Applications of Drones in Agriculture: Status and Scope

Satya Prakash
Manoj Kumar
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Bikram Jyoti
A. Subeesh
K. N. Agrawal
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C. R. Mehta
P. L. Singh
Kanchan K. Singh

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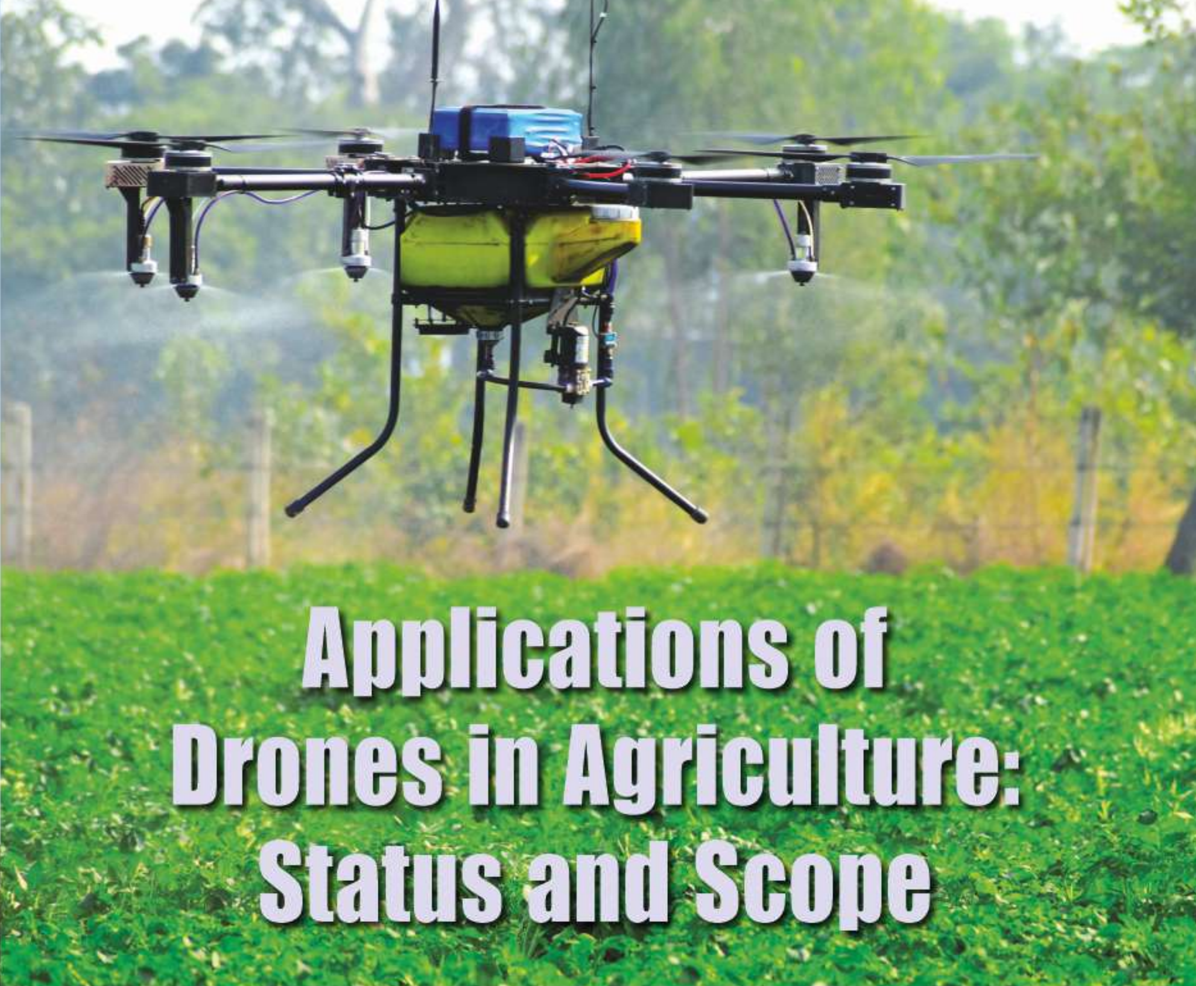

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Concept
Trilochan Mohapatra, Secretary (DARE) and DG (ICAR), New Delhi

Guidance
Dr. S.N. Jha, DDG (Agril. Engineering), ICAR, New Delhi

Editing
Dr. C.R. Mehta, Director, ICAR-CIAE, Bhopal, Madhya Pradesh
Dr. K.N. Agrawal, PC, ESA, ICAR-CIAE, Bhopal, Madhya Pradesh
Dr. P.S. Tiwari, Head, AMD, ICAR-CIAE, Bhopal, Madhya Pradesh
Dr. Panna Lal Singh, Principal Scientist, ICAR, New Delhi

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ICAR-CIAE, Bhopal, Madhya Pradesh

Design and Production
Punit Bhasin, Incharge, Production Unit, DKMA, ICAR, New Delhi

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त्रिलोचन महापात्र, पीएच.डी.
सचिव एवं महानिदेशक
TRILOCHAN MOHAPATRA, Ph.D.
SECRETARY & DIRECTOR GENERAL

भारत सरकार
कृषि अनुसंधान और शिक्षा विभाग एवं
भारतीय कृषि अनुसंधान परिषद
कृषि एवं किसान कल्याण मंत्रालय, कृषि भवन, नई दिल्ली 110 001

GOVERNMENT OF INDIA
DEPARTMENT OF AGRICULTURAL RESEARCH & EDUCATION
AND
INDIAN COUNCIL OF AGRICULTURAL RESEARCH
MINISTRY OF AGRICULTURE AND FARMERS WELFARE
KRISHI BHAVAN, NEW DELHI 110 001
Tel.: 23382629; 23386711 Fax: 91-11-23384773
E-mail: dg.icar@nic.in

FOREWORD

Climate change threatens food security. Agriculture must adapt to climate change and manage the agro-environment appropriately. ICT-driven decision-support tools and technologies are critical in this context. Agriculture must look to emerging technologies for solutions to some of its problems. The use of small unmanned aerial vehicles (UAVs), popularly known as drones is now being promoted for solving agricultural problems under field conditions. Drones are operated remotely and do not have a human pilot on board. Both in evidence-based planning and in geographical data collection, these offer enormous advantages. With regard to generating real-time quality data, the use of drones and connected analytics have tremendous potential. Similarly, drones have potential to become multi-purpose vehicle and change the future farming systems. According to estimates of Goldman Sachs, agriculture sector will become the second largest consumer of drones in the world within five years.

