Assessing Metering and Spreading Performance of Drones (UAVs) for Application of Dry Materials

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Abstract.

Along with pesticide applications, the use of drones for applying dry materials has increased rapidly in the United States. Currently, several types of product metering and spreading systems are available on commercial drones for applying dry materials. However, limited information is available on their application performance, especially their metering and spreading characteristics. Therefore, research studies were conducted to assess the performance of two commercially available drone models – DJI Agras T50 and XAG P150. The DJI Agras T50 had a gravity-fed hopper gate for metering product, whereas the XAG P150 had an auger-type metering system. Similarly, the spreading system on the DJI T50 was a horizontally mounted single-disc broadcast system, while the XAG P150 had a vertically mounted disc with baffles that oscillate back and forth to broadcast material within the swath. Cereal rye was used as a cover crop seed because of its widespread use in the US. Static testing was conducted to measure the flow rate at different hopper gate openings for the T50 and auger speeds for the P150. Field experiments consisted of assessing single-pass spread patterns across application rates of 22.4, 44.8 and 67.3 kg ha^{-1}. The simulated overlap spread patterns were generated for both drones for an effective swath of 7.3 m for all three application rates. The mean applied rate and coefficient of uniformity (CV) were calculated for the overlap spread patterns to assess and compare the spreading performance among the drones. The auger-type system on the P150 showed a linear relationship between material flow and auger speed, whereas the gravity-fed gate metering system on T50 exhibited a quadratic relationship between the material flow rate and gate opening (%). The single-pass spread patterns for the DJI T50 exhibited a leftward skewness with 54% to 61% of the cereal rye deposited to the left of the swath. In contrast, the single-pass spread pattern for the XAG P150 showed slightly rightward skewness with 50% to 54% of the material deposited to the right of the swath. Due to the vertically mounted, baffle-style broadcast system, the XAG P150 had a narrower swath (by 1.3 to 3.1 m) than the DJI T50, which was equipped with a single rotary spinner-disc system. Comparing the overlap spread patterns, the mean applied rate was closer to the target seeding rate for the XAG P150, with under-application ranging from 5% to

10%. The XAG P150 also demonstrated slightly improved distribution uniformity (CV = 20%–29%) compared to the DJI T50 (CV = 20%–35%) at an effective swath of 7.3 m. Overall, the findings from this study suggest that the application performance can vary among drones based on the metering and spreading systems. Future research needs to evaluate the effect of different operational parameters, such as flight speed and height, on the applied rate and spread uniformity.

Keywords.
Unmanned Aerial Vehicles (UAV), Drones, Spreading, Application Rate, Material Distribution

Introduction

In recent years, the use of commercially available unmanned aerial vehicles (UAVs), commonly referred to as drones, has expanded rapidly in agriculture due to their ability to apply materials precisely and efficiently during field operations (ASDC, 2024). Currently, the most common use of agricultural drones worldwide is spraying, followed by broadcasting cover crop seed (Belton et al., 2025). Most new agricultural drones on the market offer an interchangeable dry-spreading system that can be easily switched with the liquid solution system. This allows for a diverse range of applications, from spraying pesticides to spreading small, dry, solid materials such as granular fertilizer or cover crop seed. Research suggests that drones can be used to conveniently spread cover crop seed, especially where traditional applications with ground or manned aircraft cannot be performed due to field or weather challenges, and in small, irregularly shaped fields where drone applications can be more efficient (Teske et al., 2018).

For dry material applications like cover crop seed or granular fertilizer, several factors can influence the performance and effectiveness of seeding, including platform type and design, material metering and distribution system, operational parameters such as application rate, flight speed and height (Song et al., 2023), and environmental factors such as wind speed and direction. Currently, there are a few different types of product metering and spreading systems available on commercially available drones. As an example, the DJI T50 (SZ DJI Technology Co., Shenzhen, China) drone has a gravity-fed metering gate design with a single-disc spinner disc for broadcasting the material, while the XAG P150 (XAG Co., Ltd., Guangzhou, China) has an auger-type metering system with a vertically mounted disc with baffles to broadcast the material across the swath. The primary difference between these two systems lies in how the material is metered and interacts with the spreading mechanism. These two systems are the most widely used drone platforms in the United States and other countries. However, limited information exists on the metering and spreading performance of these systems. Further, the performance of these systems under varying operational parameters, such as application rate, flight height, and speed, is also unknown and is likely to affect spreading behavior.

