Agricultural Drones

A Peaceful Pursuit

K. R. Krishna

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ABOUT THE AUTHOR

Dr. K. R Krishna has authored several books on International Agriculture, encompassing topics in agroecosystems, field crops, soil fertility and crop management, precision farming and soil microbiology. More recent titles deal with topics such agricultural robotics, drones and satellite guidance to improve soil fertility and crop productivity. This volume deals in detail about agricultural drones. Agricultural drones are set to reduce farm drudgery and revolutionize the global food generating systems.

He is a member of several professional organizations such as International Society for Precision Agriculture, the American Society of Agronomy, the Soil Science Society of America, the Ecological Society of America, the Indian Society of Agronomy, the Soil Science Society of India, etc.

CONTENTS

PREFACE

Agricultural drones are set to revolutionize global food generating systems. Agricultural drones are already flocking and hovering over farms situated in a few agrarian zones. Their usage is still rudimentary in many other regions, but drones are destined to engulf almost every cropping belt. They are set to offer a very wide range of services to farmers and reduce drudgery. Drones make crop production more efficient and economically advantageous. Drone's greatest advantage is in providing accurate data to farmers, which is actually picked from vantage locations above the crop. It was never possible for the past several millennia. The imagery and digital data that drone's sensors offer is simply not feasible using human scouts, particularly at that rapidity, accuracy and cost. Drones offer data about status of crop and perform tasks such as spraying liquid fertilizers and pesticides at relatively rapid pace, and they offer greater accuracy compared to farm workers. They effectively replace usual human skilled scout's and farm workers' drudgery in fields.

This book is about agricultural drones that are destined to reduce human drudgery to its lowest limits and yet offer better crop productivity, in any of the agrarian zones. These 'agricultural drones' are contraptions for 'peaceful pursuits'. They offer automation of farms, so that in future, fewer farmers will manage larger farms. They inspect large farms of over 10,000 ha in a matter few hours, which is beyond human capabilities. They are less costly, versatile and offer a wide range of services related to farm imagery, crop status, irrigation needs and pest attacks in farms. All these are achieved using sensors (cameras) that pick digital data and are attached electronically with computer stations, iPads and push buttons.

Drones are among the most recent gadgets to invade the agrarian regions of the world. They seem to spread into all the different agro-ecoregions of the world and dominate during accomplishment of a variety of agronomic procedures. Along with ground robots (e.g., GPS-guided autonomous planters, sprayers, weeders and combines) and regular satellite guidance, they could offer total automation of farm production procedures. Drones are not expected to clog the skyline above the farms/crops.

They are required to fly past crops at low altitudes perhaps a couple of times at each critical stage of the crop, to obtain ortho-images and/or spray chemicals. Drones are expected to amalgamate well into farmers' chores and get counted as yet another gadget such as tractors, sprayers or combine harvesters.

Agricultural drones are peaceful to the hilt. Drones do not disturb soil neither its biotic factors nor the physicochemical properties. They do not disturb the standing crop, except when copters fly close to crop canopy inducing leaves to flutter a bit. Drones do not touch the crop. They quietly analyse and collect data staying at a distance from the crops, using sensors. Drones operate above the crop in the atmosphere. At the same time, soil type or crop has least influence into their functioning or efficiency in terms of gathering digital information or spraying herbicides and other chemicals. Drones could be deployed in any agrarian zone, be it wet tropics, arid and dryland stretches, hilly mountain farming terrains, or flat/undulated prairies with cereal stretches. They are expected to help farm managers with unmatched accuracy and efficiency compared to other methods presently in vogue. On a different front, we are making much noise about a stray drifting drone that may be potentially used to spy neighbours. Regulations for usage of drones, in general, and those used in farms are being finalized in United States of America and other nations.

Drones are being employed to detect droughts, nutrient dearth in field, disease and pest attacks on variety of crops grown in agrarian regions. Drones are expected to throng the agricultural fields worldwide, rather very soon. 'Agricultural drones' and their operators have a great role to play in the protection of crops, crop belts and food security. Drones could become a worldwide phenomenon sooner than we anticipate. We have to note that global crop protection using drones to scout for diseases/pests periodically, as a routine, is a clear possibility. When this is followed by pesticide spray at variable-rates, it is directly related to food security and nourishment of billions of humans. Consistent with the theme of this book, 'Agricultural Drones' bestow peace on earth through better grain harvests worldwide. They scout cropping belts rapidly and work towards better distribution of fertilizers, pesticides and water in crop fields. Global crop production is expected to become much easier through the use of drones. Ultimately, drones could be a boon to human kind by allowing us to achieve higher grain harvests. Drones could minimize human drudgery in fields markedly.

Agricultural drones are at the threshold of spreading into every nook and corner of North American farming zones. Drones have already caught the imagination and secured a role in fertile farming belts found in Europe. They say, in major farming nations of Europe, such as Germany, France, Hungary and Poland, the agricultural sector is already 'ploughed-up' to receive drones in large number. Drones are expected to initiate a technological revolution through automation of European farms. Drones have the potential to flourish in Asian farming belts as well. Here, we may have to be shrewd enough to consider drones and drone technology as an aspect not too closely connected with precision farming. The tendency to associate drone technology with precision farming, in general, has to be really weighed out well and done carefully. Drone technology applied independently has its ability to impart excellent advantages to farmers and agricultural researchers.

This book has ten chapters. An introductory chapter offers historical information about drones, their development and use in military, civilian surveillance, transportation and natural resource monitoring. It also lists and briefly describes various types of drones and their specifications. Further, a jist of our current knowledge about drones are provided. Chapters 2–9 offer greater details and discussions that concentrate on various aspects of natural resources and agricultural crop production. Agricultural drones are employed to obtain aerial imagery and accomplish a range of agronomic procedures in the crop fields. Drones are also used to detect drought, floods, soil erosion and crop stand. Chapters 3–7 deal with above aspects in detail and offer most recent information. Chapter 8 deals with one of the most important aspects of farming, namely yield forecast, using aerial imagery. Drones are used regularly to derive digital images of fields, crops, their growth, grain formation and maturity. Crop maladies, if any, are also imaged by drones. Digital images of crop growth and grain formation for several seasons are collated, layered and studied in conjunction with soil type, its fertility status, pest/disease incidence and drought incidence. Finally, computers with appropriate software are employed to decide agronomic procedures, plus, develop a grain yield forecast for the current season. Chapter 9 deals with economic aspects of agricultural drones. The cost of a drone unit, its operation, servicing and eventual fiscal advantages to farmers are also discussed. Farmers employing drones in their farms and other commercial settings have to observe certain rules and regulations. Firstly, they have to register the drone (vehicle) with appropriate governmental agency. Some of these topics are also stated in Chapter 9. Chapter 10 offers a summary of aspects discussed in the entire volume. It also lists some unique points about the way, drones have moved from exclusively military zones to agricultural crop fields and natural vegetation monitoring.

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ABOUT THE BOOK

Agricultural Drones: A Peaceful Pursuit is a treatise that deals with the role of aerial robots in managing natural resources and agricultural farms. It is currently a sought-after aspect within the realm of agriculture. Agricultural drones are billed to revolutionize the way we conduct agronomic procedures and maintain natural vegetation on earth.

