Field Validation of *Airblast Spray Advisor* Decision Support Web App for Citrus Applications

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Abstract.

Field conditions influencing the effectiveness of pesticide application in orchard and vineyard production systems are complex. As a result, growers and pesticide applicators grapple with how to make the right decisions for setting up the sprayer that will lead to the most efficient and effective outcomes. Airblast Spray Advisor, a decision support web app built on MATLAB was designed to assist with planning and evaluation of such applications when using airblast sprayers. It receives values of application, tree, orchard, and weather parameters and variables as user input and runs a field-validated spray deposition model to estimate target canopy deposition, ground fallout, and potential drift. Multiple runs of the app give the user an indication of which adjustments in application rate will produce the best possible on-target canopy deposition at the intended application rate. Preliminary end user evaluation of the decision support tool indicated that 52% were inclined to adopting it for use in their operations. To provide additional confidence in the predictions and to further promote the adoption of Airblast Spray Advisor by the intended end users, the web app's output was validated against data from a field experiment conducted in a commercial citrus orchard in California. The complete factorial study consisted of varying air assistance, travel speed, nozzle size, and number of nozzles to apply a pyranine fluorescent dye solution in 16 trial runs and evaluating canopy spray deposition by fluorometry. The resulting application rate ranged from 496 to 9,719 L/ha, about 192% extension beyond the range used in a previous field validation of the spray deposition model. Sprayed leaf samples were collected from three trees (replications) for each application rate. Least square mean deposition values from the field experiment ranged from 12 to 307 ng/cm^2 whereas canopy deposition predictions by the web app ranged from 215 to 636 L/ha.

Comparing relative deposition values between the web app and the field data in the current study revealed a significant underprediction of the web app at application rates greater than the 3,323-L/ha maximum tested in the previous validation. A closer assessment of the spray deposition model suggests that the underprediction at higher application rates could be likely due to the implementation of retention capacity a tree canopy parameter, in the model. Future studies will consider improving the implementation of retention capacity within the model to produce more reliable predictions at higher spray application rates in order to extend the applicability of the decision support tool.

Keywords.
Decision support system, citrus orchard, canopy deposition, simulation, prediction, efficiency.

Introduction

Despite recent advancements in commercial precision air-assisted spraying technologies (a.k.a. smart sprayers), adoption rates are very slow. This implies that a majority of growers still use non-precision sprayers that they are comfortable with, but which require substantial operator involvement to ensure that spray application is optimized. Even with smart sprayers, an awareness of best practice will ensure that they will be incorporated into sprayer setup and calibration. Otherwise, pest control may be jeopardized by inefficient and/or ineffective application, i.e., low coverage and deposition versus high drift and ground losses.

Field conditions influencing pesticide application effectiveness in orchard and vineyard production systems are complex. These include tree characteristics, orchard design/condition, and weather parameters. As a result of the intricate interaction of these with application parameters, identifying the best application settings for specific situations can be difficult for growers, pest control advisers, and pesticide applicators. And, because the basic phenomena of spray dispersion, deposition, and drift in orchards and vineyards are similar regardless of the technology used, both precision and non-precision sprayers alike are subject to the influence of the complex interactions to varying extents.

Orchards (and vineyards) vary by crop type, row spacing, and tree spacing within row. Within the same orchard, trees may vary by height, canopy size, and foliage density. Moreover, the exact weather conditions at different spray application times are not replicable. The implications of the complicated interaction of these parameters with the chosen application setting (including nozzle configuration, level of air assistance, and travel speed) are that even given extended field experience, it is difficult to closely determine the outcome of a spray deposition by oneself without using a tool. Therefore, the need for spray decision support systems to help identify best practices for optimizing spray application outcomes in orchard and vineyard persists.