Recent research has shown that proper calibration of drones for applying dry materials is important for achieving the target seeding rate and desired uniformity of distribution across the swath. Sizemore et al. (2026) also highlighted the inadequacy of internal manufacturer-recommended calibration to appropriately account for material properties, resulting in significant differences between the applied and target rates for cereal rye. The authors also reported the leftward-skewed spread patterns associated with a single-disc broadcast system used in their study. Similar observations were reported by Thomas (2025) for different types of cover crop species used in their study. Both studies also reported the effects of operational parameters, such as spinner-disc speed and height, on effective swath and spread uniformity. With the increasing use of drones for applying dry materials, it is important to understand and assess the application performance of different drone types, particularly their metering and spreading systems, to guide effective spreading operations. Therefore, this study was undertaken to evaluate different metering and spreading systems on commercially available drones, to better understand their performance, and to determine how these systems can be optimized for the efficient application of dry materials with drones.

Methods and Materials

Equipment and Location

The commercial drone platforms used in this study were DJI Agras T50 (SZ DJI Technology Co., Shenzhen, China) and XAG P150 (XAG Co., Ltd., Guangzhou, China). For brevity, these drones will be referred to as T50 and P150 hereafter (Figure 1). Both drones have a quadcopter arrangement; however, they have different metering and spreading systems. The T50 has a circular metering gate (available in different sizes) installed at the bottom of the hopper, where the material is metered by opening the gate to different openings and onto the single-disc broadcast disc with curved vanes. A large metering gate was determined to be the best fit for this study to achieve the target application rates. In contrast, the P150 has a horizontally mounted auger-type metering system (XAG RevoCast 4 Screw Feeder) where the material is metered using the auger (which can be changed based on the material type) onto a vertically mounted disc with baffles that oscillate back and forth to distribute the material across the swath. A medium auger was selected as the best fit for this study based on the preliminary testing. Table 1 provides some additional information about both drone types used in this study.

Two different types of testing were conducted to assess the application performance of these drones. Static flow-rate tests were conducted at the Biosystems Engineering Laboratories on the Auburn University campus in Auburn, AL, USA. All field tests were conducted at the EV Smith Research Center located in Shorter, AL, USA. For flight planning, a pre-installed DJI Agras flight application software with the DJI RC Plus remote controller was used for the T50. The P150 uses a handheld rover, XRTK6, to mark boundary points for the flight plans used during testing. During the field experiments, RTK positioning corrections were used on both platforms via the Alabama CORS network, resulting in horizontal and vertical position accuracy of ±10 cm.

Figure 1. DJI Agras T50 (left) and XAG P150 drones used to test different metering and spreading systems in this study.

Table 1. Specifications of drones used in this study.

Platform	DJI Agras T50	XAG P150
Platform weight (kg)	52	54
Dimensions unfolded (mm)	2800 x 3085 x 820	3110 x 3118 x 975
Dry Material Tank Capacity (kg)	50	70
Number of Rotors	8	4
Spread Width (m)	8	8
Maximum Speed (m s^{-1})	10	13.8
Compatible Material Diameter (mm)	0.5 - 5	1 - 10

Cereal rye seed was selected as the dry material to be spread with the T50 and P150 drones, as it is the most widely used cover crop species in the United States (Sever, 2023) and commonly broadcast with drones. The bulk and particle densities of the cereal rye seed used in this study were determined to be 68.2 kg m^{-3} and 1.2 g cm^{-3}, respectively.

Flow Rate Testing

Prior to any field testing, static flow rate testing was performed with both drones to determine the actual flow rate (kg min^{-1}) of cereal rye at different hopper gate openings (%) for the T50 and at different auger speeds (rpm) for the P150 to generate a flow rate calibration curve. These tests involved removing the spreading (broadcast) system from the drone and supporting it between two raised platforms so that a container could be placed beneath the spreader tank to catch the material dispensed from the hopper. Next, the dry tank was filled with cereal rye, and different gate openings for the T50 and auger speeds (rpm) for the P150 were entered into the controller in manual mode. At each gate opening or auger speed, the material dispensed from the hopper was collected for 20 to 30 seconds and then weighed to determine the flow rate in kilograms per minute. This process was repeated three times for each gate opening and auger rpm for both drones. A least-squares regression curve was fitted to the data to determine the relationship between the measured flow rate and hopper gate opening or auger speed.