Till date, the use of UAVs in agriculture, particularly in India, has been in its infancy. To give a boost to digital agriculture, Government of India has come out with a major plan to promote use of drones by farmers. Policy intervention coupled with technical support can accelerate the use of this technology. To have accelerated technological support from use of drones, we need to analyse the benefits of the technology along with inherent limitations and infrastructural and policy interventions required. This document has been compiled to give a holistic view of the present status of drone technology, its possible application, present policies and way forward for the promotion of technology in Indian agriculture. I congratulate my colleagues for compiling this document and hope that the information contained herein will be useful to policy planners and other stake holders in this domain to promote drone technology for the benefit of the farmers.

(T. MOHAPATRA)

Dated the 05th July, 2022
New Delhi

CONTENTS

1. Introduction

The Food and Agriculture Organization (FAO) of United Nations and the International Telecommunication Union (ITU) estimate that by 2050, the global population would need to find innovative ways to increase food production by 70% (Sylvester *et al.,* 2018). The main challenge of global agriculture is to provide food to the growing population, which is predicted to increase currently from 7.0 billion people to approximately 9.0 billion by 2050. Recent findings show that current yield improvement trends will not be enough to fulfil predicted world food demand by 2050, implying that more agricultural land would be needed. Moreover, India's population, which is now estimated at 1.34 billion, is expected to increase to 1.51 billion by 2030 and 1.66 billion by 2050. Meeting the food needs of the growing and increasingly affluent human population with the planet's limited resources is a major challenge of time (Anonymous, 2020a). In addition, Indian agriculture is facing challenges such as labour shortage, arable land scarcity and rising irrigation water demand.

The COVID-19 epidemic has had a significant impact on humanity's behaviour and activities, and agriculture is no exception. According to the Food and Agriculture Organization, COVID-19 has a substantial impact on agriculture in two areas viz. food supply and demand (FAO, 2020). These two aspects are directly related to food security, so food security is also at risk. Food demand and thus food security are greatly affected due to mobility restrictions and reduced purchasing power, and have a greater impact on the most vulnerable population groups (Siche, 2020). By 2050, food demand is anticipated to rise from 59 to 98%. This will have a significant impact on agricultural markets that we have never seen before. Farmers around the world will need to increase crop production, either by expanding the amount of agricultural land available to grow crops or by improving productivity on existing agricultural lands by making better use of agricultural inputs such as fertilizer and irrigation, as well as adopting new technologies on a daily basis (Elferink and Schierhorn, 2016).

Despite the fact that India's economy is heavily reliant on agriculture, it is still lagging in terms of adopting the latest technologies of precision agriculture (PA) for inputs management on farms. PA is an approach where inputs are utilised in precise amounts to get increased average yields as compared to traditional cultivation techniques. As a result, it is a holistic system aimed to increase production efficiency, improve product quality, improve the efficiency of crop chemical usage, conserve energy, and protect the environment by integrating key elements of information technology and management (Shibusawa, 2002; Hakkim *et al.*, 2016). In the last decade, a few new technologies have been incorporated into PA to enhance agricultural productivity in India. These technologies are useful in situations where human interaction is impossible or where skilled labour is scarce. Precision agriculture promises the possibility of significant yield growth with minimum external inputs use, especially for small farmers in developing nations (Fountas *et al.*, 2005). The overall goal in PA is to leverage information and communication technologies (ICT)/ services to combine and process data from different sources so that valuable inferences about soil understanding may be drawn, allowing for more effective crop management (Stafford *et al.*, 2000; Lamb *et al.*, 2001). There are too many developments in PA for increasing agricultural productivity in today's world.

Agriculture has undergone a fourth transformation (Farming 4.0) in recent years as ICT has been integrated into conventional farming practices (Sundmaeker *et al.*, 2016). Technologies like Unmanned Aerial Vehicles (UAVs) popularly known as drones, Remote Sensing, Internet of Things (IoT), Artificial Intelligence (AI), Machine Learning (ML), Big Data Analytics (BDA), etc. are especially promising and have the potential to usher a new era in agricultural practices (Walter *et al.*, 2017; Wolfert *et al.*, 2017). Drones are being used in precision agriculture, photogrammetry and remote sensing in developed countries (Everaerts J., 2008; Zhang *et al.*, 2012; Colomina and Molina, 2014; Natu and Kulkarni, 2016). Drones are increasingly being used in agriculture to assist cultivators with monitoring and decision-making on the field. A broad range of agricultural parameters, such as environmental condition, soil nutrient status, plant growth status, crop/soil spatial and temporal variability, irrigation water management, application of pesticides/fertilizers, weed management, and greenhouse production climate, can be monitored in precision agriculture using technology like UAV (Drone) to increase crop yields, minimize costs, and maximize process inputs (Abdullahi *et al.*, 2015; Nukala*et al.*, 2016).

Drones also played a major role during the COVID-19 pandemic due to labour shortage to control locust attacks on crop fields. It is very fast, and has the potential to reduce a farmer's workload. Hence, to fill the gap between current agricultural production and the needs of the future, drone technology and advanced image data analytics capabilities are the only feasible answer for this urgent call to increase agricultural production. Therefore, an effort has been made to summarize the usage, challenges and potential applications of drones in agriculture and allied sectors.

2. Unmanned Aerial Vehicle (Drone)

Drones are flying robots, which include unmanned aerial vehicles (UAVs) capable of flying thousands of kilometres and mini drones that can fly in confined spaces (Cavoukian, 2012). Prominent alternative terms commonly used in various parts of the world and different contexts include Remotely Piloted Aircraft (RPA), Unmanned Aerial Vehicle (UAV) and Unmanned Aircraft System (UAS).

There is a broad range of potential civil and commercial applications for which drones are attractive platforms. Drones are getting popular in the agriculture and allied sector for performing different tasks such as crop scouting, weed mapping, spraying, yield estimation, crop and water source identification, estimation of vegetation indices, assess crop insurance claims, soil analysis, health and vigour assessment of crops, and irrigation and nutrient management. Moreover, they also find their applications in forestry, fisheries, livestock management and wildlife conservation.

