



Use of Drones and IoT Sensors for Precision Nutrient Management in Mango Orchards

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Mango (*Mangifera indica* L.) is an important fruit crop grown widely in tropical and subtropical regions. Proper management of nutrients is crucial for enhancing plant growth, flowering, fruit development, yield, fruit quality, and the long-term health of the orchard. Traditional methods of applying fertilizers often use general recommendations that may not account for variations in soil fertility, tree health, and individual nutrient needs. Precision agriculture, especially through the use of unmanned aerial vehicles (drones) and Internet of Things (IoT) sensors, provides better ways to manage nutrients by offering real-time data and tailored decisions. Drones fitted with RGB, multispectral, and thermal cameras can detect variations in plant health, chlorophyll levels, and water stress. IoT sensors can monitor soil moisture, temperature, electrical conductivity, and other important environmental factors. When these technologies are combined with soil testing, leaf analysis, geographic information systems (GIS), and other tools, they can pinpoint areas where nutrients are lacking and help apply fertilizers more precisely. This review explores the principles, uses, advantages, challenges, and future possibilities of using drones and IoT devices for nutrient management in mango orchards. This integrated method has the potential to improve fertilizer use, lower input costs, help conserve resources, and support sustainable mango farming.

Introduction

Mango, often referred to as the “King of Fruits,” is a significant crop in India. Its growth, productivity, and fruit quality are influenced by balanced nutrient supply, soil fertility, irrigation, and climate conditions. Traditional methods of applying fertilizers may not account for variations in nutrient needs across the orchard, leading to inefficient use of fertilizers and higher costs. Precision agriculture, using drones and IoT sensors, offers a more effective way to manage nutrients. Drones can monitor canopy health and spot areas that may be under nutrient stress, while IoT sensors track soil moisture, temperature, and other key factors. When combined with soil testing and leaf nutrient analysis, these technologies support targeted fertilizer application, better nutrient use, and more sustainable mango cultivation. This review discusses their uses, advantages, and challenges in mango orchards.

Objectives

The major objectives of this review are:

1. To explain how drones are used to monitor the health of mango orchards and identify areas that may be lacking in nutrients.
2. To describe how IoT sensors are used to monitor soil and environmental conditions affecting nutrient availability.
3. To examine how drone images and sensor data can aid in site-specific fertilizer management.
4. To discuss the potential benefits, limitations, and future potential of these technologies in sustainable mango farming.

Methodology

This article is a narrative review based on published scientific studies, agricultural research, and institutional information related to mango nutrient management, UAV-based orchard monitoring, and IoT-enabled precision agriculture. The literature was analyzed to identify relevant technologies, their uses, and how they can aid in efficient nutrient management in mango orchards. The review considers research on UAV-based orchard monitoring, integrated nutrient management in mango, soil and leaf nutrient diagnosis, and sensor-assisted crop management. The proposed integrated approach is a summary of these findings and is not based on new field experiments conducted by the author.

Role of Drones in Precision Nutrient Management

Drones are aerial platforms that can be operated remotely or automatically. They can carry cameras and other sensors to gather information about orchard conditions. They are especially useful in mango orchards because they can cover large areas quickly and provide detailed insights into differences in canopy development and plant health.

➤ Canopy health monitoring

Drones with RGB cameras capture high-resolution images of mango trees.

These images help assess canopy size, foliage density, leaf color, canopy gaps, and variations in vegetative growth. Unusually pale leaves or poor canopy development may indicate nutrient deficiency, water stress, disease, or other growth issues.

➤ Multispectral imaging

Multispectral cameras capture reflected light in specific wavelength ranges, including the visible red and near-infrared regions. Vegetation indices, such as the Normalized Difference Vegetation Index (NDVI), can be calculated from these images to evaluate plant vigor. In mango orchards, these indices can help identify trees or areas that need further examination. However, they do not directly measure the concentration of specific nutrients. Their interpretation should be supported by leaf analysis, soil tests, and field observations.

➤ Detection of nutrient stress

Nutrient shortages can impact the amount of chlorophyll in leaves, the color of the leaves, the growth of the tree canopy, and the overall ability of the plant to carry out photosynthesis. Drone images can help identify these patterns across the field. For instance, a group of trees that appear less vigorous in their canopy may be chosen for targeted soil testing and leaf analysis for nutrients. This method allows farmers to focus their diagnostic work on areas that are most likely to need attention, rather than collecting samples from easily accessible or randomly selected spots.

