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Drones: New generation technology for crop protection

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Abstract
Agriculture is the prime source of income in developing countries with 60 percent of people directly or indirectly linked. With the advancement in the agricultural sector, the productivity of crops is increased manifold. Nevertheless, early detection and control of pest infestations are still a major concern. Delayed or improper application of pesticides at right time may favor an increase in crop loss. Though farmers keep trying to conserve crops, they are unable to succeed at the maximum level due to inadequate monitoring and proper management practices. Also, most of the producers are adopting unsuitable methods for monitoring the crops due to a lack of sufficient facilities. The involvement of hi-tech agriculture and the influence of technology in the agricultural sector have been always productive since its commencement. In recent times, various techniques and innovative technologies were introduced to replace manual involvement. Of which, drone technology was applied for various agricultural purposes *viz*., crop pest protection, crop nutrient application, crop growth monitoring etc. The use of drone technology has the potential to provide a sustainable solution in the context of enhancing the productivity as well as efficiency of the agriculture sector. The present review focused on drone technology and its significance in crop protection.

Keywords: Drones, agriculture, crop protection, pesticides

Introduction
Agriculture, with its allied sectors, is unquestionably the largest livelihood provider and contributes a significant figure to the GDP (Anonymous, 2022a) [6]. It serves mankind in diverse ways (Harris and Fuller, 2014) [24]. Agriculture can be referred to as the cultivation of plants, animals and other living organisms for food, fibre, biofuel, medicinal and other valuable products used for sustainment and enhancement of human life (Singh and Masuku, 2012) [46]. Development in agriculture is of utmost importance for improving socio-economic status and also it reduces income imbalance between rural agricultural employment (Othman, 2004) [38]. In recent years, there has been strong activity in precision agriculture, particularly in the monitoring aspect which not only improves productivity but also meets the demand of a growing population. Precision agriculture (PA) is a holistic farm system to monitor and manage the field by utilizing various components such as high-resolution data and high technology to maximize the output and minimize the input (Cano *et al.*, 2017) [16]. Furthermore, precision agriculture is also referred to as the application of 'the right input, at the right place, at the right time with the right amount (Bongiovanni and Deboer, 2004) [14] by using an integrated agricultural management system by incorporating several technologies. The technological tools often include the global positioning system (GPS), geographical information system (GIS), yield monitor (YM), variable rate technology (VRT) and remote sensing (RS) (Gago *et al.*, 2015) [20]. These tools can maximize the crop output of farming professionals.
Satellite imaging has also been used for crop monitoring; however, there are several problematic issues with satellite usage which include prohibitive cost, low image resolution and low sampling frequency (Cano *et al.*, 2017) [16]. But, precision farming came up with site-specific crop management (SSCM) or even site-specific farming, which uses sensors that are capable of detecting field variabilities, such as VRT and grain yield monitor are utilized in combination with high position accuracy GPS. But, the main concern of precision agriculture is to provide alternative and realistic ways to promote a healthier environment for humans and to reduce and optimize the usage of potentially harmful compounds by using spatial analysis like GIS tools (Chunhua and John, 2012) [18]. Sometimes, most farmers face huge financial losses due to wrong weather predictions, poor irrigation methods and timely management

practices (Chakane *et al.*, 2017) [17]. To counteract the challenges and to fulfill the needs of the farming professionals, drones, machine learning and artificial intelligence came into existence (Anonymous, 2021a) [4]. The utilization of drone technology will allow farmers to constantly monitor their crop condition by air which helps to find out the problems quickly and also reduce time consumed for ground-level spot checks. Drones are especially suitable for developing countries with small landholding farmers since other modes of aerial application are not viable.

