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AgDISP Sensitivity to Crop Canopy Characterization

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***Abstract**. As computer-based decision and modeling systems become increasingly integrated into American agriculture, it is important that users of these systems have the understanding of the effects that various inputs have on systems. The objective of the work presented is to quantify the effects that different crop canopy characteristics, such as height and canopy closure, have on aerially-applied spray deposition and downwind movement and compare these results to the predictions of spray movement and deposition by the AgDISP, a computer model.*

Six trials were conducted in cotton fields ranging from bare ground up to 1 m in height and canopy closure ranging for 0-100%. Horizontal deposition measurements were used to verify that each of applications made during each of the trials produced similar levels of deposition. Monofilament string were placed at four sampling heights (1,2 ,4 and 6 m) above the canopy at a distance of 50 m from the downwind edge of the spray swath to measure the airborne droplets at this distance. The vertical deposition values at 50 m for crop heights between 0.3 and 0.8 m were comparable between the field collected and AgDISP predicted data. The AgDISP model overpredicted by a factor of 2 the levels of spray at 1 m for the trials conducted at 0 or 1 m crop canopy height as compared to field measurements; however, at 4 and 6 m above the ground, the AgDISP and field data were very comparable. User of the AgDISP should be encouraged by the accuracy of the model but are cautioned when using the model with canopies that are closed more than 80%.

Keywords: Aerial application, AgDISP, spray drift, spray deposition, sampling

Introduction

As in all facets of modern life, computers are becoming an essential tool for the application of agricultural production and protection chemicals. Computers are used in the guidance and application systems of modern equipment and are increasingly being integrated in the decision making system of when and how a particular agrochemical should be applied. As these decisions are being made, it is important that users of these systems have the understanding of the effects that various inputs have on these decision and modeling systems.

Computer models for predicting spray deposition and dispersal have been developed over the last 30 years (Dumbauld et al., 1980, and Mokeba et al., 1998). AgDISP is the model that is currently being used in the field of aerial application. AgDISP is a near-wake model that "solves a Lagrangian system of equations for the position and position variance of spray material released from each nozzle on an aircraft" (Teske and Thistle, 1999). Teske et al. (2000) used this model to predict deposition and drift from aerial spray nozzles. Previous studies in two crop canopies have shown that while the levels of spray material that moves downwind may be similar for field-collected data and AgDISP-predicted data, the AgDISP model is very sensitive to certain model inputs (Hoffmann, 2006). Canopy height and wind speed were reported to have significant impact on the amount of material that was predicted to move downwind by the model. The comparison of field-collected data to the model prediction can improve the confidence that aerial applicators, researchers, and regulators have in the model.

Applying crop protection chemicals by aircraft is a complex combination of application equipment, operational conditions, meteorological factors, and human judgment, which come together to influence on- and off-target deposition and the overall effectiveness of an agrochemical application (Yates et al. 1974; Threadgill and Smith, 1975; Kirk et al., 1991; and Salyani and Cromwell, 1992). Droplet size and spray formulations have been found to significantly affect drift from aerial applications (Yates et al., 1976; and Bouse et al., 1990). Increased turbulence at the site of deposition may entrain smaller droplets and influence deposition at the target site (Lawson and Uk, 1979). Many studies have been conducted to investigate the influence of crop canopy and canopy interception on spray deposition and movement (Kirk et al., 1994, 1998, and Hoffmann, 2001).

The objective of the work presented in this paper is to determine the effects of different canopy characteristics, such as height and canopy closure, on spray deposition and downwind movement. These results are then compared to AgDISP predicted values.

Materials and Methods

To accomplish the research objectives, several spray trials were conducted using a fixed-wing agricultural aircraft. The trials were designed to measure the horizontal deposition and downwind movement of spray droplets over several crop canopy heights and bare ground. Horizontal samplers (100 cm^2 mylar sheets) were placed in-swath at five downwind distances from the designated flightline and perpendicular to the prevailing wind to represent a "worst-case" scenario for spray drift. The small component of the applied spray solution that deposited on the vertical samplers or strings at 50 m downwind was quantified and will be referred to as vertical deposition. These deposition data were then compared to the results that were computed or "predicted" by the AgDISP model.

Spray Treatments

The spray solution was water, Triton X-100 at 0.1% v/v, and Caracid Brilliant Flavine FFN fluorescent dye at 37 g/ha (15 g/acre). The fluorescent dye was used as a tracer to measure the deposition and downwind movement of the spray during the tests. The same AirTractor 402B aircraft was used in all tests and the operational parameters were: speed –209 km/h (130 mph); visually-assessed approximate boom height above canopy – 3 m (10 ft); swath width – 19.8 m (65 ft); spray rate – 28.0 L/ha (3 gal/acre). Twenty-five CP-03 nozzles were used with the following operational settings: orifice- 0.125; spray pressure - 206 kPa (30 psi); deflector - 30°; volume median diameter - 274µm. At each testing date, five replications were conducted in each canopy.

