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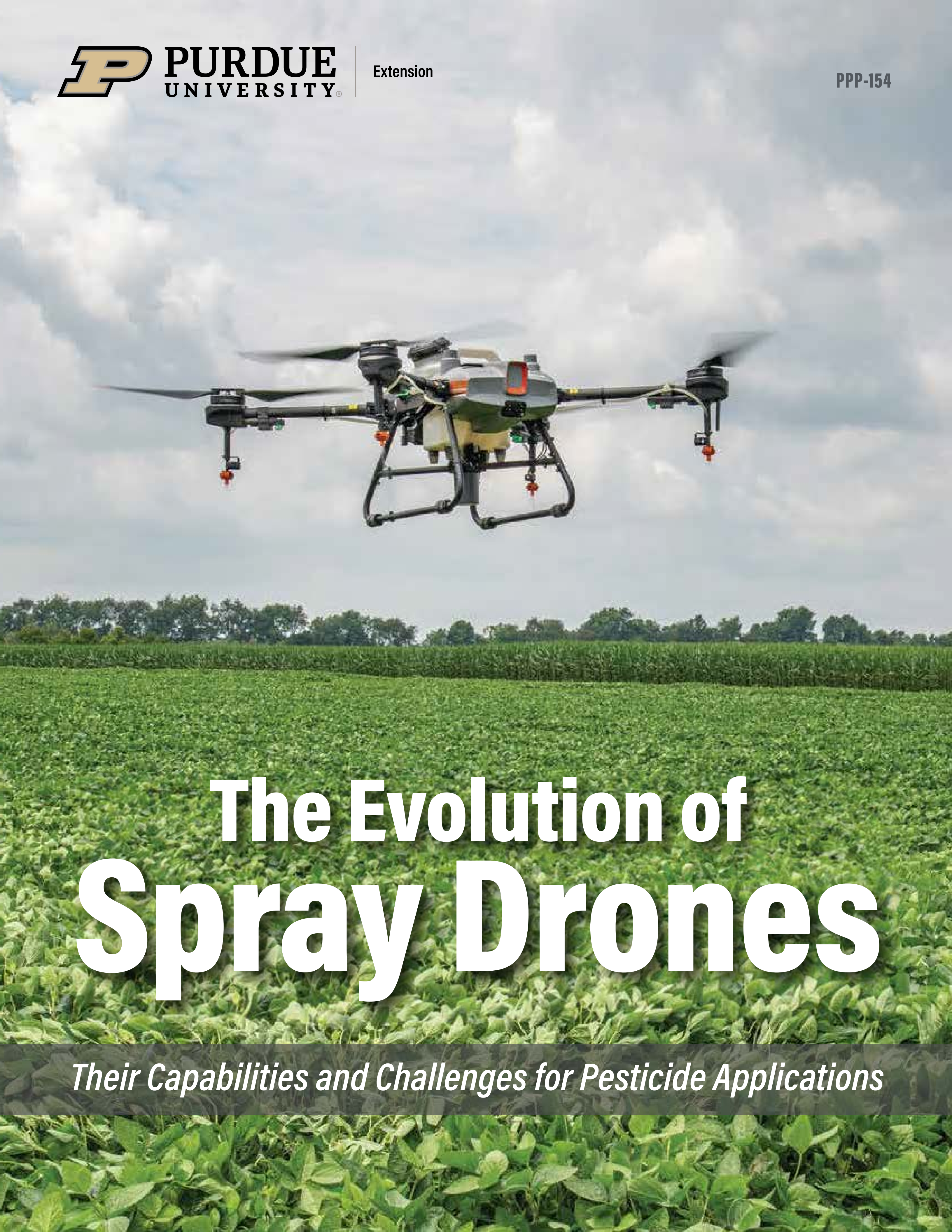

The Evolution of Spray Drones

Their Capabilities and Challenges for Pesticide Applications

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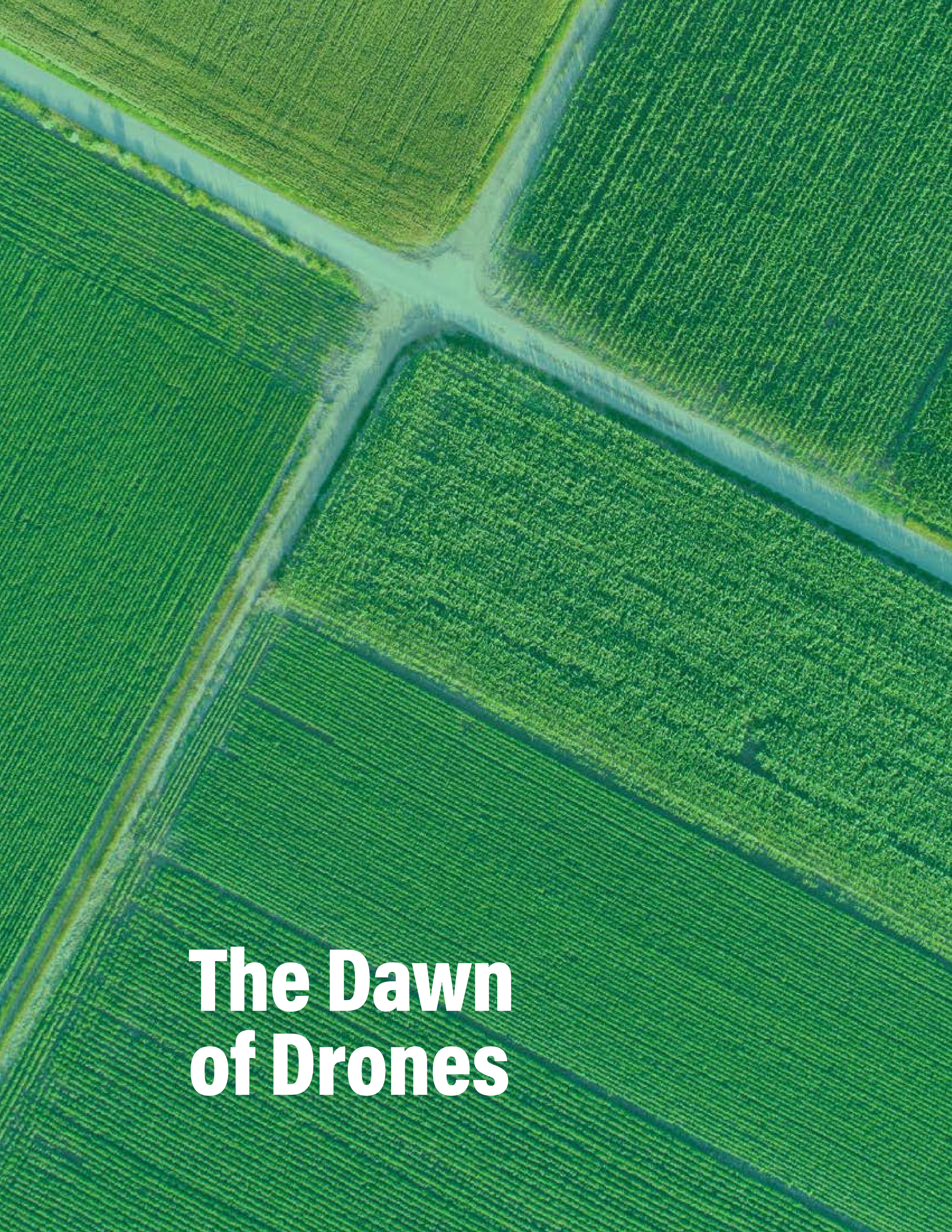
It's nothing short of amazing to see how the aviation industry has advanced since Orville and Wilbur Wright made their first flights on the sandy beaches of Kitty Hawk, North Carolina. Winning the flip of a coin over Orville, Wilbur made history on December 17, 1903, when his plane covered 852 feet at a speed of 34 miles per hour, becoming the first recorded flight.

In a little more than a century, planes have become essential for transporting people, mail, and cargo across continents and oceans. Advances in aviation technology have produced jets that can be undetected by radars, travel at supersonic speeds, and carry heavy payloads unimaginable to early aviation inventors and enthusiasts.



The Dawn of Drones

The historic flight in North Carolina ushered in the dawn of aviation, which has a direct line to the development and deployment of unmanned aerial systems. While some people refer to these systems as "drones," the term only refers to the aircraft itself. The phrase "Unmanned Aerial System," or UAS, refers to the entire system required to operate the drone, which includes the remote controller and all the other components necessary to remotely operate the aircraft. A drone can be small enough to fit in the palm of a hand or be as large as units operated by the military.

Today, drones are often considered new technology, but their military use dates as far back as the 1930s. The military invested billions of dollars to develop sophisticated hardware and interactive software programs for drones involved in surveillance operations, reconnaissance missions, and weapons deployment.

A major advantage of using drones instead of conventional military aircraft is that drones eliminate the need to account for the lives of pilots when planning military missions. This allowed decision-makers more objectivity when they considered the potential risks of operations.

The military laid the groundwork for today's drones.

The Commercialization of Drones

In recent decades, the public release of military technologies (such as the internet and GPS satellites) has had important implications for commercial uses. Those who want to commercialize drone use quickly realized that the science and technology behind military drones provided a good starting point. They looked for ways to simplify the aircraft for public use and other specialized applications in different industries.

The DJI Agras T30 is a spray drone designed for use by commercial applicators and farmers.

In the early days, one obvious disadvantage of military drones were the hefty price tags that came about from highly advanced capabilities such as detection, communication, and photographic technologies.

Additionally, military drones were designed for specialized personnel who were trained in their operations and functions. For drones to become commercialized for the general public, manufacturers needed to develop a more "turnkey" solution so people of all skill levels could operate drones for hobbies or commercial businesses.

Additional disadvantages of adapting early military drones for public use included:

- Their size and bulkiness
- Operations, features, and functions were too specialized for civilian uses
- Systems were complex
- Public operators could not use software that the military deemed confidential and restricted
- Drones lacked important features for use in agriculture and other industries
- Operators required a high level of competency atypical of the general public
- A regulatory framework was lacking for flying and application

Once drone technology was released to the public, drone manufacturers focused on the potential commercial uses of available technology. They developed new features that could be added or removed to improve the utility and value to end users. Much of the repurposing was developing, adapting, or modifying copyright-protected software that could be used by industries such as agriculture or the government.

This publication describes the current state of drone technology for making liquid pesticide applications. Our goal is to inform and provide the current best management practices to those interested in using drones for applying pesticides. We want to ensure readers will be able to operate spray drones safely and effectively.

The system on this DJI Agras T30 allows operators to select standard ground equipment nozzles for spraying.

A Drone by Any Other Name Is Still a Drone

For many people, the term "drone" is associated with a tool used by the military for surveillance operations. As a result, many users have tried to rename drones to distinguish their nonmilitary uses from those used by the military.

Some of these names include:

- Remotely Piloted Aerial Application Systems (RPAAS)
- Unmanned Aerial Vehicles (UAV)
- Small Unmanned Aerial System (sUAS)
- Remotely Piloted Vehicle (RPV)
- Remotely Piloted Aircraft (RPA)
- Remotely Operated Aircraft (ROA)
- Unmanned Aerial System (UAS)
- Unmanned Aerial Spray System (UASS)
- Unoccupied Aerial Vehicle (UAV)
- Uninhabited Aerial Vehicle (UAV)

While some of these names are used, the authors will use the more common "drone" throughout this publication when referring to the aircraft, controller, and entire system needed to operate the remotely piloted unit.

Drones Finding Broader Uses

For the reasons above, drone manufacturers had to make major modifications, including redesigning aircraft, repurposing software, and changing onboard imaging equipment. One can only conclude that the wide acceptance of drones has been a function of these enterprises accomplishing their goal of producing a product with practical uses for the public.

Drones for Recreation

Remotely controlled, fixed-winged model airplanes have been around for decades. Many can fondly remember their parents or grandparents teaching them to fly model planes or attending events where pilots competed against one another for best of class. Newer models have more intuitive controls and more advanced features than the old models.

Drones for Imaging

One of the first and most popular applications of drones was to capture aerial images. These images may be traditional photographs or images from specialized cameras, such as thermal (heat) cameras or multispectral (specific light wavelengths) cameras. Some modern drones have the ability to hover and capture a 360-degree view, allowing them to closely inspect areas inaccessible by roads, vehicles, or potentially unsafe locations.

Industries and government agencies have taken advantage of the imaging capability of drones to:

- Fly under or on the sides of bridges and buildings to inspect for cracks and other defects
- Inspect utility structures or in areas where ground equipment cannot reach

- Inspect sewer and storm drainage pipes
- Inspect the tops of silos for corrosion or other damage
- Monitor the movement of wildlife
- Examine pipes running through marshes for leaks
- Search for missing people and livestock
- Allow fire departments to determine remaining hot spots that could reignite wildfires or building fires and to assess the overall extent of fires during rescue operations
- Measure and document the impact of natural disasters such as floods, tornadoes, and wildfires
- Describe the extent of emergencies resulting from train derailments, oil spills, landslides, and collapsed roads and bridges

(A) Drones are commonly used to inspect fences; (B) survey fire damage in a field; and (C) document storm damage.

Drones are also useful for gathering immediate information about property damage. This drone information can direct people to specific areas of interest for more efficient inspections. Considering the dangers of inspecting a collapsed building, road, or bridge, the remote views drones offer can provide invaluable information while substantially reducing the risks to inspectors.

For these reasons, manufacturers worked with camera companies to equip drones with modern sensors to capture high resolution images, record high-definition video, stream these images in real-time to the pilot and crew, and document the images and videos for viewing and processing later.

Components of an Imaging Drone

(A) This quadcopter (four rotors) drone hovers near the ground. Its camera can capture photographs and video. The camera is attached to a gimbal that can adjust the viewing angle.

(B) This controller can connect to a tablet, so operators can monitor the drone's movement. Many controllers have built-in displays.

(C) The single battery on this specific drone provides enough power for approximately 25 minutes before it needs to be recharged.

(D) This image shows the drone's USB port, which is one method for transferring data.

(E) The arrow points to the drone's obstacle sensor, which notifies the pilot about nearby objects and obstacles in the drone's path. Many newer drone models have forward, rear, side, top, and bottom obstacle sensors. Many of these features are shared across makes and models of drones in use today.

In-Field Crop Scouting and Analyzing Field Conditions

Many drone companies thought that by adding better cameras or sensors, farmers would realize the benefits of seeing their farms, fields, or crops from different angles. However, farmers found it difficult to justify the expense of drones. In addition, many farmers may not have grown up with smartphones and related technology, so they may not be comfortable with operating drones with seemingly little return on their investments.

On the other hand, advanced sensors provided decision-making value to consultants, ag retailers, agronomists, and precision ag companies. Drones became another tool that was integrated into the portfolio of services they offered to their clients and customers.

Drones equipped with sensors allow users to monitor crop health over entire fields. Green plants are healthy plants, while those in red (which do not reflect the green color of chlorophyll) indicate unhealthy plants. However, what is causing these unhealthy plants is unknown — someone must evaluate the area on the ground. Maps like these are detection tools that can help better manage a crop with problems.

Some of the first drones flown in agricultural settings showed field drainage problems and detected crop nutrient deficiencies, crop weather damage, and the severity of pest damage. To some extent, satellite and traditional aircraft-based imagery was used in the past for these applications, but the resolution of these sensors was not capable of capturing subtle differences that drones could detect. Many drones with modern sensors may have a resolution of 0.25 square inches per pixel, depending on the flight height, while a satellite may have a resolution of several square feet per pixel.

A Cloud Full of Data

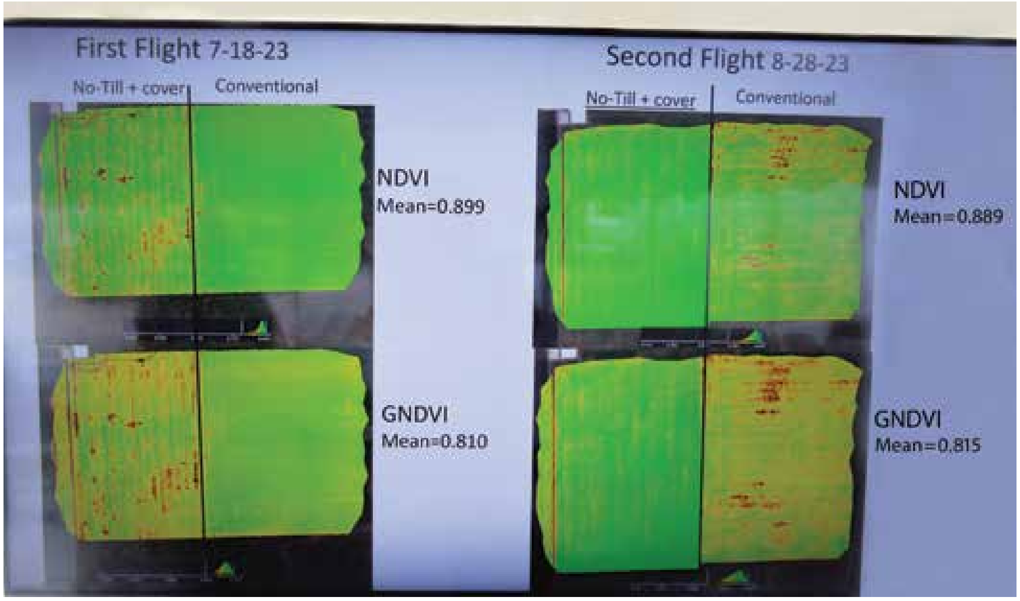
Drones normally save data to an onboard memory card. Users exchange the memory cards when the cards are full, and it is most common for users to manually transfer data to a computer. Today there are software and service providers that offer automatic data transfer to a cloud-based database or that can even visualize data in real time if an adequate internet connection is available.

Drone manufacturers were asked to equip drones to collect data. Manufacturers responded by equipping drones with built-in analytical capabilities to collect and send millions of data points from their aircraft to a receiver or computer. This data collection also allowed researchers to utilize a complex set of algorithms capable of assessing plant health status using the different wavelength bands the camera captured.

Demand for more sophisticated sensors grew as users learned about these new techniques available to monitor crop health. The new cameras needed to capture high-resolution images that collected many specific light wavelengths associated with crop stress. This led to multiple changes in sensors that are mounted on drones for data collection.

Some of the changes in sensors included:

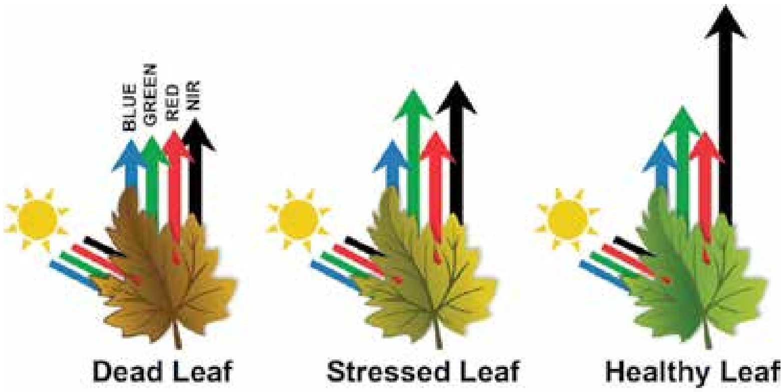
- ***Upgrades to onboard RGB cameras.*** Early digital cameras mounted on drones typically had poor resolution and no zoom features. These cameras could capture general patterns in a field. More advanced drones now have cameras that can capture high-resolution images (such as 48-megapixels) and feature mechanical zoom options. This means the camera can create pictures composed of some 48 million pixels, each pixel containing red, green, and blue color (RGB) wavelengths. These high-definition images can distinguish individual leaves and symptoms on leaves that show diseases, nutrient deficiencies, or insect pressures. Many of the cameras are comparable to professional grade photography equipment.



Drones with sensors can allow users to monitor crop health and progress at multiple periods during the growing season.

- ***Improvements in sensor resolution and angle of view.*** The latest cameras have wide-angle views and higher resolution of individual sensors than cameras used on early drones.
- ***Improvements in multi-light spectral sensors.*** Integrating multi-spectral sensors that can detect bands of light beyond RGB assisted individuals making better field decisions. These sensors include near-infrared and red edge wavelength bands. This additional information allows software to compute different indices such as Normalized Difference Vegetation Index (NDVI) or Normalized Difference Red Edge (NDRE), which determines the "greenness" or stress of a crop beyond what can be seen with the naked eye. This spectral information can create color-coded maps where green means "healthy" and yellow and red indicate "stress." Users can then analyze data through multiple vegetative indices developed by university and industry researchers.

This DJI Mavic 3M has a multispectral camera, which can capture green, red, red edge, and near infrared bands. The larger gray top is the RTK receiver.

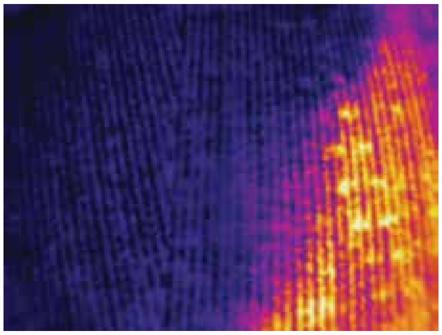


Healthy plants absorb blue light and reflect green light.
Image from midopt.com/healthy-crop.

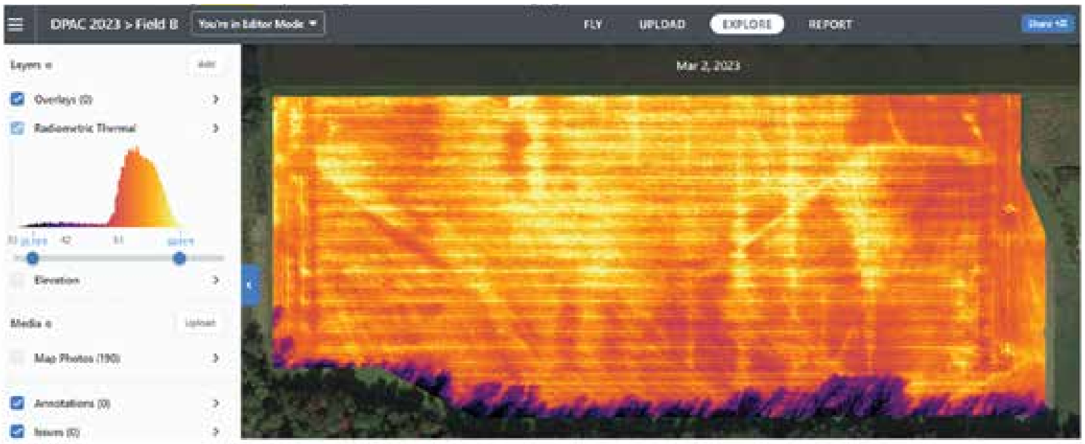
The figure above shows how a healthy leaf reflects a greater amount of near infrared (NIR) wavelength compared to the stressed and dead leaf relative to the red, green, and blue wavelengths. Indices that can exploit the near infrared wavelength have a greater chance of distinguishing between healthy and unhealthy leaves compared to what the naked eye can detect, which only sees the red, green, and blue wavelengths.

- ***Improvements in thermal and infrared (heat) sensors.*** Users added thermal and infrared sensors to measure the heat energy emanating from a crop, soil, or other objects. If objects are "hot," sensors will pick up more thermal energy, while cooler objects emit less heat on the surface. These thermal images convey information about varying levels of soil moisture across the field, detect crop canopy temperature differences, or identify plants that are water- or nutrient-deficient and stressed.

Since healthy plants with adequate water can cool themselves by evapotranspiration, the hot zones in a field may reflect poor crop growth or a reduced plant canopy. In addition to analyzing the crop, operators can use thermal imagery to inspect structures on the farm (such as barns and high tunnels) to ensure they are ventilated or insulated properly.



This photo shows the temperature difference between areas that have and have not been irrigated. The yellow and orange areas indicate much hotter temperatures (and water stress) than the blue and black areas.



This figure is a thermal image of a field before any crop was planted. The yellow regions show tile lines that have higher soil temperatures from water drainage. Darker colors are more likely to be wetter soils, indicating cooler soils. Thermal imaging can be taken on bare ground to determine elevation for ways to better manage water drainage.

Spray drones can apply pesticides, such as this one that is applying fungicide to corn.

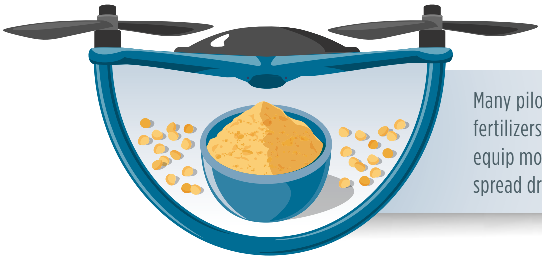
Applying Pesticides and Other Agricultural Inputs with Drone Sprayers

The next logical step in drone evolution in agriculture was to turn them into miniature aircraft equipped with spray systems to apply pesticides. Although some fixed winged drones are equipped to apply pesticides, fertilizers, and seeds, multi-rotor drones seem to be better suited for agricultural applications in fields of varying sizes, shapes, and topographies. For these reasons, much of this publication focuses specifically on rotary-wing drones, which are most common among drone applicators.

The idea of using drones to spray pesticides was put into practice first in Japan in 1997 with the Yamaha RMax drone. The drone looked like a small helicopter powered by an internal combustion engine. This high-powered drone had a single rotor with a diameter of about 10 feet, weighed 207 pounds, and had a spray tank capacity of slightly more than 4 gallons. With a full tank and spraying at 1 gallon per minute, the drone's tank was empty in about 4 minutes.

Ken Giles at the University of California-Davis, was an early pioneer with drones in North America. In 2010, he used the RMax drone that weighed 220 pounds when loaded to apply pesticides in vineyards, then on field crops and orchards. It is likely that Giles was the first to get both federal and state authorization to use drones to apply pesticides.

While this publication focuses specifically on drones applying liquid products, many pilots have found them useful for applying dry materials such as fertilizers and cover crop seeds, too. Most new drone sprayers can be equipped with optional kits to meter and spread dry products.



DRONE **FACT**

Many pilots find drones useful for applying dry materials (such as fertilizers and cover crop seeds) as well as pesticides. Users can equip most new drone sprayers with optional kits to meter and spread dry products.

Interest in Spray Drones for Pesticide Applications

The acceptance of spray drones in agriculture indicates a greater interest among growers in using and benefiting from them on their farms. We examine several documented benefits that spray drones bring to agriculture and industry on the following pages.

Spray Drones Finding Wide Utility

One thing is for sure: agriculture, industry, and government have quickly adapted to employing spray drones in ways no one could have imagined five years ago.

Each year, spray drones continue to expand into new markets. Emerging uses for spray drone technology include managing issues in several settings, including:

- Mosquito control
- Ponds and lakes
- Utility rights-of-way
- Fruit trees
- Blueberries
- Grapes
- Agronomic crops
- Pastures and rangeland
- Turf
- Forests
- Pastures and hayfields
- Vegetables
- Greenhouse roof painting
- Cover crop seeding
- Fertilizer applications
- Spot spraying invasive weeds

Drones will continually evolve to meet the ever-changing needs for each specific industry and agricultural sector.

DRONE BENEFIT:
Relatively Low Cost

Drones can be a lower cost, more suitable piece of equipment for small- and medium-sized farms. A modern self-propelled sprayer can easily cost 15 times more than a current, well-equipped spray drone. However, the cost of an enclosed trailer, mixing tanks and equipment, generators to charge batteries, and possibly a new truck can run the cost to more than $100,000.

