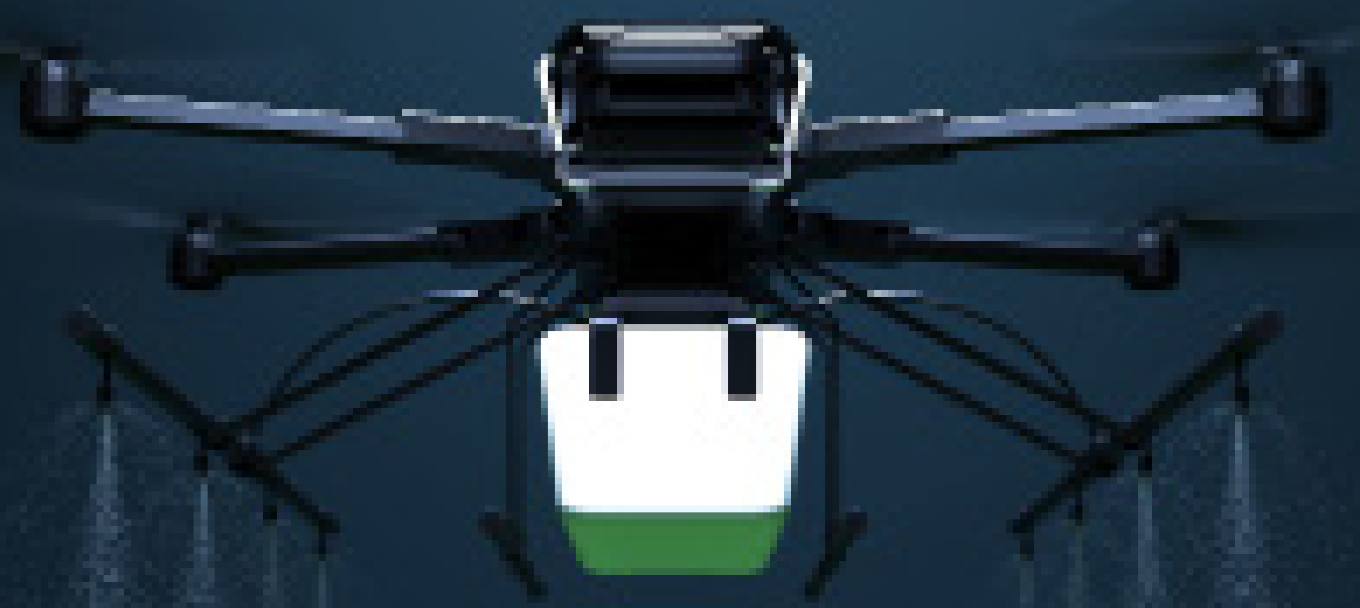

Use of Drones in Agriculture

Innovations in Pesticide Application, Crop Surveillance, and Precision Farming

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Abstract

The agricultural sector is embracing a digital transformation, and drones also known as unmanned aerial vehicles (UAVs)- are at the forefront of this change. With global challenges such as population growth, labor shortages, climate variability, and the need for sustainable food production, drones offer practical solutions to long-standing farming inefficiencies. These aerial technologies are being increasingly adopted for tasks such as pesticide spraying, crop health monitoring, and precision agriculture, streamlining operations and improving yields.

Introduction

The integration of drones into agriculture has been facilitated by rapid advancements in sensor technology, automation, and geographic information system (GIS). Their ability to capture high-resolution images, map farmlands, and perform real-time interventions has positioned them as valuable tools in modern farming systems (Zhang and Kovacs, 2012). In countries like India and China, where smallholder farming dominates, drones are increasingly promoted through government schemes to address inefficiencies in input use and promote environmental management.

1 Drone-Assisted Pesticide Spraying

Traditionally, pesticide application has relied on manual labor or ground-based equipment, which often leads to uneven distribution and significant chemical exposure to workers. Drone-based spraying, by contrast, allows for:

- **Targeted application:** Reduces overuse of chemicals by direc-

-ting sprays only where needed.

- **Time savings:** A drone can treat 1-2 hectares in 10 minutes, far faster than manual methods.
- **Safety improvements:** Operators remain at a safe distance from chemical exposure.