Initially, drones were classified by Australian researcher (Brooke-Holland, 2012), based on the minimal take-off weight, as well as how and where the drones are planned to be used. Generally, drones are classified into three categories based on their aero-dynamic characteristics viz fixed-wing, rotary-wing and hybrid (Vergouw *et al.*, 2016; Mogiliand Deepak, 2018). During the last two decades, various types of drone models have been deployed. Depending on the number of rotors, a rotary-wing drone can be categorized as tri-copters, quad-copters, hexa-copters and octo-copters that are lifted and propelled by three, four, six and eight rotors, respectively (Gonzalez-Jorge *et al.*, 2017). In a four-rotor system, two opposite rotors rotate clockwise (CW) and the other two rotate counter-clockwise (CCW). The quad-copter movement around the axis includes pitch (backward and forward), roll (left and right) and yaw (clockwise and counter-clockwise). A quad-copter's configuration is divided into two parts viz. the plus (+) model and the cross (X) model. In India, drones are classified into five categories based on their weight i.e. nano (<0.25 kg), micro (0.25-2.0 kg), small (2.0-25 kg), medium (25-150 kg) and large (>150 kg) (Anonymous, 2021a).

2.1 Hardware

- **Flight controller:** The flight controller is a small computer system, which acts as the heart of the drone and is responsible for directing the flight of drone along its flight path. Generally, it allows multiple flight modes which can be selected with the help of a transmitter switch.

- **Motor/speed controllers:** Motors in drones are responsible for spinning the propellers and make a huge impact on flight time. The selection of motors mainly depends on the weight of the drone. The motor should be capable enough to generate thrust to overcome the weight of the drone and achieve a lift-off. The electronic speed controller (ESC) helps the flight controller to control each motor individually and stabilize the system.

- **Sensors and camera:** Sensors and cameras are two major components outfitted in drones. The motion control is performed based on the sensor data received from the sensor attached to it. As continuous monitoring of position, velocity and acceleration are required; gyro, accelerometer and magnetometer combinations are incorporated as a sensor set in the drones. GPS is also enabled for tracking the live location of the drone. The multi-spectral camera collects images at specific frequencies, whereas hyper-spectral cameras are mounted for capturing images at narrow spectral bands.

- **Communication system:** The communication system is responsible for data flow between the ground control station (GCS) and the drones. The pilot can transmit task-specific commands via a radio transmitter present in the GCS. The GCS software captures telemetry data from the drones and is capable of visualizing it in the GCS user interface. The information collected from the sensors can be partially analysed in real-time or sent to the ground station for analysis.

- **Drone airframe:** Drone airframe provides the support for mounting electronic components, sensors and rotors. The frame is designed to be light in weight and has strength to carry the load. Various materials such as plastic, aluminium, fibre and wood are used for creating rigid airframes.

2.2 Software and data management

Drones have unleashed new ways for capturing data through advanced cameras and sensors that can be converted into actionable insights. Drone analytics tools enable visualization, consumption and analysis of aerial data captured by drones. Some of the most commonly used tools for drone data mapping and management include:

- **DroneDeploy:** DroneDeploy provides easy-to-use cloud-based software products for drones including automated safety checks, real-time mapping and data processing (Anonymous, 2021b). Being exclusively cloud-based, DroneDeploy can process massive amounts of data gathered from drones to produce insight-rich 2D and 3D models. DroneDeploy is capable of solving many agriculture problems such as identifying the crop damage, and pest and diseases infestation, and drawing inferences based on crop growth and responding to weather changes.

- **Pix4D**: Pix4D provides a complete software suite for drone mapping and is capable of generating solutions for industries such as agriculture, civil engineering, mining, public safety, education and construction (Anonymous, 2021c). Pix4D mapper software is designed for professional drone mapping applications and supports the processing of RGB, thermal and multi-spectral images. Maps are created rapidly with no requirement for internet connectivity. This helps in easy scouting of the farm and generating various useful outputs such as vegetation index maps, field boundaries, digital surface models, zonation maps, *etc.*

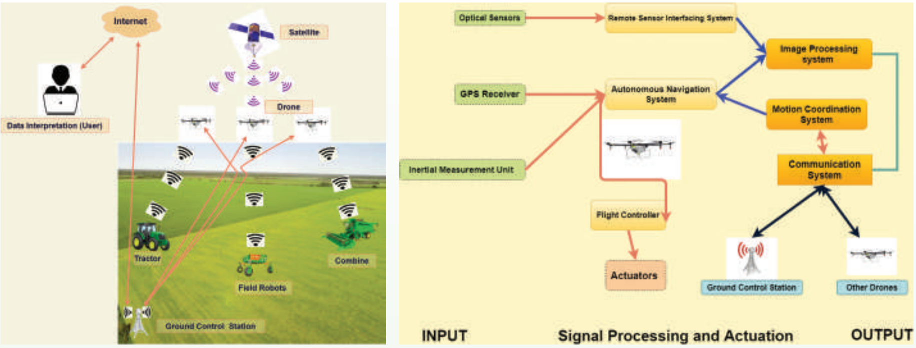
- **ArcGIS Drone2Map:** ArcGIS Drone2Map streamlines surveying and mapping process, and provides orthomosaics, 3D meshes and so on. It is a premium app for ArcGIS Online, which helps to transform the images collected by the drone into high-quality 2D and 3D models (Anonymous, 2021d).

- **DJI Terra**: DJI Terra is easy to use mapping software to transform drone-captured images into digital assets. Complex missions can be automated and the user interface is user-friendly (Anonymous, 2021e). DJI Terra agriculture version includes features such as easy mapping of orchards, precise management of crops, generating vegetation indices maps (NDVI and NDRE maps) by using multi-spectral images.

- **Agisoft Metashape:** Agisoft metashape is a stand-alone photogrammetric software solution, capable of performing geo-referenced orthomosaics and digital surface model (DSM) from images with high accuracy (Anonymous, 2021f). Using Metashape, detailed 3D models are created from images and models are exported to all external post-processing packages. The tool allows the processing of images from various sources such as RGB and multi-spectral cameras.

2.3 Working Concept of Agricultural Drones

Drones used in agriculture collect data from geographical positioning system (GPS) and sensor-equipped farm equipment and transmit data to a ground control station (GCS) via satellite. Data are then transferred to the users over the internet for data analysis and regulation of farm implements. The working concept and real-time implementation of UAVs in agriculture are shown in Fig. 1. The GCS gathers information on the drones in the fleet, such as geographic data, and prepares and manages drone fleet missions. The fleet is a collection of many drones that get a mission from GCS and work together to complete it. It is critical to ensure connectivity between drones and GCS to implement drone-assisted wireless communications and instruction to the field implements. Drones can also be used as standalone input applicators for site-specific management.



