Assessing the distribution uniformity of broadcast-interseeded cover crops at different crop stages by an unmanned aerial vehicle

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Abstract.

Unmanned aerial systems can now carry larger payloads and have become more affordable, making them a viable option to use for broadcast-interseeding cover crops in the fall, before main crop harvest. This strategy has become popular in Ohio over the past two years. However, this new strategy arose quickly with a limited understanding of field performance of the drone's distribution uniformity under different parameters such as seeding rates, swath widths, speeds, or cash crop type. Therefore, the study aims to assess the distribution uniformity of a centrifugal spreader-equipped drone using different seed species and mixes. Preliminary field assessment results indicated that the rates applied were lower than the target rates by 8.1% to 25.4%. The applied rates for a 56 kg/ha single cover crop (cereal rye) were between 41.8 kg/ha and 48.6 kg/ha. Similarly, for the 36 kg/ha seed mix (cereal rye, purple top turnips, and daikon radish) application, the applied rate ranged from 26.7 kg/ha to 33 kg/ha. These lower rates were primarily attributed to seeds being intercepted by the standing crop. Regarding distribution uniformity, the coefficient of variation (CVs) was between 17.6% and 31.2%. Overall, CVs were around 20% which has been deemed as acceptable uniformity for this type of application. Pattern testing of cereal rye, crimson clover (coated), radish, a mix of cereal rye and crimson clover (Mix A), and a mix of cereal rye and radish (Mix B) was conducted to assess how different seed types differ in swath spacing and if spread uniformity differs in a seed mix versus being spread alone. The results indicated differences between spread uniformity among cover crops plus swath spacing changes. Cereal rye had a CV of less than 20% at 8 meters when spread alone, 6 meters when mixed with crimson clover, and 12 meters when mixed with radish. Crimson clover maintained a spread uniformity CV of less than 20% up to 9 meters when spread alone and 12 meters when included in a mix with cereal rye. Radish had the most variable spread uniformity, likely due to the low rate not being able to be metered accurately with the large hopper gate, by exceeding a 20% CV at 5-meter swath spacing when spread alone and at 3 meters when mixed with cereal rye. Additional field testing is planned for the 2025 crop season to understand the spread uniformity from drone application equipment and setup to maximize cover crop interseeding performance.

Keywords.
Drones, Cover Crops

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Introduction

The implementation of unmanned aerial vehicles (UAVs), or drones, into precision agriculture practices has continuously grown and improved over recent decades (Abdullahi et al., 2015). Drones were first being used in the agriculture industry for remote sensing of crop health information (del Cerro et al., 2021). They have evolved into efficient farm equipment equipped with real-time kinematics (RTK) technologies capable of carrying large payloads to apply agricultural inputs (Kaya S. & Goraj Z., 2020). With the continued technological advances within the drone industry, they can now carry enough payload that makes them an option for field application (CAST, 2020). Producers will be able to implement drone application of cover crops efficiently and effectively into cropping systems using the parameters that result in a uniform distribution of cover crop seed. According to Andy Clark at Sustainable Agriculture Research and Education (2023), a cover crop is a plant primarily used to reduce soil erosion, improve soil health, and have many additional benefits that vary depending on the plant species. By introducing these plants, there will be an increase in biomass, which in turn will enhance soil organic matter and improve nutrient recycling as the organic matter breaks down (Fageria et al., 2005). This will then lead to a decreased amount of synthetic fertilizers applied to the fields which could otherwise end up off-site where the nutrients are not utilized. Studies have shown a reduction in surface and subsurface nutrient runoff by planting cover crops because of vegetative cover (Hanrahan et al., 2021). A reduction in nutrient runoff will improve water quality and increase atmospheric carbon sequestration (Dabney et al., 2001). While there exist multiple benefits of planting cover crops instead of leaving fields fallow, there is still some resistance among farmers to incorporating cover crops into cropping systems (Myers, R., & Watts, C., 2015).

