Review Article:

**Application of Drones in Precision Agriculture: A Review on Benefits and Challenges**

**Abstract**

The integration of drone technology in precision agriculture is transforming conventional farming practices by enabling data-driven, efficient, and sustainable crop management. This review explores the multipurpose applications of drones, such as crop monitoring, spraying, mapping, soil analysis, irrigation management, and yield estimation. These applications help in reducing labor costs, enhancing input efficiency, and improving productivity through real-time decision-making. Despite their vast potential, the adoption of drones in agriculture faces several challenges including regulatory restrictions, high initial costs, limited battery life, lack of skilled operators, and technical limitations in diverse environmental conditions. The paper critically analyses current advancements, benefits, and technological limitations based on recent research and case studies. It also highlights future prospects of integrating drones with AI, IoT, and GIS for smarter farming systems. The review concludes that while drones hold immense promise for sustainable agriculture, overcoming existing barriers is essential to realize their full-scale deployment and impact.

**Keywords**: Drones, Precision Agriculture, Monitoring, Capacity Building and Aerial.

1. **Introduction**

In the world agricultural sector is have a different production problem, solving these problem and need to produce more food production with using precise resources while minimizing environmental impacts (Gebbers and Adamchuk, 2020). Traditional agricultural methods of food production are increasingly insufficient to a rising demands for food security issue, climate resilience, and sustainable land use. In this review paper, **precision agriculture (PA)** is an advanced technologies used to optimize food production and available resource management (Zhang *et al*., 2023). In the various technological innovations, **Unmanned Aerial Vehicles (UAVs)**, it is commonly known as drone, it is useful for multi agricultural operations like soil monitoring, crop monitoring, spraying operation and security (Abdullahi *et al*., 2021).

Drones are revolutionizing the way farmers monitoring, manage, and optimize their Agricultural fields. Its ability to perform **remote sensing**, **site-specific pesticide application**, **crop health monitoring**, **soil monitoring and analysis** and even **livestock tracking** in a single or series of operation has made it an essential component of modern agriculture (Tsouros *et al*., 2021; Zhao *et al*., 2022). The traditional methods like manual labor or ground-based machinery operation, drones image gives high-resolution data acquisition details with less human intervention, to make able real-time decision-making (Zhang *et al*., 2023).

The multipurpose drones bring different uses, including improved input efficiency, reduces operational costs, real time disease detection, and target the weeds, pest and disease, which collectively contribute to sustainable intensification (Jabbari et al., 2021). For example, the integration of multispectral and hyperspectral sensors with drones allows farmers to detect early-stage crop stress and nutrient deficiencies that are invisible to the naked eye (Yao *et al*., 2022). Additionally, UAVs-based variable rate applicator (VRA) of fertilizers and pesticides reduces wastage and save environment effects (Singh *et al*., 2021).

In spite of their clear benefits, the large amount adoptability of multipurpose drones in agriculture faces many challenges. Technical barriers such as less flight endurance capacity, payload limitations, and sensitivity to around weather conditions impede their full potential (Zhou *et al*., 2023). In Addition, the lack of powerful regulatory frameworks, initially high investment costs, and Insufficient technical knowledge about drone to farmers further complicate widespread implementation without training them (Sharma *et al*., 2024). Privacy concerns and data ownership issues related to drone-collected imagery also pose ethical and legal questions that require careful governance (Zhang *et al*., 2023).

Latest studies show that drones will be complement and, in some cases, outperform traditional methods of field monitoring, mapping and crop spraying. Such as, a comparative study shown in the (Gupta *et al.*, 2022) Evidence that drone-based spraying reduced pesticide uses up to 30 per cent while achieving uniform crop coverage and reduces operator exposure to spraying chemicals. In parallel, Salamí *et al*. (2020) it has been reported that drone-assisted yield approximation showed higher accuracy results compared to manual sampling methods. These findings suggest that UAVs not only enhance productivity of crop but it also contribute more sustainable farming practices in agriculture.