(a) (b)

Fig. 1. (a) Working concept (b) Real-time implementation of UAV in agriculture

3. Applications of Drones in Agriculture and Allied Sectors

Drones (Unmanned Aerial Vehicles) are not a recent technology. They were previously used for military and security purposes. However, with the advancement of information technology, IoT and electronic boards, their use has rapidly expanded in other areas such as commerce, science and agriculture. Drones, which are devoted to agriculture to enhance production and productivity through site-specific crop management, are called agricultural drones. In the recent past, the adoption of drones in agricultural production systems has increased at a fast pace. Advancement in multi-spectral imaging techniques and electronic sensors has enabled farmers to extract detailed information on soil and crop health. Additionally, it has enhanced per capita income by reducing labour and agricultural input requirements.

Agricultural drones are considered a promising technology in precision agriculture and have a great potential to address the age-old problem of acquiring real-time agricultural data for real-time monitoring of agricultural fields. Drones are now commonly used for precise application of agricultural inputs along with growth monitoring, plant health management and yield estimation. Goldman Sachs has predicted that in coming decade, drone usage will be the second-largest in agriculture sector. Drones offer an enormous possibility for wider adaptability in agriculture by data acquisition, processing and enhancing the performance of monitoring systems. Moreover, drone is easy to operate, cost-effective and requires the least possible time to acquire field data as compared to conventional methods. A drone equipped with a high resolution camera can fly at low altitudes to acquire images with ultra-high spatial resolution. A drone provides a non-destructive way to cover a larger field in a short time as compared to ground-based systems.

Because of the far-reaching adaptability and increasing acceptability of drones in PA applications in recent years, they are widely regarded as the future of smart farming. As a result, various studies have been conducted across the globe for real-time site-specific management and plant health monitoring. Despite the fact that research on the use of drones for various agricultural operations has been done, many agricultural and related fields remain untapped. The brief details of various uses of drones in agriculture and allied sectors are given below.

3.1. Agriculture

One of the greatest impediments to boost agricultural output and quality is the lack of tools for routinely evaluating the developments in farming. This challenge is exacerbated by weather fluctuation, which alters the micro-climate of crops, putting agricultural production in jeopardy. Sensor data collected through drones are used with real-time data analytics in precision agriculture to discover spatial variability in the field and boost farm output. Drone missions produce a large amount of raw data that can be utilised to activate agricultural analytical systems. As part of precision agriculture, drones can do soil health scans, monitor crop health, assist in the planning of irrigation schedules, apply chemicals/fertilizers, estimate production statistics, and give critical data for weather analysis. When drone data are combined with data from other sources and analytic tools, actionable information is produced. Liquid insecticides, fertilizers, and herbicides can be applied by drones at precise variable rates. Drones can also be employed for computing various phenotyping traits in plants (Fig. 2). Surveys using drones are becoming more popular and cost-effective.

Drones can collect data and monitor crops, giving farmers new options for monitoring crop growth and recording variations in a field. Many recent studies have focused on estimation of crop biomass, nitrogen status and crop yield. The most important crop characteristic is biomass, which, when combined with information on nitrogen content, can be used to predict whether extra fertilizer or other activities are required. Drones have the potential to collect crop data in a consistent manner, allowing farmers to plan crop management, input utilization, plan harvesting time, soil and yield monitoring and identify any management flaws in a controlled manner. The benefits of use of drones in agriculture are as follows.

- *Increased production* -Farmers can increase production and productivity of farm produce by implementing comprehensive irrigation planning, adequate crop health monitoring, and surveillance, and responding to environmental changes.

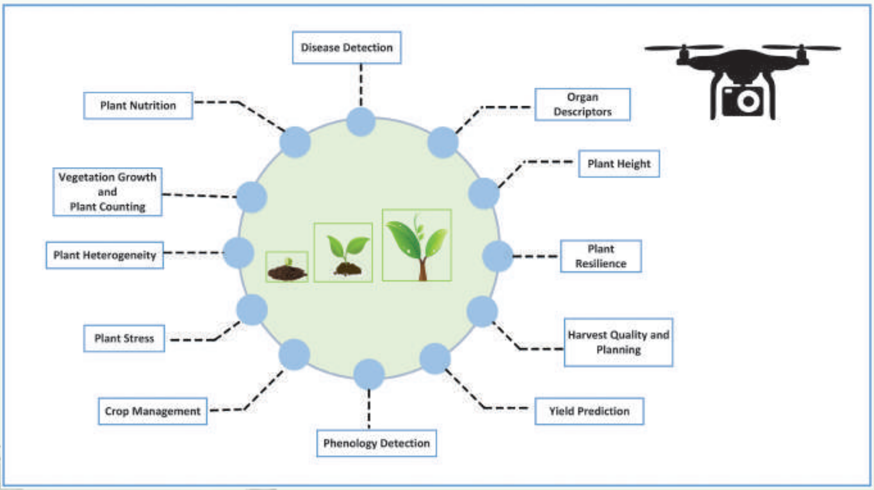


Fig. 2. Various phenotypic traits captured via drones

- *Efficient and robust farming techniques* – The use of drone allows farmers to receive regular information on their crops and aid in the development of more effective farming techniques. They can adjust to changing weather conditions and utilise resources efficiently.
- *Improved safety of farmers* - Using drones to spray pesticides in difficult-to-reach terrains, contaminated areas and taller crops are safer and more convenient for farmers. It also aids farmers in avoiding manual spraying of crops and less pollution and chemicals into the soil.
- *Faster data collection for swift decision-making* - Surveys done through drones are 10 times faster and more accurate than conventional surveying and mapping techniques. This helps in early prediction and timely management of agricultural resources. Moreover, it enables optimum usage of agricultural inputs and less wastage of resources.
- *Insurance claims* - Agricultural insurance businesses employ agri-drones to acquire efficient and trustworthy data. They keep track of the farmers' crop losses in order to compute the proper monetary compensation. In the event of crop loss, farmers may use drone data to file crop insurance claims.

3.1.1. Survey of farm lands and land use mapping

Drones fitted with various controllers and sensors such as control systems and radio remote control can perform multiple tasks and can assist in real-time mapping of agricultural fields. A drone can inspect a bigger area of agricultural land with much higher spatial and temporal details. Drones fitted with LIDAR sensors can be used to survey and monitor orchard fields. Surveying the nutritional condition of the soil at different soil types, nutrient ranges, and nutrient requirements within and between fields is another area where drones can be used. Drones can be used to reduce unlawful stubble burning in agricultural fields in India, where it is a big issue and a threat to the environment.

Soil and field analysis can be done using drones. They may be used to create precise 3-D maps that can be utilised to undertake soil analysis for soil properties, moisture content, and erosion. When it comes to seed planting patterns, this is crucial. Even after planting, these data are useful for irrigation and nitrogen management. The crop monitoring in large fields is one of the biggest challenges in farming.