Field Plots

All tests were conducted in cotton fields (30°26'39" N, 96°21'45" W, 60 m (200 ft) above MSL) near College Station, TX in the summer of 2005. The cotton was planted on 0.9 m (36 in) rows. A total of six tests were conducted with the average canopy characteristics from five plants at five locations measured at the time of each tests are shown in Table 1. The tests with a canopy height of 0 m was conducted after stalks were shredded on a plowed cotton field near the other test sites. During each test, the prevailing wind was 30-45° across the cotton rows. All sampling lines and center of the flightline were at least 100 m inside the field to minimize any field edge effects.

Table 1. Cotton canopy characteristics for the six tests.

Plant Height (m (in))	Plant Width (m (in))	Closure Canopy* (%)
0	0	0
0.33 (13)	0.25 (9.8)	27.2
0.59 (23.2)	0.36 (14.2)	39.4
0.70 (27.6)	0.46 (18.2)	50.6
0.85 (33.5)	0.72 (28.2)	78.3
1.0 (39.3)	0.91 (36)	100

* - Canopy Closure = Width/row spacing

Horizontal and Vertical Spray Deposition Measurements

A 600-m long flightline was established during each test. This flightline was laid out perpendicular to the prevailing wind and is referred to as flying crosswind. The aircraft sprayed the entire flightline, which constituted a spray trial replication. Horizontal mylar cards were held at the top of the crop canopy at nine locations: -15, -10, -5, 0, 10, 20, 30, 40, and 50 m from the downwind edge of the intended swath of the aircraft (fig. 1). Four of the samples represented in-swath deposition, while the other samplers measured downwind deposition of the spray material. A sampling station was established 50 m downwind of the center of the 600-m long flightline. At this sampling station, two vertical towers were positioned 10 m apart and orthogonal to the prevailing wind and parallel with the flightline. Monofilament line (0.5 mm in diameter) was suspended between these towers at four heights (1, 2, 4, and 6 m) above the ground. The 10-m long monofilament lines were parallel to the flightline and provided a measure of the airborne component of the spray. The AGDISP model predicted that the spray droplet size 50 m downwind from the spray line would have had a volume median diameter of 70 µm; therefore, the collection efficiency of the string at the air velocities measured in this study was near 100% for all but the smallest droplets (<10µm) encountering the string collector (May and Clifford, 1967). Since the line collected nearly all of the droplets that passed through the plane established by the projected area of the string over the time period that the strings were left exposed to the spray (approximately 5-7 minutes), the terms “deposition on the string” and “spray flux” are used interchangeably.

