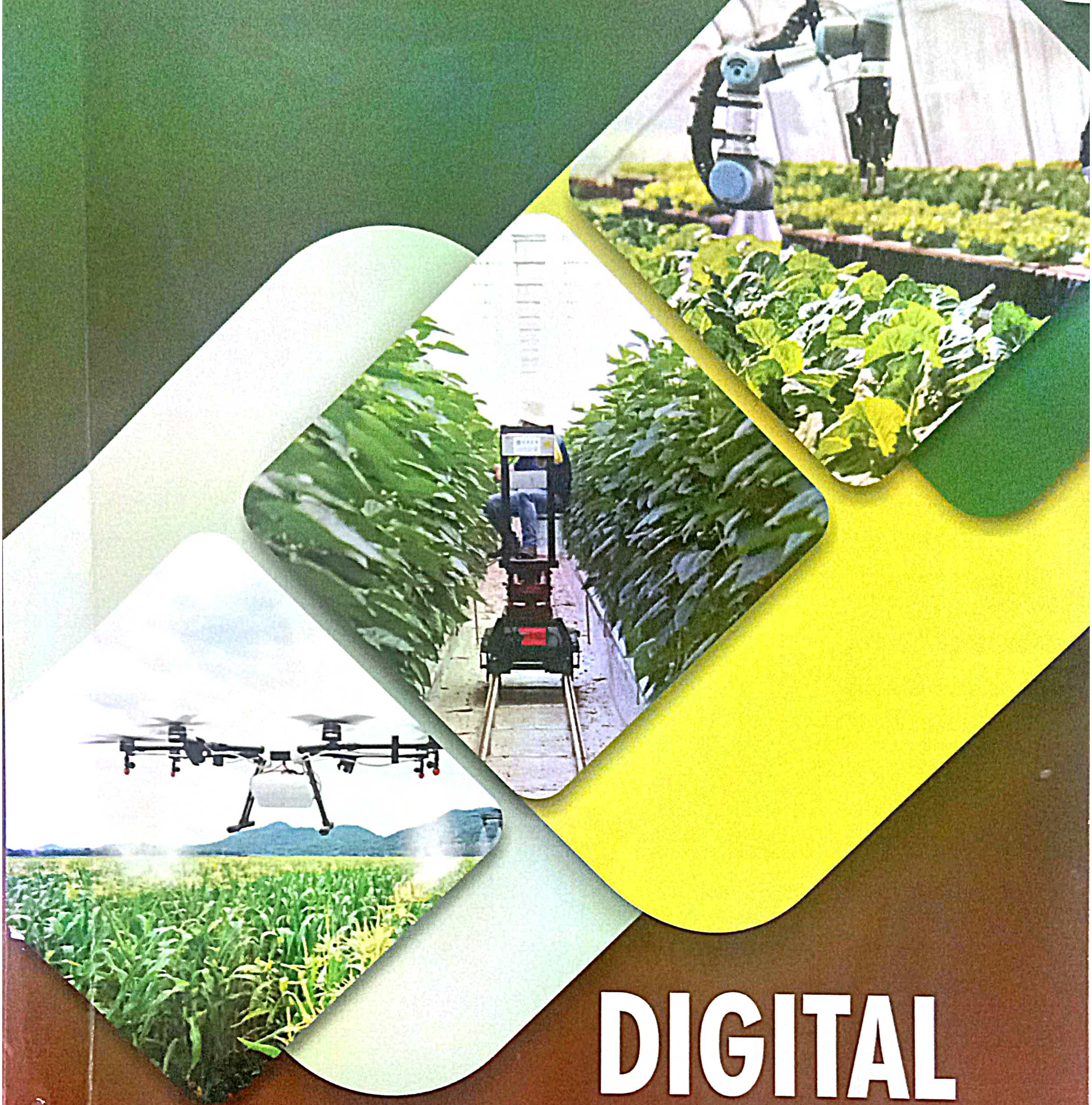

DIGITAL TECHNOLOGIES IN AGRICULTURE

Surya Rathore • Vijayalakshmi B.
V.V. Sumanth Kumar

BIOTECH

Chapter 16

Drones in Agriculture

Kancheti Mrunalini[1] *and Chandan Kumar Deb*[2]