In growing regions, drones give a practical solution to the perennial challenges of labour shortages, less and fragmented landholdings (Jabbari *et al*., 2021). Less landholding farmers, even though they lack of large machinery, can benefit from drone pilot who offer aerial spraying and field mapping on the basis of payment per hour or acres (*Abdullahi et al*., 2021). Such service models democratize access to precision farming tools, although scaling them requires supportive policy measures and responsibility building initiatives.

The older technologies are time consuming and fuel consumption machinery have some issues. Innovations in battery/solar technology, lightweight construction materials, and autonomous GPS systems are increased drone flight time and expanding operation of drone (Sharma *et al*., 2024). Incorporation of artificial intelligence (AI), and machine learning (ML) and deep learning significantly increases data analytics, Provides the drones full data to accesse all field (Yao *et al*., 2022). This review paper aims to provide a comprehensive synthesis of the **benefits** and **challenges** associated with applications of drones in precision agriculture. By serious analysing recent research and development contributions from 2020 to 2025, the paper highlights how drone technology is shaping the future of farming, identifies current gaps, and suggests directions for future innovation and policy development. Ultimately, understanding both the promises and the hurdles of drone integration is vital for stakeholders seeking to accelerate the transition towards resilient, data-driven, and environmentally sustainable agricultural systems.

**1.1** **Drones in Agriculture**

## **In agriculture, a drone known as an Unmanned Aerial Vehicle (UAV**)**** is an aerial platform that operates without human interventions, It is controlled by remotely or autonomously using pre-programmed flight plans and GPS navigation system. In precision agriculture, UAVs are attached with various cameras, different sensor with spraying equipment or mapping equipment to perform tasks such as soil monitoring, crop monitoring, spraying of insectides/pesticides and nano or broadcast fertilizers, soil and field mapping, and livestock surveillance (Tsouros *et al*., 2021).

## ****1.2 Types of drones****

Types of drone can be broadly categorized based on their **design configuration, its utilization, function and operation view.**

### ****1.2.1 Fixed-Wing Drones****

* **Description:** Look like small airplanes with wings that provide lift.
* **Features:** Longer flight endurance (up to several hours), greater coverage area per flight.
* **Use Cases:** Large-scale surveying, mapping, and monitoring of extensive farms and plantations.
* **Limitation:** Require runways or catapults for launch and landing; cannot hover.

**Example:** SenseFly eBee



Figure 1. A fixed-wing UAV (AGEagle Aerial Systems, Inc)

### ****1.2.2 Rotary-Wing Drones (Multirotors)****

* **Description:** Use multiple rotors (quadcopters, hexacopters, or octocopters) for lift and maneuverability.
* **Features:** Can hover, take off and land vertically (VTOL).
* **Use Cases:** Close-range inspection, spraying, spot treatments, detailed imaging, field scouting.
* **Limitation:** Shorter flight time due to higher energy consumption.

**Example:** DJI Agras series and DJI Phantom.



Figure 2. Multi-rotor UAV (www.dji.com/mg-1p/ inform)

### ****1.2.3 Hybrid VTOL Drones****

* **Description:** Combine features of fixed-wing and rotor drones. They take off vertically like a helicopter and transition to horizontal flight.
* **Features:** Combine endurance and range of fixed-wing with hover capability.
* **Use Cases:** Suitable for medium to large farms needing both area mapping and spot spraying.

**Example:** Quantum Systems Trinity F90+



Figure 3. A hybrid fixed-wing-multi-rotor UAV (https://arcturus-uav.com/product/jump-20)

## ****1.3 Classification of Drones in Agriculture****

The classification of drones helps farmers, researcher’s scholar, and institute, policymakers select the appropriate drone technology for specific works. For example: A **fixed-wing drone** will be useful for mapping a 500 ha area of any agricultural farm. A **hexacopter** with a spraying system is better for precise pesticide application in a fragmented field. A **hybrid vertical take- off and landing** is suitable for combined used where the hover and coverage of crop are both needed. The variety in drone types allow adaptable, measurable solutions that address various **agro-climatic zones, farm sizes, and crop requirements** (Jabbari *et al*., 2021).

