Initial Development and Validation of a Mechanistic Spray Drift Model for Ground Boom Sprayers

M. E. Teske, P. C. H. Miller, H. W. Thistle, N. B. Birchfield

Abstract. *This article summarizes the initial development of a mechanistic spray drift model for ground boom sprayers, built upon the same analytical Lagrangian approach used in the aerial spray model AGDISP. For ground boom sprayers the wake and turbulence of the aircraft are removed and more detailed modeling of the nozzle jets (and jet entrainment) is included. The model predicts the spray deposition downwind from the application area for any set of initial conditions, and recovers results compared with Spray Drift Task Force and Canadian field datasets for two ground sprayer nozzle types.*

Keywords. *AGDISP, Ground sprayer, Lagrangian modeling, Spray drift.*

Ground boom sprayers are commonly thought to apply more pesticide by mass than any other application method in the U.S., yet a validated and easy to use mechanistic model for estimating off-target deposition of spray drift from ground boom applications has not yet been developed. While a practical mechanistic spray drift model for ground boom equipment does not exist, mechanistic spray drift models for aerial application equipment have advanced greatly over the last 20 years. One development thread, from NASA to the USDA Forest Service (FS) to the Spray Drift Task Force (SDTF), resulted in the collection of a large, consistent set of field and laboratory data, which were used in development and validation of the aerial spray computer model AGDISP (Bilanin et al., 1989; Hewitt et al., 2002; Teske et al., 2002; Bird et al., 2002; Teske et al., 2003).

Within the framework of the AGDISP platform, the development of a consistent mechanistic ground sprayer model becomes the next logical step. The usefulness of such a verified analytical tool, particularly for regulatory purposes and for pre-spray estimation and post-spray evaluation, cannot be understated. There is no reasonable alternative to costly (and incomplete) field data collection other than model simulation. This article continues model development and validation previously undertaken in this area (Teske et al., 2000, 2001, 2004).

To date, several approaches have been explored for simulating the ground boom sprayer process, from the relatively straightforward to the complex. The current ground sprayer methodology found in AgDRIFT (Teske et al., 2002) provides simple screening-level deposition curves as a function of distance empirically based on SDTF field trial data. The user has the option of selecting from two boom heights and two broad categories of droplet size. With these data, the U.S. Environmental Protection Agency developed conservative deposition curves that included tolerance bounds (U.S. EPA, 1999). A multiple regression model, evaluating drift as a response to wind speed, boom height, temperature, jet velocity, and nozzle pressure, was separately developed based on collected ground sprayer data (Smith et al., 2000). As with the AgDRIFT model, this model is most accurate when the application conditions are within the limits imposed by the original data, and when only these variables are important. Zhu et al. (1994) summarized a sensitivity study regarding the effects of droplet size, release height, wind velocity, temperature, and relative humidity with FLUENT, a general-purpose computational fluid dynamics (CFD) program. The use of this model involves detailed model setup and considerable computer time for model simulation. A detailed analytical model of motion within liquid sprays was presented by Ghosh and Hunt (1994) based upon initial results presented by Ghosh et al. (1991). These authors also examined the effects of ambient wind on released spray (Ghosh and Hunt, 1998), but their results have not lead to practical model development. A non-mechanistic approach to ground sprayer modeling culminated in the refinement of various random walk techniques by Miller and Hadfield (1989) from earlier modeling efforts by several researchers. These authors suggested several simplified modeling techniques that have proven useful when developing the physics-based model presented herein.

Concurrent with preliminary model development, a large amount of field data has been collected for deposition and drift from ground sprayer operations in an effort to quantify field effects and to provide data for model development and pesticide registration requirements. Large studies have been conducted in the U.S. (Smith et al., 1982; Johnson, 1995), Germany (Ganzlemeier et al., 1995), Sweden (Arvidsson, 1997), the Netherlands (Porskamp et al., 1995), Canada (Wolf and Caldwell, 2001), and Belgium (Nuyttens et al., 2007). The early datasets do not include sufficient data (drop

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The authors are **Milton E. Teske, ASABE Member Engineer,** Senior Associate, Continuum Dynamics, Inc., Ewing, New Jersey; **Paul C. H. Miller,** Director, Silsoe Spray Applications Unit (part of The Arable Group), Silsoe, Bedford, U.K.; **Harold W. Thistle, ASABE Member,** Program Manager, USDA Forest Service, Morgantown, West Virginia; and **Norman B. Birchfield,** Senior Environmental Technology Officer, U.S. Environmental Protection Agency, Washington, D.C. **Corresponding author:** Milton E. Teske, Continuum Dynamics, Inc., 34 Lexington Avenue, Ewing, NJ 08616; phone: 609-538-0444; fax: 609-538-0464; e-mail:milt@continuum-dynamics.com.

size distributions, data collection far downwind) for accurate model simulation as defined herein. The later ones, in particular the Belgium data (Nuyttens et al., 2007), which supply the field data for recent CFD model comparisons by Baetens et al. (2007, 2009), and the Canadian data (Wolf and Caldwell, 2001) are more amenable to model comparisons.

The dataset collected by the SDTF in two ground spray field trials conducted in 1992 and 1993 (Johnson, 1995) formed the foundation for the empirical screening ground boom sprayer model programmed into AgDRIFT. This article discusses the use of these data, along with the Canadian dataset (Wolf and Caldwell, 2001), in validating a simplified mechanistic model for ground boom sprayer simulation.