[1]*Scientist (Agronomy),*
Indian Institute of Pulse Research, Kanpur – 208 024 (U.P.)
[2]*Scientist (Computer Science and Applications),*
ICAR–Indian Agricultural Statistics Reserach Institute, New Delhi

Introduction

The Unmanned Aerial Vehicle (UAV) or drone is robotic vehicle that can operate remotely for various purposes. Initially was developed mainly for the military use but gradually spread over across the different aspects of life. According to www. dronedeploy.com, in 7 continents and 160 countries over 25 million acres area is using the drone technology for one or the other reasons. Agriculture is not an exception. The agricultural community has positively accepted the drone technology in the era of labour shortage as well as the tremendous importance of precision agriculture. Only a few years ago, the drone technology was seeming to be very unreachable facility for the poor farming community but gradually situation has changed and now it is easily achievable technology with moderate financial input. It is estimated through studies that between 2015 to 2025, drone technology would create more than 70 billion Euros (Veroustraete 2015) in global economy.

Types of Drones

There are several bases for categorizing the drones but we have described the types of drones according to Watts *et al.* (2012). In this study, drones have been classified into seven categories *i.e.* Micro Air Vehicles (MAV), Vertical take-off and landing (VTOL), Low Altitude- Short Endurance (LASE), Low Altitude- Short

Endurance Close, Low Altitude low endurance, Medium Altitude and High Altitude Long Endurance (HALE).

a) **Micro Air Vehicles (MAV):** Because of their scale, they are very often called as Nano-Air aircraft, which usually allows military variants of these air craft to be carried in backpacks of soldiers and enables unobtrusive monitoring ability in cramped spaces. Such aircrafts usually operate at lower altitudes (< 330 m), with battery life constraints contributing to shorter flight times near 5–30 minutes. But, their development on commercial scale is still in infant stage.

b) **Vertical take-off and landing (VTOL):** These aircrafts do not entail a take-off and landing flight, and therefore are usually used in instances where terrain constraints demand this advanced ability. They fly at different heights, based on the mission profile but mostly at lower altitudes and high battery power demands for flight hovering restricts flight timeframes. VTOLs have major advantage of remote area network portability, without any need for pathway complexes.

c) **Low Altitude – Short Endurance (LASE):** Mini unmanned aerial systems often eliminate necessity of aircraft runways designed for fast zone deployment and conveyance. Typically it has a weight of 2 to 5 kg and less than three metre length of wingspans to launch the aircraft from catapult configuration. Weight-capacity sacrifices tend to reduce the range of strength and connectivity to 1–2 hours, but within a few kilometres of ground stations.

d) **LASE Close:** This group defines tiny unmanned aircraft which requires runways of greater weight and size with enhanced capabilities. They have relatively high flight time which can operate to an altitude of 1500 m and these constraints were addressed through explicitly modified "record-breaker" aircraft substantially.

e) **Low Altitude - Long Endurance (LALE):** United States Federal Aviation Administration gave a designation to this type of drones based on their capability to carry input payloads to an extreme upper end with a high weight (kg) at relatively higher altitude for prolonged period of time

f) **Medium Altitude - Long Endurance (MALE):** Usually these aircrafts are much bigger than low-altitude UAV groups, flying at altitudes up to 9,000 m through hundreds of kilometres of flights from their base stations which last several hours. These have magnificent role in taking strategic decisions for military defence services and inflated usage are seen in some areas of civil applications.

g) **High Altitude - Long Endurance (HALE):** These are the biggest and most complicated aircrafts, featuring the aircraft bigger than most manned aircrafts in commercial aviation. These drones have flight capability and can operate at 20,000 m and more to the extent of several thousand kilometres and flight time of more than 30 hours in space. HALE aircrafts have set their standard records for its flight altitude and duration and made them effective on cost basis at larger level. These drones can be used to assess the impact of climate change at spatial and temporal variation on regional/global scale.

