Spray Coverage Analysis of Under-Canopy Robotic Sprayer in Sorghum Crop

Pokharel, P.[1], Sharda, A.[2], Aryal, B.[2], Gadhwal, M.[2]

[1]Department of Biosystems and Agricultural Engineering, University of Kentucky, Lexington, KY

[2]Department of Biological and Agricultural Engineering, Kansas State University, Manhattan, KS

A paper from the Proceedings of the
16th International Conference on Precision Agriculture
21-24 July 2024
Manhattan, Kansas, United States

Abstract. *An under-canopy robotic sprayer system was developed for site-specific pest management in row crops. However, the effect of nozzle type and spray coverage variability at different points within the plant canopy was unknown. The objective of this study was to quantify the spray coverage at multiple locations within the sorghum crop canopy to determine the effectiveness of such robotic systems. The experiments were conducted in a sorghum field in Ashland, Kansas, using XR8001 flat fan and TXVS6 hollow cone nozzle tips under a 276 kPa nominal pressure and a 12 GPA application rate. Three rows of sorghum were selected for the study, with four spots in each row and two plants in each spot. Water-sensitive spray cards were placed at three different heights, two lateral canopy regions, two sides of the leaves, and two sides of the plants, totaling twenty-four sampling locations per plant. The treatments were randomized among all twelve spots for a completely randomized design. The water-sensitive spray cards from the experiments were digitized using a flatbed scanner at 1200 dpi and processed for spray coverage using MATLAB. Statistical analyses were conducted with RStudio. A Generalized Additive Model was formulated to comprehensively examine the influence of these multiple factors on spray coverage. To effectively address the prevalence of zero values in the data set, Tweedie was chosen as the distribution family. ANOVA tests were followed by a post-hoc Tukey pairwise comparison. The results showed that the nozzle type had a significant impact on spray coverage, with the flat fan nozzle showing much higher coverage than the hollow cone nozzle. Spray coverage significantly varied along the canopy height, with greater coverage at the top canopy height followed by the middle and bottom. For flat fan nozzles, the coverage area was significantly different at all three heights, whereas for hollow cone nozzles, only coverage at the top was significantly different. Spray coverage was also significantly different between leaf sides, with the upper side having greater coverage than the lower side. Similarly, the coverage area was significantly different between the spray side and the non-spray side, indicating less spray penetration from one side to the other. Future research should focus on identifying the optimal combinations of input parameters for spray use efficacy in row crops.*

Keywords. *Robotics, Agricultural Sprayer, Pulse Width Modulation, Pest management*

Introduction

Robotic sprayer systems have demonstrated tremendous potential for accurate site-specific chemical application. To confirm their efficiency and effectiveness, these systems must be evaluated within specific crop environments. Specifically, the robotic system's ability to penetrate the crop canopy and uniformly deposit droplets on the target is important. As-applied spray coverage is a key indicator of a sprayer system's efficacy, commonly quantified using water-sensitive paper (WSP) spray cards. In this study, spray coverage at different locations within the sorghum crop canopy was measured to evaluate the coverage variability and sprayer's performance.

Material and Methods

A robotic sprayer system was designed by integrating a robotic platform and a sprayer system for chemical application in row crops, specifically targeting aphids in sorghum crops (Pokharel, 2021). The platform was a 4-wheel drive, differential steering rover driven by battery-powered electric motors, capable of maneuvering between 76.2 cm row crop spacing. The sprayer system consisted of a 75.7-liter liquid tank and two vertical booms at the rear end of the platform, each equipped with three PWM solenoid valves for nozzle control.

Figure 1: Robotic Sprayer System

The performance of the robotic sprayer was tested by conducting an experiment in a sorghum field in Ashland, Kansas. The experiments were designed to evaluate performance under two different nozzle tips and to assess variability in spray coverage at various locations within the crop canopy. Specifically, a hollow cone nozzle tip (TXVS6) and a flat fan nozzle tip (XR801) were used. Three crop rows were selected, with four spots in each row and two plants in each spot. WSP spray cards measuring 2.54 cm × 2.54 cm were placed at three different heights (top, middle, and bottom), in two lateral canopy regions (inner and middle), on two sides of the leaves (upper and lower), and on two sides of a plant (spray side and opposite side), for a total of 24 cards per plant. The spray cards were clipped to sorghum leaves to match their natural orientation. The experiments were conducted by remotely operating the robotic sprayer at 0.45 m/s with a 12 GPA application rate under a 10 Hz solenoid frequency and 276 kPa nominal pressure.