SDTF Ground Boom Sprayer Data

Ground boom sprayer data were collected by the SDTF in two field trials in 1992 and 1993 (Johnson, 1995). Wind tunnel atomization studies (Hewitt et al., 1996) recovered drop size distributions for the 8004, 8004LP, 8010LP, and TX-6 nozzles used in these studies. Diazinon and malathion tracers were sprayed from a spray boom uniformly populated by 27 nozzles spaced at intervals of 0.51 m. The spray boom was set to either 0.51 or 1.27 m above the ground. Deposition data were recovered for four sprayer paths for each of the 48 field trials, with a swath width of 13.72 m (complete meteorological conditions were not available for two of the trials). In the later 1993 study, the deposition collected on the three sample lines was combined at half the card locations before assaying took place, resulting in a composite measurement at those locations. An evaluation of the SDTF data set was conducted by Barry et al. (1999). Hewitt et al. (2001) explained the covariate experimental design of the field studies using two treatments, applied as pairs to isolate treatment conditions (boom height and drop size distribution) from meteorological conditions. The standard treatment always used the same application setup and tank mix tracer (diazinon, Syngenta AG, Greensboro, N.C.), while the variable treatment included different treatment conditions, with malathion (Nufarm Platte Pty. Ltd., Greeley, Colo.) as a tank mix tracer. Figure 1 summarizes the SDTF ground sprayer data.

The earlier 1992 study was conducted in the summer in the high plains of Texas, while the 1993 study included two sets of data for spring and summer in southern Texas. In the spring study, the ambient temperatures were lower than in either of the summer studies, but more importantly, the 1992 study was conducted over low-growing grass, while the 1993 summer study was conducted over rough stubble. In 1993, several

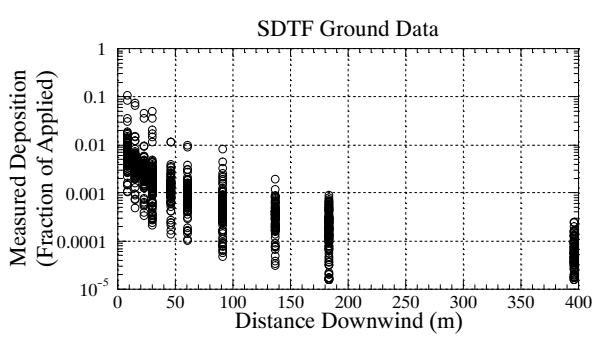

Figure 1. SDTF ground boom sprayer database as a function of downwind distance.

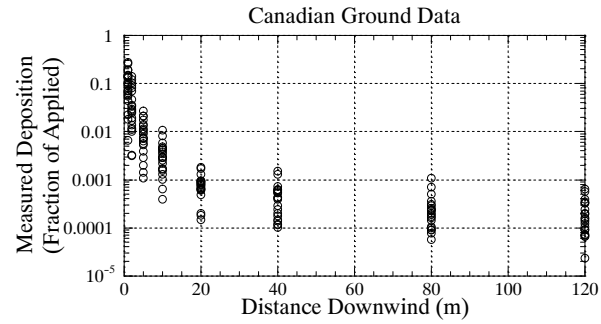

Figure 2. Canadian ground boom sprayer database as a function of downwind distance.

of the tank mixes were considered so similar to corresponding 1992 tank mixes that the 1992 drop size distributions were used rather than conducting wind tunnel atomization studies of these additional 1993 tank mixes (possibly an unfortunate decision, based upon the importance of drop size distribution and the resulting model comparisons shown below).

Canadian Ground Sprayer Data

Ground boom sprayer data were also collected by Agriculture & Agri-Food Canada in a field trial in 2001 (Wolf and Caldwell, 2001). Wind tunnel atomization studies (A. J. Hewitt, 2004, personal communication) recovered drop size distributions for the XR8003VS, TI11005, AI11004, and AI110025 nozzles used in these studies. A low rate of formulated 2,4-D-amine (dimethylamine salt of 2,4-dichlorophenoxyacetic acid) was sprayed from a spray boom uniformly populated by 36 nozzles spaced at intervals of 0.50 m. The spray boom was set to either 0.60 or 0.90 m above the ground. Deposition data were recovered for one sprayer path for each of the 21 field trials, with a swath width of 18.0 m. The study was conducted over stubble. Figure 2 summarizes the Canadian ground sprayer data.

SDTF Tier I Model

Statistical analysis of the SDTF data justified separating the results into low boom and high boom data subsets and two drop size distributions (designated as "ASAE Very Fine to Fine" and "ASAE Fine to Medium/Coarse" in the AgDRIFT model) (Teske, 2003). Single sprayer paths were achieved by curve-fitting the expression:

$$D(x) = \frac{c}{\left[1 + \frac{x}{a}\right]^b} \tag{1}$$

where $D(x)$ is the deposition level relative to the nominal application rate (in fraction of applied); x is the downwind distance, measured from the edge of the application area and assumed perpendicular to the sprayer paths; and a, b, and c are curve shape parameters determined from the data. Application of this equation (Teske, 2003) recovered the Tier I ground sprayer curves implemented in AgDRIFT, as shown in figure 3.

While these curves represent the behavior of the spray material in the specific tested conditions, they offer no ability to

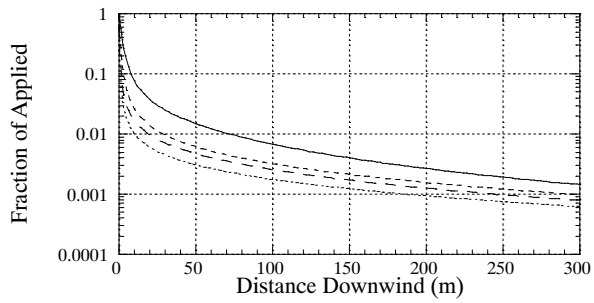

Figure 3. AgDRIFT Tier I ground sprayer 90th percentile downwind deposition curves for different boom heights and drop size classifications (Teske, 2003): high boom, very fine to fine (solid curve); low boom, very fine to fine (short-dashed curve); high boom, fine to medium/coarse (long-dashed curve); and low boom, fine to medium/coarse (dotted curve).