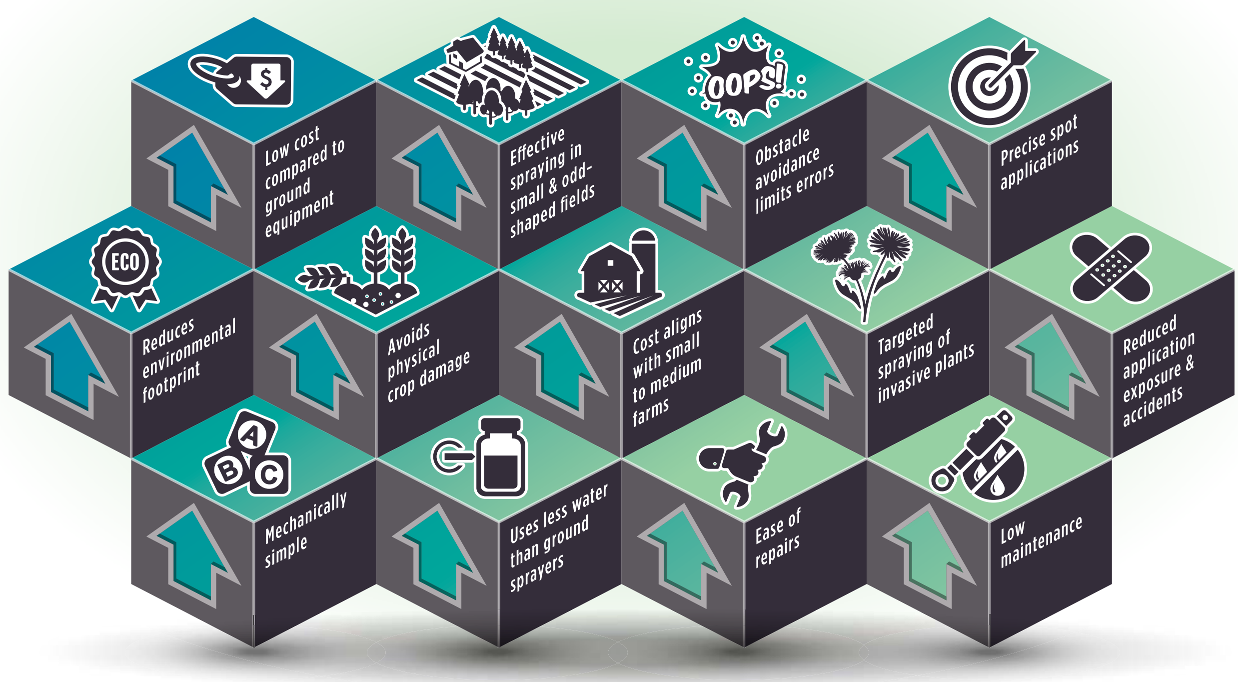
DRONE BENEFIT:
Challenging Fields and Difficult to Access Terrains

Many areas within fields or on farms may have limited access by ATV, boats, wheeled sprayers, and trucks. This is especially true for applicators trying to control mosquitos in the interior of remote areas or right-of-way companies treating brush around pipelines that run through marshes or treating under mountaintop powerlines. Aerial and ground rig operators turn this type of work down because it is not profitable based on the low number of acres and the high costs of operating the equipment.

There are situations where drones can spray fields when soil conditions are too wet for ground access. Wheel track compaction can be an issue that using drones can avoid. Furthermore, some manned aircraft or larger ground rig custom applicators require a minimum number of acres to be applied.

Drones may offer farmers with smaller operations an opportunity to hire custom spray drone services that require fewer acres. Drones can make applications to small fields much easier than some equipment; however, like other equipment, efficiency and operator satisfaction increases for drones in big square fields similar to conventional application equipment.

In many cases, steep hills can make pesticide applications with ground sprayers difficult and dangerous (think of equipment rollovers). A drone operator can fly hilly areas, which helps prevent fatigue and potential injury from people carrying backpacks up and down steep terrain and uneven ground.



THE UPSIDES OF SPRAY DRONES

Agriculture and businesses can benefit from spray drones.
Drones have particular qualities that make them worth your time and money

DRONE BENEFIT:

Autonomous Presets and Obstacle Avoidance

Spray drones flying closer to the ground (10 to 15 feet) are typically equipped with supplementary radar sensors that detect obstacles in all directions — above, below, left, and right. These sensors allow for drones to automatically follow terrain, so they can maintain altitude for proper application and avoid obstacles.

The 360-degree radar can essentially scan surroundings continuously. The drones involved with applications require cameras that show front images (that is, field views of what are you about to encounter) to create an applicator log that can track where the drone has been.

Cameras on spray drones provide real-time visuals of the approaching terrain, crop, and other obstacles during applications.

Autonomous take-off and landing flight options help overcome operator errors. These safety features are analogous to the parking sensors and back up cameras on modern passenger vehicles. The intent is to make piloting drones safer and less stressful for operators and to help avoid accidental crashes and mid-air collisions.

DRONE BENEFIT:

Applications Made Within Line of Sight

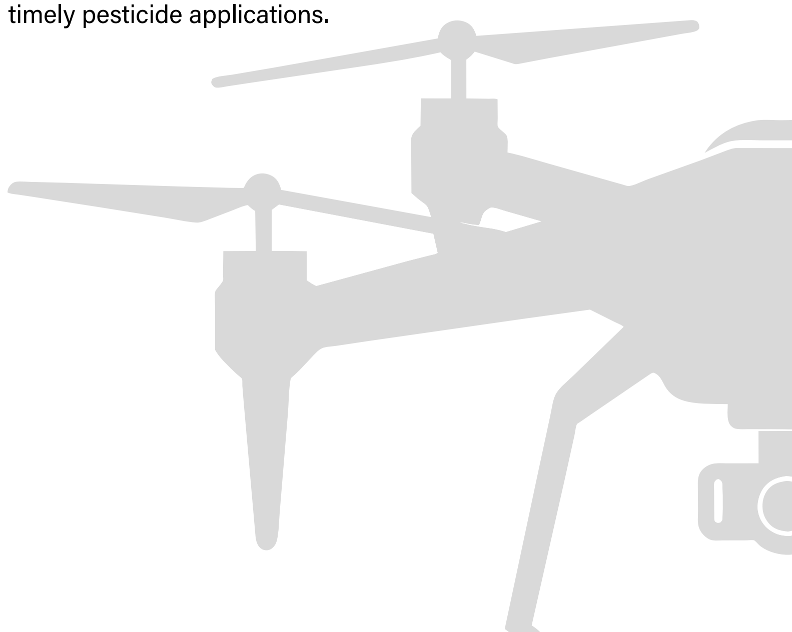
Drone operators know where they are applying, because they can view the flight paths and areas they are treating with onboard, real-time cameras during applications. In addition, pilots must maintain line-of-sight with their drones throughout their flights to monitor any performance or safety issues.

Spray drone controllers provide operators real-time information about application rates, speed, flight height, and droplet sizes in most newer drones. All of these parameters are necessary to track applications. Although line-of-sight is a current FAA regulation, at the time of this publication there are petitions to remove these requirements for pesticide applications awaiting FAA decisions.

DRONE BENEFIT:

Farmers Control Spray Timing

By owning their own drone sprayers, farmers can more easily control application timings than they can if they must rely on airplane services that have long lists of work to be done. This is more than just convenience — farmer-owned drones can enhance crop protection efforts with more timely pesticide applications.



Some fields (like this one) are easier for operators to maintain a line of sight than they could with rolling or uneven fields, especially when spray drones move farther away.

DRONE BENEFIT:

Large Pool of Potential Pilots

Drone sprayers are easy to operate and almost anyone can be trained to safely and effectively operate them in a relatively short time.

DRONE BENEFIT:

Reduced Environmental Footprint

Spray drones can reduce site disturbance, soil erosion, and site compaction compared to ground equipment.

DRONE BENEFIT:

Avoids Physical Crop Damage

Drones are also an effective and safer option for taller or thicker canopy crops where ground equipment can damage the crops, especially in the tire or tracks or in the presence of viny weeds like burcucumber and morningglory. Fungicide applications after corn tasseling have been one of the most common uses of spray drones in agronomic crops. Crop damage can also be reduced in smaller, irregular shaped fields.

DRONE BENEFIT:

Combats the Spread of Invasive Weeds

Operators can map weeds that may be growing in certain parts of fields, pastures, rangeland, or wetlands, and then use drones to spot-spray these areas at a much lower cost than broadcast applications. Because they are airborne, drones will not pick up invasive weeds, which helps to prevent their spread from field to field.

DRONE BENEFIT:

Reduced Applicator Exposure and Accidents

Using drones to spray can significantly reduce applicators' exposure to pesticides compared to making the same applications with certain types of ground-based equipment — particularly open-cab sprayers, backpacks, and ATVs. With spray drones, applicators are physically distant from the immediate area where the spraying is done. However, filling drone tanks, swapping and charging batteries, handling controllers, and taking sprayers back to trailers or trucks can create important sources of operator exposure. It is important that spray drone operators still follow the PPE guidelines on pesticide labels to minimize this exposure potential.

DRONE BENEFIT:

Work Around Obstacles

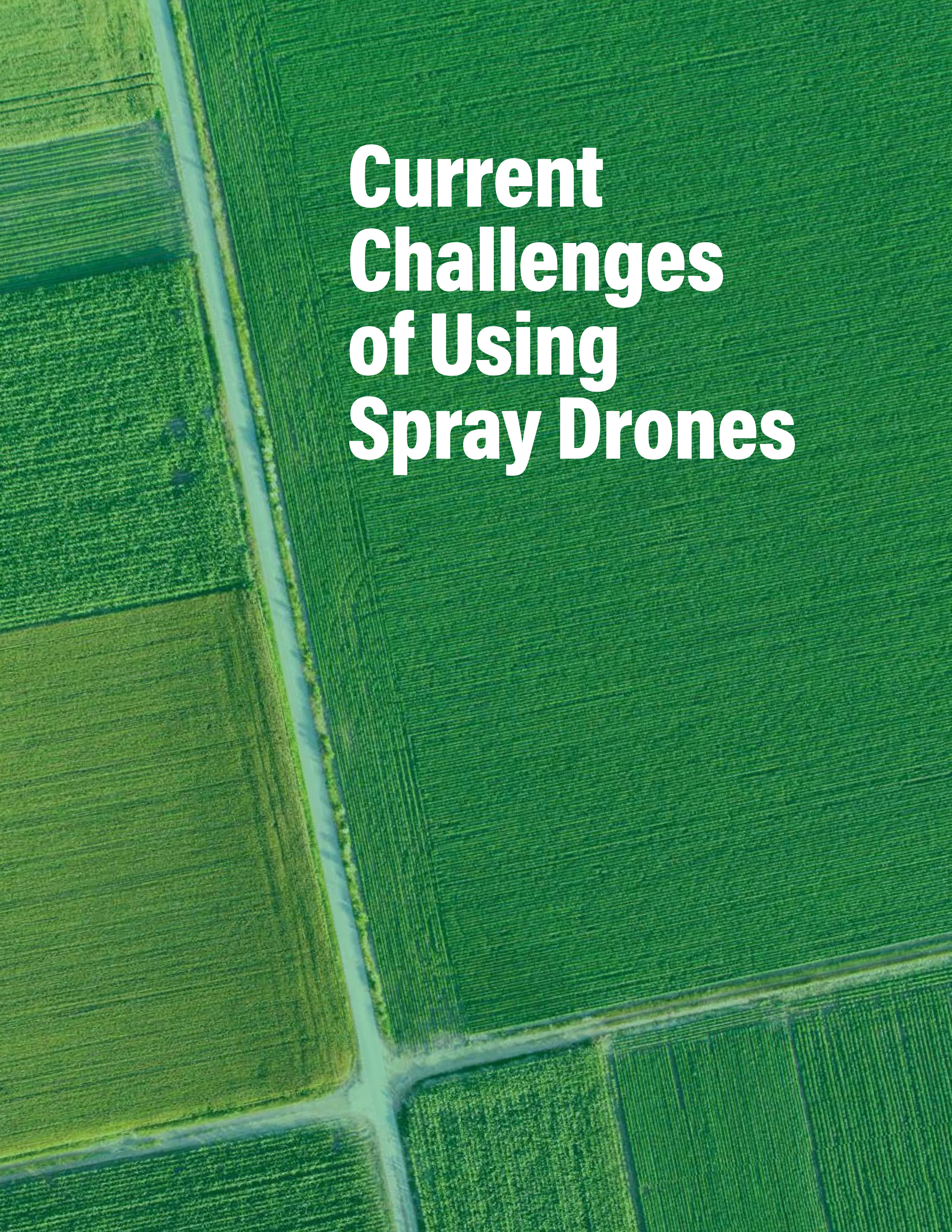
Drones can spray around obstacles and tree lines much easier than airplanes and larger ground sprayers.

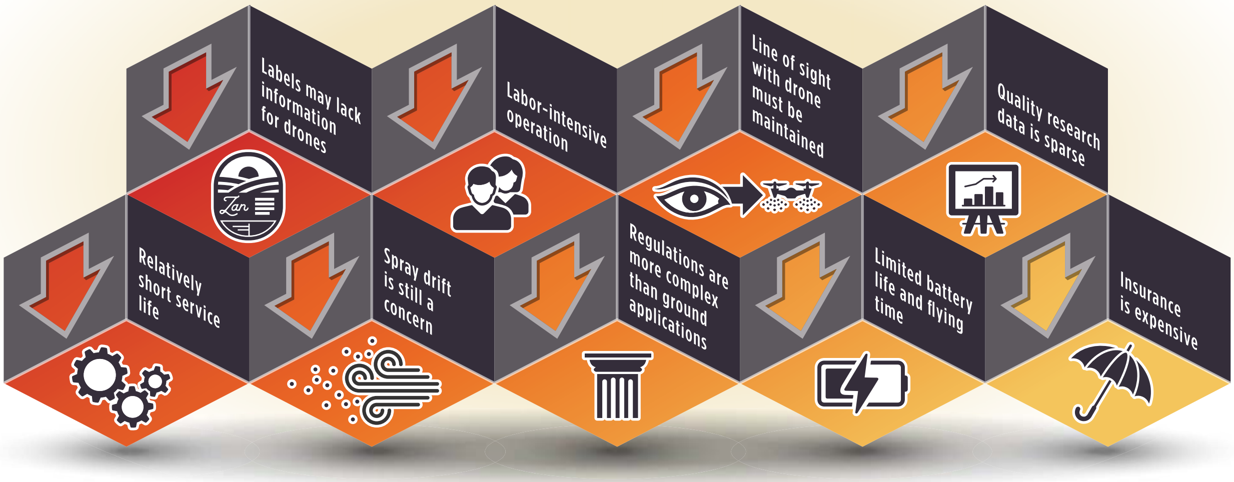
DRONE BENEFIT:

Easier Repairs

Repairing spray drones after a forced landing or crash is fairly easy. Operators can fix most of the issues simply by replacing broken or malfunctioning parts. Additionally, if operators are intimidated by the thought of repairing their own drone, there are often trained technicians available to do the repairs.

Current Challenges of Using Spray Drones





THE DOWNSIDES OF SPRAY DRONES

Although using drones in agricultural settings can be positive, there are some downsides you should consider

While there are many benefits associated with using spray drones, there remain issues, questions, and concerns that users should consider before purchasing a drone and using them to apply pesticides. We describe some of these considerations on the following pages.

DRONE CONSIDERATION:
High Volume

Drones cannot currently compete with ground rigs for applications that require high carrier volumes.

DRONE CONSIDERATION:
Pesticide Labels Lack Drone Information

In states where approved, spray drones could apply pesticides as long as the pesticide includes aerial applications on the product label. However, spray drone applications must still follow all of a pesticide label's aerial application requirements, which could be a challenge because these requirements were typically written for traditional fixed wing aircraft or helicopters.

Some pesticide labels specify that if applicators cannot follow all aerial application requirements on the label, then applicators should not apply the product. This presents a challenge for spray drones with unique qualities that set them apart from traditional aerial applications, such as travel speed, rates, and nozzle configurations. For example, many pesticides require a minimum spray volume of 5-10 gallons per acre, which spray drones may not be capable of providing. It is feasible for spray drones, but it just reduces the acreage completed per day and often increases the cost.

While both traditional aircraft and drones dispense pesticides from the air, there are likely many differences between traditional airplane and drone applications operating under standard procedures. The biggest one is the spray dynamics between both methods. Aerial application sections of pesticide labels may list spray heights, carrier volumes, nozzle types, boom widths, and travel speeds specific to manned aircraft applications that drone sprayers cannot match.

GENERAL DIRECTIONS FOR USE

Initial and residual control are contingent upon thorough crop coverage. Apply with ground or aerial equipment using sufficient water to obtain full coverage of foliage. Apply in a minimum of 2 gal per acre by air or 10 gal per acre by ground unless otherwise specified in this label. When foliage is dense or pest pressure is high (heavier insect or egg pressure, larger larval stages), use of higher application volumes and/or higher use rates may improve initial and residual control.

DRONE **FACT**

The aerial application sections of some pesticide labels provide spray heights, carrier volumes, nozzle types, boom widths, and travel speeds that were developed for manned aircraft. These instructions may not always apply to drone sprayers.

It is unknown whether pesticide manufacturers will modify pesticide labels or provide supplemental labels specific to drone sprayer applications. Many manufacturers have indicated they may consider adding drones to new pesticide product labels, but that they do not plan to modify existing product labels because of the expense involved.

Pesticide applicators are requesting label information to address pesticide safety for applicators and the environment, as well as product performance guidelines that are unique to spray drone applications. For some time, pesticide registrants have been working with the EPA on future drone labels, but dedicated drone labels are probably years away. The wide varieties of spray drone designs and operations create challenges to forming general application guidelines on labels that assure minimum adverse effects.

State-led agencies that regulate pesticides differ on how they interpret the aerial application instructions on labels. Some states allow drones to apply products under the aerial part of the label, while other states prohibit products unless the product labels specifically mention drone applications. In addition, operators often need to be licensed in each state where they will use their drones.

States also vary on what additional certification(s) — other than the ones required by the Federal Aviation Administration (FAA) — farmers and commercial applicators must have to use drones for applying pesticides. One state may require an aerial certification only, while another state may require additional certifications (such as aquatic or right-of-way) added to the aerial certification.

Contact your state pesticide regulatory agency to discuss what certifications they require to use drones to apply pesticides.

DRONE CONSIDERATION:

Federal Regulations Require Two People

Current federal regulations require two people at each drone application site, which means you need to pay two people to spray with a drone rather than just one for a manned aircraft or ground rig. The Federal Aviation Administration currently requires two people to fly one spray drone without a waiver.

One is the dedicated pilot whose sole job is to pilot the aircraft. The second person is the visual observer whose sole purpose is to watch for obstacles or other hazards such as other drones or manned aircraft during the operation. Operators have filed requests for exemptions with the FAA regarding this regulation, so there may be a shift in this rule in the future.

DRONE CONSIDERATION:

Must Maintain Line of Sight

A “visual observer” must maintain a line of sight with a drone according to FAA regulations. This rule can make applications challenging because crop canopies can restrict visual lines of sight, especially in areas with rolling topography or areas behind tree lines.

DRONE CONSIDERATION:

What You Know Today May Change Tomorrow

Consider that boom sprayers and aerial sprayers have been used for 100 years. Billions of research dollars have been invested to determine the best spraying practices for ground sprayers that will lead to the most effective crop protection and to train applicators to best utilize these practices.

With commercial spray drone use still in its infancy, research is only beginning to be discussed at professional meetings, trade associations, and cooperative extension applicator training meetings. Experts expect that some of the information developed for ground sprayers and traditional airplanes will transfer to drones. However, new research undoubtedly will show significant differences between drone applications and other application forms.

Researchers are examining ways to better understand the spray deposition and efficacy of spray drones to make proper application recommendations.

Agricultural researchers are investigating the similarities and differences between planes, drones, and ground rigs when applying the same product.

Researchers are investigating many questions that may change how drones apply pesticides in the future. The answers to these questions may also vary by drone manufacturer, model, and the overall size of the spray platform.

- What are optimum application heights?
- How will wind conditions, drone types, nozzle size/designs, or the types of pesticide being applied affect applications?
- Will spray heights vary by application type (spot versus broadcast)?
- What is the optimum carrier volume?
- Are there nozzles or droplet sizes that are better suited for drones?
- Are rotary nozzles better than traditional hydraulic nozzles?
- Will drones with linear booms perform spray differently than drones with individual nozzles immediately below the rotors?
- For drones with linear booms, what are the optimum boom lengths in relation to the location of the propellers?
- For boomless drones, what nozzle configurations and how many nozzles under the drones will provide the best applications?
- What spray nozzle pressures on drones will provide better coverage, efficacy, and reduced off-target movement?
- How do drone speeds affect spray coverage and pesticide efficacy?
- Is there an optimal flight speed where the overall application is optimized to maximize pest control and minimize spray drift?
- What drone speeds are best for canopy penetration?
- How wide can drones spray effectively?
- What application parameters affect rotor downwash?
- What are the best flight patterns for effective pesticide applications with drones? Is it along, across, or at an angle with the crop rows or the wind direction?
- How does the lack of agitation in spray drone tanks affect pesticide applications and efficacy?

Some spray drones are equipped with common ground equipment nozzles (such as the XR nozzle to the left); however, these nozzles have much smaller orifice sizes than commonly used with ground applications. More modern spray drones use rotary atomizer (spinning disc) nozzles, like that observed on the DJI Agras T40 (right).

DRONE CONSIDERATION:

What You Use Today Might Not Be Used Tomorrow

Drones were initially designed for capturing imagery and collecting data which largely remains true with today's aircraft. Just because they are equipped with a solution tank, pump, and spray nozzles does not change what they were originally designed to do.

One of the many differences among drone models is how the spraying systems are equipped. This drone is equipped with conventional nozzles underneath the spray rotors.

We expect that the commercial use of spray drones will expand and be part of an evolution that will incorporate advances in spray system design, plumbing, nozzle placement, battery life, sensors, and pump specifications. There is no universal model, design, or software system that is currently considered an industry standard.

Eventually, certain designs with the greatest efficiencies and value will come to the forefront and become the standard of how a drone should be designed for spraying. This process will be similar to the development and adoption of precision ag equipment currently used in crop production where some level of compatibility and operation has been established.

What you see demonstrated or sold today will be radically different from what you see tomorrow. Imaging and spray drones evolve with advanced technologies.

DRONE CONSIDERATION:

Spray Drift Remains a Top Priority

Pesticides moving off-target during spraying is a major concern regardless of the equipment applicators use. It is nearly impossible to completely avoid spray drift. However, operators can minimize it by selecting the best application parameters, especially the nozzles, and operating them at optimal conditions. One of the parameters that affects pesticide drift is the distance the spray droplets must travel from the nozzle to the soil or crop target.

There are smartphone and tablet applications to determine if environmental conditions are suitable for application.

For ground equipment the typical recommendation is to have the booms about 24 to 30 inches from the target canopy or soil. Even at that relatively close height, spray drift is among the biggest challenges with ground sprayers.

Of course, the rotor downwash from spray drones may influence the spray cloud and serve as an air curtain to help drive spray droplets down to the target. However, what percentage of the spray cloud is in the downward rotor downwash and is pushed either laterally away from the drone or upward into the wind current is unknown.

Preliminary results from a small number of studies indicate a drone flying higher than 10 feet above the crop canopy is likely to cause higher levels of off-target spray drift. Drift potential from spray drones is expected to increase considerably as flying speed and flight altitude increase. Boom configuration in hydraulic systems can also change drift potential based on where booms are placed on the drones and nozzle locations in that particular configuration. As with ground and manned aerial applications, boom configurations for drones must be tested for effective swath before field applications to ensure best practices.

DRONE CONSIDERATION:

Regulations a Large Hurdle

Individuals who want to operate drones have many regulatory layers to navigate, which takes time. For example, the Federal Aviation Administration (FAA) requires drone operators to comply with several requirements. Some FAA restrictions include: drones must be registered, pilots need to pass an exam, pilots must maintain a visual line of sight with their drones, and operators must obtain permission to fly in restricted air space.

This photo shows the spray distribution and swath emitted from a DJI Agras T40 using rotary atomizer (spinning disc) nozzles.

Nozzle type, spray height, and carrier volume are some of the factors researchers are evaluating to determine optimal spray drone applications.

Drone manufacturers have provided the capability to swarm, meaning one remote can operate several drones at once. If the drone is less than 55 pounds, swarming has been approved for up to five drones; however, the vast majority of spray drones operate above the 55-pound limit.

For many years, perhaps the most severe restriction was that operators could only fly one drone at a time without getting a waiver from the FAA when a drone weighs more than 55 pounds. This changed in 2024, when Hylio was granted FAA approval to fly three spray drones weighing more than 55 pounds with just one pilot and without an observer (docket ID FAA-2023-1833).

While swarming allows three drones to be flown with additional crew, that same crew of two now has three drones to refill at a time instead of just one, which would affect productivity. This has the potential to be a game-changer for drone applications and treat larger agricultural operations more quickly.

However, the exemption or waiver process may take several months. Applicants must provide proof that the extra precautions pilots have proposed to be exempt from regulation will provide a similar standard of safety as the rule provides. However, it is expected that the FAA will reduce conditions requiring exemptions and the approval period for waivers will be expedited in the future.

DRONE CONSIDERATION:

Expansion May Depend on Battery Innovations

What started off as a drone carrying two gallons of water has now increased to 18 gallons — and that increases with each new model. However, each additional gallon of water makes drones heavier. This increased weight reduces the time batteries remain sufficiently charged.

Smaller drones used for photographs can get upwards of 45 minutes from a single battery. For heavier spray drones, battery life has been reduced to approximately 7 to 12 minutes of flight. This means that each spray drone needs multiple spare batteries fully charged or actively being charged to keep the drone operating continuously over the course of a day's operations. We expect that battery research fueled by the electric vehicle industry will lead to transferable technology that will power drone batteries in the future.

Another issue associated with batteries is how long they require to recharge. Battery recharging can take anywhere from 10 to 30 minutes depending on battery size, the type of charging power available (110 vs. 240 volts), and how hot the batteries are. Generators that are large enough to produce sufficient wattage to charge multiple batteries at once can be difficult to find, are extremely bulky, and price and quality range widely.

Newer drone models allow for a fast charge at 240 volts and 50 amps. This can reduce charging time if the power supply (generator) is rated to provide the full current the battery charger needs to operate most efficiently. Efficient drone operators will typically have several batteries so they can use one battery while the other two or more are being charged (or already charged) and ready to be swapped when drones land to refill.

A spray drone contacted a transmission line and irrigation pivot, knocking out the power line (top). Beyond the damaged equipment, what other liabilities could the operator be responsible for (middle and bottom)?