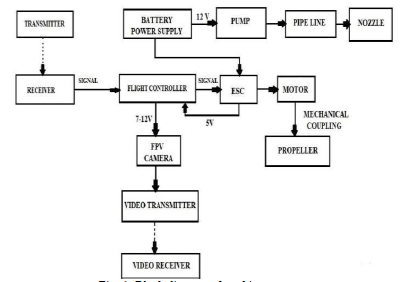
**Table 1. Drones classification**

|  |  |  |
| --- | --- | --- |
| **Classification Basis** | **Categories** | **Description** |
| **Operation Modes** | Manually, Semi-Autonomous, Fully Autonomous | Varying levels of pilot control vs. AI-based autopilot system |
| **Payload** | Imaging/mapping drones, Spraying drones, Multipurpose drones | Imaging drones carry cameras and sensors also; spraying drones carry tanks and nozzles; multipurpose drones will switch payloads |
| **Sensor Type source** | RGB, Multispectral, Hyperspectral, Thermal, LiDAR | Different sensors were provide different data types for crop health, moisture, soil variability |

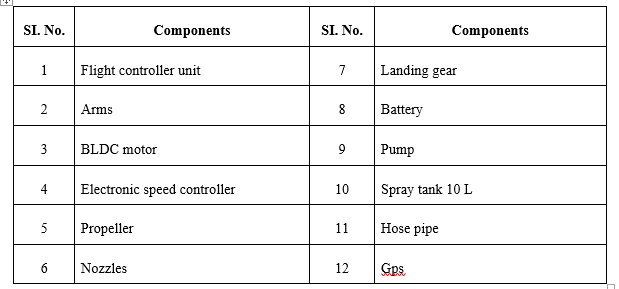
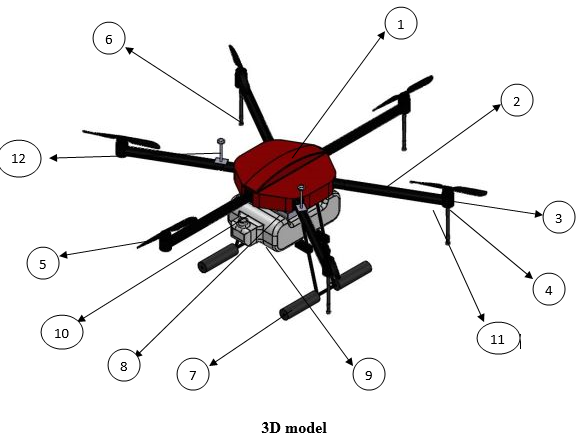
**1.4 Working Principles and Components of Agricultural Drone**

The signals are transmitted from transmitter and it is received by the receiver in the drone. From the receiver the signal goes to the flight controller where the signals are processed with accelerometer and gyroscope sensors. The processed signal is sent to the ESC, which allows the specific amount of current to the motor based on the signal it receives. The propellers are mechanically coupled to the motors so that they rotate and produce thrust. The FPV camera takes current supply from the flight controller and it records the video, the video signals are processed by the transmitter and it is received by the receiver in ground. The pump takes current supply from the Li-Po battery and pressurizes the liquid from the storage tank then the pressurized liquid flows through the pipeline and enters the nozzle then gets sprayed. The flow rate of the pump can be controlled by varying the input current which can be controlled by transmitter (Yallappa *et al*, 2017).

Drone mounted sprayer consist of two unit which are aerial vehicle (UAV) unit and spraying unit. UAV unit consists of flight controller, remote controller, transmitter, receiver, airframe, landing gear, arms, BLDC motor, Electronic speed controller, camera and GPS. Spraying unit consist of battery, DC motor, Pump, hose pipe and spray nozzle. There are different classification of drone in that medium drone was designed for lift total payload of 2 to 25 kg. The development drone-mounted sprayer is crucial for modern agriculture due to its potential to revolutionize farming practices (Ahirwar *et al*., 2019). The selection of material, drone configuration, power source, payload capacity, battery type, type of nozzles, safety measures, testing and optimization of parameters has been discussed below.