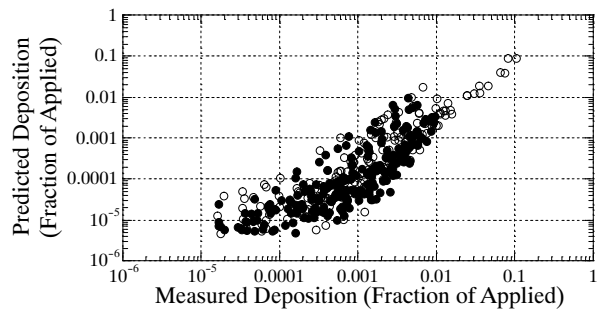

Figure 4. Ground sprayer option in AGDISP with initial jet velocity assumed using Bernoulli's law (R^2 = 0.928, even though most of the deposition is underpredicted): diazinon (solid circles) and malathion (open circles).

estimate drift in situations outside those tested. Thus, interest exists in developing a mechanistic model, validated with these and other data, that would provide the ability to estimate spray behavior with drop size spectra, boom heights, and meteorological conditions not evaluated in SDTF and other field trials.

AGDISP Wake Model

The near-wake model originally developed for AGDISP is a Lagrangian model that tracks the movement of spray material released from nozzles, from their release at the aircraft and until they either deposit or drift considerable distances downwind. The model includes the innovative step of developing ensemble-averaged turbulence equations to predict the growth of the spray cloud during the calculations, thus eliminating the need for a random component in the solution procedure. The effect of droplet exit velocity from the nozzle is not included or required in AGDISP aerial spray modeling because air turbulence at flight speed overwhelms any contribution of the nozzle jet velocity on droplet trajectory. In its current configuration AGDISP includes simplified models for the effects of the aircraft wake and aircraft-generated and ambient turbulence, and a transition to a Gaussian model for the prediction of deposition to 20 km downwind (Teske and Thistle, 2004). A modified version of the Lagrangian model, absent the effects of aircraft wake and turbulence, is used to simulate a ground sprayer.

The original AGDISP model included a ground sprayer option, wherein aircraft wake effects were removed and initial conditions could be imposed on the jet flow exiting the nozzles. A previously described first step consistent with the present analysis (Teske et al., 2004) exercised this AGDISP feature for conditions measured in the SDTF ground sprayer studies. In these trials, the jet vector was pointed downward, at an initial velocity found from Bernoulli's law, since boom pressures were recorded for all SDTF trials ($\Delta p = 1/2\rho\, U_{jet}^2$, where Δp is the pressure, ρ is the tank mix density, and U_{jet} is the initial jet velocity). This approach generated the comparison curves shown in figure 4 for all ten downwind distances where deposition data were recovered (out to 400 m). It should be noted that the diazinon (standard treatment) tracer runs were all made with the same nozzle type (8004) and nearly identical spray material, with the boom at 0.51 m above the ground. The malathion (variable treatment) tracer runs were performed with four nozzle types, at two boom heights, two tractor speeds, and several tank mixes. All of these factors were included when making the model runs.

It may be seen in nearly all cases that, on average, the default model underpredicts the deposition pattern downwind of the application area. By way of reference, relative to the aerial field drift study data, AGDISP typically underpredicts aerially applied deposition near the edge of the application area and overpredicts it farther downwind (Teske et al., 2000). The subsequent overprediction at the smaller deposition levels is not present in these results.

Ground Boom Sprayer Modeling Options

The Lagrangian model performs well for aerial application predictions (Teske et al., 2000). In this approach, the aircraft wake is modeled by point vortices created by the assumed elliptically loaded wings, augmented by propeller wake(s) modeled as a simple rotating disk; helicopters impose a downwash that transitions to rolled-up point vortices. The positions of the nozzles, but not the direction(s) they are pointing, are identified along the spray boom. The drop size distribution is broken into droplet categories, each identified by a volume-averaged droplet size carrying the volume fraction for that droplet category. The simulation proceeds by initializing the release of droplets at each nozzle location with the air speed of the aircraft, and following the paths of these droplets through the aircraft wake and the ambient crosswind to the ground, with the effects of evaporation and atmospheric turbulence included.

In the development of this approach, there was no deliberate attempt to account for the detailed flow around the wing (including its roll up to point vortices), body drag along the fuselage, or swirling effects that exist around the spray boom and nozzles. Nor was the initial jet velocity of the spray material (U_{jet} obtained from Bernoulli's law) included in the aerial model. The crosswind speed was characterized by extrapolating from the wind speed at a known reference height; ground interaction was specified by surface roughness. Because field trial data agree with model predictions, the fine details of the aircraft wake and surface interactions apparently contribute little to the final deposition solution. With regard to this point, it should also be noted that as the aircraft slows down (in the SDTF helicopter aerial trials, for example), the model does not do as well as in the higher speed, fixed-wing aircraft cases (Teske et al., 2000).

