Drones for Spraying Pesticides—Opportunities and Challenges

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Traditionally, aerial spraying of pesticides has been done using conventional fixed-wing aircraft or helicopters with a pilot onboard. However, this is changing. Small, remotely piloted aircraft are being used to apply pesticides around the world, especially in Southeast Asia. For example, about 30% of all agricultural spraying in South Korea, and about 40% of Japan's rice crop, is sprayed using drones. In contrast, drone spraying is in its infancy in the United States, but interest in this technology from pesticide applicators is steadily increasing.

A variety of names and the acronyms are associated with remotely piloted aircraft:

- unmanned aerial vehicle (UAV)
- unmanned aerial system (UAS)
- small unmanned aerial system (SUAS)
- remotely piloted vehicle (RPV)
- remotely piloted aircraft (RPA)
- remotely operated aircraft (ROA)
- remotely piloted aerial application system (RPAAS)

Although UAV and UAS are the most commonly used names given to this kind of technology, the name used most commonly by the general public is "drone," which is used throughout this document.

This publication highlights drone sprayer specifications, why they may be the choice for aerial spraying, and the challenges that reduce their usage by pesticide applicators.

Drones entered the agriculture scene initially for non-spraying applications, such as crop and field-condition data collection to increase profitability in crop production. Drones capture a number of important data points:

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- soil characteristics (type, moisture content, and nutrient content)
- location of drainage tiles
- crop nutrient stress level
- crop emergence or stand count
- weed species and infestation level
- detection of insects and diseases

Drones successfully and effectively monitor plant growth by collecting and delivering real-time data from the moment of plant emergence to harvest. With the help of fast and accurate GPS or GNNS technology, a high-resolution camera, and variable flying speeds and altitudes, drones can provide a wealth of information on the condition of every half square inch of crop or soil.

Using drones for spraying pesticides is attractive mainly for four reasons:

1. The topography or soil conditions do not allow the use of traditional ground sprayers or conventional agricultural aircraft.
2. When airplanes and helicopters are not available or are too expensive to use.
3. Drones more efficiently spray small, irregular-shaped fields.

4. Drones significantly reduce the risk of applicators being contaminated by the pesticides, especially those using backpack sprayers.

There are also emerging problems, such as tar spot on corn, which may increase the need for aerial pesticide application by drones.

Drone Sprayer Performance

Although they are small, drone sprayers have nearly all the components of large ground sprayers and conventional aerial sprayers:

- tank
- pump
- hoses
- filters
- nozzles
- flow meter

All drone sprayers are also equipped with a GNNS receiver and multiple sensors for collision avoidance. All drones also have wireless remote control. Each component of the drone plays a critical role in achieving maximum sprayer performance.

Spraying with a drone is not new. First used in Japan in 1997, the Yamaha RMax drone looks like a small helicopter (Figure 1). It has a single rotor with a diameter of about 10 feet, weighs 207 pounds, and has over 4 gallons of spray tank capacity. With a full tank and spraying at 1 gallon per minute, the tank is likely to be empty in about 4 minutes. It is gasoline powered, can run for 1 hour before refueling, can be retrofitted with three or four nozzles, and was FAA-approved for use in California in 2015. This aircraft has a terrain sensor and can be operated manually or on autopilot. The manufacturer does not sell the aircraft, rather they service it and provide a trained team (usually two to three people) to operate the aircraft.

yamahaprecisionagriculture.com

Figure 1. Yamaha RMax single-rotor drone.

Ken Giles, UC Davis

A rapid proliferation of lighter, easy-to-operate drones for spraying pesticides is currently underway. They are lightweight but powerful enough to lift a 10–15-gallon tank. Most commercial spray drones today are the multi-rotor type shown in Figures 2–4 and 6–8 on the following pages. The drones' propellers create turbulence in the canopy, which significantly improves droplet penetration into lower parts of the canopy compared to traditional ground sprayers that are not air-assisted. Multi-rotor drones have similar components but can differ in many ways:

- number of rotors
- rotor positions
- nozzle locations and configurations
- type and number of nozzles
- distance between nozzles
- vertical distance between the rotors and the nozzles under them

For example, most drones have nozzles located on the end of hoses descending a few inches below the rotors (Figure 2). A smaller percentage of drones have nozzles mounted on a boom (Figures 3 and 4). One drone type, shown in Figure 5, has four rotor arms with two rotors on each arm powering a pair of impellers that are stacked one on top of the other. This dual rotor configuration provides a more powerful lifting capacity and better flight dynamics.

