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Summary of Findings

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Integrated Crop Agronomy Cluster

Spray drift management under changing operational requirements

Introduction

This project's aim was to gain further understanding of the operational parameters affecting pesticide drift on the Canadian Prairies. High-clearance sprayers have become large machines that are operated at relatively high speed. A better understanding of their aerodynamic properties is required to maintain the high productivity of large sprayers while minimizing spray drift.

New chemical formulations and increasing crop diversity require the community to develop scientific data on the impact of operational parameters on spray drift as well as crop sensitivity to drift. This project combines computational fluid dynamics (CFD) modeling with field trials to enhance our understanding of the drift potential created by the conditions under which the spray is released. The impact of the airflows resulting from the movement of the sprayer are considered. In relation to field trials, multiphase CFD modeling is being developed to investigate the behaviour of the spray as affected by the forces (airflows) that exist when it is released from the nozzles. Data were generated to establish the physiological response of selected crops to simulated herbicide drift in field trials.

The project builds on a combination of experimental field data and numerical modeling. Agronomy experiments, drift trials, and sprayer wake characterization have generated experimental data in field conditions. Multiphase CFD modeling further describes the behaviour of the wake of the sprayer as well as the near-field drift characteristics of the spray. The project ultimately sought to generate important information on how crops are affected by herbicide drift, as well as how drift from the operation of modern high-clearance sprayers can be managed.

The project objectives were defined as follows:

1. Develop multiphase CFD models to simulate spray drift. This included field trials to characterize the wake structure expected behind the sprayer.

2. Quantify pesticide drift from a high-clearance, self-propelled sprayer as a function of i) travel speed and ii) boom height.
3. Identify the physiological response of selected crops (canola and non-dicamba traited soybeans) to simulated herbicide drift.

Objective 1

The first objective of the project was to characterize the wake structure behind a sprayer and develop a model to simulate and predict spray drift. The effect of high-clearance sprayer operational choices, namely travel speed and boom height, were thoroughly investigated using a variety of numerical and experimental methods.

Field experiments conducted in both 2019 and 2020 had ultrasonic anemometers mounted to a John Deere 4830 sprayer. While the sprayer was driven through the field under varying operational conditions (speed, boom height, travel direction relative to ambient wind), the anemometers were used to measure airspeed and direction at several locations within the wake of the sprayer. This data was analyzed to develop a characterization of the wake around and behind the sprayer. A journal article was published detailing this work (Paulson et al., 2022)

Air-only CFD models were developed and the experimental characterization of the sprayer wake helped to improve the accuracy of the machine-scale CFD model. Master thesis by Gagnon (2022) details much of the work on development of the air-only CFD model.

Several areas of the wake were investigated to further understand flow characteristics and the response to changes in operational variables. Results from both measurement and modeling showed that speed was a major contributor to detrimental wake characteristics. Depending on the area of the wake, the benefit of reducing boom height varied in magnitude. Turbulence and the direction of mean air velocity in the wake behind the sprayer indicated that drift-promoting turbulent mixing and upward components of air velocity likely contribute to the drift potential of the machine.

Both the wake data and machine-scale CFD models provided sets of reasonable boundary conditions for spray droplet simulations where particle trajectories could be tracked. From these models, the potential of drifting spray droplets could be studied further. Machine-scale models that include droplets were computationally prohibitive; however, a subsystem level spray droplet model provided insight into the mechanisms that affect in-field spray drift.

Detrimental features in the wake were identified for a variety of operating scenarios using air-only CFD simulation. The inclusion of multiphase droplets in CFD simulations provided a path to understanding when the magnitude of a given flow feature is large enough to promote near-field drift.

Several key observations and conclusions were derived from the combination of experimental and numerical activities that focused on both characterizing the wake of a high clearance sprayer in multiple operational configurations and predicting the movement of spray droplets in the context of wake features.