Role of Drones in Farming

An ever increasing global labour force does not match plant growth proportionately; thus there is widespread concern about food production sustainability. In such an effort to address this task, growers all over the world have to acclimate for the advanced and computerised solutions to maintain the world's human population farming needs, which are in constant state of flux. At present, drones are used in agricultural fields to determine crop biomass, growth and production pattern in determining precision application of input resources, aid in harvesting the produce and optimization of logistics.

a) ***Field and soil assessment:*** Before the start of the season and after crop planting, data collected by drones regarding soil analysis is instrumental in planning the crop species to be sown, pattern of planting and determining the amount and time of irrigation and nutrient application. These management decisions taken at farm level can enhance overall productivity of the farm. This kind of approach in agriculture fetches scope to adapt site specific management practices *i.e.* precision farming.

b) ***Plant establishment:*** Due to labour scarcity, now-a-days sowing of crops has become an expensive and burdensome endeavour which traditionally requires a great deal of human labour. Drones have simplified planting of crops on large scale with utmost exactness and accuracy in short time of span. This method of planting using drones has brought down the cost of planting up to 85 per cent and reduces the strenuous work through on-the-ground-planting.

c) ***Precision crop spraying:*** Site specific crop spraying can be done using drones equipped with sensors where it scans the cropped area on real time basis and ensures precise quantity of liquid (like pesticides and nutrients) is sprayed on that target place. Indeed, experts estimated that drones can complete aerial spraying up to five times faster than those of conventional spraying. It enhances accuracy in spraying, saves time and input costs of farmers. It indirectly reduces pesticide pollution in groundwater.

d) ***Crop monitoring:*** Crop production challenges *i.e.* unpredictable weather extremes create biggest obstacle in monitoring crop at field level. The greatest benefits of using unmanned drones are its simplicity and efficiency of massive-scale surveillance of crops and agricultural land. Well into the earlier days, satellite imagery had been used to get a view of the farm on a large scale, whilst helping to find potential problems in crop monitoring. At present, animations of time series can provide precise development of a crop and reveal production inefficiencies, enabling better crop management.

e) ***Irrigation management:*** Agricultural drones equipped with thermal sensing cameras have that capability to offer phenomenal perspective into particular troubled areas of the farm for irrigation application. Several insights were monitored through these thermal digital cameras from low moisture stressed condition to water logged condition, thus allowing farmers to take irrigation management decisions based on water status in the soil. It drives to precision application of water in fields.

f) ***Crop health assessment:*** Crop health monitoring is very essential to detect crop, bacterial and fungal diseases. It is done by drones using green visible light along with near –infrared light to scan the crop for assessing disease incidence in spatial and temporal variation based on crop reflectance. Early detection of disease is possible to make in before interventions to safeguard the crop.

g) ***Livestock monitoring:*** Drones have several potential applications in animal husbandry. Each individual animal is tagged with sensors or radio frequency identification (FRIDs) tags to monitor feeding activity and their movements using drones. By using this, tracking of livestock can be done in much higher frequency, with in less time and investment in personnel. Remote sensing-fencing, virtual boundaries or remote sensing-zoning essentially means in creating a virtual obstacle or security fence across spatial area of interest especially in free range practice of livestock grazing.