DRONE CONSIDERATION:

Protecting Your Investment Will Require Insurance

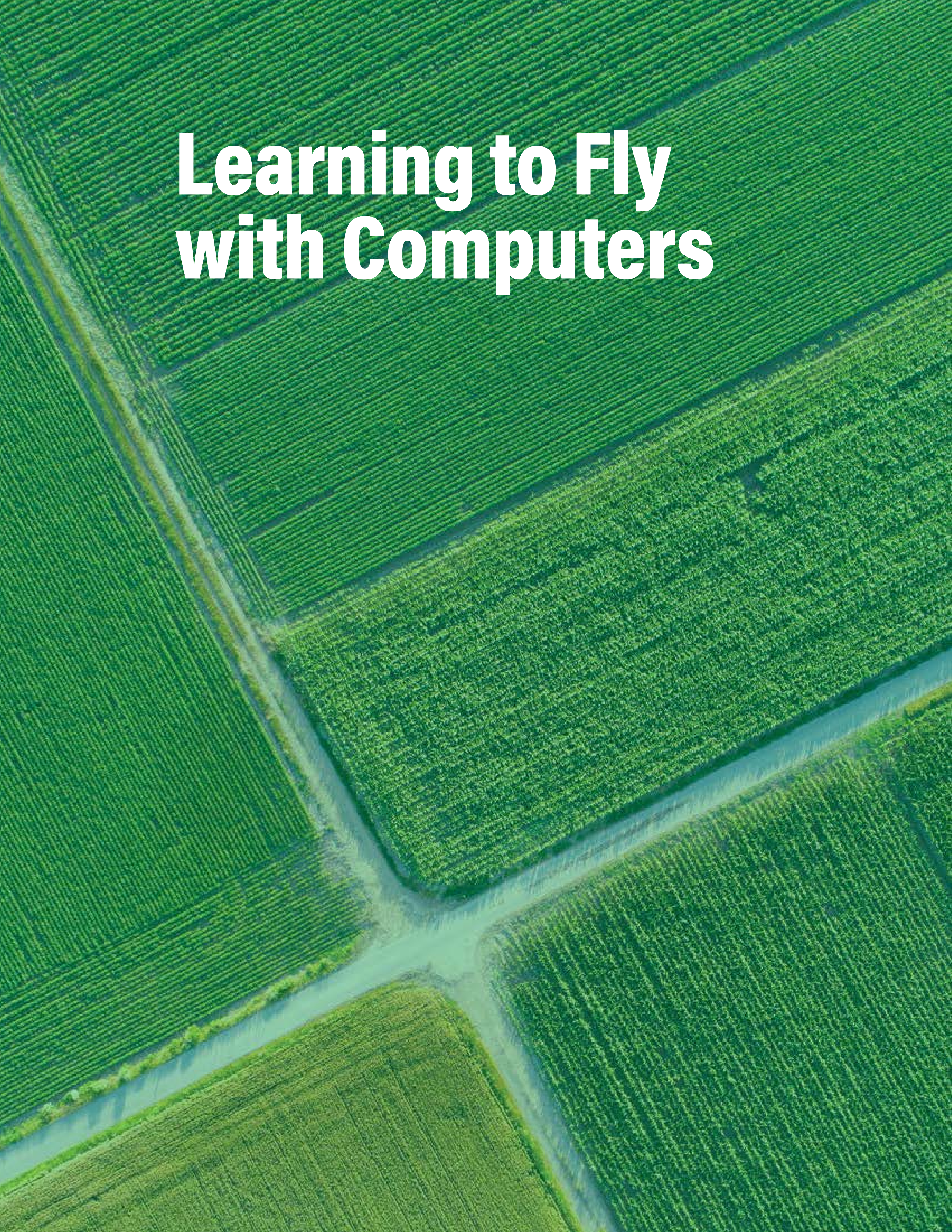
With today's drones costing $30,000 or more, crashing and destroying one without insurance coverage is risky. Flying without insurance is like buying a new truck and driving off the lot without coverage. When you have that much money invested in a drone, you don't want to take a chance on an accident or being involved in a lawsuit. Some pesticide regulatory agencies require proof of liability insurance before they will issue the certifications or licenses necessary to operate a spray drone.

Two generally accepted types of insurance are hull and liability. Hull insurance protects the drone, while liability protects against whatever damage the drone causes. Currently, there are very limited options for insuring spray drones, but this too is rapidly changing. Limited availability often means insurance coverage for a drone can be expensive, especially for liability insurance. Some drone operators are paying $4,000 to $6,000 annually per unit, but this cost includes spray drift and other liability coverages. Since drones can be repaired relatively easily, some operators only choose to get liability coverage to reduce their premiums.

If you are interested in hiring a custom spray drone application, be sure to ask if the applicator is fully licensed specifically for spray drone applications, because the insurance is not the same as what is issued for ground applications. Accidents or off-target incidents that occur from custom spray drone applications not carrying insurance could result in legal ramifications for all of the parties involved — the farmers, customers, and applicators.

For operators unfamiliar with drone software or operation, trainings are often provided at a variety of educational programs.

Learning to Fly with Computers



Each drone manufacturer has their own specific software for flight planning and controlling drone functions. Like much of agriculture's new precision technology, drone technology requires skills to effectively operate and navigate computers. For some, this may be as simple as the interface and navigation systems. Most drone technology is not much different than other common software systems or computers and displays used in modern agricultural equipment.

However, for those who are not as tech-savvy, overcoming these technologies can be daunting. Some interfaces can be difficult to manage, and some operations may be difficult to troubleshoot in the field. These challenges are compounded by a lack of adequate product and software support in the industry.

In addition to the steep learning curves with the technology, employees need to thoroughly understand the federal and state laws that govern drone use for agricultural applications. The FAA, EPA, state regulatory offices, and local governments can all be involved with creating and enforcing the rules that surround the use of spray drones. Some of those rules can be confusing, conflicting, or generally unclear because the rules and laws are continuously being updated to account for this novel technology. The good news is it should be easier to find eager employees who have both drone and computer experiences as the technology becomes more popular and widespread.

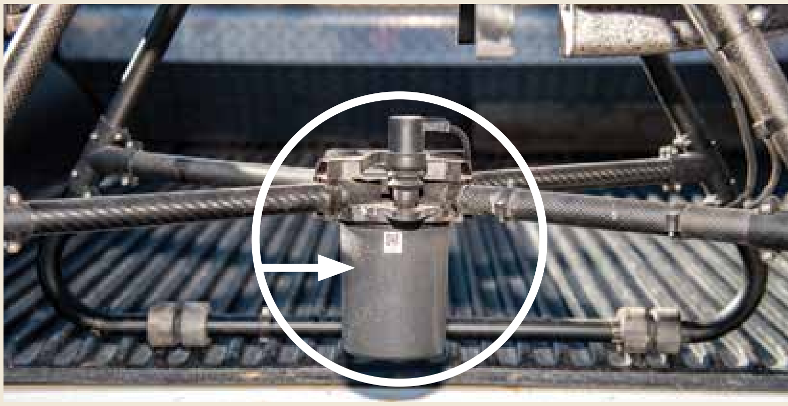
DRONE **FACT**

If you are interested in hiring a custom spray drone applicator, be sure to ask if the applicator is fully licensed and insured specifically for spray drone applications.

Components of a Spray Drone

This DJI Agras T10 has a camera in the front and is flanked on either side by an obstacle avoidance sensor.

The drone receives a signal from the controller via its two antennae. The two black panels on the side of the receiver allow air flow that helps keep the hardware in the drone from overheating.



This device is called an omnidirectional digital radar system. It measures the altitude that is recorded on the controller.

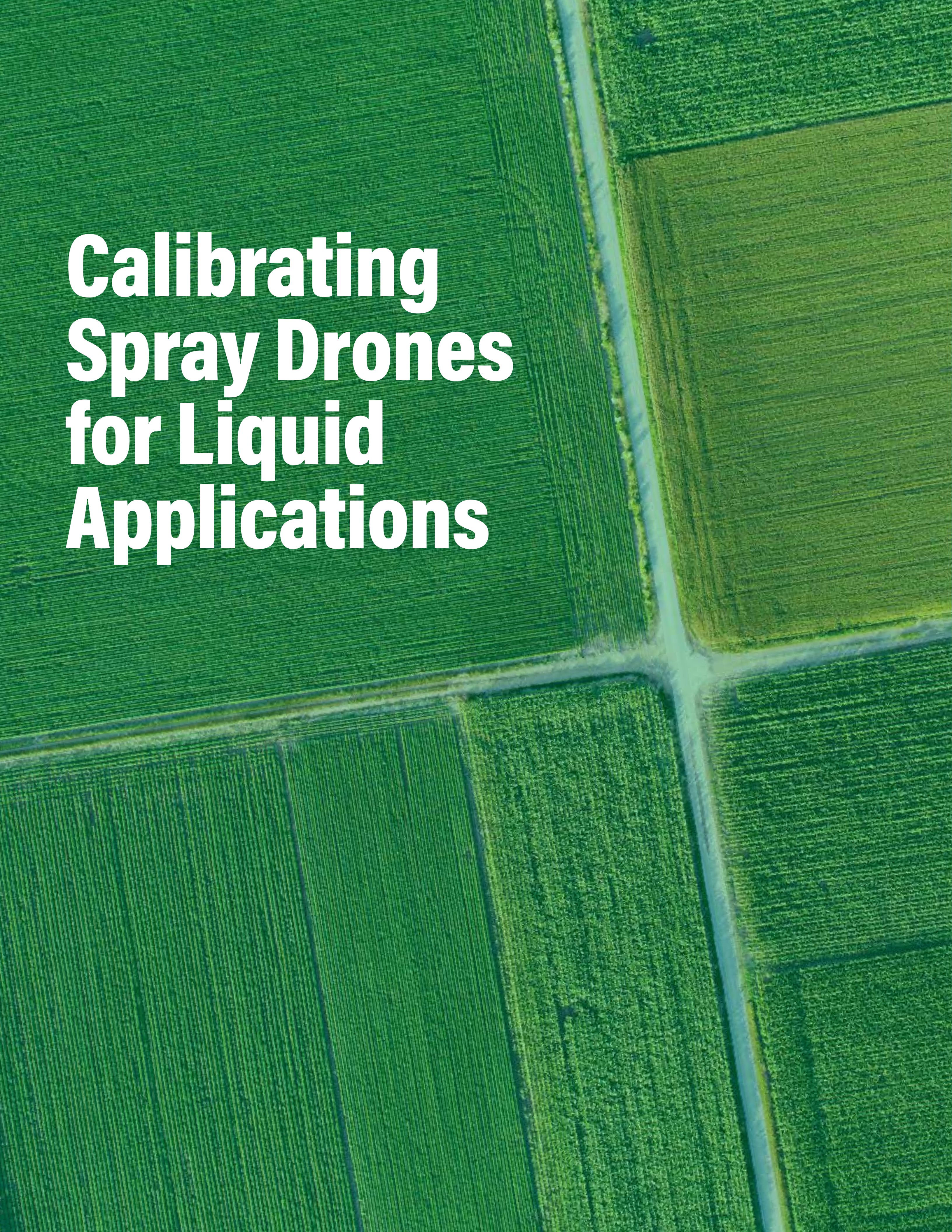
This battery snaps into place. The four light panels on the battery indicate how much battery life remains.

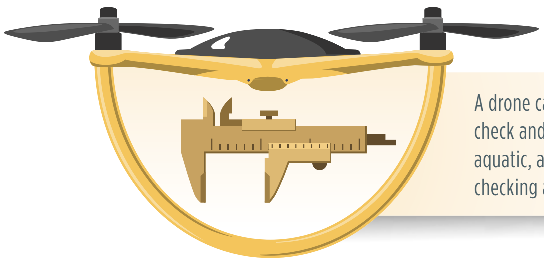
This drone's tank holds 2.5 gallons.

The drone with the spray tank removed.

This drone has four nozzles. When flying autonomously, only the nozzles in front of the travel direction turn on for spraying. In other flight mode types and higher application rates, the drone can turn on additional nozzles.

Calibrating Spray Drones for Liquid Applications





DRONE FACT

A drone can only be effective, efficient, and safe if operators properly check and calibrate them for each type of application (corn, pastures, aquatic, and so on). Maintaining accuracy depends on periodically checking and calibrating drones during spraying season.

You might assume that manufacturers would perform a standardized calibration test on their spray drones before shipping them out of the factory. It appears to be a pretty straightforward process: open the box, assemble the drone, enter the flight parameters into the controller, and mix and pour the product into the tank. You are now up and running, ready to start spraying.... right? If only it was this easy!

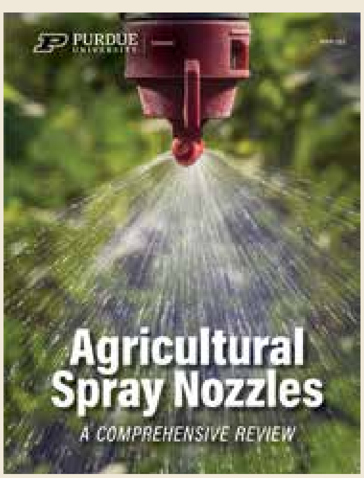
This "ready-to-spray out of the box" assumption can lead to some major application problems because every spray drone must be calibrated properly to ensure it applies products at the correct rates and across the desired swaths. This should not come as any great surprise because the same holds true for new ground sprayers or any application equipment.

Regardless of the type of sprayer used, sprayers can only be effective, efficient, and safe if they are properly checked and calibrated before they are taken to the field. Accurate applications also depend on periodically checking and calibrating drones during the spraying season. This is especially important when operators significantly change any of the components in the set up (such as new nozzles, nozzle spacings, and so on).

The primary goal of calibrating spray drones is to determine the actual application rate over a given area for a given time. Operators should adjust their equipment if there is more than a 5 percent difference between the actual application rate and the intended application rate.

Selecting Nozzle Type and Size

Although nozzles are some of the least expensive components of spray drones, they significantly influence sprayer performance. Nozzles meter the amount of liquid sprayed per unit area, control the application rate, and affect the uniformity of spray within the swath. Nozzles also influence droplet sizes, which affects both target coverage and spray drift risk.



Purdue Pesticide Programs offers a detailed publication about spray nozzles:

Agricultural Spray Nozzles: A Comprehensive Review (Purdue Extension publication PPP-153).

It is available from Purdue Pesticide Programs (ppp.purdue.edu) or the Purdue Extension Education Store (edustore.purdue.edu).

Drones are often equipped with flat-fan nozzles, but the spacing and orientation can be very different from traditional application equipment.

Nozzles come in a wide variety of types and sizes. Generally, nozzles with a flat fan spray pattern are preferred for spray drones using nozzles, but spacing and orientation can be very different from traditional application equipment.

We don't have as many nozzle options for drones as we do for ground equipment because spray drones have smaller pumps and limited output. The electric pumps on spray drones may be limited to less than 5 gallons per minute (GPM) depending on the drone's size (these pump systems are similar to ATV spot sprayers). This is why most drones use nozzles with low flow rates (0.1 or 0.15 GPM) instead of the higher flow volumes fitted on ground sprayer booms.

Using nozzles with higher flow rate capacities will likely create problems because drone pumps will not be able to generate enough flow to operate the larger nozzles effectively. It should be noted that our nozzle selection and calibration discussion here does not include rotary atomizer nozzle types that are used in newer spray drones. For a more thorough review of these spray drones and nozzles, see page 45.

To determine the size (flow rate in gallons per minute) of a hydraulic nozzle that will adequately satisfy your intended application rate in gallons per acre, follow these steps:

Step 1. Select the desired application rate in gallons per acre (GPA).

Step 2. Select a practical and safe flying speed in miles per hour.

Step 3. Determine the effective spray swath for the drone in inches. Do not use the maximum swath manufacturers list in drone manuals. See page 39 for differences in maximum and effective spray widths. This step differs from traditional spray calibrations that use the width of the nozzle spacing for the calculations.

Step 4. Determine the flow rate (GPM) the drone requires for the application:

$$\text{Gallons per Minute (GPM)} = \frac{\text{GPA x MPH x W}}{5{,}940}$$

(By the way, the 5,940 number used in this equation is a constant to convert GPA, MPH, and inches to GPM).

Let's use an example that shows the calculations using a T30 that has 16 nozzles, but only turns on 12 when spraying. You want to spray a fungicide at 2 GPA, at a speed of 15 mph. There are 12 nozzles on the drone, and you would like to maintain a swath width of 25 feet (300 inches). Based on the inputs, what flow rate per minute must the nozzle need?

Option 1. Enter the values given above into the equation:

$$\text{Gallons per Minute (GPM) for entire drone} = \frac{\text{GPA x MPH x W (in inches)}}{5{,}940}$$

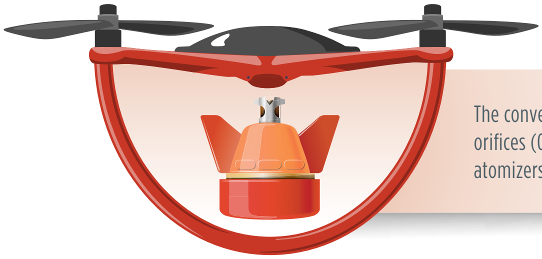
$$\text{GPM} = \frac{2 \times 15 \times 300}{5{,}940} = 1.515 \text{ GPM for entire drone}$$

Step 5. Divide the output for the entire spray drone by the number of nozzles activated during a spray pass.

$$\frac{\text{GPM for entire drone}}{\text{Number of working nozzles}} = \text{GPM per nozzle}$$

$$\frac{1.515}{12} = 0.126 \text{ GPM per nozzle}$$

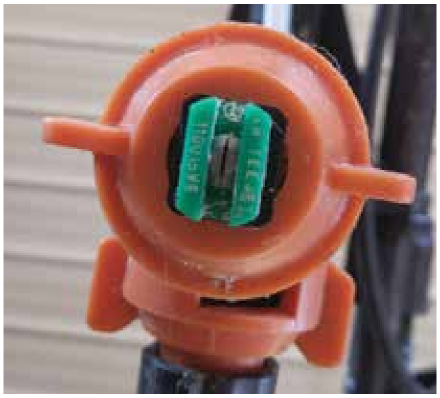
Please note that most drones come equipped with nozzles from the factory or have rotary atomizers. We are verifying if the nozzle that is on the drone meets our application requirements.



DRONE **FACT**

The conventional hydraulic nozzles on spray drones have small orifices (01 and 02), which tend to clog. Spray drones with rotary atomizers are relatively less prone to clogging.

Select a nozzle size from the manufacturer's catalog (or from their website) that will provide the flow rate (GPM) that you determined in Step 5 when the nozzle is operated within the recommended pressure range. For drones with nozzles, you are basically limited to using only two sizes — 0.1 and 0.15 — because drones cannot generate enough flow and pressure to operate larger orifice nozzles properly. So, you should select a nozzle that will deliver 0.126 gallons per minute of spray output.



These two nozzles have a 110° spray width. The nozzle on the top (green tip) is a 0.15-gallon per minute nozzle (at 40 psi), while the nozzle on the bottom (orange tip) has a flow rate of 0.1 GPM (at 40 psi). The green nozzle would more closely align with what we expect to get out of the drone.

Take care when using spray width (W) in the equation above to determine the nozzle flow rate (GPM). Several things will affect the actual effective swath width that you should use in the equation, including the flight altitude. This is explained in the section that follows.

Determining Effective Spray Swath Width

One of the variables in the equation used to determine the gallons per minute flow rate is the spray swath. It is extremely important when determining a value for W in the equation, you should use the effective swath width, not the maximum swath width the drone user manual may provide. The effective swath width considers the need for some spray overlap between passes to achieve a uniform application across the field. Thus, the effective swath width is what you should use for the distance between each sprayer pass.

Spray drone manufacturers often advertise their maximum swath widths. The values they provide represent how far away from the drone some droplets may deposit on the spray target. However, the deposition pattern of droplets across the spray swath will not be uniform. A relatively small number of droplets reach the outer edges of the spray pattern while there are greater deposition levels toward the center of the drone.

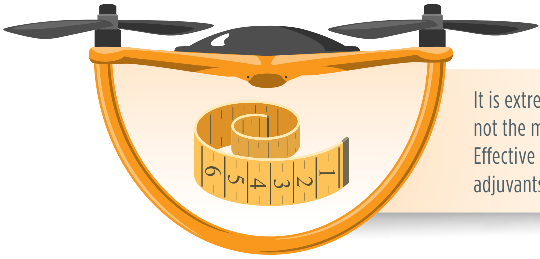
A general rule of thumb from the authors' experiences, the scientific literature, and practitioners is that the effective spray width is between 65 and 75 percent of the advertised spray swath width. For example, if a drone has a maximum spray width of 30 feet, it would have an effective spray width between 20 and 22 feet. This can vary, so you should verify the effective spray width by performing a swath test. Researchers should come up with methods to find effective spray widths easily to better refine effective spray widths in the near future as new findings are reported.

A fungicide application to corn failed to control the pathogen because of incomplete overlap and ineffective spray coverage. Always conduct pattern testing on your drones to determine effective spray swath width and ensure pattern uniformity no matter the body of research or database of aircraft setups for make and model. Very small differences in drone setup can change both pattern quality and swath width.

For that reason, the drone operator using the controller screen shown below has entered 25 feet for Route Spacing instead of the 30 feet maximum swath width suggested by the drone manufacturer.

One other factor that will play a key role in determining the actual spray swath is flight altitude. The lower the flight altitude (height from the ground or the crop canopy), the narrower the spray swath will get. You also should consider altitude when you select nozzle sizes.

This drone is using 25 feet for an effective spray width instead of the maximum spray width. Using a reduced spray swath allows the drone to overlap between passes to achieve a more uniform application. Sprayers101.com provides an excellent explanation of the difference between maximum and effective swath widths when using spray drones.



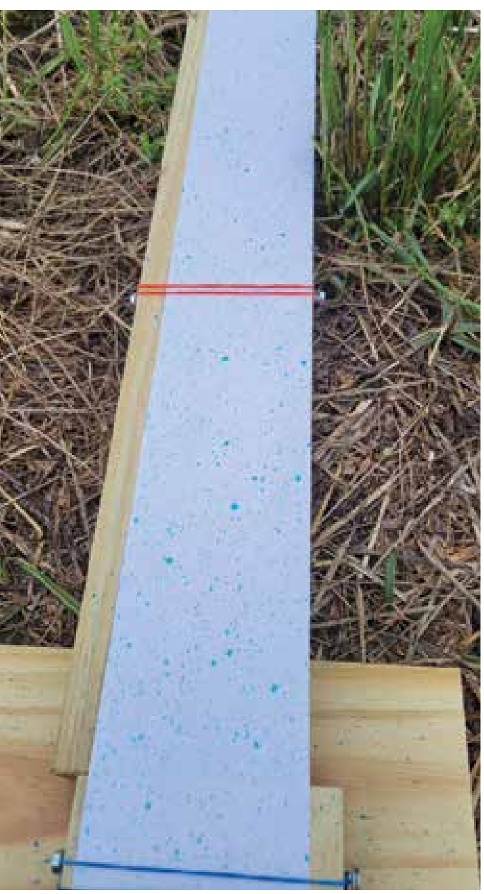
DRONE **FACT**

It is extremely important that you use the ***effective swath width,*** not the maximum swath width the drone user manual may provide. Effective swath widths may change according to carrier volumes, adjuvants, spray heights, and vegetation.

Notes from the Field

Crosswinds can cause swath displacement, which drone operators should account for when establishing spray passes. When flying in-wind, spray speeds and pressures will likely change whether flying against a headwind or with a tailwind. This can also affect how the spray swath lays down. This reemphasizes the need to swath test in multiple different environmental scenarios.

Considering the variations in nozzle sizes, spray pattern angles, wind direction, wind speed, and flight altitudes, there is no theoretical mathematical solution to determine the effective swath width. Ideally, operators can check the spray swaths of their drones using methods and instruments that can quantify the spray solution volume or the amount of spray droplets being deposited across the swath. However, this may be limited to university researchers and spray application consultants who commonly use these methods.



The most practical way to find out if a spray deposition is uniform is to add a very small amount of dye to the sprayer tank, and then make several passes over a tape laid on the ground just like you would be spraying the area. The dye used for sprayer foam marker systems is commonly used to visualize spray deposits. It also is safe and inexpensive for calibration runs.

Next, observe the deposition of spray droplets on the tape. Heavy dye concentration on parts of the tape is a good indication of too much overlapping of adjacent passes. No dye on some sections of the tape indicates not enough overlap. This may require you to change flight altitude and/or distance between each pass. Individual applicators can use several pattern evaluation systems, including Swath Gobbler, DropFlight, and AccuPath.

The best way to determine the spray deposition from multiple passes is to visually observe the variations in the spray deposits across the sprayed area. For visual observation, the most effective approach is to lay a strip of white paper tape or water sensitive paper (WSP) under the drone's flight path. Add some food-grade coloring or foam marker dye in the spray tank, and then fly the drone over the tape or WSP and observe the spray pattern and droplet size spectrum as shown in the photographs below.

Depending on what you observe, you may have to change the flight altitude and/or the overlapped distance between each flight pass. You will need to replicate several adjacent spray passes until you are satisfied with the uniformity and deposition of the spray across the test area.

An inexpensive and practical way to determine effective spray width, spray uniformity, and spray drift is to use water sensitive paper (WSP). Here, the applicator fastened WSP to boards laying on the ground perpendicular to the drone flight path. Operators can use the information from the WSP to adjust the settings (height, speed, etc.) that determine effective spray swath.

Height Influences Spray Pattern

A drone sprays two feet above pavement.

2 FEET

Spraying 5 feet above the pavement is not high enough to deliver an acceptable and uniform pattern.

5 FEET

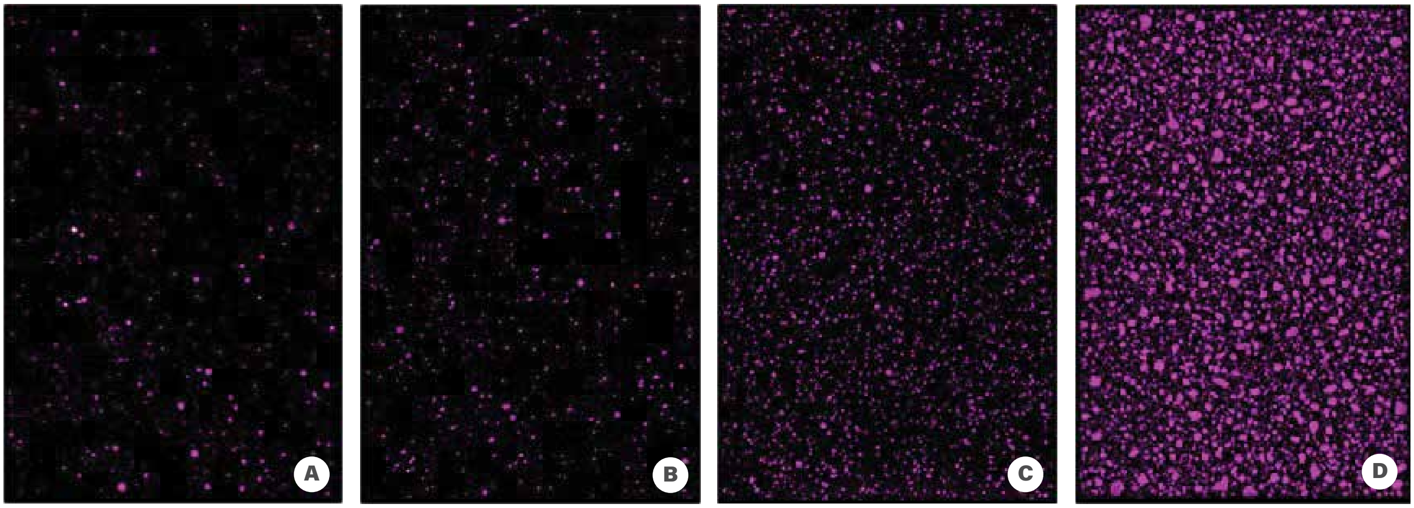
A drone spraying 10 feet above pavement.

