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Use of drones in precision pest management

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Abstract
The integration of drones in precision pest management marks a transformative step in modern agriculture, offering a high-tech approach to monitoring and controlling pests. Drones, equipped with advanced sensors such as multispectral, hyperspectral, and thermal imaging, enable early detection of pest infestations by capturing detailed aerial data. This real-time information allows for the precise identification of affected areas, leading to targeted pesticide applications that are both effective and environmentally friendly. The precision offered by drones significantly reduces the amount of pesticide needed, thereby minimizing the environmental footprint and lowering costs for farmers. Unlike traditional methods that often involve blanket spraying, drone-based precision agriculture ensures that pesticides are applied only where necessary, preserving beneficial insects and reducing the risk of pesticide resistance. Moreover, drones can cover large areas quickly and efficiently, making them particularly useful in large-scale farming operations. Their ability to operate in difficult terrain further enhances their utility, ensuring that even hard-to-reach areas are monitored and treated. The adoption of drones in pest management also aligns with sustainable agricultural practices. By optimizing pesticide use and enhancing pest control efficiency, drones contribute to higher crop yields and better-quality produce. This technology not only supports the economic viability of farming operations but also promotes environmental sustainability by reducing chemical inputs and preserving biodiversity. In conclusion, drones in precision pest management offer a cutting-edge solution that enhances the efficiency, sustainability, and effectiveness of pest control in agriculture. As this technology continues to evolve, it is poised to play an increasingly important role in the future of farming.

Keywords: Drone, precision pest management, pesticide application, pest monitoring

Introduction
Insect pest prevalence in fields, crops, and orchards sometimes shows non-uniform or aggregated regional distributions. There is proof that some pests, like aphids, have their highest population densities near field boundaries (Nguyen and Nansen 2018) [1]. The brown plant hopper concentrates at the base of the rice stem, just above the waterline. Abiotic stressors such as drought and nutrient deficiencies also tend to have higher populations of two-spotted spider mites in fields (West and Nansen 2014) [2]. Therefore, in order to effectively manage pests that are spatially aggregated, precision pest management techniques should be used.

Precision pest management is based on making decisions based on precise subfield-scale information about pest infestations instead of pest density averages at the field scale (Naud *et al* 2020) [3]. Precision pest management yields two key benefits for agricultural sustainability: it reduces the use of pesticides and increases the use of non-chemical techniques targeted at populations in particular sectors of the field. Only implementing control measures in areas and at the times when pest numbers approach economic thresholds is termed as precision pest management (Park *et al* 2007) [4]. In certain pest management scenarios, precision management may reduce the number of resources required because the spatial distribution of various insects is aggregated (Park *et al* 2007) [4]. Subfield management zones are the foundation of precision pest management systems. The zones, based on plant development and health, represent uniform field regions.

Therefore, the two primary objectives of precision pest management are: (1) identifying plant attack zones by detecting groups of plants that have been attacked by insects (using ground-based, airborne, or orbital remote sensing technologies) and (2) implementing localized control measures on plants that have been harmed by insects (natural enemies, pesticide, sterile insects).

Basic technologies like visual inspection and global positioning technology can be used to assess the distribution of insects and damaged plants. Spectral remote sensing has been proposed as a tool to identify damaged plants more recently (Nansen and Elliott, 2016) [5]. In this review paper, we are discussing about use of drones in precision pest management.

What is drone?

Drone means 'dynamic remotely operated navigation equipment'. They can fly autonomously or be piloted remotely and can be expendable or recoverable. A UAV (Unmanned Aerial Vehicle) is a flying device that can fly a pre-set course with the help of an autopilot and GPS coordinates Drones are uncrewed aerial vehicles (UAVs), which are used in various sectors such as, mining, construction and military. In agriculture, they can be applied for analyzing images, ground monitoring, and in-depth situation analysis of a crop. In precision pest management, they are used from detection and delineation of pest injury and pest habitat to delivery of organisms and materials to mitigate pest concerns.