Research shows that UAV spraying systems can achieve comparable efficacy to conventional sprayers, with reductions in water use and drift loses (Xiongkui et al., 2017). These features make them especially useful in crops grown in difficult terrains, such as rice paddies or hilly plantations

2 Monitoring
crop health with drone imagery

Drones equipped with multispectral, hyperspectral, or thermal cameras can monitor plant health across large tracts of farmland. These aerial platforms collect real-time visual data that can be analyzed to assess:

- Plant vigor through vegetation indices like NDVI (Normalized Difference Vegetation Index).
- Nutrient deficiencies by detecting discoloration or chlorosis in leaves.
- Pest or disease outbreaks through anomaly detection in canopy structure or color

Such early detection is crucial for preventing widespread crop losses and implementing timely interventions (Hunt et al., 2005). In particular, the use of NDVI imaging has proven effective in identifying water stress, guiding precision irrigation practices (Bendig et al., 2013).

3 Precision
agriculture and field mapping

One of the most valuable applications of UAVs lies in precision agriculture, which emphasizes site-specific crop management. Drones contribute by producing 3D terrain models and field maps that help identify soil variability. Zonal prescriptions for variable-rate applications of fertilizers and pesticides. Crop stand counts and biomass estimations, essential for forecasting yields. When integrated with GPS and AI-powered analytics, drone data supports farmers in making data-driven decisions, reducing input waste and improving overall productivity (Guebsi et al., 2024).

Drones are scalable across farm sizes and adaptable to a range of crops, from cereals and pulses to fruits and vegetables. Advantages of drone use in farming are enlisted in Table 1

Benefit	Impact
Reduced chemical input	Precision in pesticide/fertilizer usage
Lower labor dependency	Automation of routine tasks
Improved yield quality	Timely detection of stress and diseases
Environmental sustainability	Decrease in runoff and over-application
Better record-keeping	Real-time georeferenced data storage

Table 1. Advantages of drone use in farming.

4 Precision agriculture and field mapping

Despite their promise, drones face several limitations in agricultural deployment:

- **High initial cost**: While drone prices have dropped, many small-scale farmers still find them unaffordable without subsidies.
- **Technical skill gap**: Drone operation, maintenance and data analysis require training and literacy.
- **Battery and payload limits:** Most drones can carry 10-20 litres of spray solution and operate for under 30 minutes per charge.
- **Regulatory constraints:** Airspace regulations and licensing requirements vary widely, limiting commercial deployment.

Addressing these issues requires capacity-building programs, extension services and supportive policies (FAO, 2018).

5 Government initiatives and policy support

Recognizing the potential of drones in boosting agricultural productivity, several governments have introduced policy frameworks and financial assistance. For instance, in India, the Kisan Drone Yojana offers incentives to promote drone use in pesticide spraying and crop assessment. Under the Sub-Mission on Agricultural Mechanization (SMAM), Farmer Producer Organizations and cooperatives can avail up to 50% subsidy on drone procurement. Moreover, the Drone Rules, 2021, simplified UAV regulations to facilitate wider adoption in non-defence sectors. These efforts are complemented by public-private partnerships aimed at training youth and agri-entrepreneurs in drone-based services.

6 Future outlook

Drones in smart farming systems

Looking ahead, drones are expected to evolve from data collection tools to fully automated decision-making platforms. Integration with IoT sensors, AI algorithms and cloud-based farm management systems will make them central to smart farming ecosystems. Emerging trends include:

- Swarm technology, where multiple drones coordinate to cover large fields.
- Automated pesticide reloading stations.
- Real-time variable rate control based on drone-collected sensor data.
- Drone-based seed broadcasting and pollination services.

These advancements will further improve agricultural resilience, especially in the face of climate change and rising food demand (Jha et al., 2019).

Conclusion

Drones represent a significant leap in the modernization of agriculture. Their applications- from pesticide spraying and crop monitoring to soil mapping and decision support demonstrate their capacity to improve efficiency, profitability, and sustainability in farming systems. However, realizing their full potential requires coordinated efforts in training, policy and infrastructure development. With ongoing innovations and supportive frameworks, drones are poised to become indispensable allies in ensuring global food security and climate-resilient farming.

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