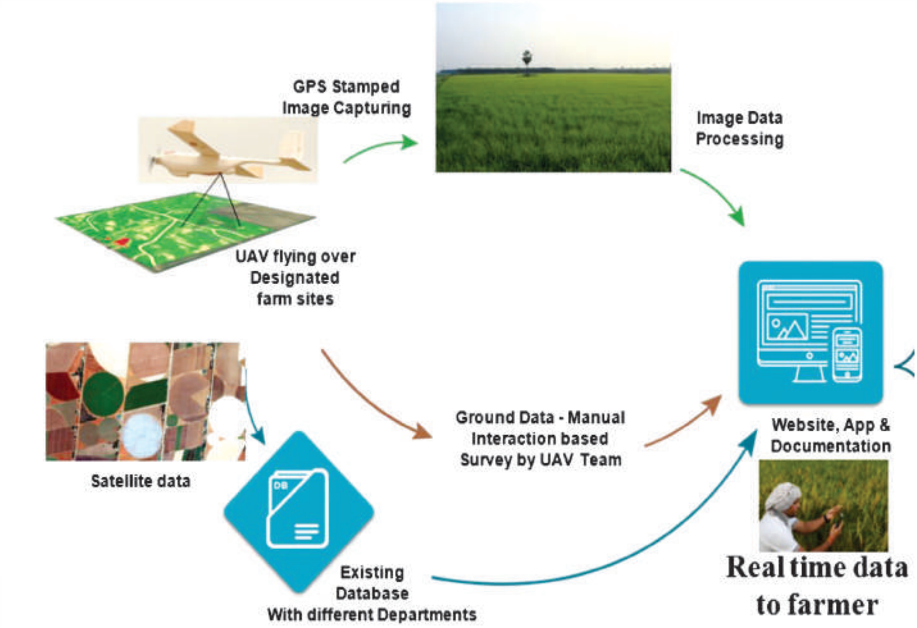


Fig. 3. Role of drones for crop health monitoring and image data processing

Drones can be used to create time-series animations that depict accurate agricultural progress, revealing inefficiencies in production and resulting in superior crops. Role of drones for crop health monitoring and image data processing is shown in Fig. 3. Drone can be used for collection of data for crop monitoring, yield prediction etc. followed by data interpretation about crop damage, yield and coverage and to facilitate effective crop management techniques to increase income and improve crop quality. The complete procedure is facilitated with GCS and GPS imagery.

3.1.2. Remote sensing and field mapping

Drones that can fly at low altitudes be utilized in crop phenotyping and field mapping using various remote sensing approaches. Studies have established that aerial remote sensing using drone can acquire plant canopy temperature and NDVI of breeding plots effectively. Moreover, drones are becoming increasingly useful in agricultural phenotyping for high yield and real-time phenotyping of large number of test plots. Aerial-based remote sensing platforms like drones are fitted with multi-spectral cameras, digital cameras, infrared thermal imagers, hyper-spectral sensors and light detection and ranging (LIDAR) sensors. Drone equipped with remote sensing equipment allows growers to gather, visualize, and analyse crop and soil health conditions at various stages of crop production in a simple and cost-effective manner.

3.1.3. Weed management

Weed mapping is one of the most prominent uses of drones in precision agriculture. Weeds can cause complications during harvesting, in addition to causing problems with crop growth (Subeesh et al., 2022). To solve these concerns, drones can be used for site-specific weed management (SSWM). Drones have been used in agriculture to produce high-resolution photographs that can distinguish individual crops and weeds on a miniature scale. They have already tried to spray herbicides spatially based on weed density assessed by drone-collected hyper-spectral images. Because, weed plants usually grow in a few regions of the field, the field is divided into management zones, each of which receives its own treatment.

3.1.4. Pest management

Crop health is a critical element that must be checked, as infestation in crops can result in large financial losses owing to lower yields and lower quality. Crops should be closely monitored to observe diseases early and prevent them from spreading. Traditionally, this duty has been carried out by human experts on the ground. This, however, can be very intensive, as inspecting a whole crop can take months, preventing the benefits of "continuous" monitoring. Pesticide use on specific dates is another typical disease control approach. This procedure is expensive, and pesticide residues in the crops increase the danger of groundwater contamination. Disease detection is possible because infections cause changes in the crops' bio-physical and bio-chemical features. Crop imaging data can be used by drone-based data processing tools to assess variation in biomass and the health of plants. As a result, infections can be recognized early, allowing farmers to respond to minimize losses.

Drones have been employed globally to fight against pest and disease attacks. Timely detection of pests, insects, locusts and armyworms infestation by drones equipped with multi-spectral imagery system can help in timely spraying of agricultural chemicals and minimising the crop loss. During the recent past, drones were employed to spray pesticides to control locust swarms in solitary and gregarious stages.

Spraying with drones can help to reduce operator exposure while improving the capacity to distribute chemicals in a timely and spatially manner

(Fig. 4). Drones follow the curve of the ground while maintaining a constant height. They may spray the appropriate amount of spray chemical based on the crop site, changing both its height and the amount to be sprayed.Therefore,the use of drones to battle pests, insects, locusts and armyworms is a quick, safe, and a practical solution.

Courtesy: ICAR-CPRI, RS, Jalandhar

Fig. 4. Use of drone for chemical spraying

3.1.5. Irrigation management

Crop irrigation uses 70% of all water on the planet, stressing the importance of precision irrigation. Farmers can save time and money by identifying areas that need to be irrigated extensively. Precision agriculture techniques, on the other hand, can boost crop productivity and quality. Precision agriculture divides the land into many irrigation zones to manage the resources in a better way. Drone technology can be used to regulate irrigation water in precision agriculture. It is feasible to identify sections of a crop with water and nutrient stress using drones equipped with the relevant sensors that require extra fertigation. Simultaneously, the aforementioned technologies allow for the construction of a particular map that displays real-time soil moisture content, allowing for more efficient irrigation planning. Moreover, drone survey helps to improve water use efficiency and detect potential leaks in irrigation by providing irrigation monitoring. Drones with hyper-spectral, thermal, or multi-spectral sensors, recognize areas that are too dry or need irrigation by the farmer (Fig. 5).

3.2. Horticulture

Drones can offer various solutions in many areas of horticulture like crop characterization, retrieving crop growth dynamics, yield estimation and many others (Fig.6). A few important applications of drones in horticulture sector are mentioned below

Fig. 5. Drone with multispectral camera for irrigation scheduling

- Crop-based leaf area indexing for determination of plant health (biotic and abiotic stresses), tree density etc.
- Imaging of horticultural crops in challenging situations like changing weather conditions, terrain, effect of sunlight, fog, etc.
- Plant yield monitoring, scouting and bird scaring.
- Ascertaining the land surface temperature, spatial variability in crop yields, water inventories of ground water, retrieving type of irrigation, etc.