History of drones in precision pest management

- 1921-USDA in collaboration with US army developed UAV for crop dusting
- 1939-Royal New Zealand Air Force Assisted with spread of seeds mixed with fertilizers
- 1960-Tesla induced radio waves in 1898, lead to development of Remote-controlled airplanes
- 1974-Abraham Karem-First functional agricultural drone in Agriculture
- 1985-Thurling-camera fixed in a drone for taking weed images in oilseeds
- 1987-World's first practical-use unmanned helicopter-R-50 for pesticide applications, with a payload of 20 kg
- 1993-Used for monitoring climatic conditions in USA
- 1997-Introduction of Yamaha RMAX helicopter for rice spraying in Japan
- 2001-RC-aircraft equipped with a camera to fetch agriculture field images in France
- 2006-Personal drone concept (flying camera), Dominance by DJI company
- 2009-Fixed-wing drone for monitoring weed infestation and spraying, Detect locust swarms
- 2010-Parrot (French company) induced Wi-Fi drone (first-known smartphone-operated drone)
- 2018-First use of drones for release of sterile insects in Canada
- 2020-India became first country to use drones for locust management
- 2021-SOPs on drones in India
- 2022-Amistar top fungicide by Syngenta becomes first approved pesticide by CIBRC for drone spraying

Classification of drones

There are various ways to classify drones like on the basis of size, rotors, application, range, altitude, and speed. UAVs with weights greater than or equal to 25 kg have specific rules and laws to fly.

Based on size, these are

- Nano drones (<250 grams)
- Micro drones (250 grams to 2 kgs)
- Small drones (2kgs to <25 kgs)
- Medium drones (25 kgs to <150 kgs)
- Large drones (>150 kgs)

Based on rotors

- Fixed wing
- Single rotor
- Multi rotors
- Hybrid VTOL (vertical take-off and landing)

Two rotors make up a single rotor; one is small and fixed on the tail, and the other is an additional, oversized rotor on top. A multirotor system can be a quadcopter, hexacopter, octocopter, or tricopter, depending on the number of rotors and intended use. Drones using multiple or a single rotor (helicopters) do not need special infrastructure to take off or land. They can also hover and manoeuvre with agility, which makes them useful in situations (such as pesticide treatments or crop and orchard inspections) when precise movement or the capacity to keep a long-term sight on a target are necessary. Drones with many motors in particular are often inexpensive and simple to operate. Compared to rotor-based systems, fixed-wing aircraft are often bigger and quicker. Drones used for detection of pest hotspots are here referred to as sensing drones, while drones used for precision distribution of solutions are referred to as actuation drones. Both types of drones could communicate to establish a closed-loop IPM solution. Importantly, use of drones in precision pest management could be cost-effective and reduce harm to the environment. Sensing drones could reduce the time required to scout for pests, while actuation drones could reduce the area where pesticide ap plications are necessary, and reduce the costs of dispensing natural enemies.

Use of Drones in Precision Pest management

- Pest Monitoring
- Pesticide Application
- Release of Biological Control Agents
- Release of Sterile Insects
- Release of Mating Disruption Products
- Direct Killing of Insect Pests

Pest monitoring

Traditional field scouting for pest infestations is often expensive and time-consuming (Hodgson *et al* 2004[6], Dara 2019[7]). When dealing with arthropod pests that are too tiny to perceive with the naked eye, live in the soil, or are found in towering trees, it might be practically difficult. In some farming systems, a deficiency of trustworthy pest sampling methods makes scouting less successful. Using remote sensing technology, precision pest management may be used to monitor crops and detect pest-affected areas. Based on this information, control measures like pesticide spraying can be implemented to avoid infections.

Remote sensing is the detection of energy emitted or reflected by various objects, either in the form of acoustical energy or in the form of electromagnetic energy (including ultraviolet [UV] light, visible light, and infrared light) (Usha and Singh 2013) [8]. It is a non-invasive, relatively labour-extensive method that could be used to detect plant stress before changes are visible by eye. For crops, remote sensing equipment generally assesses the spectral range of visible light or photosynthetically active radiation (PAR, 400-700 nm) and near infrared light (NIR, 700-1,400 nm), with most studies referring to the 400-1,000 nm range (Nansen 2016) [9]. Particular stressors, such as arthropod infestations, induce physiological plant responses, causing changes in the plants' ability to perform photosynthesis, which leads to changes in leaf reflectance in parts of this spectral range.

Compared to conventional platforms for remote sensing, such as ground-based, aerial (with manned aircraft) and orbital (with satellites such as Landsat [30 m spatial resolution], Sentinel 2 [10 m] or RapidEye [5 m]; Mulla 2013) [10], Sensing drones are becoming popular for use in precise pest monitoring because of their many benefits. Sensing drones can cover a larger area than portable, ground-based equipment. Because they may travel at lower altitudes than human aircraft and orbital systems, pictures have better spatial resolution and fewer mixed pixels. Moreover, they are less expensive to acquire and deploy than satellites and manned planes, and they may use higher monitoring frequencies due to their shorter revisit times than satellites (Maes and Steppe 2019) [11].