For many government funding opportunities, such as cost-share programs or incentives for implementing cover crops, it is required to plant cover crops within a period typically depending on location. In the Midwest, there is a short time frame for drilling cover crops due to the timing of main crop harvest and colder temperatures in the fall (Roesch-McNally et al., 2021). Thus, to meet the cover cropping requirements, producers have explored alternative establishment options by hiring custom applicators for aerial or high clearance equipment for spreading cover crops around late summer and early fall (Peterson, et al., 2019), prior to main crop harvest. For Ohio, these planting dates are between early July and mid-November depending on the cover crop (U.S. Department of Agriculture, 2019). Previous interseeding options were expensive as they require large, specialized planters that could cause crop damage, and aerial application by airplane or helicopter, with increased drift risk, is not feasible for small or irregularly shaped fields (Stark et al., 2013). During this time, depending on the planting date, the crops could still have green, partial senescence, or full senescence canopy. One of the limitations of these alternative establishment options is the adequate distribution of the cover crop being broadcasted and at times intercepted by a green or senescing canopy of the main crop. Berner, Chojnacki (2017) and Zhan et al. (2022) provide evidence that during spray applications, the effects of downwash airflow from the drone rotors on droplet deposition change as the payload changes, due to the varying lift required to maintain flight height. Recent studies have shown that an acceptable distribution uniformity of granular materials being broadcast by drones can be met under certain height and speed parameters, the coefficient of variation (CV) is lower than 20%, and improved working efficiency will be seen under certain parameters for flight height and speed (Song et al., 2023).

With drone spreader application technology still in the early stages of adoption into agricultural systems, there is little information on how different drone parameters will affect the distribution uniformity of granular materials such as cover crops. To provide recommendations that will result in the optimal field performance of drone spreaders and cover crop adoption, more research is needed for understanding the effects of conditions such as flight height, flight speed, and spinner disk speed. Other factors that play a role in affecting swath width are granular material's physical characteristics, wind speed, and when spreading into cash crop, the canopy will affect ground distribution of seed. Another factor that plays into the swath width of cover crops being affected is whether a single cover crop specie is being spread, or a mixture of species (mix of species is common to explore further other benefits). It is important to understand the effects of each of these factors as producers are looking to effectively implement practices that will improve the sustainability and conservation efforts of farmers that also ensure they are still profitable.

Materials and methods

Preliminary research was conducted with farmer collaborators in Darke County-Ohio during mid-September 2023. Standardized collection pans of 500mm x 500 mm x 89 mm with divided compartments, measuring 79 mm x 79 mm x 79 mm to reduce particle bounce, were randomly placed within the field before application, shown in Figure 1. A DJI Agras T40 equipped with a spinner disc spreader was used for all fields. Seeds captured in individual pans were weighed to compute the rate applied at that location. An overall mean rate and CV (%) were computed for each field to evaluate performance. A single cover crop, cereal rye, was applied at a rate of 56 kg/ha on three corn fields and a cover crop mix of cereal rye, oats, and radishes at 36 kg/ha was spread on one corn field and one soybean field. Crops in these fields were characterized as still having a large percent of green canopy and only partially senescence.

Figure 1. Collection pan set up under corn canopy

The drone used was the DJI Agras T20P (Da-Jiang Innovations, Shenzhen, China) equipped with centrifugal broadcast spreading systems. The pattern test took place at the Molly Caren Agricultural Center in London, Ohio, and followed the ASABE Standard 341.5 (2022). The products used for these pattern tests were cereal rye, crimson clover (coated), and radish at target rates of 69.7, 24.4, and 4 kg/ha, respectively. A mix of the cereal rye and crimson clover (Mix A), and cereal rye and radish (Mix B) with the target rate being the same as the single seed rates but combined for comparison when each seed species was spread individually. The hopper gate, shown in Figure 2, controlled the metering of the products with large openings that originally came with the spreader system. The drone flew at an altitude of 15 feet above the pans and 19 ft/sec (feet per second) ground speed for the single seeds. All of the settings were the same except ground speed, which was limited by the controller for the set rate. For Mix A, the ground speed was 11.3 ft/sec and Mix B was 17.7 ft/sec. The products then fell onto a single spinner disk that was set to 1300 RPM (rotations per minute). During each pass, the wind speed was measured using a Kestrel 3000 anemometer. The application method, shown in Figure 3, was a single-pass perpendicular to two rows of at least thirty-three standardized collection trays.

