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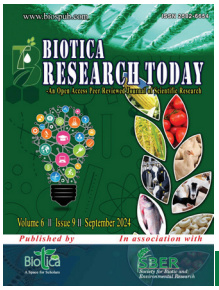

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Drones in Vegetable Farming: Precision Agriculture for the Future

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Abstract

The rapid growth of the global population has sharply increased the demand for food, putting immense pressure on traditional farming system. Vegetable production, which is crucial for human nutrition, also presents considerable environmental challenges. To address this challenge, the use of drones or Unmanned Aerial Vehicles (UAVs) in agriculture is needed. By utilizing drones for tasks like applying water and pesticides more precisely, farmers can achieve more sustainable and efficient vegetable production. Drones are becoming essential in modern vegetable farming, because they help farmers monitor the health of crops, manage weeds and apply water and pesticides more efficiently. The article underscores the significant potential of drone technology to improve both the sustainability and efficiency of vegetable crop production, making it a vital tool in modern agriculture.

Keywords: Drone, UAV, Vegetables, VTOL

Introduction

Vegetables are rich in essential vitamins, minerals and fiber, playing a key role in combating malnutrition and promoting health. However, their cultivation is often associated with significant environmental challenges. Whereas, the rapid increase in the global population has significantly intensified the demand for food, driving the need for advancements in agricultural practices to ensure both sufficient and sustainable production. Traditional farming methods are increasingly inadequate to meet these demands. To address these issues, the agricultural sector is embracing cutting-edge technologies, with drones, Unmanned Aerial Vehicles (UAVs) as emerging as a transformative tool (Kutyauripo *et al.*, 2023). In the context of agriculture, drones have emerged as a valuable tool, offering numerous advantages to modern farming operations. These aerial vehicles are primarily used for yield optimization and monitoring crop health, growth and production. By providing detailed information on crop and soil variations, drones assist farmers in making informed decisions to enhance agricultural efficiency. Agricultural drones, a specific type of UAV, are equipped with a range of optical and thermal sensors that enable them to detect and analyse conditions that are otherwise invisible to the human eye. These drones provide high-resolution imaging and real-time monitoring of crops and soil, with options for autonomous GPS operation or manual control *via* smartphone or remote, offering farmers customizable monitoring solutions. As well as the use of drones in vegetable crops is also rapidly transforming the way farmers manage their fields (Chaudhari *et al.*, 2024). Drones can be equipped with sprayers to apply fertilizers, pesticides and herbicides directly to the crops that need them, reducing waste and minimizing environmental impact. Drones significantly enhance vegetable farming by capturing high-resolution images across spectral bands to assess plant health and detect stress or pest issues. This enables early intervention and better crop management, including monitoring maturity for optimal harvest timing, ultimately improving production efficiency and reducing losses in delicate vegetable crops.

Drone and Its Types

Definition

A drone, also known as an Unmanned Aerial Vehicle (UAV), is a type of aircraft that operates without a human pilot onboard. Instead, it is controlled either autonomously by onboard computers or by a remote-control system operated by a human on the ground.

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Types of Drones

There are various types of agricultural drones as discussed below.

1. Multi-Rotor

Multi-rotor drones are the simplest type of drones, equipped with features that allow them to capture images from a top-down perspective (Figure 1). They offer precise control over their positioning, which leads to more accurate results. However, their limitations include lower endurance and speed, which means they are suitable for only certain agricultural tasks.

Figure 1: Multi-Rotor Drone

2. Fixed-Wing

Fixed-wing rotor drones operate using wing-like structures similar to airplanes (Figure 2). Their take-off method differs from other drones, requiring an initial external force to generate the necessary inertia.

Figure 2: Fixed-Wing Drone

3. Single-Rotor

A single Rotor helicopter drones are having more advantages if compared with other type of drones. For sustaining more endurance, it is fixed with the gas-controlled system. The Aerodynamic rules stress that, if any system is having larger rotor blades, then the spin will be less and efficiency of the system will be more (Figure 3).

4. Fixed Wing Hybrid

Fixed-wing hybrid VTOL (Vertical Take-Off and Landing) drones combine features of both UAVs (Unmanned Aerial Vehicles) and hover-capable drones. This hybrid design allows them to take off from a stationary position and hover over an area while maintaining vertical flight (Figure 4).

Figure 3: Single-Rotor Drone

Figure 4: Fixed Wing Hybrid Drone

Different Types of Agriculture Drone Cameras

1. RGB Cameras

• RGB cameras capture images in the visible light spectrum, utilizing red, green and blue channels.

• These are the most commonly used cameras in agricultural drones, ideal for basic crop mapping and monitoring.

• They produce high-resolution images, making them effective for identifying plant health, growth patterns and other visual traits.

• RGB cameras can also generate detailed 3D models of the terrain.

2. NIR (Near-Infrared) Cameras

• NIR cameras detect wavelengths of light that are invisible to the human eye, between visible red and infrared.

• They are useful for identifying plant stress and disease, as stressed plants reflect light differently than healthy ones.

• NIR cameras are also employed to create NDVI (Normalized Difference Vegetation Index) maps, which help pinpoint areas needing irrigation or fertilization to boost crop yield.

3. Multispectral Cameras

• Multispectral cameras capture images in multiple spectral bands beyond the visible spectrum.

• These images are analysed to detect plant stress, nutrient deficiencies and other issues.

