6-2010

An Interactive Spray Drift Simulator

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Abstract

The off target movement of pesticides, known as spray drift, results in a reduction in application rates, damage to non-target organisms, and environmental concerns. Much of this drift can be eliminated if its prevalence is understood and best management practices are implemented. Drift prediction software has been developed to serve as a management tool in determining the effects of applying pesticides under certain operating conditions. To further increase the usefulness and instructiveness of such programs, a program was developed which links spray drift prediction software (DRIFTSIM) with a GPS simulator to obtain a two dimensional representation of drift for simulated ground based spraying event. The program was evaluated using a variety of operating conditions to determine their respective effects on drift deposition levels. Results from the simulations show the importance of choosing the largest sufficient nozzle size, operating under low wind speeds, and spraying at the lowest possible boom height. Analysis of multi-swath simulations showed patterns of increased and reduced application rates due to spray drift.

Keywords

Spray Drift, Drift Prediction, GPS Simulator, DRIFTSIM, Random Walk Model

Disciplines

Bioresource and Agricultural Engineering

Comments

ASABE Paper No. 1008842

An ASABE Meeting Presentation

Paper Number: 1008842

An Interactive Spray Drift Simulator

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**Written for presentation at the
2010 ASABE Annual International Meeting
Sponsored by ASABE
David L. Lawrence Convention Center
Pittsburgh, Pennsylvania
June 20 – June 23, 2010**

Abstract. *The off target movement of pesticides, known as spray drift, results in a reduction in application rates, damage to non-target organisms, and environmental concerns. Much of this drift can be eliminated if its prevalence is understood and best management practices are implemented. Drift prediction software has been developed to serve as a management tool in determining the effects of applying pesticides under certain operating conditions. To further increase the usefulness and instructiveness of such programs, a program was developed which links spray drift prediction software (DRIFTSIM) with a GPS simulator to obtain a two dimensional representation of drift for simulated ground based spraying event. The program was evaluated using a variety of operating conditions to determine their respective effects on drift deposition levels. Results from the simulations show the importance of choosing the largest sufficient nozzle size, operating under low wind speeds, and spraying at the lowest possible boom height. Analysis of multi-swath simulations showed patterns of increased and reduced application rates due to spray drift.*

Keywords. Spray Drift, Drift Prediction, GPS Simulator, DRIFTSIM, Random Walk Model.

Introduction

Pesticide use is essential for efficient agriculture production. Each year over 2.2 billion kg (5 billion lbs) of pesticide are used worldwide (Kiely, 2004). While the necessity for pesticide use is evident, damage from these pesticides to non-target organisms is of increasing concern. Spray drift, the off target movement of pesticides during application, results in reduced application rates and environmental contamination. While it is impossible to completely eliminate drift, it is an applicators responsibility to minimize it through the use of best management practices.

Extensive research has been devoted to identifying and determining the impact of the many variables influencing spray drift. This research includes analytical methods as well as lab and field testing. The goal of such research is to obtain models which can be used to better understand drift and through this understanding, reduce its magnitude.

The majority of the analytical techniques developed to model spray drift fall into one of two categories, plume or random walk. Plume or dispersion models treat the drift as a single cloud of which portions settle out based on diffusion. The plume model and its verification are described by Bache and Sayer (1975). Plume models are popular when analyzing drift from aircraft due to their somewhat greater accuracy in expressing long distance drift for high flow rates. Random walk models are generally more accurate for near field drift. These models account for the movement of each droplet individually as it travels from its point of release until it either evaporates or deposits. Random walk models use a numerical approach in determining the path of the droplet. Weight and drag forces, as well as a random component due to the wind turbulence are used in determining its trajectory. Thompson et al. (1983), Hall (1975), and Miller et al. (1989) each describe variations of the random walk model used to predict spray drift. Holterman et al. (1997) developed a model which is three dimensional (3-D) near the nozzle to account for air entrainment due to high initial droplet velocity. This model is reverted back to the basic two dimensional (2-D) random walk model once the air entrainment is no longer prevalent.

Development of regression models is commonly the goal of field and lab tests. Field testing is difficult due to the every changing weather conditions, especially wind speed and direction. Smith et al. (1982) developed regression models from 99 in-field tests. Five equations were derived using 18 variables. Boom height and wind speed were included in each of the equations due to their significant influence on drift. Smith also found that the operator has direct influence on 68-90% of the amount of drift which occurs during spraying. Threadgill et al. (1975), Bode et al. (1976), and Smith et al. (2000) also derived regression models from in-field testing for a wide range of variables. While these regression model can have relatively high coefficients of determination (0.83 to 0.87 in the case of Smith et al.), they also have several limitations. The ranges of each tested variable are constricted due to the large amount of time and resources needed to collect data for wider ranges. Secondly, drift distances are rarely measured over 30 m, again due to the scope of a project required to measure a larger range. These restrictions limit individual regression models to only being able to describe near field drift for a narrow range of each variable.

Several software programs which use variations of regression models as well as analytically derived equations have also been created. The ability of the analytical methods to be applied to a variety of conditions makes them especially useful in such venues. AGDISP and DRIFTSIM are two such programs. AGDISP uses a Lagrangian approach to predict drift for both aerial and ground applications (Bilanin et al., 1989). DRIFTSIM, was developed specifically for ground boom applications. It was created using FLUENT, a computational fluid dynamics (CFD) program, through the implementation of random walk model to predict drift (Zhu et al. 1995). AGDISP represents drift in terms of deposition levels (L/ha or gal/ac) while DRIFTSIM reports

drift as distances for individual droplet sizes. These programs are excellent tools to educate applicators on the influence of operating parameters on drift. The impact of weather conditions such as wind speed, temperature, and humidity and sprayer operating parameters like nozzle type (droplet size), boom height, and pressure can be quickly analyzed and the knowledge gained from such programs can be applied in the field to reduce drift.