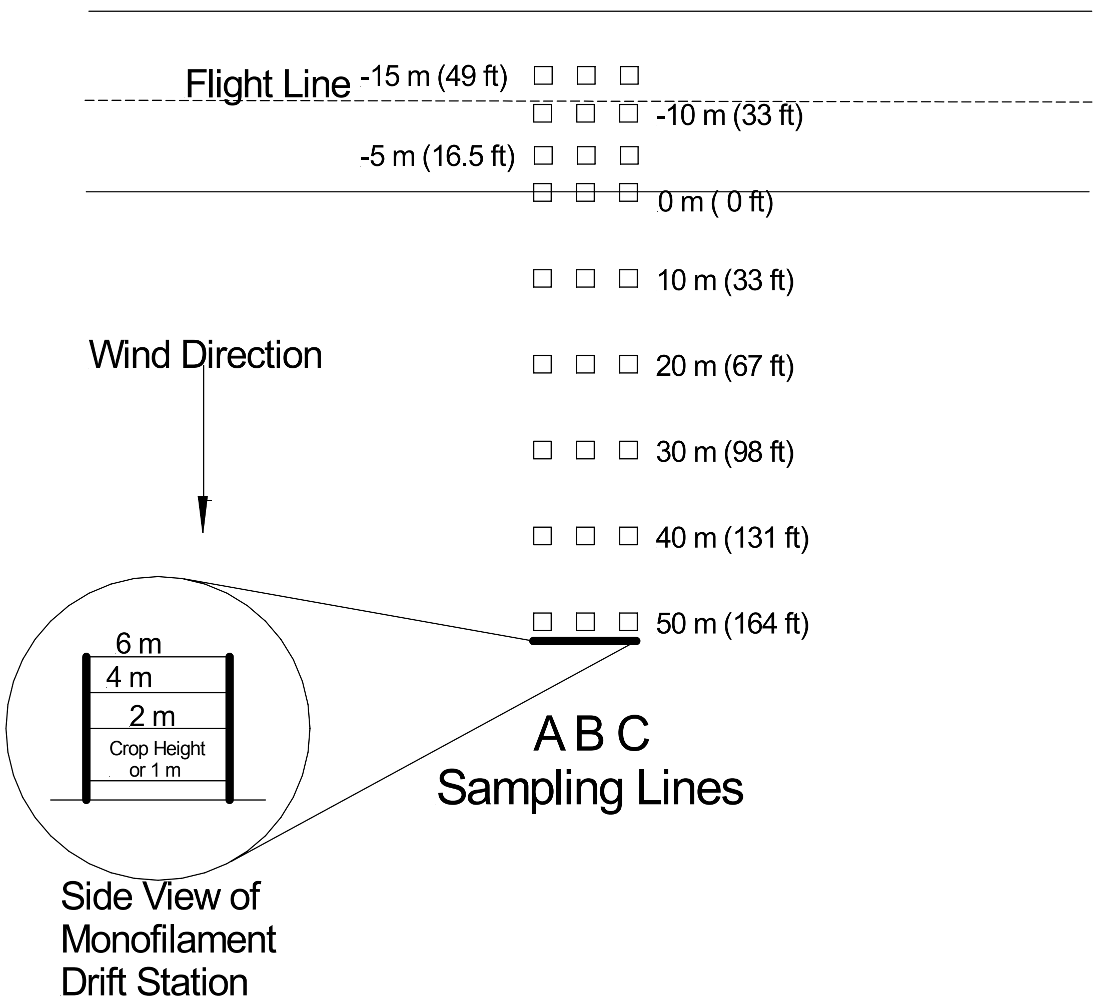

Figure. 1. Field test layout.

After each replication, the towers were lowered and the monofilament lines were collected on spools that were built for this study. These spools allowed the line to be collected without touching the crop canopy or ground. All lines were collected within 10 minutes of the application to minimize any chance of significant dye degradation. Each spool was placed in a labeled plastic bag, stored in an ice chest, and transported to the laboratory for quantification. After pipetting 40 ml of ethanol into each bag, the bags were agitated, and 6 ml of the effluent was poured into a cuvette. The cuvettes were then placed into a spectrofluorophotometer (Shimadzu, Model RF5000U, Kyoto, Japan) with an excitation wavelength of 453 nm and an emission at 488 nm. The fluorometric readings were converted to µg/cm² using a projected area of the monofilament line of 50 cm² (1000-cm length times

0.05-cm line diameter). The readings were corrected using tank samples from the actual spray in each test. The minimum detection level for the dye and sampling technique was 0.00007 µg/cm².

Meteorological Conditions

Meteorological conditions for each spray replication were taken with a portable weather station located near the test sites but upwind to avoid any air disturbances caused by the aircraft. The air temperature, wind direction, and wind speed measurements were made at a 2 m height. The data presented in Table 2 represents a 1-minute average at the time of the application with all 5 replications averaged for each test.

Table 2. Meteorological Conditions and AgDISP Input Parameters

Test	Wind Speed (m/sec)	Temp (◦C)	RH (%)	Height (m)	Canopy Roughness (m)	Canopy Displacement (m)	Surface Roughness
1	3.5	34.1	47	0	0	0	0.005
2	2.6	31.8	50	0.33	0.046	0.231	0.04
3	2.0	31.8	72	0.59	0.083	0.413	0.04
4	2.6	31.9	50	0.70	0.098	0.490	0.04
5	2.1	31.5	73	0.85	0.119	0.595	0.04
6	3.6	33.8	48	1.0	0.140	0.700	0.04

AGDISP Model Inputs and Meteorological Conditions

Computer models are highly dependent on the inputs into the model. The specific weather conditions and model inputs for the tests presented in this manuscript are shown in Table 2. The canopy roughness and canopy displacement variables are calculated by the model and are a function of the crop height input by the user. The surface roughness is selected by the user from a list of suggested values based on the surface conditions at the site of application. The authors used the USDA-ARS Nozzle Models for the spray droplet spectrum data inside the model. The spray solution used in the USDA-ARS models was the same solution used in the field trials, except for the presence of the dye. The model sensitivity to different spray droplet spectrums was not a part of this study. The total nonvolatile fraction of the spray material was 0.0023, which represents the portion of the spray containing the dye and surfactant, and the active fraction was 0.0013, which represents the dye component of the spray solution. The active fraction is used by the model to predict the spray flux through various vertical points at a given distance, which was 50 m in this study. Data presented in the above sections were used to configure the other inputs into the model, such as aircraft and application conditions.

Results and Discussion

In-Swath Deposition

The purpose of measuring the in-swath deposition was to evaluate the consistency of the application for each of the test. The deposition directly under the aircraft is less subject to the differing environmental conditions that have a significant impact on sample sites downwind from the site of application. Overall, each test had similar in-swath deposition readings, except the -15 m and -10 m sites for the 0.58 m canopy and the 0.85 m canopy (fig. 2). However, the 0.58 m and 0.85 m canopy height tests created deposits similar to the other treatments at the other two in-swath sampling locations. These two tests had the lowest wind speeds, which would eliminate swath displacement due to high winds as a probable cause. One possible cause of the two low readings may have been off-line applications by the pilot; however, the swath guidance system on the aircraft was inoperative at the time of the test so this speculation can not be verified. The case for off-line application is strengthened by the downwind deposition discussed in the following section. Overall, one can conclude that the applications for each of the six tests were consistent.