It may initially be assumed that several of the features neglected in aerial application may be important in ground sprayer application. Under the relatively windy conditions of the field trials, little or no influence from the tractor drive speed was noted on measured downwind deposition levels. The more dominant effect is expected to be from the jet velocity from each nozzle, and the plume that is created. This effect was recognized in the original AGDISP model by permitting the user to define the initial conditions of the spray as it leaves the nozzle. However, adjusting jet velocity alone fails to bring measured and model values into close agreement (fig. 4), so it appears that other effects may be important.

The analysis has considered the following modifications to the original ground sprayer model:

1. An initial sensitivity study encompassed changing the variables thought to be influential in the ground boom sprayer model. These variables included the ambient relative humidity (to check for possible evaporation effects), release height, initial jet velocity, and solution time step size. Artificially adjusting any of these variables did little to correct the model predictions from those presented in figure 4.

2. A backtracking algorithm (Teske et al., 2001) was applied to the drop size distribution in an attempt to quantify the size of the droplets that contribute to deposition downwind of the application area. It was assumed that larger droplets, beyond a cutoff size determined by the algorithm, would impact the ground or foliage and would be removed from the problem before evaporation made them small enough to drift (in the aerial problem, larger droplets evaporate to smaller droplets and drift). This approach truncated the drop size distributions of the four nozzle types, but did not offer a physical way for this effect to happen.

3. The cross-sectional details of the exiting jet (its initial cross-sectional shape and velocity profile) were then explored. We suspect that the apparent need for this detail formed one of the driving reasons for exploring ground boom sprayer predictions with the use of more sophisticated computational tools such as FLUENT (Reichard et al., 1992; Weiner and Parkin, 1993; Zhu et al., 1994). Such a simulation would include the development of the wake from each nozzle, including its entrainment of the surrounding ambient air. In considering that the liquid stream from each nozzle must first break up into droplets (at a height lower than the release height), we find that these droplets are predicted to move at speeds slower than the liquid speed computed from Bernoulli's law (Sturgess et al., 1985). However, when this speed detail is included in the Lagrangian ground boom sprayer model, it does not improve the data comparison shown in figure 4.

4. The influence of the presence of the jet (its initial cross-sectional area and turbulence level) was then explored. In the aerial problem, the behavior of the spray from the nozzles does not influence the deposition model due to the intensity of the aircraft-generated vortices. Here, however, it seems reasonable that the behavior of the spray from the nozzles tends to overwhelm local ambient conditions. To account for these effects, we added a consistent initial size of the spray from each nozzle (σ = 0.03 m), and a consistent turbulence level ($\Delta q = 0.1U_{jet}$).

5. Finally, the effects of jet entrainment were added. As the spray issues from the nozzle, it creates a liquid stream that entrains the surrounding air. This air entrainment effect supports and sustains the further movement of the spray toward the surface. The model (Miller and Hadfield, 1989) accounted for air entrainment by incorporating the analytical and empirical results from Briffa and Dombrowski (1966), who studied atomization and transport of flat fan sprays. The resulting expression for the velocity v of the entrained air along the axis of the spray is (Miller and Hadfield, 1989):

$$v = U_{jet}\left(\frac{L}{h}\right)^{\delta^2/2K} \tag{2}$$

where L is the coherent length of the liquid sheet, and h is the distance below the nozzle. The parameter δ has a value of 0.4 for sprays emitted into air, and the parameter K has a typical value of 0.14 for continuous, agricultural flat fan sprays (Briffa and Dombrowski, 1966). The resulting value for $\delta^2/2K$ was 0.57, but was adjusted by Miller and Hadfield (1989) to 0.95 for better agreement between observed and predicted spray droplet velocity results. These authors also found that use of an initial droplet velocity 0.88 times the liquid sheet velocity resulted in greatest agreement with velocity data. Giles and Ben-Salem (1992) confirmed these results with a terminal velocity experiment. Miller et al. (1996) assumed a power law of 1.0 and added a velocity term to account for the drag force between the droplets and the air, and then confirmed their model by experimental data.

The effect of air entrainment is the feature added to the ground boom sprayer model described by Teske et al. (2004) to provide significant improvement in the ability of the model to match the SDTF data.

SDTF Ground Boom Sprayer Modeling Results

The results of the modified ground boom sprayer model, when applied to the SDTF ground boom sprayer data, are shown in figure 5, separating the diazinon and malathion treatments by spray years. Field data were collected to 400 m downwind. The best correlation between data and model was obtained with L = 0.14 m and a power of $\delta^2/2K$ = 0.57 (results change little with changes in these parameters). From wind tunnel observations, a sheet length of 0.14 m appears to be longer than the lengths at which sheet breakup begins on ground sprayer nozzles (A. E. Hewitt, 2004, personal communication) but shorter than lengths needed to complete sheet breakup in aerial nozzles (I. W. Kirk, 2004, personal communication). Overall, the ground boom sprayer predictions generally match the data, with R^2 = 0.964, with the smallest deposition levels several orders of magnitude below the lowest recorded deposition in the SDTF aerial trials. From figure 5 it may be seen that diazinon deposition is underpredicted close to the spray block (larger values of deposition) and overpredicted farther from the spray block (smaller values of deposition), the overprediction consistent with aerial model prediction, while malathion deposition is predicted quite well from close to the spray block to farther from the spray block, except for an increase in spread of the model predictions. Overprediction farther from the spray block (for diazinon) and increased spread farther from the spray block (for malathion) may be attributable to model simulation of the behavior of fine droplets (Teske and Thistle, 2009), especially those not well-defined by the drop size distributions used in 1993.