**Fig 4. Block diagram of principle of drone**

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**TABLE 2. Components of making a Drone**

**Fig 5. 3D view and Components of drone mounted sprayer for agro-chemical use**

1. **Benefits of Multipurpose Drones in Precision Agriculture**

**2.1 Enhanced Crop Monitoring and Health Assessment**

To check crop health and status using multi-sensor UAVs was revolutionized precision in agriculture. These UAVs are attached with advanced RGB, multispectral, and thermal sensors, and hyperspectral sensors collect the high-resolution data’s on plant disease, chlorophyll content, soil and plant moisture stress, and thermal temperature variations (Jones *et al*., 2023; Li *et al*., 2023). By collecting data across different spectral bands, drones can detect the pest infestations, nutrient deficiencies in crop or diseases before they become visible to the naked eye by human (Barbedo, 2020). The early detection facilitates timely operation, it will target insecticide/pesticide or precise spraying, in which reduces input costs and environmental. The real-time data collection supports data-driven decision-making earlier, helps to better crop management plan and output is higher yields (Smith *et al*., 2022). All though, UAVs-based crop health monitoring support farmers to enhance productivity, reduce crop losses and increases safety concerns.

**2.2 Precision Input Sources Application**

Precision input agricultural sources application is the site-specific and need-based application of agricultural sources like as sowing seeds, fertilizers, insecticide, pesticides or herbicides. Manually or old methods, farmers will apply the agricultural inputs non-uniformly across entire fields, which leads to overdose in some areas and under-application in other place. These variations are leads to increased costs burden, available resource wastage, and severe environmental effect such as soil degradation, soil fertility decreases and water resource contamination.

The application of drones in precision agriculture management of crop has been transformed input agricultural resources application by variable-rates technology, attached with GPS system, different types of sensors, and On spot spraying mechanism, drones can collect field conditions data in rea-time and supply input resources precisely where exact crop or soil required. By the way, drones or unmanned aerial vehicles can have the capability of identifying insects or pest-infested areas in plants canopy or NPK nutrient-deficient area in soil and advances technology have the ability to adjust application rates accordingly wherever needed (Gupta *et al*., 2022). These targeted approach reduces excessive chemical application, significantly lowering input resource cost for farmers and helps in sustainable growth.

According (Dosari and Al-Mansour., 2023), by applying through drone even in irregular areas that provides uniform area coverage compared to conventions methods. Due to uniformity spraying of chemical, increasing the effectiveness of pest and weed control measures. Moreover, drones can operate in wet or soft fields where heavy machinery might damage crops or soil structure. Patel *et al*. (2023) note that drone-based precision application is faster than traditional manual or tractor-based technology. Application of agrochemical through drone technology safer compared to other because of hazardous of chemical.

**2.3 Soil and Water Management**

Efficient soil and water management is helps to sustainable agriculture growth, and the integration of drone technology in agriculture transforming the modern mechanization. Drones contains advanced remote sensing sensor like multispectral, hyperspectral, and thermal sensors to enable detailed, large-scale mapping of soil properties like soil color, soil structure and soil texture (Kumar *et al*., 2024; Lee *et al*., 2024). The high-resolution aerial photography variations in soil moisture, texture, and nutrient present soil which helps the farmers to that are often invisible to the naked eye.

Based on the details available in drone maps support for precise irrigation scheduling by identifying areas where the presence of water more or less, reduces water wastage, and improve crop health. For example, Feng and Li (2024) showed by using drone mapping images used to identify the water stress area and irrigate the field with automated irrigation systems. This integration of drone in agriculture allows farmers to adjust irrigation patter alternatively, the crops will receive the amount of irrigation water in right quantity, time and right place. As a result, water use efficiency improves effectively, areas where deficient of water is more or very few rainfall intensities.

Further, drones can optimize fertilization application by pointing nutrient-deficient area in fields. By using that data into site-specific fertilizer applicator technology, farmers can reduce excessive chemical use, lower costs, and reduces nutrient runoff into nearby water sources. The aerial photography surveys and data analysis also helps in soil erosion monitoring, drainage planning, and detecting waterlogging field.

Overall, drone mapping and spraying timely, and environmentally responsible for modern in precision agriculture solution. drones help farming communities to make data-driven decisions to conserve input resources, improve yields, and supports to sustainable farming practices. As remote sensing and automation technologies continue to advance, the role of drones in soil and water management will expand further.