While these models are excellent teaching tools, they are limited to representing drift distances or deposition levels in one dimension, either graphically in the case of AGDISP or through a tabled output in the case of DRIFTSIM. A 2-D drift simulator would increase the educational abilities of these programs as well as allowing for the impact of wind direction and multi-pass events to be modeled.

Specific objectives for a 2-D drift simulator are as follows:
- Provide user interface for easy entrance of influential drift variables.
- Predict drift using an established model.
- Extend drift prediction to 2-D.
- Link drift predictor with GPS simulator for enhanced interfacing.
- Store continuously updated drift deposition data within program during application.
- Write drift deposition data to ".txt" file at conclusion of simulation for analysis.

Program Development

DRIFTSIM was developed solely for ground applications whereas AGDISP is currently better suited for aerial applications. The focus of this project was on ground applications therefore DRIFTSIM was chosen as the drift prediction model for the 2-D drift simulator. (see Zhu et al., 1995 for DRIFTSIM development). DRIFTSIM contains the resulting drift distances from the FLUENT simulations of over 2.5 million unique sets of weather/operating conditions. Variables and tested ranges of each are shown in table 1 (Zhu et al. 1995).

Table 1. DRIFTSIM variable ranges

Variable	Units	Range
Temperature	°C	10-30
Nozzle Height	m	0-2.0
Droplet Velocity	m/sec	0-50
Relative Humidity	%	10-100
Wind Velocity	m/sec	0-10
Droplet Size	µm	10-2000

The accuracy of FLUENT was evaluated by Reichart et al.(1992). The results of this research show FLUENT to be highly accurate for the drift distances tested with correlations between the measured and calculated data above 0.95; however this testing was done for short drift distances (< 2 m). The correlation for greater drift distances is unknown. The random walk model evaluated by Miller et al. (1989) was very accurate up to drift distances of 30 m, with the model under-predicting at greater distances. While Miller's model is slightly different than that used in FLUENT, similar trends are expected.

DRIFTSIM functions by recalling drift distances from "lookup" tables based on input operating conditions. While effective for single predictions, this method of determining drift distance would take valuable processing time and reduce the update rate of the continuously running 2-D drift

simulator. An equation relating the operating conditions to the drift distance of droplets was derived to eliminate the lookup tables and reduce this prediction time (equation 1). This equation was developed using the non-linear regression application in SAS (SAS, 2004) and has a coefficient of determination of 0.65. It is important to note that this equation was derived from data produced from FLUENT rather than experimental field data thus it is difficult to gauge it true accurateness. While it has a lower coefficient of determination than those equations developed by Smith et al., it is applicable to a much wider range of operating conditions, and is thus preferred for this application.

$$DD = 383.9 * \frac{NH^{0.45} * WS^{0.35} * RH^{0.24}}{DS^{0.84} * NV^{0.05} * Temp^{0.04}} - 3.67 \qquad (1)$$

Where:
DD=drift distance (m), NH=nozzle height (m), WS=wind speed (m/sec), RH=relative humidity (%), DS=droplet size (μm), NV=nozzle velocity (m/sec), Temp=temperature (°C)

From equation 1 it can be seen that varying temperature or nozzle velocity within typical operating ranges has little impact on the magnitude of drift distance. Varying the nozzle height, wind speed, relative humidity, or droplet size however does result in significant changes of drift distance. This equation tends to over-predict near field drift while under-predicting far field drift when compared to data from FLUENT simulations. The benefit from using this equation rather than the lookup table method was a 60% reduction in computing time.

A C++ language program was written to take inputs applied through a user interface and produce drift deposition levels at distances relative to a sprayer position. The program provides for serial inputs of GPS coordinates through National Marine Electronics Association (NMEA) data strings to determine current sprayer position and corresponding deposition locations (latitude and longitude). Serial communication allows position inputs from a GPS simulator for as-applied drift data. The user interface contains buttons for startup, stopping calculations, and writing of the produced data to a ".txt" file (see figure 1). This data can then be uploaded to imaging software such as GIS or Spatial Management System (SMS; Ag Leader, Ames, IA) for evaluation.
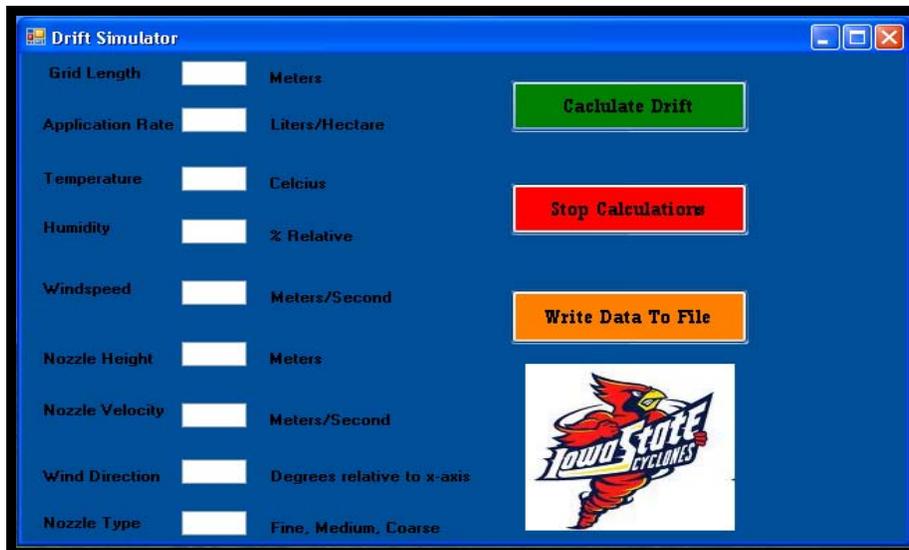