Fig. 6. Use of drone for yield estimation

3.3. Livestock Management and Animal Husbandry

Drones have been in great demand in livestock management for sanitization of farm areas as well as inside of the animal sheds by spraying the sanitizers, conducting behaviour studies/phonemics and onsite delivery of semen/vaccines/medicaments/fertile eggs. Drones can also be employed for reaching far-flung areas for delivering vital inputs as well data collection and recording of livestock and poultry management practices. Additionally, it can be utilized for animal/poultry population enumerations particularly for the nomadic/pastoralist populations, tracking the home tract as well as migration of livestock population and mapping feed and fodder grasses areas. Additionally, drones have a lot of potential for counting animal/poultry populations, especially for nomadic/pastoralist populations and tracking the cattle population's travel as well as the home tract.

3.4. Fisheries

The governments of a number of countries, including the Republic of Palau, Belize, Jamaica, and the Republic of Costa Rica, are currently using drones to detect illegal fishing and aid in the prosecution of fisheries criminals. Drones have also been employed to feed the fish in water valleys, where the movement of humans is difficult.

3.5. Forestry

In the field of forestry, drones can be used to construct an integrated information system for forest conservation. Drone images are combined together to create massive, high-resolution ortho-maps. These ortho-maps can subsequently be utilised to analyse, plan, and manage data in GIS system. Drone technology is being utilised to help with forest management and operations planning, as well as to keep an eye on unlawful behaviour and encroachment. It also assists in the collection of forest metrics such as carbon sequestration, tree canopy analysis, conservation features, native species tracking, bio-diversity monitoring, and ecological landscape aspects, among others.

4. Status of Drone Uses in Indian Agriculture

In India, number of drone-based agricultural projects are in operation (Anonymous, 2021g). The Indian government initially approved the use of drones for agricultural research for the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), Hyderabad. The government hopes that by taking this step, emerging researchers and entrepreneurs would be inspired to look at low-cost drone solutions for India's 6.6 million farming community. A Bengaluru-based drone start-up collaborated with the Indian unit of Swiss agri-business major Syngenta to utilise drones to analyse the cultivable regions for corn in India as a part of an effort to adopt precision agriculture. Last year, agricultural drones developed by Kakkanad-based start-ups sprayed micro-nutrients over the paddy fields of Alathur in Kochi district of Kerala. Swarms of locusts have infested numerous parts of India particularly Rajasthan state in 2020. Drones have been used in Rajasthan state for efficient spraying of organo-phosphate insecticides in small and concentrated amount to control locust attack. They can spray insecticides across one hectare area in less than 15 min.

Some state agriculture universities have already begun use of unmanned aerial vehicles (UAVs) for agricultural purposes. In Andhra Pradesh, Acharya NG Ranga Agriculture University (ANGRAU) is intending to deploy drones in the agriculture sector to spray pesticides. Recently, the university purchased five different drones under the APSARA (Centre for AP Sensors and Smart Applications Research in Agriculture) programare under testing (Anonymous, 2021h). Negotiations are currently underway with both the Central and State governments in order to conduct field testing, and if successful, the technology will be used on a broad scale for conventional farming. Ministry of Civil Aviation (MoCA) and Directorate General of Civil Aviation (DGCA) have granted conditional exemption from Unmanned Aircraft System (UAS) Rules, 2021 to 10 organizations. These exemptions are valid for a period of one year from the date of approval or until further orders, whichever is earlier, and shall be subject to the terms and conditions of the SOP issued by DGCA (Anonymous, 2021i). Furthermore, Tractors and Farm Equipment Limited, Chennai, is experimenting with drone-based aerial spraying to check crop health and prevent crop disease from spreading. Agricultural trials using drones and precision spraying on rice and hot pepper crops are being carried out by M/s Mahindra & Mahindra, Mumbai, in the states of Telangana and Andhra Pradesh, respectively. Bayer Crop Science based in Mumbai is doing agricultural research on agricultural spraying using drones.

The use of agricultural drone technology is unquestionably the future of the Indian agrarian sector. It has the potential to revolutionise traditional farming processes in number of ways. Even though this technology is more difficult to become familiar with, it will produce results in a short period of time after it has been learned. Agriculturalists must be familiar with the entire process. The determination of goals, the creation of equilibrium in the drone and software deployed, and the familiarity with the concepts of employing such technology will be difficult tasks to do. For the collection of valid data, the farmers will unavoidably require extensive training or collaborations with third-party professionals in the drone business. Drones have altered the direction of data collection in practically every sector, and they will only continue to grow in importance and use in the coming years.

5. Manufacturing/Import of Drones in India

There are many companies working in the field of drone manufacturing in India. In India, 16 manufactures have registered their 22 Remotely Piloted Aircraft (RPA) models on the digital sky platform of DGCA (Anonymous, 2021j). The "Unmanned Aircraft System (UAS) Rules, 2021" were introduced by the Ministry of Civil Aviation in August 2021. According to the regulations, UAS or any part or component thereof may only be manufactured in India by an authorized UAS manufacturer from the DGCA's digital sky platform. Each unmanned aircraft system manufactured or imported by an authorized manufacturer or importer must comply with the certificate of manufacture and airworthiness. Type certificate shall not be required for manufacturing/importing a UAS or for operating a model remotely piloted aircraft system (RPAS) or a nano UAS. The Directorate General of Foreign Trade may provide an import license for UAS.

Currently, 90% of drones in use in India are imported. There is no component ecosystem in the country and most of the major components are imported, especially from China. The Union Cabinet on 15 September, 2021 cleared a production-linked incentive (PLI) scheme to make India a drone hub by 2030 and notified by Ministry of Civil Aviation in the Gazette of India vide S.O. 4044 (E) dated 30th September 2021. The PLI scheme will provide up to 20% incentive to manufacturer of drones and drone components. It comes close on the heels of the recent liberalisation of rules, which has made owning and operating drones easier. The government has allocated Rs 120 crore for the scheme and it will be spread over three years. The government expects the drone manufacturing sector to attract investment of over Rs 5,000 crore.

