum utilization of resources without compromising yield and effective supply chain management.

To make the system acceptable to farmers, it should be economical and affordable.

The system is scalable, and it has commercial viability, looking into the needs and affordability of the stakeholders. It is suitable for deployment among larger, smaller, and marginal landholders.

Benefits achieved

The key advantages of an IoT-based smart irrigation system are water conservation, nutrient uptake, lower total energy consumption, and increased yield in various fruit crops. This could be due to irrigation optimization based on climatic conditions, soil moisture levels, crop age, and crop yield potential. Furthermore, the smart irrigation system will greatly reduce deep percolation of water by keeping soil water content below field capacity (10-15% less). Switching tensiometer-based automatic irrigation control system (AICS) lowered irrigation requirement by 40 to 50% without compromising the tomatoes yield. Precise amount of water in smart irrigation system leads to reduction in energy consumption, human labour usage, and operational cost. The delivery of precise volumes of water in automatic and sensor-based irrigation systems improves water and nutrient use efficiency. Irrigation using capacitance-based soil moisture-based AICS reduced irrigation water requirements by 30 to 80% compared to single or daily fixed-time irrigation, greatly reduced nitrogen leaching, and improved nitrogen-use efficiency and production. A precise amount of irrigation water delivered at the optimal moment for crop growth leads to increased nutrient uptake. For example, banana plants under the automated irrigation system exhibited greater concentrations of N, P, and K (1.79-2.49%, 0.12-0.19%, and 1.25-1.58%, respectively) than those with manual irrigation (1.52% N, 0.16% P, and 1.21% K). Consequently, 15% higher yield (69.84 t/ha), quality fruits (with higher TSS and lower acidity), and water productivity (40% higher) were obtained with the sensor-based irrigation system.

Opportunities for future

Nonetheless, the IoT-based smart irrigation system is in its early phases of deployment. Perhaps it requires extensive interventions and adaptations to accommodate all types of farmers in India.

- Cost-effective IoT-based smart irrigation systems, sensors, and accessories may be encouraged to be developed in India.
- Research on easy-to-use operating systems for farmers.
- Research on the applicability and feasibility of sensor-based irrigation systems for various soil types.
- The impact of extreme weather conditions on the reliability and precision of sensor-based irrigation systems.
- Suitability of a sensor-based irrigation system for deep-rooted fruit crops.
- Integration of sensor-based irrigation and fertigation in fruit crops.
- Fertilization programs can be designed using plant indices.
- Wireless systems for fast installation and removal of smart irrigation systems.
- Effectiveness of smart irrigation systems for intercropping in fruit crops.
- Cost-effective water-soluble fertilizer grades enabling easy adoption of fertigation.
- Comparative studies on feasibility of different irrigation systems (conventional, automatic smart irrigation system).

SUMMARY

Artificial intelligence (AI) and machine learning (ML) are now integrated into every business operation. Technological advancements must be integrated into high-value horticulture crops in order to make it more productive and sustainable. Implementing IoT-based smart irrigation systems in fruit crops can enhance water and fertilizer-use efficiency. The use of IoT-based smart sensing systems in farms may assist farmers in better understanding their crops, increasing input efficiency. These AI and machine learning-based solutions are being used successfully in protected fruit and vegetable

farming around the world. The appropriate use of these technologies contributes to the conservation of agricultural inputs, improved crop growth and yield, energy conservation, effective management of labour shortages, and lower production costs. However, these smart irrigation systems come with their own set of pros and constraints. Effective and economically feasible smart irrigation systems can be an alternative to traditional flood and drip irrigation systems. Indeed, smart irrigation is the future of environment friendly sustainable farming in locations with limited irrigation water supply.

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