Figure 1. Drift Simulator user interface

User inputs to the drift simulator include grid length, application rate, temperature, humidity, wind velocity, boom height, nozzle velocity, wind direction, and nozzle classification (fine, medium, coarse). Droplet spectrums for each nozzle type and the number of nozzles on the boom were hardcoded into the program. A flowchart showing the drift prediction and deposition routine for a single nozzle is shown in figure 2. The grid length input by the user determines the size of each grid for which a level of drift deposition is calculated. Entrance of a grid length creates an array of grid cells, each of area "length" squared. This array is representative of a square field. Upon startup of a new drift simulation, the centermost cell of the array is assigned the first set of GPS coordinates received from the GPS simulator, "Lat_initial" and "Long_initial". When new GPS coordinates are read into the system, a new cell location is assigned to the sprayer based on the haversine equation (equation 2) and the grid-length (used to calculate "del_x" and "del_y" in figure 2). The program then calculates the drift distance for droplet size "i", based on the nozzle type input by the user.

$$sin^2\left(\frac{d}{2R}\right) = sin^2\left(\frac{\Delta Latitude}{2}\right) + cos(Lat_1)cos(Lat_2)sin^2\left(\frac{\Delta Longitude}{2}\right)$$

(2)

Where:
d= distance between two geographical coordinates
R=radius of sphere (average of 6367 km for earth)

Droplet spectrums measured according to ASAE S572.1 (1999) for the available nozzle types are stored as vectors Fine, Medium, and Coarse. With the drift distance known, the exact grid cell of deposition for each droplet size is determined from the sprayer's current location, the drift distance, and the wind direction "θ". The volume deposited within this grid is equal to the percent of the nozzle spectrum containing the applied droplet size "i" multiplied by the volume dispensed from the nozzle over the duration for which drift occurs to the cell. This sequence is carried out for all droplet sizes defined by the nozzle spectrum. Statistical properties regarding wind speed fluctuations during the flight time of the droplet are included in the drift distance predictions for each droplet size to account for air turbulence. In the development of DRIFTSIM, random walk models were evaluated using 20% turbulence, therefore wind speed variances measured from field tests by Leung et al. (1996) at this turbulence were applied to the drift prediction model. The program assumes that 10% of the volume within each droplet size category is acted upon by wind speeds one standard deviation greater than the input wind speed, and 10% of the volume is acted upon by wind speeds one standard deviation less than the input wind speed. This statistical inclusion provides a smoothing effect on the resulting deposition data.
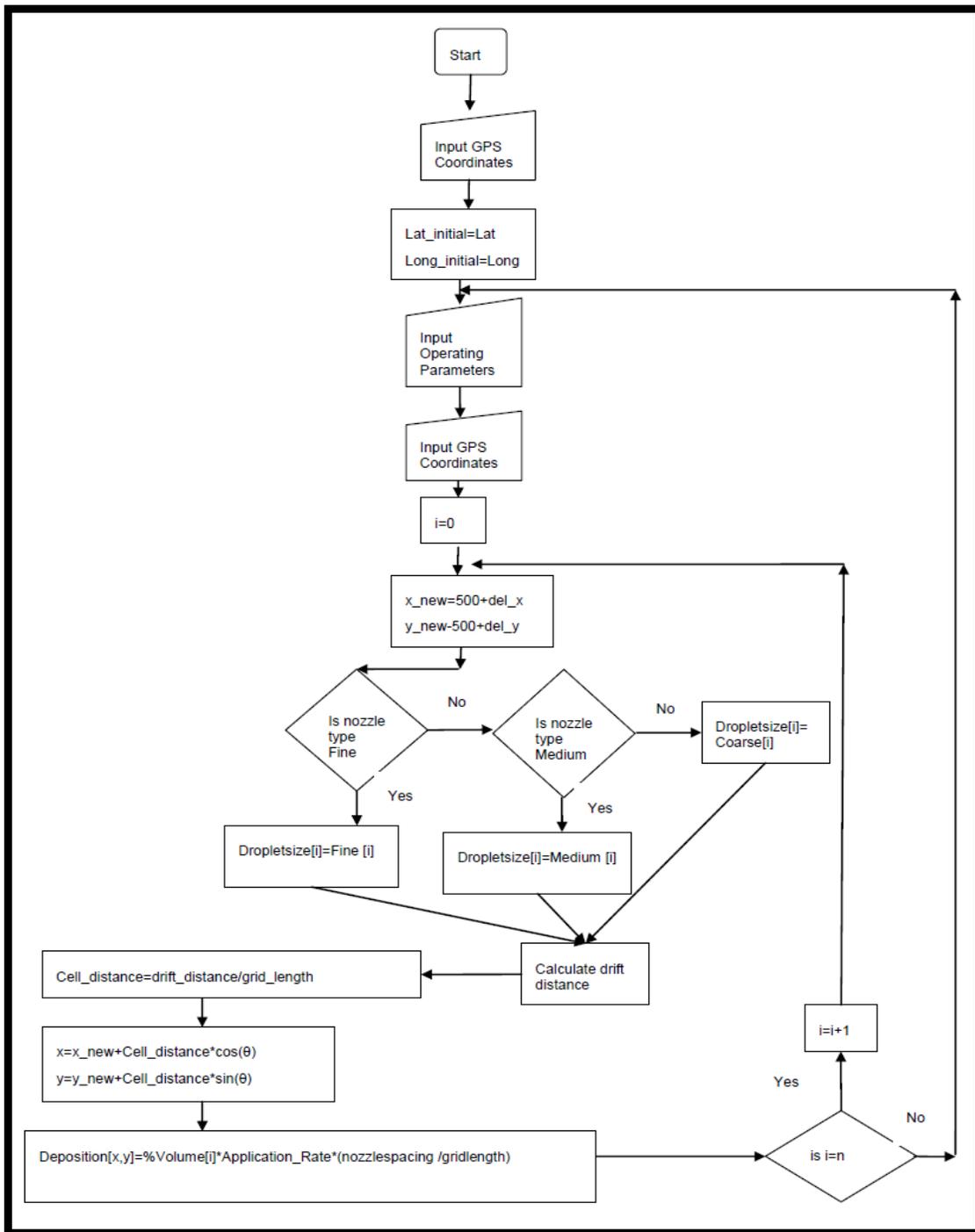
Figure 2. Drift simulator flow chart