Drone technology

Drones, the next-generation technology in agriculture, popularly known as Unmanned Aerial Vehicles (UAVs), it doesn't merely enhance overall performance but also encourages farmers to solve other assorted barriers and receive plenty of benefits through precision agriculture. The drone technology excludes any guesswork or ambiguity and instead focuses on accurate and reliable information. Agriculture drone empowers farmer to adapt to specific environments and make mindful choices accordingly. The gained data helps to regulate crop health, crop treatment, crop scouting, crop damage assessments etc. (Anonymous, 2020) [3]. Typically, drones include a navigation system, GPS, multiple sensors, finest cameras, programmable controllers and tools for autonomous drones. Some of the best practices of drone technology are (i) Aerial imaging, (ii) Irrigation monitoring, (iii) Monitoring and surveillance of crop health, (iv) Crop damage assessment, (v) Analysis of field soil (vi) Livestock tracking and (vii) Application of pesticides. Drone technology has ushered in a new era for precision agriculture. First UAV (unmanned helicopter) for pesticides application was introduced by Yamaha Motor Co. Ltd., Shizuoka Japan in 1983 (Giles and Billing, 2015) [21]. The chemical application using drones has great potential as we move towards commercialization and it helps to achieve precision in crops. Agri-drones have reservoirs filled with pesticides for spraying on crops in very little time as compared to traditional methods (Anonymous, 2021a) [4]. Overall, drones with a flight height of 2-3m, a flight speed of 3-5m/s, two fan nozzles, four rotor UAV and 15 L payload are found to be optimal to undertake pesticide sprays in agricultural crops (Zhang *et al.*, 2011) [55].

Conventional application and drone spraying

Conventional methods of pesticide spray application may lead to several problems *viz.*, excessive application of chemicals, lower spray uniformity, unnecessary deposition and non-uniform coverage. Also, results in excessive wastage, water and soil pollution as well as higher expenditure on pesticides. With conventional manual sprayers, the safety of operators is also a major concern. The use of drone technology is a modern farming technique aimed at making production more efficient through the precise spraying of pesticides. This approach not only ensures accuracy, but it would also maintain uniformity in a spray across the field and reduces manpower requirement, application time and water volume and also lessens the chemical use. Meanwhile, it minimizes the drift to the environment along with the reduction in exposure of the hazardous chemical to operators and other human beings within the area. The wastage will also be comparatively less in drone application technology than in conventional spraying (Anonymous, 2022b) [7].

Types of UAVs

A UAV is an aircraft that can fly without a human pilot and is controlled by a radio channel (Mogili and Deepak, 2018) [36]. There are different types of rotors, classified based on the number of rotors in their platform.

Table 1: Different types of UAV models developed for precision agriculture

S. No.	Types of UAVs used	Model description
1.	Fixed-wing UAVs	Different in their design compared to multi-rotors and the aerodynamic shape of two wings gives an easy glide for UAVs (Spoorthi *et al.*, 2017; Herwitz *et al.*, 2002; Pederi and Cheporniuk, 2015; Maurya, 2015) [48, 25, 39, 35].
2.	Single rotor helicopter	This model has one big sized rotor on top and one small-sized on the tail of the UAV (Yallappa *et al.*, 2017); Cai *et al.*, 2010; Huang *et al.*, 2014; Qin *et al.*, 2018; Xinyu *et al.*, 2014) [53, 15, 27, 41, 52].
3.	Quadcopter	Multi-rotors that are lifted and propelled by four rotors in which two opposite rotors are turned in a clockwise direction and the other two turn in a counterclockwise direction (Sarghini and Vivo, 2017; Achtelik *et al.*, 2011; Gupte *et al.*, 2012; Kabra *et al.*, 2017; Kale *et al.*, 2015; Kedari *et al.*, 2016) [44, 1, 22, 29, 30, 31].
4.	Hexacopter	Multi-rotors that is lifted and propelled by six rotors (Herwitz *et al.*, 2004; Berner *et al.*, 2017; Anthony *et al.*, 2014; Primicerio *et al.*, 2012; Yanliang *et al.*, 2017) [26, 13, 9, 40, 54].
5.	Octocopters	Multi-rotors that is lifted and propelled by eight rotors (Huang *et al.*, 2009; Qing *et al.*, 2017; Bendig *et al.*, 2012 [28, 43, 12].

Fixed-wing UAV: These UAVs have stationary wings in the shape of an aerofoil which creates the lift needed when the vehicle reaches a certain speed.