The outcome of an application comprises the portion of the applied spray that desirably deposit on the target, as well as the portions that undesirably deposit on the ground and drift outside the application site. As a balanced system, these portions sum to unity or 100% of the applied amount. Conventional airblast sprayers discharging spray continuously unavoidably waste spray applied over shorter trees, under higher canopies, between trees within the same treatment orchard. Conversely, smart sprayers utilizing canopy sensing technology with individual nozzle or sectional boom control may save as much spray as possible in these orchard areas. However, considering the spray directed to just the target canopy, its dispersion and interaction with the canopy components remain the same under equal air-assistance. Thus, after accounting for savings in spray volume, predicting spray deposition on the target canopy will lead to the same results.

Considering the convoluted interactions influencing air-assisted sprays, a mechanistic model was developed to predict spray deposition in citrus applications (Larbi & Salyani, 2012b, 2012c, 2013). Field validation of the model in 2012 covered application rates from 192 to 3,323 L/ha in a Florida orchard. The model was implemented in the *CitrusSprayEx* expert system built in MATLAB which simulates an application based on user inputs to predict canopy deposition, ground fallout, and potential drift (Larbi & Salyani, 2012a). Recent further development of *CitrusSprayEx* has led to the new *Airblast Spray Advisor* decision support web app with an improved graphical user interface and accessibility (Larbi, 2024a).

Preliminary end user evaluation of *Airblast Spray Advisor* decision support tool indicated that 52% were inclined to adopting it for use in their operations. To provide additional confidence in the predictions and to further promote adoption by the intended end users, this paper discusses the validation of *Airblast Spray Advisor* utilizing a field experiment conducted in a commercial citrus orchard in California. The results will provide insight into modifications that will improve the accuracy and utility of the web app.

Materials and Methods

Field Validation Data Generation

To validate the MATLAB-based spray decision support web app *Airblast Spray Advisor*, a field study in citrus is presented. The experiment is briefly described subsequently; a more detailed description is provided by Larbi (2024b). The complete factorial study consisted of varying air assistance, travel speed, nozzle size, and nozzle configuration to apply a pyranine fluorescent dye solution in 16 trials. Two levels of air assistance were achieved using two conventional airblast sprayers (Air-O-Fan, Reedley, California, USA): a single-fan D-39 sprayer (henceforth, single-fan sprayer) and a double-fan D-2/40 sprayer (henceforth, double-fan sprayer). The sprayers traveled at either 1.6 or 4.8 km/h. Two disc-core nozzle sizes were used (TeeJet Technologies, Wheaton, Illinois, USA): D3-25 and D6-45. Nozzle configuration comprised either one or two rows per side of sprayer with nine nozzles per row. A view of spray application in progress inside orchard during the experiment is shown in Figure 1. The application setting combinations resulted in application rates ranging from 496 to 9,719 L/ha (Table 1); air assistance did not affect application rate. This range extends about 192% beyond the range used in the original field validation (≤3,323 L/ha) of the spray deposition model performed by Larbi & Salyani (2012c).

Table 1. Summary of application rates achieved in different spray treatments.

Spray Treatment [1]			Application Rate (L/ha)
Travel Speed (Km/h)	**TeeJet® Disc-Core Nozzle Size**	**Number of Open Nozzles per Side**	
1.6	D3-25	9	1478
1.6	D3-25	18	2956
1.6	D6-45	9	4864
1.6	D6-45	18	9719
4.8	D3-25	9	496
4.8	D3-25	18	982
4.8	D6-45	9	1618
4.8	D6-45	18	3236

[1] Treatments were replicated using an Air-O-Fan D-39 sprayer and a D-2/40 sprayer.

After applying the spray treatments, three random trees (replicates) were selected for sampling in each tree block corresponding to a treatment. Sprayed leaf samples were collected at three canopy heights (H1 = 1.2 m; H2 = 1.7 m; H3 = 2.2 m) and four canopy depths (D1 = 0 m; D2 = 0.6 m; D3 = 2.7 m; and D4 = 3.4 m), placed in labeled plastic sample bags, and temporarily stored in an ice chest in the field before transporting to the lab to be stored in a refrigerator while awaiting analysis.

Figure 1. Spray application in progress inside orchard during the experiment.