Field Pan Testing

This test focused on capturing the applied material in collection pans placed on the ground as the drone passed over them to assess the applied rate and distribution uniformity within the swath. An application area, approximately 150 m long and 30 m wide, was selected within the field for these tests. A line of collection pans, measuring 0.5 x 0.5 m and spaced 0.6 m apart, was arranged towards the center of the selected area (Figure 2). This arrangement of pans was perpendicular to the flight path and was directly centered under the drone pass. During each test, the drone performed a single pass over the collection pans with the desired application rate preset in the controller and broadcast the material within the application area. These field tests were conducted in accordance with the procedures outlined in the ASABE standard S386.2, Calibration and Distribution Pattern Testing of Agricultural Aerial Application Equipment (ASABE, 2024). For each drone, data were collected at three different target seeding rates of 22.4, 44.8, and 67.3 kg ha^{-1}, while all other operational parameters, including flight speed and height, were kept constant.

Figure 2. Illustration of collection pans placed within the application area and perpendicular to the drone pass for assessing the distribution uniformity of cereal rye across the swath.

After each drone pass, the material collected in each pan was weighed and converted to an applied rate (kg/ha) for each pan location within the swath. Further, single-pass and simulated overlap distribution patterns for an effective swath of 7.3 m were generated from the applied rate calculated across the swath. To analyze and compare the single-pass patterns, the total material applied within the swath (kg), maximum single-pass swath width (m), and pattern skewness (%) were calculated. For simulated overlap patterns, the mean applied rate (kg/ha) and coefficient of variation (CV%, to assess spread uniformity) were calculated to compare mean rate and spread uniformity across different rates and among the drones.

Results and Discussion

Flow Rate Curves for Cereal Rye

Figure 3a and 3b show the flow rate for cereal rye at different gate openings and auger speeds for the T50 and P150 drones, respectively. For T50, a quadratic relationship between the metering gate opening and flow rate was observed, whereas a linear relationship was observed for P150. The regression equations for both drones exhibited an R^2 of 0.99. For T50, this quadratic relationship differed from the somewhat linear relationship suggested by the manufacturer-provided calibration, which is concerning because it can result in considerable metering-rate errors during application. Based on this data, the maximum flow rate for cereal rye with the large metering gate for T50 was 140 kg min^{-1}, whereas the maximum flow rate for P150 with the medium auger was approximately 75 kg min^{-1}. This was an interesting observation, as P150 was assumed to have a higher flow rate, but it was also a function of auger size: a larger auger would exhibit a higher flow rate, and vice versa. Determining the maximum flow rate and understanding these values is important, as it helps select optimal parameters, such as the target seeding rate, flight speed, and swath for the seeding operation. To achieve a consistent target seeding rate, the drone adjusts the flow rate to account for the speed changes for a given spreading swath. In some cases, it may be necessary to adjust the target rate and/or flight speed, given the maximum flow rate achievable with the specific metering gate or auger for the given product.