Work Done in Agriculture

Automated crop phenotyping is one of the prominent areas of the drone technology. Many of the previous studies have been carried out on the phenotyping of crops using drones (Grenzdörffer, 2019; Holman *et al.* 2016; Yang *et al.,* 2017; Watanabe *et al.,* 2017; Sugiura, *et al.,* 2017). The image processing and drone technology is a parallel technology that works simultaneously in many of the studies. The deep learning technology along with the aerial image taken by drone too has been used in number of instances. The weed identification has been done using the drone technology (Barrero *et. al* 2015; Bah, *et al.,* 2018; Lopez, *et al.* 2016; David *et al.,* 2016; Pena *et al.,* 2015; Bah, *et al.,* 2018; Stroppiana, *et al.,* 2018; Milioto, *et al.,* 2017). Identification and analysis of the water stress (Park, *et al.,* 2017) and structural stress (Gago, *et al.,* 2015; Moranduzzo, *et al.,* 2014) of the plant, abiotic stress, pest and disease stress (Singh, *et al.,* 2016; Barbedo, *et al.,* 2019; Xiongkui, *et al.,* 2017; Liu, *et al.,* 2014) may be done using drone technology. In a small area, the drone can be used for plant ecology and by using aerial images taken from drone, the plant disease analysis (Cruzan, *et al.*, 2016; Yamamoto, *et al.*, 2017; Martinelli, *et al.*, 2015) can be done.

Irrigation, crop monitoring and spot spraying are some of the important aspects of the drone technology that have significance in agriculture. Livestock farming include animal health, livestock monitoring, geo-fencing *etc.* The drone technology can also help in combating with the natural calamities that can have the potential to crop damage (Erdeli, *et al.*, 2017). Drones can also assess and prevent natural calamities, automatic planting and the change analysis over time.

Adoption Statistics in Agriculture

In agriculture, drones will contribute around 7 billion USD economy globally. This is a promising anticipation for the global agriculture. The adoption rate varies from country to country. About 84 per cent of the US farmers use drones daily or weekly, approximately 73 per cent uses for crop monitoring and 43 per cent are using drones for soil and field analysis. This adoption rate is very less in developing countries like India. By the decision taken by Amazon to begin the trials on drone based delivery has ignited the industry. The emergence of several aircraft-based companies have since been experienced and also the development was here to remain as several industries exploit the potential of unmanned aircraft to gather vital insights.

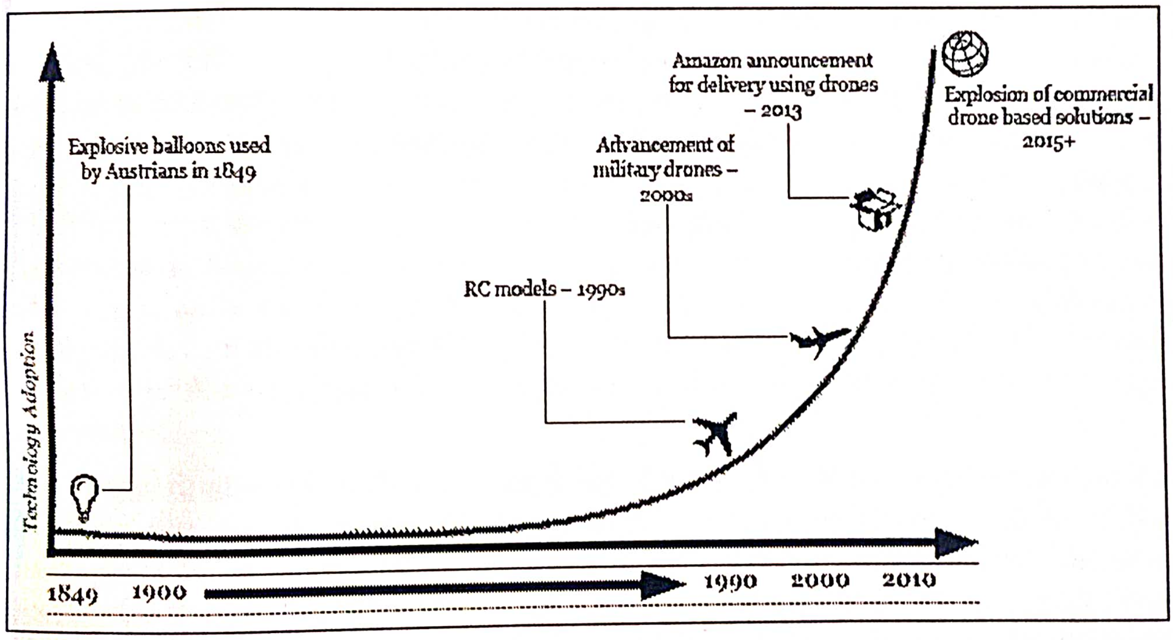

Figure 16.1. Data on Wings – A Close Look at Drones in India. (*Source*: Aiman Faraz).