Figure 2. Large opening hopper gate

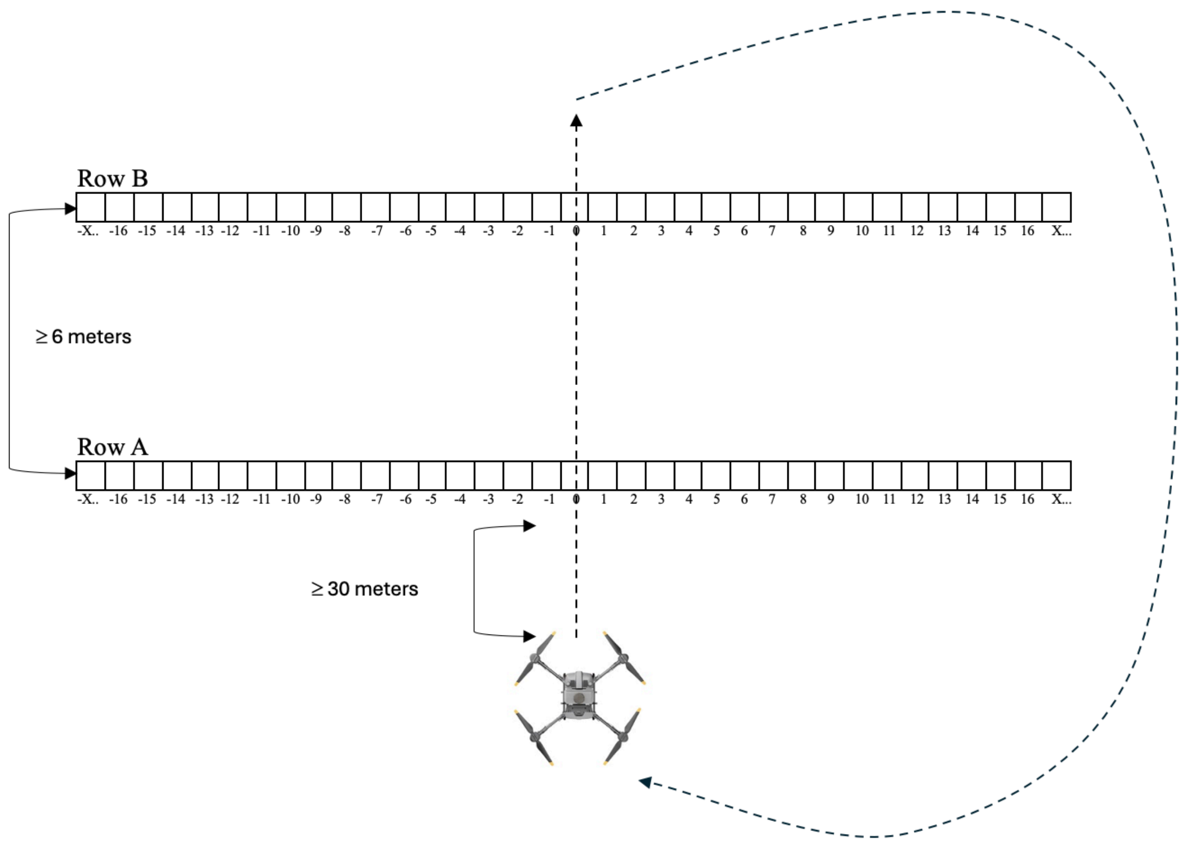

Figure 3. Pattern test pan set up and drone flight path, each row of pans was spaced at least 6 meters apart. Negative pans are on the left of the drone flight path, and the positive numbers are on the right of the drone path. The drone flight began at least 30 meters before the pans for seeding rate and flight speed to reach the targets and to normalize.