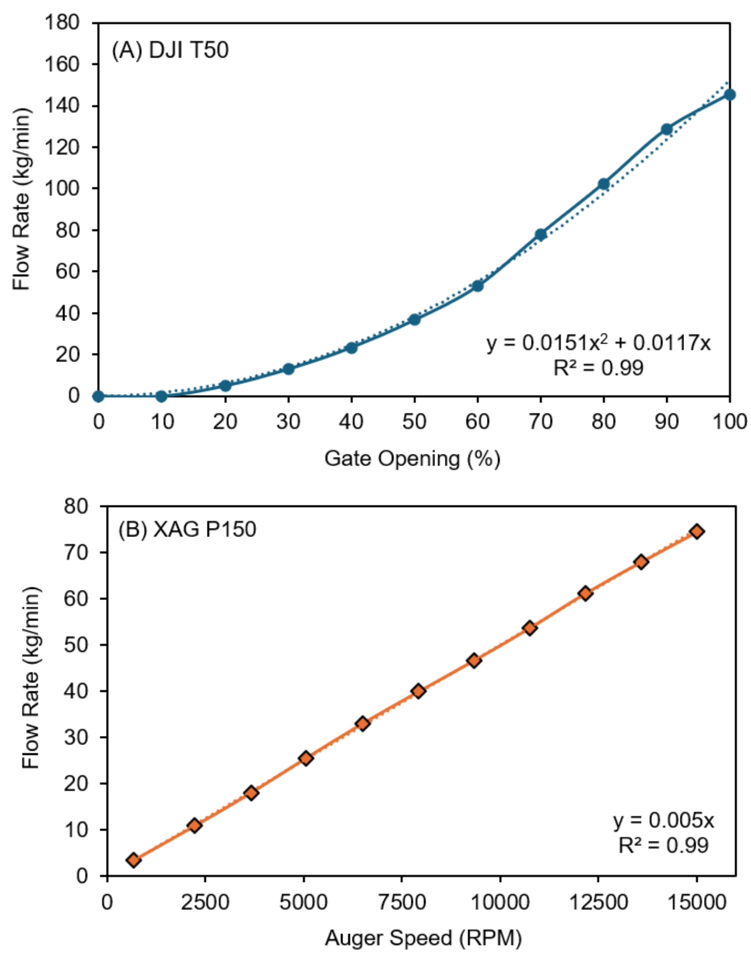


Figure 3. Flow rate curves depicting the relationship between material flow and gate opening or auger speed for (A) DJI T50 and (B) XAG P150.

Single-Pass Spread Patterns

The single-pass spread patterns for the T50 and P150 across different target seeding rates are presented in Figures 4a and 4b, respectively. For the T50, the spread pattern exhibited a leftward skewness, typical of single-disc broadcast spreaders, with most of the material concentrated towards the left of the swath. For the P150, the pattern was more centered with the swath, with a heavy deposition peak in the middle and two smaller peaks towards each side of the swath. Interestingly, there was more material on the left side of the swath than on the right. For both drones, the shape of the spread patterns remained relatively similar across the different target rates, with the magnitude of the patterns increasing as the rate increased.

Table 2 presents summary statistics for the single-pass spread patterns for both drones at different target application rates. For both drones, the total mass within the swath increased with higher application rates, as expected due to the greater amount of material metered. In comparison among the drones, the P150 showed slightly more material deposition within the swath than the T50, which was interesting, as both drones were set to deliver the same target rates. For the maximum single-pass swath, the T50 had a wider swath (1.3 to 3.1 m) than the P150, which can be attributed to its single-disc broadcast-spreading system compared with the vertical-baffle-style system on the P150. It was also observed that, for T50, the swath increased with higher target rate, likely due to more material reaching farther. However, the single-pass swath remained relatively consistent (13.4 to 14.1 m) for the P150, regardless of the target rate.