Information provided by the Stockholm International Peace Research Institute (SIPRI) clearly shows that India leads the pack in drone-importing nations with 22.5 percent of the world's drones' imports. CAGR is expecting Indian drone market to grow by 18 per cent during the years 2017-23. In 2018 regarding market share of drones in India, it is primarily dominated by long wave range of Medium Altitude and Long Endurance (MALE) segment whereas the Mini-UAV segment has reported healthy growth in recent years.

In addition, Indian government is trying a "Make in India" strategy to boost the domestic production of such drones in the years ahead. Commercial aircrafts have many applications such as Farming and Forest ecology, Entertainment, Surveying and Surveillance and Others that will boost the entire market of unmanned aircrafts during the coming quarters attributable to the inflated demand from these industries. Further, Indian government legislation has augmented increased demand of commercial drones.

Instead of limiting and debilitating legislation, the advancing technology requires opportunities. Regulations ought not to be intrusive regulations, and authorization for drones should really be given through a single-window procedure. Several consumers such as growers, e-commerce firms, *etc.* would accept the move from 1st December 2018 to open up the use of drones in airspace. The legislations proposed by government should be loosened for further progress in the use of drones in commercial scale.

Drone Technology Legislation in Indian Scenario

For several years, the Civil Aviation Ministry worked to create a global leading ecosystem for drones in India. Considering the law and order, officials were concerned about unregulated drone flights and the threat they pose, rules were created to prevent illicit operations and securing public safety. Towards the end, the creation of international standard drone legislation was required which would include appropriate regulations for the industrial use of various drone techniques. All of this took several years to prepare these drone regulations by means of a Civil Aviation Requirement (CAR) since: (1) drone technological innovations have progressed quite quickly; (2) several countries have been tinkering with their drone legislation and thus no ICAO (The International Civil Aviation Organization) stands were drawn up; and (3) the ambient defence in India requires additional precautions.

The new politics of drones has a big digital root. India has developed an all-digital framework instead of simply digitizing a paper based mechanism for the registration and service of drones. The Digital Sky Platform is the National Unmanned Traffic Management (UTM) platform which is of its first kind that implements "no authorization, no take-off" (NPNT). Stakeholders are expected to have their drones, pilots and owners registered once. Consumers will be needed to instantly request permission to fly on a mobile app for each flight (specifically excluded for the Nano category) and an instant mechanism authorizes or refuses the request. Any drone without a digital flight permit would simply not be able to take off, flights not allowed and to guarantee public safety. The UTM works in the drone airspace as a traffic regulator and communicates closely with defence and civil air traffic controllers to ensure that drones remain on permitted flight paths.

Regulations for Drones 1.0

Such regulations must allow secure, unmanned aircraft use with effect from 2018. Regulations for drones 1.0 Day-only visible line-of-sight operations with a cruising altitude of 400 feet were allowed to be designed. Air conceptual space was spliced as Zone Red (no allow to fly), Zone Yellow (limited airspace), and Zone Green (automatic authentic permission).

There are five groups in Remote Piloted Aircraft System (RPAS) via Sky Platform on digital basis and categorized by weight according to the regulation; namely Nano, micro, small, medium and large. Every RPAS excluding Nano are registered with Unique Identification Number (UIN) and are owned by ARC, National intelligence Agencies and NTRO. Flight Information Centre (FIC) or Air Defense Clearance (ADC) number is required for flying in controlled airspace.

The regulation specifies "No Drone Zones" close to international borders, in and around airports; secretariats of capitals in all states, destinations which are strategic and other military and national services.

Drone Regulations 2.0

1. Certification of drone hardware and software for safe and controlled operation
2. Air space management by automated operations connected to an overall structure in airspace management
3. Over and above visual track-of-sight operations
4. Contribution to build global set of norms
5. Suggestions for changing the law on existing CARs and new CARs.