During a spraying simulation event, the prediction loop in figure 2 will occur for each of the nozzles on the boom, offsetting the deposition location based on the distance of the nozzle from the center of the boom. In addition to calculating drift for each of the nozzles on the boom, the program "fills in" grids between prediction vectors thus creating a continuous drift prediction area (see figure 3). This filled in region is based on an assumed straight line path from the last vector written to the deposition grid to the current vehicle location with constant operating conditions over the path.
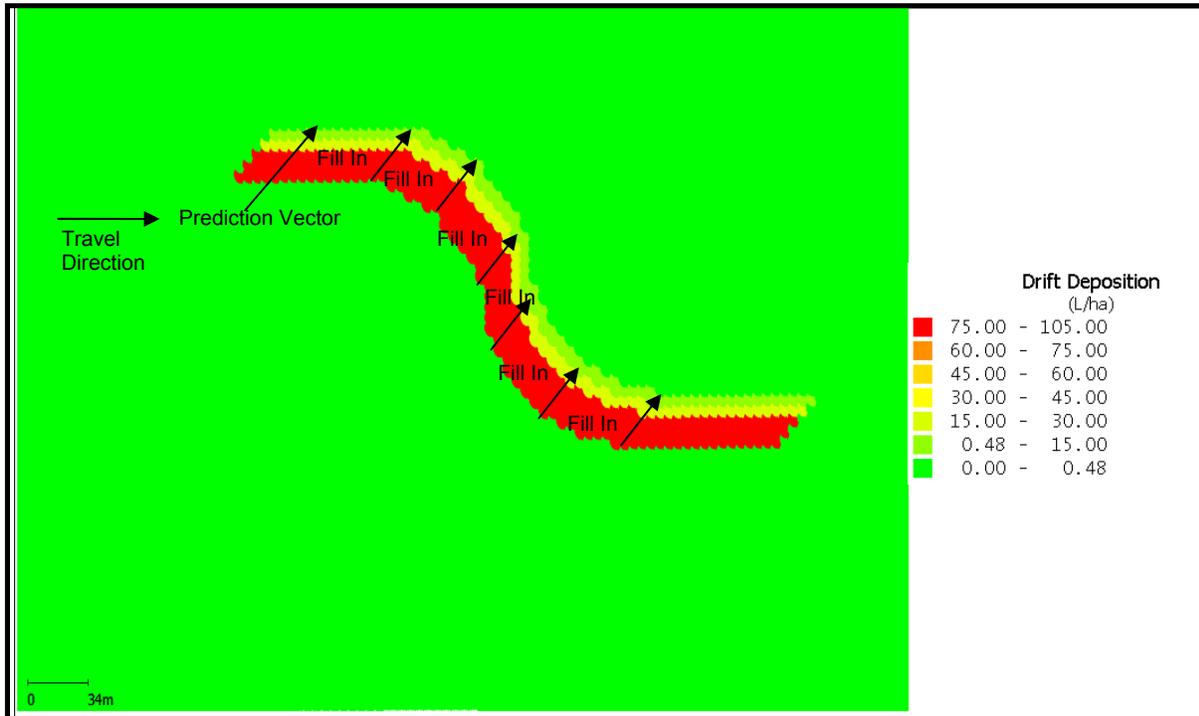

Figure 3. Drift fill in between prediction vectors

The drift simulator maps drift from the center of the boom. This allows representation of deposition within half of the boom width and beyond the end of the boom up to 200 m. The 2-D representation of drift allows for viewing of the impact of wind direction on drift. The wind direction determines the line of travel of the droplets as they leave the sprayer. Within the program, the wind direction is accounted for from 0°-360° in 45° increments. When the sprayer experiences a headwind or tailwind, drift deposition is accounted for across the full width of the boom.

The size of the grid arrays constrain the maximum field size for which drift can be mapped subject to storage memory. This array is set within the program as 1000 units by 1000 units or one million grid cells. The maximum field size is then based on the grid length input by the user. The program can handle grid lengths from 1 m to 100 m. Larger grid lengths result in larger mappable fields and faster processing times which can lead to greater program accuracy but they reduce resolution of the drift representation. A recommended grid length of 5 m results in a maximum mappable area of a little more than 2400 ha (6000 ac). While this maximum area is

relatively large, linking the center of the grid to the initial sprayer position limits the maximum length of initial straight line travel in a single direction to 2.4 km (1.5 miles).

The 2-D Drift simulator requires 400 MB of RAM for simulations using one million grid cells. When run on a 1.8 GHz computer, a drift prediction is performed every 0.5 seconds for 5 m grid spacing. For a sprayer operating at 24 km/hr (15 mph) this correlates to an update every 3.3 m (11 ft). Operating conditions can be changed during simulation to analyze changing conditions within the field.

Upon completion of a simulation event, the user can write a ".txt" file containing the drift deposition levels within each grid. In addition to the deposition level the file also contains the latitude and longitude of each grid. Due to the number of grids this file is relatively large, approximately 25 MB.

Results

The drift simulator was run for a variety of conditions to represent the impact of operating conditions on drift deposition and the ability of the simulator to express these impacts. The operating conditions tested were as follows:
- Wind speed
- Boom height
- Nozzle type
- Wind direction
- Multiple swaths

Operating parameters, when not being tested, were held constant throughout each of the tests. These parameters were as follows:
- Application rate: 100 L/ha (10.7 gal/ac)
- Temperature: 26 °C (79 °F)
- Relative humidity: 60%
- Wind speed: 4.4 m/sec (9.8 mi/h)
- Nozzle velocity: 20 m/sec (44 mi/hr)
- Wind direction: 0° (Due East)
- Direction of travel: 90° (Due North)
- Nozzle type: Medium
- Nozzle (boom) height: 0.6 m (2 ft)

The ".txt" files created from these simulations were uploaded into SMS software. SMS provides an easy linkage of attributes to GPS coordinates for mapping. Once uploaded, exact deposition levels within grids can be analyzed in addition to viewing data trends through the legend spectrum.