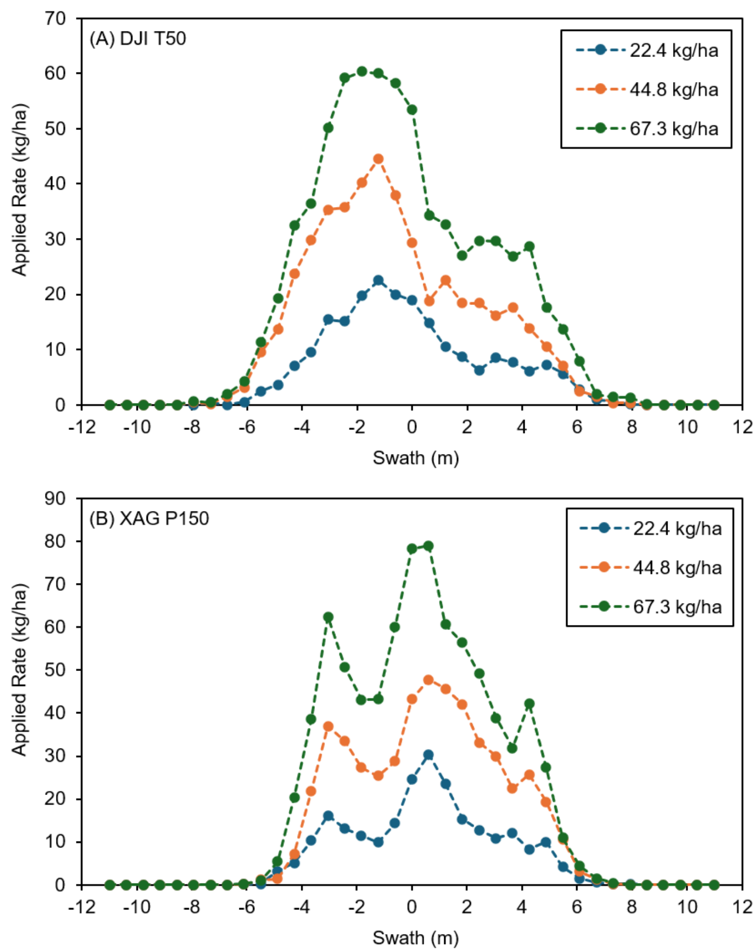


Figure 4. Single-pass spread patterns for the (A) DJI T50 and (B) XAG P150 drones at various target seeding rates.

Table 2. Summary Statistics for the single-pass spread patterns for cereal rye applied with the drones at different application rates.

Drone	Target Rate (kg ha^{-1})	Total Mass (kg x 10^{-3})	Maximum Swath (m)	Skewness % (L/R)
DJI T50	22.4	5.4	15.3	54/37
	44.8	11.3	15.9	61/33
	67.3	17.5	16.5	56/36
XAG P150	22.4	6.0	14.0	35/54
	44.8	12.7	13.4	36/55
	67.3	20.2	13.4	40/50

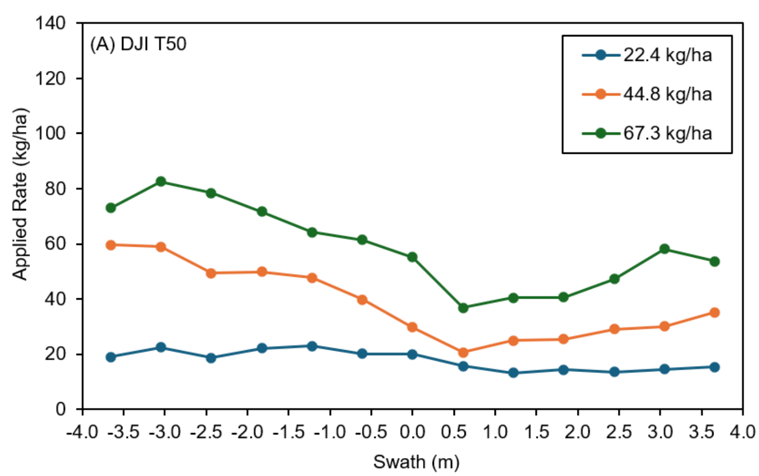
For the spread pattern skewness, the T50 exhibited leftward skewness, with 54% to 61% of the material deposited to the left of the swath and 33% to 37% to the right. In contrast, the spread pattern for the P150 was slightly shifted to the right, resulting in 50% to 55% of the material deposited to the right of the swath and 35% to 40% to the left. This shift could be due to the drone not being centered directly within the swath or due to the effect of wind during testing.

Simulated Overlap Spread Patterns

Figures 5a and 5b present the simulated overlap-spread patterns for cereal rye applied using the T50 and P150 drones, respectively, across different target seeding rates. These patterns were generated for an effective swath of 7.3 m (24 ft), which is a common and the widest swath currently used by drone operators for applying cover crop seed. Similar to the single-pass patterns, the overlap spread patterns exhibited a similar shape across different target seeding rates, with the magnitude increasing with the rate.

Table 3 presents summary statistics for the simulated overlap spread patterns for both drones. The mean T50 rate was 12.7% to 20.3% lower than the target seeding rate, indicating an over-application if this effective swath were used to apply cereal rye. For P150, the mean rate was very similar to the target seeding for 67.3 kg ha^{-1}, but was 5.2% to 10.6% lower than the target rate for other seeding rates. Interestingly, for both drones, the under-application decreased as the target seeding rate increased.