10 FEET

This photo shows a spray width testing card showing deposition after being sprayed by a drone.

Another approach researchers have used for decades to determine spray deposition uniformity with ground equipment is to use water-sensitive spray cards (page 43). Users place spray cards perpendicular to the sprayer's travel route. The cards turn blue anywhere water drops hit them. In general, the more water that hits the cards, the more blue droplet stains appear on the cards, and the better the spray deposition or coverage.

As you would expect, water-sensitive cards placed toward the end of the swath show less coverage compared to the center. Researchers will study the distribution of spray droplets and use analytical methods to better quantify the intensity of those spray droplets. There are some phone applications (like DropLeaf) that can quantify the differences in the spray cards. Just take a photo of the card and the app will generate spray droplet data.



Using a fluorescent dye along with Kromekote cards show spray distribution when applicators use (A) 1 GPA; (B) 2 GPA; (C) 3 GPA; and (D) 15 GPA.

We will need new research as new technologies appear in the marketplace.

Calibrating the Spray Drone

Regardless of the type of sprayer you use, you can only achieve your goal of protecting crops against pests if you properly check and calibrate the sprayer before you take it to the field (and recalibrate and recheck periodically during the spraying season). Like ground applications, the various combinations of pesticides, adjuvants, and other chemicals can alter the physical properties of the spray solution. In turn, those properties influence sprayer calibration, swath width, and spray deposition.

Arguably, the chemical inputs in spray solutions from drone applications may have an even greater impact because the concentrations are 5 to 10 times more concentrated than the more diluted ground applications. The primary goal of calibrating a spray drone is to determine the actual rate of application in gallons per acre, and then to make the necessary adjustments if there is a difference greater than 5 percent between the actual application rate and the intended application rate.

As is true for all sprayers, travel speed, nozzle type, flow rate, and spray pressure (which influences both the flow rate and the droplet size) all affect application accuracy. The three rules of application accuracy apply to all spraying equipment, including spray drones:

1. Maintain a uniform flight speed. This is essential to keeping the application rate relatively uniform throughout the operation. Faster flying speeds will result in lower application rates, while slower flying speeds will do the opposite — higher application rates. Most spray drones are equipped with rate control capabilities that provide consistency in application when speeds change; however, application speed should remain the same throughout the field.

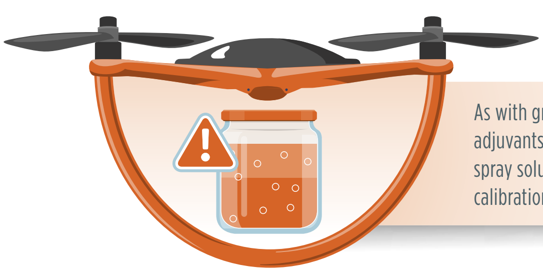
2. Maintain an optimum spraying distance between the nozzle and the target. Drones have radar altimeters to take care of height. Operators cannot control height during autonomous flights with most drones. This often requires operators to make hard choices about productivity and coverage.

Speed Versus Performance

Operators will always be tempted to push the limits by maximizing speed and width to allow their drones to cover more ground quicker. In such situations, you are pushing the pumps and spray widths to their limit.

While getting a job done as quickly as possible is important, making sure the application is done properly the first time should be your primary goal. Having to respray a field not only costs you money, but also time you could have used to generate new revenue.

3. Maintain a uniform spraying pressure. This is essential for keeping both the application rate and droplet size consistent during the application. Lower spray pressure leads to lower application rates and larger droplets. Conversely, high spray pressure leads to higher application rates and a greater number of smaller, drift-prone droplets. Both extremes waste pesticides and provide poor pest control.



DRONE FACT

As with ground applications, various combinations of pesticides, adjuvants, and other chemicals can alter the physical properties of spray solutions in drone tanks. The results can influence sprayer calibrations, swath widths, and spray deposition.

However, directly setting and adjusting spray pressure may not be possible because spray drones do not have pressure gauges or pressure controls. Alternatively, operators could adjust travel speeds to reach desired GPA outputs. Similarly, keeping spray height uniform could be difficult if a drone is not equipped with a terrain sensor. Luckily most, if not all, spray drones come with terrain sensors.

All spray drones come with controllers that allow drone operators to set their spray parameters such as height, swath width, gallons per acre, and travel speed. Controllers also allow users to plan autonomous routes for applications. These are good starting points for accurate spraying. However, operators can only attain proper application rates if sprayers are in proper working order and correctly calibrated. Sprayers that are not accurately calibrated may apply too much or too little chemical, resulting in unsatisfactory efficacy and wasted pesticides. Poor calibration can also increase the risk of injuring the crop, fail to control the pest, or increase drift risk.

In several ways, calibrating drone sprayers is somewhat similar to calibrating ground sprayers. Drone remote flight controllers are really acting like in-cab display controllers on ground sprayers. Both systems require initial calibration checks before hitting the field for the first time after purchase or at the beginning of each spray season.

For ground sprayers, you enter calibration mode and run water through the sprayer for a known amount of time, and then measure the volume you catch from the nozzles during that period. You record the volume you caught and enter that into the in-cab spray controller, so the computer can correct the built-in calibration settings. This essentially improves the accuracy of the flow meter to the new calibration amount or flow rate.

This controller says the drone is applying 3.0 gallons per acre. The only way to know if this is accurate is to measure the flow rate in GPM and convert it into an application rate in GPA.

When 1 Gallon Is Not Equal to 1 Gallon

Several drones may use imperial gallons instead of U.S. gallons.

An imperial gallon equals 1.20 U.S. gallons. In the calibration section, two gallons per acre using imperial gallons would require 2.4 U.S. gallons. Review the owner's manual or contact the sales representative to see which gallon unit your drone uses.

Spray drone remote-control modules do not have ways for users to enter any calibration data. Drone control modules will use internal application formulas to control the output through the pump and flow meter. You cannot directly influence the flow rate of a nozzle by turning a knob or entering a value in a pop-up window that alters the pump and flow meter. We are also at a disadvantage of not knowing the spray pressure, because this is not displayed on the controller. There are several lesser-known brands that have this type of control.

There are several ways to calibrate spray drones to work around this problem. Use the calibration method that you are accustomed to if it happens to be different than the procedure outlined in this publication. Regardless of the method you use to calibrate sprayers, you will have to take certain measurements. You should follow the important operational principles mentioned in this publication to achieve maximum efficacy from the chemical applied.

There are a few things you must do before starting the calibration process. Needless to say, you will always wear gloves and goggles for safety reasons when mixing, spraying, and calibrating sprayers. After you have your proper PPE, clean spray systems to remove any pesticide residues to allow for safe calibration.

Next, run the sprayer on the ground, inspect it for leaks, make sure all vital parts function properly, and that the sprayer has a good set of nozzles. Check the flow rate of each nozzle for a set period (minimum 30 seconds) to identify the nozzles that may be clogged or worn out. If it is difficult to run the spray process with the drone on the ground, you could remove the nozzles from the drone and put them on a standard sprayer to check the flow rate.

Spray drone nozzles are more prone to clogging because the nozzles designed for drones have smaller orifices to accommodate the lower carrier volumes drones apply. Compounding the problem is that most drone nozzles do not have screens in the nozzle body assembly. Furthermore, drone sprayers apply more concentrated spray solutions, which have a greater risk for chemical incompatibility and for particulates to build-up in the tank. For these reasons, you must frequently check the flow rates of spray drone nozzles. Even partially clogged nozzles will cause under-application and non-uniform spray deposit on the ground.

Be sure to clean all clogged nozzles before you calibrate sprayers and clean nozzles daily (especially after spraying mixtures that contains dry products). Never use sharp objects (such as wires or knives) to unclog nozzles. They will damage nozzle orifices, which will affect the spray pattern. You should also not hold any nozzle close to your mouth and blow air into it — you don't want any chemical or debris in the nozzle splashing on your face or eyes. Always use a soft brush to unclog nozzles.

Chemical incompatibility and not wearing gloves — a bad combination.

If the flow rate of an existing nozzle on a drone exceeds 10 percent of the flow rate of a new nozzle of the same type and size (at the same pressure setting), then consider the nozzle on the drone worn-out, and replace it with the new one of the same type and size.

A word of caution: Larger spray drones usually have two sets of pumps and flow meters. Each set controls one set of nozzles. So, when you check flow rates on such spray drones, pay attention to which pump and flow meter the nozzle is connected to. If there is a noticeable difference between the flow rates between the pumps, it is likely that the discrepancy may be caused by a malfunctioning pump or flow meter.

Once you complete these pre-calibration checks and you have a good set of nozzles on the drone, you are ready to fine tune your spray operation by going through a set of steps we describe as calibration. Although the concepts presented here for calibrating drone sprayers apply to most drones makes and models, we encourage you to check if your drone's manufacturer provides specific procedures because drones may come with different nozzle configurations.

There are eight steps to calibrate a spray drone, which applies to most drone types.

Step 1. Measure and mark off an area equal to at least 1 acre (make it larger for more accuracy).

Step 2. On level ground, completely fill the sprayer tank with water, or fill it up at least more than half the tank volume, and mark the water level on the tank. Prime the sprayer and note the volume remaining in the tank.

Step 3. Spray the marked area from Step 1.

Step 4. Return and land the drone to its launch point.

Step 5a. Fill the tank to the same level you marked before spraying the marked test area. Record the volume of water you added to refill the tank to the marked level. (Note: Weighing the drone before and after application can be an alternative if you have a reliable scale available where you calibrate).

Step 5b. Subtract the volume of water you added to refill the tank from the volume of water you originally put in the tank. This will determine how much liquid the drone used. This can work if the tank has site markings on it and they are accurate enough to make a reasonable estimate.

Step 6. The refill volume is equal to the application rate per marked test area.

Step 7. Convert the number of gallons used to treat the test area in step 6 to gallons per acre.

Step 8. Compare the measured (actual) application rate with the recommendation on the pesticide label (the intended rate). If the difference between the recommended rate and the measured rate is greater than 5 percent of the recommended rate, adjust the drone sprayer to reduce the application error so that it deviates less than 5 percent of the intended rate.

An Alternative Approach

An alternative method for calibrating drone sprayers is to record the time it takes to spray the marked area, and then collect and measure the spray from each nozzle for the same time period.

The total spray you collect is the number of gallons applied in your test area (as in Step 6). Then, follow Step 7 above to convert this to gallons per acre.

How to Reduce Application Error

Currently, there is no way for drone operators to adjust the flow rate except by entering a slightly lower or higher value in the controller. With ground sprayers, when applicators need to adjust the application rate, they usually do one of three things:

1. Change the travel speed
2. Change the spray pressure
3. Change the nozzle (if the first two methods are impractical)

Unfortunately, there is no ability to adjust the flow rate in drones by changing spray pressure because only the internal control system adjusts the pressure.

Working Through a Calibration Example

Let's say you want to spray a product using a drone that has 10 nozzles at a rate of 2 gallons per acre (based on label recommendations) while flying at a speed of 10 mph.

To determine the actual application rate, you marked off an area equal to 1.5 acres. From start to stop, it took 4 minutes to spray this area. Then you landed the drone and ran the pump in the same way as the calculation, but with each nozzle directed into a bucket for 4 minutes (see photos on page 49). You measured the amount of liquid in each bucket: 315 ounces. This would be the total for all nozzles in the sprayer, not from an individual nozzle.

As with traditional sprayer calibration methods, operators can use a calibration catch to determine the accuracy of the spray drone's output. Although the sprayer was cleaned, it is always a good idea to wear protective chemical gloves.

What Is the Application Rate in Gallons Per Acre?

First, convert 315 ounces to gallons — a gallon is 128 ounces.

$$\frac{315}{128} = 2.46 \text{ gallons}$$

Next, determine the application rate per acre.

You applied 2.46 gallons to a test plot of 1.5 acres.

2.46 gallons ÷ 1.5 acres = 1.64 gallons per acre

What Is the Percent Application Error?

Your intended rate is 2 gallons per acre, but the actual rate was 1.64 gallons per acre. Subtract the actual rate from the intended rate and divide that by 2 gallons, then multiply by 100 to get your application rate as a percentage.

$$\text{Application Error} = \frac{2 - 1.64}{2} \times 100 = 18\%$$

This 18 percent application error (under application in this case) is more than the 5 percent acceptable margin of error. Therefore, you must make some changes to bring the application error as close to 0 percent as possible — but at least less than 5 percent.

One way to do that is to enter a higher value in the controller (2.5 GPA), and then catch it and see how close we are to the target rate of 2 GPA. Another approach is to tell the drone to spray 2.36 GPA if it is underapplying by 18% (2 gallons x 0.18 = 0.36 gallons; 2 gallons + 0.36 gallons = 2.36 gallons).

Care and Calibration of Rotary Disc Atomizers

Some new spray drone models come with a set of rotary disc atomizers instead of hydraulic flat-fan nozzles to atomize the spray solution. An advantage of rotary atomizers is that operators can use their tablet/controller to select from a range of droplet sizes — very fine to very coarse — without having to change nozzles. However, there is limited research to verify whether the rotary atomizers actually achieve those classifications as designated through ASABE S572.

Rotary atomizers, as seen on many new drones, allow operators to easily change droplet size by selecting the desired size in the remote controller. More research is needed to verify how accurate these droplet sizes are and if they meet label requirements for droplet size specification.

The calibration process for drones with rotary discs is generally the same as that for drones equipped with hydraulic nozzles. You start with a set of rotary discs that come with the drone when you purchase it. You do not need to worry about the type or size of nozzle you should have on the drone, as you would if you had hydraulic nozzles.

To determine if you are getting the intended gallons per acre application rate from drones with rotary discs, use the same procedure explained earlier for spray drones with hydraulic nozzles. With a rotary atomizer, you cannot use a single-catch container under each nozzle, because the rotary atomizer sprays liquid in all directions. Instead, use a bag that can guide all the spray into it. Although it is a bit more difficult to do, you will still need to check the flow rate of the disc atomizer and calibrate the drone as described earlier.

Examples of rotary atomizers equipped on several new drone models.

Clogging is not a major issue with these atomizers. However, other issues may surface after extended use of the rotating disc assembly.

Some have suggested that the increased pump sizes on newer drones have resulted in rotary atomizers being "flooded." This has led to improper droplet formation and a "drooling" type effect. In such cases, the drones produce larger droplets and deposit a high concentration directly beneath the nozzles, leading to streaking in fields.

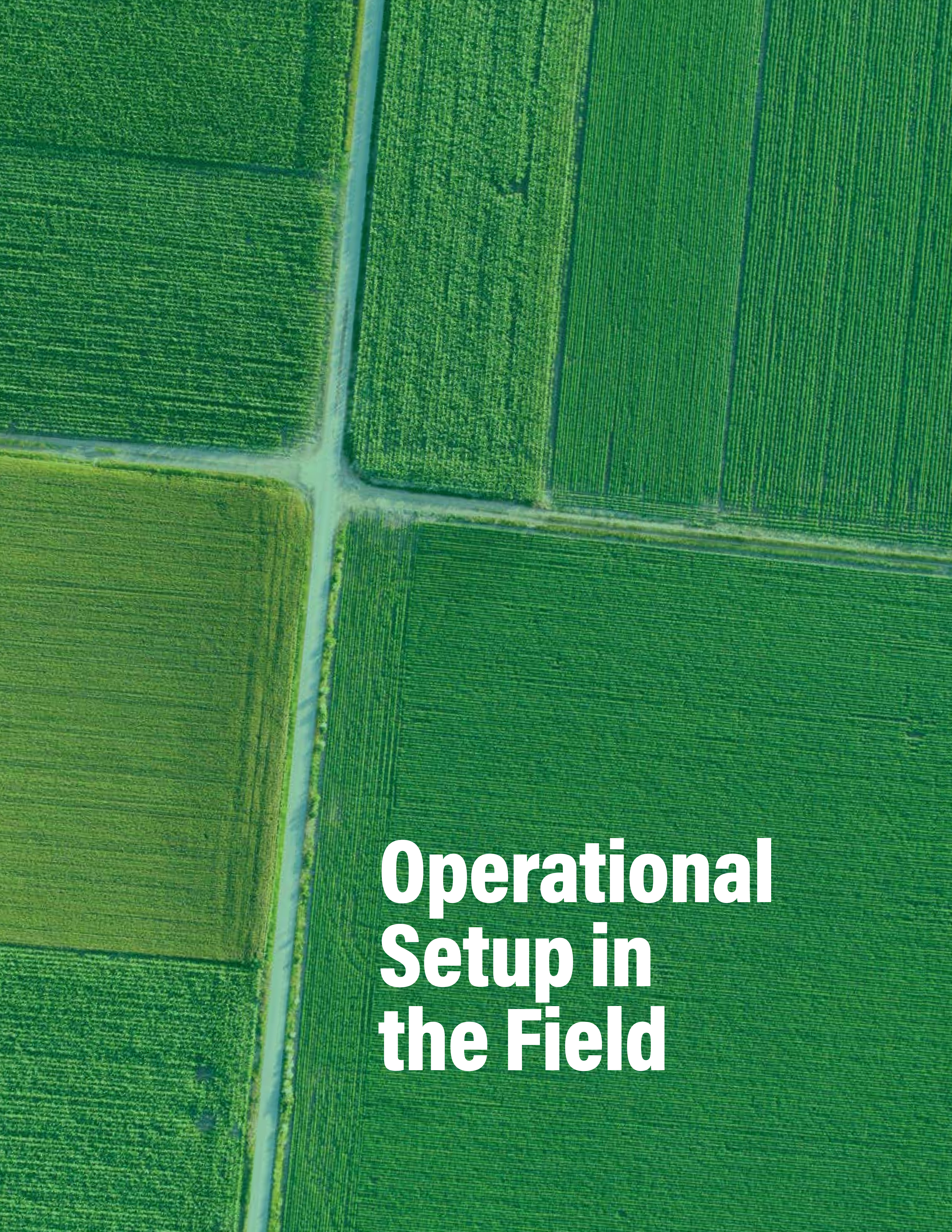
Another potential issue is the change in rotation speed of the discs. The rotation speed of the discs influences spray droplet size. Higher rotation speeds tend to produce smaller droplets, while lower rotation speeds tend to produce larger droplets.

Unfortunately, it is not easy to determine the rotation speed of these discs. It requires having a digital tachometer, which many newer models now have. If you have one, stick a tape on the side of the disc and while the disc is rotating, aim the digital tachometer on the tape. This will tell you the speed of the rotating disc in revolutions per minute (RPM).

The rotary atomizer (spinning disc) nozzles (like the ones shown here) can create a very uniform droplet size distribution, but more research is needed to fully validate their capabilities on spray drones.

You need to compare your measurement with the motor's top RPM. Some manufacturers recommend when operators should replace these discs. Droplet formation will also be affected, to a smaller degree, by cleanliness of the serrations (groves) on the disc. So, cleaning the discs (and other parts of the drone) becomes even more important if spray mixtures contain solid particles.

The small grooves in the spinning discs act as tiny channels that distribute liquid while it is dispersed. The liquid eventually forms droplets as it leaves the spinning disc. The grooves wear with more abrasive materials. Always carry spare discs to quickly replace them in the field.



Operational Setup in the Field

Grass lanes within fields provide excellent places to set up drone operations.

Arguably, spraying with a drone takes more effort to prepare and complete than a ground rig in the same field. While drones appear simple, setup and operation can be quite involved.

Before entering a field, you must consider the following:

- What equipment, materials, and supplies you must bring to each site
- Where to park a trailer or truck
- Where to take-off and land to protect the pilot and equipment from spray drift, dust, and debris
- Where to position the pilot and visual observer so they can always have a visual line of sight during flight while avoiding pesticide exposure
- Where to place the generator and batteries so they do not overheat but are easily accessible for frequent charging — charging efficiency is better in the shade
- Where chemicals will be mixed
- Where to place a nurse tank and/or where the nearest fill station is located
- Where the drone should be rinsed and cleaned
- Field size, which will help determine whether a single flight or multiple flights will be conducted

Field terrain can vary by location. This is why it is always important to be aware of the surroundings of the drone application.

- Topography of the field and flight direction
- Locations of infield irrigation equipment

Irrigation pivots can be obstacles for drones to work around. A common practice is to split the application into two separate fields to avoid collisions.

- Locations of sensitive crops, sensitive areas, water bodies, highways, residential areas, and nearby commercial properties
- Local wind speeds and the potential for temperature inversions
- Locations of potential overhead hazards, such as power lines and tree limbs that can hinder safe take-offs and landings

A drone, with its relatively small tank size and limited battery life, requires all of the items it needs to continue operating strategically positioned at the application site to improve the efficiency of the operation.

Scan the Application Area for Flight Obstacles

Investigating the lay of the land remains a top priority when using drones to apply pesticides. Take a few minutes to scope out the property to save hours or days dealing with a problem that should have been spotted before the start of the mission. A collision with an obstacle due to hasty flight planning can shut down operations for the day, or even longer, depending on the severity of the drone damage and part availability.

Identifying obstacles in the field before flight is critical. Recognize obstacles pre-flight to avoid collisions, such as a drone becoming entangled in wires. Even obstacles around field perimeters are important if they may intersect the drone's return path to your loading site.

While many drones have obstacle-avoidance sensors, it is best to leave a large buffer around obstacles to avoid accidents.

A crashed drone might mean it has flown its last mission. That means an outlay of cash for a new drone, a significant amount of time to receive it, and time to file the proper paperwork to legally operate it. The good news is that if you have the parts, most repairs are rather straightforward.

What we see as obstacles can change how we fly the field to work around them. Scout the property for powerlines, irrigation pivots, radio towers, high tension lines, guy wires, fence lines, trees, and over-extending branches in and around a field.

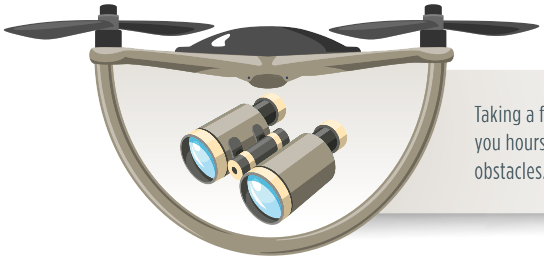
In larger row crop fields, operators can use smaller, less costly mapping or recreational drones to keep the hours off the spray drone. Operators can also use binoculars to help look for nearby obstacles. However, the quickest first step in reconnaissance could simply be viewing the area on various platforms that provide free satellite imagery, such as Google Earth.

Notes from the Field

A drone operator indicated:

"We mitigate obstacle hazards with a scouting flight before we start each field. This allows us to observe the field for any unexpected hazards that would not show up on satellite imagery. It also allows us to verify that our boundaries are far enough away from hazards, by observing the relationship between the boundary on our screen, the drone icon on our screen, and the drone's location relative to the hazard in the real world.

"For example, if we fly the drone to the minimum safe distance away from the power lines in the field before application, and then observe the relationship between the drone's position on our screen to the boundary of our application area, we can determine if our boundary needs to be moved closer or farther away from the power lines to optimize our application."



DRONE **FACT**

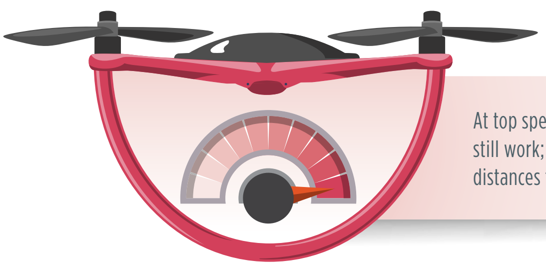
Taking a few minutes to scope out an application site can save you hours or days by preventing your drone from crashing into obstacles.

Exercise caution when using satellite imagery because it may not be up to date — new infrastructure could have been added or certain obstacles could have been removed. Satellite image resolution is also low, which prevents you from seeing obstacles well.

Drones have onboard sensors that are programmed to sense and avoid obstacles. The sensors can stop the drone in mid-air several feet from the object, but some drones can begin to detect obstacles up to 30 feet or more away. Unfortunately, avoidance systems can fail to detect powerlines, guy wires, and smaller branches along tree lines (especially when the branches have lost their leaves or when you're operating drones at maximum speeds).

It's also important to map obstacles beforehand and mark them in the mission, because most drones are operated at full speeds for application. While obstacle avoidance systems still work at top speed, drones require longer distances to slow down. Some applicators operate their drones at top speeds by disabling the obstacle avoidance. So, when radar detects the obstacle, it might be too late. Experienced drone operators concede after the fact that it doesn't take much of a limb sticking into a field or a misjudged power line to bring a drone down.

Obstacle avoidance systems give you room to manually maneuver around or above detected obstacles. Stopping in mid-flight to avoid a detected obstacle is an important safety measure, but realize that hovering can quickly drain batteries, which could lead to forced landings. Fortunately, once drones detect an obstacle, they will shut down pumps, thus stopping product application until the obstacle can safely be avoided. Afterward, safe application can resume.



DRONE FACT

At top speeds, obstacle avoidance systems on some drones may still work; however, drones flying at high speeds need greater distances to slow down compared to lower speeds.

Can You Believe What That Tree Branch Did to My Drone?

We recommend setting up a no-spray buffer that is one-half of the spray width or 10 feet around fence lines with trees and brush.

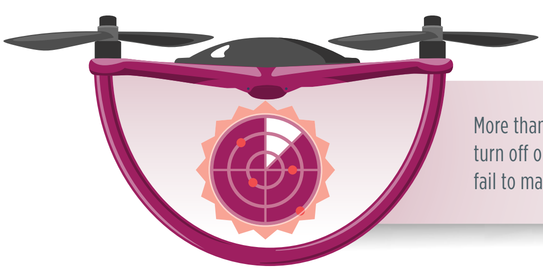
Red waypoints mark an area the drone will recognize as a "no-spray" zone.

More than 90 percent of spray drone crashes were caused by operators flying drones with obstacle avoidance radar turned off or by operators who failed to map obstacles and wires before flight. We strongly recommend you map obstacles before flight to avoid the drone continuously sensing and avoiding them in flight.

Photos A, B, and C. Unexpected landings can place drones into unwanted and unsafe landing zones, which may substantially damage drones.

This drone encountered an obstacle while returning to home base with no remote-control signal and paused. The drone hovered until its battery reached a critically low level, and then attempted to land through the canopy of a mature deciduous forest.

Crossing waterways can cause obstacle avoidance sensors to stall a drone after it lowers into the depression of the waterway. The drone may identify the abrupt change back to the tall corn on the other side of the waterway as an obstacle. A related problem is flying too low. A tall pigweed or random plant can stall a drone. Make sure that powerlines, trees, and guy wires are not part of the flight pattern as it takes off and lands and are not a concern in the return to home route.