• They are also effective in identifying weeds and pests, providing farmers with critical information to address these common agricultural challenges.

4. Thermal Cameras

• Thermal cameras detect heat sources, making them valuable for spotting hot spots or areas of stress in crops.

• They have become an essential tool in agriculture, offering precise insights into crop health.

• Thermal cameras can identify regions with inadequate water supply, helping farmers adjust watering schedules and optimize resource use.

5. Hyperspectral Cameras

• Hyperspectral cameras provide highly detailed data by capturing images in numerous narrow, contiguous spectral bands.

• They offer precise information on crop stress, nutrient deficiencies and early signs of disease or pests without needing additional sensors.

• These cameras provide detailed spectral information that allows for a thorough analysis of plant health and growth patterns.

Advantages of Drones in Vegetable Crops

1. Enhanced Safety: Agriculture sprayer drones are operated remotely by trained pilots, minimizing farmers and labourers exposure to hazardous chemicals and challenging working conditions.

2. Increased Efficiency and Capacity: Drones can cover 50-100 acres day^{-1}, thanks to their minimal turnaround time and operational delays. This efficiency is about 30 times greater than that of traditional knapsack sprayers.

3. Reduced Pesticide Waste: With high atomization, drones save approximately 30% of pesticide use. They can deliver pesticides as a fine mist to all levels of the crop, reducing waste.

4. Water Conservation: Drones employ ultra-low volume spraying technology, conserving up to 90% more water compared to conventional methods.

5. Cost Savings: Drone spraying is up to 97% cheaper than traditional spraying methods, significantly lowering operational costs.

6. User-Friendly and Low Maintenance: Agricultural drones are built to be durable with minimal maintenance needs. They have a long lifespan and parts can be easily replaced, simplifying upkeep for service providers.

Utilization of Drones in Vegetable Crops

Drones are increasingly being utilized in vegetable crops to enhance various aspects of farming, from planting to harvest (Canicatti and Vallone, 2024). The following application in this sector provides several key benefits, making agricultural practices more efficient, precise and sustainable (Sylvester, 2017).

1. Monitoring and Surveillance: Drones with high-resolution and multispectral cameras offer real-time aerial imagery to monitor crop health. They detect plant stress and health variations using various wavelengths and thermal imaging. By generating vegetation indices like NDVI, drones enable early detection of issues such as nutrient deficiencies and water shortages, surpassing ground inspections.

2. Pest and Disease Detection: They can detect early signs of pest infestations or diseases by analyzing aerial images, often revealing distinct patterns of damage caused by pests.

3. Precision Agriculture: They improve precision agriculture by delivering detailed information on crop health, soil moisture and plant density. Using high-resolution images and multispectral sensors, they help farmers apply fertilizers, pesticides and water more accurately. This targeted approach, guided by precise maps, reduces waste and improves crop yields through Variable Rate Technology (VRT).

4. Fertilizer Application: By analysing drone data, farmers can determine which areas of the field need additional nutrients and which areas have sufficient levels. This helps in applying the right amount of fertilizer only where it's needed, avoiding over-fertilization and reducing nutrient runoff.

5. Pesticide Application: Drone imagery can identify areas with high pest infestations. Farmers can then apply pesticides only to those affected areas rather than treating the entire field. This targeted approach reduces pesticide use and minimizes environmental impact. Early detection of plant diseases through drone data allows for targeted pesticide application, reducing the spread of disease and improving crop health.

6. Mapping and Planning: Drones are invaluable for mapping and planning in agriculture, offering detailed aerial imagery that aids in field layout, planting strategies and irrigation systems. High-resolution images and multispectral data reveal topography, soil types and crop distribution. Drones create 3D models and topographic maps, showing elevation changes and terrain features essential for planning.

7. Planting Pattern Optimization: Drones help farmers analyse soil and crop health, enabling optimized planting and irrigation. By creating detailed field maps, drones aid in efficient resource use, reducing waste and boosting yields. This results in cost savings and sustainable farming practices, making field management more precise and effective.

8. Crop Health Assessment: Advanced sensors on drones assess plant health by measuring indicators like chlorophyll levels. Multispectral and hyperspectral cameras analyse light reflection to detect nutrient deficiencies, water stress, or disease early on. This precise information allows for targeted interventions, such as adjusting fertilizer or irrigation, improving crop health and optimizing resource use.

9. Irrigation Management: Drones enhance irrigation management by identifying areas needing water and evaluating irrigation system performance. Thermal and multispectral sensors detect soil moisture levels and plant water stress, allowing for precise water application and better resource utilization.

Conclusion

Vegetable production faces significant challenges, including declining productivity, climate change and sustainability issues. Drones are emerging as an innovative solution, offering benefits across social, economic and environmental dimensions of sustainable farming. Equipped with advanced sensors and imaging technologies, drones enable farmers to monitor crop health, assess nutrient levels and optimize water usage with remarkable accuracy. They play a vital role in nutrient management by identifying areas with nutrient deficiencies or excesses, allowing farmers to tailor their fertilization strategies effectively. This targeted approach ensures that nutrients are applied precisely where needed, reducing waste and preventing overuse. Additionally, drones with infrared and thermal sensors enhance irrigation efficiency by accurately monitoring soil moisture levels. Overall, this technology supports sustainable agricultural practices by optimizing resource use, minimizing environmental impact and boosting productivity, ultimately contributing to a more resilient and sustainable farming landscape.

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