Performance of unmanned aerial vehicles to broadcast-interseed cover crops at different crop stages

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Abstract.

Unmanned aerial vehicles (UAVs) are increasingly being used to broadcast-interseed cover crops into standing cash crops prior to harvest, offering producers a flexible alternative to traditional aerial or ground-based seeding methods. However, limited information exists regarding the application performance of UAV spreaders and the influence of crop canopy conditions on seed deposition. The objective of this study was to evaluate cereal rye seed deposition and distribution uniformity when broadcast-interseeded with a UAV into corn and soybean canopies at different stages of senescence. Eight field-scale trials were conducted in corn and soybean fields at the Molly Caren Agricultural Center in London, Ohio. Applications were made using a DJI Agras T20P drone at three canopy conditions: green canopy, approximately 50% senescence or defoliation, and harvest-ready (100% senescence or defoliation). Seed deposition was quantified using collection pans positioned across the effective swath, and application rates and coefficients of variation (CV) were calculated following ASABE standards. Statistical analyses were performed using Kruskal-Wallis and Dunn's post-hoc tests (α = 0.05). Mean application rates were generally below the target rate of 56 kg ha $^{-1}$, with field averages ranging from 26.9 to 48.2 kg ha $^{-1}$ and spread uniformity CVs ranging from 17.6% to 32.2%. Across all tests, average spread uniformity was approximately 22%. Canopy condition significantly influenced seed deposition patterns. In soybean fields, applications made into green canopies consistently resulted in greater seed deposition than applications made after partial or complete defoliation, likely due to canopy-mediated redistribution that concentrated seed within the crop rows. Corn responses were less consistent, although significant canopy effects were observed in some fields. Differences among crop types diminished as senescence progressed, and no significant differences in application rate were detected among fields when canopies were fully senesced. Results indicated that crop canopy structure plays an important role in UAV-based cover crop interseeding, particularly under green canopy conditions. Understanding canopy interactions and improving spreader performance will be critical to optimizing UAV cover crop establishment and application consistency.

Keywords. *Drone, UAS, Cover Crops, Spreading, Broadcast Spreading, Application.*

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Introduction

Drone utilization for interseeding cover crops into a cash crop is just one way drones can open up new paths for producers to adopt a new practice and technology into their current production systems. Clark (2023) described a cover crop as a plant used primarily to reduce soil erosion, improve soil health, and have many additional benefits that vary depending on the cover crop species and goals. By introducing these plants, the cover crop biomass is expected to increase the soil organic matter over time, especially when combined with conservation tillage practices (Balkcom, 2023) and improve nutrient recycling as the organic matter breaks down (Fageria et al., 2005). Nutrient credits can be provided by cover crops, especially nitrogen with legumes, because of the nitrogen-fixing capabilities (Bundy et al., 1997). This will then lead to less need for synthetic fertilizers applied to the fields, reducing the amount of fertilizer that could potentially leach or runoff to other locations where the excess nutrients could have negative effects on water quality (Londo et al., 2015). 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 to improve water quality and increase atmospheric carbon sequestration, which will increase soil organic matter, could be seen in some cover cropping systems (Dabney et al., 2001). Cereal rye, even if low emergence is experienced, can reduce nitrogen leaching and, during breakdown, will release these nutrients back into the soil (Koehler-Cole and Elmore, 2020).

While the abundance of benefits from implementing cover crops instead of leaving fields fallow has been shown, there is still resistance to incorporating cover crops into cropping systems among farmers (Myers and Watts, 2015). Successful emergence and growth of the cover crops before termination is important for seeing the benefits of implementing cover crops and could be limited by rainfall (Brooker and Renner, 2020), adding some financial risks. For many government funding opportunities, such as cost-share programs or incentives for implementing cover crops, it is required to plant different species of cover crops within a period, typically depending on location. For Ohio, these planting dates are between early July and mid-November, depending on the cover crop species (U.S. Department of Agriculture, 2019). In the Midwest, there is a short time frame for drilling cover crops due to the timing of harvest in Fall and colder temperatures towards the end of the year (Roesch-McNally et al., 2021), not allowing time for the cover crop to be planted or to become well established before freezing temperatures arrive. Malone et al. (2023) explained the benefit of planting cover crops before cash crop harvest is the reduced labor required at the time of harvest of the cash crop, which will increase the adoption of cover crops.

