Sensor-Based Fertigation for Real-Time Nutrient Delivery and Crop Optimization

Pritika[1]*, Dr. Narender K Sankhyan[2], Dr. Kanika Baghla[3], Divya Rana[1], Akanksha[1], and Yashaswi Sood[1]

[1]*Mater's Research Scholar, Department of Soil Science, CSK HPKV, Palampur, HP, India-176062*
[2]*Head cum Principal Scientist, Department of Soil Science, CSK HPKV, Palampur, HP, India-176062*
[3]*Assistant Professor, Department of Soil Science, CSK HPKV, Palampur, HP, India-176062*

Corresponding Author
Pritika
Email: pritikanandnalwa@gmail.com

OPEN ACCESS

Keywords

Agriculture, Fertigation, Optimisation

How to cite this article:

Pritika, Sankhyan, N. K., Baghla, K., Rana, D., Akanksha, and Sood, Y. 2025. Sensor-Based Fertigation for Real-Time Nutrient Delivery and Crop Optimization. *Vigyan Varta* 6 (5): 115-119.

ABSTRACT

The integration of fertigation with sensor-based technologies is a revolutionary approach in modern agriculture, addressing critical challenges related to water scarcity, nutrient management and sustainable farming. Fertigation, which combines irrigation and fertilization, optimizes nutrient delivery directly to plant roots, reducing wastage and improving crop productivity. Sensor-based technologies enhance this process by providing real-time data on soil moisture, temperature, electrical conductivity (EC) and nutrient levels, enabling precise and automated control over fertigation systems. The adoption of automated and semi-automated fertigation solutions, supported by Internet of Things (IoT) and artificial intelligence (AI), allows for efficient resource utilization, cost reduction and improved crop yields. This article explores the components, benefits and challenges of sensor-based fertigation systems. Additionally, prospects, such as nano-sensors, self-powered wireless sensors and advanced fertigation software, are discussed to illustrate the potential of this technology in transforming global agriculture.

INTRODUCTION

Agriculture has evolved significantly over the past few decades, with technological advancements revolutionizing traditional farming practices. Water and nutrient management remain major concerns in modern agriculture, particularly as population pressures and climate change impact soil and water resources. Traditional irrigation methods often result in inefficient water use, soil salinization, erosion and excessive fertilizer application, leading to environmental degradation and economic losses.

Fertigation, an innovative agricultural technique that integrates irrigation with fertilizer application, has emerged as a solution to these challenges. By delivering water-soluble fertilizers directly to plant roots through irrigation systems, fertigation enhances nutrient efficiency, reduces wastage and improves soil health. The incorporation of sensor-based technologies further optimizes fertigation by enabling real-time monitoring and automated adjustments to nutrient and water application.

What is Fertigation?

Fertigation is the process of injecting fertilizers into an irrigation system, allowing plants to absorb essential nutrients efficiently (Adawadkar et al. 2019). It is commonly used in precision agriculture, particularly in drip and sprinkler irrigation systems, where water-soluble fertilizers are delivered directly to the root zone of crops.

Key Components of a Fertigation System

A fertigation system consists of several critical components:

- Water Supply System – Ensures a continuous and adequate supply of water for both irrigation and fertigation. It may include wells, reservoirs, or municipal water sources
- Fertilizer Injection System – Introduces fertilizers into the irrigation water, typically using venturi injectors, pumps or other dosing mechanisms
- Filtration System – Removes impurities and prevents clogging of emitters or sprinklers, ensuring smooth nutrient delivery
- Distribution System – Consists of pipelines, valves and drip or sprinkler components that transport the nutrient-rich water to the crops efficiently
- Control and Monitoring System – Regulates and optimizes the fertigation process
- Water-Soluble Fertilizers: Water-soluble fertilizers are fertilizers that dissolve totally in water, allowing rapid and efficient nutrient uptake by plants. They ensure uniform nutrient distribution, quick plant response and minimal residue. Their precise nutrient formulation makes them ideal for improving crop yield and nutrient-use efficiency in modern, precision agriculture.

All components of a fertigation system work in coordination to ensure that nutrient-rich water is mixed, filtered and delivered to the crop root zone in a controlled and efficient manner, optimizing both irrigation and fertilization.