Drones with a boom, and especially those with booms extending beyond the rotors as shown in Figure 4, usually are not preferred. These drones are likely to become obsolete because of relatively poor spray coverage compared to the boomless spray drones as shown in Figure 2.

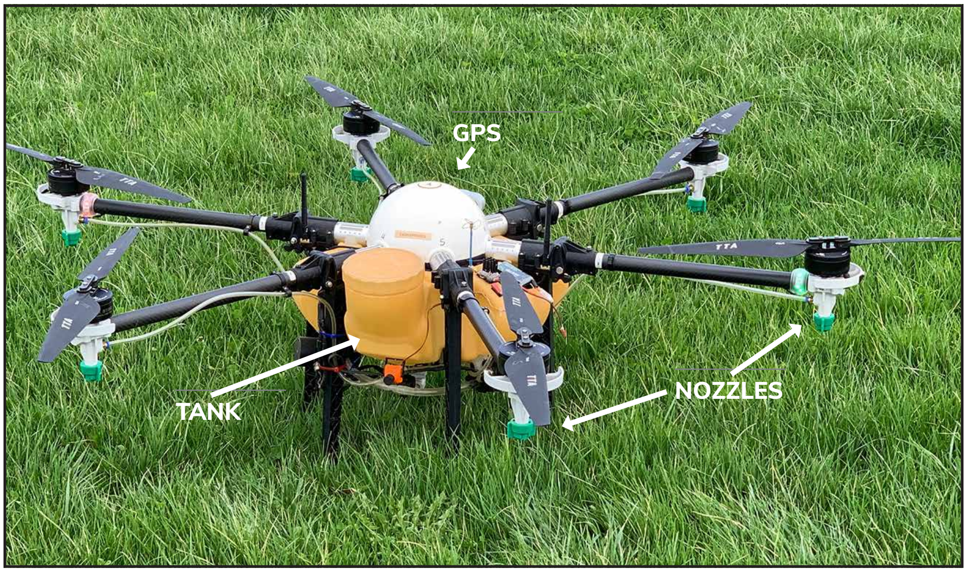

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Figure 2. Spray drone with no boom.

They also have a higher drift potential influenced by vortices that appear near both ends of the boom as shown in Figure 6. Having a larger number of nozzles on the boom, and having a boom that does not extend too far outside the rotors may help avoid this problem, resulting in much better penetration of spray droplets into the target plant canopy and a better coverage of the target surface with droplets.

The newest design for discharging spray from drones uses rotary atomizers positioned under large propellers (Figures 7a, and 7b, next page). These atomizers are sometimes referred to as controlled droplet atomizers (CDAs). The spray droplets are produced by the rotational speed of a cup, which allows the spray mixture to be emitted using very low pressure. This design produces relatively uniform droplets as opposed to the wide range of droplet sizes produced by conventional flat-fan nozzles.

Some of the more recent and relatively more expensive drone models, like the one shown in Figure 8 (next page), are equipped with a larger, 10-gallon spray tank with multiple nozzles per nozzle outlet, larger batteries that can provide power for heavier payloads, and wireless connectivity.

Unfortunately, as demonstrated by the small sample of drone sprayers shown in this fact sheet, no standards exist for the most optimum spray drone design, especially related to the location and configuration of nozzles on the drone. As a result, drone purchasers are faced with a number of unanswered questions:

- Is it better to have a drone with a boom under the rotors, or is it

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Figure 3. Spray drone with a boom.

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Figure 4. A spray drone with a boom extending too far away from the rotors is not preferred because of poor spray deposition and coverage, and high drift potential.

DJI.com

Figure 5. Spray drone with two rotors at each arm, powering a pair of impellers one above the other one.

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Figure 6. Drift potential from drones with a boom may be excessive depending on the size of the boom and the type and size of nozzle used.

DJI.com

Figure 7a. Spray pattern produced by the dual spray atomizer.

Dr. Steve Li, Auburn University

Figure 7b. Close up of a Controlled Droplet Atomizer (CDA).

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Figure 8. A sprayer drone with a 10-gallon tank and multiple nozzles under each rotor.

better to have nozzles directly under each rotor?