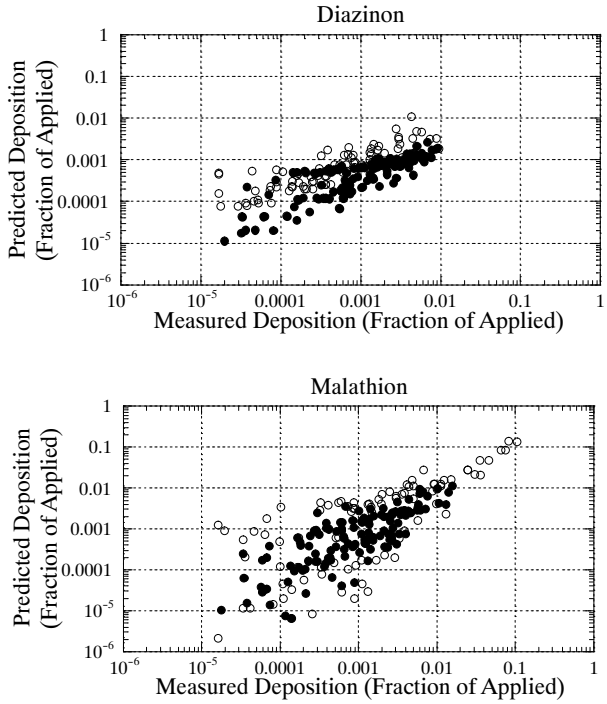

Figure 5. Modified ground sprayer results for L = 0.14 m and $\delta^2/2K$ = 0.57 (R^2 = 0.964 overall): diazinon (top), malathion (bottom), 1992 data (solid circles), and 1993 data (open circles).

A detailed examination of the 23 pairs of data (diazinon and malathion) finds some interesting effects:

Model comparisons with data are consistent across changes in surface roughness, wind speed, wind direction, temperature, and relative humidity. The effect of relative humidity appears unimportant in both the ground sprayer data and model (relative humidity was unimportant in the SDTF aerial data, but important in the aerial model, a major part of the data/model discrepancy). The locations of the field studies, and the years they took place, seem unimportant as well, although the non-measurement of drop size distributions in the second year of testing may have negative impact on deposition predictions because of drop size distribution importance in model simulation. Appendix A summarizes the field data and includes typical model comparisons with data.

The largest model comparison errors occur where malathion was sprayed from an 8010LP nozzle, with a measured $D_{V0.5}$ = 625 μm. These results (fig. A5) appear similar to the large droplet helicopter runs in the aerial field trials, and were at the higher sprayer speed, which has been reported to increase near-field drift (van de Zande et al., 2008). Large droplets tend to fragment easily, and wind tunnel measurements of droplet size may not accurately reflect the droplet size released in the field, where additional turbulence and spray boom vibrations may potentially generate finer droplets than measured under laboratory conditions. Test runs made by substituting drop size distributions with smaller $D_{V0.5}$, in this case around 360 μm, suggest that the model can be made to more nearly match the data by changing only the droplet size.

The lack of model agreement in some of the trials (especially diazinon) suggests that details of the jet exiting the nozzle may play an important role in modeling the ground boom sprayer. While the aerial model (with a dominant axial motion) is insensitive to these details, they may be important in a ground application. In the vicinity of the nozzles, the effects of wing structures and vortices may play a decidedly different role in aerial application than the effects of jet entrainment on a hollow cone or flat fan nozzle do on a ground boom sprayer.

The need to determine a modeling parameter ($\delta^2/2K$), even one for which model predictions appear insensitive, requires model testing on additional independent data sets to establish confidence in model verification.

Canadian Ground Boom Sprayer Modeling Results

The results of the modified ground boom sprayer model, when applied to the Canadian data, are shown in figure 6. Field data were collected to 120 m downwind. Since the nozzles used in the Canadian field study were not flat fan, the exponent in the jet entrainment formula does not apply. A model sensitivity study recovered the best agreement with data when $\delta^2/2K$ equals 2.04, approximately 3.5 times larger than the value determined by Briffa and Dombrowski (1966). No other parameters were changed from the model developed for the SDTF data. One further adjustment could have been the jet velocity factor for the air injection nozzles (AI110025 and AI11005), as some researchers suggest that the exit velocity can be 0.70 to 0.75 of a liquid-only nozzle, while other data comparing air injection nozzles with liquid-only nozzles (I. W. Kirk, 2004, personal communication) suggest that the exit velocities remain nearly the same with or without air injection. This factor did not change model predictions.

The model generally overpredicts the data near the spray block. This overprediction could not be corrected by any reasonable change in expected physical values (such as changing the wind speed by a factor of two or changing the surface roughness by a factor of two), nor by any additional change in the modeling mechanism. Since the correlation with data is somewhat lower than for the SDTF data, these results suggest that more information should be collected with regard to the differences in the nozzles used in the SDTF study (flat fan nozzles) and the nozzles used in the Canadian study. The modeling constant for nozzles other than flat fan should also be determined by a laboratory experiment consistent with the experiment of Briffa and Dombrowski (1966). Appendix B summarizes the field data and includes typical model comparisons with data.

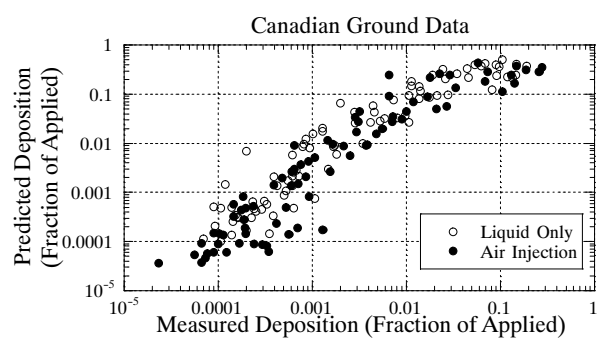

Figure 6. Ground boom sprayer model comparison with Canadian data (Wolf and Caldwell, 2001) (R^2 = 0.919).