The WSP spray cards were dried for about 10 minutes before being placed in Ziplock bags. The cards were then digitized using a flatbed scanner (ScanJet Pro 3500 f1, HP Inc., Palo Alto, CA, USA) at 1200 dpi. The spray cards were processed in MATLAB (R2019a, MathWorks Inc., Natick, MA, USA) to remove the borders and shades, and were assigned a value of either 0 or 1 based on pixel intensities. The spray coverage was then calculated as the ratio of the number of droplets exposed to water to the total number of droplets. Statistical analyses were performed using

RStudio (Version 4.3.1, RStudio IDE, Boston, MA, USA). To thoroughly investigate the impact of various factors on spray coverage, a Generalized Additive Model was developed (Equation 1). The Tweedie distribution was selected to effectively handle the high frequency of zero values in the dataset. ANOVA tests were then carried out, followed by post-hoc Tukey pairwise comparisons. This information was then used to evaluate the impact of nozzle tips on coverage and the variability in coverage at different locations within the crop canopy.

$$y_i = \beta_0 + \sum_{i=1}^{5} \beta_i \ x_i \ + \sum_{i=1}^{4} \ \sum_{j=i+1}^{5} \beta_{ij} \ x_i x_j \ + \epsilon_i \qquad (1)$$

Results and Discussion

The ANOVA tests reveal compelling evidence that nozzle type significantly influences spray coverage, highlighting its importance in optimizing the spray application process. Similarly, spray coverage exhibits notable variations across different plant heights, leaf sides, and plant sides, indicating substantial variability within the crop canopy. These findings were derived after accounting for the effects of other variables included in the model.

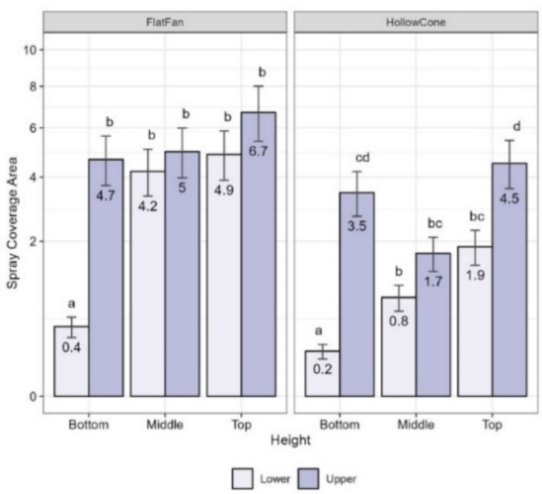

Figure 2: Spray coverage at three plant heights and two leaf surfaces using flat fan and hollow cone nozzle tips.

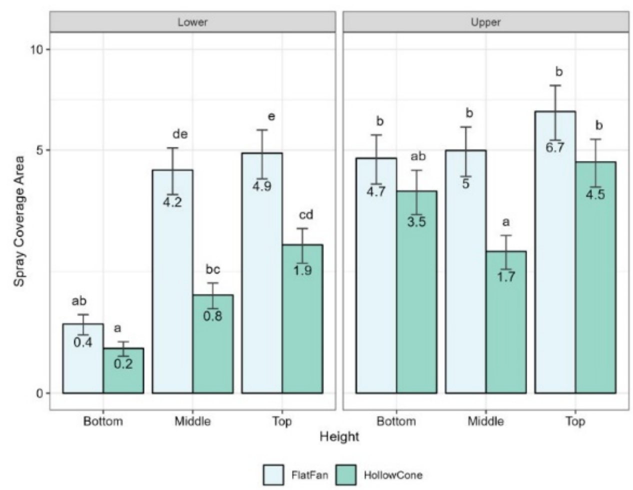

Figure 3: Spray coverage on the lower and upper leaf surfaces at all three plant heights using flat fan and hollow cone nozzle tips.

It was found that the mean spray coverage for a flat fan is 2.4 times higher than that of hollow cone nozzle tips. This disparity is attributed to the finer droplets produced by hollow cone nozzles, which are more susceptible to drifting in the field environment. Notably, spray coverage varies significantly along the canopy height, with greater coverage observed at the top canopy height followed by the middle and bottom. For flat fan nozzles, coverage at the top and middle is significantly higher than at the bottom, while for hollow cone nozzles, coverage at the top surpasses that at the middle and bottom. Interestingly, there is no significant difference in spray coverage between the two lateral canopy regions. Moreover, spray coverage significantly differs between leaf sides, with both nozzle types demonstrating higher spray coverage in the upper part of the leaf compared to the lower part. Additionally, the statistical analysis unveils a significant interaction between nozzle type and plant side, suggesting that the effect of nozzle type on coverage varies between the spray side and non-spray side. Specifically, the flat fan nozzle tip is inferred to offer superior canopy penetration compared to the hollow cone nozzle tips.