Studies have been conducted comparing the planting of cover crops preharvest with a broadcast spreader and postharvest with a drill. Marcos et al. (2023) study over two years reported that when broadcasting cereal rye preharvest in Iowa, there was more biomass growth seen due to the earlier planting date than the drilled cereal rye and that weather played an important role in establishment and growth. A three-year study conducted at 18 sites in Maryland with highly variable weather each year reported similar results with a brassica-legume-cereal cover crop mix, with the earlier aerially seeded cover crops performing better than postharvest drilled seeding in terms of biomass growth, N content, and NO3-N leached (Sedghi et al., 2023).

Lack of access to resources such as equipment is a limiting factor for new adopters of cover cropping and limits the adoption rate (Han and Niles, 2023). Previous interseeding options were expensive as they require large, specialized ground rigs that could cause increased crop damage during crop reproductive stages (Klopp et al., 2024), and aerial application by airplane or helicopter may not be feasible for small or irregularly shaped fields (Stark et al., 2013). To meet the cover cropping requirements, some producers hire custom applicators with specialized equipment for spreading cover crop seeds around late summer and early fall (Peterson, et al., 2019) when the crops could still have green, partial senescence, or full senescence canopy. For each of these stages the crop may be in, there could be an influence on the amount of seed making it to the ground.

To gain a better understanding of canopy effects on drone interseeding of cover crops, a DJI T20P was used for interseeding into corn and soybeans. The objectives of this study were to 1) compare the deposition of cover crops being interseeded at green, partial senescence, and harvest-ready corn and soybeans, 2) determine if differences existed in cover crop seed deposition between corn and soybean fields, and 3) evaluate if differences existed between cover crop seed deposition between soybeans planted on 76-cm and 38-cm row spacings.

Materials and Methods

Eight fields were used for interseeding cover crops into cash crops at the Molly Caren Agricultural Center (MCAC) in London, Ohio (Figure 1). Fields 2CDN, 2CDS, and 4B were planted in corn on 76-cm row spacing. Fields 6 and 3A were soybeans planted on 76-cm row spacing. Fields Penin, 4A, and 5 were soybeans planted on 38-cm row spacing.

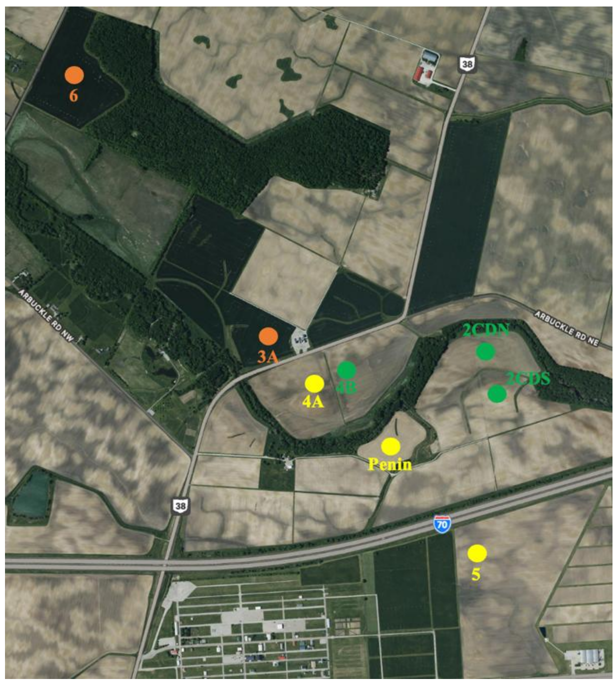


Figure 1. Field locations at MCAC of corn (green), 76-cm row spacing soybeans (orange), and 38-cm row spacing soybeans (yellow).

Each field was laid out in a randomized complete block design of 12 plots. The treatments considered the canopy maturity, with Treatment 1 being a green canopy, Treatment 2 being when the canopy was 50% dry leaves in corn and 50% leaf drop in soybeans, and Treatment 3 being when the canopy was harvest ready with the corn canopy completely dried down and soybeans had 100% leaf drop (Figure 2). These treatments were replicated four times in each field.