- If a boom is better, what should the boom width and its distance from the rotors be?
- If having nozzles at the end of a drop-down hose under each rotor is a better option, what should be the length of the hose?
- What are the best type of nozzles for different spraying jobs?
- Is there an optimum distance between nozzles?
- Should there be one nozzle at the end of the drop hose, or multiple nozzles as shown in Figure 8?

So far, drone configurations do not have the standardization seen in conventional, piloted aerial aircraft. This is because no studies have been conducted, or models developed, to determine the most optimum drone design parameters to minimize drift and to maximize deposition and spray coverage on the target.

Operating Characteristics of Multi-rotor Spray Drones

The application rate of spray drones in row crops is usually 1.5 to 2 gallons per acre. The rate depends on many factors, but is mainly a function of the spray tank capacity, flying speed, spray swath width, number of nozzles or rotary atomizers on the drone, and the flow rate (volume sprayed per minute). For example, a 5-gallon tank may take 2–3 minutes to empty. Some drones have a tank sensor to indicate the liquid level. This sensor can also be programmed to pause spraying and return the drone to home base when the tank needs a refill. Once replenished, the drone flies back to continue spraying where it stopped.

The maximum flying speed of multi-rotor drones varies between 10–30 miles per hour. They are usually flown 7–12 feet above the ground or crop canopy. Forestry applications may require the drone to fly over 30 feet above the ground to avoid obstacles. All current models of drones have a terrain sensor that maintains the optimum flight height to spray uneven and hilly terrain and automatically navigate hills and slopes.

The price of spray drones varies between $20,000 and $40,000, depending on size, spraying capacity, manufacturer, and other features. Most spray drone models are compatible with Real Time Kinematics (RTK), which provides centimeter-level, locational precision during flight.

Best Spraying Practices

Success in pesticide application is heavily dependent on knowing and following best spraying practices. Unfortunately, not much operational information is available for spray drones.

However, many of the general principles for operating conventional piloted agricultural aircraft also apply to spray drones. One of the crucial determinations in aerial spraying is knowing the effective spray swath width so that each subsequent pass can be adjusted accordingly. Flight altitude affects the swath width, the quality of spray deposition into the target canopy, and the pesticide coverage on the canopy. Regardless of the spraying equipment used, there are two common ways to increase coverage on the target:

1. Reduce the droplet size. This option is not recommended for any type of aerial application because it can increase risk of drift.
2. Increase the gallons per acre application rate either by using a nozzle which has a higher flow rate capacity (gallons per minute), or by flying at a slower speed. However, increasing the gallons/acre application rate may require dilution of the spray mixture in the tank to ensure that the maximum active ingredient rate per acre detailed in the product label is not exceeded.

Another way to increase deposition of product applied in the target canopy is to minimize spray drift—the spray that leaves the target area without depositing on the target. Wind velocity is usually the most critical factor affecting drift. The greater the wind speed, the farther a droplet will deposit off-target. Even in light breezy wind conditions, leave a buffer zone between the area being sprayed and any field with sensitive crops downwind. Untreated areas can be sprayed when the wind is blowing away from the sensitive crops that are adjacent to the area being sprayed.

Flight altitude does not change the initial droplet size after it is released from the nozzle, but high altitudes expose the droplets to weather conditions such as wind, relative humidity, and temperature. This exposure increases drift potential of the droplets as their sizes get smaller. Also, smaller droplets may never reach their target under low relative humidity and high temperature conditions. To guard against these challenges, the flight height should be as close to the target as possible to reduce spray drift. However, always consider other unintended issues that may result from flying too low:

- safety of drone operation
- collision avoidance radar being frequently triggered, causing the drone to slow down or stop
- skips in spray deposition on the target that could significantly and negatively affect the efficacy of product applied, especially when spraying herbicides and defoliants

There is not a universally accepted set of guidelines for the operation of spray drones, especially their optimum flight speed. According to one source (CropLife 2020), aerial spraying by a conventional, piloted airplane is normally conducted when the surface wind speed is less than 15 mph—a safe speed for aircraft handling. Spray drones are considerably lighter and may suffer problems at wind speeds more than 7 mph. The optimum speed of application for most multi-rotor spray drones is around 13 mph. These are 2020 guidelines, and they change from manufacturer to manufacturer for the various spray drone models. Therefore, it is best to operate a spray drone in the optimum conditions outlined in its operator manual.

When spraying is completed, drones are usually folded up and secured properly to avoid any movement of the drone during transport. The drone should be secured in a separate compartment that is isolated from the driver of the vehicle and/or any passengers. When not in use, the spray drone should be stored in a locked and secure place away from any dwelling, people, or animals.