Wind speed

The drift simulator was run for wind speeds of 0.44 m/sec, 1.1 m/sec, 2.2 m/sec, 4.4 m/sec, 6.6 m/sec, and 8.8 m/sec. Figure 4 displays the result file from this test. Shown are the drift deposition levels to the right of the center of the boom. The default boom width is 30 m therefore much of the drift deposition occurs within the boom width or first 15 m. For subsequent results, distances are given from the boom edge rather than the center of the boom. For the 0.44 m/sec

wind speed, drift occurs up to 10 m, where there is 5 L/ha of deposition. For the 8.80 m/sec wind speed, deposition at 10 m is 40 L/ha and occurs up to 25 m from the boom edge. Deposition near the center of the boom is around 95 L/ha, with the rate increasing to above 100 L/ha as position moves toward the end of the boom. This increasing rate within the boom width is due to the compiling drift levels from each individual nozzle.
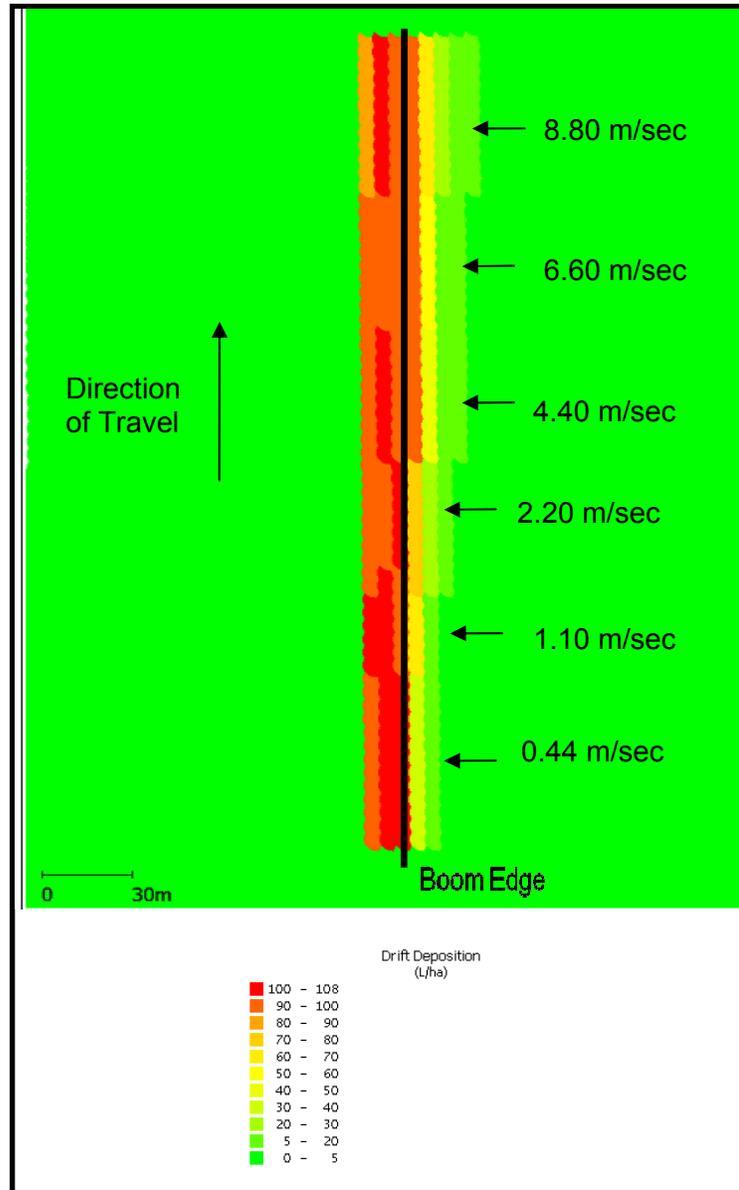