Enforcement Actions

The legal actions include (a) brake/cancelation of UAOP/UIN in the light of an infringement of legislative stipulations; (b) Policies under sections Aircraft Acts 1934 and Aircraft Legislation in issue, or for further legislative provisions, and lastly (c) punishments under applicable IPCs (such as 287, 336, 337, 338, or any applicable clause of the IPC).

Challenges and Opportunities in Agriculture

The existence of too restrictive or even impaired rules and regulations regulating the importation and use of UAVs may impede the creation of a highly promising industry which could attract and engage educated professionals in rural areas. It is rather challenging to analyse how these have impact on usage of drones in agriculture activities. Nonetheless, certain countries have switched to a federal ban on importing and using UAVs. The following were the major challenges:

1. Drone technology, training integration and deployment is perceived to have higher costs.

2. With respect to UAVs, there is still a grey area. Legislations are meagre, little or a low interpretation of laws in aviation that don't fit perfectly for UAVs. Therefore, legislation needs to be drafted to control the emerging UAV prospects and application areas. Nations such as the United Kingdom, the United states, Spain and Germany are paving the way in this direction by establishing guidelines for drone use and areas where they could be incorporated. Nevertheless, other countries around the world are indeed very behind.
3. Considering business perspectives, it is difficult to justify regarding profitability for drones in agriculture sector. Although there is a contend about usage of drones could have long term savings on cost and trigger claims regarding the specific operating expenses of UAVs. Compensation, can be put forward, replacement of wrecked UAVs, procurement of high-resolution image lenses as well as the associated technology solutions and other maintenance costs. This makes it difficult to market to farmers and entrepreneurs in agriculture.
4. System integration and data analytics of high performance systems of drones enable control of drones in collection of real time visuals and transmission of information and machine learning applications for useful insights to operate drones. It also showcases the technical challenges involved in adaption of drones in agriculture.
5. Many fear the use of UAVs for tracking and surveillance will result in their privacy being violated. A lack of standard operating and technical protocols for the UAVs to operate safely is a major challenge. Global positioning, tapping and intrusion may occur due to various internal security loopholes in UAV operations.
6. Aerial spraying is not permitted under the Insecticide Act. Drones and autonomous vehicles can in many ways be dangerous instruments for spraying hazardous chemicals. It can be disastrous to enable aerial spraying, using drones and autonomous, remote controlled vehicles. Pursuant to the provisions of the Insecticides Act 1968, the Central Insecticides Board (CIB) requires approval/authorisation for aerial application of pesticides. Therefore, the CIB has in the past not given permission/approval for the use of drones for spraying pesticides.
7. UAV flight time depends on the power of the batteries. In most UAVs, especially the multi-rotor type, batteries can indeed only sustain a flight time of about 10 to 30 minutes and could be poorer while flying at high wind speeds. Battery technology needs to be improved and a way to use batteries with larger capacity yet small footprint in UAVs needs to be found. Drones used for crop spraying are efficient only in areas where other technology is not accessible like in hilly areas; these are far less reliable and far costlier than a wider range of field-based spraying devices.

8. Because of the small size of the majority of drones, they cannot hold much inputs at once. Hence, their uses are limited to simple aerial imagery and visualization. Although there are large-size UAVs, but flight time is a major hindrance which is shortened even when the drone is loaded to its maximum capacity.
9. Drones are still very much in their infancy to use as data gathering devices. There is a need to establish successful acquisition of data and data multiplication techniques which are highly significant in transforming such data into relevant information.
10. There are also the manufacturing issues, and meeting farmers' demands for UAVs. This is largely anticipated as Agricultural use cases are still being investigated and tested by industry. In India, manufacturing is carried out on a limited scale, as well as the capital costs stay high.