Agricultural drones are a recent phenomenon that have been introduced into agrarian regions. They are expected to spread into crop lands of different continents. These are small unmanned aerial vehicles that are operated using remote control or flown above the crop fields using pre-programmed flight paths. They are fitted with a range of cameras that pickup images of fields, soil status, crop growth, and grain formation. The cameras obtain images from a distance of 100–400 ft. above the crop, using sensors at visual, near infrared, or infrared spectral bandwidths. Agricultural drones provide accurate images that provide details about seed germination, seedling establishment, crop growth, and maturity status. These drones are used efficiently to collect data about leaf chlorophyll and plant nitrogen status in order to decide on fertilizer dosages. Drones fitted with thermal sensors help in detecting water status of crops/soil and in prescribing irrigation at variable rates. Agricultural drones help in keeping vigil over crop fields, particularly in regard to disease and pest attacks, if any. They are destined to become most efficient in conducting plant protection procedures, such as spraying and dusting. These drones are gaining in acceptance in agricultural experiment stations since they offer spectral data related to a crop's performance. They are highly useful during plant breeding and genetic evaluation of elite genotypes. Drones fly very rapidly past the crop fields and obtain digital data, rather too slowly, like human scouts.

Agricultural drone companies (start-ups) are now a growing trend in North America and Europe. There are several models produced for farmers to use and reap better harvests at lowered cost. Agricultural drones replace human farm workers, and reduce use of fertilizers and plant protection chemicals. Agricultural drones are expected to improve economic advantages during crop production.

This book, *Agricultural Drones: A Peaceful Pursuit* has ten chapters. An introductory chapter provides historical data, details about various models of drones, most recent and popular agricultural drones in usage, and a glimpse about drones in farming. The other chapters deal specifically with topics such as drones in soil fertility, in production agronomy, in irrigation, in weed control, in pest and disease control, in grain yield forecasting, and about economic gains due to drones. The last chapter provides a summary.

Agricultural drones are really a recent topic. There are no detailed treatises on this topic. Hence, this book will be timely and useful to professors, agricultural extension officers, and students. Farmers and farm consultancy agencies will find the book useful to becoming conversant with recent developments about drones. This book is also informative to the general public. This book should serve as an excellent textbook for students in agriculture, engineering, geography, etc.

LIST OF ABBREVIATIONS

3D	three-dimensional
ADC	analog-to-digital converter
CEC	cation exchange capacity
CIMMYT	International Maize and Wheat Centre
CSM	crop surface models
CWSI	crop water stress index
DSLR	digital single-lens reflex
DSM	digital surface model
EC	electrical conductivity
FAA	Federal Aviation Agency
GAI	green area index
GIS	geographic information system
GM	genetically modified
GNDVI	green normalized difference vegetative index
GPS	Global Positioning System
HALE	high-altitude long endurance
HT	herbicide tolerant
IC	internal combustion
IR	infrared
LAI	leaf area index
MALE	medium-altitude long endurance
NASA	National Aeronautics and Space Agency
NBI	nitrogen balance index
NDVI	normalized difference vegetative index
NIR	near infrared
SAVI	soil adjusted vegetation index
SLR	single-lens reflex
SOM	soil organic matter
SPAD	soil plant analysis development
SSM	surface soil moisture
UAS	unmanned aerial systems
UAVs	unmanned aerial vehicles

USDA	United States Department of Agriculture
Vis	vegetative indices
VRAs	variable-rate applicators
VRT	variable-rate technology
VTOL	vertical take-off and landing

CHAPTER 1

DRONES IN AGRICULTURE

CONTENTS

1.1 INTRODUCTION

Agricultural drones are flocking and hovering over crop fields nowadays. They are expected to spread to every nook and corner of agrarian belts on earth. Drones offer aerial images from vantage points above a crop, 'a bird's eye view' but with great analytical detail and accuracy obtained using sophisticated visual, infrared (IR), near-infrared (NIR) and thermal sensors. They offer farmers with insights about their crops in such a detailed way that was never possible during the past several millennia. Drones allow us to study and compare soil types, assess influence of agronomic procedures and assess performance of several hundred crop genotypes with high accuracy. Drones collect and allow us to store a large posse of digital data about crops, soil and disease/pest attack that are required during precision farming. Drones offer economic advantages to farmers by reducing inputs and need for farm labour. They are quick in action, accurate, reduce farm drudgery to a large extent and make crop production efficient. Agricultural drones are a peaceful pursuit to the hilt, so much that they do not even touch or disturb the soil or the standing crop. Drones are totally non-destructive while analysing crops. At a stretch, drones stay in the atmosphere above the crop from few minutes to a maximum of couple of hours only, as required by farmers.

1.2 HISTORICAL ASPECTS OF DRONE TECHNOLOGY

First efficient use of drones was seen during military conflicts starting from early 20th century. For a long stretch of time, say a few decades, their usage was confined and stayed within the preserves of military engineering groups. Drones were initially developed to counter the enemy Zeppelins in World War I. It seems, earliest drone to be used in military warfare was developed in 1916. During the period between World Wars I and II, there were several modifications and improvements to drone technology (Nicole, 2015). It led to development of a range of models to suit different purposes related to military. Keane and Carr (2013) and Newcome (2004) have reviewed the historical aspects of drone technology. They suggest that efforts to develop drones for military use are at least 95–110 years old now. Actually, unmanned aerial vehicles (UAVs) have been around, for a duration much longer than most people imagine. Their development got initiated during World War I. They were known as aerial torpedoes or fling bombs. At present, drones are among the most dreaded military weapons in the West Asian conflict region.

Regarding data on development of drones in recent history, one of the lists suggests earliest use by British in the Mediterranean region. Drones were launched from an aircraft carrier named 'HMS Argus'. They were also used by Germans during the combat in 1944. In the same year, the United States of America used drones to bomb Japanese positions in Ballele islands (Arjomani, 2013).

Major advancements in drone technology that occurred in the United States of America during the 1950s and 1960s were represented by the use of *Ryan Firebees* series. During recent decades, UAVs engaged in warfare named Global Hawk, Predator and so forth are noteworthy. These are high-altitude drones of long flight endurance. They cover long distance in a day to seek the targets (Tetrault, 2014). Global Hawks are among the most efficient drones used by the United States of America in the Gulf War of 1991. It seems, until past decade, most of the drones used in surveillance and military zones were fixed-wing type. However, drones with rotary copters are also in vogue in many regions of the world. Reports suggest that 'RQ-*

Fire Scout' was among the earliest of drone copters to be used in missile launching and enemy scouting (Tetrault, 2014). It has been pointed out that characters such as excellent adaptability, safety and greater accuracy offered by copter drones are important during military actions. Such characters provide an edge over other types of war machinery. Report by Schwing (2007) suggests that drone technology went through a period of stagnation and lack of recognition until their consistent success in Vietnam. They have been utilized as most versatile and low-cost, effective military offence gadgets by Israelis since past two decades (Schwing, 2007). Drone technology for military and civilian usage was initiated in the United States of America in 1960. It was done under a program code named 'Red Wagon'. Reports suggest that drone usage in the U.S. military has ranged from apparent disinterest prior to 1980s to deployment for aggression, if need be, during surveillance and bombing enemy positions (Kennedy, 1998).