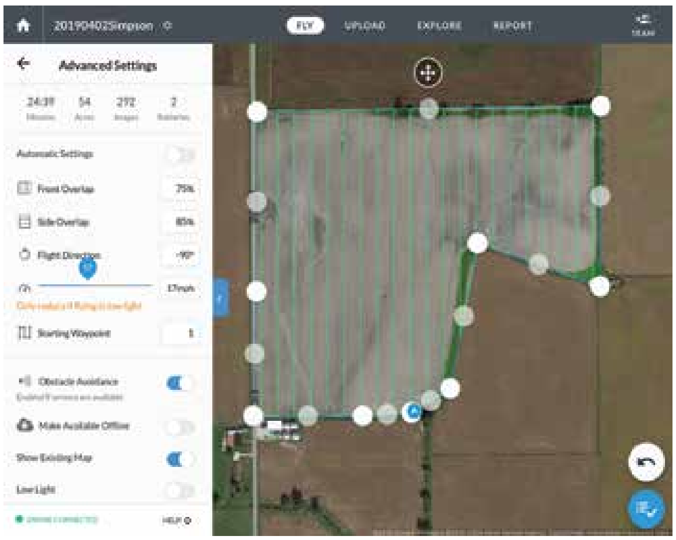
DRONE **FACT**

More than 90 percent of spray drone crashes occur when operators turn off obstacle avoidance systems while flying or when operators fail to map obstacles and pay attention to wires before flying.

Setting the Field Boundaries and Inputting Variables into the Controller

There are many ways to map the boundaries of a field to help keep your drone on a set spray pattern. One method is to drive around a field using an ATV. For every 30 to 50 feet, enter a waypoint (boundary point) into the controller or tablet.

If there are obstacles the drone needs to fly around, then operators need to manually add more waypoints. Most modern spray drones allow users to mark around the obstacles with different waypoints. Certain brands also allow users to map no-spray waypoints so drones will fly over these areas without spraying any product.



Several programs are available for marking field boundaries.

A second option is to set the boundary by using the spray drone software and background imagery to mark waypoints when the field has too many obstacles or is inaccessible to ATVs for mapping boundaries. Some models and brands do not have these capabilities.

In many cases, field edges run alongside roads and steep ditches, making it impossible to drive ATVs in those areas. A field might be adjacent to a tree line or marsh, which also limits ATV access. Of course, one of the benefits of using spray drones for pesticide applications is their ability to spray fields with irregular shapes. Thus, mapping a field's boundaries that tracks the entire perimeter may be necessary instead of a simple four-corner field.

A third option to mark field boundaries is to use mapping programs from Google Earth, Google Maps, DroneDeploy, ArcGIS, and other precision ag software. You can export the boundaries as shapefiles and upload them to the drone remote controller. These mapping applications provide acceptable resolution at the time the images were made. If the field remains unchanged, then these satellite images work well for drawing the boundaries. However, make sure to do a site verification before actual flight.

This is an example of the software available with many drones. This image shows an application in progress after the operator developed a detailed flight plan. Yellow lines indicate the drone's flight paths. Each purple dot is a waypoint that indicates a change in the application boundary, which signal the drone to change direction.

Remember satellite images cannot spot small obstacles and telephone line poles are hard to see. If you use a precision ag software platform, you can make accurate field boundaries from planting, application, or harvest maps that most farmers currently use.

Don't forget that with satellite imagery the data displayed might be a few years old. This is only a problem if, for example, the field has added or removed a building, parts of the property were sold for homes, powerlines or cell towers were added, or trees were removed to make larger fields. Sometimes, the satellite data will document the image dates; however, in-person scouting is always required to confirm that the satellite imagery is correct, and the operation can be safely completed. When using these images, it is best to scout the field to verify the boundaries and any obstacles the imagery could have missed.

A fourth option is to map the field with an RGB drone, download the images from the drone to a computer, and then stitch images into a precision map (technically called orthomosaic map). This option can easily mark obstacles and field boundaries on the orthomosaic map, and then export those to the spray drone as shapefiles. This is also the most time-consuming method, but precision level is the highest among all other planning options mentioned above.

Operators may input certain application variables in the planning phase or at the edges of fields. Operators enter spray variables, such as height above canopy, drone flying speed, spray volume (gallons per acre), and application swath width. On newer drones with rotary atomizers, there is also an option for selecting desired droplet size. Operators can enter other parameters (such as distance offset from the boundary) in the field. Operators also need to determine flight directions that result in more efficient operations with the fewest turns. These input variables can change from field to field depending on the crop being treated, product being used, and field conditions.

Can You See the Drone?

There are several horticultural crops like orchards, vineyards, and fruit and bush crops that may make it very difficult to maintain a visual line of sight. It is not easy and will require a lot of thought and changes in practice to accomplish the legal requirement for visual line of sight.

The Pilot's Eyes Focused on Drone

Under federal law, the pilot and visual observer are required to have a visual line of sight with the drone, so the operator can maintain full control of the unit and safely ground the aircraft if unforeseen circumstances occur. It is important to find an area where you have a continuous and clear line of sight to watch the drone as it makes its application across the field, pond, or county right-of-way. That position is no longer limited to the entrance of the application site like ground equipment, because now you can select a location that gives you a clear view of the area being treated.

A useful tactic to maintain the line of sight is to find the highest elevation where you can watch the drone make the application across the field. This spot becomes the staging area where you will land and take-off. For fields with low canopy crops, you can also walk along field boundaries to have a line of sight. In some cases, you may need to relocate the staging area to have a better line of sight. This is not always a fixed spot but can change as needed to maintain line of sight and to attain greater efficiency with drone applications.

Another advantage of using an optimal field observation site has to do with keeping the drone and controller in constant communication. The antenna on the remote controller uses a radio signal to remain connected to the drone. Drone and controller communicate best when there are no major obstacles interrupting the signal. If communication is lost, the drone may initiate the return-to-home function. Furthermore, finding a central staging location can help make efficient use of the batteries to limit empty payload flight time return to refill.

When standing on the edge of a tall crop (like tasseling corn) or rolling hills the controller and the drone can drop the signal with one another. This can result in the pilot losing the ability to direct the drone in flight. Flying from higher ground to lower ground helps maintain a strong signal and provide the pilot full operational control.

A flight can be autonomous (preprogrammed flight) when the drone is programmed to fly only over a certain area. Autonomous flights are typical of most applications because it can be difficult to achieve optimal and constant speed, height, and field coverage during manual flight.

Always pick the highest point possible for a staging area, which will give you a clear view of the field and obstacles.

This is an example of a difficult field to fly because of the rolling hills and potential to lose contact and visual line of sight with the drone. The operator may have to fly half of the field from this end of the field and find another vantage point to cover the rest of the field.

With an autonomous flight, the operator creates the flight by uploading data from the controller to the drone. If the drone and controller lose connection during an autonomous flight, the drone can continue its programmed mission until the radio signal is reestablished with the controller. However, you will not be able to control the drone until the signal between drone and controller is reestablished. Be aware that current rules require that if the drone loses communication with the remote controller for a longer period, then it must initiate its return-to-home function so that the drone will return to the take-off location and communication can be regained.

An important consideration with autonomous flights is battery life. If the return-to-home function is set to initiate when battery life is lower than what is required to return to the home base, the aircraft will be forced to land. This can damage the drone if the landing area is not ideal for the drone, such as in the middle of a corn field.

The return-to-home function also poses a risk when the signal connection is lost. When a drone is on the return-to-home by itself and you cannot control it, it will fly a straight line back to home. This means the drone can run into obstacles. In such cases, it will either crash into or stall in front of the obstacle. If it stalls in front of the obstacle and connection cannot be reestablished before the battery runs out, the drone will do a forced landing and crash into the crop or whatever is on the ground, which could be an irrigation pond.

Those operating drones are developing innovative solutions to seeing over tall crops and other obstacles. For instance, spraying fungicides on tall corn presents unique challenges to keeping lines of sight on drones. One recommendation is for the pilots to stand on double deck trailers to see above the top of corn. Operators should also use signal enhancing devices to extend signal range.

(A) This photo shows the antennae on the controller. (B) This photo shows antennae on top of the drone that receives the signal from the controller.

This pilot placed a ladder on a flatbed trailer to improve line of sight. Safe ladder use now becomes an issue that must be addressed.

Drone operators have found many ways to equip vehicles to operate drones in the field.

Highly specialized trailers can support spray mixing, loading, battery charging, and elevated observing. In addition, they can provide adequate room for safely landing and walking around drones for inspections and repairs between flight missions.

A grass strip, if one is available, makes for a perfect launching and landing site.

Taking Off and Landing From 'Hard' Surfaces

Spray drones produce strong downdrafts when taking off and landing. The downdrafts throw dirt, dust, and small pebbles into the air. In dusty areas, operators may need to clean drone motors, connectors, and electronics more often due to debris finding its way to the inside the drones. Dust storms during take-offs and landings frequently clog flat fan nozzles, which is yet another concern.

This makes it important that drones take off and land on grassy sites or landing areas that do not have much debris to reduce the amount of dirt and dust around the drones. Many commercial operators purchase or build trailers customized for drones where they can store the supplies, aircraft, and essentials. These trailers can also have higher decks where drones can land and allow pilots and observers to have good vantage points of the operations. Custom trailers can add significant expense to an operation, but may be necessary for efficient, legal, and safe operations.

(A) A landing platform, such as the one shown here, can provide a solid base from which to operate a small drone. (B) However, application drones are much larger and require larger landing pads.

DRONE **FACT**

When drones take off and land, their downward drafts can kick up dust and other debris that may clog flat-fan nozzles and disrupt the drones' motors and electronics.

Equipping a Trailer for Your Spray Drone

Tanks and product mixing typically will be like larger ground rig operations except on a smaller scale, since drones apply a lower volume of water in a given area. However, drone operators will need to add power generators and charging stations that ground sprayer operators do not normally need.

A Clean Water Supply

Under most circumstances, application sites do not have accessible clean water for mixing pesticides, rinsing or flushing tanks, washing off residue from drone surfaces, or cleaning hands. The amount of clean water operators bring to application sites varies by the size of the operations. Consider the number of acres you plan to apply in a day and at what volume you plan to apply to estimate the amount of water you will need.

For example, if a drone pilot plans to fly 200 acres at 2 gallons per acre, the operator will need at least 400 gallons of water, plus additional water for rinsing, cleaning, and hand washing. If the application site is near a farm, the operator can refill smaller tanks. But areas may be far away from a water source, so it is always best to bring all the water you need for that day.

Think Personal Safety First

Not all spray drone operators have applied pesticides with ground equipment or even worked around pesticides.

Regardless of the mixing method, make sure operators follow all safety precautions for handling and mixing pesticides. At a minimum, all operators should wear gloves, which are fundamental to personal safety. We also suggest operators wear at least one layer of clothing (long sleeves and pants). After a day's application, be sure to wash these clothes separately from household laundry.

It is vital that drone operators carry separate fresh water supplies with them. Not only is this for operator safety, but operators need fresh water to rinse out drones and clean equipment. Use pressure regulated pumps and garden hoses to ensure plenty of fresh water.

Mixing Operations

There are two options for mixing pesticides at the job site:

1. Add the pesticide product(s) directly to the drone solution tank for mixing
2. Fill the drone from a premixed solution of the pesticide product

You should avoid the first option as much as possible for several reasons. Products may be incompatible, there may be a lack of agitation during mixing, it could compromise worker safety, and increase the risk of spills. Filling drone tanks by hand also can be very inefficient.

We recommend using pre-mixed pesticide solutions in large mixing tanks. Newer mixing trailers/trucks even have enclosed mixing systems that can directly draw chemicals from original containers into mixing tanks, then pump premix from mixing tanks to drone tanks without exposing chemical handlers. Still, you should wear gloves and any other necessary personal protective equipment pesticide labels require when mixing and loading spray mixes.

(Top) This photo shows an operator filling a drone solution tank. (Bottom) Mixing tanks offer enclosed systems to directly transfer mixed pesticide solutions to drone tanks.

Incompatibility Issues

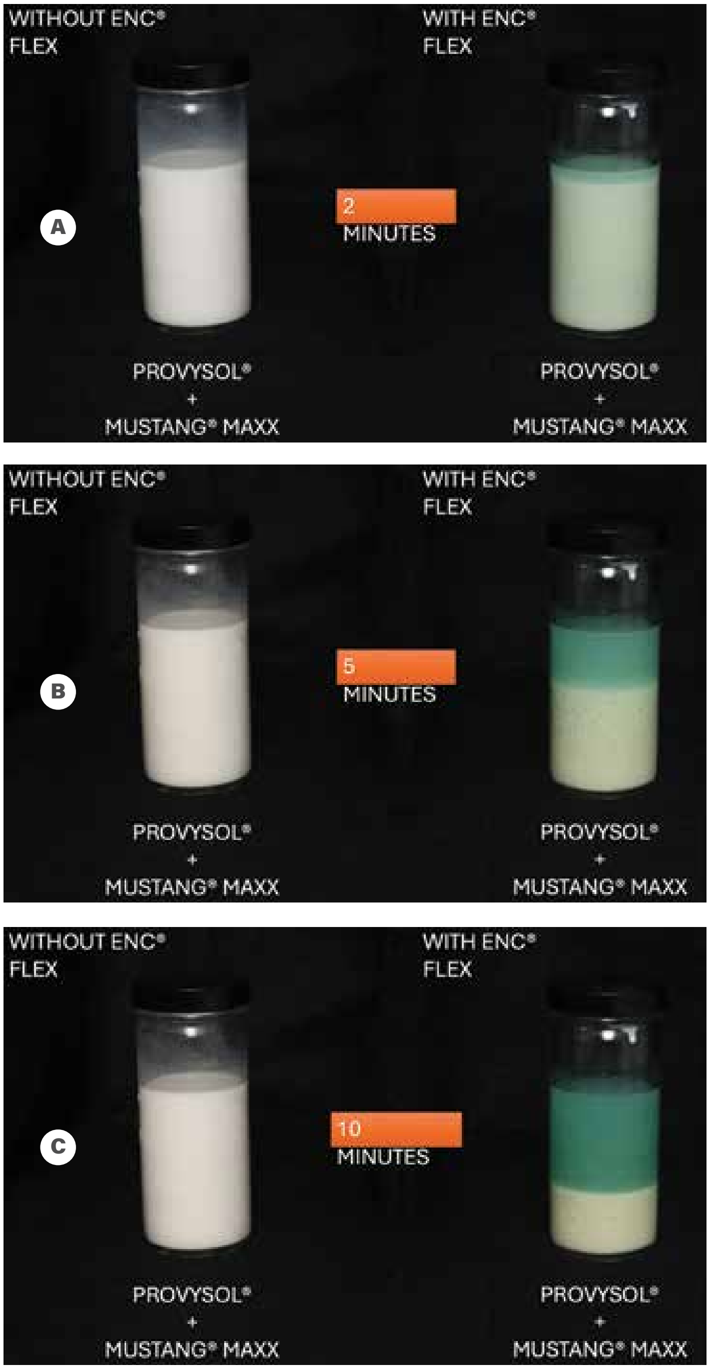
Since drone applications use carrier volumes of 2 to 3 gallons per acre, which are dramatically lower than ground applications, the pesticides mixed for drones are in highly concentrated forms. With so little water and no agitation in the spray tank, some products that work well in more dilute concentrations using 10 to 20 gallons per acre may be incompatible at the higher concentrations in drone tanks. Such mixtures can clog nozzles, spray lines, flow meters, and pumps. Mitigating clogged nozzles requires operators extra time to clean and flush the spray system.

Preventing Liquids from Gelling

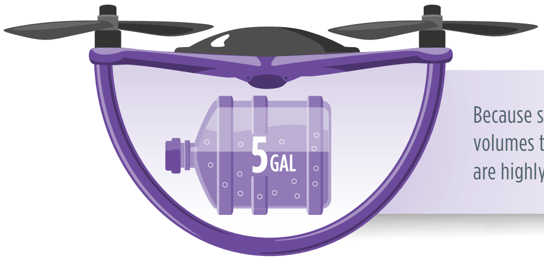
To optimize tank mixes, first add 1/2 to 2/3 of the required water to the tank, then add the pesticide, and finally top the remainder of the tank with the rest of the required water.

Never mix concentrated pesticides together first. You should always add each pesticide individually to the tank with water to reduce incompatibility.

We highly recommend you conduct a jar test if you are mixing more than one pesticide into a drone. A detailed explanation of how to conduct a jar test is in *Avoid Tank Mixing Errors* (Purdue Extension publication PPP-122), available from Purdue Pesticide Programs (ppp.purdue.edu) or the Purdue Extension Education Store (edustore.purdue.edu).



Examples showing how products can negatively interact with each other. Adding one product within a few minutes can cause the products to separate (right side). (A) Reaction after 2 minutes. (B) Reaction after 5 minutes. (C) Reaction after ten minutes.



DRONE **FACT**

Because spray drone applications use dramatically lower carrier volumes than those used ground applications, pesticides on drones are highly concentrated.

Poor Mixing Due to Lack of Agitation

Most drones lack agitation systems that are common in ground application equipment. We should keep in mind that the pumps and spray configurations on drones are more similar to ATV spot-spray systems than they are to sophisticated commercial ground application systems. Agitating the spray tank on a drone requires two people on both sides of the drone to pick it up and shake the tank to mix the product.

An example of incompatibilities between glyphosate and 2,4-D when mixed in low volumes of water.

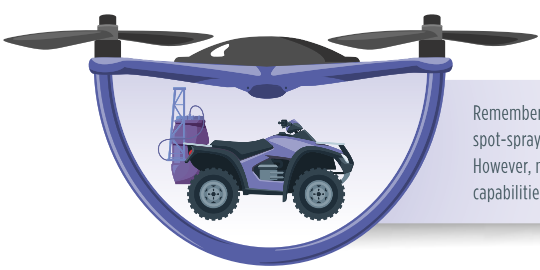
Anything other than pesticides that easily dissolve in water will have difficulty becoming suspended due to the lack of agitation. It is important to start spraying as soon as possible to avoid chemicals settling to the bottom of the tank and clogging the flow meter, pumps, nozzles, and filters. Also, at the end of the day do not let leftover spray solution sit in the tank after the drone gets back. The best option is always to spray any remaining solution out in the field and come back empty.

Mixing Pesticides in Drone Tanks Is Inefficient

Given the relatively small solution tanks on drones, operators may need to load and mix a fresh spray solution every two to five acres. If you decide to mix pesticides in the drone tank, you will be devoting considerable time to both mixing the product and agitating the product once it is in the tank. This method also introduces more opportunities for mixing errors, which can reduce pest control or severely injure crops.

Premixing Pesticide Solutions in Large Supply Tanks

The general consensus of experienced drone operators is that operations are more efficient when they premix pesticides in larger tanks such as shuttles or minibulks. Make sure to mix only what you need. This process would be like many commercial applicators that mix “hot loads” in larger supply tanks at mixing facilities, and then transfer them to sprayers in the field.



DRONE **FACT**

Remember, the pump and spray configurations on drones resemble ATV spot-spray systems more than sophisticated commercial ground systems. However, most new drones are equipped with rate and droplet size control capabilities that are comparable to those found on ground rigs.

Race Car Pit Stop Mentality

Watch a pit stop when a race car driver enters for fuel and tires. In a matter of seconds, the driver is back out on the racetrack. Some drone operators have a similar philosophy: one minute on the ground and the drone needs to be back in the air.

When this drone returns to base, the operator swaps the battery, quickly fills the tank from the larger one (sitting in a utility vehicle), and sends the drone back out to spray with minimal loss of time. Many commercial operations are set up with larger-volume tanks to be more efficient when filling up drone sprayers. But the extra weight might mean operators need to upgrade trailers and trucks.

These larger tanks should be equipped with the ability to agitate mixtures and to pump chemicals directly into a drone's spray tank. Remember, since these mixtures are highly concentrated, some form of agitation in the shuttle or minibulk may be required to ensure that operators achieve the correct dosage and compatibility from their first fill to the last.

Tip From the Field

One operator offers this tip.

"We commonly use IBC totes because they are readily available and often free. They are a challenge to properly agitate and clean out because of the flat bottom. We highly recommend using agitation and some kind of round tank with a sump for complete, thorough cleanout."

Battery Management at the Job Site

Batteries are generally the heaviest components on empty spray drones. Battery capacity is important because it determines flight time and the effective payload. However, there is not a firm answer to the question, "How long will a battery last?"

The answer is that it all depends on the drone's load, battery size, battery age, drone weight, field layout, route design, and local weather conditions. An empty drone may be able to fly for 15 minutes, while the same drone fully loaded may only fly six to eight minutes. This is why it is important to plan your operation strategically. For example, you do not want a fully loaded drone to fly to the other end of the field (and use up half of its battery life) before it begins dispensing product.

It is true that larger payloads allow drones to treat more acres per tank, but the extra weight from the larger spray tanks also reduces battery life. Heavier drones (such as those with larger payloads) will discharge their batteries quicker to keep them aloft and spraying. Operators must replace batteries on spray drones more often than on drones used solely for imaging and surveillance.

How fast a battery discharges can also depend on the effects the ambient air has on a drone — wind speed and direction, air density, humidity, and temperature can all affect battery life. Battery life can also be linked to the mission itself. Manual flying requires more battery power as the pilot adjusts the drone's course, speed, and altitude. Autonomous flying can help conserve battery life and improve efficiency.

Keep Batteries Charged

It may be a good idea to replace your spray drone's battery each time you refill the tank — even if the battery is partially charged.

You don't want to run out of battery life before you need to refill the tank. When its battery gets low, a drone is programmed to stop the mission and go back to the staging area even if it has material in the tank.

All drone spray operations will vary by site. Missions that have many turns or short rows will use more battery power. Turning also makes the operation less efficient because the drone must slow down as it approaches the end row, then speed back up once it begins its next swath. When planning a mission, minimize turns as much as possible because they slow down the drone. Flight plans with longer rows will get longer battery life than flight plans that contain many turns.

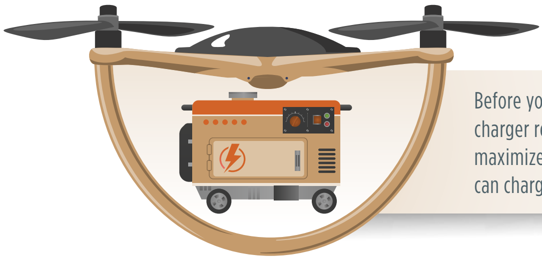
Battery life is also significantly reduced when the drone spends time hovering and operating at slower speeds. If possible, fly in long rows without losing the signal, and then fly at higher speeds with moderate swaths. This increases the drone's efficiency when it comes to maximizing battery life. Be careful when flying on very sunny summer days with temperatures greater than 95°F. Batteries can overheat and cause the drone to make a forced landing.

Always arrive at a job site with your full complement of charged batteries. The number of batteries you need will vary depending on the drone, battery charger, and the generator you use to power the charger. Some chargers charge batteries as quickly as drones can discharge them, while other chargers are much slower. If you have slower chargers, you will need many batteries to support continuous flight.

Most batteries have lights that indicate how much battery life remains. (A) These four lights indicate the battery is fully charged. (B) This battery has used up half of its battery charge.

Depending on the type of drone you purchase, you need a minimum of three batteries or as many as 12 for continuous flying. Some batteries have a history of overheating and may require cooling stations to keep them within specified operating temperatures. Overheated batteries can cause aircraft to unexpectedly lose power in midflight, potentially resulting in crashes.

It is always good to speak with people who have experience with the specific drone you are interested in purchasing. They will have insight on how many batteries and chargers you will need to keep your drone in the air.



DRONE **FACT**

Before you purchase a generator, check your drone's battery charger requirements and make certain the generator can safely maximize the battery charging process. How quickly a generator can charge batteries is important for spray drone applications.

Generators for Charging Batteries

It is never wise to purchase a generator for your drone without knowing the generator specifications or your battery charger requirements. A generator will be the workhorse behind the scenes while the drone is operating. Generators work constantly to recharge batteries while operators continually swap them in and out during the drone's operation.

Some charging systems run on 110v supply, but you can achieve a faster charge rate if converted to a 220V and 50A system that may be custom designed. Electronic load management for the generator is always a nice feature. This feature can minimize fuel consumption and noise during periods of reduced generator demand.

Before you purchase a generator, check the requirements for your charger. You want to be sure any generator can maximize the efficiency of your charger. Additionally, you might consider how loud the generator might be — there are low-noise options if the pilot and visual observer will be near the generator all day long.

Generators may differ in the number of outlets they have and in their output ratings for the circuit. Sometimes the generators require special wiring to achieve what you need. To provide faster charging for current spray drone batteries, operators require a 240v 50 AMP plug. This means generator output needs to be greater than 9500v when running. Remember, generators may also be running agitation pumps, cooling fans, or other electronic needs at an application site so make sure your generator is properly sized and has the number of outlets you will need.

Tip From the Field

Some advice from a drone operator.

"Most air-cooled, gas-powered generators are not designed to operate at maximum capacity 12 hours per day in 80° to 90° heat in July.

"Many operators rely on these small engines and get by in the short term, but in the long term, a better option might be a liquid cooled generator. We utilize commercial grade, liquid-cooled diesel generators that are enclosed in noise deadening housings. These will provide service for years to come, and ensure we deliver proper voltage to our chargers because we are only operating between 50 and 70 percent of generator capacity.

"We do not require our operators to wear hearing protection because of a screaming small engine all day. The drawback of our commercial units are cost, size, and weight; although we feel in the long run that cost will be comparable to constantly replacing consumer-grade generators."

Generators are necessary for operations that include multiple batteries that require charging. Do not charge batteries under full sunlight because they can overheat very quickly. In addition, do not place generators inside sealed trailers because the exhaust is a health hazard and oxygen depletion will eventually compromise a generator's engine combustion. Remember that generators that are too small or that do not have well-regulated voltage output can damage drone battery chargers.

Cargo-Carrying Trailers Are Popular Additions

As an alternative to trucks, operators often use open and enclosed-type trailers to carry drones and other items they need for spraying, mixing chemicals, and charging batteries. These trailers are comparable to farmers outfitting trailers with minibulks, tanks, water, pesticides, adjuvants, pumps, and metering systems to keep their operations functioning.

Enclosed trailers offer additional advantages. They can protect equipment and supplies against dust and poor weather conditions, and they can deter theft because people cannot see what is inside. For additional information about equipment theft, see *Protect Your Trailers and Contents from Theft* (Purdue extension publication PPP-134), available from the Education Store (edustore.purdue.edu) or Purdue Pesticide Programs (ppp.purdue.edu).

Operators can place generators in enclosed trailers if the trailers are ventilated to the outside. Be aware that carbon dioxide can build up in trailers and can choke out combustion for the generators. Keeping generators in ventilated trailers can keep operators from having to load and unload some supplies at every job site.

An advantage of enclosed trailers is that operators can park them overnight by simply disconnecting them from their trucks. Getting to the field is as simple as hooking up the trailers and getting to the first job that day, or simply keeping trailers constantly connected during the busiest times of the year.

One major benefit of enclosed trailers is that you can outfit the tops with landing surfaces or observation decks that provide a higher elevation to maintain line-of-sight with the drone during flight.

Other options for transporting necessary equipment to the field for drone applications exist. Light- to medium-duty trucks with flatbeds may already be available and you can convert them to spray service on a seasonal basis. This same style of trucks may have an enclosed bed known as a box truck. Some examples on farms would be "retired" moving trucks, such as U-Haul vehicles or retired food service trucks used to supply commercial passenger aircraft. Box trucks can provide a secure storage area for equipment and supplies, plus allow for a possible landing and observation deck on top of the box.

Tips from the Field

Here is some insight from a drone operator.

"Open versus enclosed trailers come with trade-offs.

"We prefer open trailers, because that way, we always have a landing zone on the back of our trailer. When moving from field to field, the drone lands in its transportation spot and we do not have to carry the contaminated drone into our enclosed trailer. Furthermore, by landing on our open trailer we reduce the amount of dust and debris that is kicked up into the air on takeoff and landing. Finally, we land the drone on the same level that our operators stand, so there is no up and down ladder or stairs for our operators to climb to refill the drone and swap batteries.