The materials collected by the trays were then placed into bags to be weighed to compute the application rate being applied at each pan location. This process was done twice for each seed and seed mix. For weighing seed mixes, the two seed types were separated and weighed individually to determine individual seed rates. The samples from each collection tray were weighed to 0.01-gram accuracy on an OHAUS Navigator scale and the application rate was calculated using the equation:

$$R = (K \times W) / (A \times E) \tag{1}$$

Where:

R is application rate, kg/ha (lb/a)

K is constant, 100,000 (13,830)

W is sample mass, g

A is the area of the collector opening, cm2 (in.2)

E is collector efficiency, normally 0% to 100%, but can exceed 100% (expressed as a decimal in this equation).

$$X = (\sum X_i)/N \quad (2)$$

$$Standard\ Deviation\ (SD) = \{(\sum[(X_i - X)^2 / (N-1)\}^{1/2} \quad (3)$$

$$CV = (SD \times 100)/X \quad (4)$$

Where:

X is the arithmetic mean

X_i is accumulated sample weight

N is the number of trays used

A progressive pass (back and forth) application which is the most common flight method was simulated from the average of seed collected for each of the correlating pan's distance from the center to calculate the CV of swath spacing using the applied total values within the effective swath width, an example of the simulated passes is shown in Figure 4 and the CV is shown in Figure 5. The CV is used to determine the effective swath width, where the CV is lowest and the swath spacing is highest.

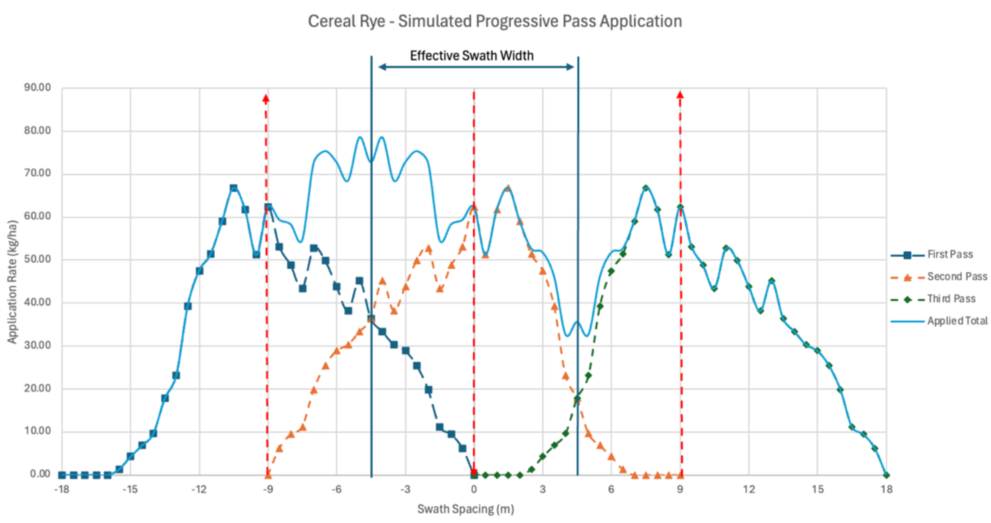

Figure 4. Using a single-pass application to create a simulated overlapping progressive pass application.