Figure 4. Wind speed test

Boom height

The influence of boom height on drift deposition, as determined by the drift simulator, is shown in figure 5. Boom heights of 0.30 m, 0.61 m 0.91 m and 1.21 m were tested in this simulation. The 1.21 m boom height results in an increase in maximum drift distance of 10 m when compared to the lowest boom height. For the 1.21 m boom height at 10 m, drift deposits of 61 L/ha are found whereas for the 0.30 m boom height this deposition at the same distance is only 7 L/ha.
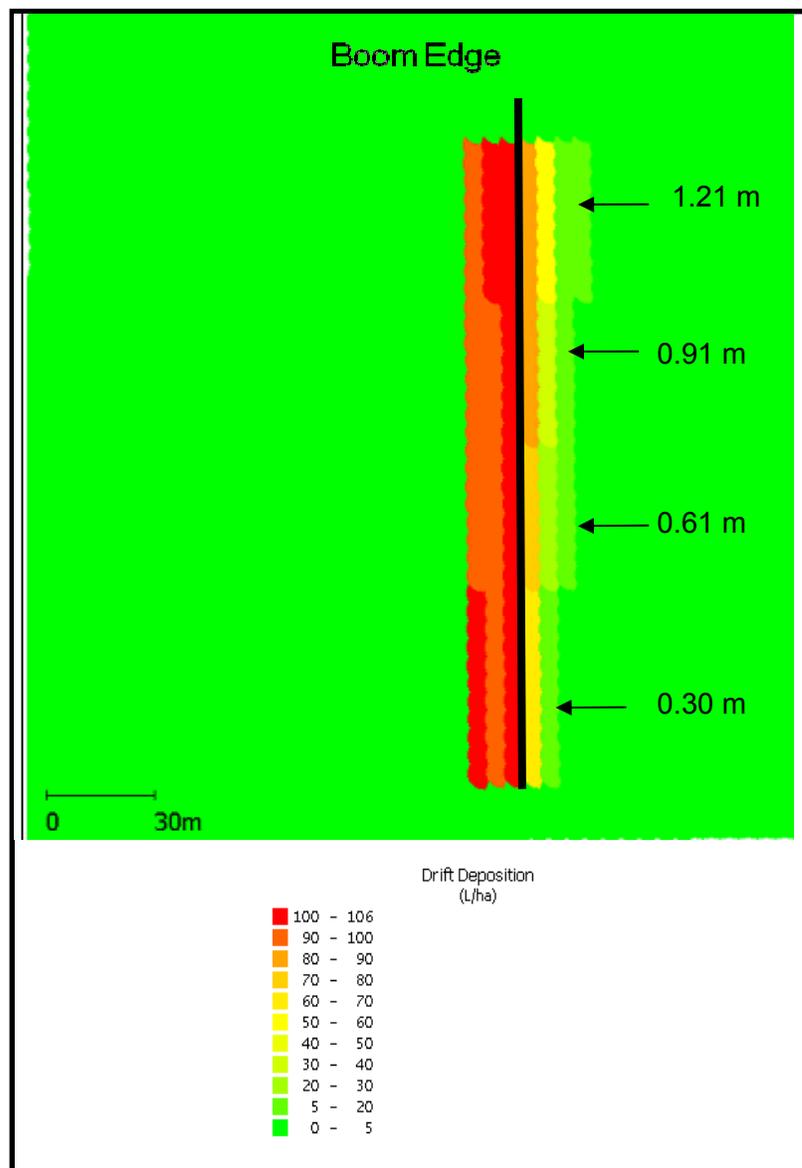

Figure 5. Boom height test

Nozzle Type

Nozzle type was tested and the results shown in figure 6. Fine, medium, and coarse nozzles droplet spectrums measured according to ASAE S572.1 (2000) were stored within the program allowing for this analysis. At 7 m from the end of the boom, the fine nozzle produces 40 L/ha of deposition, while the medium produces 15 L/ha, and the coarse 6 L/ha. For the deposition as a whole, there is little difference between the coarse and medium nozzles; however there is a large difference for the fine.
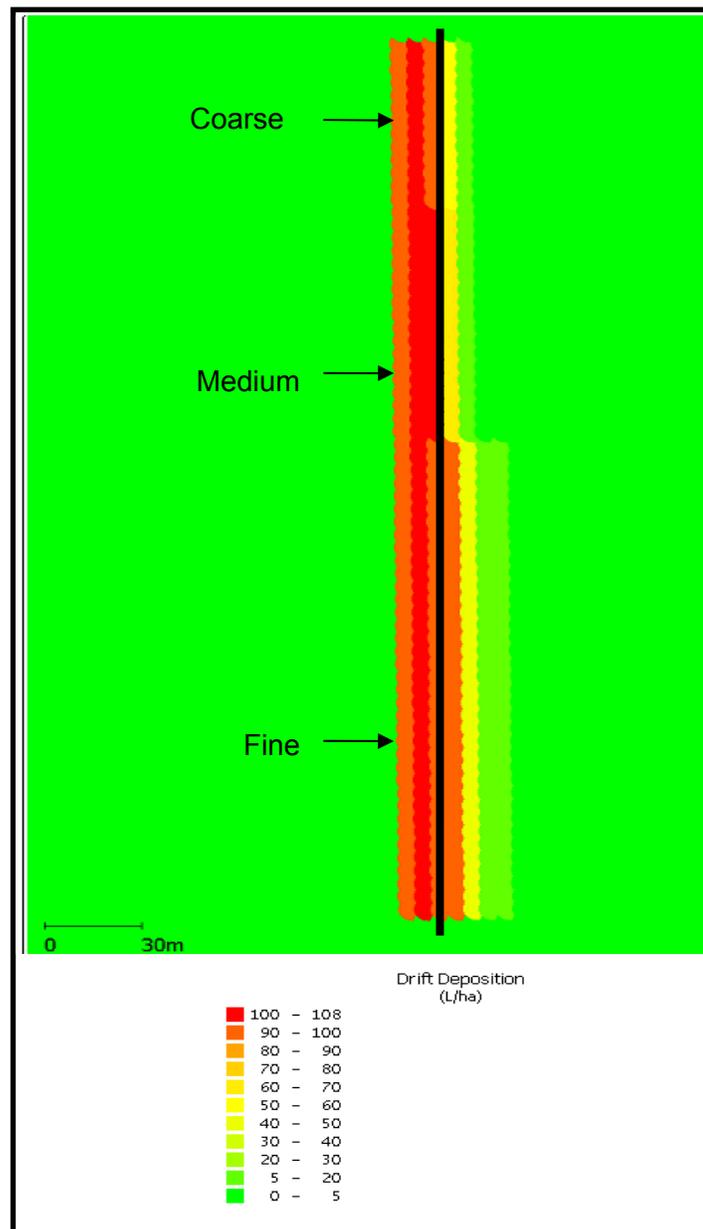