It seems even now, in 2015, the United States of America and Israel are the major users of drones for military purposes. Reports in 2013 suggested that over 52 nations are regularly using drones for variety of purposes (Gale Encyclopaedia of Espionage and Intelligence, 2014). They are used mainly to obtain high-resolution aerial imagery of enemy positions. They are equipped with computer decision systems and payload with bombs to destroy targets with great accuracy. Drones are efficient and quick in providing action and are highly economical as they cost less and their loss is not felt much. Fleets of drones could be manufactured fresh in a matter of days by ancillary industries that support military.

It is believed that there are several catalysts that have induced development and use of drones. In the general realm of public affairs and maintenance, it is the need for surveillance of events, towns, installations and natural resources that has given rise to constant demand for improvement in drone technology. Drones are essential in places that are dangerous and treacherous to human beings. For example, drones are required while handling and/or transporting dangerous chemicals. Most recent and supposedly most *prolific* reason is the agricultural uses of drones. Drones could potentially revolutionize crop production techniques. They are expected to reduce use of farm work force and human energy to, perhaps, the lowest levels that we can imagine (Gogarty and Robinson, 2012). Removing agricultural drudgery and making crop production more efficient is after all a priority concept since ages. Latest development in many of the developed nations is the formation of agencies that cater drone services. They cover a range of aspects, such as general aerial survey, aerial video monitoring and movie making, monitoring mines and industries, natural resource management, monitoring volcanoes and lava flow for example, in the Pacific North Western United States of America, aerial archaeology and local weather reports (Drone Services Hawaii, 2015). Such drone service facilities have sprung up in high numbers in the North American continent and Europe. We may note that unarmed drones have been effectively used to study the wild life, animal migration, and to guard the monuments within Egypt and other parts of North Africa (Gounden, 2013).

Drones were first utilized to study the weather pattern and follow thunderstorms/tornados by meteorologists of the United States of America during 1946. Since then, drones have been regularly used by the U. S. Meteorological Department to obtain weather data and gauge atmospheric processes. It is both interesting and useful to note that drones, particularly smaller versions that cost less, have been used to fly into clouds, cloud formations, storms and tornadoes. The aim is to collect data and study a range of parameters. This is actually done to analyse and accrue knowledge about factors that cause such weather patterns. For example, in the Central Plains of North America, Oklahoma, known as a tornado valley, drones have been sent in to detect and relay data about tornado's core, its periphery and impact on ground. Particularly, they intend to know effect of tornadoes on crops and farm infrastructure (Juozapavicius, 2013).

1.3 HISTORICAL ASPECTS OF AGRICULTURAL DRONES

Historically, agricultural world has been introduced with variety of implements, gadgets, automatic machines, new crop species, improved cultivars and methods to supply inputs such as soil nutrients and water or those that control diseases and pests. From ancient times, simplest and earliest of the implement to impinge the agrarian zones has been the wooden plough. It allowed farmers to grow crops on soil with better tilth. Plough hastened soil disturbance process and reduced weed infestation. Its use required a certain degree of drudgery but offered better crop stand and fairly systematic plant spacing. The spread of ploughing as an advanced technique must have taken a long stretch of time. This is attributable to constraints such as lack of interaction by humans situated in different regions/continents.

We should note that inability to travel frequently and easily was a major constraint to transmit new techniques during ancient period.

Later, during medieval period, a wide range of contraptions were devised to aid agrarian pursuit. Their spread was dependent on human migratory trends and ability to produce the new gadgets. During recent history, some of the most striking inventions to intrude the agrarian regions were the McCormick harvester in the mid-19th century, and later tractors with internal combustion (IC) engines that were energised by petrol. They reduced farmers' drudgery in fields. Sprayers and dusters during the early 20th century and combine harvesters in the mid-20th century were other machineries to impinge agrarian belts. These farm vehicles and gadgets revolutionised crop production procedures. As a consequence, large farms could be managed by farmers. Farmers could easily break limits stipulated by human physiological traits such as insufficient power and fatigue. Yet, human preoccupation with soil, water and crops supported well by farm drudgery were essential if farmers intended to operate large crop production units. Aspects, such as crop scouting, gathering accurate data about crop health, supplying fertilizers and water, spraying plant protection chemicals and so forth, all needed long stretches of farm labour. Further, availability of farm labour became a constraint in many regions.

As stated earlier, drones have been associated mostly with military pursuits such as reconnaissance and targeting enemy position with guided bombs. However, recent history about these aerial contraptions clearly shows that they have begun to play a peaceful role in global food generation. Approximately, since 2000–2005 A.D., agricultural drones have been evaluated and used to accomplish a range of different agronomic procedures in field and plantation locations. Actually, drones are among the latest gadgets to impinge the agrarian zones and their environments. They are relatively highly mobile, versatile and useful to farmers in several ways. They may also, in due course, affect several other aspects of agricultural world directly or indirectly.

In 1983, Yamaha Motor Company (Japan) launched the now popular RMAX copter drone. It seems it was actually designed and developed in response to a request by the Japanese Agricultural Department. They had requested Yamaha Company Ltd. to supply them with crop-dusting drone (Yamaha, 2014). First commercial use of Yamaha's R50 had begun by 1987. At present, RMAX is a popular agricultural drone in the farms of Far East. It is used to spray pesticides to rice crop.

Most recent reports suggest that use of field drones of small-to-medium size may gain in popularity, in the near future (Glen, 2015). They may be adopted to gather information about almost each and every plant that thrives in the field. They offer data good enough to be used during precision farming, that is, variable-rate techniques. A few types of such small drones are in testing stage, and a couple of them are still in the drawing board. However, there are also fantasies galore about the range of farm operations that could be accomplished by agricultural drones.

Agricultural drones made of low-cost wood and cameras attached to them have been in vogue, since past 5 years in Latin American nations such as Peru. Such low-cost drones are gaining in acceptance in smaller farms. They are relatively recent introductions into cropping zones. They provide excellent high-resolution imagery of crops such as potato and wheat (Cisneros, 2013).

Drone service agencies that cater to farmer's immediate needs are a very recent development within the realm of agriculture. Such commercial drone agencies began appearing in 2010. These drone agencies along with facility for satellite imagery are becoming invaluable, to large farms in Americas and Europe. They offer a range of services from aerial imagery of large cropping belts to a small management block in a farm. Drone companies, in particular, offer instantaneous images of crop growth and nutrient status, monitor diseases/pests and offer digital data to variable-rate applicators (Drone Services Hawaii, 2015; Homeland Surveillance and Electronics LLC, 2015).