Drones outfitted with RGB (red, green, blue) sensors, hyperspectral sensors (which have hundreds of small spectral bands), or multispectral sensors (which have three to twelve wide spectral bands) can be used for airborne remote sensing. While inexpensive, an RGB sensor only provides a small amount of spectrum information. More spectrum information is produced by a multispectral sensor, but a hyperspectral sensor often distinguishes minute variations in canopy reflectance considerably more clearly than a multispectral sensor. Hyperspectral sensors would, however, need to be mounted on drones designed to carry bigger payloads because they are often larger. Additionally, they are often more costly, and data processing takes more expertise and time, which limits their usage for individual farmers.

In combination, these sensors can give a 3D GPS accurate model of your field and data that the human eye cannot pick up on much less track easily over time. Normalized Difference Vegetation Index (NDVI) and Normalized Difference Red Edge (NDRE). NDVI is basically a measure of plant health based on how a plant reflects light at specific frequencies. Healthy plants reflect large amounts of near-infrared light (NIR) where unhealthy plants absorb more.

Hence, one of the main drivers for the implementation of drone-based remote sensing technologies into agriculture is the potential time saved by automatizing crop monitoring, making the technology cost-effective for growers.

Pesticide application

Helicopters driven by humans are usually used for aerial spraying. Several restrictions on terrestrial ecosystems are addressed by aerial spraying. They don't require any passageways. Spraying may cover a vast area on a single trip. There are drawbacks to aerial spraying. The human aircraft must be flown at notably higher heights, which will increase the aircraft's distance from the crop. When pesticides are sprayed from such heights, they are unable to target the insect on the crop, which causes spray drifts that contaminate the environment. (Xue *et al* 2016) [12]. With this premise, UAVs are being investigated as a safe and high precision alternative for spraying pesticides (Huang *et al* 2009) [13]. The downwash impact of UAVs aids in directing spray towards crop canopies and plantations even if they are not equipped with pilots. As part of the lifting process, downwash in aeronautics refers to the activity of altering the direction of air diverted by the aerodynamic aerofoil, wing, or rotor in motion. (Yang *et al* 2018) [14].

Parameters to be considered in drone for pesticide application

The set operational parameters such as flight speed, height, and endurance need to be optimized to use drones appropriately in agriculture and allied sectors. In addition, parameters related to drone-based spraying such as droplet size, spread, density, uniformity, deposition, and penetrability should also be factored in when implementing drone-based mitigation strategies (Subramanian *et al* 2021, Zhang *et al* 2015) [15, 16]. Further, meteorological parameters like wind speed, temperature, and relative humidity can affect the efficacy of pesticide sprays under field conditions (Wang *et al* 2018) [17]. One of the critical factors to be considered for the effectiveness of drone-enabled spray is droplet deposition. The parameters used for measuring the effectiveness of droplet deposition include density, area coverage, and arithmetic mean of droplet size and variation coefficient (Zhu *et al* 2011) [18].

Drones for Desert Locust Control in India

- Used for spot application, including high trees, dense plantation and inaccessible areas
- 15 drones each equipped with 10 L tank and supplied with eight batteries to treat 1 hectare in 15 min
- Flat fan nozzles for spraying a mixture of two insecticides (100-120 ml), 5% lambda-cyhalothrin and 2.8% deltamethrin
- Capacity of one drone-12-15 hectares/day
- Flight height-12.2-13.7 m
- Flying speed-10 to 20 km/h
- Swath width-1 to 5 m
- Mortality-50 and 90 per cent at various locust stages
- No ULV formulations were sprayed

Information Required for Developing Crop Specific SOPs

1) Crop details
2) Drone details
3) Spraying system
a) Tank capacity
b) Nozzle
(1) Mounting
(2) Type and number
(3) Angle
(4) Droplet size
(a) Discharge flow rate
c) Pesticide
i) Name and formulation
ii) Concentration
iii) Dosage
iv) Water volume
d) Environment
i) Flying speed
ii) Height above canopy
iii) Swath
iv) Flight direction
v) Area covered
e) Control Efficacy
f) Phytotoxicity