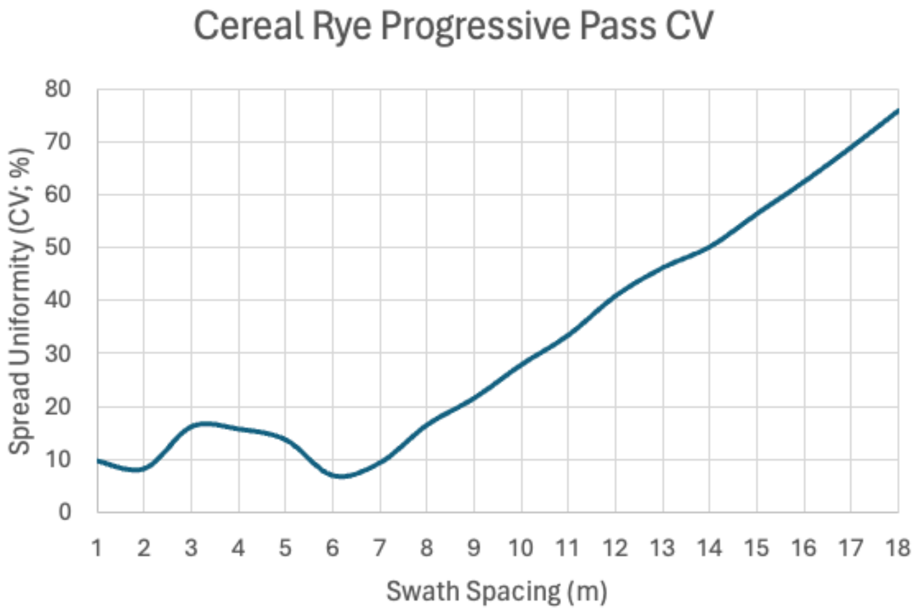

Figure 5. CV of the cereal rye application

Results and discussion

Results from field applications indicated that the rates applied were lower than the target rates by 8.1% to 25.4%. For the 56 kg/ha single cover crop applications, the applied rates were between 41.8 and 48.6 kg/ha. Similarly, the target rate at 36 kg/ha ranged from 26.7 and 33 kg/ha. These lower rates were primarily attributed to seeds being intercepted by the crop. In terms of distribution uniformity, CVs were between 17.6% and 31.2%. Overall, CVs were around 20% which has been deemed as acceptable uniformity for this type of application.

Before doing pattern testing, each of the seed species and mixes went through material calibration on the DJI controller, which determines the flow rate of material at different hopper gate opening percentages so adjustments can be made as ground speed and rate changes will adjust the hopper gate opening percentage to apply an accurate rate. Following previous pattern testing, adjustments were made to the remote controller rate to get closer to the target rates. The drone flew from west to east and winds throughout the day came from the north. During pattern testing of the cereal rye, wind speeds during the first pass were 7.2 km/h and for the second pass, it was 5.8 km/h. When performing the pattern test for crimson clover, wind speeds for the first pass were 4.6 km/h and 4 km/h for the second pass. For the pattern testing of radish seed and both mix A and B wind speeds were less than 1.5 km/h.

As seen in Figure 6, there is an increased amount of seed being deposited directly under the drone and on the negative side of the flight path, with a steeper decline in rate as drone was further from the flight path than on the positive side of the flight path. This shows a slight skewness of the seed distribution, which is observed in both the individual seed species and seed mixes.

With the low rate of 4 kg/ha being used for the radish seed application, the hopper gate was not opening enough for a consistent flow of material. The rate was raised on the controller until a consistent flow of seed was observed to be coming from each of the hopper gate openings. This shows that when spreading seeds at lower rates, there are limitations to the metering of material with the large hopper gate. Future tests will look into the consistency of metering using a hopper gate with smaller openings that DJI has commercially available for their spreader system.