Single rotor helicopter: It has a single set of horizontally rotating blades attached to a central mast for producing lift and thrust. It is capable of take-off vertically and landing, flying forward and backward and it hovers at a particular place. These features allow the use of helicopters in jammed and remote areas where fixed-wing aircraft are unable to operate.

Multi-copters: Rotorcraft with multiple sets of horizontally rotating blades (4-8) can provide lift and control movements of drones (FAO, 2020) [19].

In the past decade, the UAVs market was captured by fixed-wing and helicopters. Nowadays, the utilization of small drones in precision agriculture has shifted focus towards multi-copters. At present, it covers almost 50% of the available UAV model (Hafeez *et al.*, 2022) [23].

Table 2: Observations of drone usage in crop protection

S. No.	Crops	Purposes	Results	References
1.	Rice	To manage brown plant hopper (BPH) as it causes damage at the later stage of crop growth and often colonizes the lower part of the crop.	Studies have shown that superior efficiency in controlling BPH when operated at an altitude of 1.5m and a velocity of 5m/s.	Qin *et al.*, (2016) [42].
2.	Rice	To study the efficacy of fungicide spray: Copper Oxychloride 53.8% @ 35g per 16 litres against bacterial and fungal diseases in rice fields.	Preliminary investigation showed that optimal flying height (3m), speed (5m/s), swath (4m), and area coverage (4 min/acre) has found to be efficient.	Subramanian *et al.*, (2021) [49].
3.	Cotton	To control cotton aphid and spider mite population.	The control of aphids and spider mites was found to be 63.7% and 61.3% respectively. UAV spray was slightly less effective in comparison to boom spraying due to the spiral arrangement of leaves in cotton.	Lou *et al.*, (2018) [33].
4.	Pepper	To fight against the fungal infestation (*Phytophthora* blight) and aphid attack.	Observation showed that the efficiency of drone spray was more effective and one-third concentration of pesticide was found optimal in comparison to the conventional spray.	Xiao *et al.*, (2020) [51].
5.	Sugarcane	To control fall armyworm (FAW) and mitigate the labour issues and also to overcome the complex canopy arrangement.	The application of Chlorfenapyl - Chlorantraniliprole - Lufenuron through drones showed the efficacy of 94.94 and declined the pest population by about 94.86%.	Song *et al.*, (2020) [47].

Research and developments in UAV-based pesticide spraying

Manual spraying of pesticides affects human beings and may lead to complex diseases like cancer, hypersensitivity, asthma and other disorders (Koc, 2017) [32]. To overcome these shortcomings, a drone-mounted sprayer is being employed. A drone is designed with a carrying capacity of up to 40-litre pesticide tank and follows pre-mapped routes to spray crops according to the requirements. It shows great potential in covering the fields which is difficult to access for tractors and aircraft. Spoorthi *et al*., (2017) [48] developed a drone named Freyr for uniform spray applications in the field. For this, a user-friendly android app was developed with a Wi-Fi interface. A smart controller board (Arduino Mega-2560) was used to control the system process. Balaji *et al.*, (2018) [11] designed a hexacopter using a Raspberry Pi controller to make agriculture technologies farmer-friendly where Python language programming was utilized for disease and weed detection in crop monitoring. Anand and Goutam (2019) [2] designed a drone named Aero Drone for field monitoring and chemical spraying. A simulation platform was proposed to assign the mission on the field and to check the sensibility and accuracy of this plan. Besides, Wen *et al.*, (2019) [50] developed a UAV integrated variable spray system based on an artificial neural network (ANN). Also, an octocopter with a lower weight spraying system was designed which was found suitable for farm monitoring on large scale (Shaw *et al*., 2020) [45]. The above findings proved that there is a ramp in drone application for precision agriculture.

Infrared thermal imaging

Thermal imaging is a technique to improve the visibility of reference objects in a dark environment. This technique is based on the principle of detection of reference objects using infrared radiation and creating an image based on the information obtained. After the drone spray, there will be changes in leaf temperature and this technique detects infrared-specific band signal of object thermal radiation by optoelectronic technology. To avoid external interference, closed environmental chambers can be employed along with the acquisition of thermal images after the spray test (Lv *et al.*, 2019) [34]. Tamil Nadu Agricultural University (TNAU), has initiated work on infrared imaging of rice fields using a quadcopter attached to a sensor to monitor the health status of the crop (Subramanian *et al.*, 2021) [49].