Role of sensor-based technologies in fertigation

Sensor-based technologies in agriculture have revolutionized precision farming by providing real-time data on soil and crop conditions. These sensors measure parameters such as soil

moisture, temperature, pH and nutrient levels, helping optimize fertigation processes.

Types of sensors used in fertigation

1. Moisture sensors: Detect soil water content to prevent over- or under-irrigation.
2. pH and EC sensors: Ensure nutrient solutions are within optimal ranges.
3. Temperature sensors: Help regulate water and fertilizer application based on environmental conditions.
4. Leak sensor: Detects leaks in irrigation systems, preventing water and fertilizer wastage. It helps maintain uniform fertigation and ensures nutrients reach the intended areas.
5. Hyperspectral and multispectral sensors: Used in drones to analyze soil fertility and crop health.
6. LiDAR sensors and RGB cameras: Capture high-resolution imagery for precision monitoring.
7. Ultrasonic sensor: Often used for water level detection in irrigation tanks, reservoirs, or soil moisture monitoring, ensuring that the right amount of water is available for fertigation.

These sensors, when integrated into a fertigation system, improve nutrient use efficiency, optimize water usage and enhance crop growth while minimizing environmental impact.

How Sensor-Based Fertigation Works

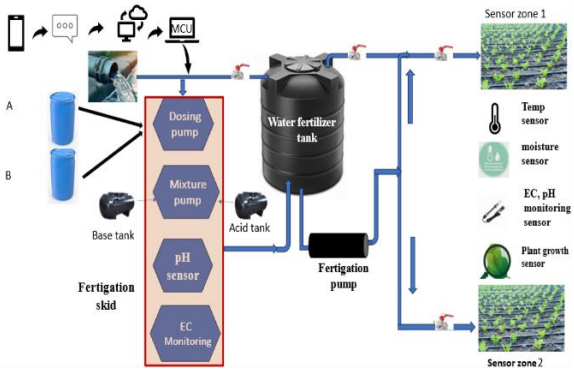

Fig 1: Sensor-Based Fertigation system

Automation in fertigation systems

Types of automated fertigation Systems

- Semi-automatic fertigation: Requires some manual intervention
- Fully automated fertigation: Operates autonomously with IoT-based control

Working mechanism and advantages of automated fertigation

Automated fertigation systems utilize soil sensors to monitor moisture and nutrient levels in real time. Based on this data, the system calculates the exact amount of water and fertilizer needed and activates pumps to deliver them through irrigation lines. Once optimal levels are reached, the system shuts off automatically, ensuring efficient resource use. This technology not only enhances precision in nutrient application but also reduces labor, energy consumption, and input costs. It improves crop yield by ensuring timely and accurate delivery of nutrients, while also promoting environmental sustainability by minimizing wastage and runoff.

Technological advancements in automated fertigation

Recent innovations have further enhanced the efficiency and sustainability of automated fertigation systems. Solar-powered setups now utilize renewable energy to operate sensors, pumps, and control units, greatly reducing dependence on conventional electricity and lowering operational costs, especially in remote farming areas (Visconti et al. 2020). In hydroponic farming, automated fertigation enables the precise preparation of nutrient solutions and the reuse of drained leachate. This leachate is treated to ensure it is pathogen-free and nutrient-balanced before being returned to the system, significantly reducing waste and improving nutrient-use efficiency (Pandey et al. 2023).

Additionally, sensor-mounted drones have emerged as a transformative technology in large-scale agriculture. These drones monitor crop health, nutrient status, and moisture levels from above, and can directly apply fertilizers through precision nozzle spraying. This not only eliminates the need for extensive distribution systems but also enables highly localized, data-driven fertigation, enhancing overall productivity and sustainability.