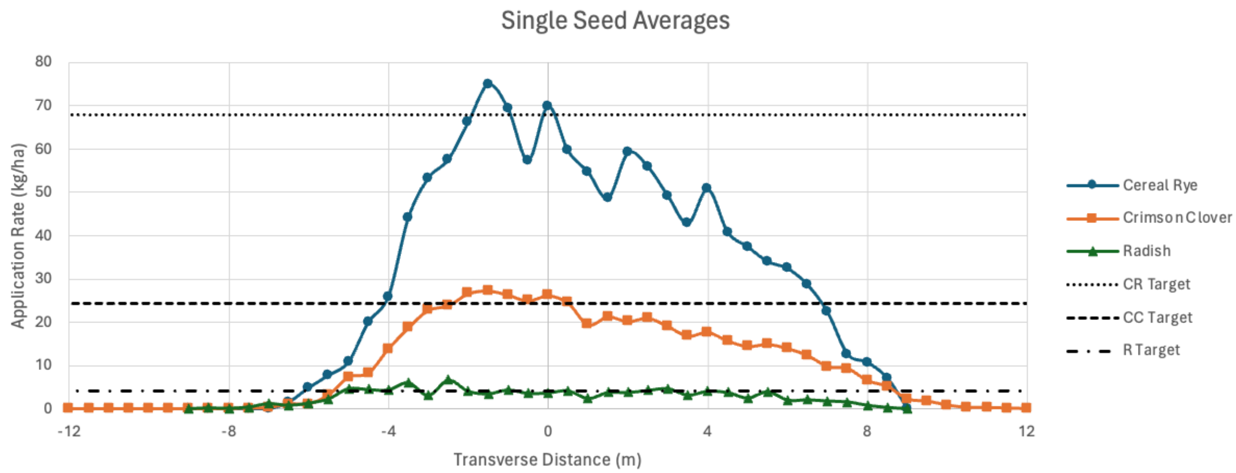

Figure 6. Average of each seed species rates collected across the transverse distance across the swath

The graphical representation of the calculated CVs for the simulated progressive path application from the single pass data of each of the seed species alone is provided in Figure 7. Cereal rye and crimson clover were observed to have a more uniform spread at wider swath spacings than the radish seed.

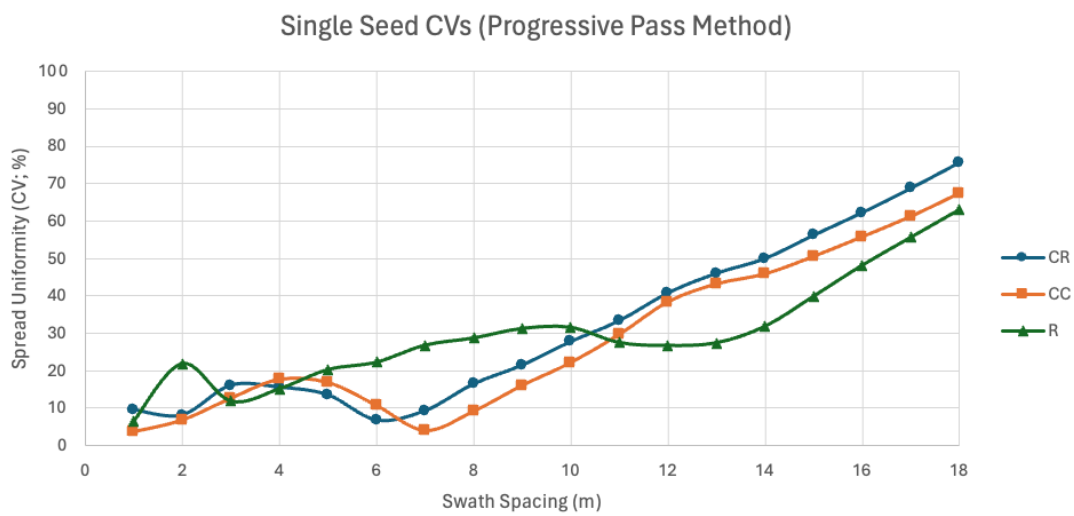

Figure 7. CV as swath spacing increases for each seed species

Table 1 shows the calculated CVs for the simulated progressive pass application using the single pass data. This provides the swath spacing at which the effective spread width can be determined, with the CV being the lowest at the widest swath width. In the table, bold are the values where the CV is less than 20%, which has been deemed acceptable for this type of application. The crimson clover maintained a CV of less than 20% when spread alone for the widest swath spacing of 9 meters, with cereal rye at 8 meters. Radish seed was the most variable seed species with a CV of 15.1% at 3-meter swath spacing when spread alone. This is likely due to a minimum spread rate limitation of the large hopper gate to accurately meter the seed. When the cereal rye was mixed with the crimson clover, a decreased spread uniformity was observed for the cereal rye, with the CV being almost 20% at 6 meters, but the crimson clover's CV remained below 20% at a 12-meter swath. When the cereal rye was mixed with radish, the cereal rye's swath spacing of 12 meters was 15.97% and the radish seed was still highly variable with only being below 20% at the 2-meter swath spacing.