Conclusions

Drones are considered to be robots which essentially fly. Initially these drones were used in military for defence but now the applications have spread to different areas like agriculture and animal husbandry management. Agricultural drones are blooming like any other farm equipment which seems to be an incredible innovative technology in Indian agriculture. Visual imageries captured in integrated camera are used in identification and control of weeds, soil fertility analysis, animal health monitoring, pests and disease identification and management. This technology can be widely adopted with advantages such as site specific precision information on spatial variation of different management practices which can lead to increased productivity and enhance input use efficiency at farm level. Drones are being used efficiently for spraying purpose in agricultural production systems. Although, drones are well suited for many agricultural operations but adhering challenges are limiting its adoption. First and foremost, constraint is initial investment along with its operational and maintenance costs, reduced flight time, frequent replacement of battery and legislation procedures in use of drones are some of the major barriers to be scaled up to find their better place in agriculture. This technology can be widely adopted with advantages such as site specific precision information on spatial variation of different management practices which can lead to increased productivity and enhance input use efficiency at farm level.

REFERENCES

Apvrille, L., Roudier, Y., and Tanzi, T. J. (2015, May). Autonomous drones for disasters management: Safety and security verifications. In *2015 1st URSI Atlantic Radio Science Conference (URSI AT-RASC)* (pp. 1-2). IEEE.

Bah, M. D., Dericquebourg, E., Hafiane, A., and Canals, R. (2018, July). Deep learning based classification system for identifying weeds using high-resolution UAV imagery. In *Science and Information Conference* (pp. 176-187). Springer, Cham.

Bah, M. D., Hafiane, A., and Canals, R. (2018). Deep learning with unsupervised data labeling for weed detection in line crops in UAV images. *Remote sensing*, *10*(11), 1690.

Barbedo, J. G. A. (2019). A review on the use of unmanned aerial vehicles and imaging sensors for monitoring and assessing plant stresses. *Drones*, *3*(2), 40.

Barrero, O., Rojas, D., Gonzalez, C., and Perdomo, S. (2016, August). Weed detection in rice fields using aerial images and neural networks. In *2016 XXI Symposium on Signal Processing, Images and Artificial Vision* (*STSIVA*) (pp. 1-4). IEEE.

Cruzan, M. B., Weinstein, B. G., Grasty, M. R., Kohrn, B. F., Hendrickson, E. C., Arredondo, T. M., and Thompson, P. G. (2016). Small unmanned aerial vehicles (micro UAVs, drones) in plant ecology. *Applications in Plant Sciences*, *4*(9), 1600041.

David, L. C. G., and Ballado, A. H. (2016, November). Vegetation indices and textures in object-based weed detection from UAV imagery. In *2016 6th IEEE International Conference on Control System, Computing and Engineering* (*ICCSCE*) (pp. 273-278). IEEE.

Erdelj, M., Król, M., and Natalizio, E. (2017). Wireless sensor networks and multi-UAV systems for natural disaster management. *Computer Networks*, *124*, 72-86.

Erdelj, M., Natalizio, E., Chowdhury, K. R., and Akyildiz, I. F. (2017). Help from the sky: Leveraging UAVs for disaster management. *IEEE Pervasive Computing*, *16*(1), 24-32.

Gago, J., Douthe, C., Coopman, R., Gallego, P., Ribas-Carbo, M., Flexas, J. and Medrano, H. (2015). UAVs challenge to assess water stress for sustainable agriculture. *Agricultural Water Management*, *153*, 9-19.

Grenzdörffer, G. J. (2019). Automatic generation of geometric parameters of individual cauliflower plants for rapid phenotyping using drone images. *International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences.*

Holman, F. H., Riche, A. B., Michalski, A., Castle, M., Wooster, M. J., and Hawkesford, M. J. (2016). High throughput field phenotyping of wheat plant height and growth rate in field plot trials using UAV based remote sensing. *Remote Sensing*, *8* (12), 1031.

Liu, P., Chen, A. Y., Huang, Y. N., Han, J. Y., Lai, J. S., Kang, S. C., and Tsai, M. H. (2014). A review of rotorcraft unmanned aerial vehicle (UAV) developments and applications in civil engineering. *Smart Struct. Syst*, *13*(6), 1065-1094.