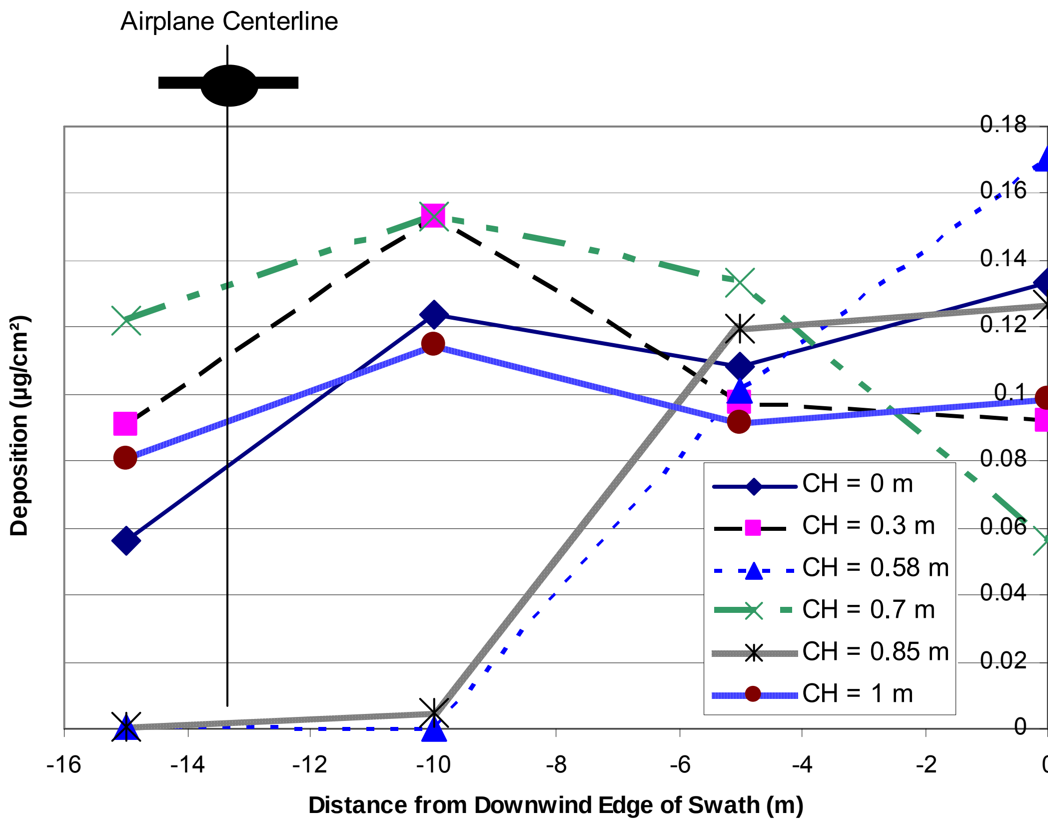

Figure 2. In-swath deposition reading for six different canopy height (CH) tests.

Downwind Deposition

The downwind deposition for each of the tests as measured by horizontal mylar plates at crop height is shown in Figure 3. The two highest readings at 20 m are for the two treatments, 0.58 m and 0.85 m heights, mentioned in the previous section and indicative of an off-line application. The authors can only speculate that the application was made over the downwind edge of the swath (the 0 m reading) rather than over the indicated flightline at -12.5 m from the downwind edge. The likely cause of this was that the cones used to indicate to the pilot the location of the flightline were misplaced, as sometimes happens in field work.

To compensate for the suspected misapplications, the horizontal deposition for the two trials in question was adjusted by -10 m, which effectively shifted the flightline upwind 10 m. This resulted in better alignment of the deposition measurements (fig. 4). The two tests with the highest downwind deposition at the 20 m measurement site using the adjusted distances were the 0 m and 1 m canopy height tests (fig. 4), which also had some of the lowest in-swath deposits. The canopy for the 1 m test was completely closed (Table 1). This condition would tend to prevent the spray from penetrating into the canopy and created similar conditions as that of spraying on bare ground. The four intermediate treatments were indistinguishable based on horizontal downwind deposition at 20 m. These trends continued to the 50 m measurement location (fig. 5); however, the data for the 0.58 and 0.85 m canopy heights is unavailable due to the shifting of these two data sets.