Table I. CV comparison between seed species and mixes

Comparison of CVs when seed is spread by itself versus mixed (%)							
	Cereal Rye			Crimson Clover		Radish	
Swath Spacing (m)	Single	Mix A	Mix B	Single	Mix A	Single	Mix B
1	**9.58**	**4.45**	**2.67**	**3.73**	**2.04**	**6.37**	22.63
2	**8.13**	**5.93**	**5.97**	**6.83**	**10.89**	21.86	**16.53**
3	**16.10**	**5.84**	**5.44**	**12.64**	**8.78**	**11.84**	21.45
4	**15.59**	**8.04**	**10.71**	**17.68**	**9.44**	**15.10**	33.10
5	**13.55**	**11.88**	**9.27**	**16.86**	**6.84**	20.24	25.85
6	**6.79**	**19.63**	**10.89**	**10.76**	**10.39**	22.23	33.50
7	**9.26**	24.70	**16.16**	**4.06**	**16.68**	26.78	30.87
8	**16.43**	24.80	**18.40**	**9.18**	**19.42**	28.70	27.51
9	21.45	22.36	**12.24**	**16.07**	**17.27**	31.26	29.26
10	27.77	21.74	**9.27**	22.16	**12.59**	31.56	32.80
11	33.35	25.81	**10.31**	29.68	**12.35**	27.50	30.85
12	40.78	35.06	**15.97**	38.38	**19.83**	26.71	34.51
13	46.07	45.03	24.93	43.17	30.00	27.43	41.37
14	50.01	53.15	33.51	45.85	39.44	31.83	44.83
15	56.24	60.89	42.65	50.50	48.98	39.87	48.31
16	62.29	68.08	50.93	55.76	57.23	48.16	52.37
17	68.79	74.45	58.54	61.17	63.93	55.62	58.33
18	75.69	80.52	65.52	67.30	70.53	63.05	65.79

The table included the CV (%) of the seeds captured when spread individually and in a mix. The values in bold have a CV that is less than 20% and values not bolded are CVs greater than 20%.

Conclusion

As drones become a more adopted technology for applying agricultural inputs, a deeper understanding of the working parameters that will result in the highest efficiency and accuracy should be studied to ensure the goals of implementing cover crops are being met, while increasing operational efficiencies. With the large variety of cover crops available with a wide range of benefits, there are different physical characteristics between seed types and cover crop species that will require adjustments before being broadcasted in crop fields, especially when cover crop seed mixes are utilized leading to different requirements. Our preliminary pattern test results showed that cereal rye had an acceptable CV of 16.4% at 8-meter swath spacing when spread alone, 19.6% at 6 meters when mixed with crimson clover, and 16.0% at 12 meters when mixed with radish. The crimson clover seed had an acceptable CV of 16.1% when spread at a 9-meter swath spacing alone, and 19.8% at 12 meters when mixed with cereal rye, but this mix may be limited by cereal rye's CV exceeding 20% after 6 meters. Radish's acceptable CV of 15.1% was at a 4-meter swath spacing when alone, and 2 meters when mixed with cereal rye. With the radish being spread at such low rates, more research will be done using a smaller hopper gate opening in order to more accurately meter the seeds applied at smaller rates. However, when mixed, this will be limited to the larger seed in the mix, or if the rate is higher, it will require a large hopper gate as was seen when mixing with cereal rye. It was observed that with different cover crop mixes, the spread uniformity could be positively or negatively impacted due to different seed types. This should be studied further because using a seed mix is a common practice in cover cropping. The results from this study show that under the parameters listed, using drones for the spreading of cover crops is a feasible option, but fine-tuning these practices is necessary. Further testing is planned for 2025 to work on improving the spread uniformity by flying under different parameters such as different flight altitudes and spinner disk speeds, as well as comparing how the spread patterns are affected when spreading into different cash crop canopy structures and timings.

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