Poster Articles

DRIFTSIM -- A User-Friendly Computer Program to Predict Drift Distances of Droplets

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Abstract

A Visual BASIC language computer program (DRIFTSIM) in Windows Version was developed to rapidly estimate the mean drift distances of discrete sizes of water droplets discharged from atomizers on field sprayers. This program interpolates values from a large data base of drift distances originally calculated for single droplets with a flow simulation program (FLUENT). The simulations of drift distances up to 200 m (656 ft) included temperatures (10-30 °C; 50-86°F), discharge heights (0-2.0 m; 0-6.56 ft), initial downward droplet velocities (0-50 m/s; 0-164 ft/s), relative humidities (10-100%), wind velocities (0-10.0 m/s; 0-32.8 ft/s), droplet sizes (10-2000 µm), and 20% turbulence intensity. The program requires about 15.5 Mb of disk space. Variables can be either in metric or English units and input can be either individual droplet sizes or size classes with portion of volume in each class.

Introduction

Large amounts of pesticides are applied worldwide on a wide variety of crops. Usage on only the ten major field crops in the U.S. in 1992 was estimated at 219 million kg (482 million lb.) of active ingredient (USDA, 1992). Pesticides are essential for high quality, abundant food and fiber production.

However, they pose risks if applied improperly. Drift from pesticides has, in some cases, caused pollution of the environment and danger to humans. Accurate and rapid determination of spray drift has been a concern for many years. Many field experiments have been conducted to measure spray drift from various applications. Field experiments, however, have the limitation that weather conditions, especially wind, cannot be controlled throughout the test period and can vary during a single pass with a sprayer. Terrain and vegetation also often vary among drift measurement sites and these can influence local wind conditions and drift deposits. There is usually considerable variation among spray drift deposits even between consecutive passes of a sprayer (Fox et al., 1993; Salyani and Cromwell, 1993). Computer simulation provides a means of determining the relative effects of various factors on spray drift. There are now at least three commercial, computer models that can predict spray drift and deposition; FLUENT (Fluent Inc., Lebanon, NH 03766), AgDRIFT and AgDISP (Continuum Dynamics, Princeton, NJ 08543) and a model by Picot (University of New Brunswick, Fredericton, N.B., Canada). The latter three models are utilized primarily for simulating aerial sprays on forests. FLUENT was developed mainly for other uses besides modeling spray drift, but its accuracy in predicting spray droplet drift was verified with tests in a wind tunnel (Reichard et al., 1992a).

FLUENT has been used to simulate various aspects of agricultural pesticide applications during recent years (Reichard et al., 1992b; Almekinders et al., 1992; Sidahmed and Brown, 1993; Walklate et al., 1993; Zhu et al., 1994a, Tsay, et al., 2002a and 2002b). The program, however, has some limitations for applications. It is expensive and requires a fast computer with considerable memory, and a computer operator with special skills to run the program. Also, to model spray drift with FLUENT, a considerable amount of time is required to set up the computational conditions and calculate flow fields.

The objective of this project was to develop an easy to use BASIC language program, with values from a large data base calculated from FLUENT, to determine the effects that several variables have on the mean drift distances of water droplets up to 200 m (656 ft) from point of discharge.

Computer Program Description

Development of DRIFTSIM

First, we used FLUENT (V3.02) to establish 100 air flow fields for wind velocities in 0.5 m/s (1.6 ft/s) increments, from 0.5 to 10 m/s (1.6 to 32.8 ft/s), each with 10, 15, 20, 25, and 30°C (50, 59, 68, 77, and 86°F) ambient temperatures. The domain for the flow field simulations was 200 m (656 ft) long and 5 m (16.4 ft) high. Variables and ranges used for the data base were ambient temperature (10-30°C; 50-86°F), discharge height of droplet (0-2.0 m; 0-6.56 ft), initial vertical droplet velocity (0-50 m/s; 0-164 ft/s), relative humidity (10-100%), wind velocity (0-10.0 m/s; 0-32.8 ft/s), droplet size (10-2000 µm), and 20% turbulence intensity. Turbulence intensity is an indicator of how much the wind velocity varies about the mean (Lumley and Panofsky, 1964). Turbulence intensity can vary considerably in field conditions, but based on the frequency of 20% turbulence intensity in some of our field measurements we selected it for our simulations. The values for all variables used in the simulations are listed in Table 1. The simulated conditions and physical properties of both air and water droplets were the same as those given by Zhu et al. (1994b).