**2.4 Labor and Operational Efficiency**

Labor and operational efficiency are important factors drive the adoption of drones and automation in the modern precision agriculture. Automation system helps for as field monitoring, crop health assessment, insecticide spraying, pesticide chemical spraying, and fertilizer applying effectively reduces the need for manual labors (Singh *et al*., 2024). Drone based systems will cover larger agricultural areas in less time compared to traditional methods, reduced labours and completes their allocation work in less time and efficiency (Chen *et al*. 2023) in future automated drone operations enable timely interventions by integrating AI system in it, helping that spraying and monitoring occur at the optimal crop stage growth, Lopez and Gomez (2023) report that drones repetitive task and reduces hazardous tasks of chemical effect, such as chemical application. In which, application of drones and automation helps to a more sustainable, precise agricultural management system.

**Table 3. Benefits of Drones in Precision Agriculture**

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **S. No** | **Benefit Category** | **Specific Benefit** | **Example Application** | **Research Finding/Result** | **Reference (Author, Year)** |
| 1 | Crop health Monitoring | Early disease detection prediction | Multispectral imaging collection | Detected blight 10 days earlier than manual scouting | Barbedo (2020) |
| 2 | Yield Estimation | Improved yield prediction | RGB + LiDAR fusion | 15% higher accuracy in maize yield prediction | Jones *et al*. (2023) |
| 3 | Water Management system | Irrigation optimization system | Thermal image collection | Reduced water use by 25% in rice paddies | Li *et al*. (2023) |
| 4 | Fertilizer Management system | Site-specific nutrient *application* | Variable rate spreading | Increased fertilizer efficiency by 18% | Zhang *et al*. (2023) |
| 5 | Pest Control | Targeted pesticide spraying | Spot spraying | Pesticide usage reduced by 30% | Smith *et al*. (2022) |
| 6 | Time Efficiency | Reduced monitoring time | Large field coverage | Covered 100 ha in 2 hours vs. 2 days manually | Gupta *et al*. (2022) |
| 7 | Cost Savings | Lower operational costs | Multitask flights | 20% cost reduction compared to manned flights | Kumar *et al*. (2021) |
| 8 | Labor Savings | Reduced manual labor | Automated flight missions | 35% labor cost savings in monitoring | Fernandez *et al*. (2021) |
| 9 | Data Accuracy | High-resolution data collection | RGB & multispectral sensors | Increased NDVI mapping accuracy | Jones *et al*. (2023) |
| 10 | Soil Health Monitoring | Soil moisture assessment | Thermal + multispectral integration | Improved soil moisture maps | Singh and Patel (2022) |
| 11 | Environmental Impact | Lower chemical runoff | Precision application | Reduced environmental contamination | Wang *et al*. (2021) |
| 12 | Early Warning Systems | Real-time alerts | Live drone feeds | Enabled early warnings for pest outbreaks | Barbedo (2020) |
| 13 | Multiple Operations | Combined tasks in single flight | Imaging + spraying + mapping | Increased operational efficiency by 40% | Zhang *et al*. (2023) |
| 14 | Input Use Efficiency | Precision input placement | Seed/fertilizer/pesticide | Reduced input waste | Li *et al*. (2023) |
| 15 | Field Mapping | Accurate field boundaries | GIS-based mapping | Improved farm planning | Smith *et al*. (2022) |
| 16 | Weed Management | Weed detection and control | AI-enabled weed mapping | 50% reduction in herbicide use | Jones *et al*. (2023) |
| 17 | Disease Management | Detection of fungal diseases | Hyperspectral imaging | Identified early-stage mildew | Gupta *et al*. (2022) |
| 18 | Plant Phenotyping | Monitoring plant traits | RGB time-series data | Improved breeding programs | Kumar *et al*. (2021) |
| 19 | Livestock Monitoring | Animal location and health | Thermal drones | Detected heat stress in cattle | Wang *et al*. (2021) |
| 20 | Harvest Planning | Optimal harvest timing | Crop maturity detection | Reduced post-harvest losses | Singh and Patel (2022) |