The trees were 3.7 m tall with canopy diameter of 3.4 m on average and were planted at row spacing of 5.5 m and tree spacing of 2.4 m. The foliage density was visually determined by experience to be medium density. Sixteen tree blocks each consisting of six trees were sprayed according to the application rate treatments. Sprayed leaf samples were collected after each trial from four canopy depths and three sampling heights as footnoted in Table 1. Leaf samples were obtained from three trees (replications) for each application rate treatment, placed in labeled sample bags, and transported to the lab in coolers. The samples were analyzed in the lab by fluorometry (Larbi, 2022) to generate spray deposition data.

App Simulation Data Generation

Airblast Spray Advisor web app was designed to assist with planning and evaluation of pesticide application in orchard and vineyard production systems when using airblast sprayers. It receives values of application, tree, orchard, and weather parameters and variables as user input and runs a field-validated spray deposition model (Larbi & Salyani, 2012b, 2012c, 2013) to estimate target canopy deposition, ground fallout, and potential drift. Multiple runs of the app give the user an indication of which adjustments in application rate will produce the best possible on-target canopy deposition at the intended application rate.

Eight simulation runs of *Airblast Spray Advisor* were performed, varying input values to mimic the field trials conducted with the single-fan sprayer. The app output canopy deposition, ground fallout, and potential drift in L/ha as well as in percentage of the application rate (%AR). However, since only canopy deposition was measured in the field experiment, only canopy deposition as an output was of concern in this paper. The deposition quantities represent the amounts obtained from the entire orchard as defined by user inputs and were neither evaluated at canopy depth scale nor at canopy height scale.

Comparison of Simulation and Field Data

As *Airblast Spray Advisor*'s simulation is based on a single-fan sprayer, Rears Power-Blast sprayer, the app's simulation data was validated with the field data from only the single-fan sprayer. Since the final field data was in ng/cm^2 but the app's output is in L/ha (and %), the corresponding datasets were transformed into relative deposition, with reference to the deposition value obtained with the lowest application rate, for appropriate comparison of trend. Relative deposition (a unitless quantity) from the app and the field were compared by evaluating the following metrics: bias, mean squared error (MSE), root mean squared error (RMSE), mean

(RRMSE), RMAE, modeling efficiency (EF), and correlation coefficient (r). The values obtained jointly gave an indication of the closeness of *Airblast Spray Advisor* app predictions to the field data.

Results and Discussion

Results of the field experiment, app simulation, and validation are presented subsequently.

Field Validation Data Generation

Overall, spray deposition on the target canopies decreased with increasing canopy depth (Figure 2), which conforms to observations of Farooq & Salyani, (2004) and Salyani & Hoffmann (1996). The decrease was more linear for the single-fan sprayer across the trunk axis, specifically within the first three depths. However, deposition did not significantly differ between the last two depths (2.7 and 3.4 m) for both the single-fan and double-fan sprayers despite the double-fan sprayer showing significantly less deposition values at all canopy depths. Since the level of spray deposition is an indication of the availability of both spray and leaves to capture the spray, it can be inferred that there was less spray availability overall in the case of the double-fan sprayer. This is possibly due to the combination of spray liquid runoff from leaves and spray having been blown through the medium-foliage canopies from excessive air-assistance. Of a critical note is the large dip in deposition at the sprayer nearside canopy boundary (0.0 m depth) when the sprayer switched from the single-fan sprayer to the double-fan sprayer, which is most likely the result of high rate of leaf runoff.

Combining spray deposition at the different sampling heights indicated no significant change over height for both sprayers (Figure 3). However, like observations over canopy depth as discussed above, overall deposition from the single-fan sprayer was significantly greater than that from the double-fan sprayer. The difference is mainly influenced by deposition values at the sprayer near side canopy depths (0.0 and 0.6 m) which were about 7-fold those at the far side canopy depths (2.7 and 3.4 m). A summary of mean canopy deposition with respect to spray application rate (Figure 4) establish that deposition increased with increasing application rate (dose) over the entire range of application rate. Furthermore, deposition obtained with the single-fan sprayer was consistently greater than that obtained with the double-fan sprayer over this range. A more complete discussion of the results from the experiment can be found in Larbi (2024b).