Table 1. Variables and values used in simulations for database

Variable	Units	Range	Increment
Temperature	°C (°F)	10-30 (50-86)	5 (9)
Discharge height	m (ft)	0-2.0 (0-6.56)	0.25 (0.82)
droplet velocity	m/s (ft/s)	0-20 (0-65.6)	5 (16.4)
		20-50 (65.6-164)	10 (32.8)
Relative humidity	%	10-100	10
Wind velocity	m/s (ft/s)	0-10 (0-32.8)	0.5 (1.64)
Droplet size	µm	10-100	10
		120-300	20
		350-1000	50
		1100-2000	100

After the 100 flow fields with 20 wind velocities (0.5-10.0 m/s; 1.6-32.8 ft/s) and five ambient temperatures (10-30°C; 50-86°F) were established, a batch file was written to run FLUENT and calculate the mean drift distances of 100 water droplets for all combinations of values and all increments within the ranges of variables listed in Table 1. Due to wind turbulence, the flight paths of individual droplets, especially small droplets, can vary. However, some exploratory tests indicated there was little variation in the mean drift distances among groups containing 100 droplets. The mean drift distances for all combinations of the values were stored in files corresponding to specific values for each variable. The 2,816,000 simulated mean drift distances calculated with FLUENT were collected and stored in 3200 data files.

The simulated mean drift distances were arranged in files corresponding to specific variables in 320 subdirectories. Five subdirectories were setup for five temperatures (10-30°C; 50-86°F). Each temperature subdirectory contained eight subdirectories for eight discharge heights (0.25-2.0 m; 0.82-6.56 ft). Each discharge height subdirectory contained eight subdirectories for eight droplet velocities (0-50 m/s; 0-164 ft/s). Each droplet velocity subdirectory contained ten files for ten relative humidities (10-100%). Each relative humidity file contained 880 mean drift distances (ASCII format) of water droplets, one for each combination of droplet size and wind velocity, listed in Table 1.

Based on our previous DRIFTSIM in DOS version (Zhu et al., 1995), a Visual BASIC language was used to upgrade the DRIFTSIM in Windows. The program used drift distances calculated with FLUENT to determine the mean drift distances for any desired condition within the range of variables listed in Table 1. Because the increments of variables between calculations with FLUENT were small, drift distances were assumed to vary linearly between the two closest points calculated with FLUENT. DRIFTSIM interpolates between the two closest points to obtain the drift distance for the desired value. Figure 1 shows a simplified flow chart for DRIFTSIM. The program selects the closest higher and lower values that FLUENT used for every variable to determine the lower and higher value subdirectories and files.