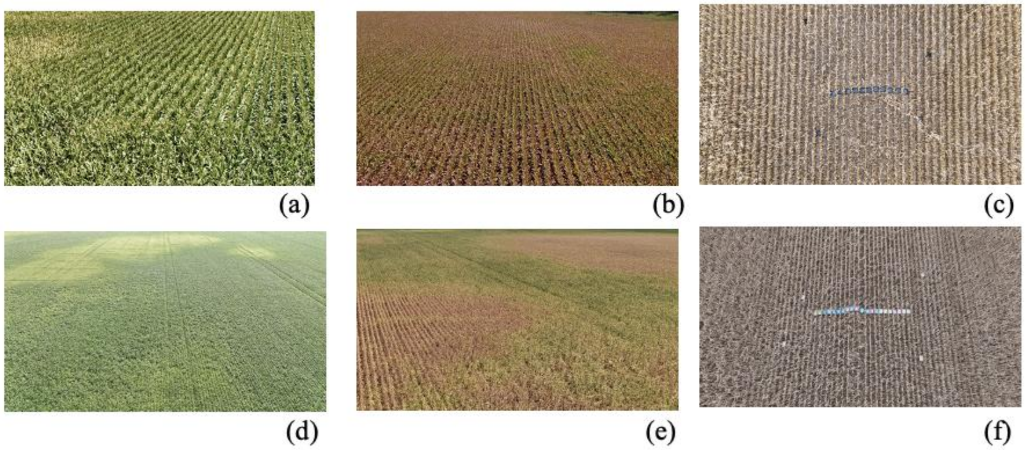


Figure 2. Images of the crop canopy at the time of spreading for the three timings. Corn at green canopy (a), corn with a canopy that has ~50% dried canopy (b), corn that has ~100% dried canopy (c), soybeans with a green canopy and no defoliation (d), soybeans at ~50% defoliation (e), and soybeans at 100% defoliated (f).

Each of the plots was 61 meters long and 23 meters wide. The 23-meter plot width provided enough area for the drone to make three progressive passes. The plot length was long enough to provide the drone adequate time to get up to the set speed and for the spreading hopper gate opening to normalize before getting to the pans, which were placed roughly 30.5 meters into the plot. The 76-cm row spacing plots had 11 collection pans from the Tray Testing Kit supplied by SCS Spreader & Sprayer Testing Ltd, placed across the center pass of the application. The 38-cm row spacing plots used 21 collection pans supplied by New Leader Manufacturing and were placed across the center pass of the application. Due to the number of pans being put out and the distance from the launch area, dividers were not used in the pans as recommended by ASABE standards. There may be some effect on the seed collected in the pans due to bouncing or prop wash effect closer to the flight path.

Cereal rye was selected as the cover crop seed interseeded for this study. It is the most commonly planted winter cover crop in the United States for corn, soybeans, and cotton because of its winter hardiness, low seed cost, and high biomass production (Huddell et al., 2024).

For this study, a DJI Agras T20P was operated in Route Mode, the most commonly used configuration for aerial cover crop seeding. Plot boundaries were developed in ArcGIS Pro and exported as shapefiles for upload to the drone controller. The target application rate was set at 56.0 kg ha^{-1} consistent with USDA NRCS guidelines. Operational parameters included a flight speed of 10 m s^{-1}, an application height of 4.6 m above the canopy, a spinner disk speed of 1300 rpm, and a swath spacing of 6.1 m. The influence of propeller wash on seed distribution patterns has not yet been quantified and represents a potential source of variability. Following each plot application, the drone returned to the launch area and was refilled to approximately the same mass to minimize variability in payload across replications.

All spreading applications occurred after all of the dew was off to reduce the chances of canopy interception. Before spreading each plot, the wind speed was measured using a Weatherflow WEATHERmeter. Wind speeds for most plots were less than eight kph. When spreading plots when wind speeds exceeded eight kph, the crop rows happened to be oriented parallel to the wind, so the wind speed did not affect the swath pattern of these plots. The drone was filled with roughly 25 kg of cereal rye before each application. When each plot was selected, the controller was held at the center row of the plot, and the flight path alignment was adjusted as needed to align the center pass over the center pan. After the operation, each pan was collected with material placed in a Ziploc bag and labeled by the pan's location.

Each bag was then emptied into a dish, weighed using an OHAUS Navigator 622 scale, and mass recorded in Microsoft Excel. These weights were then converted to a rate (kg/ha) for summary and analysis. These results were imported into RStudio to visualize the data and perform statistical analysis. ASABE Standards 341.5 (2018b) and 386.2 (2018a) were referenced in order to compute the mean applied rate and CV for the effective swath width.