Wake features are more detrimental in the context of pesticide drift with a higher boom height. These features increased the height of droplets downstream of the sprayer. Furthermore, in the presence of a crosswind, small droplets (<100µm) remained indefinitely suspended in much of the wake downwind of the sprayer. This behaviour was also documented in other literature. This reinforces the practice of selecting nozzle tips that result in the most course spray as possible within product recommendations.

Droplets in the wake of the spray tractor, particularly downstream of the wheels, were susceptible to being influenced by the airflow patterns of the wake. Limiting the injection of smaller droplets into this region of the wake through nozzle selection is suggested. While the effect of selecting courser-than-recommended nozzle tips for nozzles behind the tractor was not evaluated in this work and thus not endorsed, future experiments (numerical models, field deposition trials, and field efficacy trials if warranted) should be considered for high risk/high impact application combinations.

Both experimental measurements and simulation results highlighted various opportunities to reduce detrimental wake features through improvements in sprayer design and geometry. Although some of the following aerodynamic performance observations are specific to the sprayer model simulated and tested, they are only intended to be illustrative of the effect of the design feature and not an opinion or endorsement of the model or brand:

- Increased turbulence and wake size was present downstream of the vertical flat bar structural elements of the boom. Additionally, the wider dimension of the cross-section was presented to the flow.
- For geometry of this particular boom (but not uncommon, generally, across many sprayer models), most airflow blockages, such as structural members and non-structural components (hydraulic hoses, various brackets), were located in the bottom half of the vertical profile of the boom. Considering the presence of the wake downstream of these elements that was observed in the CFD results, it is suggested that a less aerodynamically disruptive arrangement of components and structural members is possible. Intentional streamlining of bluff body components would further reduce their impact on the wake of the boom.
- The complex patterns behind the sprayer tank are predominantly due to the unguided infill of the air downstream of the tank. A configuration of elements that result in a more streamlined infill of air in this region of the wake would help to bring order to the chaotic airflow that was generally viewed as detrimental to spray drift performance.
- The boom height influenced the direction of the vertical velocity component of the airflow near the boom behind the tractor; this was due to a suspected interaction with airflow from beneath the tractor. Further study to eliminate this sudden change in the flow field with boom height would result in more predictable performance.
- Air flow around, between, and behind the tires of the sprayer tractor was complex and detrimental to the wake characteristics with regards to spray drift. The literature indicated that tire mud guards are influential on the downstream flow field. Further work to streamline flow in this region would reduce the potential of spray drift.

The results of the moving boom CFD, while preliminary, suggest that boom motion may have a notable effect on the wake, including the magnitude of the upward velocity in the wake near the nozzles. It is anticipated that boom height control systems would help to reduce vertical boom motion, and thus reduce its potential influence. Reducing dynamic inputs via reduced travel speed through rough and undulating terrain is ultimately one of the most effective operational choices to reduce the vertical velocity of the boom.

Atmospheric turbulence effects were not present in the model; therefore, the first-order impact of atmospheric turbulence levels on the development of sprayer wakes was not studied. Furthermore, it was assumed that their second-order impact was to increase the risk of drift, particularly when more spray volume was present at higher elevations and greater distances downwind. Additionally, evaporation was not modeled in the simulations despite it worsening the risk of drift. Droplets that remained airborne further downwind were assumed to be at a greater risk of size reduction, and therefore drift risk, due to evaporation.

Objective 2

The second objective of the project was to quantify pesticide drift from a high-clearance, self-propelled sprayer as a function of i) travel speed and ii) boom height. Experimental field trials were conducted to assess drift under different sprayer operational conditions, utilizing fluorimetry and plant assessments. The trials were repeated twice at different sites (one in 2019 and one in 2020) in fields of Round Ready (non-dicamba traited) soybeans.