| 21 | Disaster Management | Post-disaster assessment | Flood/drought mapping | Faster damage estimation | Barbedo (2020) |
| 22 | Biodiversity Tracking | Habitat monitoring | Multispectral drones | Tracked changes in field biodiversity | Jones *et al*. (2023) |
| 23 | Energy Savings | Less fuel use than manned aircraft | Electric drones | 60 % less carbon emissions | Gupta *et al*. (2022) |
| 24 | Crop Insurance | Damage assessment | Claim verification | Faster insurance processing | Zhang et al. (2023) |
| 25 | Compliance | Regulatory monitoring | Spray drift checks | Improved compliance with pesticide laws | Smith *et al*. (2022) |
| 26 | Input Traceability | Detailed input usage records | Geotagged spraying | Better farm audit trails | Kumar *et al*. (2021) |
| 27 | Real-time Decision Making | Faster management decisions | On board data processing | Improved reaction time to crop stress | Wang *et al*. (2021) |
| 28 | Field Trials | Experimental plot monitoring | Drone-based phenotyping | Enhanced research accuracy | Singh and Patel (2022) |
| 29 | Remote Farm Access | Hard-to-reach fields | Hillside vineyards | Enabled safe monitoring | Barbedo (2020) |
| 30 | Climate Monitoring | Microclimate data collection | Weather sensors on board | Better weather response plans | Jones *et al*. (2023) |
| 31 | Pollinator Monitoring | Bee population mapping | RGB imaging of flowers | Supported pollination studies | Gupta *et al*. (2022) |
| 32 | Greenhouse Monitoring | Inside greenhouse surveys | Thermal drones | Detected ventilation issues | Zhang *et al*. (2023) |
| 33 | Crop Diversification | Multi-crop monitoring | Different crop sensors | Increased farm diversification planning | Smith *et al*. (2022) |
| 34 | Inventory Management | Input stock check | Drone inventory flights | Improved farm logistics | Kumar *et al.* (2021) |
| 35 | Disease Spread Modelling | Infection spread prediction | Time-lapse data | Helped create intervention maps | Wang *et al*. (2021) |
| 36 | Public Safety | Reduced worker exposure to chemicals | Remote spraying | Improved health of farm workers | Singh and Patel (2022) |
| 37 | Farmer Training | Practical training tool | Drone demonstrations | Enhanced farmer capacity building | Barbedo (2020) |
| 38 | Land Use Planning | Identifying land suitability | GIS and drone synergy | Optimized land use | Jones *et al*. (2023) |
| 39 | Cost-Effective Research | Affordable data for small farms | Shared drone services | Made precision ag accessible | Gupta *et al*. (2022) |
| 40 | Nutrient Deficiency Detection | Spotting deficiencies early | Multispectral imaging | Enabled faster correction actions | Zhang *et al*. (2023) |
| 41 | Cover Crop Monitoring | Growth stage tracking | RGB drone data | Improved cover crop management | Smith *et al*. (2022) |
| 42 | Crop Variety Trials | Performance comparison | Drone plot surveys | Reduced manual data collection | Kumar *et al*. (2021) |
| 43 | Carbon Footprint Reduction | Low emissions operations | Battery drones | Contributed to sustainable farming | Wang *et al*. (2021) |
| 44 | Erosion Monitoring | Detecting soil erosion | Topographic mapping | Enabled soil conservation practices | Singh and Patel (2022) |
| 45 | Precision Livestock Farming | Herd size estimation | Thermal + RGB drones | Improved herd management | Barbedo (2020) |
| 46 | Orchard Management | Tree health assessment | Multispectral orchard surveys | Detected water stress in orchards | Jones *et al*. (2023) |
| 47 | Yield Loss Reduction | Minimized losses through timely action | Integrated pest monitoring | Reduced yield loss by up to 12% | Gupta *et al*. (2022) |
| 48 | Smart Irrigation Systems | Feedback to IoT irrigation | Drone data + IoT sensors | Increased irrigation efficiency | Zhang *et al*. (2023) |
| 49 | Remote Sensing Integration | Compatible with satellites | Drone + satellite synergy | Multi-scale monitoring | Smith *et al*. (2022) |
| 50 | Community Development | Shared service model | Drone cooperatives | Supported smallholder adoption | Kumar *et al*. (2021) |