Using this data, a comparative analysis was done between the mean applied rate of the within the corn, soybeans planted on 38-cm row spacing, and soybeans planted on 76-cm row spacing, using the Kruskal-Wallis test. If the p-value is less than 0.05, showing there was a statistical difference between treatments, the post-hoc Dunn's test was used to determine which of the treatments had statistical differences with a p-value less than 0.05.

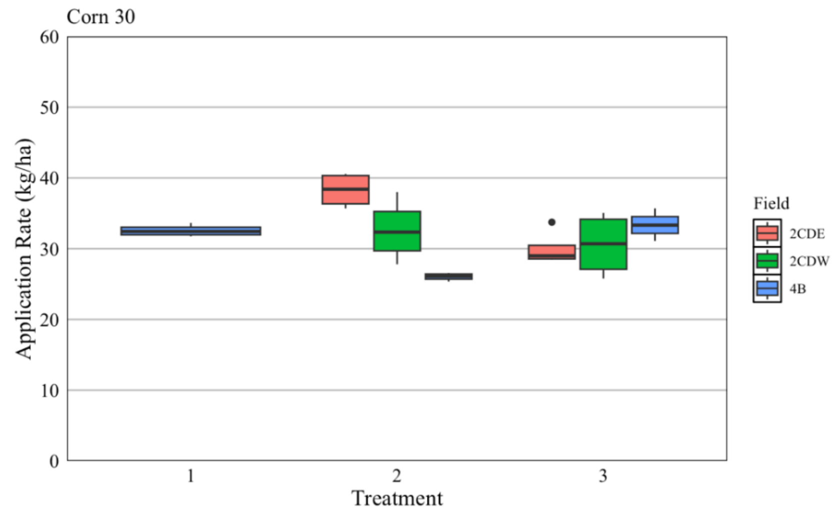
Results

Results summarized in Table 1 quantify application performance across five fields and demonstrate both within-field variability and between-field differences under a consistent drone platform configuration and rye seed source. Mean application rates derived from randomized pan measurements were consistently lower than the prescribed target rate for all fields, with the greatest deviation observed in Field 4. Field 4 exhibited a pronounced reduction in application rate relative to the target, with a mean of 26.9 kg ha^{-1}, a minimum of 17.9 kg ha^{-1}, and a maximum of 37.0 kg ha^{-1}. Coefficient of variation (CV) values further quantified application uniformity, with four of the five fields exhibiting CV values below 25%. Although typical ground-based spreading operations often target CV values between 15% and 20%, the observed variability may be considered acceptable for aerial interseeding applications. In contrast, Field 1 exhibited a CV of 32.2%, indicating comparatively lower uniformity of application. This variability is likely attributable to a combination of spreader calibration uncertainty and canopy interception effects, which may reduce the proportion of seed reaching the soil surface. Despite identical operational settings across fields, application performance differed among sites, suggesting sensitivity of the system to field-specific conditions.

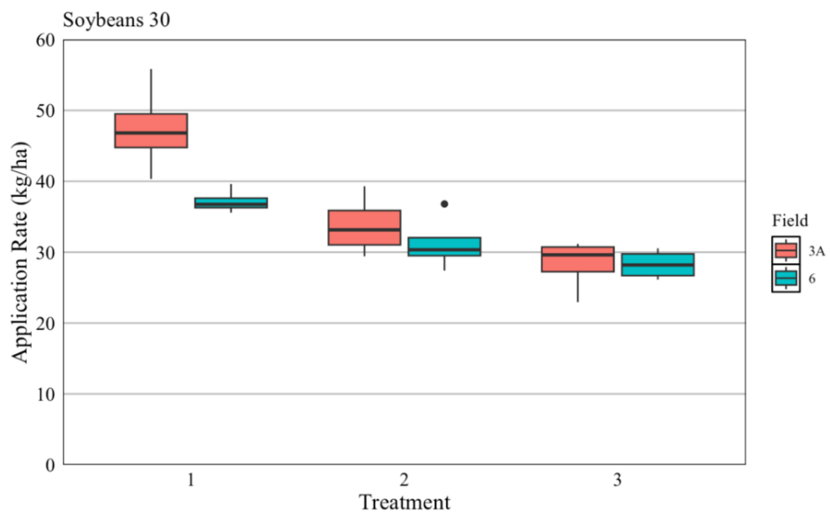
Table 1. Summary of cover crop seed collected over 4 corn fields and 1 soybean field applied when the crop was nearly desiccated or dried prior to harvest. The CV represents the calculated spread uniformity for each field at the time of applying the rye cover crop.