Discussion

These two model/field comparisons suggest that our initial model has captured the essential physics of the ground boom sprayer problem, and that we have obtained a working model for the simulation of ground boom sprayer operation. However, several shortfalls have been identified:

- The model predicts higher deposition close to the edge of the application area than is seen in the two data sets.
- The behavior of the model with respect to boom height is unclear.
- The model has only two nozzle types (the ones field tested) and is not directly applicable to other nozzles.
- There is some question about whether the model properly accounts for ligament breakup into droplets, where that phenomenon occurs, and the effect of ambient cloud meteorology (specifically relative humidity).

An additional, systematic dataset for nozzle properties is needed to improve the existing model. This library of information must include wind tunnel studies to measure the spread of the spray from the nozzle, the density of the spray as a function of exit angle from the nozzle, the ligament distance before droplet formation, the drop size distribution as a function of exit angle from the nozzle, and the influence of neighboring nozzles on the behavior of the nozzle spray.

In the proposed study, it may be worth considering other parameters and effects as well. For example, with the nozzles pointed downward, the spray material has an opportunity to reach the surface rapidly. This effect suggests that droplet shattering, bouncing, re-entrainment aloft, and coalescence are all possible effects that may have to be part of a more detailed mechanistic model. Thus, surface effects have the potential to be far more important in ground application than in aerial. While the logarithmic wind velocity profile, parameterized by surface roughness, seems sufficient for aerial application, such an approximation may be too simple for ground application, where the nozzles are much closer to the surface, and the spray creates a blockage effect between the boom and the top of the canopy.

Conclusions

This article describes the initial development of an analytical ground boom sprayer model, based on the Lagrangian approach applied to aerial spraying in the computer model AGDISP. The current model is different from aerial AGDISP predictions in that the aircraft wake and its turbulence are absent, and the ground boom sprayer model includes a more detailed treatment of spray behavior near the nozzle. Model predictions of downwind deposition tend to overpredict close to the spray block and underpredict farther from the spray block, when compared with the SDTF and Canadian datasets. The model has been compared with only two sets of field data, and is not directly applicable to any other nozzle types than those correlated herein. Nor does the model account for any refinements, such as canopy interaction. Nonetheless, as a first analytical tool, the model may be useful in estimating spray drift levels from ground boom sprayers in the absence of other modeling techniques. AGDISP versions that accurately incorporate the ground model are 8.20 and higher.

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Appendix A

The SDTF ground boom sprayer field trials are summarized in table A1. Figures A1 to A5 illustrate model comparisons with the SDTF data.

Table A1. Critical parameters related to the SDTF field studies. The standard treatment was run with the same nozzle and the same boom height, but at the atmospheric conditions indicated for the corresponding variable treatment. Trial 09 took place in 1992 (surface roughness of 0.0488 m); trial 16 took place in 1993 (surface roughness of 0.0109 m).

Test No.	Nozzle Type	Boom Height (m)	Wind Speed (m/s)	Wind Direction (°)	Temp. (°C)	RH (%)
Standard:	8004	0.51				
Variable:						
0902_3	8004LP	0.51	1.68	-98.0	32.0	39.1
0902_4	8004LP	0.51	2.95	-123.0	26.7	61.8
0903_3	TX-6	0.51	3.72	-91.0	32.9	35.2
0903_4	TX-6	0.51	2.36	-94.0	32.2	39.9
0904_1	8004	0.51	2.87	-103.0	27.7	44.0
0904_2	8004	0.51	2.70	-112.0	27.7	43.4
0905_1	8004LP	0.51	4.82	-100.0	23.6	81.5
0905_2	8004LP	0.51	5.07	-103.0	25.6	72.8
0906_1	TX-6	0.51	3.89	-100.0	29.6	54.3
0907_1	8004	1.27	4.65	-116.0	30.5	53.8
0907_4	8004	1.27	3.63	-111.0	24.8	69.3
0908_2	8004	0.51	5.24	-100.0	31.9	33.0
0908_3	8004	0.51	3.04	-108.0	27.7	63.2
1602_1	TX-6	1.27	5.61	-96.0	6.7	56.0
1602_2	TX-6	1.27	5.81	-96.0	9.4	43.0
1603_2	TX-6	0.51	4.99	-103.0	28.9	8.0
1603_3	TX-6	0.51	5.27	-111.0	27.8	9.0
1604_1	8004LP	0.51	8.59	-91.0	16.1	39.0
1604_2	8004LP	0.51	6.03	-91.0	13.3	30.0
1605_1	8010LP	1.27	6.51	-94.0	11.1	50.0
1605_2	8010LP	1.27	5.05	-106.0	24.4	8.0
1606_1	8010LP	0.51	6.37	-95.0	7.8	63.0
1606_4	8010LP	0.51	2.84	-100.0	23.9	21.0

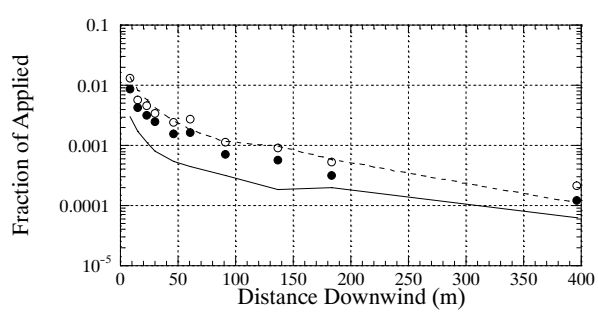

Figure A1. Comparison between AGDISP model predictions and data for the SDTF ground sprayer field trial with the highest ambient temperature (32.9°C), field trial 0903_3, nozzle types 8004 (diazinon, $D_{V0.5}$ = 312 μm) and TX-6 (malathion, $D_{V0.5}$ = 162 μm): diazinon data (solid circles), diazinon model (solid curve), malathion data (open circles), and malathion model (dashed curve).