Historically, drones are recent introductions into farming belts, say during 2007–2012. Dobberstein (2013) states that drones, having got a foothold in military, are now engulfing agrarian regions. They may soon spread out into farming belts all over the world. Drones are actually set to change the face of no-till systems. With their ability to rapidly scout the farms, they can provide clear images about weed infestation. Weeds are generally rampant during no-tillage farming systems. Drones could be conducting several of the major farm tasks such as three-dimensional (3D) imagery and scouting, spot spraying on pathogen-/pest-attacked patches, also spraying liquid fertilizers to supply in-season split dosages. Drones are getting popular because they also help farmers in decision-making.

There are many reports suggesting that drones are probably the most important next wave of agricultural technology. Drones may not entirely replace farm workers in some situations. For example, Ottos (2014) believes that drones do the primary imaging, rough sketching and show the farmers where to look for problems and where to apply amendments such as nutrients, herbicides, pesticides and so forth. At present (i.e. 2012–2015), industries producing drones for agricultural usage are being initiated and developed in large numbers.

History of drone introduction into farming stretches is no doubt very recent. Perhaps, they have become slightly conspicuous since past 5–10 years. This is despite absence of clear regulatory instruction for their commercial use in agriculture (Bowman, 2015). Drone usage is already in vogue on some crops. Soybean belt in the United States of America received drones in 2010 and since then they are getting common in the agriculture through their usage on soybean (United Soybean Board, 2014). Main purposes for which drones are employed on soybean crop are mapping the crop with high-resolution visual, NIR and IR cameras; crop scouting and monitoring work progress in soybean fields; assessing seedling emergence and crop stand so that replanting, if any, could be done efficiently. Drones are also used to obtain data on pest and disease, to fix crop-dusting schedules (United Soybean Board, 2014). The enthusiasm to introduce drones into agriculture has been increasing among farm vehicle producers and selling agents. Usually, a wide range of advantages are quoted for drones in farms, particularly, during precision farming. Polls and opinions among farm companies and farmers suggest that 75% believe that sky is the limit for drone-related advantages to farmers (Zemlicka, 2014). Drones have been called 'flying tractors' as in near future they are expected to throng farms, just like those other ground vehicles.

Drones are being tested in several different geographic locations, agrarian belts and on different crop species. The aim is to accomplish certain farm operations efficiently. For example, in Florida, drones are in use to monitor citrus groves for growth characters, weed infestation and to detect Huanglongbing disease since 2007 (Lee et al., 2008; Li et al., 2012; Garcia-Ruiz et al., 2013). Similarly, drones were introduced into the grape orchards of California in 2005 (Bailey, 2013).

1.3.1 AGRICULTURAL DRONES

It is now clear that, in addition to military, in due course, drones found their niche in different aspects of human endeavour. They were used to survey geologic sites, mines, natural reserves, public events and so forth. Drones were effectively used in highway patrolling and shadowing techniques. Drones found their way into agricultural regions only recently. Agriculture seems to support the most prolific use of drones to survey land, soil and to monitor the crop periodically. They offer excellent digital data for precision farming practices, so that farmers can apply fertilizers and chemicals at variable rates. Agriculture engulfs vast regions with wide variation in terrain, water resources, cropping system, disease/pest occurrence and economic returns. Drones that are apt for each situation could be expected to appear in different agricultural regions of the world. A look at the range of drone companies in North America, Europe and Far East clearly suggests that, drones are going to throng almost every corner of agrarian regions of the world. They are expected to help the farmers to reduce drudgery in fields, and obtain accurate information about crops in short time.

A drone could be defined as an aircraft (flat winged or copter) *sans* a human pilot. Drones were initially controlled using remotely situated ground stations with radio network connections. Incidentally, ‘drone’ is a terminology relatively primitive and more commonly employed in military. This term was used to identify totally or partially autonomous flying machines with ability for wide range of activities needed by military engineers. However, drones are not confined and exclusive to military usage anymore. Agricultural drones are gaining in popularity. During recent years, terms that are accepted as more accurate for autonomous aircrafts with computer-based decision-support systems and predetermined autonomous navigation are ‘UAV’ or ‘unmanned aerial systems (UAS)’. UAVs and UAS come with iPads to control flight pattern and speed. They possess sensors with ability to fend obstacles. Drones that are offered with accessories for several different types of activities, such as spectral imagery, instantaneous transfer of images, computer decision systems, containers to hold agrochemicals and variable-rate nozzles, are called UAS. This explanation pertains to drones in agricultural farming. The Federal Aviation Agency of the United States of America has preferred to use the acronym ‘UAVS’, that is, ‘unmanned aerial vehicle systems’ (The UAV, 2015). The word ‘system’ denotes the entire range of ground stations with control equipment, range of sensors and computer programs to decode and evolve accurate imagery. It includes accessories for activities such as spraying pesticides, fertilizers, spreading seeds in replant regions and so forth.

1.3.2 TYPES OF DRONES AND THEIR CLASSIFICATION

Drones are classified and grouped using several criteria. On the basis of the purpose for which they are deployed and used in military, drones could be classified as ‘target and decoy types’. They provide ground and aerial gunnery. Drones could be used exclusively for reconnaissance and battle intelligence. There are also combat drones providing the military with wide range of possibilities to attack enemy positions (e.g. dropping bombs).

Research and development drones are widely distributed all across the globe. They are used to watch large installations, industrial set-up, pipelines, roads, shipping lines and so forth. Civil and commercial drones are another set of drones. They are used in agriculture and several other activities related to commerce (AIRX$_3$ Visual Solutions, 2015; The UAV, 2015).

Several types of drones are produced by companies worldwide. Some are highly versatile and suitable for use in different situations. A few of them are specific to a particular function, say imagery of natural resources, vegetation and crops. A few are specific to pesticide application at variable rates, detection of disease and so forth. These are low-flying drones capable of close-up shots of crops, even leaves/canopy, so that occurrence of disease could be judged accurately. There are other drones such as ‘RMAX’ produced by Yamaha Motor Inc. or ‘Venture Surveyor’ by Volt Aerial Robotics Inc. that suit variety of situations. We may also note that it is now becoming common to develop and use drones with local material and expertise. They are targeted to overcome specific local problems related to crop production. Sophistications are added later as and when required (Zhao and Yang, 2011; Ministry of Agriculture, 2013). Drones could also be ordered to suit the specific role in agricultural crop production. Drone models are also leased to complete tasks such as pesticide spraying and so forth (Homeland Surveillance and Electronics LLC, 2015).

Drones are also classified on the basis of variety of traits. They could be either flat-wing types or copters. Flat-wing types need a stretch to gain height and become airborne, whereas copters have ability for vertical liftoff from any point in a crop field (see Krishna, 2016). However, recently, parachute-type drones have also been used effectively to map farms, soil types and demarcate ‘management zones’, during precision farming (Thamm, 2011; Thamm and Judex, 2006; Pudelko et al., 2008, 2012). A large balloon with helium or blimp can also serve as UAV. A modern blimp with its payload can be controlled using remote controller, but the balloon is generally unstable if the wind speed is beyond threshold (Yan et al., 2009).

Regardless of the type and purpose of the drones, some of the most important performance characters of drones are: (a) weight, (b) endurance and flight range, (c) maximum altitude, (d) wing load, (e) engine type and (f) power source (Arjomani, 2013). Therefore, drones have been frequently classified using the above characters as criteria.