➤ Nutrient application planning

Maps of the orchard created using drones can be combined with GIS software and data from nutrient tests to create management zones. These zones can be grouped based on the overall health of the trees, the fertility of the soil, or confirmed nutrient shortages. These maps can then be used to plan the precise placement of fertilizers, the timing of fertigation, or other tailored actions. If suitable equipment is available, drones can assist in the precise application of approved agricultural products, as long as they are used according to the product labels, equipment settings, and relevant rules.

Role of IoT Sensors in Nutrient Management

The Internet of Things involves devices that are connected and can collect, send, and process information through digital networks. In mango orchards, IoT sensors can provide regular or almost real-time data about the soil and environmental conditions that affect how nutrients are available and absorbed by plants.

➤ Soil moisture sensors

Soil moisture sensors measure how much water is present in the area where the roots are located. The right amount of soil moisture is essential for dissolving nutrients, moving them towards the roots, and allowing the plant to take them in. Too little or too much water in the soil can both hinder plant nutrition. By using the readings from these sensors, farmers can schedule irrigation based on the actual needs of the orchard, which helps manage water and nutrients more efficiently, especially when using fertigation.

➤ Soil temperature sensors

Soil temperature plays a role in root activity, the activity of soil microbes, and how nutrients change and become available in the soil. Keeping track of these temperatures continuously can help explain how nutrient availability and conditions in the root zone change throughout different seasons.

➤ Electrical conductivity sensors

Electrical conductivity (EC) measures the concentration of dissolved ions in soil water or a suitable soil extract. This measurement can help identify salinity issues and track changes linked to fertilizer use. However, EC alone cannot determine the exact concentration of individual nutrients or confirm if a specific nutrient is lacking. Laboratory testing is still essential for an accurate diagnosis.

➤ Soil pH and nutrient sensors

Soil pH influences how available certain key nutrients are. Monitoring pH can help detect conditions that limit nutrient absorption. Some commercial sensors can estimate certain nutrient levels, but their accuracy depends on factors such as sensor design, soil type, calibration, and validation. Nutrient recommendations should not be based only on unverified low-cost sensors. Soil laboratory results and leaf analysis are essential to confirm nutrient deficiencies and decide on appropriate fertilizer amounts.

➤ Weather and microclimate sensors

IoT-enabled weather stations can track air temperature, relative humidity, rainfall, and other environmental conditions. These measurements assist in understanding changes in crop health and timing nutrient applications appropriately. When linked to a digital dashboard, the sensor network can send alerts about dry or overly wet soil or environmental factors that affect nutrient uptake and fertilizer management.

Integration of Drones and IoT Sensors

The best use of these technologies is when they are used together. Drones offer spatial data across the orchard, while IoT sensors provide ongoing data from specific monitoring points. When combined with lab analysis, they help turn raw data into useful nutrient management decisions.

A suggested precision nutrient management system for mango orchards involves the following steps:

- 1. Orchard mapping:** Divide the orchard into management zones using tree locations, soil features, canopy condition, and terrain.
- 2. Drone survey:** Capture RGB or multispectral images at regular intervals to find areas with unusual canopy growth or reflectance.
- 3. Sensor monitoring:** Install soil moisture, temperature, pH, or EC sensors at suitable root-zone depths and locations.
- 4. Ground verification:** Collect soil and leaf samples from healthy and stressed trees and test them in a lab.

- 5. Data integration:** Combine drone maps, sensor readings, lab results, and orchard management data using GIS or decision-support software.
- 6. Nutrient recommendations:** Decide on nutrient needs based on confirmed deficiencies, tree age, variety, growth stage, soil properties, and local fertilizer guidelines.
- 7. Site-specific application:** Apply fertilizers or micronutrients to the identified zones at appropriate rates and times using calibrated equipment.
- 8. Follow-up monitoring:** Conduct more drone surveys and check sensor data, leaf nutrient levels, tree growth, fruit development, and yield to evaluate the results. This combined method allows a shift from uniform fertilization to nutrient management that is tailored to each part of the orchard.

Results and Discussion

Combining drones, IoT sensors, and scientific nutrient analysis offers a promising way to improve mango orchard nutrient management. Drone images help spot differences in canopy health and leaf condition, enabling farmers to locate trees that need further examination. IoT sensors provide data on soil moisture, temperature, and electrical conductivity, which aid in evaluating conditions affecting nutrient availability and uptake. When this information is combined with lab soil tests and leaf nutrient analysis, it leads to more accurate diagnosis of nutrient deficiencies. Also, using organic manures, biofertilizers, and chemical fertilizers as needed can help maintain soil fertility and balanced plant nutrition. Drone maps and sensor data can guide precise fertilizer application, potentially reducing unnecessary inputs and production costs. Overall, these technologies support sustainable mango growing, but field trials are needed to determine their impact on fertilizer efficiency, fruit yield, and quality under different conditions.