Limitations of Spray Drones and Obstacles to Their Adoption

Acceptance of spray drones by individual farmers has been slow for several reasons:

- Not enough research data comparing drone performance (e.g., efficacy and spray drift) to ground sprayers and conventional aircraft is available. The limited published data on performance of spray drones may not be usable and can be contradictory because of the wide variation of design parameters among drones being tested.
- Fewer acres are covered per hour of operation compared to airplane and ground sprayers.
- The battery powering the drone lasts a short time (5–15 minutes with a full tank) and requires recharging between tank refills. Having three charged batteries per drone and fast charging at 240v eliminates long interruptions in spraying to charge the drone’s battery. Maintaining three charged batteries allows replacement of a discharged battery while refilling the spray tank. The spent battery can then be

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Figure 9. "Swarm spraying" with drones.

recharged and ready for the next refilling.

- The FAA imposes several operational restrictions on drones, such as: a drone must weigh 55 pounds or less including its payload, the pilot flying the drone must maintain a visual line of sight with the drone, permission must be obtained when flying in restricted air space, and drones can be flown only from 30 minutes before sunrise to 30 minutes after sunset. Perhaps the most severe restriction is that an operator can fly only one drone at a time. However, swarm spraying (Figure 9) is practiced legally and successfully in other parts of the world, especially in southeast Asia, mainly China, South Korea, and Japan. Fortunately, the FAA allows pilots to apply for waivers for several of these limitations, such as the 55 lb maximum weight of the drone sprayer, night spraying, and maintaining a line of sight.
- Chemical product labels do not provide clear information related to drone spraying. Some labels do not allow aerial application of any form. Some labels allow aerial application of the product, but don't specify the type of aircraft that can be used. Currently, no pesticide label provides specific instructions on how the product can be sprayed using a drone. It is anticipated that pesticide labels will eventually refer to drone spraying. The EPA allows drone use for spraying if the pesticide is already labeled for conventional aerial application and if FAA rules for operating drones are followed.

Regulations Related to Using Drones to Spray Pesticides in Ohio

Two certificates must be obtained from FAA to spray using drones: an FAA "Part 107 Certificate" to fly a drone and a "Part 137 Certificate" to apply pesticides using drones or to apply pesticides using drones while under the direct supervision of a person who holds this certificate. However, spraying pesticides in Ohio requires more than these two FAA certificates. An applicator must also complete the Ohio Commercial Pesticide Category 1 training course, which covers "the application of pesticides, except fumigants, by aircraft."

Resources for Information on Obtaining Certificates to Apply Pesticides Using Drones

Flying a drone is subject to many restrictions, including a requirement that the pilot be at least 16 years old and that the drone has a maximum weight of 55 pounds, unless an exemption is granted. To find out all the requirements to be a drone pilot, obtain the pilot certificate (FAA Part 107), and legally apply pesticides using a drone (part 137), visit the FAA web site at **faa.gov/uas/commercial_operators**.

Another informative and useful resource is the FAA Remote Pilot Study Guide at **faa.gov/sites/faa.gov/files/regulations_policies/handbooks_manuals/aviation/remote_pilot_study_guide.pdf**. Prospective pilots can also do an internet search for "FAA remote pilot study guide." Topics covered include airspace classification, operating requirements and flight restrictions, effects of weather on aircraft performance, emergency procedures, radio communication procedures, determining the performance of aircraft, physiological effects of drugs and alcohol on pilot performance, and registration and marking requirements.

A web site prepared by Alan Leininger, Extension educator in Ohio, is also an excellent source of practical information related to drone spraying and the FAA requirements for certification to fly a drone. Leninger's website is located at **henry.osu.edu/program-areas/agriculture-and-natural-resources/precision-agriculture-technology**.

The Ohio Department of Agriculture's (ODA) website is another resource that includes information on the application of pesticides using drones. This website provides answers to many of frequently asked questions such as, "What pesticide licenses are required by ODA to apply pesticides via a UAV (aerial drone)?" It can be accessed at **agri.ohio.gov/divisions/plant-health/pesticides/uas/**.

Future of Spray Drones

Drone sprayers will never replace ground or conventional aerial application technology, but they may complement existing spray practices. The future of drone spraying will be mainly affected by the economics, timeliness of crop protection (i.e., which option may get the job done in the shortest time), the type of spraying to be done (broadcast vs. targeted), and availability of local companies offering drone spraying.