Weight: First category of drones using their weight as a characteristic is 'Super heavy drones' that weigh over 2 t. They hold sufficiently large amounts of fuel. They fly at high altitudes serving military reconnaissance (e.g. Global Hawk). Next are 'heavy weight drones' that weigh between 200 and 2000 kg (e.g. Fire Scout). 'Medium-weight drones' weigh 50–200 kg. All of these drones are capable of holding more fuel and travel long distances with greater endurance. 'Light-weight drones' weigh 5–50 kg. They are useful in agricultural fields (e.g. RMAX, Yintong, Autocopter). 'Microdrones' are those weighing less than 5 kg. They are handy, quick to lift off and fly at relatively lower altitudes (e.g. Raven). These are more common in agricultural fields and are portable as they weigh less than 5 kg (e.g. Precision Hawk's Lancaster, eBee, Swinglet, CropCam).

Endurance: On the basis of endurance (flight period) and range of distance that drones can fly without fuel refill, they can be classified into long-, medium- and low-endurance types. Long-endurance UAVs can stay airborne for 24 h or more and travel 1500–20,000 km without refill, for example, Global Hawk. Medium-endurance drones fly for 5–24 h without brake. They transit long distances on the basis of speed. Low-endurance drones fly for an hour at a stretch and cover 100 km. Drones used in agricultural fields have very short endurance. It ranges from 30 min to 1 h. They cover over 50 km of predetermined path above the fields. It is generally believed that, as drones are powered by mechanical engines, their endurance in the air could be enhanced to help farmers to scout and survey fields for periods much longer than it is possible now (The UAV, 2015).

Altitude: Using altitude attained by drones during reconnaissance and imagery of ground conditions as a characteristic, we can classify the drones into low-, medium- and high-altitude drones. Low-altitude UAVs are most apt for close-up imagery of crop fields. Such drones fly just up to 100–1000 m above the crop canopy. Medium-altitude drones are also utilized in agriculture, particularly in obtaining NIR and thermal imagery of crops. They fly at about 1000–10,000 m above the crop height. High-altitude drones are commonly used in judging natural resources and for military reconnaissance. They fly at a height above 10,000 m above ground surface.

Wing Loading: Wing loading of a drone is yet another useful trait to classify them. Wing loading is actually a value derived by dividing the total weight of the drone by total wing area. The wing loading value for various agricultural drones or others may range from 5 to 250–300 $kg \cdot m^{-2}$. Drones with wing loading of over 100 $kg \cdot m^{-2}$ are classified as high wing loading types (e.g. Global Hawk). Those with 50–100 $kg \cdot m^{-2}$ are classified as drones with medium wing loading (e.g. Fire Scout, X-45). Those with less than 50 $kg \cdot m^{-2}$ are grouped as low wing loading ones. Most of the agricultural drones, particularly, the fixed-wing types are low wing loading types. A few copter drones have medium to high wing loading range.

Engine Type: Engines used in drones are usually run using petrol or electric batteries. Engine types commonly encountered are turbofans, two-stroke piston engines, turboprop, push and pull and electric with propeller. Agricultural drones, particularly, flat-winged small ones are energised mostly by electric batteries. Larger copter drones such as RMAX or Auto-copter are energised through petrol or diesel engines. Drones with electric batteries run only for short time. Their endurance is small, but they are highly useful in quick scouting and in obtaining close-up shots of crops.

Energy Source: On the basis of the energy source, we can group the drones into those possessing precharged electric batteries and a second group comprising of drones with IC engines dependent on petrol.

There are few other criteria that could be adopted to classify drones. According to Gogarty and Robinson (2012), modern drones could be classified as micro, small, medium and large. On the basis of the altitude and endurance considered together, they are referred as medium-altitude long endurance (MALE) or high-altitude long endurance (HALE) drones. Generally, drones for military surveillance, scouting and bombing are MALE or HALE types, because they have to travel long distances and high altitudes without detection, and return to barracks after completing the tasks. It seems drones such as Global Hawk and Predator could easily travel for 7500 miles from the launch site, identify the target, drop bombs and return. All these aspects are accomplished at the push of buttons and on the iPad or a computer screen (Gale Encyclopaedia of Espionage and intelligence, 2014). On the contrary, agricultural drones are usually micro or small, low-altitude or very low-altitude types. They have short endurance of around 30 min to 2 h. They are lightweight machines.

Agricultural drones could also be classified on the basis of range and quality of accessories. In other words, we consider cost of purchase, extent of complexity and tasks that drones can perform. There are also drones that may last for long period with ruggedized body or those with frames (platforms) made of light material. Hence, they require periodic corrections to platform.

On the basis of flight craft and takeoff, agricultural drones are grouped into vertical take-off multi-rotor drones. Flat-winged drones could be grouped as either short or long take-off drones. Next, on the basis of flight controllers used, agricultural drones could be semi-autonomous, when skilled farm technicians guide the drone's flight path, and autonomous when the flight path and imagery are predetermined using computer decision-support systems (see Krishna, 2016).

1.3.2.1 SENSORS ON DRONES

About 100 years ago, farming stretches in North America experienced a drastic change from animal-drawn implements to combustion-powered machines and tractors. The transition had impact on crops and their productivity. Thomasson (2015) suggests that a revolution or transition of similar proportion and impact has taken roots in agrarian belts. However, this time, it has been engineered by drones, sensors, Global Positioning System (GPS) and computer-aided decision systems. *Sensors are the centre piece of agricultural drone technology.* Most commonly used sensors on agricultural drones are the red, green and blue in the visual bandwidth, NIR and IR. Each and every improvement in sensors utilized in agricultural drones is always received eagerly by drone technologists and farmers. The resolution and accuracy with which they depict crop field and the happenings in greater detail decides how useful is the aerial imagery. Sensors should be simple to attach or detach. They should be small enough to fit the payload and space on the small drone. Current trends are to use small and swift drones to capture aerial images and collect digital data. Low-flying and hovering-type copters are preferable, if close-up shots with greater details of plant organs (leaf, twigs, pod etc.) are required. Whatever is the type of platform, sensors have to be really very sharp with high resolution. They should be able to get details of minutest items that farmers require, during monitoring of crops. Recently, researchers at Ecole Polytechnique Federal de Lausanne have developed 'super sharp sensors' in which three photodetectors forming a triangle are covered with a single lens. This optical device can focus on crops and relay images to microprocessers that map the images of fields. The optical device is very small—just 2 mm in length. It fits into any of the really small and micro-drones that hover above individual plants in a crop field (Floriano, 2015). Incidentally, this development mimics the compound eye of an insect and is destined to provide farmers with some excellent aerial imagery with details of their fields.

1.3.3 DEFINITIONS AND TERMINOLOGIES RELEVANT TO AGRICULTURAL DRONE TECHNOLOGY

Let us consider a few definitions, acronyms and important terminologies relevant to drones and their role in agriculture as described by Gogarty and Robinson (2012). They are as follows:

Unmanned Vehicle: It is any vehicle that is guided remotely without being driven/piloted by human beings. It includes several types of ground vehicles, robots and flying machines.