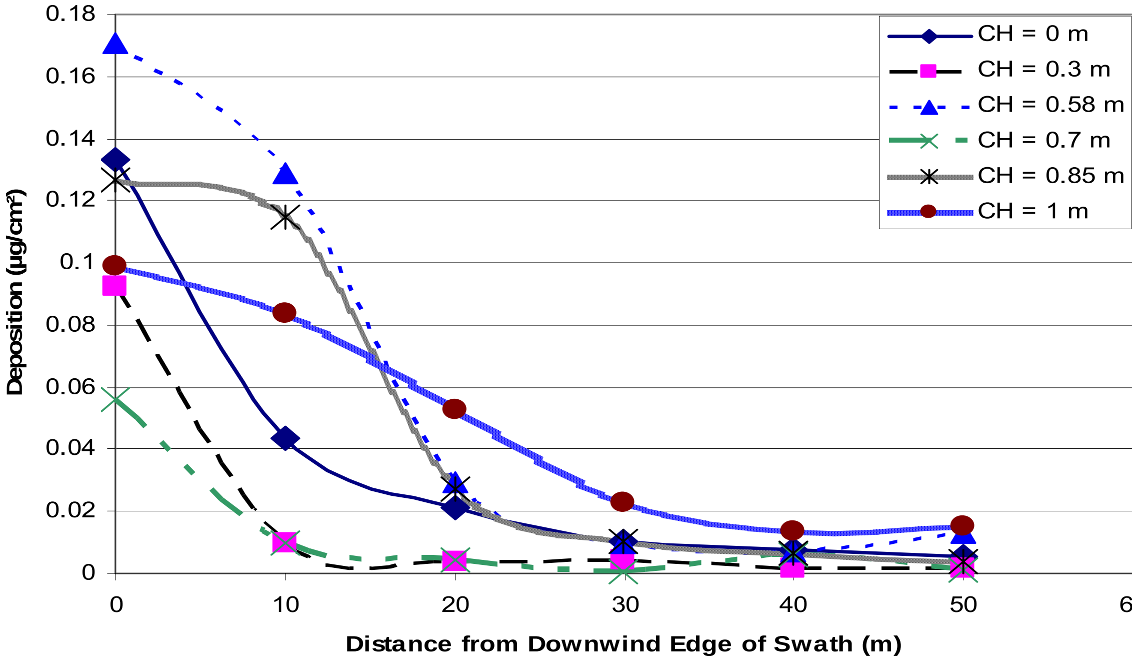

Figure 3. Downwind deposition for six different canopy height (CH) tests.

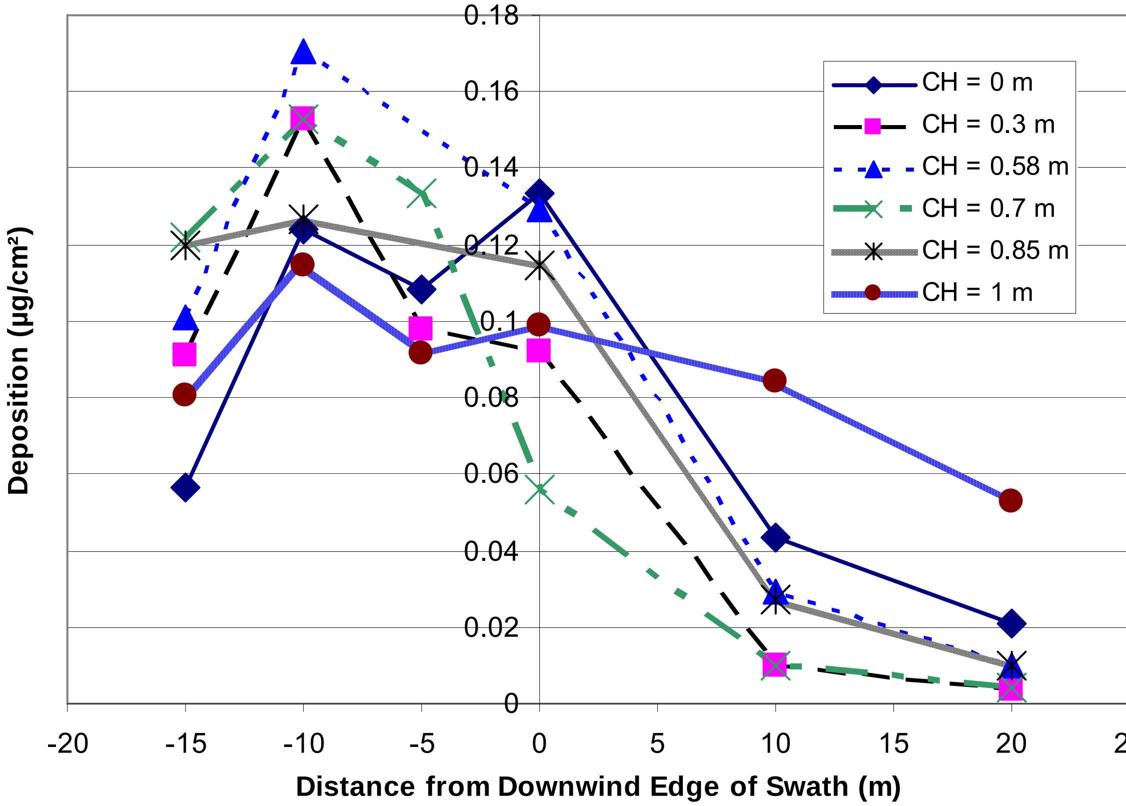

Figure 4. Deposition with 0.58 and 0.85 m canopy height tests deposition results shifted upwind 10 m to account for suspected misalignment of flightline.