Figure 6. Nozzle type test

Wind direction

A wind direction of 135° relative to due east is shown in figure 7. This figure represents spraying around a sensitive area within a field, such as a pond, and was created by changing the sprayer path within the GPS simulator. The sprayer approaches the pond from the lower edge of figure 7 and drives counter-clockwise around the pond. The pond has an area of 0.73 ha, however spraying with the boom up next to the edge of the pond reduces the unsprayed area to only 0.6 ha due to drift. The bottom left turn of the pond result in 96 L/ha being applied within the pond. Such practice could cause considerable harm to the sensitive area. Also noticeable from figure 7 are several very high application rates that result from turning within the field as well as the wind direction. The application rate is doubled in some areas due to this combination of events.
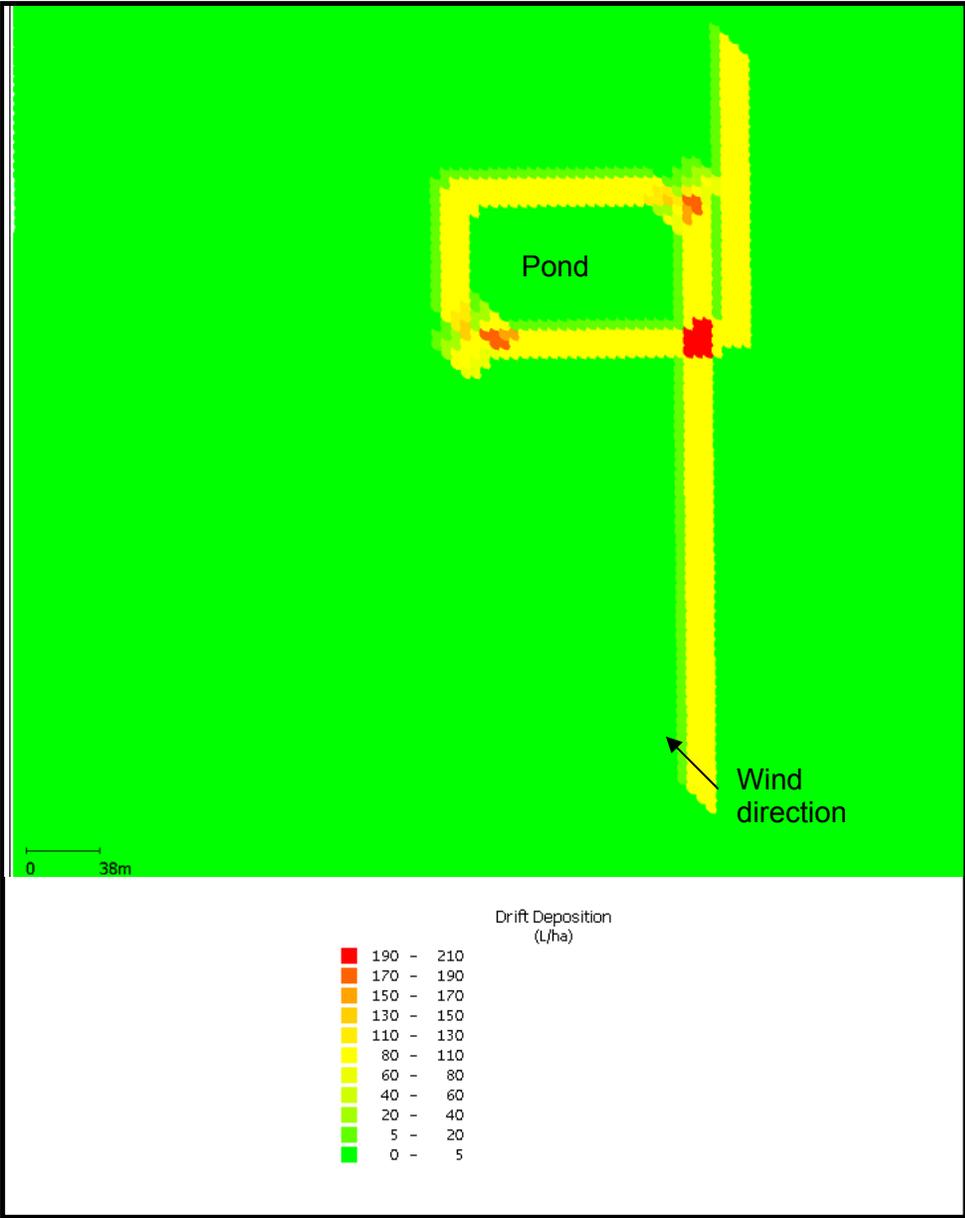

Figure 7. Wind direction test

Multiple swaths

Figure 8 shows a multi-pass spraying event. In the simulation of this event, the sprayer made four swaths within the field, starting at the lower right corner of figure 8. While the in-swath deposition for half of the boom is not accounted for in the plot, the patterns resulting from drift are still evident. Strips within the swath receive only 60 L/ha of deposition while others receive as much as 160 L/ha. On the end rows, deposition doubles and even triples in some areas due to overlap as well as drift.
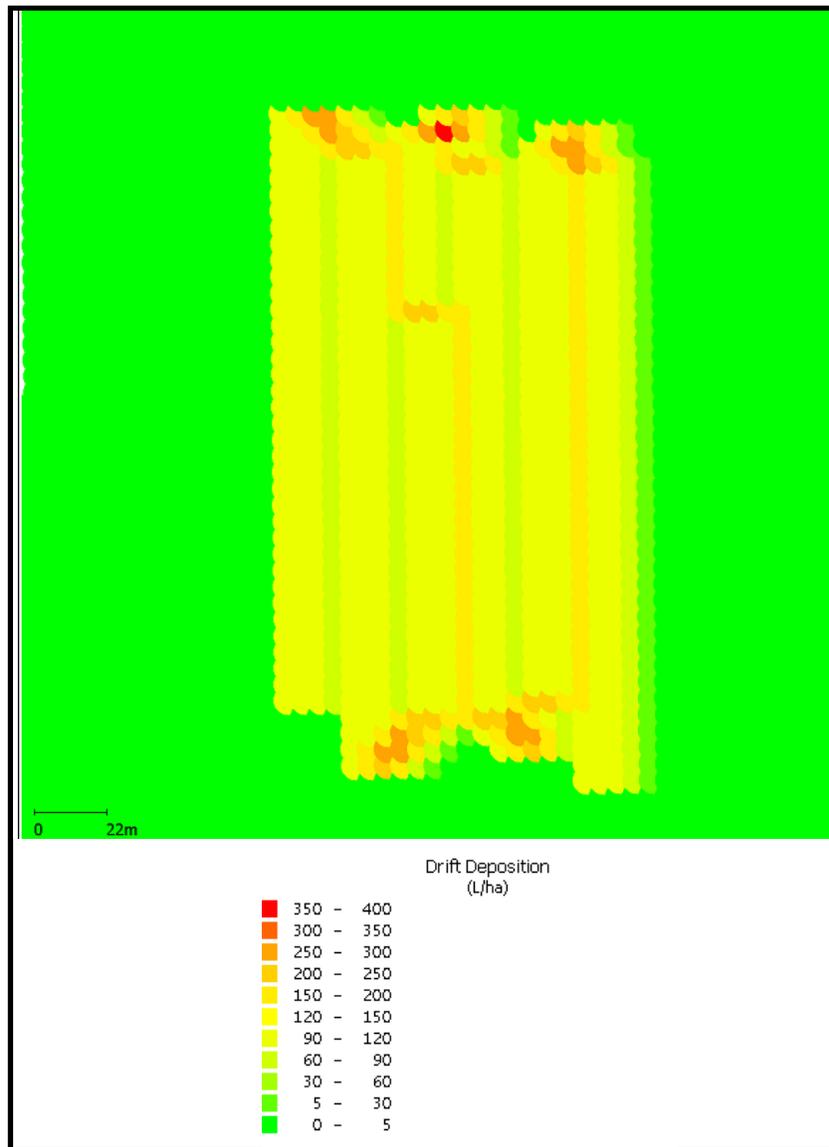