Field	Target Rate (kg ha^{-1})	Mean Applied Rate (kg ha^{-1})	CV (%)	Minimum Applied Rate (kg ha^{-1})	Maximum Applied Rate (kg ha^{-1})
1 -Corn	56.0	48.2	32.2	25.8	70.6
2- Corn	56.0	43.7	17.6	31.4	56.0
3- Corn	56.0	41.5	20.2	29.1	54.9
4- Corn	56.0	26.9	21.3	17.9	37.0
5 - Soybeans	56.0	32.5	24.8	20.2	44.8

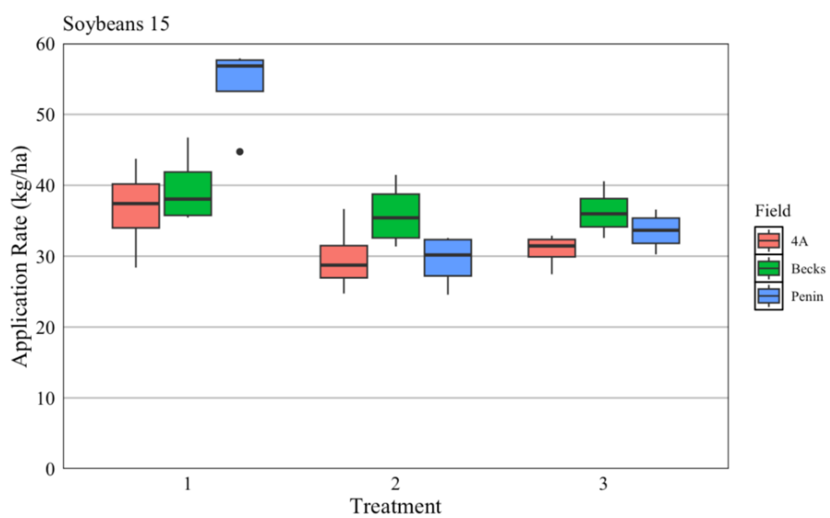
Figure 3 presents a summary of the effective swath mean application rate when cereal rye was applied in corn and the two different row spacings in soybeans over the three different crop conditions (1 = green; 2=50% desiccated, and 3 = 100% desiccated or dry). In the boxplots for each of the crops and row spacings there was at least one canopy conditions that resulted in statistical differences between fields. This could be due to a few different factors that could not be narrowed down, but some trends provided results that matter from a practical standpoint. Figure 3 (a) indicates that there are statistical differences in the application rate collected between fields at the same interseeding canopy conditions and withing fields at the different canopy conditions. Figures 3 (b) and (c), the soybean fields the application rates showed to be slightly higher at the green canopy spreading, while there were also some statistical differences between fields at the same interseeding canopy conditions.



(a)



(b)



(c)

Figure 3. Boxplots of the effective swath mean application rate of cereal rye collected for corn (a), soybeans planted on 76 cm rows (b), and soybeans planted on 38 cm rows (c) by field and treatment. Treatment 1 (green canopy), 2 (50% dry leaves for corn and 50% leaf drop for soybeans), 3 (harvest-ready, 100% dry for corn, and 100% leaf drop for soybeans)

Due to the varying field results statistical analysis was conducted comparing between fields instead of comparing by crop. Using the mean application rates for each field at the three different canopy conditions that were interseeded, Table 2 indicated that there were statistical differences between the different canopy conditions in each field. In the corn fields results varied, but most applications had application rates ranging from 30.0 to 33.4 kg/ha, with the maximum (38.3 kg/ha) and minimum (26.0 kg/ha) occurring during the 50% dry corn canopy. Both of the soybean fields planted on 76-cm row spacing followed similar trends with the green interseeding having the highest application rate, 50% defoliated was slightly less, and 100% defoliated was significantly less. While the 38-cm soybean fields, 4A and Becks, had no statistical differences in application rate between interseeding into different canopies, the green canopy resulted in slightly higher application rates than 50% or 100% defoliated. When interseeding at the green canopy in field Penin, the mean application rate was significantly higher than the 50% defoliated application, and slightly higher than 100% defoliated. The application rates in the soybean fields provided some insight that when interseeding into the green canopy, there was a higher rate of product collected than at 50% or 100% defoliated. The results from the corn fields do differ and could be due to differences in canopy interception. Interception of the cereal rye seed that was observed when colleting pans after spreading did vary as there could be none or multiple seeds on a leaf or in the collar as shown in Figure 4. Further testing to have a better understanding of how the different canopy conditions effect the cover crop deposition to the soil.