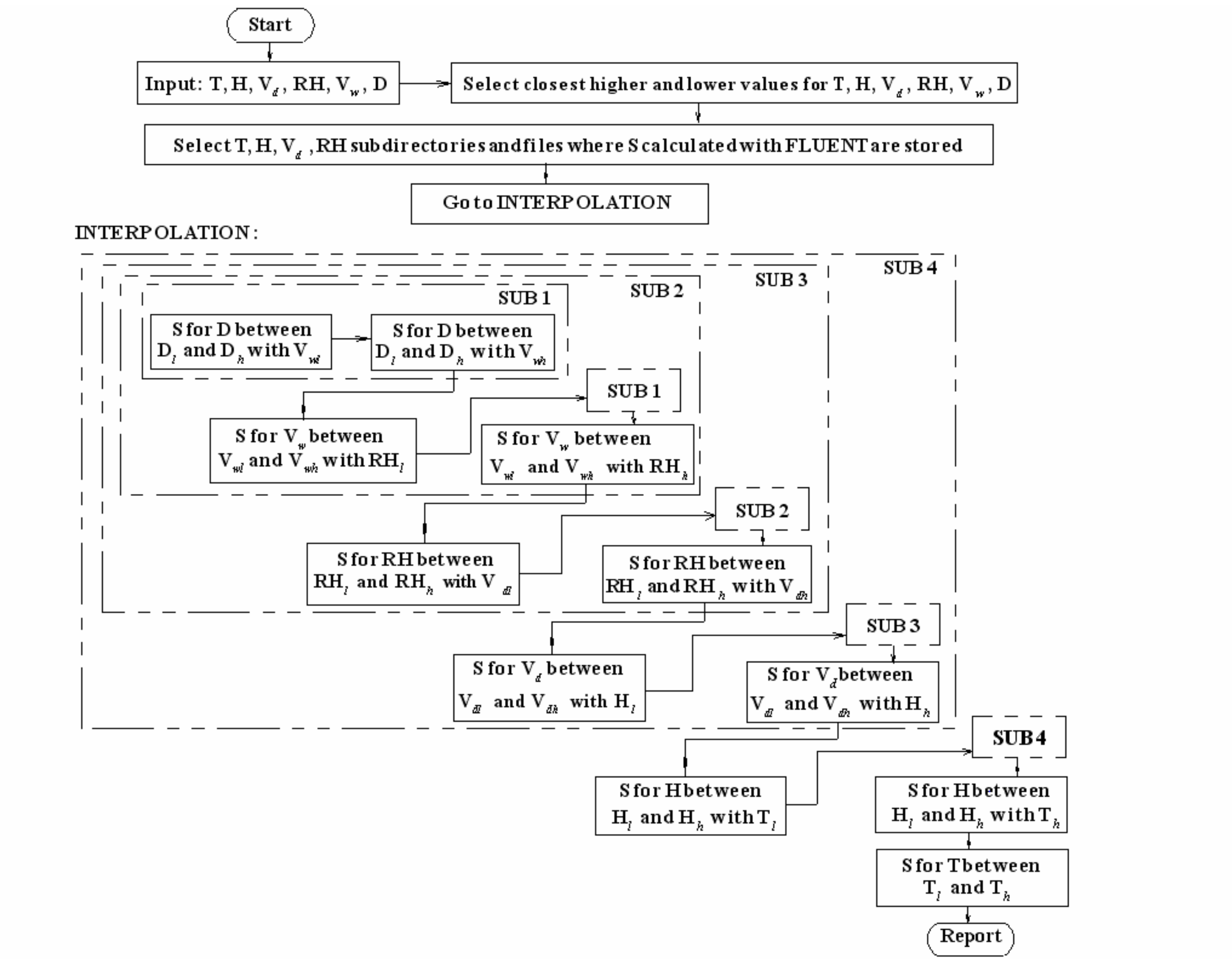

Figure 1. Flow chart of DRIFTSIM program. (T, ambient temperature; H, discharge height; V_d, initial downward droplet velocity; RH, relative humidity; V_w, wind velocity; D, droplet diameter; S, interpolated drift distance; subscript l, the closest lower value; subscript h, the closest higher value; and SUB 1, 2, 3, 4 are subroutines.)

DRIFTSIM contains four subroutines (SUB 1-4) that are repeatedly used to interpolate new drift distances for the combinations of each lower or higher value of one input variable with both lower and higher values of all other input variables. The order of interpolating the mean drift distance (S) for the input variables is droplet diameter (D), wind velocity (V_w), relative humidity (RH), initial droplet velocity (V_d), discharge height (H), and temperature (T) (see INTERPOLATION in figure 1). The interpolations start by interpolating the drift distance (S) for D between Dl and Dh with lower values of V_w , RH , V_d , H and T. Subscripts l and h indicate the closest lower and higher value of the variable. The program then interpolates the drift distance for D between D_l and D_h with higher value of V*w* and lower values of RH, V_d, H and T. Next it interpolates the drift distance for V_w between V_{wl} and V_{wh} with lower values of RH, V_d, H and T. SUB 1 (figure 1) does two interpolations. First it interpolates the drift distance for D between D_l and D_h with lower value of V_w and each combination of lower or higher value of RH with both lower and higher values of V_d, H and T. Then it interpolates for D between D_l and D_h with higher value of V_w and each combination of lower or higher value of RH with both lower and higher values of V_d, H and T. The interpolations continue through the last interpolation which interpolates the drift distance for T between T_l and T_h. If none of the values of the input variables are the same as the values of variables that FLUENT used, there will be 64 values of drift distances calculated with FLUENT and 63 interpolations to calculate the mean drift distance.