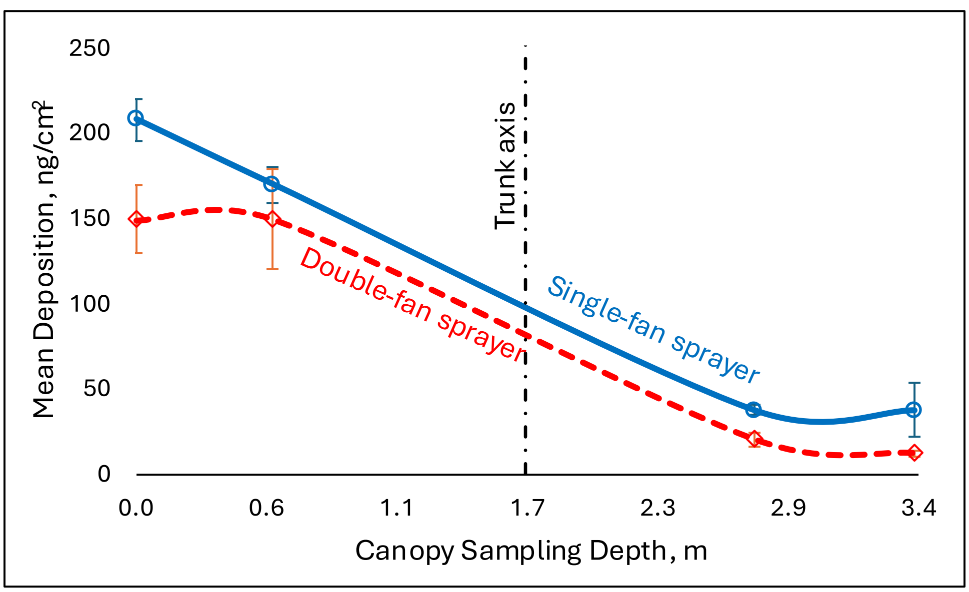

Figure 2. Overall mean deposition for all treatments over canopy depth.

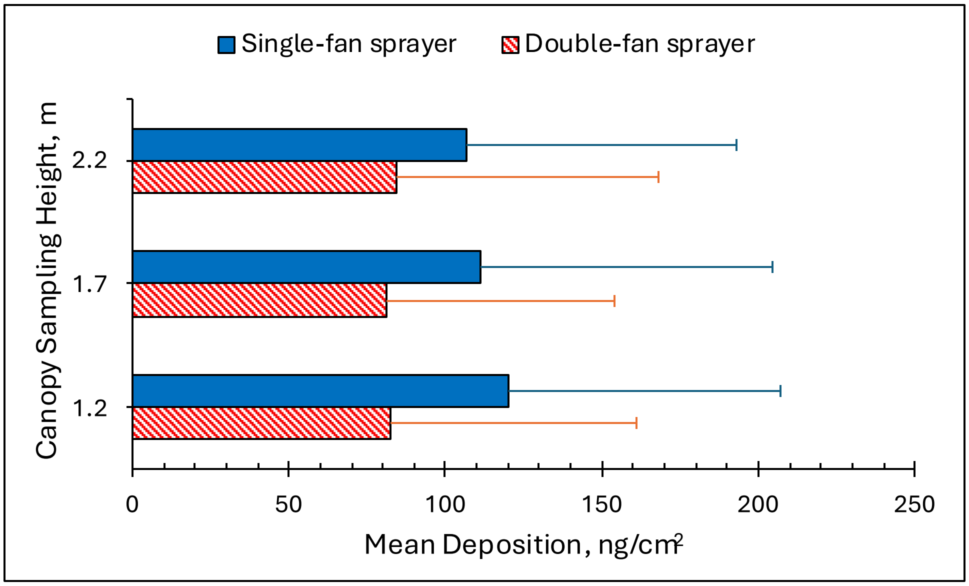

Figure 3. Overall mean canopy deposition for all treatments over sampling height.