"We can park inside overnight and thus, theft protection is not a concern for us. Also, many enclosed trailers are not built heavy-duty enough to carry the weight required for all the water and spray solution we need to operate all day."

Tips from the Field

Here is some insight from a drone operator. "Many times, trailers need some special modifications to securely hold down all this equipment for transport.

"It is important to carefully consider equipment placement and adding the necessary secure points to make sure the equipment stays in working order and does not get jostled. This is especially important when traveling on rough terrain to reach a site/recharge point."

On-Site Parts and Repairs

Just like other mechanical devices, drone parts break down and need to be replaced. Keeping spare parts on-hand can reduce downtime and get you up and running within a day or sometimes within several hours. The main supporting frames of most drones are constructed of carbon fiber, a material that is light but durable. However, drones are also constructed of plastic materials to reduce their weight, so it is easy to see how external parts can degrade by sunlight.

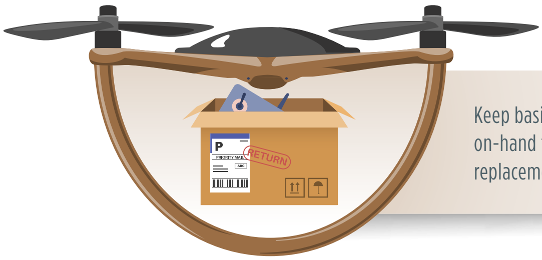
Common operational factors can also cause wear-and-tear on drones. Rotors get chipped and broken when they hit obstacles or make rough landings. Motors can fail if dirt and debris infiltrate the internal parts.

Having spare parts on-hand can save a lot of time, considering it might take days to get your shipment anywhere from within the United States. Your spare parts inventory could include nozzles, inline valves, pumps, flow meters, batteries, electronic speed controllers, motors, and a set of rotor blades.

How many of these parts you carry in your inventory will depend on how quickly you can access parts from dealers or manufacturers. If you have a reliable dealer who can ship parts quickly, you may not have to keep as many items in stock.

Quick access to spare parts could mean a job only comes to a standstill for a few minutes rather than days. Some argue that keeping replacement parts in inventory is a lot of money just sitting there. While that is true, ask the question: "How much money are you losing while the drone is inoperable?" A $10-part can cost you hundreds, if not thousands, of dollars in down time. It can also upset customers while they wait for their fields to be treated.

Down time is money lost for you and potential crop losses for the farmers you serve. Furthermore, replacing drone components can be relatively simple. Circuit boards and motors are often connected with a few screws and a plug that you can switch quickly. While some diagnostics are too difficult for the average person to do, some dealers can help diagnose an issue over the phone or with a simple video call. As drones become more popular, increased customer and technical support will become available, too.



DRONE **FACT**

Keep basic spray drone parts (such as rotors and nozzles) on-hand to save time and money. It could take days to ship replacement parts.

Personal Safety Like Any Other Application

Apply the best management practices for handling and mixing pesticides with a drone that you normally follow for any other application method. First, operators must wear whatever pesticide product labels list as the minimum personal protective equipment (PPE).

What makes drone applications different is the higher pesticide concentration of the product solution compared with application methods that use higher carrier volumes and more dilute solutions. While both methods apply the same amount of pesticide active ingredient per acre, the pesticide solution in the tank can be more concentrated at the extremely lower carrier volumes that drones use.

A Difference in Concentration

Keep in mind that drone tank mixtures are low-volume applications rather than what you may be accustomed to dealing with in other equipment. With ground rigs, some pesticides are often diluted in 10 to 20 gallons of water per acre.

However, drones may be applying the same pesticide rate per acre in 2 gallons of water. You are mixing, applying, and handling a more concentrated spray solution. That requires you to follow additional safety precautions when spraying with drones. At a minimum, you need to follow all label-recommended PPE.

This photo perspective shows a good example of maintaining a line-of-sight even when spraying over a tall crop like corn.

It is important to wear chemical-resistant gloves when handling spray drones because the aircraft exterior will have pesticide residues.

Make sure that no one is working or playing in application areas. It goes without saying that you should not operate drones when people are fishing on a pond, highway workers are repairing the shoulder of a road, workers are weeding in a tomato field, or students are detasseling corn.

An issue you need to address early is the wind direction relative to the staging area. If you would be uncomfortable spraying with a ground rig because of the potential for spray drift, then there is no reason to apply pesticides with a spray drone. Always follow label directions regarding wind speeds and/or specific state requirements.

While the tops of hills provide good lines of sight as required by the FAA, pilots and visual observers should be aware they could be positioned downwind of applications. Even if they are not positioned downwind of spray passes, droplets may still drift toward staging areas during the first couple passes made. You can always relocate yourself and crew temporarily until you complete those passes to avoid exposure to spray drift.

Common Questions Regarding Spray Drone Applications

In this section, we answer frequently asked questions about using drones for pesticide applications.

Q: Should I rinse the tank if I'm planning to use the same product tomorrow?

If you plan to use the same product the next day, the best practice is to flush out the system so that the product does not remain overnight in hoses.

Remember, the higher pesticide concentration in drone tanks present greater risks to drone parts over time. As products sit in tanks and lines for extended periods, there are more opportunities for pesticide solutions and formulation solvents to seep into lines, hoses, and poly tanks. They could even allow solid residue to form on surfaces of solution tanks. Studies with blue dye show some products have the potential to remain in lines for weeks. Rinsing out the system reduces the likelihood that materials will solidify, which may corrode pumps, seals, and rubber parts.

The problem with spray drones is that there are no rinse tanks with clean water onboard to flush lines like there are with ground rigs or manned spray planes. What remains in partially filled tanks must be sprayed over the edges of fields or back over recently sprayed fields. After that, rinse drone tanks with clean water and spray it out, repeating the process several times.

Q: Should I use a tank cleaner when I switch products?

After you rinse a drone, you should use a tank cleaner when you switch from one pesticide to another or if you switch to another crop that may be sensitive to a chemical you have previously used. Just like traditional ground sprayers, when you use tank cleaners with proper technique, they will remove and break down any remaining ingredients and make them inactive.

Make sure to remove and flush out any internal screens your drones may be equipped with. Sometimes, you can remove drone spray tanks, which allow you to add tank cleaner solutions to tanks and manually shake them.

Many drone solution tanks have removable strainers that allow for easier cleaning.

Q: How do I agitate the mixture in the tank?

Currently, there are no agitation devices on spray drones. Mixing pesticides directly in the tank requires two people to pick the unit up and shake it.

If you use anything other than a water-soluble formulation, it is best to make a slurry of water and the pesticide mixture in a 5-gallon bucket or a 2.5-gallon jug to get the products well suspended throughout the mixture. Another option is to use a separate mixing tank that has a built-in agitation pump to improve mixing before transferring it into the drone.

Q: Should I rinse off a drone before leaving an application site?

When drones are spraying liquid pesticide solutions, some of the spray mixture will undoubtedly get on drone exteriors. It is a misconception that you cannot rinse off a spray drone with water. Many mistakenly believe that rinsing drones damages electronic components. In reality, spray drones are largely watertight, which prevents damage to the onboard electronics when you rinse their exteriors.

Getting into a habit of rinsing drones helps remove solvents that could "gum up" moving parts and remove grime from sensors. Rinsing drones not only protects them, it also will keep unwanted residues out of the trailers or truck beds when you store the drones.

Due to the wind turbulence drones produce, pesticides are often deposited on drones, requiring thorough cleaning. Use a mild detergent solution from a squirt bottle and then rinse after a few minutes.

We do not recommend using any type of power washing equipment to rinse drone surfaces — water can get into electronic modules with high pressures. Periodically scrubbing drone surfaces is required to remove oily residues. In addition, removing those residues can help prevent carrying unwanted, sometimes herbicide-resistant weed seed, from one field to another.

Although the concentration of chemicals in rinse water is extremely low, it is a good idea to rinse tanks in areas far away from ditches or other areas (such as grass waterways) that present a risk of the rinse water reaching nearby water resources.

Consider using large confinement trays in your trailers or truck beds to place drones on after you rinse them. Confinement trays keep any water from dripping onto trailer and truck floors. The trays also could contain possible spills if drones still have pesticide in their tanks as you travel from site to site.

Dumping Product Never a Good Thing

One option for leftover solution in spray tanks you should never consider is dumping a tank's contents on the ground.

Dumping is illegal and can lead to serious consequences with federal, state, and local regulatory authorities. It is one of the easiest ways to tarnish your reputation and image.

Q: How should I handle leftover pesticides in the tank that are no longer needed?

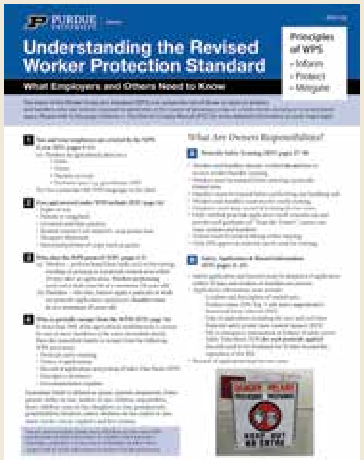
In a pesticide application, the guiding philosophy is that you should leave minimal product in spray tanks. Consider this principle when you are mixing pesticide solutions. Consider the size of the field to be applied or the overall job. Assume 1 gallon left in the spray tank.

Some think it would be much easier to empty a tank's contents back into the premix tank that it was originally pulled from. However, there is always a risk that the leftover mixture is contaminated and that you would be combining contaminated mixture with uncontaminated premix. While the likelihood of that might be slim, why take the chance?

Draining tanks directly on the ground is not a good option either. There is a high risk that the person opening the drain cap under the tank will get tank mix all over their hands, arms, and legs, creating excessive chemical exposure. Then there are always the regulatory repercussions of dumping chemicals on the ground.

The only real option is to dilute leftover mixture and spray it on the field you just sprayed or around the field edges. Normally, you will need to apply less than a gallon or two. Putting herbicide products to use on field edges where weeds are normally thicker is a good idea, while insecticides and fungicides can go back over the crops.

As long as the sprays from previous application have dried, going back over it a second time with drones will not wash off any previously applied products. It is important to dilute the remaining chemical mixture as to not over-apply any chemicals beyond label limits.



Purdue Pesticide Programs offers a detailed publication:

Understanding the Revised Worker Protection Standard: What Employers and Others Need to Know (Purdue Extension publication PPP-131).

It is available from Purdue Pesticide Programs (ppp.purdue.edu)
or the Purdue Extension Education Store (edustore.purdue.edu).

Q: How do I manage wind and streaking?

Streaking is a function of improper swath management. You can help prevent streaking by swath testing and adjusting application parameters (height, speed, or droplet size) to determine effective swath widths. Swath displacement caused by excessive winds can also result in streaking because product deposition will be highly concentrated in certain portions within the swath.

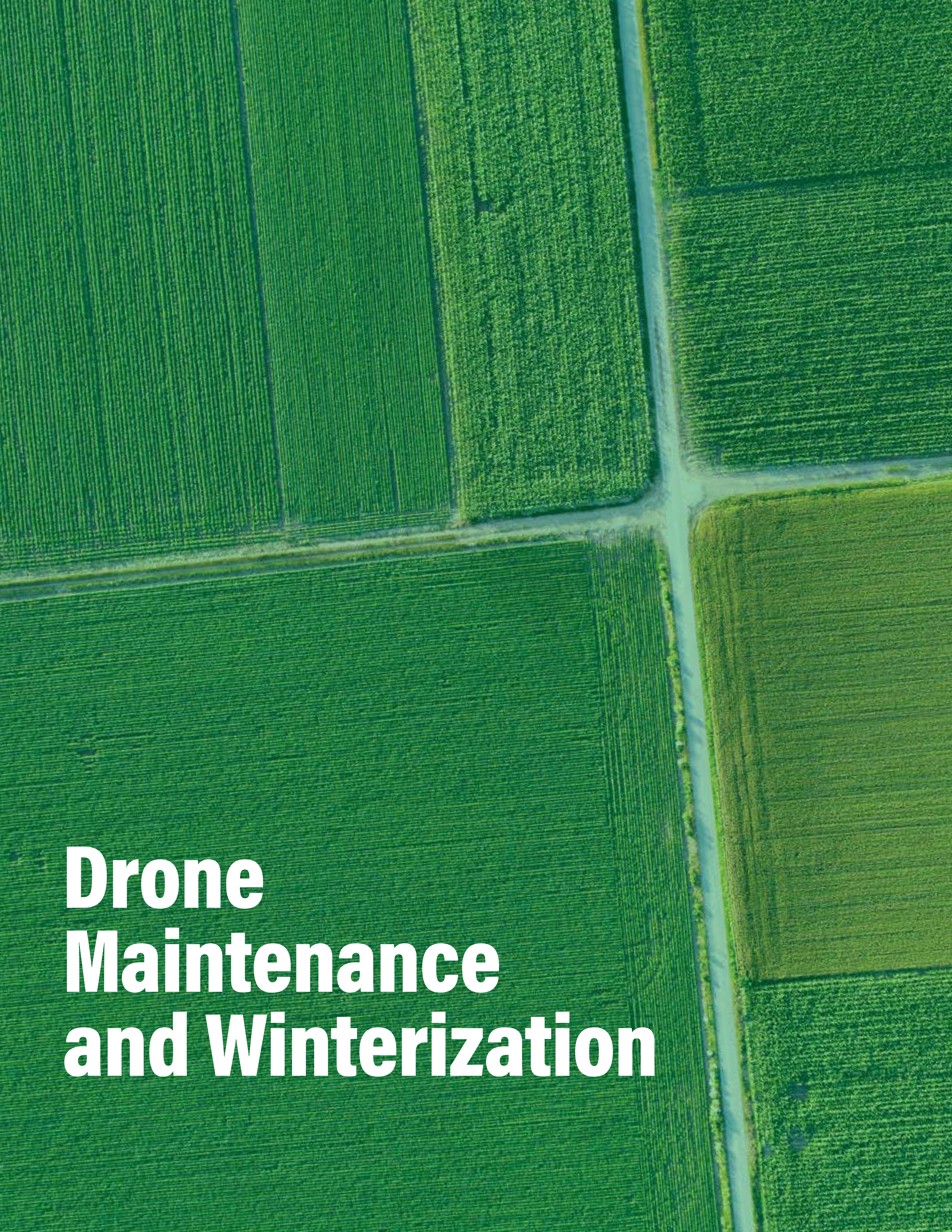
Q: Do I have to post and/or leave information at the field?

Following any pesticide label's use directions includes meeting the requirements of the Agricultural Use Requirements box. This box provides further instructions about posting, reentry times, and information exchange when the area treated is a farm, forest, nursery, or enclosed space production (for example, a greenhouse). If the area being treated is not one of the above areas (for example, aquatic), consult the box called Non-Agricultural Use Requirements that is shaded and placed directly below the Agricultural Use Requirements.

For more information, see *Understanding the Revised Worker Protection Standard: What Employers and Others Need to Know* (Purdue extension publication PPP-131), available from the Purdue Extension Education Store (edustore.purdue.edu) or Purdue Pesticide Programs (ppp.pudue.edu).

DRONE **FACT**

Following a pesticide label's use directions includes meeting the requirements in the Agricultural Use Requirements box. This box provides instructions for postings, reentry times, and information exchanges when treated areas are farms, forests, nurseries, or greenhouses.



Drone Maintenance and Winterization

It is important to observe and inspect drones before and after operations to detect any damage that may have occurred.

End-of-season maintenance on drones ensures quick startups in the spring. Winterizing drones is straightforward, since most of the time, they will be stored in temperature-controlled rooms like heated shops.

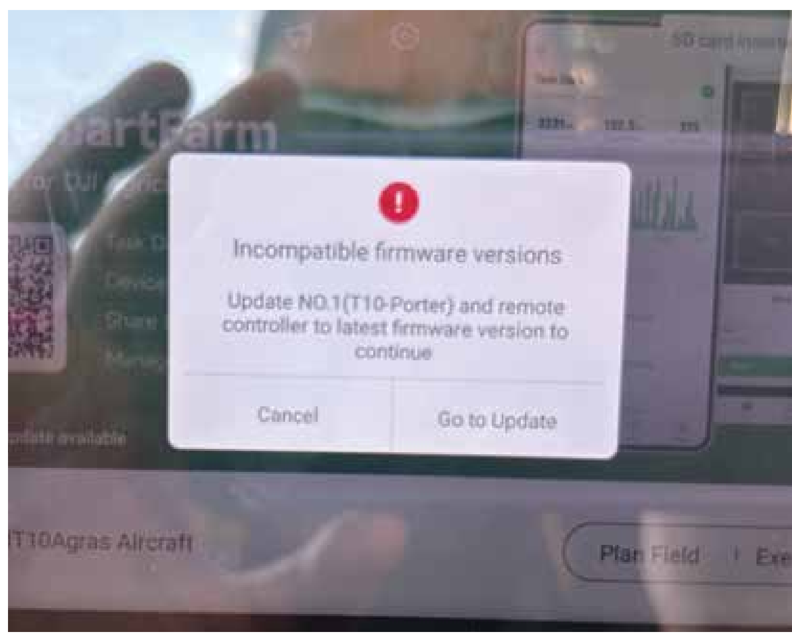
Perform a visual inspection that focuses on looking for cracking and splits in the frame, because there is a lot of torque when drones take off and impact force when they land. Check all the parts to see if anything needs tightening or replacing. Make sure to replenish your spare parts inventory so you are not surprised the next time you need that part in the field.

There is really no inspection you can perform with the drone's software. The software is designed to check the functionality of the electronic components. Drones will go through self-check diagnoses when they are first powered on. The propellers move a little, the cameras will move, and lights will flash. If any part fails the self-diagnosis, the controller will tell you there is a problem. A message will appear on the controller saying the drone can't take off because the following issue x, y, or z needs to be addressed.

What Is My Dadgum Password?

Make sure you have carefully noted your username and password to log into drone software and keep it where you have easy access to it when you want to use the drone next season.

It is important to ensure that you are using current firmware for your drone's software. Manufacturers may send software updates to fix bugs or other issues. It is also important to ensure drones and battery firmware are compatible, otherwise a pilot may show up to the field and not be able to fly until the software is updated with current software patches. If you have not flown for a while, power up the drone and controller at the shop where you have a consistent internet connection to help avoid any untimely firmware updates at jobsites.



Software errors, like this one, are often displayed when starting up a drone. It is important to keep software up to date to ensure best performance.

When batteries are not in place, electrical components are exposed and are at risk for damage.

Make sure to keep a battery in place to help protect the copper connection when you wash a drone and even when not in use. Use a paper towel or cloth to wipe any water from the copper connectors. Do not take out the battery because this exposes terminals and can short if water is present.

Before storing batteries, examine each battery for signs of swelling on the top and sides of the unit. It is always a good practice to label your batteries 1, 2, 3, etc. The labels help ensure that you use each battery regularly instead of charging and using the same battery over and over again. The owner's manual should provide directions on how you should store batteries.

Triple rinsing drone tanks, flushing out lines and pumps with clean water, and using tank cleaners overnight are good practices to help remove any unwanted chemical residues. Replace hoses that appear to be checkered from sunlight damage or appear to be stained or colored from absorbing chemicals.

DRONE **FACT**

When cleaning drones, do not pressure wash them or remove any components (such as batteries) to avoid getting water into the drones.

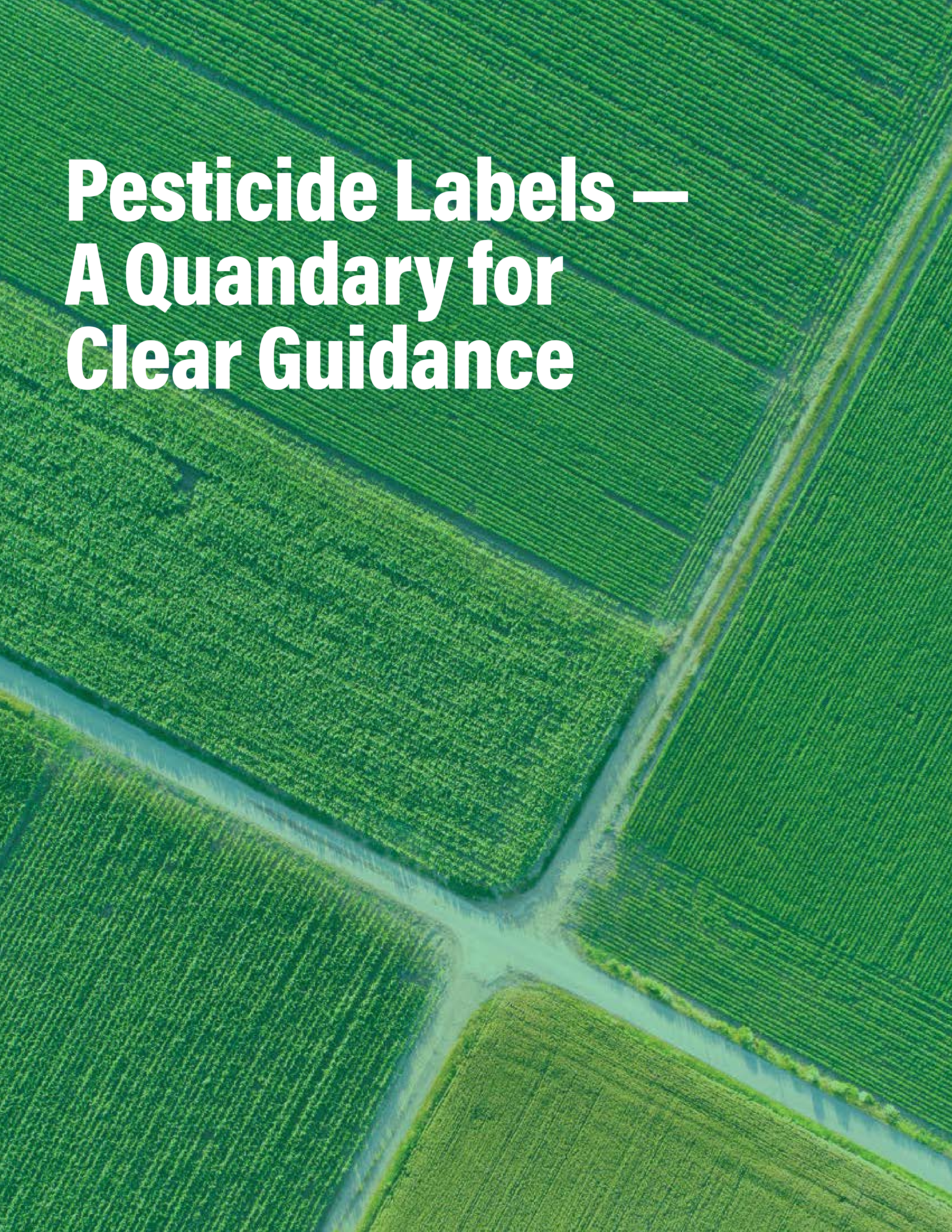
Batteries can swell if they overheat, which in turn decreases performance or causes permanent damage.

If your drones will be subjected to freezing temperatures, then you should flush their systems with RV antifreeze after cleaning them. This will help prevent any remaining water from freezing. Remove as much water as possible by emptying tanks, open any valves to release any trapped water, and blow air through the systems. Fill drone tanks with enough RV antifreeze to flush the entire drone.

At first, the color of the antifreeze coming out of the nozzles will be lighter, because it has been diluted with any remaining water left in the drone. Continue to flush until the antifreeze coming out of the nozzle is the same color as the antifreeze you put in.

Drones should not be stored in freezing temperatures. However, rinsing drone lines with RV antifreeze helps prevent damage that may occur from cold environments and extends the life of such components.

Pesticide Labels — A Quandary for Clear Guidance



There is a high degree of interpretation of what label instructions say when it comes to using drones for spraying pesticides. Currently, specific information about the carrier volumes, application heights, nozzle types, and droplet sizes that are typical of drone applications are not incorporated in the aerial application sections on product labels. However, we do expect that information for drone use will begin to appear on pesticide labels as soon as reputable sources adequately research the issue and regulatory agencies review further application requirements or considerations that need to be provided.

Warning: Regulations and Interpretations Are Changing

In this document, we provided what we believe is true as we were writing it. It is always important to check with FAA websites and your state pesticide regulatory agency for up-to-date regulations and policies.

Can I Spray any Pesticide Using a Drone

To answer the general question of whether you can use any pesticide using a spray drone, you should ask yourself three specific questions.

Question 1: Does the Pesticide Label Prohibit Aerial Equipment?

Many pesticides work well when sprayed with drones. No one could have foreseen that drones would be applying products on golf courses, greenhouses, ponds, tree plantations, and nurseries. Regardless, if a pesticide label has language that reads "Do not apply this product using aerial equipment," then the answer to this one question is clear: You can't legally apply this product with a drone.

If a product label prohibits drone applications, then drone operators take full responsibility if it fails or causes problems whether on- or off-site. Manufacturers have no liability when applicators use their products if labels prohibit that application method. There could also be repercussions from regulatory agencies for using the product off-label.

Instructions on product labels may be different from one product to the next even though the chemicals contained in those products are similar or almost identical. For example, some generic 2,4-D formulations typically used in burndown herbicide applications are labeled for aerial application. However, some 2,4-D formulations, which have been developed to spray post-emergence in 2,4-D-resistant soybeans, are not approved for aerial equipment. Although both pesticides are 2,4-D, they cannot be treated the same with a drone.

You must read and follow label instructions for the specific pesticide you are using. Do not make assumptions that it is OK to use drones to spray this one pesticide because you previously used a similar product by different manufacturer with the same active ingredient that allowed using drones.

Question 2: Does the State Regulatory Agency Allow Drones to Follow Aerial Labels?

The U.S. EPA currently allows each state regulatory agency to determine whether drones can operate under instructions for aerial applications. You will need to ask your state pesticide regulatory agency if they allow drones to apply pesticides using the instructions provided on product labels for aerial applications. You also should ask what state-specific pesticide certifications they require for you to use drones to apply pesticides. These certifications will vary from state to state. Not all states observe reciprocity, so applying across state lines may require multiple examinations and certifications.

Question 3: Can the Drone Follow Aerial Application Instructions?

If a pesticide product has an aerial application section, then a drone (if your state allows) can apply it by following all requirements listed under the label's aerial section. You are required to follow the minimum or recommended application rates per acre, carrier volume, and other criteria listed on the product label. If you cannot follow some of the aerial application label requirements because of unique application parameters used with drones, then you cannot legally apply the pesticide with a drone.

Only following part of the label and ignoring requirements on other sections can create efficacy problems, increase the chance of pesticide resistance evolving, and allow illegal residues to remain on harvested commodities. It also violates one of the key statements on all labels: "It is a violation of federal law to use a product inconsistent with its labeling."

How you interpret a label depends on how the instructions are worded. A label's recommended carrier volume is often a make-or-break deal for legally using spray drones. Remember, drones use significantly less carrier volume of water per acre than ground rig applications. Some pesticide labels may require 10 to 20 gallons of volume per acre for ground rigs and 5 gallons per acre aerially. Spray carrier volume rates exceeding 2 or 5 gallons per acre become difficult for some drones to accomplish because these rates severely limit drone efficiency. At that point applications can become cost prohibitive.

How would you interpret the following label direction about the application rate?