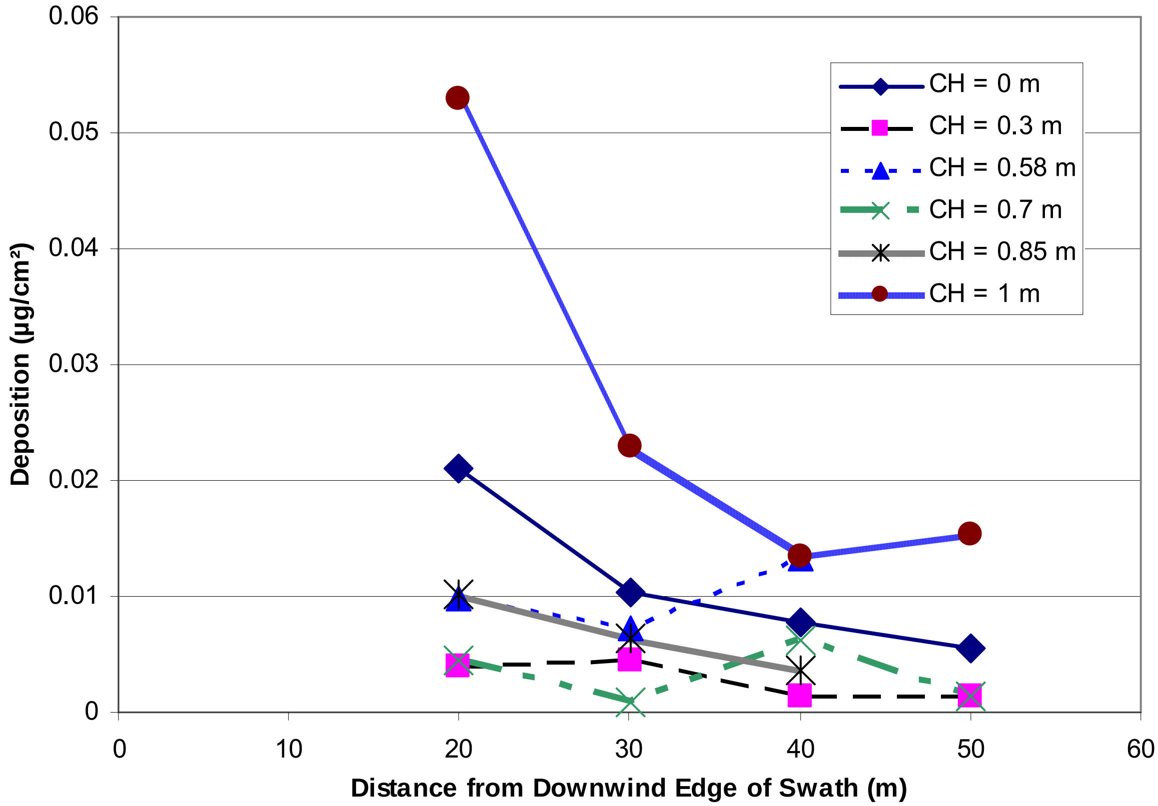

Figure 5. Downwind deposition with 0.58 and 0.85 m canopy height tests deposition results shifted upwind 10 m to account for misalignment of flightline.

Vertical Spray Deposition at 50 m

The airborne component of the spray released 50 m upwind was measured using 0.5-mm diameter strings. There was approximately a 100-fold decrease in the deposition reading as compared to the deposition readings within the intended spray swath (fig. 6). As found with the horizontal downwind deposition samples, the 0 m and 1 m canopy height tests generated the highest levels of downwind spray concentrations. These higher depositions are likely indicative of the canopies inability to absorb some of the spray plume and decrease the amount spray that moves downwind.

Teske et al. (1993) investigated the effect of aircraft vortices decay in relation to application height; however, they did not discuss canopy porosity or the ability of the vortices to penetrate the canopy. The authors speculate that the high deposition values at 4 m for the 0.85 m and 1 m canopy heights may be a reflection of the percent canopy closure for these two tests (Table 1). The 80-100% canopy closure may have prevented the vortices from the aircraft from fully penetrating the canopy resulting in a lifting of some of the smaller spray droplets into the air.