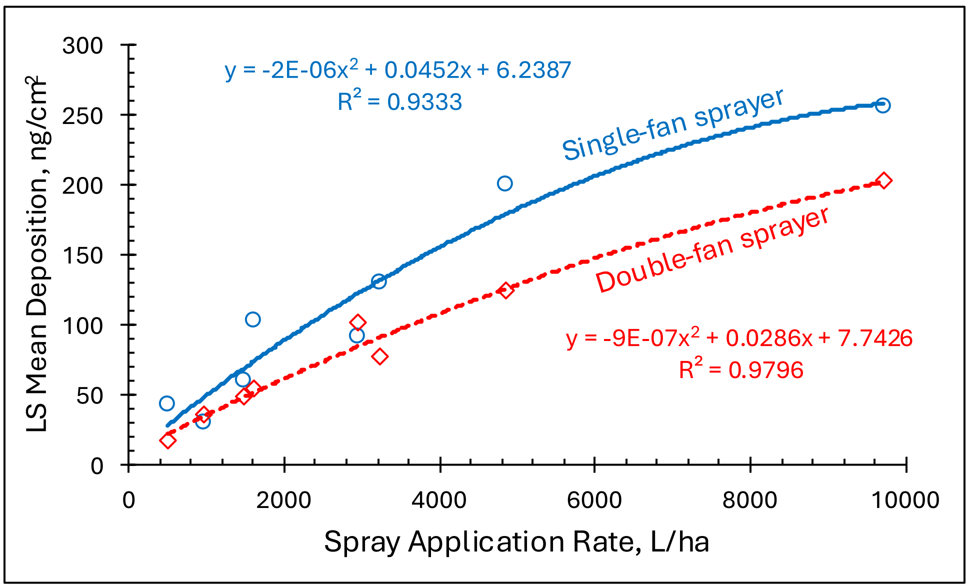

Figure 4. Mean canopy deposition measured from different spray application rates.

Simulation Results

Figure 5 shows plots of mean predicted canopy deposition in both L/ha and %AR over the range of spray application rate. It generally shows an increasing trend in deposition up to application rate of 3,236 L/ha, similar to the measured field data. However, unlike the field data, predicted value stall after 3,236 L/ha. Predicted deposition in %AR had an opposite trend to that of predicted deposition in L/ha, which is consistent with field observations of (Cunningham & Harden, 1998). The overall outlook is that the accuracy of deposition may be limited to under application rate of 3,236 L/ha.

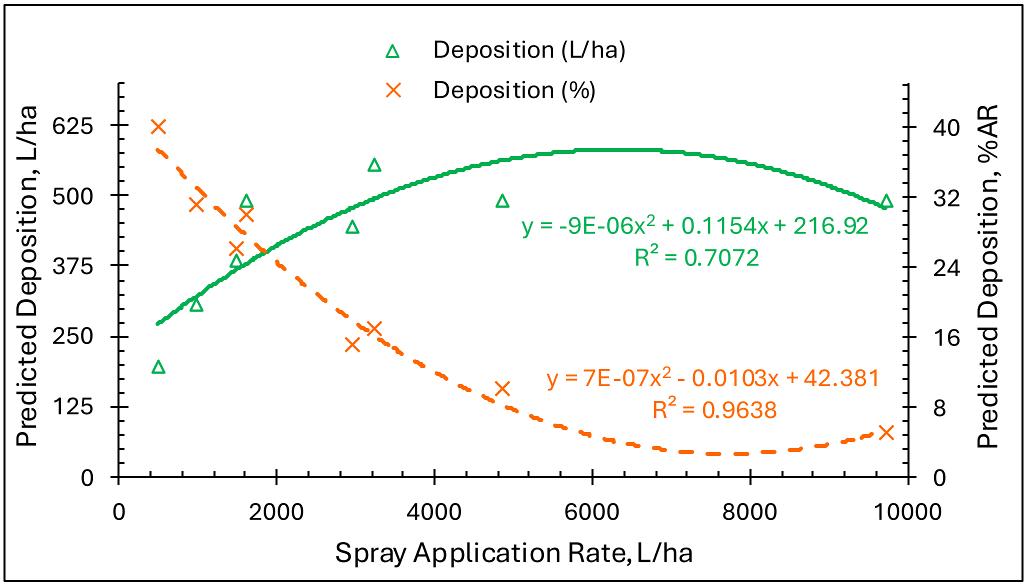

Figure 5. Mean predicted canopy deposition over range of spray application rates.