UAV: It refers to aerial robots or drones that fly on the predetermined path or using commands from a computer/command control system. Handheld remote controllers are most commonly used to control flight path of such UAVs.

The word 'drones' is the most commonly used and widely recognized synonym within the realms of military, agriculture and public usage. On the basis of the extent of autonomy of drones, they could be identified as semi-autonomous drones or fully autonomous drones.

Since many of the drone models are small and have short endurance within the realm of agriculture, farmers may use them in swarms, if possible. They can then complete the task of crop imagery at the quickest possible time (Gogarty and Robinson, 2012). This is comparable to using several tractors, simultaneously, to plough a large field, in time, to catch up with first rains. The entire farm of over 10,000 ha or more could be covered by 'drone swarms' in a matter of minutes. Drones could be directed to pick high-resolution pictures for definite purposes such as detection of disease, pests, leaf water status, leaf nutrient status and so forth. Therefore, 'drone swarms' may become more common in near future. Relay of digital information and inter-drone communication have to be sharp, accurate, quick and well thought out. Generally, the period of drone's flight is too small; therefore, coordination of flight path and imagery has to be accurate. In future, perhaps, 'drone swarms' could also be connected to ground robots so that farm operations could be done at one stretch with the help of digital information and directions from the drones. It seems easier said than done. Orchestration of ground vehicles and inter-vehicle communication with drones could be a complex task. It definitely requires further research input.

1.3.4 EXAMPLES OF AGRICULTURAL DRONES: THEIR NAMES, BRANDS, COMPANIES PRODUCING THEM AND THEIR USAGE DURING CROP PRODUCTION

At present, industries producing agricultural drones are well distributed in North America, Europe and Far East. In addition, there are innumerable computer agencies/companies that process the imagery derived from drones. Drone manufacturing units, in fact, are sprouting in big number because they reduce burden on hiring farm labour. In addition, they offer exceedingly accurate data about crop growth status. They can assess crop's nutritional status particularly plant-N, water status, weed infestation and pest/disease attack. Farmers need good knowledge about the drone models available. They should identify drones which suit their purpose best. For example, a lightweight, flat-winged drone (e.g. SenseFly's *eBee*; Precision Hawk's Lancaster; CropCam etc.) that passes over the crop field at a rapid pace is good enough to pick aerial imagery. However, if farmer wants to spray liquid fertilizer formulation or granules swiftly over a large field, then a rotor drone such as Yamaha's RMX with containers and variable-rate nozzles is best. Equally important is the knowledge about technical specifications of the drone model. We should note that brochures of certain companies that produce agricultural drones clearly compare and contrast various specifications, advantages and disadvantages. Further, they mention exact suitability of a particular drone model (see Zufferey, 2012). Usually, a wide range of accessories, particularly, those related to sensors are listed from which to pick. Following is a list of drones, their major function in farms and technical aspects. This list is only indicative. There are really a large number of agricultural drone models that are currently accessible to farmers.

1.3.4.1 FLAT-WINGED DRONES

1.3.4.1.1 Precision Hawk's Lancaster

This is a small fixed-wing drone used in agricultural surveillance and imagery services. It weighs about 1.5 kg. Physically, it is easy to handle this model as it spans just 4 ft in length and breadth. It holds sensors, mainly composed of visual, NIR, red-edge and thermal cameras. They can relay images swiftly to ground control computers that sew the images using appropriate computer software. They provide crucial information about crop genotypes and their growth status to the farmers. Precision Hawk's Lancaster can transmit images covering over 20 ac in a matter of few minutes (Reich, 2014). Such Lancasters (drones) can also offer useful data about water status of the crop and its variability, pests and disease incidence, if any, on the crop. It is produced by a company situated in Indianapolis, Indiana and Raleigh in North Carolina, United States of America. These are portable and cost about 3000–5000 US$ per piece. It comes with all accessories such as sensors, mapping and image processing software and facility to relay digital data and variable-rate applicators.

Technical Specifications: Precision Hawk carrying visual and multispectral cameras flies over crop fields and covers 500 ac in a 45-min flight period. There are options to replace broken/torn airframe and damaged cameras. The Lancaster platform has a 4 × 750 Hz Linus CPU with real-time embedded processors. It interfaces and interacts with commands via Wi-Fi, Ethernet, Bluetooth, USB and so forth. There are temperature processing units. The drone equipment is light in weight. It has a wingspan of 4 ft. Lancaster can take off from water or ground. Water kits could be attached when required. The package comes with live video streaming of crop fields via Internet. The resolution of cameras could be enhanced up to 6 mm per pixel. Cameras with lenses of longer focal length are fixed for high-resolution imagery. Precision Hawk usually carries a high-performance video/audio processor such as Texas Instruments' OMAP3730.

1.3.4.1.2 Swinglet Cam

It is a small flat-winged drone. It serves farmers with useful data about topology, soil type variations, crop growth and yield forecasts. It primarily offers high-resolution imagery of farmer's fields. It is a portable drone that fits into a small brief case, so that it can be carried to different locations and launched for use. Swinglet Cam costs about 7000 US$. It is produced by SenseFly Inc. situated at Cheseaux-Lausanne, in Switzerland.

The Swinglet package consists of drone and complete electronic system in ready-to-fly condition. It has a set of multispectral sensors and image storage memory card and cables. It also has radio modem for remote control and guidance during flight. It is powered by a set of lithium-polymer batteries and the package has a charger too. In addition, there are spare propellers, remote control spares, iPads and user manuals. Drone becomes ready for flight in a matter of few seconds, once removed out of the case. Swinglet Cam can be shifted from one spot to other without being dismantled or packed. Software user codes are also provided. For example, *eMotion 2* helps in controlling and setting up flight pattern. Next, *Postflight Terra LT* allows quick check on image overlap and calculates a rough ortho-mosaic in a matter of minutes, even while the drone is still above the crop field. The data from Swinglet Cam can be interfaced using *Postflight Terra* to rapid image processing centres located on the ground (SenseFly, 2013; Grassi, 2013). The data from computer decision-support systems could be later relayed, to variable-rate applicators on tractors or spray drones.

Technical Specifications: Swinglet Cam is a small drone with 80-cm wingspan. It weighs about 1.2 lb (600–700 g). It is powered by lithium batteries that keep the drone in flight at a stretch for 30–35 min, without recharging. Its endurance allows a flight distance of 36 km at a cruise speed of 10 m s^{-1}. It resists wind speeds of 25 km·h^{-1} during flight. Its radio contact equipment operates and keeps it linked for up to 1-km length. The cameras provide a 3-cm resolution on the pictures. In addition, Swinglet Cam has facility for data logging on board. It easily covers 6 km^2 area in one flight and offers accurate 3D images of crop field/terrain. The remote controllers and iPads allow farmers to simulate its flight path, prior to actual use. Swinglet drones can be used in swarms (SenseFly, 2013; Grassi, 2013). The package has software to correct flight path and avoid mid-air collision. Flight history can be stored in digital form and retrieved at any point of time.