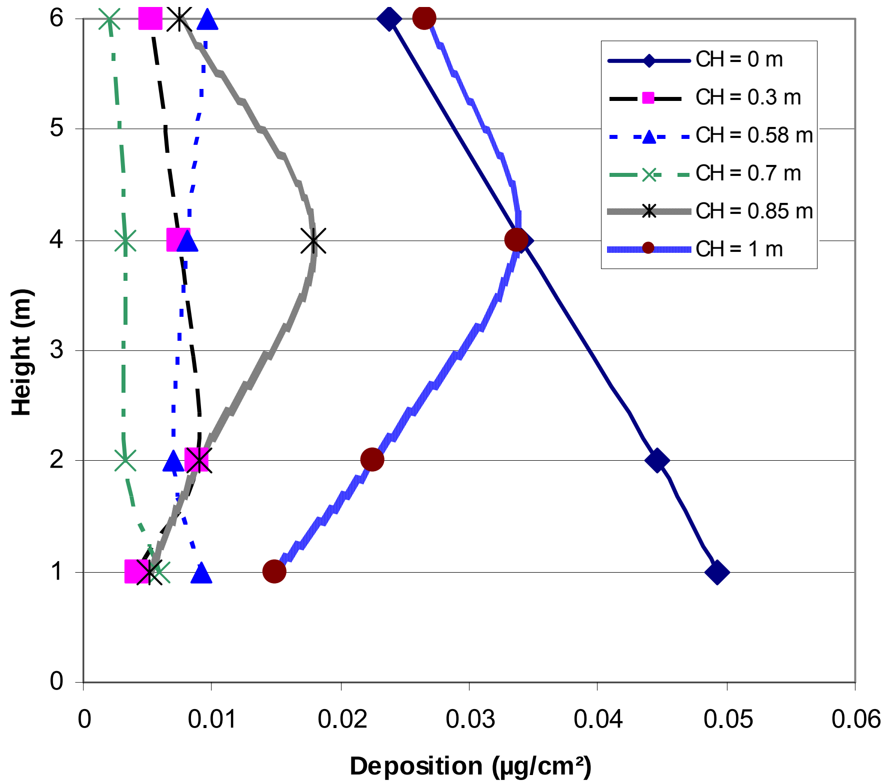

Figure 6. Deposition on horizontal strings located 50 downwind of the application site at different heights.

AgDISP Predicted Results

As demonstrated in previous studies (Hoffmann, 2006), AgDISP predicts that as canopy height increases, vertical spray deposition or flux decreases if the wind speed is held constant. The predicted results for these tests show the same general trend with some variation due to the differences in wind speed during the different tests. The meteorological and canopy parameters presented in Table 2 were used in the predicted data in Figure 7. The deposition levels predicted by the AgDISP (fig. 7) are essentially the same for the four intermediate crop heights as that measured during the field trials (fig. 6), except at 4 m for the 0.85 m canopy height test. This close agreement shows that the AgDISP model can be used with high confidence in modeling spray movement in canopies between 0.3 and 0.8 m.

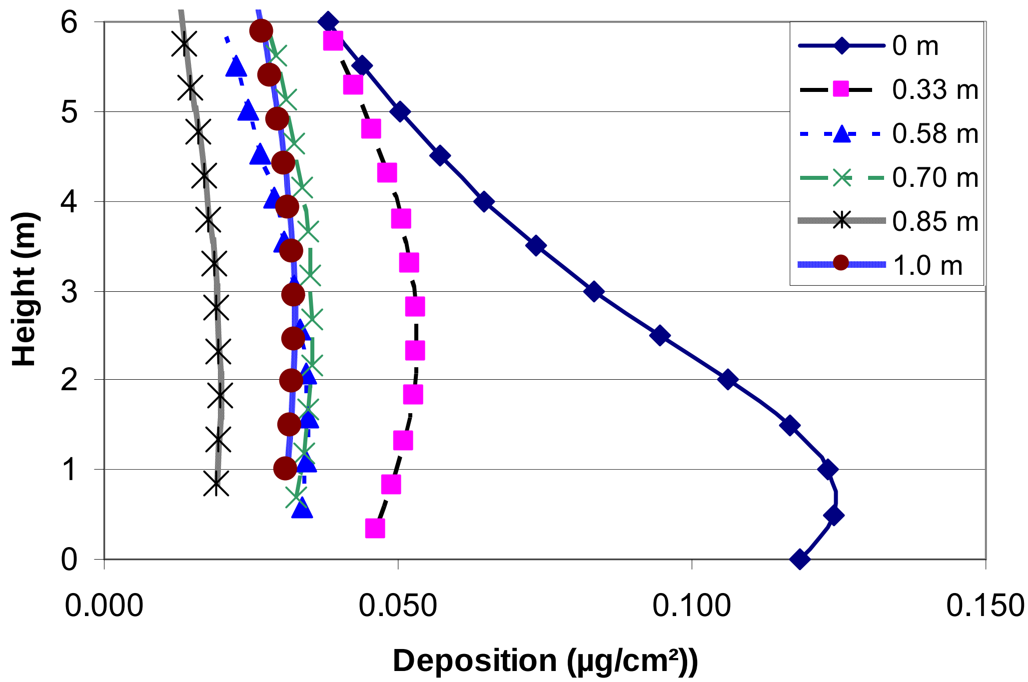

Figure 7. Predicted vertical deposition based on canopy height from the AgDISP model using the inputs shown in Table 2.