Comparison of Simulation and Field Data

Measured relative deposition ranged from 0.67 to 6.70 while predicted relative deposition ranged from 1.0 to 2.82. A superimposition of the measured and predicted relative deposition appropriately scaled for visual comparison and computed residuals comparing them are shown in Figure 6. Within the chosen scales, the logarithmic trend lines are similar indicating that further transformation of the data can bring the two datasets closer in resemblance. The residual plot shows amplification of errors indicating substantial underprediction at application rates of 4,864 and 9,719 L/ha. Examining the one-to-one plot and residual plot in Figure 7, one can infer that the app's prediction fell short beyond measured relative deposition of about 3.0. This is an indication of a limiting component in the spray deposition model run by the app. A closer assessment of the model suggests that the underprediction at higher application rates could be likely due to the implementation of retention capacity of leaves, which is a tree canopy parameter within the model.

A summary of the measures of agreement between the predicted and measured relative deposition is provided in Table 2. These were computed using both data for application rate range ≤3,237 L/ha (to compare with and confirm results of original model validation) and data for the entire range ≤9,719 L/ha. Obviously, the latter gave poorer results overall given the above mentioned underprediction. However, for the data corresponding to application rate range ≤3,237 L/ha, while the results do not very closely compare with previously reported bias of -0.03, RMSE of 0.23, and r of 0.9214, the present EF of 67% is even better than the 61.3% reported earlier. This is an indicator that *Airblast Spray Advisor* web app is substantially a better predictor of the measured data than using the average of the measured data. For application rate range >3,237 L/ha, further work is needed to finetune the estimates for leaf retention capacity to improve the accuracy of predictions.