1.3.4.1.3 eBee

It is a flat-winged, fully autonomous small drone. It is capable of obtaining high-resolution aerial imagery from above the crop fields. It offers digital data that can be converted instantaneously into 2D ortho-mosaics and 3D models. It has a ruggedized body and the entire drone fits into suitcase so that it can be carried to any location for launch. It is hand launched. At present, *eBee* is in use in the wheat production zones of Europe and in other continents. *eBee* is a recent model released for use in the year 2012. Its latest updated version was developed and released in 2015 (SenseFly Inc., 2015a, 2015b).

Technical Aspects: Its platform is flat winged and is powered by lithium batteries. *eBee* is also a very light drone weighing just 450 g. It is a very small drone and its payload is 0.15 kg. The endurance per flight is 45 min. The maximum speed while transiting above the crop fields is 90 kmph. It reaches altitudes higher than 1000 m. As the drone is small and light, it can only withstand wind speeds of 12–15 kmph in the atmosphere while in flight. *eBee's* flight path could be totally preprogrammed prior to launch. Its landing is smooth and predetermined. It carries a series of sensors such as cameras that operate at red, green and red-edge bandwidth. In addition, it has a thermal mapping facility. The digital data it relays can be used to prepare 2D ortho-mosaics and 3D models (SenseFly Inc., 2015a, 2015b).

1.3.4.1.4 Wave Sight

This is a multipurpose flat-winged drone used mainly to accomplish aerial scouting of farmland and crops, at different growth stages. These drones are launched using a catapult. Wave Sight has bays, where in, we can fix different cameras operating at different wavelength band. Cameras such as visual single-lens reflex, NIR, red edge and thermal IR could be fixed. The camera bay usually houses a 20 megapixel visual band camera, 20 megapixel NIR camera and an IR radiometric camera with ability to store GPS data. These cameras could be fixed with zoom lenses for close-up shots of crops during pest/disease detection. The sensors allow mapping of crops spread over 12 km^2 or 3000 ac per flight of 2 h. Wave Sight drones come with their own ground stations and remote controller, if the intention is to guide the path of the drone. Drones could be provided with predetermined flight instructions.

Technical Aspects: The wingspan of 'Wave Sight' is 7.5 ft, length is 4.5 ft, and it weighs about 20 lb. Wave Sight can gain a cruise speed of 73 kmph. It operates safely in the atmosphere withstanding wind speeds of 45 kmph. Flight endurance is 2 h (Volt Aerial Robotics, 2015; Paul, 2015).

1.3.4.1.5 CropCam Unmanned Aerial Vehicle

CropCam is a sleek, small and lightweight agricultural drone that can be packed into a small brief case. It can be transported to any location and launched swiftly in a matter of few minutes (CropCam, 2012). It is a mini-drone that helps in management of crops. It offers imagery of various natural resources, installations in the farm and so forth. It is most commonly used to map the crop and monitor its growth. The primary purpose depends on the cameras and sensors fixed on it. The flight path of this drone can be predetermined using GPS connection. Its flight path could also be controlled using remote control with wireless connection.

Technical Aspects: The average speed of CropCam in flight is 60 kmph. It withstands wind speed of 30 kmph in the atmosphere. Its electronic circuitry stops working below −20°C. As the drone flies at low altitudes, it offers excellent images of the crop. CropCam is 6 lb in weight and can be launched from anywhere using a catapult. It is 4 ft in length and the wing-span is 6 ft. Its endurance, that is, flight duration without brake is 53 min (CropCam, 2012, 2015; see Krishna, 2016).

1.3.4.1.6 Trimble's UX5 Agricultural Drone

This is a flat-winged drone that swiftly flies close to the crop canopy. It offers aerial images of the field. It is also used to obtain 3D map of terrain and soil. Digital data obtained while in flight can be relayed instantaneously to the ground station for use in variable-rate techniques. Most commonly, it is used to get normalized difference vegetative index (NDVI), plant chlorophyll and thermal imagery. It is useful in monitoring ranches and cattle (see Krishna, 2016; SPAR Point Group Staff, 2015). This drone has also been used to prepare work schedules and keep watch on general activity in farms, particularly, movement of ground vehicles such as tractors, fertilizer inoculators and so forth.

Technical Aspects: This flat-winged drone flies at 80 kmph above the crop fields, on the basis of predetermined flight path. It has 50-min flight endurance. This drone adapts well to high-speed aerial imaging. UX5 picks images from 180 ac (73 ha) per flight. This drone offers 3D images plus digital surface model of crop fields. It withstands wind speeds of 37 kmph while in flight. Landing is smooth and precise due to reverse thrust (Trimble, 2015a, 2015b). Trimble's UX5 is fitted with cameras modified to capture image at visual and NIR bandwidths. Such images help in detecting crop's health, pests, weeds, mineral deficiencies and potential soil-related problems like erosion.

1.3.4.1.7 Agribotix Hornet Drone

This is a flat-winged drone that could be used during precision farming. It is a low-cost drone with ruggedized and light body. It is commonly used to obtain routine images of crop fields and monitor work schedules. It is equipped with visual and IR sensing. High-resolution images of 3-cm ground resolution are possible. This drone covers about 160 ac per flight (Barton, 2015). The drone system comes with image processing software. Hence, we can relay crop growth and nutrient status data instantaneously depending on the software used. Software such as SST, Agleader, SMS and *SoilMapper* offer excellent help during precision farming (Agribotix, 2015a).

Technical Aspects: Hornet Drone is fully autonomous during takeoff, flight and landing. Its flight path can be predetermined. Ground control stations with computer connectivity and telemetry is also a possibility. It is energized using four rechargeable batteries for short flight and eight if used for longer endurance. The imaging system has Go-Pro-Hero camera (four numbers) that have high-quality visual lenses and NIR filters. This drone has two bays to fit the cameras. Additional R, G and B cameras could also be fitted. An Agribotix Field extractor software is used to select, prepare and upload images to Agribotix cloud processing service. The data processing solution that costs extra includes preparation of full colour maps of crops and their health. Agribotix's 'management zone map' helps to adopt precision farming methods. The software that helps in data storage, retrieval and analysis (Agribotix, 2015b) are also included.

1.3.4.2 ROTARY-WINGED DRONES

1.3.4.2.1 RMAX

Among the agricultural drones in use, RMAX models are slightly heavier at 80–90 kg·unit^{-1}. They are produced by Yamaha Motor Company of Japan. RMAX is used mainly to scout crops and natural vegetation. They are also used to spray pesticides, fungicides, liquid fertilizers and to spread tree seeds during replanting programs. RMAX's flight path can be controlled using remote controllers or even predetermined using computer connectivity. At present, RMAX is a popular agricultural drone in the rice, wheat and soybean production zones of Japan and other Far Eastern countries (RMAX, 2015).