Advantages of drones in pesticide application

- To reduce spray drift
- To make it easy for pesticide application in large areas
- To make it convenient for pesticide application in areas where labour is costly or not available

- To reduce amount of pesticide used
- To reduce time taken in pesticide application
- To ensure safety of the operator

Release of Biological Control Agents

An environmentally friendly substitute for the use of pesticides is biological control. According to Van Lenteren *et al.* (2018) [17], augmentative biological management, which depends on the widespread release of natural enemies to provide instant pest control, may benefit greatly from the deployment of drones. By distributing the natural enemies precisely where they are required, they may improve the effectiveness of biocontrol agents and cut down on distribution expenses. The suggested method of dispersing *Phytoseiulus persimilis*, an essential natural opponent of the two-spotted spider mite, is to sprinkle the contents onto individual plants. The plant material is available in bottles combined with the mineral substrate vermiculite. *Trichogramma* species are commonly used to combat the European corn borer, a significant pest of sugarcane and sweet corn.

Release of Sterile Insects

A potential new area for use of drones in pest management is the release of sterile insects. Codling moth (*Cydia pomonella*) is a major problem in apple orchards (Judd and Gardiner, 2005) [20], and pilot programs to release sterile insects with drones have been successful in controlling codling moth populations in New Zealand, Canada, and the United States (Timewell, 2018) [21]. Through irradiation, the sterile insect technique (SIT) creates sterile or partially sterile insects. There are either no offspring or sterile offspring after mating with wild insects, which lowers pest numbers. SIT is a crucial IPM strategy since it is species-specific, ecologically harmless, and works well with other management techniques like biological control (Simmons *et al* 2010) [22]. Drone release of the sterile insects may be cheaper and faster than ground release, which occurs for instance by means of all-terrain vehicles, or release by manned aircraft (Tan and Tan, 2013) [23].

Advantages of drones

- Reduce the risk of pesticide to operator
- Useful in spot spraying or precision application over large areas
- Drones provide stressed and healthy images of crops
- Reduce the amount of formulation during spraying
- Drones are portable, foldable and accessible to inaccessible areas
- Drones change the flight velocity flexibly to reduce drift hazard

Drone Regulations by Directorate General of Civil Aviation (DGCA) of India

The operation of drones in India is governed as of date by the Unmanned Aircraft System (UAS) Rules 18-Part VI. The DGCA RPAS Guidance Manual17 provides procedures pertaining to issue of Unique Identification Number (UIN), Unmanned Aircraft Operator Permit (UAOP) and related activities. The general laws of using drone are listed below-

- Avoiding densely populated areas of large crowds is essential
- Should fly during daylight hours and in good weather conditions
- Use of drones or camera drones is prohibited in sensitive areas, such as government or military facilities, within 5 km of airports or in areas where aircraft are operating
- Drone user must be qualified drone pilot and should have attained the age of 18 years
- A license plate with the operator's information and contact information must be attached to the drone
- A single person cannot control multiple UAVs at the same time
- Drone flying is prohibited within 50 km of the country's border
- Drones must not be flown more than 500 m out to sea from the coast

Limitations of drones

- Expensive vehicle cost
- Flight endurance and Payload constraints
- Small volume of the liquid tanks
- Short flying time
- Concerned about drift hazard
- Flight drones are covered by aviation law

Challenges of Adopting Drone Technology in Precision Pest Management

- Weather dependent
- Limited battery life
- Lack of knowledge and training
- Cost
- Fear of job loss
- Regulatory barriers

Conclusion

Drones are increasingly being used for precision pest management. Drones with remote sensing equipment (sensors) are used to monitor crop health, map variations in agricultural performance, and detect insect outbreaks. During pest outbreaks, various drones (actuators) could be deployed to provide timely solutions like as insecticides and natural enemies with accuracy and precision. Drones could be used as decision support tools for detection, vast area coverage, spray volume optimization, manpower savings, quick response time, and timely operation before pests reach ETL. Thus, it is clear that drone technology plays a critical role in precise pest management.

Future thrust

There is need to study the compatibility of different formulations for spraying, along with pesticide effects on non-target organisms. There should be awareness promotion and demonstrations of drones in rural areas. Multi-disciplinary research with collaboration of agricultural scientists and engineers should be there. There is need to develop software programs to diagnose specific insect pests and for data analysis.

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