In both 2019 and 2020, a single spray pass of dicamba (XtendiMax with VaporGrip Technology) was applied in the soybean field perpendicular to the wind direction. Two different sprayer operational parameter treatments were used: i) fast travel speed and high boom height and ii) slow travel speed and low boom height. The spray mixture contained dye so that spray movement could be quantified using fluorimetry. On-swath and downwind deposits were captured using an array of 150 mm diameter petri plates and vertically arranged drinking straws at 1, 2, 5, 10, 20, 40, 80, and 160 m downwind in three parallel rows, 25 m apart. On-swath deposits were measured using an array of petri plates placed in six rows of three on the spray swath.

It was found that soybeans exhibited dicamba exposure symptoms at all drift distances, although symptomology was less severe at the furthest distances where not all plants exhibited symptoms. Despite the higher dosage and wind speeds, symptoms were less for the low boom and slow speed treatment than the fast speed, high boom treatment. Spray drift damage, expressed by visual ratings, varied linearly with the log of distance. The effect of distance on symptoms was the same for both treatments. However, the greater severity of symptoms at all distances for the fast speed, high boom treatment was evident.

The reduction of travel speed and lowering of boom height reduced spray drift by approximately 50% at 40 to 80 m downwind of the spray swath. Both the petri plate and drinking straw methods of measurement showed a similar magnitude in the drift reduction. These improvements may be considered additional to other practices such as the use of coarser sprays, whose benefit is already well documented.

Objective 3

The third objective of the project was to identify the physiological response of selected crops to simulated herbicide drift. Tasks included are as follows:

- Establish canola and soybean plots.
- Apply treatments, conduct visual rating, plant height, maturity, and seed yield measurements.
- Conduct nonlinear regression to calculate dose-response parameters for crops, herbicides, and growth stages.
- Identify the dose required to cause 10%, 50%, and 90% reduction in various plant response parameters.
- Compare plot results for soybean dose response to in-field trials conducted as part of Objective 2 and prepare dose response equations to estimate spray drift doses received at various downwind distances.

Dose response plot trial experiments were conducted in both soybeans and canola in each of 2018 and 2019.

In these trials, Roundup Ready soybeans (non-dicamba traited) were found to be extremely sensitive to both dicamba formulations (Engenia and Xtendimax). In 2018, estimated ED50s were estimated to be 1.45 and 1.73 g ae ha-1 for Engenia and Xtendimax respectively. In 2019, soybeans exhibited similar results for Engenia and Xtendimax with estimated ED50s of 3.54 and 2.85, respectively. Soybeans showed higher tolerance to 2,4-D (Enlist) with an estimated ED50 of 54.1 g ae ha-1 and 36.18 in the years of 2018 and 2019, respectively. Soybeans were 10 to 37 times more sensitive to dicamba than 2,4-D.

Roundup Ready canola was also found to be sensitive to the herbicide treatments tested (Simplicity, Varro, and Paradigm). In 2018, ED50 values for Simplicity, Varro, and Paradigm were 4.81, 0.61, and 2.0 g ai ha-1 for Simplicity, Varro, and Paradigm, respectively. The estimated ED50s equate to 0.3, 0.1, and 0.2 times the label rate for Simplicity, Varro, and Paradigm, respectively. 2019 results showed a similar trend, where the ED50 values for Simplicity, Varro, and Paradigm were 1.86, 0.38, and 10.36 g ai ha-1, respectively. Although the differences between ED50s for the three herbicides were not statistically significant ($p < 0.05$), there was a tendency for canola to be slightly more sensitive to Varro.

Although the attempt to unify the soybean plot trial results to the field trial results completed as part of Objective 2 was unsuccessful (the two dose responses differed by a factor of 2 to 15), the field trials in soybeans confirmed that dicamba poses a significant drift risk to non-dicamba traited soybeans. Dosages as low as 0.0005x, which occurred at 80 m downwind, resulted in 20% visual damage. The severity of the damage dissipated with time, and 20% yield losses occurred at higher doses than expected from the initial phytotoxicity ratings. The severity of the damage tended to be over-estimated by visual ratings, but was nonetheless very significant.