For example, the program calculates the mean drift distance in the following steps when the input values are T=20°C (68°F), H=0.61 m (2.0 ft), V_d=17 m/s (55.8 ft/s), RH=55%, V_w=2.8 m/s (9.2 ft/s), and D=155 µm. (1) Determine the closest higher and lower value subdirectories and files for each variable. For the input conditions, the program would select the following higher and lower value subdirectories and files: T_l=T_h=20°C; H_l=0.5 m (1.6 ft), H_h=0.75 m (2.5 ft); V_{dl}=15 m/s (49.2 ft/s), V_{dh}=20 m/s (65.6 ft/s); RH_l=50%, RH_h=60%; V_{wl}=2.5 m/s (8.2 ft/s), V_{wh}=3.0 m/s (9.8 ft/s); and D_l=140 µm, D_h=160 µm. (2) Search for the corresponding drift distance for each combination of the above lower or higher value of each variable with both lower and higher values of all other variables in the data files. (3) Repeatedly interpolate with the four subroutines (figure 1) for a new drift distance using the following equation.

$$\boldsymbol{S = S_l + (S_h - S_l)\frac{M - M_l}{M_h - M_l}} \qquad (1)$$

where

M=the input value for a variable such as V_w=2.8 m/s (9.2 ft/s)

M_l=the closest lower value used with FLUENT for the variable such as V_{wl}=2.5 m/s (8.2 ft/s)

M_h=the closest higher value used with FLUENT for the variable such as V_{wh}=3.0 m/s (9.8 ft/s)

S_l=interpolated drift distance from M_l

S_h=interpolated drift distance from M_h

S=interpolated drift distance for M.

The initial S_l and S_h were the values calculated with FLUENT for D_l and D_h. If M=M_l=M_h (for example, T_l=T_h=20°C or 68°F), equation (1) will be S=S_l.

Usually the mean drift distance (S) is calculated with equation (1) as described above, but two situations are special. One is when the selected variable value is located between two values where the droplet completely evaporated before deposition at one value, and deposited at the other value. The program uses equation (1) to interpolate drift distance between the two closest values. DRIFTSIM will then indicate that droplet may completely evaporate after drifting downwind distance of S for M-Ml<M_h-M, and the droplet may deposit after traveling downwind distance of S for M-M_l≥M_h-M. The other special situation occurs when the selected variable value is located between two values where the drift distance is within 200 m (656 ft) at one value, and beyond 200 m at the other value. The program will assume S_h=200 m in equation (1), and will report that the drift distance of the droplet exceeds the mean drift distance (S) for this condition.

Execution of DRIFTSIM

Input to DRIFTSIM can be in either English or metric units, discrete droplet sizes or droplet size classes with portion of volume in each class such as provided by many droplet size analyzers. The program also requests values for initial downward droplet velocity, discharge height, wind velocity, ambient temperature and relative humidity. When the input consists of droplet size classes, the program uses the midpoint of each class size as the droplet size to represent the corresponding class. For input consisting of class widths, the output is a table which includes the mean drift distance for the droplet size at the midpoint of each class.

The output of DRIFTSIM will be a statement similar to one of the four following statements.

1. Droplet would completely evaporate after traveling about (S) distance downwind. For example, with D=45 µm, V_d=21 m/s (68.9 ft/s), H=0.45 m (1.48 ft), V_w=2.7 m/s (8.9 ft/s), T=20°C (68°F), and RH=54%, a statement in the output would be "Droplet would completely evaporate before depositing after traveling about 9.75 m (32.0 ft) downwind."
2. Droplet would drift about (S) distance downwind. For example, with the same conditions as in example (a) except D=145 µm, the output report would be "Droplet would drift about 0.86 m (2.82 ft) downwind."
3. Droplet may completely evaporate (or deposit) after traveling about (S) distance downwind. For example, with the same conditions as for example (a) except droplet diameter within the 60 to 70 µm diameter range, the following occurs. A 60 µm diameter water droplet would completely evaporate before depositing after traveling 11.3 m (37.0 ft) downwind, and a 70 µm diameter droplet would deposit after traveling 8.7 m (28.4 ft) downwind. The output for a 63 µm water droplet would be "Droplet may completely evaporate before depositing after traveling about 10.2 m (33.3 ft) downwind." The output for a 68 µm diameter droplet would be "Droplet may deposit after traveling about 9.6 m (31.46 ft) downwind."
4. Droplet would drift beyond (S) distance downwind. For example, with T=20°C (68°F), H=0.5 m (1.6 ft), V_d =22 m/s (71.2 ft/s), RH=100%, and V_w=10 m/s (32.8 ft/s), the mean drift distance of 20 µm diameter droplets was beyond 200 m (656 ft), and for 30 µm diameter droplets the mean drift distance was 169.4 m (555.8 ft). With the same conditions except D=25 µm, the output would be "Droplet would drift beyond 185 m (606.0 ft) downwind."