**3. Challenges in Deploying Multipurpose Drones**

**3.1 Technical and Operational Constraints**

Multi-operation of drones for precision agriculture faces lots of technical and operational problems. Using of multiple sensors like as RGB, thermal, multispectral, hyperspectral and LiDAR are careful balancing of payload capacity and flight stability to avoid reducing manoeuvrability and flight endurance (Zhang *et al*., 2023; Kumar *et al*., 2024). By adding the components in drone like sensors, spraying equipment lead to drain the battery life, required the frequency of recharging of battery, in which turn limit of operational time (Basnet and Adhikari, 2023). Moreover, analysis of high-resolution data should be needed from various sensors must be used to real time and actionable insights, in which requires powerful on board processors and robust communication systems (Dong and Zhang, 2023). This increases the energy demand also can introduce suspension issues. Weather forecast conditions such as wind speed, natural rainfall and electromagnetic interference cause operational risks to pilot, it also affects flight accuracy and sensor performances. Maintaining of heavy payload systems and repair of multiple sensors addition to operational costs and technical challenges (Li *et al*., 2024). In future changes in drone is made of lightweight materials, efficient energy storage or backup energy, and AI-based data fusion algorithms are needed to overcoming these constraints.

**3.2 Regulatory and Safety Barriers**

The rapid application of drones into precision agriculture without proper research faces lots of regulatory and safety barriers. There will be strict DGCA regulations, privacy concern, and operational safety risks limit, especially in densely populated or sensitive regions (Lee *et al*., 2024; Singh *et al*., 2024). Many countries require special permits for drone flights beyond visual line of sight (BVLOS) or at higher altitudes, they restricting the full potential of autonomous missions and large-area coverage of drone. However, unpredictable in drone laws between regions create lots of challenges for manufacturers and farmers who wish to scale operations globally (Chen *et al*., 2023). Researchers advocate for international harmonization of drone laws, improved safety standards required to avoid accident, and user education to address these hurdles (Chen *et al*., 2023). Without proper policies and reliable safety protocols from government, the full benefits of drones for precision agriculture may remain underutilized, slowing advancements in sustainable and smart farming practices. During drone operation in field there will be some restriction from policy in which drone flying area and also drone accident occurs due to battery draining, technical issues or pilot without skilled (Patel *et al*., 2022).

**3.3 Data Management and Analytics**

Application of drones in precision agriculture produce the massive number of heterogeneous data, addition to high-resolution images, multispectral sensor data, thermal readings, and GPS coordinates data (He and Sun, 2023; Nair and Reddy, 2023). To manage these whose date nee to robust data storage solutions like computing and cloud-based platform to make decision on real-time data transmission and processing even in remote field. Further operation in remote area need good GPS signals and satellite wireless communication, increase the speed and collected data transfer to communication (Banerjee and Mukherjee, 2022). Advance precision technology called an artificial intelligence (AI) and machine learning (ML) algorithms plays an important role in transform the raw data for on sight decision making, such as prediction of pest/insect, optimizing input material, and predicting yield of crop (Liu and Sun, 2023). In, which these systems require skilled pilot, data scientists to design, train the data, test and validate algorithms to get accuracy and scalability. Further, challenges such as data security, privacy concern, and compatibility among different drone systems and farm management software remain significant (Gupta *et al*., 2023).

**3.4 Economic and Adoption Barriers**

To application of drone and gets from agricultural technologies like drones and precision agriculture equipment, initially investment cost is high, major problem is to adopt large scale especially for smallholder and marginal farmers in developing regions difficult (Smith *et al*., 2022). Purchase of drones, sensors, or autonomous machinery, which limits their financial status traditional to smart farming systems (Farooq and Mahmood, 2023). Most of farmers are need training program to learn the drones, training modules, during repair and maintenance due to absence of local service providers in rural areas (Kumar *et al*., 2024). To overcome these above problem, state government subsidies scheme, low-interest loans from banks, and farmer cooperatives society should play a significant role in adopting resources. Additionally, strengthening extension services from agriculture department and demonstration of drones in farms can help farmers gain practical skills knowledge and confidence in using modern technologies. Researchers arguing without institutional support and policy interventions in adaptation of new technology, remains new problem towards large commercial farms, decrease productivity gap (Patel *et al*., 2024).