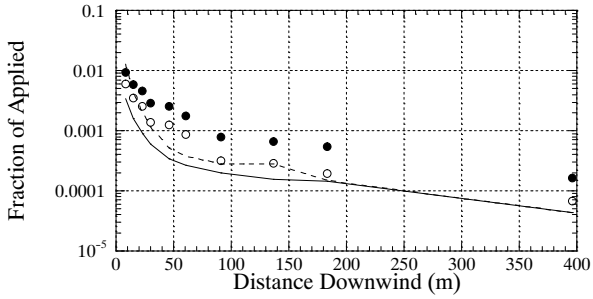

Figure A2. Comparison between AGDISP model predictions and data for the SDTF ground sprayer field trial with the highest ambient relative humidity (81.5%), field trial 0905_1, nozzle types 8004 (diazinon, $D_{V0.5}$ = 312 μm) and 8004LP (malathion, $D_{V0.5}$ = 298 μm): diazinon data (solid circles), diazinon model (solid curve), malathion data (open circles), and malathion model (dashed curve).

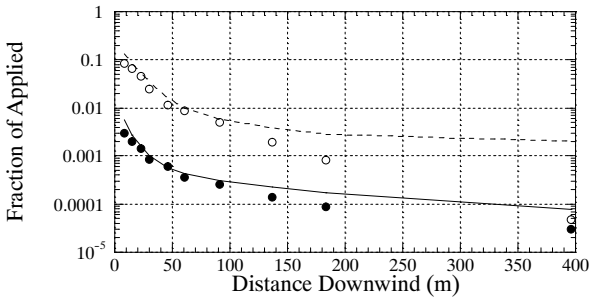

Figure A3. Comparison between AGDISP model predictions and data for the SDTF ground sprayer field trial with the lowest ambient temperature (6.7°C), field trial 1602_1, nozzle types 8004 (diazinon, $D_{V0.5}$ = 312 μm) and TX-6 (malathion, $D_{V0.5}$ = 162 μm): diazinon data (solid circles), diazinon model (solid curve), malathion data (open circles), and malathion model (dashed curve).

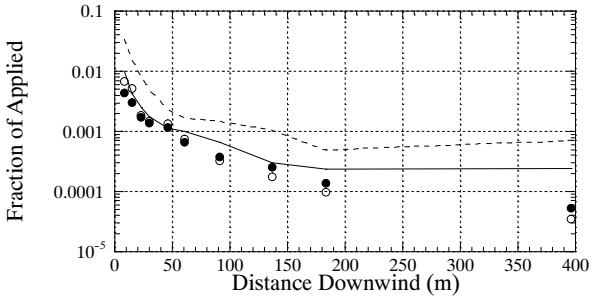

Figure A4. Comparison between AGDISP model predictions and data for the SDTF ground sprayer field trial with the highest wind speed (8.6 m/s), field trial 1604_1, nozzle types 8004 (diazinon, $D_{V0.5}$ = 312 μm) and 8004-LP (malathion, $D_{V0.5}$ = 298 μm): diazinon data (solid circles), diazinon model (solid curve), malathion data (open circles), and malathion model (dashed curve).

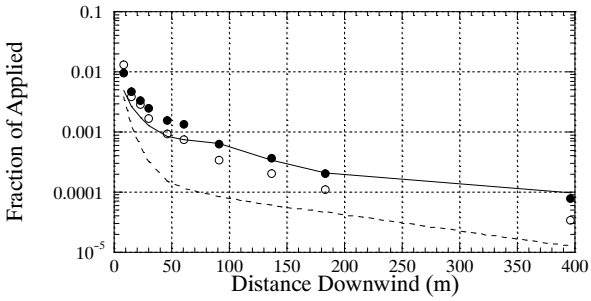

Figure A5. Comparison between AGDISP model predictions and data for one of the SDTF ground sprayer field trials with the largest $D_{V0.5}$, field trial 1605_2, nozzle types 8004 (diazinon, $D_{V0.5}$ = 312 μm) and 8010LP (malathion, $D_{V0.5}$ = 625 μm): diazinon data (solid circles), diazinon model (solid curve), malathion data (open circles), and malathion model (dashed curve).

APPENDIX B

The Canadian ground boom sprayer field trials are summarized in table B1. Figures B1 to B5 illustrate model comparisons with the Canadian data.

Table B1. Critical parameters related to the Canadian field studies. The surface roughness averaged 0.00543 m.