Table 2. Comparison of drift distances calculated with FLUENT and DRIFTSIM T=20°C (68°F), RH=55%, H=0.53 m (1.74 ft), V_d=25 m/s (82 ft/s).

Droplet size	Wind velocity		Drift distance, m (ft)				Difference	
µm	m/s	(ft/s)	FLUENT		DRIFTSIM		m	(ft)
15	0.5	(1.6)	0.47	(1.5)*	0.57	(1.9)*	0.10	(0.33)
15	5.0	(16.4)	3.00	(9.8)*	3.40	(11.1)*	0.40	(1.31)
15	10.0	(32.8)	4.82	(15.8)*	5.49	(18.0)*	0.67	(2.20)
110	0.5	(1.6)	0.50	(1.6)	0.53	(1.7)	0.03	(0.10)
110	5.0	(16.4)	5.00	(16.4)	5.24	(17.2)	0.24	(0.79)
110	10.0	(32.8)	10.20	(33.5)	10.65	(34.9)	0.45	(1.48)
325	0.5	(1.6)	0.01	(0.03)	0.01	(0.03)	0.00	(0.00)
325	5.0	(16.4)	0.07	(0.23)	0.08	(0.26)	0.01	(0.03)
325	10.0	(32.8)	0.14	(0.46)	0.17	(0.56)	0.03	(0.01)
1050	0.5	(1.6)	0.00	(0.00)	0.00	(0.00)	0.00	(0.00)
1050	5.0	(16.4)	0.01	(0.03)	0.01	(0.04)	0.00	(0.00)
1050	10.0	(32.8)	0.02	(0.07)	0.03	(0.09)	0.01	(0.03)

* Droplet completely evaporated before deposition.

Accuracy of DRIFTSIM

Table 2 shows the differences between drift distances calculated with FLUENT (additional calculations for exact conditions) and values interpolated from the data base by use of the DRIFTSIM program. Droplet sizes listed in Table 2 were selected because they were midway between the droplet sizes used in the original calculations with FLUENT. Generally the greatest error due to interpolation would occur near the midpoint between values calculated with FLUENT. Table 2 indicates that drift distances calculated with DRIFTSIM agreed well with distances calculated with FLUENT. The largest difference between drift distances calculated with FLUENT and DRIFTSIM was 0.67 m (2.2 ft), or 14%, for 15 µm droplets with 10.0 m/s (32.8 ft/s) wind velocity. When the selected variable values are closer than midway between pairs of values calculated with FLUENT, the difference between the mean drift distances calculated with DRIFTSIM and FLUENT will be smaller.

DRIFTSIM was developed to predict spray drift distances for water droplets because most sprays applied with field sprayers are mainly water with a small portion of chemical. The range of relative humidity used in the DRIFTSIM program is from 10 to 100%. If the spray is non-volatile and its density is close to the density of water, drift distances of droplets would be approximately the same as those calculated with DRIFTSIM for water droplets with 100% RH.

Limitations of DRIFTSIM

Because values of some variables usually are not precisely known and change during field applications, drift distances of droplets predicted by FLUENT and DRIFTSIM will not be exact for field applications. For example, the type and size of vegetation and terrain conditions influence amount of turbulence and local wind velocity and direction. Turbulence intensity is assumed to be 20% for all drift distance calculations with FLUENT and DRIFTSIM. Due to turbulence there is a range of drift distances for specific values of the other variables. Reichard et al. (1992b) described the effects of turbulence intensity on the range of drift distances predicted by FLUENT and indicated that for water droplets 200 µm diameter and larger there was little change in the mean drift distance as turbulence intensity increased. DRIFTSIM calculates the mean drift distance of 100 droplets with 20% turbulence intensity. DRIFTSIM may not accurately predict drift distances of very small droplets when their drift distance is between two points where the droplet at one value completely evaporated before deposition or drifted beyond 200 m (656 ft), and the droplet at the other value deposited. Also, if the spray mixture contains a large portion of material that evaporates much more slowly than water, the drift distances of small droplets could be different from that predicted by the program. In spray cloud, small droplets may not evaporate as fast as the program predicts for individual droplets. The program should only be used to simulate drift distances of droplets from field sprayers without air assistance. DRIFTSIM is also setup to only consider the initial vertical velocity component of the droplet. If the droplet has a large initial horizontal velocity component, its drift distance could be different from the distance predicted by DRIFTSIM. Drift distances predicted by DRIFTSIM are only valid for the conditions selected when setting up FLUENT and DRIFTSIM. The program will indicate the relative effects of the input variables on drift distances and should, especially for large droplets, provide reasonable accuracy for many field applications.