Users of the model should be more cautious when modeling spray movement under conditions of no canopy (CH = 0 m) or when the canopy is closed or very dense. For the 0 m canopy height data, the model consistently overpredicts the vertical spray flux by a factor of 2 at all sampled heights. The model overpredicts by a factor of 2 the downwind vertical deposition at 1 m (fig. 8) for the 1 m canopy height as compared to the field collected data. This is likely the result of higher rates of filtering (i.e. spray material depositing on imperfections in the shredded field) in the field tests than the model predicted. However, the AgDISP and field data agree at the 4 and 6 m sampling heights. The same trend holds for the 0.85 m canopy height, where the model overpredicts at the crop and wind profile boundary levels but accurately predicts the spray flux at heights above 4 m.

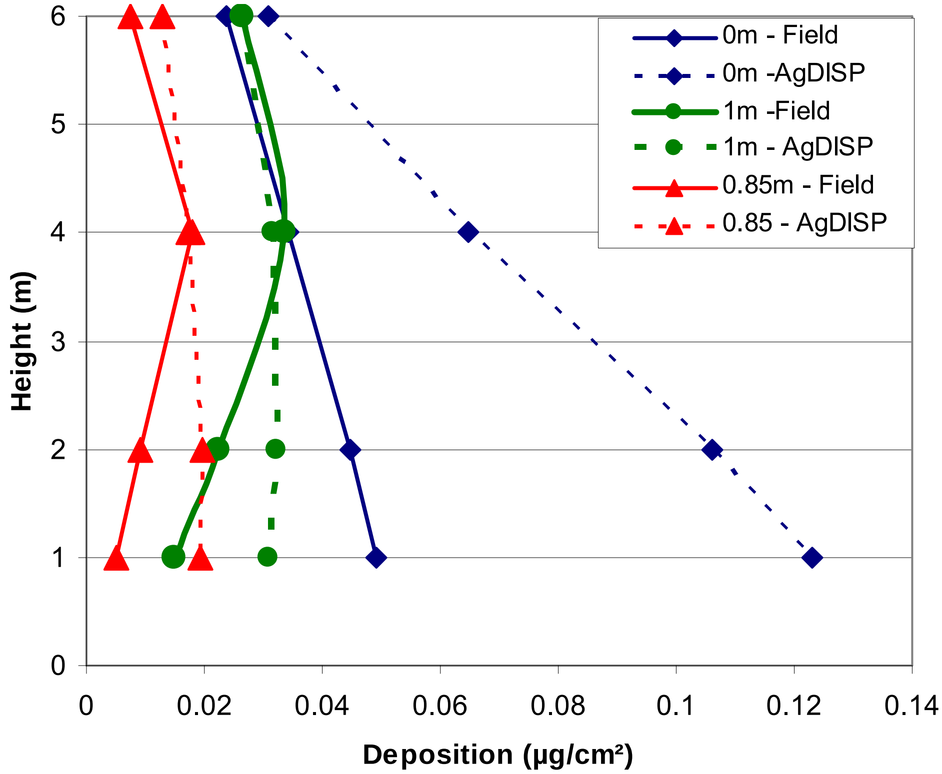

Figure 8. Comparison of field and AgDISP vertical deposition data for three of the six canopy height studies.

Conclusions

Field trials were conducted to compare field collected deposition measurements to computer model predicted values. Trials were conducted in fields ranging from bare ground to a 1 m cotton canopy. Horizontal deposition measurements were used to verify that each of applications made during each of the trials produced similar levels of deposition. Monofilament string were placed at four sampling heights (1, 2 ,4 and 6 m) above the canopy at a distance of 50 m from the downwind edge of the spray swath to measure the airborne droplets at this distance.

Conclusions resulting from this study were:

- The vertical deposition values at 50 m for crop heights between 0.3 and 0.8 m were very comparable between the field collected and AgDISP predicted data;
- The AgDISP model overpredicted by a factor of 2 the levels of spray at 1 m for the trials conducted at 0 or 1 m crop canopy height as compared to field measurements; however, at 4 and 6 m above the ground, the AgDISP and field data were very comparable.
- User of the AgDISP should be encouraged by the accuracy of the model but are cautioned when using the model with canopies that >80% closed.

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