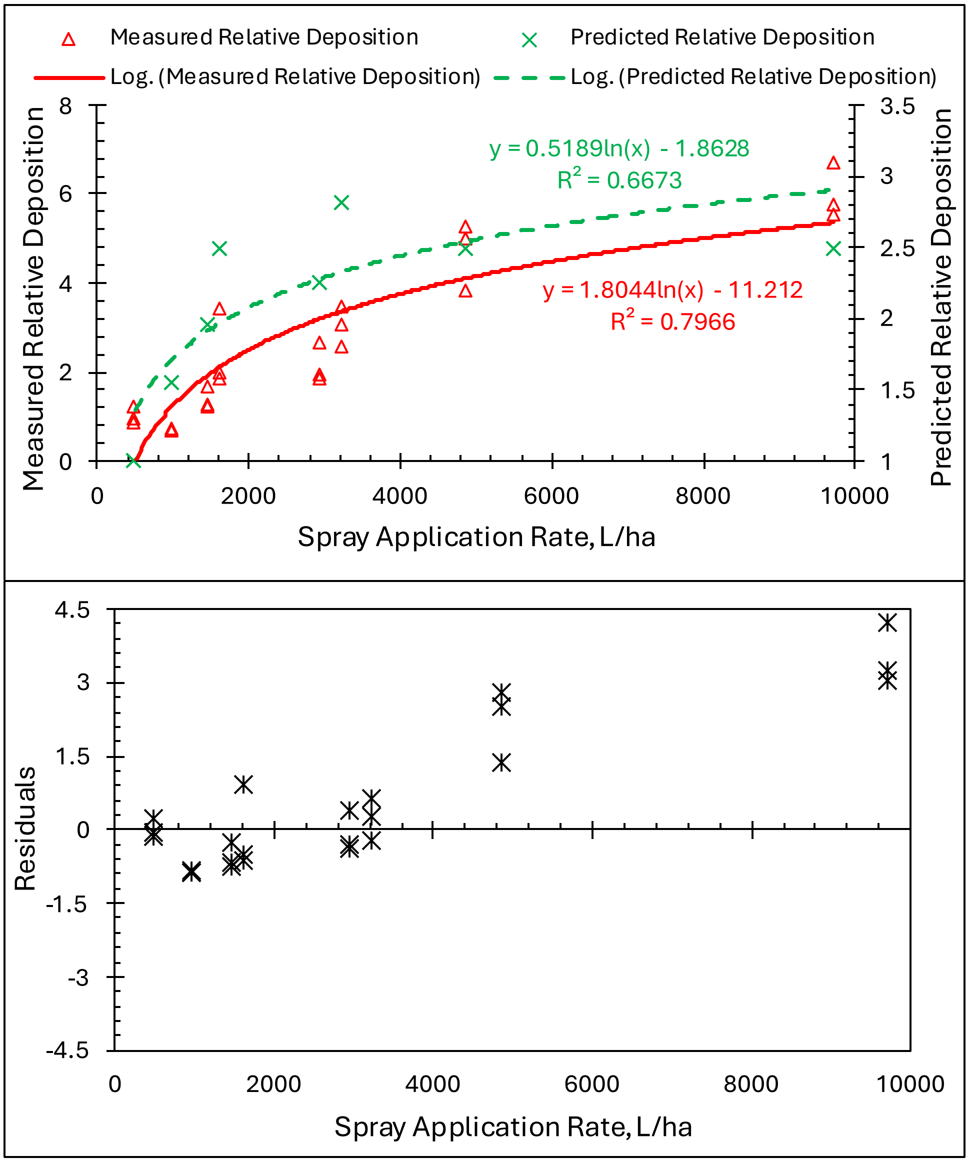

Figure 6. Measured and predicted relative canopy deposition (top) and residuals (bottom) versus application rate.