Summary and Conclusions

A spray droplet drift simulation program was developed to predict the drift distances of spray droplets for a wide range of conditions including droplet size, discharge velocity and height, wind velocity, relative humidity and temperature. The drift simulation program, DRIFTSIM in Windows version, is written in Visual BASIC language, and is easy to use. The program prompts the operator for values of all variables. Many inexpensive, portable computers would be sufficient to run DRIFTSIM. The program requires about 15.5 Mb of disk space to store the data base and to calculate drift distances with all variables. If desired, the program can be separated to require 3.1 Mb of disk space to calculate drift distances with all variables for each of the five temperatures (10, 15, 20, 25, and 30°C; 50, 59, 68, 77, and 86°F).

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References

Almekinders, H., H.E. Ozkan, D.L. Reichard, T.G. Carpenter, and R.D. Brazee. 1992. Spray Deposit patterns of an electrostatic atomizer. Transactions of the ASAE 35(5):1361-1367.

Fox, R.D., D.L. Reichard, R.D. Brazee, C.R. Krause, and F.R. Hall. 1993. Downwind residues from spraying a semi-dwarf apple orchard. Transactions of the ASAE 36(2):333-340.

Lumley, J.L. and H.A. Panofsky. 1964. The Structure of Atmospheric Turbulence. New York: Interscience Pub.

Reichard, D.L., H. Zhu, R.D. Fox, and R.D. Brazee. 1992a. Wind tunnel evaluation of a computer program to model spray drift. Transactions of the ASAE 35(3):755-758.

Reichard, D.L., H. Zhu, R.D. Fox, and R.D. Brazee. 1992b. Computer simulation of variables that influence spray drift. Transactions of the ASAE 35(5):1401-1407.

Salyani, M., and R.P. Cromwell. 1993. Adjuvants to reduce drift from handgun spray applications. Pesticide Formulations and Application Systems: 12th Volume, ASTM STP 1146, B.N. Devisetty, D.G. Chasin, and P.D. Berger, Eds., American Society for Testing and Materials, Philadelphia, pp.363-376.

Sidahmed, M.M., and R.B. Brown. 1993. Prediction of droplet trajectories from air-blast sprayers. ASAE Paper No.93-1003. St. Joseph, MI: ASAE.

Tsay, J., H.E. Ozkan, R.D. Brazee and R.D. Fox. 2002a. CFD simulation of moving spray shields. Transactions of the ASAE 45(1):21-26.

Tsay, J., R.D. Fox, H.E. Ozkan, R.D. Brazee and R.C. Derksen. 2002b. Evaluation of a pneumatic shielded spraying system by CFD simulation. Transactions of the ASAE 45(1):47-54.

USDA Economic Research Service. 1992. Agricultural Resources, Inputs Situation and Outlook Report (February). Bull. 13p.

Walklate, P.J., K-L. Weiner, C.S. Parkin. 1993. Computational fluid dynamics: a tool for evaluating air assistance sprayer design concepts. Second international symposium on pesticide application techniques, 101-107. Strasbourg, France: BCPC.

Zhu, H., D.L. Reichard, R.D. Fox, R.D. Brazee, and H.E. Ozkan. 1994a. Simulation of drift of discrete sizes of water droplets from field sprayers. Accepted for publication by Transactions of the ASAE.

Zhu, H., D.L. Reichard, R.D. Fox, R.D. Brazee, and H.E. Ozkan. 1994b. Computer simulation of spray drift from ground sprayers. ASAE Paper No. 94-1096. St. Joseph, MI: ASAE.

Zhu, H., D.L. Reichard, R.D. Fox, H.E. Ozkan and R.D. Brazee. 1995. DRIFTSIM, a program to estimate drift distances of spray droplets. *Applied Engineering in Agriculture* 11 (3): 365-369.