Technical Aspects: RMAX is a roto-copter with a payload of 24–28 kg. The overall height is 108 cm and width is 72 cm. The fuselage has two containers (8 L × 2) that carry liquid formulation, granules or seeds. This drone can be fitted with nozzles that respond to computer decision-support systems, to release pesticides/granular fertilizers at variable rates. The drone flies at 150–400 m above the crop canopy. Its flight duration, that is, endurance without refuelling is 60 min. RMAX has two-stroke IC engine (245 cm^3) that is energised using petrol. Most importantly, this drone carries visual, IR, NIR and thermal cameras to pick imagery of crops. Aerial images could be processed immediately using computer programs (RMAX, 2015).

1.3.4.2.2 Yintong

It is a Chinese design copter drone. Along with other models of drones, Yintong's agricultural drones are touted to help farmers in the agrarian regions of China. Yintong's agricultural drone is said to offer great advantages during precision agriculture. It is a hovering type drone which is light in weight and needs no special landing site. It draws power from electric batteries and is relatively small. This drone surveys, relays crop imagery and it is equipped with variable-rate nozzles for dusting and spraying. Application of pesticide using Yintong's drones is said to reduce the requirement of pesticide by 50% compared with spraying done by human scouts on the ground. This copter has been widely tested in China on vast stretches of wheat, rice, cotton and fruit plantations (Yintong Aviation Supplies Company Ltd, 2012; Krishna, 2016).

Technical Aspects: Flight weight including pesticide is 15 kg; flight altitude ranges from 0 to 1000 m above crop; flight speed is 5–10 mph, spraying speed is 0.5–2.3 $L \cdot min^{-1}$; spraying perimeter is 2.8 m. This drone covers an area of 2.25 $km^2 \cdot min^{-1}$. Yintong drone holds about 5-kg pesticide in containers.

1.3.4.2.3 Venture Outrider and Venture Surveyor

Venture copters are highly versatile drones that are operated above crop fields. They move relatively slowly and can even hover for a longer time at a spot. This trait helps in monitoring crops in greater detail and in obtaining excellent close-up shots of crops. Brochures suggest that Venture Outrider and Surveyor both are rugged. So, they can be used in any harsh environment. They are autonomous, but remote-controlled navigation is also possible. These copter drones have slightly extended flight endurance of 45–60 min. They can cover up to 100 acres per flight. The payload usually consists of 20-megapixel visual and NIR cameras and aerial mapping facility. Instantaneous relay of digital data to sprayers is also a possibility (Volt Aerial Robotics, 2010; Paul, 2015). Sensors in the drone allow each and every image to be tagged with GPS coordinates. High-definition videos are also produced using Venture drones with sensors. These copters are suited to monitor disease/pest attack on crops.

Technical Aspects: Venture Surveyor has an overall dimension of $83 \times 83 \times 24$ cm. It weighs 3 kg per unit (6.62 lb per unit). The cruise speed is about 30 kmph. It can withstand ambient wind speed of 35 kmph. Flight endurance ranges from 15 to 30 min.

1.3.4.2.4 EnsoMOSAIC Quadcopter

This is a quadcopter developed especially for use in agricultural fields. However, it can also be used for deriving NDVI of natural vegetation and to monitor progress of work in mining zones or even to track city traffic.

Technical Aspects: EnsoMOSAIC copter is about 67 cm with a takeoff weight of 3.7 kg. It supports a payload of 8.0 kg. The flight endurance is 25 min with full payload. The copter withstands atmospheric wind speed of 8 $m \cdot s^{-1}$. The copter follows a predetermined path or it can also be guided using remote controller. The EnsoMOSAIC copter usually has a Sony Alpha 6000 (24 megapixel) and NIR cameras to obtain imagery of crops and terrain. EnsoMOSAIC copter also comes with 3D camera and software attached with it to map topography of crop fields (Mosaic-Mill, 2015).

1.3.4.3 PARACHUTE AND BALLOON DRONES

1.3.4.3.1 SUSI-62 UAV

It is a parachute-type drone. SUSI floats and drifts above the crops at relatively slower speeds than flat-winged/copter drones. SUSI is currently in use in Germany and Polish crop production zones. It moves autonomously over crops. It collects images and information about crop's water status, pests and fungal diseases (Thamm, 2011). SUSI-62 can be guided using iPads or ground computer station. Flight routes could also be predetermined (Thamm and Judex, 2006).

Technical Aspects: The frame of the SUSI is made of steel. It is 62 m^3 in size with a payload of 5 kg for locating sensors. The frame has four robust wheels. SUSI is powered by a two-stroke IC engine that sits in the payload chamber. SUSI parachute needs a small runway over a cliff or a location at an altitude to gain height. It moves in the atmosphere above crops at speeds ranging from 20 to 50 kmph. It withstands wind speeds of 10–20 km without distraction to its flight path. Most importantly, its payload contains digital single-lens reflex visual, IR and NIR cameras. Flight parameters and GPS video data can be conveyed within 6 km. This parachute drone has autopilot option (Thamm, 2011).

The above classification and list of agricultural drones mentioned utilizes engineering traits such as wing type, endurance, flight speed, sensors and a few other aspects to classify the drones. Flat-winged and copter types are the most common way to identify and classify further. However, within the realm of agricultural crop production, we can classify drones on the basis of actual agronomic procedure for which they are meant. The sub-classification includes

a. Seeding (aerial) and seedling-monitoring drones;
b. Canopy and growth-stage-scouting drones;
c. Crop protection drones that detect disease/pests and spray plant protection chemicals;

d. Crop-monitoring drones that collect data regarding NDVI, leaf chlorophyll and plant-N status. Such drones could also be utilized to apply liquid fertilizer-N, if the fuselage has such a facility with nozzles;
e. Harvesting drones detect the crop maturity. They map the entire field of over 10,000 ha and provide accurate digital data/imagery for combine harvesters to operate. Sometimes, digital data could be applied to the robotic combine harvester. These machines later offer yield maps to farmers; and
f. Data drones are those vehicles that provide periodic data about the soil-type variations, seeding trends, seedling emergence, crop growth parameters, grain maturity and so forth. Such drones add vast amount of data to the 'big data bank'. Many of the computer-based decision-support systems rely on data banks.

1.4 UTILITY OF DRONES

1.4.1 DRONES ARE VERSATILE IN USAGE

Drones have been shrewdly used by us in a variety of situations and with great advantage. In many cases, drones are better than manual operations in terms of efficiency. Drones have been expertly utilized in aspects such as surveillance of natural resources, observing weather conditions, recording natural disasters, study of general topography, forests, wildlife migrations, monitoring civilized inhabitations, waterways, railroad, tramways, buildings, military equipment, electric transmission systems, oil pipelines, traffic movement and guidance. Drones are used efficiently for large-scale seeding aimed at developing natural vegetation. They are also needed for monitoring of crops periodically and spraying chemicals in the fields.

Let us consider few examples of drone usage. Several of them may become routine and essential in future. Many of these tasks are performed with great ease and accuracy by the small flying machines called micro-drones. There are actually several compilations about different uses of drones, which relate to human endeavour. Gogarty and Robinson (2012) have listed a few conspicuous uses of drones. They are mostly related to drone's usage in the military warfare, in monitoring naval vehicles and offshore inspection of installations, in border security, policing of military