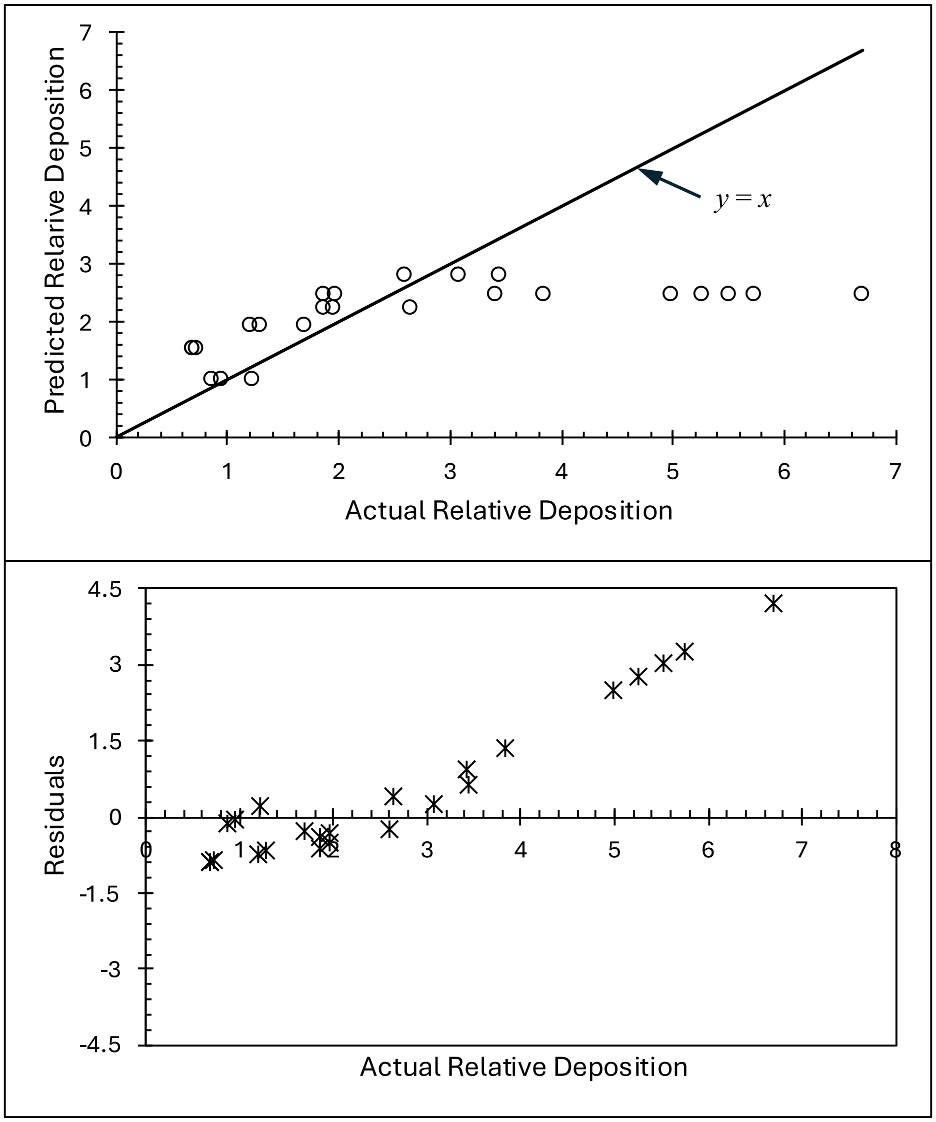

Figure 7. Predicted relative deposition (top) and residuals (bottom) versus measured relative deposition.

Table 2. Measures of agreement between measured and predicted values (Wallach, 2006).

Measure	Equation	Application Rate	
		≤3,237 L/ha	≤9,719 L/ha
Bias	$Bias = \frac{1}{N}\sum_{i=1}^{N}(Y_i - \hat{Y}_i)$	-0.234	0.538
Mean squared error (MSE)	$MSE = \frac{1}{N}\sum_{i=1}^{N}(Y_i - \hat{Y}_i)^2$	0.325	2.461
Root mean squared error (RMSE)	$RMSE = \sqrt{MSE}$	0.570	1.569
Mean absolute error (MAE)	$MAE = \frac{1}{N}\sum_{i=1}^{N}\lvert Y_i - \hat{Y}_i\rvert$	0.500	1.088
Relative root mean squared error (RRMSE)	$RRMSE = \frac{RMSE}{\bar{Y}}$	0.260 (26%)	0.588 (59%)
Relative mean absolute error (RMAE) [a]	$RMAE = \frac{1}{N}\sum_{i=1}^{N}\frac{\lvert Y_i - \hat{Y}_i\rvert}{\lvert Y_i\rvert}$	0.404	0.433
Modeling efficiency (EF)	$EF = 1 - \frac{\sum(Y_i - \hat{Y}_i)^2}{\sum(Y_i - \bar{Y})^2}$	0.670 (67%)	0.222 (22%)
Correlation coefficient (r)	$r = \frac{\sum(Y_i - \bar{Y})(\hat{Y}_i - \bar{\hat{Y}})}{\sqrt{\sum[(Y_i - \bar{Y})^2]\sum\left[(\hat{Y}_i - \bar{\hat{Y}})^2\right]}}$	0.756	0.656

[a] Measured values equal to zero not included in calculation.

Conclusion

To provide additional confidence in the predictions of *Airblast Spray Advisor* decision support web app and to further promote its adoption by the intended end users – particularly growers, pest control advisers, and pesticide applicators – the app's output was validated against data from a field experiment. The app was able to accurately capture trend in the data for spray application rate range up to 3,237 L/ha. However, beyond 3,237 L/ha, the app underpredicted. This is an indication of a limiting component in the spray deposition model run by the app. A closer assessment of the model suggests that the underprediction at higher application rates could be likely due to the implementation of retention capacity of leaves, which is a tree canopy parameter within the model. Future studies should consider improving the implementation of retention capacity within the model to produce more reliable predictions at these higher spray application rates in order to extend the applicability of the decision support tool.

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