Dose responses from both the plot dose trials and in-field drift trials have quantified the dose levels at which adverse crop responses can be expected. This data provided a valuable link between how much drift may be tolerated for a given yield reduction.

Operational Implications and Project Conclusions

The effect of high-clearance sprayer operational choices, namely travel speed and boom height, were thoroughly investigated using a variety of numerical and experimental methods.

The airflow patterns at multiple locations around a high-clearance sprayer were characterized with field measurements and CFD simulations, leading to insights about the increase in severity of detrimental flow field features that resulted from a higher boom height (0.64 m versus 1.14 m) and from increased windspeed due to both ground speed (4 m/s and 11 m/s were considered) and wind conditions. The bluff nature of the sprayer tractor and exposed wheels were major contributors to chaotic flow downstream of the tractor. Considering this, a wider spray boom would decrease the proportion of the spray swath affected by the wake of the tractor (other factors being held constant).

The total impact of boom and travel speed on drifted quantities was investigated through field drift trials that focused on the drift risk of dicamba (XtendiMax with VaporGrip Technology) on non-resistant soybeans. Increased drift deposition with the higher boom height and travel speed were measured 160 m downwind of the sprayed swath in nominal weather conditions. The potential sensitivity of even small doses of unintended chemical applications on soybeans and canola was further demonstrated both in plot trials; the severity in yield reduction was greater in the plot trials, due in part to application method (hand sprayer) and orientation (primarily downward droplet movement).

In typical spraying conditions, even when the additional dosage at a low speed was not corrected for in the yield response, the downwind distance for soybean yield to recover to the untreated level increased from between 20 to 40 m to 40 to 80 m when sprayer speed and boom height were increased. Plot-scale dose response trials indicated even greater sensitivity. This suggests that in a practical scenario where dicamba (XtendiMax with VaporGrip Technology) is applied upwind of another field containing Roundup Ready (non-dicamba traited) soybeans, even the low boom height and slow travel speed operation setting (50 cm boom height traveling at 4 m/s) in moderate wind conditions would likely result in damage to neighbouring crop. Accordingly, great diligence should be paid to environmental and operation conditions when applying the “outside rounds” of a field that is adjacent to a highly sensitive crop. The specifics that inform the choice of exact operational conditions of the sprayer will vary due to a multitude of factors (wind, temperature, and humidity conditions, the crop type and staging of both target and adjacent fields in combination with the pesticide being applied); however, the important conclusion is that these factors be contemplated prior to application.

Both the experimental and simulations highlighted the contribution of headwind to the size and severity of the wake. The difference between the low-speed and high-speed wakes were significantly different, yet the speed difference represented operating at 7.5 m/s with a 3.5 m/s head/tail wind. Considering the differences that were observed along with the predicted and/or measured difference in droplet behaviour, noticeable variation between head and tail wind passes would be expected in an application scenario. Again, many other factors need to be considered during operation, but spraying with or against the wind did not appear to be an advisable preferred orientation. This further highlights the need for situational awareness, both during application on the outside rounds of a field that is adjacent to crop(s) with high susceptibility to damage, as well as throughout the period of applications.

The repeatability challenges of field drift trials (and thus the cost associated with them) are well understood by the community. Thus, separating the sources (boom motion and vibration, component design effects, various environmental influences) of different wake and deposition results scenarios solely through experimental A/B field comparisons is a costly path forward. Considering the numerical methods developed through this work, multiphase CFD simulations are a good candidate to inform the selection of limited future experimental treatments.

Recommendations for Future work

Gaps were identified in experimental methods and modeling approaches during this work, along with areas to consider in future research.