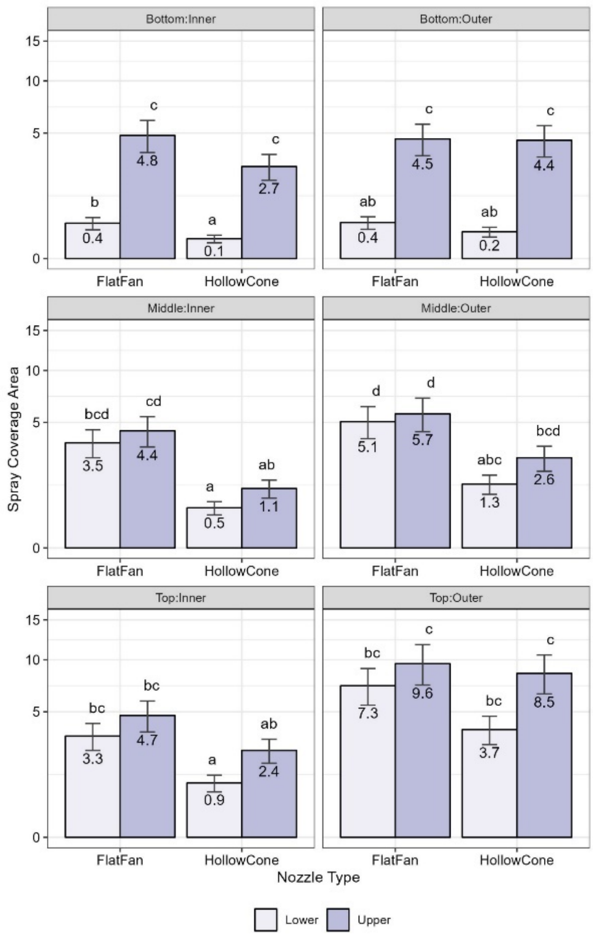

Figure 4: Spray coverage on the upper and lower leaf surfaces for both the inner and outer canopy regions, using flat fan and hollow cone nozzle tips.

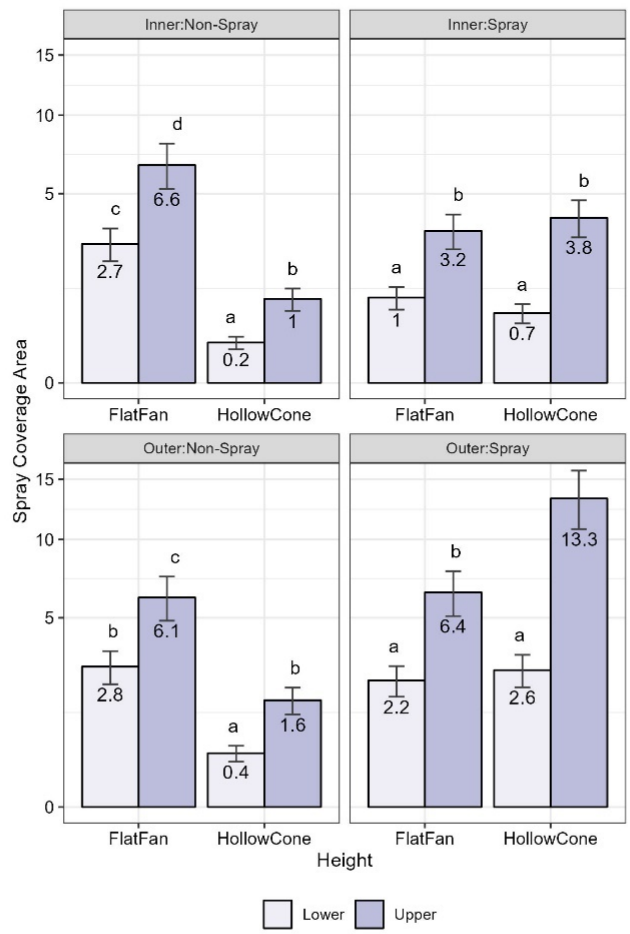

Figure 5: Spray coverage on the upper and lower leaf surfaces for both the spray and non-spray sides, using flat fan and hollow cone nozzle tips.

Conclusions

The preliminary findings indicate a notable impact of nozzle type on spray coverage, alongside significant variability within the crop canopy. This underscores the importance of testing robotic systems under diverse conditions, including varying application rates, emitter types, and mounting conditions. Such comprehensive testing is essential for identifying optimal application strategies to enhance the effectiveness and efficiency of these robotic systems in row-crop environments.

Acknowledgments

This work was supported by the USDA-NIFA, under the NSF National Robotics Initiative Program, under grant number 2019-67021-28996.

References

Pokharel, P. (2021). *Design, Development, and Verification of a Robotic Spraying System and Study on the Application Strategies for Coverage Optimization during Site-specific Chemical Application.* Kansas State University.