Table 2. Effective swath mean application rates for each field at green, 50% dried canopy, and 100% dried canopy with an LSD designation to indicate statistical difference within each field at the different canopy conditions (row-wise comparison).

		Mean Application Rate (kg/ha)		
		-------------------- Canopy Condition --------------------		
Crop	Field	Green	50%	100%
Corn	2CDN	-	38.3 a	30.0 b
	2CDS	-	32.6 a	30.6 a
	4B	32.6 a	26.0 b	33.4 a
Soybeans - 76	3A	47.4 a	33.8 ab	28.3 b
	6	37.2 a	31.2 ab	28.3 b
Soybeans - 38	4A	36.7 a	29.7 a	30.8 a
	Becks	39.6 a	35.9 a	36.3 a
	Penin	54.1 a	29.4 b	33.5 ab

*LSD designations compare mean application rate between canopy conditions within fields (rows).

Figure 4. Corn canopy interception of the cereal rye seeds observed on the leaves and in the leaf collar at 50% dry down.

Comparison of mean application rates among fields within each canopy condition (Table 2) provided additional insight into expected deposition patterns when interseeding into different crops. Under green canopy conditions, soybean fields exhibited either slightly or significantly higher mean application rates than the corn fields. This observation is consistent with the hypothesized canopy “funneling” effect (Figure 5), where the dense soybean canopy may redirect and concentrate cereal rye seed into the inter-row space where collection pans were located.

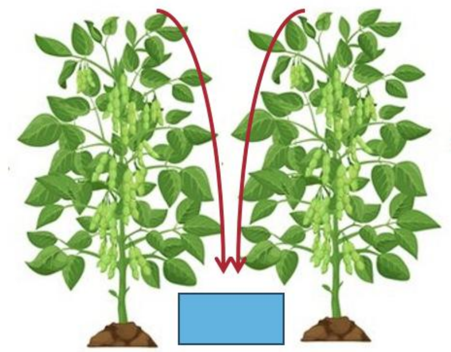


Figure 0. Illustration of the funneling effect of the green soybean canopy, causing the product to be concentrated between the plant rows. In this case, this leads to a higher rate of cereal rye seeds in the collection devices.

Although not presented, coefficients of variation (CVs) representing spread uniformity averaged 22% across all tests, with individual field measurements ranging from 17.6% to 31.2%. These values are provisionally considered acceptable given the limited body of literature evaluating the engineering performance of UAV-based broadcast spreading systems. However, this range of variability highlights the important research gap in understanding the mechanics of seed distribution, including factors influencing spatial uniformity. Overall, the results indicate that spread uniformity with current single-disk drone spreaders is variable and warrants further investigation to improve application consistency.

As canopy senescence progressed, this effect diminished. At approximately 50% canopy dry-down or defoliation, application rates among fields were more variable, with corn fields exhibiting both the highest and lowest mean values, while most other field comparisons were not statistically different. By the time the canopy reached 100% dry-down or defoliation, no significant differences in mean application rate were detected among fields.

These results indicate that canopy structure plays a pronounced role in influencing seed deposition during interseeding when vegetation is green and intact. As the canopy dries and defoliates, its influence on seed redistribution decreases, and deposition becomes more uniform across crop types. Ultimately, once the canopy is fully senesced or defoliated, residual soybean stems and leaf litter appear to have minimal impact on cover crop seed deposition to the soil surface.

Conclusions

Canopy condition significantly influenced cereal rye deposition during drone interseeding. Within fields, significant differences ($p < 0.05$) were observed across canopy conditions, particularly in 76-cm soybean systems where mean application rates were highest under green canopy and decreased with increasing defoliation. In contrast, corn responses were inconsistent, with significant differences in some fields but no uniform trend. Between crop types, soybean fields exhibited slightly to significantly higher ($p < 0.05$) application rates than corn under green canopy, consistent with canopy-mediated redistribution. These differences were no longer significant ($p > 0.05$) at 100% canopy dry-down. Row spacing effects were variable, with significant differences more evident in 76-cm soybeans than 38-cm systems ($p > 0.05$ in most cases). Overall, canopy effects diminished with senescence, indicating improved uniformity when interseeding after partial defoliation.

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