As discussed in Pesticide Drift Quantification – Objective 2, a considerable difference was observed in the GR50 dosage between plot trials and field experiments. Multiple potential factors were identified outside of growing season differences, including the impact of tank mix components, cultivar influence, and crop staging. Considering the difference in measured drift between petri plates, sampling straws, and plants, the trajectory of the drift droplets may have also contributed to differences. Additionally, the documented impact that tank mix can have on droplet size distribution and drift potential suggests further work is warranted in understanding both the difference in these experimental results and the larger impact of fluid physical properties on drift potential. Observed interactions with nozzle types further complicates assessing specific operation practices.

Representing large rotating lugged tires in CFD remains an active challenge. In this work, a tangential velocity equal to the travel speed was applied to the tire body; however, introducing tread geometry involves some numerical error because only tread faces that are tangential to the local flow field transfer momentum. Alternatively, some simulations were conducted where treads were removed, and numerical surface roughness was then introduced into the CFD calculations to represent some of the momentum transfer that would occur due to treaded geometry. Methods to improve the accuracy of the flow between tread blocks were identified during this work (Hobeika & Sebben, 2018). However, the suitability of this method to the application of large agricultural tires should be investigated further. Given the distinct disturbance that was caused by the sprayer tires found in the work herein, improvements to the accuracy of their representation would benefit future predictions of the flow field near the tires.

Ultimately, there is a need to reconcile the typical approach of drift testing where a crosswind is present with wind-tunnel-like CFD simulations that focus on a head wind. Head wind simulations leverage model symmetry to reduce the model size by 50%, but limitations do exist with this modeling method. Teske et al. (2016) demonstrated the effect of the angle of wind in scaled wind-tunnel experiments. Incorporating asymmetry and varying wind angles into the CFD modeling approach developed in this work will be aid in identifying wake features that contribute to experimentally measured drift. Notable improvements in computing hardware are necessary to expand the simulation domain beyond what was considered in this work.

The size droplet distribution of a medium spray nozzle was used as a starting point in this work. The methodology used herein could be applied to assess, numerically, other droplet size distributions, and potentially nozzle technologies (e.g., air induction). This would enable numerically testing various operational practices such as locally changing nozzle tips based on local wake characteristics.

Further validation of moving boom simulations is required before strong conclusions can be drawn. Time-average quantities were extracted from the experimental airflow measurements. Accelerometers were mounted on the boom during some of the measurement runs; initial effort in verifying data quality would be required, but potential (dynamic) validation data could be extracted from these measurements. Introducing validated boom motion into full-scale (or even partial boom) simulations would open up opportunities for other aspects of operational choices to investigated using numerical methods.

Finally, front-mounted booms configurations were not assessed in this work. While only speculative, the injection of liquid droplets further away from the detrimental drift features noted in this work is suspected to be beneficial in terms of drift reduction (all other factors being equal).

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References

Gagnon, B. J. 2022. *CFD study of the wake of a high-clearance agricultural boom sprayer [master's thesis].* Saskatoon: University of Saskatchewan.

Hobeika, T., & Sebben, S. (2018). CFD investigation on wheel rotation modelling. Journal of Wind Engineering and Industrial Aerodynamics, 174, 241-251.

Paulson, I. W., Gerspacher, J., Gagnon, B. J., Landry, H., Wolf, T., Sumner, D., & Bergstrom, D. J. (2022). Experimental Characterization of the Aerodynamic Wake of a High-Clearance Sprayer with Changing Operating Parameters. Journal of the ASABE, 65(3), 665-679.

Teske, M. E., Thistle, H. W., Lawton, T. C., & Petersen, R. L. (2016). Evaluation of the flow downwind of an agricultural ground sprayer boom. Transactions of the ASABE, 839-846.

Teske, M. E., Thistle, H. W., Petersen, R. L., Lawton, T. C., Guerra, S. A., & Funseth, T. G. (2016). Evaluation of the wake of an agricultural ground sprayer with the wind from any direction. Transactions of the ASABE, 59(5), 1205-1219.