6. Policy Framework

6.1. Rules and Regulations for Use of Drones in India

The International Civil Aviation Organization (ICAO) and DGCA have taken the lead in developing rules and regulations for drone operations at the global level and in India.The drone operations are being permitted by MoCA and DGCA through the conditional exemption route. MoCA has published 'Drone Rules 2021' vide GSR No. 589(E) dated 25th August 2021 to regulate the use and operation of drones in India, which shall be complied for all drone applications (Anonymous, 2021a). In India, the use of drones in agriculture (especially agriculture spraying) needs special permission. The details of general guidelines for use of drone in India are given below:

- The procedure for use of drones is reduced to a user-friendly single-window system operated by digital sky platform.
- Safety and security features like 'No permission - no take-off' (NPNT), real-time tracking beacon, geo-fencing, capability *etc.* to be notified in the Official Gazette in future.
- Densely populated areas or large crowds must be avoided.
- Fly during daylight hours and under good weather conditions
- Drone user must be trained drone pilot and should have attained the age of 18 years and not more than 65 years.
- All drones (except nano drones)must have valid third party insurance policy to cover the liability that may arise on account of mishap.
- Basic drone laws must be followed while flying a drone over 250 grams weight.
- **Certification of UAS**: No person shall operate a UAS in India unless it is certified by type certificate or exempted under drones rules.
- **Registration:** All drones (except exempted from the requirement of a unique identification number under these rules) must be registered and issued a Unique Identification Number (UIN). This UIN shall be linked to the unique serial number provided by the manufacturer.

- **Operation of unmanned aircraft:** The drone can be flown on the basis of interactive airspace maps which include green, yellow and red zone. The airspace map is available on DGCA's digital sky platform at https://digitalsky.dgca.gov.in/home. Before flying a UAS, a remote pilot should complete mandatory pre-flight verification of zonal restrictions. No one can operate a drone in the yellow or red zone without prior permission and follow Carriage of Dangerous Goods Rule, 2003. The Green zone includes the airspace up to a vertical distance of 120 m that has not been designated as a red zone or yellow zone above the land areas or territorial waters of India and the airspace up to a vertical distance of 60 m above the area located between a lateral distance of 8 km and 12 km from the perimeter of an operational airport.

- **Remote Pilot License (RPL):** Only remote pilot license (RPL) holding person enlisted in digital sky platform can operate a drone. In RPL, category, sub-category and classification of the unmanned aircraft system or a combination of these should be mentioned. Whereas, no remote pilot license shall be required for operating a nano and micro UAS for non-commercial purposes.

- **Research, development and testing:** Any research and development entity/educational institution under the administrative control or recognized by the central government or state government or Union Territory Administration/Start up recognized by the Department for Promotion of Industry and Internal Trade/authorized testing entity/ unmanned aircraft system manufacturer having a Goods and Service Tax Identification Number shall not require a type certificate, UIN, prior permission and RPL for operating unmanned aircraft systems for research, development and testing purposes.

- **Fee for different services:** Fee for issuance of type certificate; issuance, transfer/deregistration of unique identification number and issuance or renewal of remote pilot license has been reduced to Rs. 100, while authorization or renewal of authorization of remote pilot training organization has been reduced to Rs. 1000.

- **Penalty:** The maximum penalty for violations of drone rules is reduced to Rs. 1.0 lakh.

6.2. Guidelines for drone application in agriculture under Sub-Mission on Agricultural Mechanization (SMAM)

The additional guidelines for providing agricultural services through drone technology under Sub-Mission on Agricultural Mechanization (SMAM) has been released by Mechanization & Technology Division of Department of Agriculture & Farmers Welfare, Ministry of Agriculture & Farmers Welfare, Government of India on 17th January, 2022 (https://farmech.dac.gov.in/revised/2022/OM_for_Drone_Guidelines_underSMAM.pdf).

i. Financial assistance will be provided for establishment/upgrading the Custom Hiring Centres (CHCs)/Hi-tech Hub for providing agricultural services through drone application

ii. Necessary Compliances to be ensured by the demonstrating institutions and providers of agricultural services through drone application.

iii. Guidelines of Ministry of Civil Aviation, CIB & RC shall be applicable to all drone users/operators/CHC service providers using drone for agricultural purpose.

6.3. Standard operating procedures (SOPs) for use of drones

The Government of India has brought Standard Operating Procedures (SOPs) for use of drones in pesticide and nutrient applications that provide concise instructions for effective and safe operations of drones. The detail guidelines are available at https://farmech.gov.in/New_Folder/SOPforDrone.pdf

(a) Applying pesticides for crop protection

The SOPs for use of drone for pesticide application for crop protection in agricultural, forestry, non-cropped areas, etc cover important aspects like statutory provisions, flying permission, area distance restrictions, weight classification, overcrowded area restriction, drone registration, safety insurance and piloting certification, operation plan, air flight zones, weather conditions, SOPs for pre, post and during operation, emergency handling plan etc. The critical parameters have been also considered for drone based pesticides application such as drone related, pesticides/insecticides, environment limitations, pilot training, drift management, critical operational parameters, safety precaution during operation, registration requirements of pesticides for drone application, spray monitoring form and data submission, etc.

(b) Spraying soil and crop nutrients

The use of drones in assessment and application of soil nutrients has potential in precision agriculture enabling saving of the resources, minimizing environmental risk, labour and cost saving and economic productivity. The detailed procedure for use and application of crop nutrients, the caution for storage of nutrients (liquid/granules/powder), etc., are given in the SOPs. The procedure for drone servicing/operation, different standard and perquisites for using drone to reduce the drift and air pollution are also given in the SOPs.

7. Training and Testing of Drones

7.1. Standards on Drones

(a) ISO Standards

The ISO (International Organization for Standardization) has developed ISO Committee Draft (CD) and Preliminary Work Item (PWI) ISO 23117 on "Agricultural and forestry machinery-unmanned aerial spraying systems" for uniformly applying liquid and minimizing environmental damage (Anonymous, 2020 b & c). The brief details of developed ISO standards for environmental requirements and field testing of unmanned aerial spraying systems are given below.

ISO 23117/CD (Part 1): This part of ISO 23117 specifies the requirements and the means for verification of the design and performance of UAS fitted with spray systems for agriculture and forestry with regard to minimising the potential risk of environmental contamination during use.

ISO 23117/PWI (Part 2): This part of ISO 23117 is applicable for unmanned aerial spraying systems that is attached to the unmanned agricultural aircraft systems (UAAS) with intention of applying liquid evenly over a horizontal surface. It specifies field measurements of spray deposition to determine the quantity and distribution of spray in a plane surface area in the transverse direction, treated by UASS with downward directed application.

ISO 23117/PWI (Part 3): This part of ISO 23117 specifies field measurement method of spray drift for UAV chemical application.