Procedures to be followed in drone based crop protection

Every country has its regulatory guidelines for the use of drones in agriculture (Ayamga *et al.*, 2021) [10]. Ministry of Agriculture and Farmer's Welfare, Government of India, has come up with standard operating procedures (SOP) which need to be followed by the users while adopting drone-based crop protection technology. This covers important aspects including statutory provisions, flying permissions, area distance restrictions, weight classification, overcrowded areas restriction, drone registration, safety insurance, piloting certification, operation plan, air flight zones, weather conditions, SOPs for pre, post and during operation, emergency handling plan etc. (Anonymous, 2021b) [5]. The drone operations are being permitted by the Ministry of Civil Aviation (MoCA) and the Director General of Civil Aviation (DGCA) via a conditional exemption route. Some important procedures are as follows:

- Operators should obtain an unmanned aircraft operator permit (UAOP) from DGCA for commercial usage.
- Needs to confirm the safe flying condition and calibration of the drone spray system.
- The leakages need to be checked beforehand.
- Proper take-off area and place for tank mix operation should be chosen.
- Ensure operators are trained on operations and in the use of pesticides.
- Public has to be intimated at least 24 hours in advance about drone spraying in written intimation to the executive officer of Gram Panchayat and Panchayat Samiti and also to the agricultural staff of the concerned area.
- Flying over public events/places, airports, government or military limits is not allowed without prior permission.
- During spraying, the operator must wear personal protective equipment (PPE).
- Avoid drinking, eating and smoking while spraying.
- Ensure two-step dilutions for the complete dissolving of pesticides. Initially, spraying with pure water has to be done to test the operation.
- Appropriate wind speed, humidity, temperature etc. needs to be checked properly.

- Appropriate flying height, water volume, flying speed etc. needs to be checked properly.
- Avoid spray during the active bee foraging period in a day and avoid spray drift to flowering nectar crops.
- After spraying, the operator should move to fresh air for some time.
- Empty container needs to be rinsed properly and avoid leaving the empty container on the field premises.
- Only DGCA approved drones shall be permitted to use for agriculture spray.
- Central insecticides board and registration committee (CIB&RC) approved pesticides/insecticides only be used with the proper recommended dose.
- Only DGCA certified pilots shall be permitted to fly the agriculture drones.
- Buffer zone as per CIB&RC permitted guidelines shall be maintained to avoid spray on non-target crops.

Limitations of drone spraying
There are ample advantages attached to drone technology, in the meantime, a few limitations are remains in concern.

Internet connectivity problem: Often, internet connection is inaccessible in rural zones. Under such conditions, a farmer or user needs to invest more in internet connectivity, which can turn into a recurring expense.

Weather dependent: Drones are reliant on good weather conditions. During rainy or windy weather circumstances, it is not desirable to use drones in agricultural operations.

Requirement for more knowledge and skill: Utilizing new technology is a warm change but appropriate usage needs the right skillset and adequate knowledge. An average farmer may struggle to recognize drone functions. Either he must gain the knowledge or remain dependent on experienced individuals (Anonymous, 2022c) [8].

Conclusion
Drone technology is the major component of precision agriculture befits uniformity, accuracy and reduction in the wastage of resources. It also helps in reducing the cost of cultivation, work burden and labour force. The field management can be improved by utilizing drones to increase productivity which is foremost important to safeguard food security. This technology may not solve all the problems in the field as a whole but it can sort out specific issues in agriculture (Norasma *et al*., 2019) [37]. The usage of drones especially for pesticide spraying has been effective and superior in protecting crops from pest infestation. However, the big challenge remains in concern that users need to be familiar with the principle and methodologies involved in operations. The farmers certainly need comprehensive training and collaboration with third-party specialists in the drone industry for the attainment of reliable data. Drones have changed the course of obtaining data in almost every type of industry, and will only deem to become bigger and better in the coming years.

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