For spread uniformity, both drones exhibited CV values ranging from 20% to 35%, with most applications below 30%, which is considered acceptable for dry-material applications with drones. The highest CV was observed at the 44.8 kg ha^{-1} rate for the T50 drone, indicating greater variability in material distribution within the swath than at the other rates and compared to the P150. For P150, it was also observed that distribution uniformity improved as the application rate increased. This trend was not observed for the T50. While the simulated overlap analysis was performed only for an effective swath of 7.3 m, it can be assumed that spread uniformity will likely improve at narrower swaths, such as 6 or 5 m.



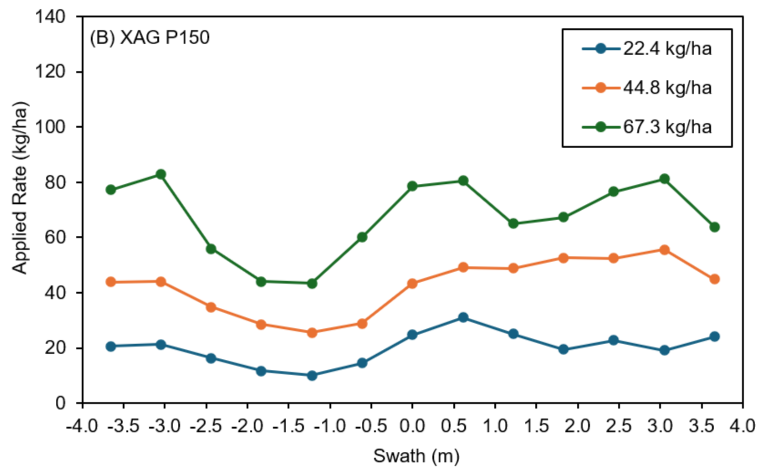


Figure 5. Simulated Overlap spread patterns for the (A) DJI T50 and (B) XAG P150 drones at various target seeding rates for an effective swath of 7.3 m.

Table 3. Summary Statistics for the simulated overlap spread patterns for cereal rye applied with the drones at different seeding rates for an effective swath of 7.3 m.

Drone	Target Rate (kg ha^{-1})	Applied Rate (kg ha^{-1})	Difference[a] (Applied – Target, %)	CV (%)
DJI T50	22.4	17.9	-20.3	19.9
	44.8	38.5	-14.1	34.5
	67.3	58.8	-12.7	25.4
XAG P150	22.4	20.0	-10.6	29.1
	44.8	42.5	-5.2	23.5
	67.3	67.4	0.2	20.2

[a] negative values indicate under-application.

Conclusion or Summary

The metering and spreading performance of two commercially available drones, the DJI Agras T50 and the XAG P150, for applying dry materials (cereal rye seed) was assessed and compared. The static flow rate testing showed a non-linear (quadratic) relationship between the cereal rye flow rate and the gate opening for the gravity-fed hopper gate metering system on the T50, whereas this relationship was linear for the auger-type metering system for the P150, where the flow rate increased with an increase in auger speed (rpm). The single-pass spread patterns for the single-disc broadcast system on the T50 showed a leftward skewness, with the majority of the cereal rye deposited to the left of the swath. In contrast, the single-pass spread pattern for the P150 equipped with the vertical baffle-style spreading system showed a more even material distribution within the swath than the T50. Due to the differences in the spreading system, the T50 exhibited a wider single-pass swath (1.3 to 3.1 m greater) than P150. The single-pass swath also increased with application rate for T50 but stayed consistent for P150 across different target rates. For simulated overlap spread patterns, both drones showed under-application (ranging from 5% to 20%) for an effective swath of 7.3 m. In comparison, the under-application was lower for the P150 than the T50. For spread uniformity, the CV values ranged from 20% to 35% across both drones, with most applications below the acceptable 30%. Overall, the results from this study suggest varied application performance for the tested drones due to the differences in metering and spreading systems. Future research needs to evaluate the application performance of these drones under overlap spreading patterns and compare the applied rate and distribution uniformity under varying application conditions. The effects of operational parameters, such as flight speed and height, on the performance of these metering and spreading systems also need to be evaluated.

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