Benefits of Drone- and IoT-Based Precision Nutrient Management

- **Early stress detection:** Drones help detect changes in canopy health, which can point to possible nutrient deficiencies or other stress factors.
- **Efficient fertilizer application:** Orchard maps allow fertilizers to be applied based on the specific nutrient needs of different areas.
- **Reduced input costs:** Precision use and better irrigation planning can lower fertilizer, water, and labor costs.
- **Improved productivity and quality:** Balanced nutrient management supports flowering, fruit development, yield, and fruit quality.
- **Better water and nutrient management:** IoT sensors help monitor soil moisture and improve irrigation and fertilization scheduling.
- **Environmental Sustainability:** Using fertilizers in a precise manner helps reduce the loss of nutrients and lowers pollution in the environment.
- **Data-Based Decisions:** Digital records assist farmers in tracking the performance of their orchards and enhance how they manage their farms in the future.

Challenges and Limitations

Although these technologies have promise, several factors might hinder their widespread use in mango orchards.

- **High Initial Investment:** The cost of drones, multispectral cameras, sensors, communication devices, software, and maintenance can be high, especially for small and small-scale farmers.
- **Technical Expertise:** Operating drones, analyzing images, understanding vegetation indices, and properly setting up sensors needs proper training.
- **Sensor Accuracy and Calibration:** Soil characteristics, temperature, moisture levels, salinity, and where sensors are placed can affect the accuracy of measurements. Regular calibration and lab testing are necessary.

- **Difficulty in Identifying Specific Deficiencies:** Similar signs in the tree canopy can be due to nutrient lack, water shortage, pests, diseases, or root issues. Drone images alone cannot clearly tell the exact cause in all cases.
 - **Connectivity and Power Supply:** Poor mobile networks, unreliable electricity, and challenging landscapes can make it hard to transmit data continuously in some orchard areas.
 - **Dense Canopy and Image Interpretation:** Mango trees have complex canopies, and factors like shade, tree structure, soil background, and seasonal changes can impact image analysis.
- Regulatory Requirements: Using drones and applying nutrients from the air must follow aviation, privacy, and farming rules.
- **Limited Crop-Specific Validation:** Suggestions and models from one variety, region, season, or soil type may not work well in other conditions. Local testing is important.
 - These issues can be overcome through training for farmers, shared drone services, cost-effective sensor systems, reliable calibration processes, locally developed decision tools, and working with agricultural universities and research centers

Future Prospects

The future of precision nutrient management in mango orchards will depend on integrating remote sensing with reliable ground-based measurements and practical agronomic recommendations. Artificial intelligence and machine-learning techniques may help classify canopy conditions, identify unusual growth patterns, and support nutrient stress prediction when trained and validated using representative local data. Low-cost IoT networks, cloud-based dashboards, mobile applications, and cooperative drone services could make these technologies more accessible to smallholder farmers. Combining drone imagery with soil tests, leaf nutrient analysis, weather records, yield data, and farm management histories may improve the reliability of nutrient recommendations. Future field experiments should compare conventional nutrient management with integrated drone–IoT approaches across different mango cultivars, orchard ages, soil types, and growing seasons. Important evaluation parameters include fertilizer-use efficiency, soil and leaf nutrient status, fruit yield, fruit quality, production costs, and environmental impacts.

Conclusion

The use of drones and IoT sensors offers a promising approach to precision nutrient management in mango orchards. Drones provide high-resolution spatial information on canopy condition and help identify areas that require further investigation, while IoT sensors provide continuous information about soil moisture, temperature, electrical conductivity, and other relevant environmental conditions. When these technologies are integrated with soil testing, leaf nutrient analysis, GIS mapping, and locally recommended fertilizer practices, they can support more accurate and site-specific nutrient management. The major potential benefits include improved identification of orchard variability, more efficient fertilizer and water management, reduced unnecessary input use, and improved sustainability. However, drone imagery and sensor measurements cannot replace laboratory nutrient analysis or sound horticultural judgement. Their successful application depends on reliable data, appropriate calibration, technical training, economic feasibility, and field validation. Overall, integrating drones and IoT sensors with established nutrient management practices can help move mango cultivation towards a more precise, resource-efficient, and environmentally sustainable production system. Wider adoption should be supported by locally validated research, farmer education, and affordable technology solutions.

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