Figure 8. Multi-swath test

Conclusion

A 2-D drift simulator was developed to increase the educational potential of a drift prediction software previously developed. This drift simulator possesses capabilities to be linked to a GPS simulator to provide insight into deposition resulting from spraying events within the field. The drift simulator accounts for temperature, humidity, wind speed, boom height, nozzle velocity, droplet size, and wind direction. These variables can be altered during a spraying simulation to analyze the impact of each on the resulting deposition.

Results from simulations show the high impact of wind speed, boom height, and nozzle type on drift deposition. Boom height appears to have a greater impact on drift deposition than wind speed, as evidenced by simulations as well as equation 1. Boom height varied from 0.3 m to 1.21 m resulted in a 54 L/ha increase in deposition 10 m from the boom edge. Varying wind speed from 0.44 m/sec to 8.80 m/sec corresponded to a deposition increase of 35 L/ha at 10 m. The medium nozzle greatly reduced deposition when compared to the fine nozzle (45 L/ha difference) however there was little difference in the medium and course nozzles. The similarity between deposition of the medium and course nozzles is due to both having a small percentage of the droplet spectrum less than 200 μm.

Additional testing of the drift prediction equation used within the drift simulator is required to evaluate its ability to represent drift at distances greater than several meters. Modifications to the program such as additional available nozzles and increased wind direction resolution would add to the programs functionality. A secondary program modification which would add to the programs usefulness would be to add several additional drift prediction equations such as that from Smith et al. (2000). An additional section in the user interface could allow for selection of the model used for drift prediction. The model selection process could also be handled by the program based on the operating conditions and the models strengths, to maximize accuracy.

References

ASAE. 1999**.** ASAE Standard S-572 AUG 99**:** Spray nozzle classification by droplet spectra. American Society of Agricultural Engineers, St. Joseph, MI.

Bache, D.H., and W.J.D. Sayer. 1975. Transport of aerial spray, I. A model of aerial dispersion. *Agricultural Meteorology* 15:257-271.

Bode L.E., B.J. Butler, and C.E. Goering. 1976. Spray Drift and Recovery as affected by spray thickener, nozzle type, and nozzle pressure. *Transactions of the ASAE 19(2):*213-218.

Dumbauld, R.K., J.E. Rafferty, and J.R. Bjorkland. 1977. Prediction of spray behavior above and within a forest canopy. USDA Forest Service Report. TR-77-308-01.

Hall C.D. 1975. The simulation of particle motion in the atmosphere by a numerical random walk model. *Quarterly Journal of the Royal Meteorological Society* 101:235-244.

Holterman H.J., J.C. van de Zande, H.A.J. Porskamp, and J.F.M. Huijsmans. 1997. Modeling spray drift from boom sprayers. *Computers and Electronics in Agriculture* 19:1-22.

Kiely, T., D. Donaldson, and A. Grube. 2004. Pesticides and Industry Sales and Usage: 2000 and 2001 Market Estimates. U.S. EPA.Washington, D.C.

Leung D.Y.C, and C.H. Liu. 1996. Improved Estimators for the standard deviations of horizontal wind fluctuations. *Atmospheric Environment* 30(14): 2457-2461.

Miller P.C.H, and D.J. Hadfield. 1989. A simulation model of the spray drift from hydraulic nozzles. *Journal of Agriculture Engineering Research* 42:135-147.

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

SAS. 2004. *SAS User's Guide: Statistics.* Ver. 9.2. Cary, N.C.: SAS Institute, Inc.

Smith D.B., F.D. Harris, and C.E. Goering. 1982. Variables affecting drift from ground boom sprayers. *Transactions of the ASAE* 25(6):1499-1523.

Smith, D.B., L.E. Bode, and P.D. Gerard. 2000. Predicting ground boom spray drift. *Transactions of the ASAE* 43(3):547-553.

Thompson N., and A.J. Lev. 1983. Estimating spray drift using a random-walk model of evaporating drops. *Journal of Agriculture Engineering Research* 28:419-435.

Threadgill E.D., and D.B. Smith. 1975. Effects of physical and meteorological parameters on the drift of controlled-size droplets. *Transactions of the ASAE* 18:51-56.

Zhu, H., D.L. Reichard, R.D. Fox, H.E.Ozkan, and R.D. Brazee. 2005. DRIFTSIM, a program to estimate drift distance of spray droplets. *Applied Engineering in Agriculture* 11(3):365-369.