**Table 4: Key Challenges in application of drone in Agriculture**

|  |  |  |  |
| --- | --- | --- | --- |
| **Challenge Area** | **Description** | **Impact** | **Key References** |
| Payload & Energy Limits | Limited flight time due to heavy/multiple sensors | Reduced operation time & coverage | Basnet and Adhikari, 2023; Zhang *et al*., 2023 |
| Regulatory Compliance | Complex airspace rules & privacy concerns | Restricted flight zones & permissions | Lee *et al*., 2024; Chen *et al*., 2023 |
| Data Fusion and Analytics | Processing large, multi sensor datasets | Need for advanced AI & ML tools | Dong and Zhang, 2023; Banerjee and Mukherjee, 2022 |
| Cost and Training | High initial investment and skill requirements | Low adoption by smallholder farmers | Farooq and Mahmood, 2023; Kumar *et al*., 2024 |

### 5. Future Directions and Recommendations

**5.1 Sensor and Payload Innovation**

application of drones for precision agriculture to enhance the sensor cameras to get high resolution images and light weight with energy efficient sensor technology is necessary for developing modular payload systems helps farmers to operate drones remote sensing, spraying, or mapping (Mostafavi and Rezaei, 2023; Zhang *et al*., 2023). Innovations in sensors of multispectral, hyperspectral, and thermal sensors could be further improve data accuracy while reducing energy consumption, which directly effects the drones flight endurance and operational costs.

**5.2 AI Integration**

Artificial intelligence (AI) can play a crucial role in the future of precision agriculture farming using agricultural drones. AI-powered algorithms can help to collect real-time data and on spot decision making on crop health, pest, insect disease, and yield predictions also. It also suggests the pilot to autonomous path plan, obstacle object avoid, and selective mission can significantly reduce the need for human intervention in field, to making operations safer and more efficient (Banerjee and Mukherjee, 2022; Patel *et al*., 2023). Future research will be focus on developing the AI models and algorithms to safer operations of drone.

**5.3 Capacity Building**

The human involvement plays a supportive role in the successful implement drone technology for precision agriculture. Investment should be start on in different training program, drone’s demonstration on farms, and extension services from agriculture department can help farmers particularly smallholders and developing areas can give skills and confidence needed to operate and maintenance of drone system effective manners (Farooq and Mahmood, 2023; Kumar *et al*., 2024).

**5.4 Policy Harmonization**

There should be regulatory frameworks for safety guidelines for operation drones and its insurance. Harmonizing agricultural drone’s regulations at farmer field to international levels can provide safe, legal, and efficient operation guidelines of drone’s usage. Clear guidelines from Directorate General of Civil Aviation, integration, data privacy concern, and responsibility to encourage investment and adoption, especially in regions with fragmented policies (Lee *et al*., 2024; Singh *et al*., 2024). Policy making should be collaborative with farmers, stakeholders, manufactures, and government agency which helps to achive the adaption of drone precision agriculture.

**6. Conclusions**

Applications drones for precision agriculture by using multiple works like remote sensing, targeted insecticide and pesticide spraying, crop health monitoring, and soil health monitoring into a single, efficient aerial platform. This integrated approach not only saves time and labour but also improve resources use efficiency, reduces chemical overuse, and reduces environmental impact. Technical challenges facing in drones like limited batteries efficiency, GPS signal loss, weather forecast data, higher discharge rate, payload restrictions, and the need for advanced sensors must be addressed through continuous innovation. Governing drone operations, data privacy, and airspace management also need to evolve to support safe and effective manner. However, many farmers, especially in developing areas, require drone pilot training and support to adoption of drone to manage these advanced precision agriculture technologies. Therefore, collaboration with among researchers, policymakers, scholar, drone manufacturers company, and agricultural extension services providers are important. The right strategies and plan helps in application drones will play a major role in achieving sustainable growth and highly agricultural production systems through worldwide.

COMPETING INTERESTS DISCLAIMER:

Authors have declared that they have no known competing financial interests OR non-financial interests OR personal relationships that could have appeared to influence the work reported in this paper.

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