Lopez-G, F., Torres-Sánchez, J., De Castro, A. I., Serrano-Pérez, A., Mesas-Carrascosa, F. J., and Peña, J. M. (2016). Object-based early monitoring of a grass weed in a grass crop using high resolution UAV imagery. *Agronomy for Sustainable Development*, *36*(4), 67.

Mahlein, A. K. (2016). Plant disease detection by imaging sensors–parallels and specific demands for precision agriculture and plant phenotyping. *Plant Disease*, *100*(2), 241-251.

Martinelli, F., Scalenghe, R., Davino, S., Panno, S., Scuderi, G., Ruisi, P., and Davis, C. E. (2015). Advanced methods of plant disease detection. A review. *Agronomy for Sustainable Development*, *35*(1), 1-25.

Milioto, A., Lottes, P., and Stachniss, C. (2017). Real-time blob-wise sugar beets vs weeds classification for monitoring fields using convolutional neural networks. *ISPRS Annals of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, *4*, 41.

Moranduzzo, T., and Melgani, F. (2014, July). Monitoring structural damages in big industrial plants with UAV images. In *2014 IEEE Geoscience and Remote Sensing Symposium* (pp. 4950-4953). IEEE.

Park, S., Ryu, D., Fuentes, S., Chung, H., Hernández-Montes, E., and O'Connell, M. (2017). Adaptive estimation of crop water stress in nectarine and peach orchards using high-resolution imagery from an unmanned aerial vehicle (UAV). *Remote Sensing*, *9*(8), 828.

Peña, J. M., Torres-Sánchez, J., Serrano-Pérez, A., De Castro, A. I., and López-Granados, F. (2015). Quantifying efficacy and limits of unmanned aerial vehicle (UAV) technology for weed seedling detection as affected by sensor resolution. *Sensors*, *15*(3), 5609-5626.

Singh, A., Ganapathysubramanian, B., Singh, A. K., and Sarkar, S. (2016). Machine learning for high-throughput stress phenotyping in plants. *Trends in Plant Science*, *21*(2), 110-124.

Stroppiana, D., Villa, P., Sona, G., Ronchetti, G., Candiani, G., Pepe, M.,. and Boschetti, M. (2018). Early season weed mapping in rice crops using multi-spectral UAV data. *International Journal of Remote Sensing*, *39*(15-16), 5432-5452.

Sugiura, R., Tsuda, S., Tamiya, S., Itoh, A., Nishiwaki, K., Murakami, N., and Nuske, S. (2016). Field phenotyping system for the assessment of potato late blight resistance using RGB imagery from an unmanned aerial vehicle. *Biosystems Engineering*, *148*, 1-10.

Veroustraete, F. (2015). The rise of the drones in agriculture. *EC Agriculture*, *2*(2), 325-327.

Watanabe, K., Guo, W., Arai, K., Takanashi, H., Kajiya-Kanegae, H., Kobayashi, M.,. and Iwata, H. (2017). High-throughput phenotyping of sorghum plant height using an unmanned aerial vehicle and its application to genomic prediction modeling. *Frontiers in Plant Science*, *8*, 421.

Watts, A. C., Ambrosia, V. G., and Hinkley, E. A. (2012). Unmanned aircraft systems in remote sensing and scientific research: Classification and considerations of use. *Remote Sensing*, *4*(6), 1671-1692.

Xiongkui, H., Bonds, J., Herbst, A., and Langenakens, J. (2017). Recent development of unmanned aerial vehicle for plant protection in East Asia. *International Journal of Agricultural and Biological Engineering, 10*(3), 18-30.

Yamamoto, K., Togami, T., and Yamaguchi, N. (2017). Super-resolution of plant disease images for the acceleration of image-based phenotyping and vigor diagnosis in agriculture. *Sensors, 17*(11), 2557.

Yang, G., Liu, J., Zhao, C., Li, Z., Huang, Y., Yu, H.,. and Zhang, R. (2017). Unmanned aerial vehicle remote sensing for field-based crop phenotyping: current status and perspectives. *Frontiers in plant science, 8*, 1111.