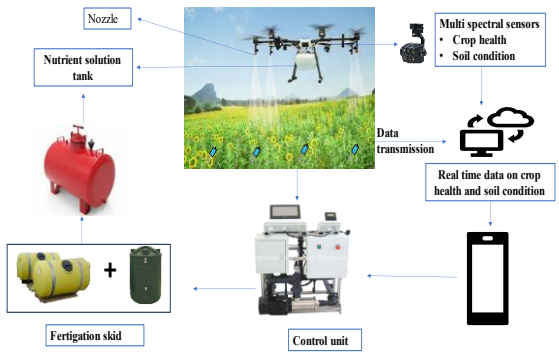

Fig 2: Drone based fertigation system

Advantages of sensor-based fertigation

Sensor-based fertigation enhances precision in nutrient and water management by detecting real-time soil moisture and nutrient status. This allows the system to deliver the exact amount of inputs required by the plants, reducing wastage of water and fertilizers. As a result, it improves nutrient-use efficiency and crop yield. Additionally, the use of sensors minimizes the need for manual supervision, leading to significant savings in labor and energy. By automating the fertigation process based on actual field conditions, sensor-based systems promote sustainability and ensure consistent crop performance across the field.

Challenges in sensor-based fertigation

- High initial investment: Advanced sensor technology, IoT devices, and automation systems require significant investment. Small-scale farmers may find it financially unviable without government subsidies or incentives
- Technical complexity: Calibration and maintenance of soil sensors, fertigation units, and IoT systems require technical expertise. Sensor malfunctions, connectivity issues, or software bugs can disrupt operations and lead to incorrect nutrient applications
- Data accuracy and reliability: Sensors may degrade over time, leading to inaccurate pH, moisture and nutrient readings. Variability in soil composition across different farm locations can cause inconsistent sensor performance.
- Resistance to adoption by farmers: Many conventional farmers may be resistant to adopting high-tech fertigation systems due to unfamiliarity or skepticism. Lack of training programs and awareness makes it difficult to promote widespread adoption
- Connectivity Issues: In remote or rural areas, poor internet connectivity and power outages can hinder real-time data transmission. Wireless sensor networks (WSN) depend on stable power sources, which may not always be available.

Despite these challenges, continuous advancements in AI, IoT and automation are making sensor-based fertigation more accessible and reliable. Addressing these issues through cost reductions, improved connectivity, farmer training, and standardization will be crucial for widespread adoption in precision agriculture.

Future prospects in sensor-based fertigation

- **Advancements in sensor technology**

❖ Nano sensors: Miniaturized sensors for real-time monitoring.

❖ Wireless and self-powered sensors: Solar or kinetic energy-based sensors.

❖ Multi-parameter sensors: Capable of measuring multiple factors simultaneously.

- **Affordable and scalable solutions:** include the development of low-cost, scalable fertigation systems for small and medium-sized farms, supported by government initiatives and subsidies to encourage widespread adoption.

- **Training and awareness programs:** Promoting automated fertigation through farmer training programs and encouraging the adoption of digital platforms for monitoring and decision-making.

CONCLUSION

Sensor-based fertigation is a transformative approach that integrates advanced monitoring systems with precision irrigation, ensuring efficient resource utilization and sustainable agricultural practices. By enabling real-time data collection and automation, this technology significantly improves crop yields while reducing fertilizer and water wastage. Although the initial investment in sensor-based fertigation is relatively high, the long-term benefits outweigh the costs, making it a promising solution for the future of agriculture.

Although the initial cost is higher than conventional methods, the long-term benefits in productivity and resource optimization make it a sustainable and cost-effective solution for modern agriculture. Continued research and development, along with efforts to make these technologies more affordable and accessible, will be essential in driving widespread adoption. As global challenges related to food security and climate change intensify, smart agricultural technologies such as sensor-based fertigation will play a crucial role in shaping the future of farming.

REFERENCES:

Adawadkar MP, Deshmukh MM and Wadatkar SB. 2019. Effect of drip fertigation with different fertilizer levels and traditional method of fertilizer application on growth and yield of brinjal. *International Journal of Current Microbiology and Applied Sciences* 8: 2793-2800

Pandey k, Singh KG and Singh A. 2023. Multi sensor based smart nutrient reuse management system for closed soilless culture under protected cultivation. *Computers and Electronics in Agriculture* 204: 107495

Visconti P, De Fazio R, Primiceri P, Cafagna D, Strazzella S, Giannoccaro NI. 2020. A solar-powered fertigation system based on low-cost wireless sensor network remotely controlled by farmer for irrigation cycles and crops growth optimization. *International Journal of Electronics and Telecommunications* 66(1):59-68.