Test No.	Nozzle Type	Boom Height (m)	Wind Speed (m/s)	Wind Direction (°)	Temp. (°C)	RH (%)
00-01	AI110025	0.60	3.56	-118.0	28.4	29.1
00-02	XR8003VS	0.60	5.92	-114.4	28.2	29.1
00-03	TT11005	0.90	2.81	-103.5	28.2	29.1
00-04	AI11004	0.90	3.94	-82.7	28.4	29.1
00-05	AI11004	0.90	3.75	-100.1	13.3	36.8
00-06	TT11005	0.90	3.33	-70.4	13.7	36.8
00-07	XR8003VS	0.60	3.44	-91.5	13.7	36.8
00-08	AI110025	0.60	4.61	-87.7	14.1	36.8
00-09	TT11005	0.90	6.61	-96.8	12.1	50.0
00-10	AI11004	0.90	5.19	-96.8	12.1	50.0
00-11	AI110025	0.60	6.61	-99.4	12.7	50.0
00-12	XR8003VS	0.60	5.92	-95.4	13.1	50.0
00-13	AI11004	0.90	5.75	-92.7	22.6	12.9
00-14	TT11005	0.90	6.11	-80.9	23.0	12.9
00-15	XR8003VS	0.60	5.33	-83.6	23.5	12.9
00-16	AI110025	0.60	4.42	-80.9	23.6	12.9
00-17	XR8003VS	0.60	4.75	-101.8	15.3	45.0
00-18	AI110025	0.60	8.64	-101.8	15.3	45.0
00-19	AI11004	0.90	9.17	-101.8	15.3	45.0
00-20	TT11005	0.90	8.56	-101.8	15.3	45.0
00-21	XR8003VS	0.60	8.33	-101.8	15.3	45.0

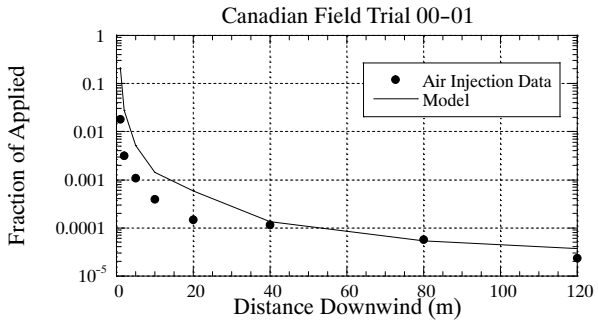

Figure B1. Comparison between AGDISP model predictions and data for Canadian field trial 00-01: nozzle type = AI110025, boom height = 0.60 m, wind speed = 3.56 m/s, temperature = 28.4°C, and relative humidity = 29.1%.

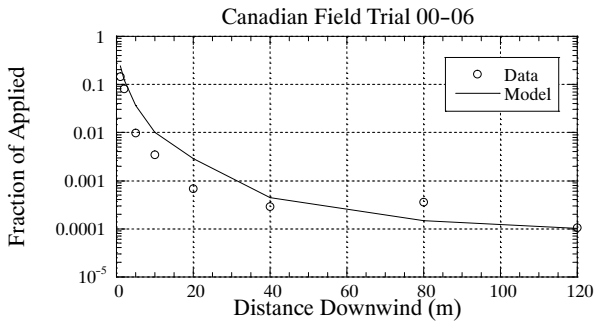

Figure B2. Comparison between AGDISP model predictions and data for Canadian field trial 00-06: nozzle type = TT11005, boom height = 0.90 m, wind speed = 3.33 m/s, temperature = 13.7°C, and relative humidity = 36.8%.

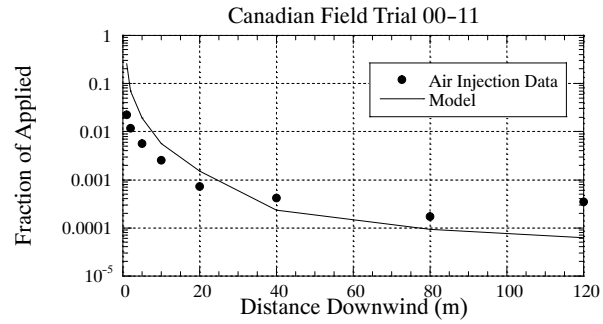

Figure B3. Comparison between AGDISP model predictions and data for Canadian field trial 00-11: nozzle type = AI110025, boom height = 0.60 m, wind speed = 6.61 m/s, temperature = 12.7°C, and relative humidity = 50.0%.

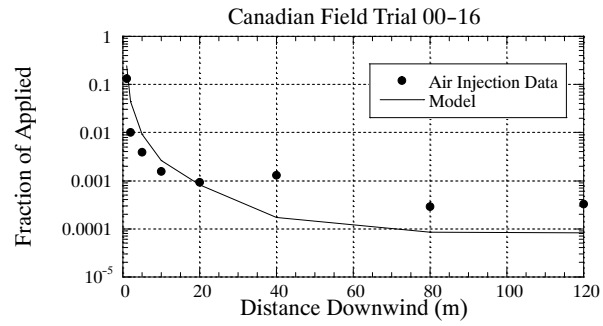

Figure B4. Comparison between AGDISP model predictions and data for Canadian field trial 00-16: nozzle type = AI110025, boom height = 0.60 m, wind speed = 4.42 m/s, temperature = 28.6°C, and relative humidity = 12.9%.

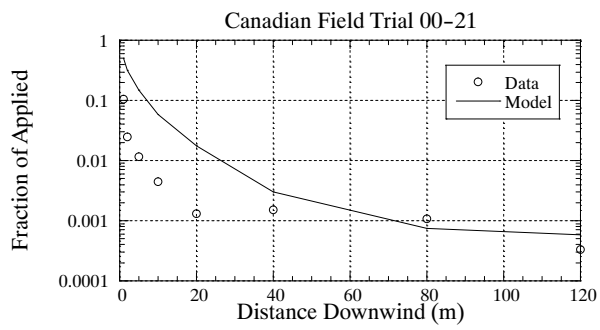

Figure B5. Comparison between AGDISP model predictions and data for Canadian field trial 00-21: nozzle type = XR8003VS, boom height = 0.60 m, wind speed = 8.33 m/s, temperature = 15.3°C, and relative humidity = 45.0%.