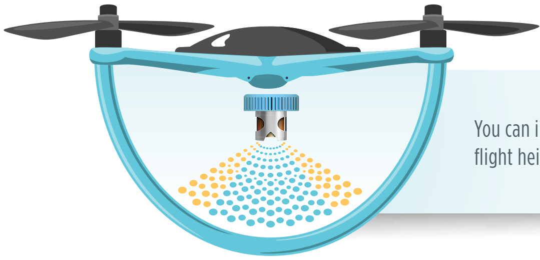
"Do not use less than 10 gallons of spray solution per acre."

There is no flexibility in this language. The label clearly states that you must spray this solution at a rate of 10 gallons or more per acre, which means you would be off label if you use a drone (or any other application method) to apply less.

Other labels are written with some flexibility. For example, two labels provided the following information:

1. Use the recommended rates in 3 to 25 gallons and
2. Minimum spray volume per acre is 2 gallons

Such language gets you into the lower range of volumes that drones can take advantage of. It also means that the manufacturer has done the research to support that the amount of carrier they recommend on their label will work and that doing so adheres to other regulatory safety conditions such as crop residues.



DRONE **FACT**

You can increase drone spray coverage by optimizing swath speeds, flight heights, adjuvants, spray tips, and spray volumes.

Regardless of what spray equipment they use, the goal of sprayer operators is to adequately cover the target with the pesticide while minimizing spray drift.

There are two common ways to increase coverage on the target:

1. Increase the gallons per acre application rate — perhaps by using nozzles that have higher flow rate capacities (gallons per minute)
2. Reduce droplet size

Relatively smaller spray droplets are highly susceptible to spray drift. To minimize this risk, pesticide manufacturers have been including droplet size recommendations on labels (for example, ASABE Droplet Category). Some labels may even recommend not using fine spray droplets to avoid spray drift.

Unfortunately, to achieve maximum coverage with low application rates of drones, most drone operators apply their products using nozzles that produce smaller droplets. However, some current research indicates that larger droplet sizes do not have the same coverage penalty from drone applications as they do from ground-based applications, so larger droplet sizes could be used for both drift mitigation and coverage. Remember, the label is the law. Therefore, you should read the label carefully to determine if there are specific requirements on the label related to droplet sizes, nozzle types, and spray pressures when using the specific nozzles.

Manufacturers commonly equip spray drones with standard nozzle bodies, so applicators can select which spray tips fit their specific needs for their intended applications and the pesticide requirements. Alternatively, spray drones may come with rotary atomizer nozzles that applicators can adjust to deliver a range of spray droplet sizes (photos to right). These "spinner" nozzles are similar to the controlled droplet applicator (CDA) nozzles that were popular for ground applications in the 1980s, but lost favor due to the complexity of the system being driven by hydraulic motors. Current atomizer nozzles on drones use electric motors.

Rotary atomizers provide some value because applicators may not have to change spray tips to adjust the spray droplet sizes. However, additional electric motors add weight to drones, which can drain batteries faster.

Rotary atomizers also have the advantage that they don't clog like hydraulic nozzles can. You can spray a thick tank mix with rotary atomizers, which often is not possible with standard hydraulic nozzles fitted for drones. Rotary atomizers are not without challenges, because the spray quality can be compromised if the gallons per acre and travel speed are set higher than the intended nozzle capacities. Furthermore, adding spray adjuvants may alter the performance of rotary atomizers and impact droplet sizes from what is indicated on controller displays.

Federal Aviation Administration Regulations

The United States Congress assigned the federal regulatory oversight of drones to the Federal Aviation Administration (FAA). With commercial use of spray drones being a recent phenomenon in the United States, FAA regulations and policies outlining who can pilot drones and under what conditions they may operate them are still in flux. Note that the following descriptions about current drone regulations will surely change as policies evolve.

Therefore, we advise you to check the FAA website (www.faa.gov) often for the most current regulations concerning drone use. Additionally, when drone operation requirements conflict with FAA rules, for which no authorization or waiver authority is available, the Secretary of Transportation has exemptive authority to grant conditional exemptions based on petitioners' requests.

The FAA regulations drone users must follow depends largely on three factors:

1. Whether the drone is flown for recreational purposes or commercial uses (all spray drones will be classified as commercial use)
2. Overall weight of the drone
3. Commercial use of the drone — that is, applying agricultural products versus capturing images

Recreational Versus Commercial

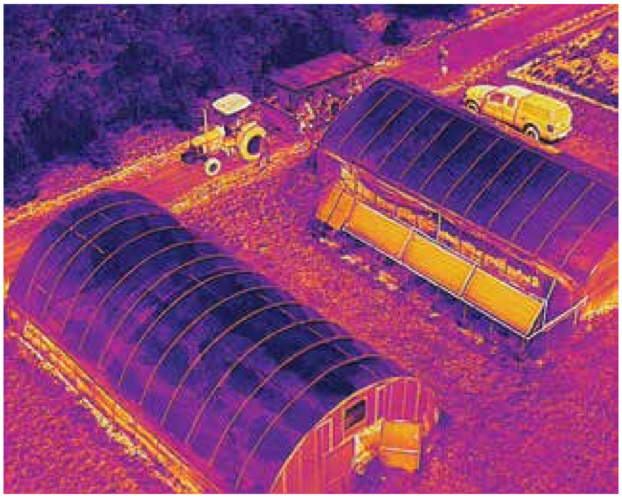
Although the FAA has a clear definition of recreational, or hobby, drones, the interpretation of the rules can encompass purposes that are not well defined, especially in the world of agriculture. If you buy a drone to fly over your farm for enjoyment, then you would assume you are flying for recreational uses. But what if you see something in your crop field and you take a closer look and find out that you need to control some weeds? Or, what if you see a nutrient deficiency that you go out and remedy?

Do these still count as recreational since you made business decisions?

Our interpretation is that drones used for recreational purposes includes flying drones for fun, using them in competitive races, or taking pretty photographs. Conversely, drones that provide any value to a business or farm is designated as commercial.

For instance, a drone flying a field sends back images that suggest a pesticide applicator in a ground rig had not cleaned out the booms properly before spraying the field. The drone provided the farm a commercial benefit. Taking photographs with your drone that you use on advertising brochures or websites would also be considered commercial use. As with most cases, if you are unsure if the use is recreational or commercial, it is best to play it safe and follow the rules of a commercial drone pilot.

Although taking photographs of the top of a forest or watching a combine work a field could be viewed as recreational, you should always read the information given by FAA on what is considered "recreational use of a drone."



Using a drone to measure heat loss or to see a pesticide tank contamination complaint would be considered commercial use of the drone. Operators are using both photographs to make decisions that affect the revenue or profits for a business or farm and would be classified as commercial uses.

Drone Weight Divided into Three Categories

Some FAA drone regulations apply to all drones regardless of their size, while other regulations are targeted to certain weight classes.

The FAA currently divides drones into three weight categories:

1. Less than or equal to 0.55 pounds
2. Greater than 0.55 and less than 55 pounds
3. Equal to or greater than 55 pounds

A drone's total weight is calculated by adding the weight of the platform, all onboard accessories, and the payload it carries.

Drones that weigh less than 0.55 pounds have limited commercial uses. These lightweight drones do not require federal registration and can be flown without being a certified pilot if they are used for recreational purposes.

This is an example of a drone that weighs less than 0.55 pounds and is exempt from many FAA regulations.

This drone weighs around 11 pounds.

DRONE **FACT**

If you are unsure whether you are using your drone for recreational or commercial purposes, it is best to get a commercial license and follow the commercial drone operation rules. If you are using it for agriculture, your drone is mostly likely considered commercial.

All drones that weigh more than 0.55 pounds and used commercially must comply with a set of baseline FAA regulations that deal with pilot certification and drone registration as well as product applications.

Requirements include:

Remote Pilot Certification for Commercial Drones

The FAA requires certification for pilots to operate aircraft remotely (operators not in cockpits of planes) for commercial purposes. The multiple-choice exam, called the Airman Knowledge Test (or Part 107), is taken at an FAA approved testing site under review of a proctor.

You will need to visit the Integrated Airman Certification and Rating Application (IACRA) website to create a personal identification number. This number, known as the FAA tracking number (FIN), is unique to you and is used to complete your airman certification application. In addition, you will need to provide proof of identity and current address at the time of testing.

Once you receive notice that you have passed the test, you will need to complete FAA Form 8710-13. Bring the completed 8710-13, a photo ID, and online course completion certificate to an official site to validate your identity (see Step 5 at the following website: www.faa.gov/uas/commercial_operators/become_a_drone_pilot#keepCurrent).

Alternatively, you can also fill out this form online, and you will receive your certificate in the mail. At that time, you will receive a temporary airman certificate. In several weeks, the FAA will send you a permanent remote pilot certificate.

Remote pilot certifications are valid for two years. At the end of each two-year period, you can renew your remote pilot certification by retesting or by completing a free online continuing education course known as FAA Drone Pilot Recurrent Training for Part 107 Small Unmanned Aircraft Systems Course.

After 24 months, you will need to have a recurrent certificate of achievement with you in addition to your Remote Pilot Certificate whenever you fly. You can complete this additional training online using a computer at your business or home. Continuing education is an easier way of keeping apprised of changing FAA regulations, polices, procedures, and interpretations than the retesting option.

Pesticide Certification Through Pesticide Regulatory Agencies

All states require individuals applying pesticides through spray drones to be certified.

Some states may require a basic core test and possibly additional tests. This includes both commercial businesses and private applicators (farmers).

The National Pesticide Information Center provides a state list of pesticide regulatory agencies and contact information at npic.orst.edu/reg/state_agencies.html.

Register the Drone with the FAA

All drones greater than 0.55 pounds must be registered with the FAA. When you register a drone, the FAA will assign a unique number specific to that aircraft. This is like a vehicle registration. The FAA also collects information about who owns the drone and their address. The FAA number must be attached and outwardly visible on the drone. If a drone goes down or someone gets hurt, the number carried on the drone can help identify the pilot or owner of the aircraft.

The current FAA registration process depends on the weight of the drone and its intended use. Drones weighing less than 55 pounds can be registered online in a few minutes. A drone that weighs 55 pounds or more requires a notary to validate the purchase of the drone and that the purchaser is the one registering the aircraft.

NICKNAME	UAS MANUFACTURER	UAS MODEL	SERIAL NUMBER	REMOTE ID	DEVICE TYPE	REGISTRATION	ISSUED	EXPIRES	STATUS	ACTIONS
Mavic 3E Multispec	DJI	Mavic 3M	1581F5FKD23280...	Yes	Standard Remot...	FA3YN77L4W	04/27/2023	04/27/2026	Active	⋮
Extension Hylio A...	Hylip	AG-110	2020269	Yes	Standard Remot...	FA3TYRM4AX	08/14/2023	08/14/2026	Active	⋮
Phantom 4 PRO ...	DJI	WM331S	11UCF4U0A30892	No	Traditional UAS	FA3H3EN4CH	10/19/2018	10/19/2024	Active	⋮
Mavick3E	DJI	Mavick3E	1581F5FHB229F...	No	Traditional UAS	FA3L3ARCYM	02/24/2023	02/24/2026	Active	⋮

This table shows a comprehensive list of drones registered to one of the authors.

The letter designation that precedes the FAA assigned registration number differs somewhat between drones that weigh more and or less than 55 pounds. A drone that weighs 55 pounds or more will be designated with the letter N, which is similar to manned aircraft registration. Drones that weigh less than 55 pounds will designated with the letters FA. The image on the previous page shows the pilot has four drones that fell in the 0.55-to-55-pound category.

Can you identify which one of these two drones weighs more than 55 pounds or less than 55 pounds? Clue: check the registration number.

Commercially registered drones that weigh less than 55 pounds must be renewed every three years at a cost of $5. Drones that weigh 55 pounds or greater must be renewed every seven years — like manned aircraft. The number assigned to a drone remains the same throughout repeated renewals.

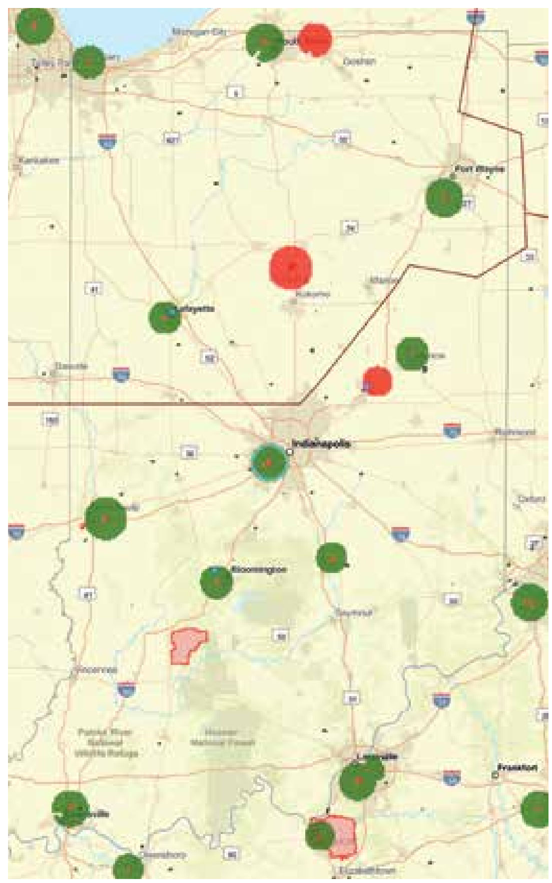
FAA RemoteID Requirements

As of 2022, all drone manufacturers are required to have a built-in RemoteID that broadcasts the ID of the drone with its location and pilot's location. For drones manufactured before September 16, 2022, without RemoteID hardware, the drone must be retrofit with a RemoteID module to fly in an FAA Recognized Identification Area (FRIA).

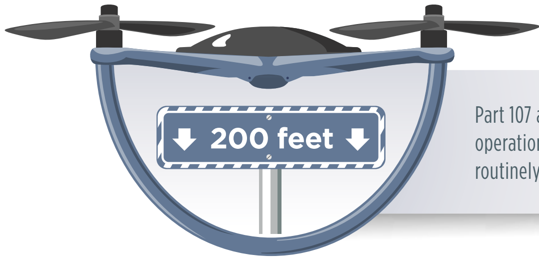
The RemoteID signal can be accessed by the public using applications like DroneTag or Drone Scanner. However, the drone owner's name and contact information can only be obtained by the FAA or law enforcement as a means of protecting the pilot's privacy.

Altitude Flown Depends on Airspace Restrictions

A drone may not fly more than 400 feet above the ground without an altitude waiver. Most spray drones fly up to a maximum of 50 feet. This includes 15 to 20 feet during application and 40 to 50 feet during takeoff and bringing it back to land.



This image shows some of the airport-controlled airspace in Indiana from the FAA website faa.maps.arcgis.com. Green squares represent authorization can be obtained by a LAANC service supplier, while the areas outlined in red require using the FAA DroneZone website.



DRONE **FACT**

Part 107 allows drones to fly up to 400 feet, but spray drone operations are limited to 200 feet. However, spray drones routinely stay within 10-30 feet of the ground or crop canopy.

With crewed aircraft (the pilot is onboard) flying no lower than 500 feet is a requirement. This ideally provides a 100-foot buffer between drones remotely operated and other aircraft with the pilots onboard.

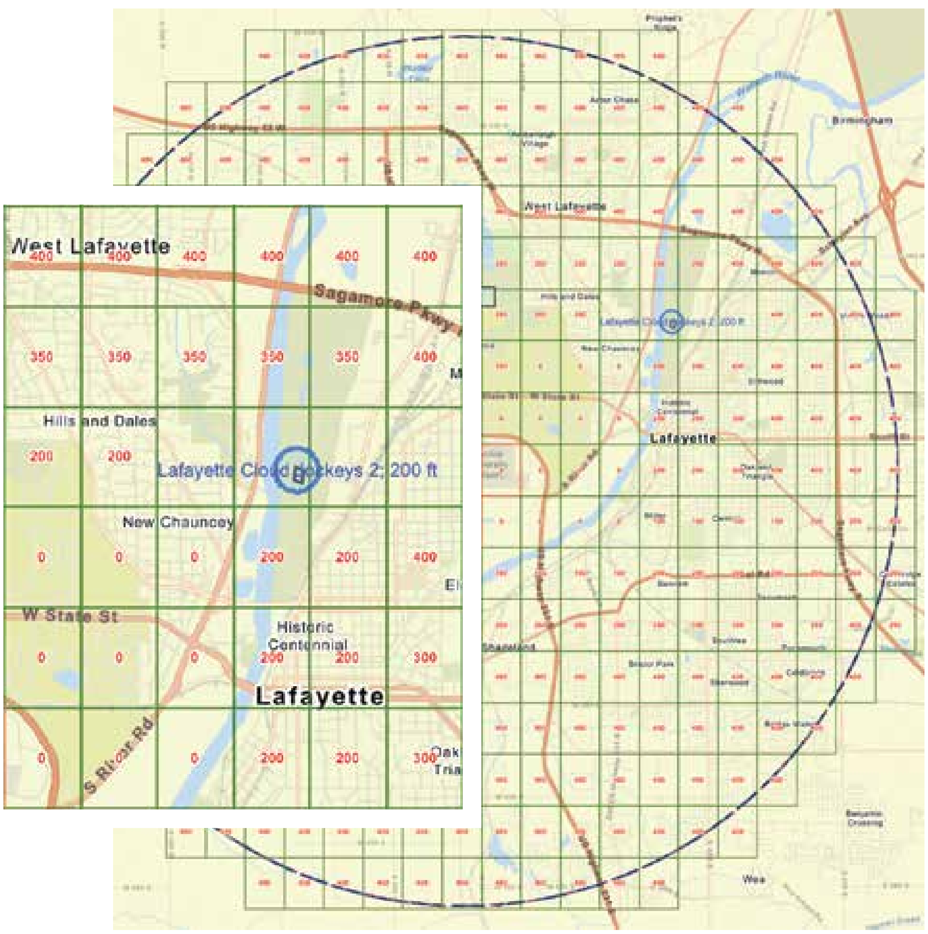
There are limitations when working in and around an airport in an area known as controlled airspace. Air Traffic Control manages controlled airspace. Flying in controlled airspace is more restrictive and requires clearance before flying in. Rarely are drones allowed to fly higher than 400 feet in controlled airspace without additional authorization.

Within each airport-controlled airspace at surface level, the FAA has established a set of grids to describe the maximum altitude a drone may be flown with prior authorization. It starts at 400 feet when entering the airport-controlled air space, but the maximum altitude is lowered as the drone nears the airport and runways.

The FAA requires pilots flying within controlled airspace to get authorization for operating within that airspace. Pilots flying under Part 107 rules may request immediate authorization to fly in controlled airspace from a Low Altitude Authorization and Notification Capability (LAANC) service supplier. More information about LAANC is available from the FAA: www.faa.gov/uas/programs_partnerships/data_exchange.

When a smartphone places a marker pin for the pilot's location in a LAANC application, the FAA reviewer will know the pilot's exact location. Some drone software is integrated with LAANC as well. This service can be used to quickly preapprove your flight plan from your controller or smart phone without any advanced notice in airspace that may have low-altitude flight restrictions. If the operation is in a Zero Altitude grid or a higher altitude is needed than provided in the grid, you may request an Airspace Authorization through the FAA DroneZone website: faadronezone-access.faa.gov.

Using the altitude assigned for your location within that grid, the reviewer will check the flight altitude provided to them on the waiver application. If you fly at or below the maximum allowed altitude within that grid, it generally means they will quickly approve your flight plan. The approval is sent to you via text or email and serves as documentation that the flight was preapproved.



By clicking on the airport that you will be working around, the FAA website (faa.maps.arcgis.com) provides this level of detail. This is the controlled airspace for the Purdue University Airport in West Lafayette, Indiana.

The FAA requires pilots flying within controlled airspace to get authorization for operating within that airspace. You can obtain this authorization in a short time by using a smartphone and following guidelines provided by the FAA. These examples show what the process looks like on a smartphone when you ask approval through the LAANC request.

(A) Applying for approval to fly in restricted air space.

(B) Selecting date and time for flight approval.

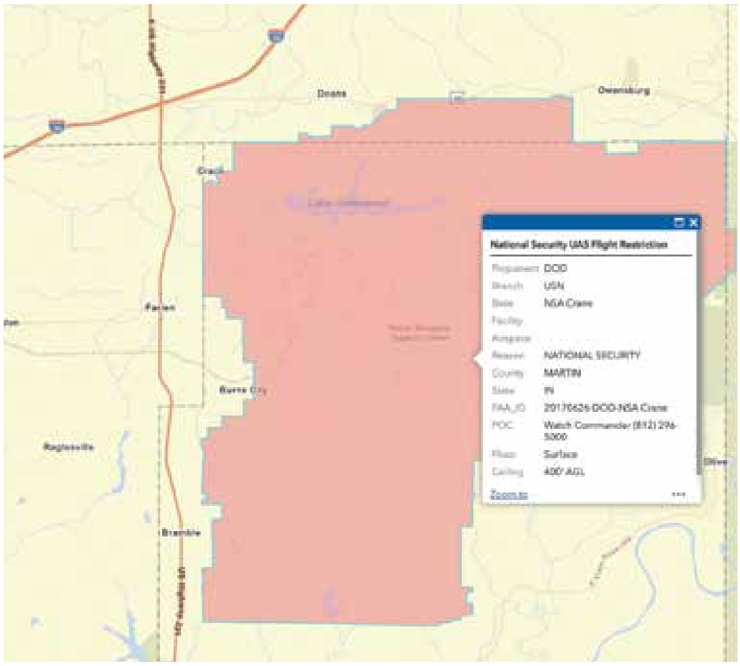
(C) Selecting the area within restricted airspace we are seeking approval to fly.

(D) FAA approval to fly.

The airspace around most military installations is either restricted or prohibited.

Restricted airspace includes areas where drones may operate but are subject to restrictions when determined necessary to confine or segregate activities considered hazardous to nonparticipating aircraft. Prohibited means that a drone cannot fly within the designated area — for example, members of the public are prohibited from making flights around the White House.

Knowing whether you are near or in a restricted or prohibited airspace is important before you fly a drone. You can use an FAA application called B4UFLY (www.faa.gov/uas/getting_started/b4ufly) to check which airspace you are currently in and whether you need any waiver or are not allowed to fly at all. Failure to comply with airspace restrictions can create significant regulatory enforcement actions by FAA investigators.



The Crane Naval Base in southern Indiana is listed as prohibited airspace on the Federal Aviation Administration website faa.maps.arcgis.com. Prohibited airspaces do not have grids, which indicates drones and other aircraft are not allowed within the shaded borders.

Pilots Required to See 3 Miles from Their Locations

Under Part 107, a drone can be flown if aerial visibility is at least 3 statute miles, 500 feet below clouds, and 2,000 feet laterally. This ensures that drone pilots can easily see manned aircraft and take evasive actions in case aerial applicators are in proximity of drone operators. Waivers or exemptions are required when pilots want to operate drones when visibility is less than 3 statute miles. Drone pilots should always yield to crewed aircraft in the case they are operating in the same vicinity.

Night Flying Allowed with Anti-Collision Lights

Pilots can fly their drones at night if the aircraft are equipped with anti-collision lights that can be seen from 3 statute miles away, and they flash at a sufficient rate to prevent collision. No waiver is required. However, we do not recommend applying pesticides at night regardless because of concerns about temperature inversions and, often, reduced pesticide activity.

'Waiver,' 'Authorization,' and 'Exemption' Are Different Terms

When flying under Part 107 rules, there are certain actions that are not allowed, but may be waived. Pilots or operators may apply for waivers and explain what their operations are, what safety precautions they are taking, and what kind of training will be required for remote crew members.

An application for authorization is similar to a waiver but involves access to controlled airspace that the LAANC does not grant immediately. The FAA reviews the proposed wavier or authorization and will accept or deny the application within 30 to 90 days.

An exemption on the other hand, is required to perform an operation that is strictly prohibited or "unwaiverable" under the current FAA rules.

May Not Carry Hazardous Materials

Agricultural products are considered hazardous materials by FAA definitions. At the time of this publication, if the operator wants to use a drone to apply pesticides, fertilizers, or other ag products deemed hazardous by FAA definitions, they must petition the FAA to issue exemptions from certain rules that govern the use of drones.

This includes carrying hazardous materials in spray tanks and for drones that weigh more than 55 pounds. The listed rules of Part 107 on the following pages are not a comprehensive list, but only a small subset of rules that are most applicable to using spray drones. You can find a full list and description of the Part 107 rules you must follow when operating a commercial drone on the FAA's website.

Applying Agricultural Products from a Drone

Any drone that weighs less than 55 pounds that is used to dispense dry or liquid pesticides (referred to as economic poisons in FAA statutes), plant nutrients, and other products to agricultural, horticultural, and forest areas are subject to rules under CFR 14 Part 137 and Part 107. To legally operate under Part 137, an organization must first obtain a Part 137 operating certificate. Part 137 provides FAA clear authority to provide oversight of aerially applied products. Remember that pesticides applied with drones are regulated by both the EPA and FAA.

Since drones that weigh less than 55 pounds are operated under Part 107 rules, and agricultural operations operate under Part 137, pilots or operators must comply with both 107 and 137. However, as previously stated there are certain rules that spray drones cannot meet, such as the rule outlined under Part 107.36 Carriage of Hazardous Material. Since spray drones and spray drone pilots cannot abide by all the rules outlined in Part 107 and Part 137, pilots or organizations must ask the FAA to be exempt from certain rules.

Fully loaded, this drone can weigh as much as 75 pounds.

The first step to obtain a Part 137 operating certificate is to petition for exemption from certain rules that cannot be abided. A list of rules that the organization or operator needs to request to be exempt for less than 55-pound drones include:

- Part 107.36 Carriage of Hazardous Material
- Part 137.19(c) Certification Requirements, Commercial Operator — Pilots
- Part 137.19(d) Certification Requirements — Aircraft
- Part 137.19(e)(2)(ii) Certification Requirements; Knowledge and Skill Tests; Skills; Approaches to the Working Area
- Part 137.19(e)(2)(iii) Certification Requirements; Knowledge and Skill Tests; Skills; Flare-outs
- Part 137.19(e)(2)(v) Certification Requirements; Knowledge and Skill Tests; Skills; Pull-ups and Turnarounds
- Part 137.31(a) Aircraft Requirements; Certification Requirements
- Part 137.31(b) Shoulder Harnesses
- Part 137.33(a) Carrying of Certificate; Certificate Carried on the Aircraft
- Part 137.33(b) Registration and Airworthiness Certificates Available
- Part 137.41(c) Personnel; Pilot in Command; Demonstration of Knowledge and Skills; Commercial Certificate
- Part 137.42 Fastening of Safety Belts and Shoulder Harnesses

For the FAA to approve an exemption, the petitioners must explain how they will maintain a comparable level of safety that the rule creates. The exemption process can be challenging and confusing. Some organizations and operators defer to a legal authority to write the exemption for them, or, in some cases, the drone manufacturer or sales company may assist operators in submitting exemption requests.

What Regulations Am I Following?

Part 137 regulations cover all spray drones, regardless of weight. Part 107 regulations govern all drones less than 55 pounds. Parts 61 and 91 regulations apply to all drones that exceed 55 pounds.

Any pilot who flies a spray drone (regardless of weight) must have a Part 107 pilot's license. To alleviate the manned pilot license required for Part 61, FAA regulations allow the Part 107 pilot's license to serve as a substitute.