Although drone spraying does not seem to be a viable option to compete with ground sprayers and conventional, piloted aircraft in the application of pesticides to large fields, some companies offering drone spraying indicate that their rates are competitive with or more economical than the cost of spraying done by ground equipment and conventional aircraft.

Acceptance and adoption rate of spray drones by individual farmers is likely to increase in the near future due to these changes in regulations and technological upgrades:

1. FAA regulations and restrictions on use of drones may be eased, especially restrictions on "swarming," in which multiple drones are operated by one pilot or autonomously.
2. Improved design and manufacturing may result in longer lasting batteries, wider spray width, higher flow rates, and faster operational speeds.
3. Larger drones with larger sprayer tanks may be designed and possibly approved by the FAA.
4. Upgrades to drone technology may result in improved variable-rate application, precision spot spraying and route planning, and better obstacle avoidance.

Even without the changes outlined above, spraying with available drones may be the best option under the following conditions:

- Up until 2023, the main use of spray drones in the United States was for fungicide application on wheat, corn, and some soybean acres. But spot spraying of tall weeds that survived a previously applied herbicide, as shown in Figure 10, is a concept that is being investigated at this point. Spot spraying of weeds with a drone can be much more efficient than spraying a whole field with typical ground equipment or a conventional aircraft. However, be aware that most herbicides are not labeled for use with spray drones currently, and none of the herbicides that can be used for post applications have approval by EPA for late-season use. The cutoff date for most of such applications is early to midsummer at the latest. Spray drone operators are advised to check the information on the chemical label before spraying the product. In addition, it's questionable how effective herbicides would be on big weeds that presumably have some level of herbicide resistance.
- Portions of a field that cannot be reached by large, heavy ground sprayers because the soil is too wet, which happens frequently in some parts of Ohio, can be sprayed with drones.
- Drone spraying may be the best choice to avoid soil compaction and crop damage caused by ground equipment traffic when spraying fields with established crop canopies. Even after the wet ground dries enough to allow the large ground sprayer to get in the field, the sprayer is likely to cause a significant level of soil compaction resulting in reduced crop yield.

Spot spraying, variable-rate spraying, or spraying a portion of the field that does not allow heavy equipment to get in the field, all can be accomplished easily with drone spraying technology. This usually is a two-step process. First a drone with an RGB or multispectral camera flies over the field and establishes the coordinates of the area to be sprayed or the operator maps out the areas to spray on a digital map by drawing polygons. The mapped areas are then uploaded to the flight plan of the spray drone. This drone then flies over the field and its nozzles spray pesticide when the drone reaches the appropriate GPS coordinates.

Dr. Jeff Stachler, Montana State University

Figure 10. Spot spraying with a drone to control weeds that survived the previously applied herbicide can be much more efficient than covering a whole field with typical ground equipment or conventional aircraft.

Summary and Suggestions

Currently, there is tremendous interest in using drones to spray crop-protection products. Drones are now a viable option when choosing equipment to spray pesticides, and the number of companies offering drone spraying services is rapidly increasing in Ohio and other places in the United States. But is drone spraying a good option for everyone? If you are well informed about this technology, aware of all the rules and regulations, and have viable usages identified, then consider buying one. Otherwise, wait until you are adequately informed about all aspects of drone spraying. As is the case with other technologies in agriculture, developments in drone sprayer designs and capabilities are changing rapidly. Check websites of drone sprayer manufacturers to learn about the new features of their current models.

Regulations too may change rapidly in the future because of the increasing interest in drone spraying and the high level of public demand for relaxation of current rules and regulations. Universities, government research centers, and other independent research organizations are interested in conducting research to determine if drone sprayers provide pest control that is as effective as ground sprayers or aerial spraying using conventional aircraft. This research will provide much more reliable information on this topic than what is available now. Stay up to date by regularly checking in with the appropriate resources:

- Stay informed on research, pesticide product labels, FAA and EPA regulations, and new drone designs.
- Visit the FAA website at **faa.gov** to check current regulations governing the use of spray drones.
- Remember that drone spraying is one form of aerial spraying, that people using spray drones must comply with aerial labeling, and that there have been no labels developed for spray drones yet.

And, as always, contact the OSU Extension office in your county for additional information on certification and licensing required to apply pesticides using any kind of sprayer, including drones.

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