(b) Draft Indian Standard

One draft standard for UAV has also been developed by BIS, which includes general requirements, specifications of UAV, requirements for agro-chemical compatibility, operational requirements like before application, during the application, post-application, weather considerations, safety requirements for operation of UAV, pilot training and marking information on UAV(Anonymous, 2021k).

7.2. Training Organizations for Flying Drones

In India, only an authorised UAV operator is permitted to operate a UAV, except a nano class. No unmanned aircraft flight shall take place until authorization has been acquired through an online platform in accordance with the Director General's instructions. Wherever possible, the UAV must be operated by an authorised person with the assistance of a qualified remote pilot. Eight training organizations are listed on the DGCA's digital sky platform for training on use of drones (Anonymous, 2021l).

8. Challenges with Use of Drones in Agriculture

The challenges associated with the use of drones in agriculture are as follows.

- **Battery life:** UAVs available today can only fly for a limited time (15-30 min) and for the uninterrupted operation of the drone, frequent charging is required. Unmanned aerial vehicles can be used to their full potential and economic impact only when they are capable to stay in flight for a longer duration.
- **Cost:**The development of UAVs is quite expensive due to the requirement of training and integration of various components, technical and deployment expertise, *etc.* This makes drones unaffordable to small and marginal farmers for agricultural purposes.
- **Licensing and legislations:** Before UAV deployment, proper licensing and legislation are necessary. The drone operators must be alert about the flight restrictions, restricted airspaces and presence of other small planes in the vicinity.
- **Balancing and stability:** UAV applications such as spraying require a change in payload continuously and this affects the balancing of the drone.

- **Weather conditions:** Weather conditions such as strong winds, precipitation, temperature, *etc.* can hinder the operation of drones. High temperature reduces the performance of the drones because of the low air density at altitude.
- **Failure-free operation:** The development of failure-free system is critical as there are possibilities of component failures due to poor quality of motors, rotors and controllers. Loss of all communications between the UAV and the control station in case of failures results in havoc on vital information collected.
- **Safety and security:** Accidents, air collisions, safety and security risks are always associated with drone usage. Also, fault offset delivery in case of critical operations like the application of hazardous pesticides may cause a threat to human life.
- **Privacy:** As UAVs are capable of collecting huge amounts of data from any location, the public may view this as an intrusion to their privacy.
- **Skill in drone operation**: Trained and skilled drone operators are required.

9. Way Forward

During the last decade, UAVs have played an increasingly important role around the world, particularly as an emerging technology for precision agriculture. In developed countries, agricultural drones have given farmers the ability to choose the right inputs for their crops at the right time by anticipating crop and environmental conditions. Drones' utility for various agricultural tasks in India should be understood in the same way that it is in other developed countries.

9.1. Research and Development

There are several opportunities in agriculture in which drones can assist the farmers in addressing challenges like soil and field planning, seeding and planting, effective tillers counting, soil moisture stress-based irrigation, crop nutrient-based fertilization, disease detection and classification, crop health monitoring, crop scouting, and assessment of crop damage in the field. Some of the major researchable areas for use of drones in agriculture are:

- Scouting crops like sugarcane, coconut, etc., where manual surveillance is very difficult
- Crop water stress monitoring for irrigation scheduling

- Spraying in difficult areas such as hilly regions, tall and dense field crops, etc.
- Image acquisition of the field for weed localization and management using deep learning and vision-based systems
- Survey of farmland for quick estimation of yield loss due to crop damage. This will assist the government in providing appropriate compensation and insurance coverage.
- Estimation of biomass to provide advisory to farmers to prevent stubble burning.
- Detecting illegal fishing to assist in the prosecution of criminals in fisheries industry, and map in-channel habitats.
- Regulate and guide animals during grazing
- Monitoring the behaviour of sick animals.

9.2. Manufacturing, Standardization and Testing

Standardization of protocols is a pre-requisite in the design, manufacturing and safe use of drones. Drones are being manufactured on a small scale in India and most of the parts of drones are being imported from other countries. Furthermore, there is no global harmony on the operation of drones, due to which the rules and regulations governing them are constantly changing depending on the region. Following are some recommendations for manufacturing, standardization and testing of drones:

- Promote local production and streamline the manufacturing process
- Development of Indian standards for testing of drones for their effective use for agricultural purposes
- Rules and regulations relating to manufacture and import of drones should be simplified so as to facilitate export, import, manufacturing, trade, leasing, transfers, etc.
- Farm Machinery Testing Centres need to be strengthened for testing of agricultural drones
- Drone operators in the agriculture industry should benefit from uniform legalization by determining the best compliance model.

9.3. Policy Paradigm Shift

Personal privacy, public safety, airspace, and civil rights are the four broad categories of policy challenges associated with use of drones. The use of drones in agriculture and allied sector will be successful only when laws, taxation and civil liberties are all integrated in a symbiotic manner.

- Educated rural youths should be trained on operation and maintenance of drones for their use in agriculture and allied sectors. Such training programmes may be organized through Krishi Vigyan Kendras at the district level.
- The chapter on drones should be included in the curriculum of graduate program of agriculture and allied sectors.
- Skill development programmes should include operation of drones in agriculture.
- Drones uses for agricultural purposes should be included under subsidy program of the government.
- Promote the services of drones on custom hiring basis or cooperative use through Custom Hiring Centres.
- Proper facility for repair and maintenance of drones at block/district level.

10. Conclusions

In recent past, application of mechatronics, sensors, IoT *etc.* in agriculture has become inevitable. In order to map variability across the agricultural fields and apply agricultural inputs effectively, drones can be one of viable options. Drones have numerous applications in agriculture and allied sectors such as livestock management, horticultural, fisheries and forestry. It can be used at every stages of the plant growth from seed germination to harvesting. Drone can enable a farmer to monitor his field from the sky to identify a specific stand of plants that are not growing properly. It provides a better overview and allows the farmer to take better decisions about various agricultural tasks. The required precise input application rate can be attained with the deployment of an autonomous drone.The draft standards for testing of drones have been prepared by ISO for uniform application of agriculture inputs and minimizing environmental damage. DGCA is continuously making efforts to fly drones efficiently for performing different agricultural tasks in India and permission has already been granted to some government and private organisations for use of drones for different tasks. In India, some manufactures have registered their drone models on the digital sky platform of DGCA under Startup India initiation. With the full integration of drones, the agriculture industry will receive a significant boost due to the ongoing evolution of all industries around the world.

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ICAR

For more information please contact:

ICAR-Central Institute of Agricultural Engineering
Nabibagh, Berasia Road, Bhopal 462 038
Telephone No : +91-755-2737191, 2521001
Email : director.ciae@icar.gov.in
Website: ciae.icar.gov.in