Notes from the Field

A drone operator indicated:

"There are many lawyers who help with exemption filings. It is a very common practice and has become quite streamlined. What used to take six months is now flowing through in six weeks."

Part 107 only applies to drones that weigh less than 55 pounds, so spray drones that weigh 55 pounds or more require exemption from 14 CFR Parts 61, 91, and 137. Parts 61 and 91 take the place of Part 107, since drones that weigh 55 pounds or more are not "small" drones, so they are covered under rules more like manned aircraft (for example, aerial applicators).

A list of rules that organizations must ask to be exempt from when flying drones that weigh 55 pounds or more include:

- Part 61.3(a)(1)(i) Requirement for Certificates, Ratings, and Authorizations
- Part 91.7(a) Civil Aircraft Airworthiness
- Part 91.119(c) Minimum Safe Altitudes: General
- Part 91.121 Altimeter Settings
- Part 91.151(b) Fuel Requirements for Flight in VFR Conditions
- Part 91.405(a) Maintenance Required
- Part 91.407(a)(1) Operation after Maintenance, Preventive Maintenance, Rebuilding, or Alteration
- Part 91.409(a)(1) Inspections
- Part 91.409(a)(2) Inspections
- Part 91.417(a) Maintenance Records
- Part 91.417(b) Maintenance Records
- Part 137.19(c) Certification Requirements, Commercial Operator — Pilots
- Part 137.19(d) Certification Requirements — Aircraft
- Part 137.19(e)(2)(ii) Certification Requirements; Knowledge and Skill Tests; Skills; Approaches to the Working Area
- Part 137.19(e)(2)(iii) Certification Requirements; Knowledge and Skill Tests; Skills; Flare-outs

- Part 137.19(e)(2)(v) Certification Requirements; Knowledge and Skill Tests; Skills; Pull-ups and Turnarounds
- Part 137.31(a) Aircraft Requirements; Certification Requirements
- Part 137.31(b) Shoulder Harnesses
- Part 137.33(a) Carrying of Certificate; Certificate Carried on the Aircraft
- Part 137.33(b) Registration and Airworthiness Certificates Available
- Part 137.41(c) Personnel; Pilot in Command; Demonstration of Knowledge and Skills; Commercial Certificate
- Part 137.42 Fastening of Safety Belts and Shoulder Harnesses

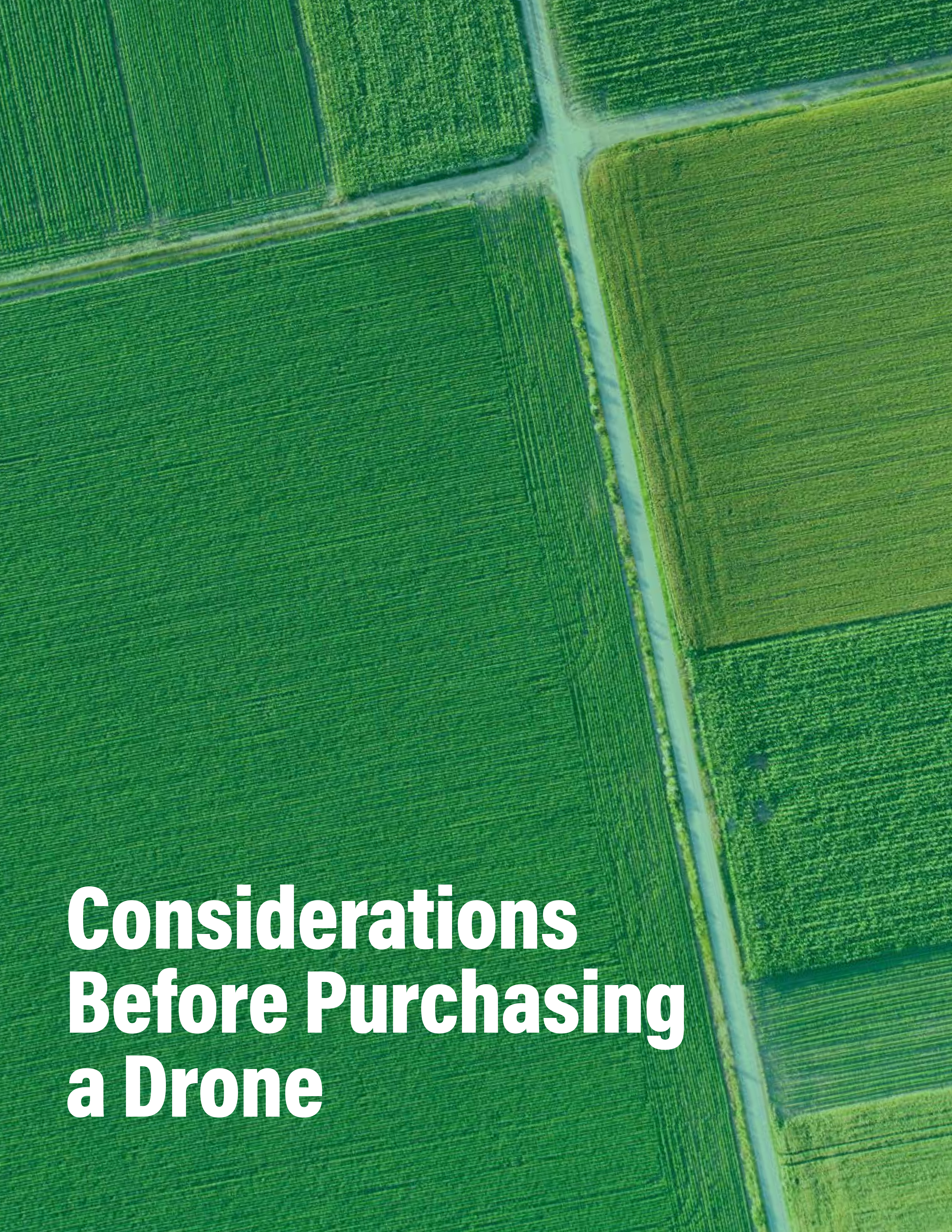
To see an example of an exemption that was written to allow Purdue University drone pilots to operate spray drones, visit regulations.gov, and type in "Purdue spray drone" in the search bar. You can also search specific drone manufacturers and drone model numbers or company names to find exemptions written for each particular case.

Once you submit the exemption, the FAA will approve your exemption petition, decline your petition request, or ask for more information. This process may take many months to complete and can be the most time-consuming part of obtaining a Part 137 operating certificate.

If the FAA approves the exemption, they will send a document that outlines the conditions and limitations in which you must operate to comply with the wavier. The document also will explain when the exemption will expire and when it will have to be amended to remain current.

Once you secure the proper exemptions, you may apply for your operating certificate by filling out form 8710-3 and sending it and the exemption to the FAA authority over 137 drone certifications (UA137Certificates@faa.gov). Once the FAA processes the request, a knowledge and skills test can be self-administered where previously a group from your FAA Flight Standards District Office (FSDO) would have administered the exam. This streamlined application process has greatly increased the speed in which operating certificates are processed and distributed.

Once you have satisfactorily completed the certification requirements, you will receive an operating certificate that designates the chief supervisor of the operation and any exemptions that the organization is operating under. The chief supervisor is the person who self-administered the exam and will be in charge of the Part 137 operations for your organization. Once you identify a chief supervisor, that individual will oversee the pilots who operate within your organization and will have to ensure compliance with FAA rules and regulations.



Considerations Before Purchasing a Drone

Drones, particularly spray drones, are not cheap, especially when you add the expenses of generators, trailers, and supporting equipment. Individuals who are considering purchasing a spray drone should spend time thinking about how they will use the drone and their return on investment in the form of saving time, generating profits, or solving particular application problems. While the marketplace is not very competitive now, different companies manufacture a number of spray drone models.

Timely Applications Can Justify the Cost

Some drone owners upgrade their drones every few years because newer models may provide distinct advantages, such as being able to fly at a higher speed. A farmer might be able to justify the cost of a drone based on the need to make timely applications, particularly to high-value cash crops like watermelons, tomatoes, sweet corn, or seed corn. In some seasons, manned applications may be delayed because of high demand during critical time windows or sub-par weather and field conditions. It's not that there is a problem with fixed-winged aircraft or helicopters, but your need to get a timely spray application might not align with their availability or with weather conditions.

Even if growers see drones as worthwhile purchases and good fits for the farm, then they still must consider who will make the applications and whether there will be time to do their own spraying. Most importantly, growers must carefully consider who will be responsible for obtaining and keeping up with the changing technologies and regulations.

Spray drones are time-consuming for meeting the regulatory challenges (for example, obtaining pilot certifications) and obtaining any waivers that are needed to operate drones for spraying pesticides and other products. For any drone to pay for itself, growers must understand how the drone operates and work out how they will find the time and labor during the busy season to make those applications.

More Than an Alternative

It is important to highlight that spray drones are more than just an alternative to traditional aircraft. Spray drones may be the only option available to apply to fields with unique shapes, small sizes, or flight obstacles that traditional ground equipment and aircraft cannot perform.

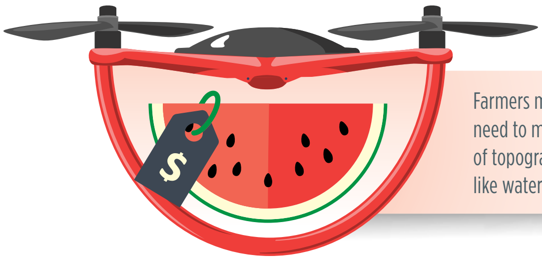
There are many instances of ground-based or manned aerial applicators who do not want to treat smaller fields because it is not profitable for them. It is becoming more common for application companies to refer the work they do not want to perform to drone companies.

Most growers are so busy with tillage, planting, and side-dressing that they have little time left for spraying with drones. This is why many farmers currently prefer to hire commercial applicators for chemical applications. Time challenges do not change just because you have a drone. Using a drone might even be more difficult in busy times because the visual observer requirement currently in place ties up two people. This alone may be impractical if you do not have more than one person working on a regular basis.

Some farm operations may not have any labor available from spring through midsummer to perform drone pesticide applications. Thus, buying a drone to perform preplant herbicide applications in the spring (including cover crop termination) may not be a great fit for labor demands. The same would be true for late-season insecticide or fungicide applications in the spring for fall-seeded small grains like wheat.

A couple of points are worth considering from the perspective of a grower who is considering buying a spray drone. The first question is: Am I really going to use it?

Without a lot of use it would be difficult to justify the cost of a drone because of the accelerated electronic depreciation of most drones. Also, keep in mind that the drone you buy today could become obsolete in the near future. It is worth mentioning depreciation here because



DRONE **FACT**

Farmers might be able to justify the costs of drones based on their need to make timely applications where fields are inaccessible because of topography or rain. This is especially true for high-value cash crops like watermelons, tomatoes, sweet corn, and seed corn.

spray drones are electronic consumables, just like televisions, computers, phones, and tablets. They do not hold value over time, even if they are still brand new in their boxes and never opened.

The second question to ask is: Does the farm have enough acres to help spread the cost of the drone over those acres?

This question is no different than one you would ask for ground equipment. One farmer may have a land base large enough to spread the cost of a $650,000 self-propelled ground sprayer, while another farmer with less land would not be able to pencil it out. Before you buy a drone, you should calculate the costs of buying and operating it, and then compare that with how much you are charged for custom applications.

Considerations for Using Drones Commercially

The number of commercial businesses offering drone services to their customers has been increasing steadily. These commercial businesses can gear up by employing multiple drones to make applications.

Asking questions about doing commercial work with drones are similar to questions you ask about commercial ground, plane, or helicopter applications. How many acres are best applied with a drone versus other sprayer types that are already available? What will my labor and equipment costs be? What is my cost per acre for the application? What is my expected return on investment? These and many other questions are all part of the equation of making sure the spray drones you are considering will provide enough value to your farm operation.

As you explore purchasing a drone for commercial use, consider these questions:

- Will this be my full-time business or just seasonal?
- What crops am I going to target?
- What licensing and certification will I need from the state pesticide regulatory agency and FAA?
- Does my state allow drone pesticide applications if the pesticide label does not provide specific instructions about drone sprayer use?
- Can I find reasonably priced commercial insurance? What will it cost? Drones cost as much as new cars or trucks these days, so you should think about getting insurance on them for the same reasons you do for your other vehicles.
- What market(s) can I fit into? Some operators focus on row crops (like spraying fungicides on corn and soybeans). Others use their drones to treat specialty crops like blueberries, grapes, or other fruits. Outside of crop production, drone applications can be used for forests, ponds, highways, and livestock operations.

The drone model you choose comes down to personal preferences and recommendations from applicators with prior experiences.

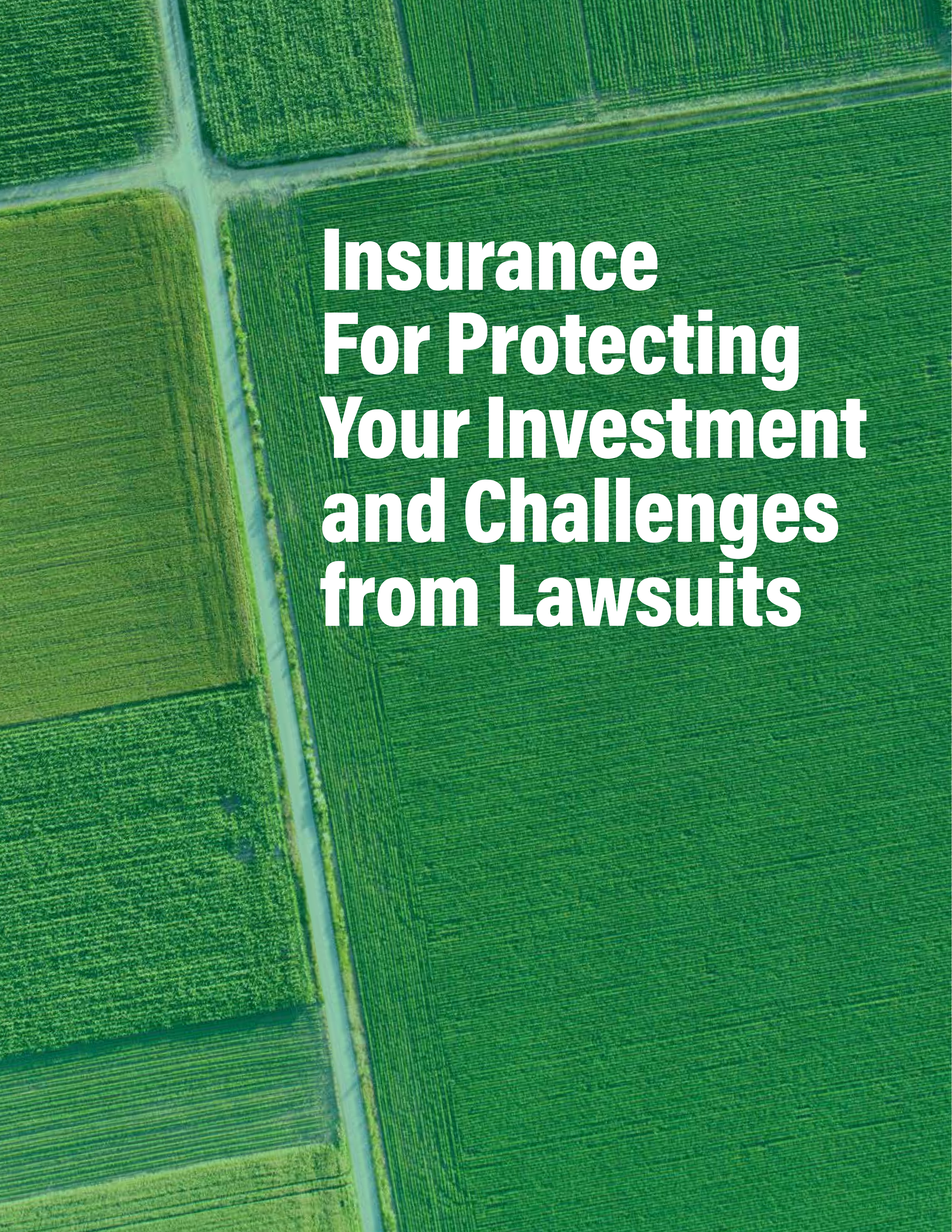
- Do I plan to use a drone under a government contract? Make sure that performing work for a government agency does not require using a drone that is different than what you have or what you are thinking about purchasing. The United States Department of Agriculture and the United States Department of Defense have concerns about digital security breaches, so they don’t allow drones that are manufactured by certain companies to operate on state and federal property.
- How many acres can I cover with a single drone? You will want to ensure your fleet is big enough to cover enough acres to make your investment worthwhile.
- What is the backup plan if a drone goes down?
- Will I rely on someone else to keep track of the regulations? Either you or someone on your team will need to be comfortable with understanding the ever-changing state and federal rules, regulations, and policies. Rules can be complex and require more than just filling out paperwork. Putting those requirements into practice will require forethought and patience.

- Can I find qualified labor? Justifying the cost of a drone may not be a problem, but finding people to work will be tough when there are labor shortages or when you need to find workers who can put in the long hours often necessary in agriculture. Many potential employees are unwilling to work the long hours outdoors, evenings, and weekends that are required in agriculture.
- Are the products your customers commonly use labeled for aerial applications?
- Will you or the customer provide the chemicals for applications?
- What size spray tank will you need? Larger fields require tanks with larger capacities. But larger drones bring more stringent FAA regulations. Depending on the market, a drone with a smaller tank capacity might work just as well.

Several spray tanks have labels that indicate different volumes, which can be helpful for accurate mixing. This 38-liter tank is equivalent to 10 gallons.

- Does the drone manufacturer provide customer service? Are they able to supply parts quickly to repair drones?
- Where will I get the drone repaired?
- How will I map the field for boundaries and obstacles with highest efficiency?
- Can I be competitive with manned aerial and ground applicators?
- What will be my travel limit? Some applicators have been known to travel as many as 12 hours to do a job, while others will not take on work outside of a two-hour radius.
- How will I promote my business and gain new business outside of my area, since spray drone trailers can easily travel on highways across the state?
- What software comes with the drone package? Every drone comes with a software package. This question is important, because at this time, you cannot add third-party vendor packages to spray drones as you commonly can with ground equipment. Even if a vendor says they have better technology and software, drone manufacturers will not allow access to their drone's software. The FAA may need to permit the adaptations because the software could compromise flight capabilities.
- How comfortable are you using the software and flying the drone? Is it worth investing your time to understand the software by accessing websites and attending trade shows? Make personal contact with manufacturing representatives or with extension educators who can demonstrate their drones at your place of business.
- What other supplies or equipment will you need to purchase? As you have read in this publication, the drone is just one component of the operation. Think of your total cost by adding expenses such as an additional truck, specially designed trailers, generators, tanks, spare parts, and other supplies. These all will raise the total investment required for a drone spraying operation. This may be especially challenging for start-up businesses.
- Will you be doing only single-rate applications? Or will you also consider variable-rate applications? Not all drones can do variable-rate applications so you will need to think ahead.
- Do you plan to also provide application services for applying dry products like urea or cover crop seeds? If so, then you need to think about purchasing a dry box that can handle different dry product rates.
- What will be the equipment depreciation?

A drone applying fertilizer or cover crop seeds can add a lot of value to a drone.



Insurance For Protecting Your Investment and Challenges from Lawsuits

Protecting your investment in your drones and shielding yourself against liability claims are two reasons to consider insurance as part of your protection plan. Insurance is not just about replacing a drone after it crashes in a field. You also should consider having coverage in the event your drone hits a vehicle on the highway, crashes into a building, produces spray drift that lands on an organic farm or commercial apiary. Even more dangerous is if your drone hits a person who is unaware of the ongoing application.

Some drone owners inadequately insure their drones to save on their insurance premiums, but some state regulatory agencies may require operators to carry minimal liability insurance to cover drift or other accidents. Some drone operators also wrongly assume that their current vehicle insurance policy will automatically cover them for drone replacement and liability lawsuits. Without proper insurance coverage, everything you own could be up for grabs by the person who alleges your drone physically hurt them or damaged their crop or property.

As a general rule, insurance companies typically exclude coverage for all aerial applications, including those made by drones. When speaking with an insurance company, make sure they understand if you are seeking coverage for a drone that will be used for monitoring or if you are seeking coverage for a drone that will be applying pesticides. It might change their answer about whether they provide coverage and for how much.

Sometimes a policy might provide limited coverage for a drone used for monitoring and surveillance only. It is almost guaranteed that a drone that sprays pesticides will not be covered under most insurance policies. More than likely, your insurance company has contacts with other providers that deal with aerial applications and who can provide coverage.

These three important points deserve to be restated:

1. Don't assume that the liability insurance for your property, vehicle, or trailer will also cover your drone operation.
2. Don't assume that the insurance you have for ground application equipment will also cover your drone.
3. Just because you have a million-dollar liability policy that does not mean the drone is covered for that much. Read the policy carefully because you may only have a limited amount of coverage to replace a wrecked drone or when facing a lawsuit.

Know What Is in Your Policy

There are three main areas regarding spray drone insurance. Each area can be purchased or excluded, which can influence the premium.

1. General liability property casualty
2. Chemical liability/crop spraying liability
3. Hull coverage

Let's use an example to illustrate how these might fit together.

Let's say your drone crashes into a car traveling on the highway. The crash ruptures the tank, which releases a fungicide into a nearby creek and causes a fish kill.

The general liability coverage is used to cover damage to the car. It does not cover the fish kill nor damage to the drone.

The chemical liability covers the fish kill.

The hull coverage takes care of damages to your drone.

The main point is that the general property casualty insurance excludes any liability resulting from the contents of the spray tank. That can include a drift issue, or environmental hazard, or crop injury to a crop that was sprayed. People often think that a $1 million general liability limit will cover all exposures from flying a drone. But unless you carry chemical liability insurance, that is not true. Some insurance agents suggest that hull coverage is the least valuable of all, as its premium relative to coverage ratio is poor. If an operator is looking to save on insurance, hull coverage is the place to make a cut, not the general or chemical liability.

In any case, it is better to visit with your insurance agent to make sure you fully understand what your policy will and will not cover. Only a handful of companies in the United States offer special spray drone insurance with liability coverage. Without competition, a spray drone insurance premium can be $4,000 to $5,000 dollars versus a $35,000 cost for a new drone. But you must evaluate insurance costs with what you might lose in the event of an accident where someone is hurt. It is a rare event, but always possible.

Ask your insurance agents about coverage for medical care.

Conclusion

Attending classroom lectures and field demonstrations are good ways to find the newest information. Keeping current is important because drone technology changes so quickly.

The drone application industry is evolving so quickly that new models are becoming available as quickly as smartphones and other consumer electronics — and, like phones, they are becoming obsolete after a few years. This is what makes buying drones so different than buying ground sprayers, which you know can be used for decades to come.

Still, drones present new opportunities for making pesticide applications that we have not had before. Drones are viable and have been effective in other countries for a long time, like farmers in Japan who use them to spray rice fields.

Using drones for pesticide applications is mostly positive because it checks a lot of boxes that we have been unable to do with traditional ground and aerial equipment. Drones have become very versatile tools used across many different application sites beyond traditional agriculture.

We have seen spray drones used for forestry, mosquito control programs, container nurseries, vegetable crops, invasive weeds, roadside spraying, greenhouses, fly control in dairy operations, and organic production. However, drones require specific calibration procedures, application considerations, and insurance — commercial operations, in particular, require these things to use drone technology legally, safely, and effectively.

Spray drones are unique pieces of application equipment compared to ground boom equipment. Researchers are evaluating drones to find optimum use practices.

While spraying with drones has many positive attributes, it is unlikely that they will replace ground rigs, spray planes, or helicopters in the foreseeable future. However, drones complement these other application methods precisely because there are situations where drones are a better fit than other methods. Traditional aircraft or ground sprayers can generally cover more acres in a day because they travel faster, have wider spray widths, and can carry greater payloads. When weather conditions are ideal and operators must cover many acres, ground rigs, airplanes, and helicopters typically are more effective.

A 21st Century Career Opportunity

Does the next generation of the workforce have experience with handheld controllers, joysticks, and software systems? We could never be more confident of an emphatic "yes."

Drones will attract a new generation of employees who are computer and technology savvy. Ag technology companies and government agencies will use their skills to provide valuable insights on using this mode of application to its fullest.

However, we should not undervalue drones because they likely will evolve into another critical tool to augment ground, water, or aerial applications. In some cases, using drones to spray pesticides could be the only viable and safe option we may have.

There are many unknowns the research community will need to address if drone applications of pesticides and other inputs will achieve the same successes everyone is hoping for. Drones are a different type of aircraft, designed differently, and have significant differences in how they spray compared to traditional fixed-wing agricultural spray planes and helicopters. Ongoing research at many research institutions around the world is currently identifying those differences.

Technological advances and improvements are made through more research and testing. Designs, spray characteristics, regulations, and business models are also subject to change considerably as more research and testing pave the way for technological advances and improvements.

Notes from the Field

A drone operator indicated:

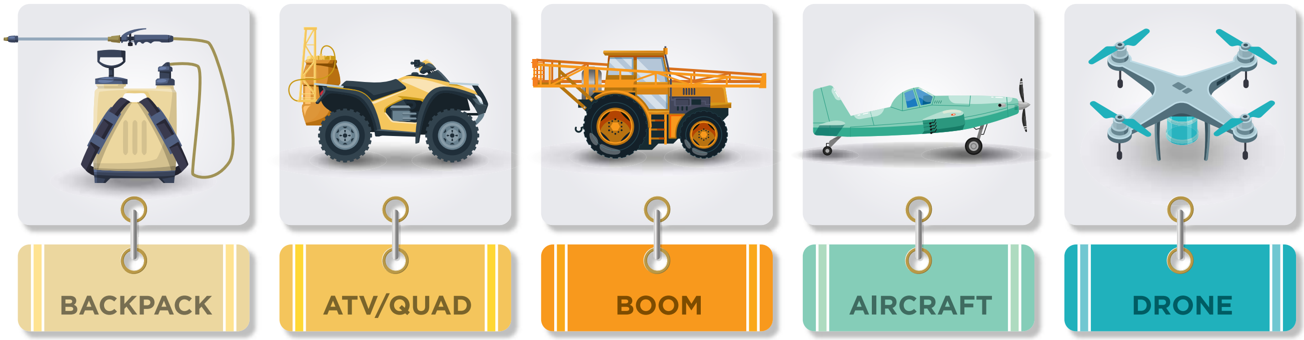
"I encourage people to not be threatened by this new technology.

"Rather, think through how drones can supplement or improve what we are currently doing. Also do not look only at what it is now, but what it could be in the future."

This new research will undoubtedly help create new science-based guidelines that will guide spray drone operators. The good news is that (as application scientists mention) drone platforms have more in common with each other than they have differences.

If we look back only a few years, we see that drones could only do small fields or certain high-value applications. Today, a pilot can spray a couple hundred acres or more when conditions are right. Spray drone technology will continue to evolve as the customer base increases and demand increases for more features and practical applications. This means that current pilots (with or without much experience) will be required to keep current with changing technology.

The benefits of using spray drones with today's technologies outweighs the many concerns just raised. We are just seeing the tip of the iceberg when it comes to what we can do with drones. Keep your nose up and stay tuned.



DRONES: ANOTHER SPRAY TOOL

Drones are another effective application tool that can be part of a pest management toolbox

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