Evaluation of Upwind/Downwind Boom Switching and Propeller Direction on Drift of Aerially Applied Spray

Steven J. Thomson, USDA-ARS-APTRU, Stoneville, MS;
Alvin R. Womac, University of Tennessee, Knoxville, TN;
Joseph Mulrooney, USDA-FS-WPIRU, Starkville, MS;
Sidney Deck, North Carolina State Government, Raleigh, NC

Abstract

A study was conducted to provide preliminary data on the effect of alternate boom switching and corresponding propeller direction on aerial spray drift from a turbine-powered aircraft. Nine horizontal alpha cellulose spray sampling sheets were placed in the swath to collect in-swath deposit and at three sample lines to collect drift fallout 104, 134, 195, and 317 meters downwind, perpendicular to the flight path. At each sample line, the alpha cellulose samplers were placed 30-m apart. High volume (Hi-Vol) vacuum motor air samplers with 10.2-cm diameter TFA2133 glass fiber filters collected airborne drift and were placed at the same intervals and locations downwind as the alpha cellulose samplers. An aqueous mixture of malathion at a spray rate of 19 L/ha was applied from the aircraft through fifty D6-46 hollow cone tips. Five total replications were conducted over two days. Each replication had four treatment combinations of boom switch (left or right, on or off) and airplane direction. Propeller wash effects were surmised from boom selection and aircraft direction. For each treatment, four passes were made applying 0.11 kg chemical/ha on each pass. Swath width was 23-m and tips were directed straight down to induce measurable drift at an aircraft speed of 56 m/s. Wind was steady, producing highly favorable conditions for testing on both days. Residue analysis of in-swath fallout showed no discernable patterns between treatments. When all five replications over two days were analyzed, neither active boom nor boom location was statistically significant for either sampling method. Analysis was then limited to the second day of testing since wind speed and direction were different between days. For this analysis, active boom/boom location (upwind or downwind) interaction (Boom*UD), propeller wash direction (PW), Boom*UD interaction with distance, and PW interaction with distance were all significant at p=0.10 for fallout sheets. For Hi-Vol samplers, the corresponding variables were not statistically significant. Treatments applied with the direction of propeller wash rotation that rolled on the ground surface in the upwind direction tended to reduce drift. The interaction of the propeller wash with the ground surface may be as important as the slipstream effects on released droplet trajectories.

Introduction

Determining off-target drift of applied chemical continues to be a challenge. Meteorological effects, atomization variables, and aircraft design all interact to make this issue a complex problem. In recent years, there has been some interest in the relative effects from either upwind or downwind wings and the direction of propeller wash on spray drift. Propeller wash turbulence carries droplets from nozzles to the right of the fuselage and deposits them beneath or to the left of the fuselage. This results from the clockwise propeller air helix spiraling into the fuselage (Univ. of Nebraska, 2004). Huddleston et al. (1994) performed a test where left and right booms of an aircraft were switched and drift of malathion and chlorpyrifos were detected using string samplers placed 33- and 91-m downwind. Results suggested that the right boom contributed more to drift than the left boom (p=0.0968) 91m downwind. Increased contribution of the right boom was more pronounced at the 33-m sampler distance (p=0.0251). Wind ranged from 1.3 to 3.1 m/s throughout the test, but it was not clear whether wind speed or direction were accounted for in the statistical design.

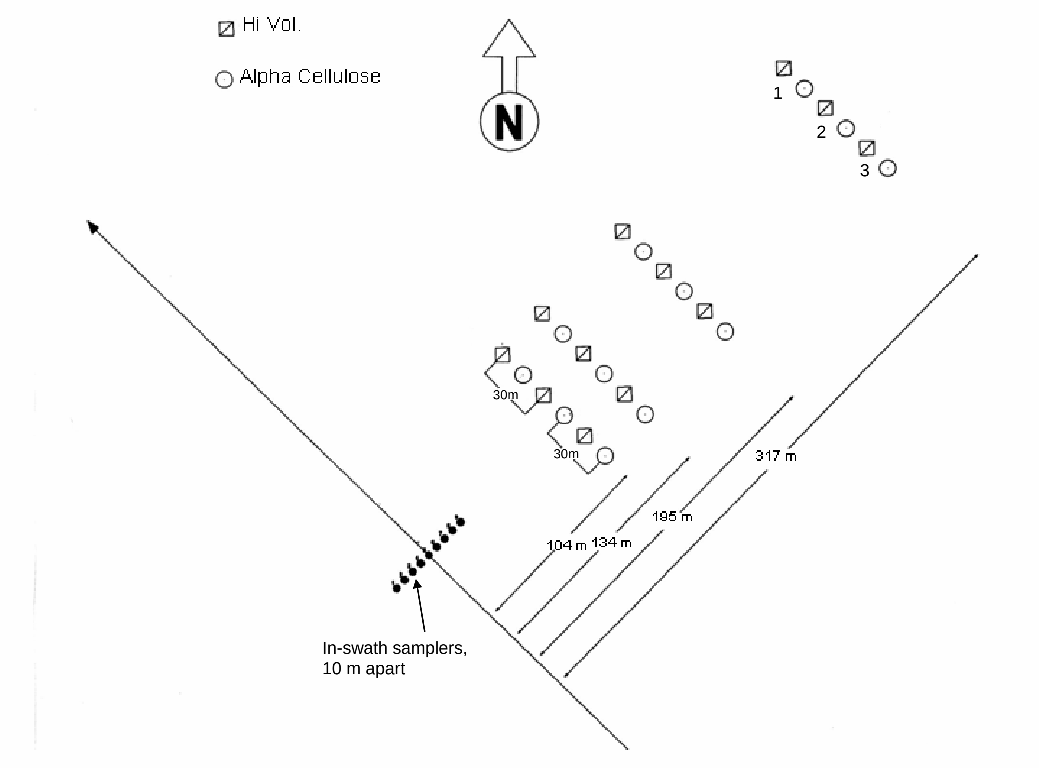


Figure 1. Field sampler layout

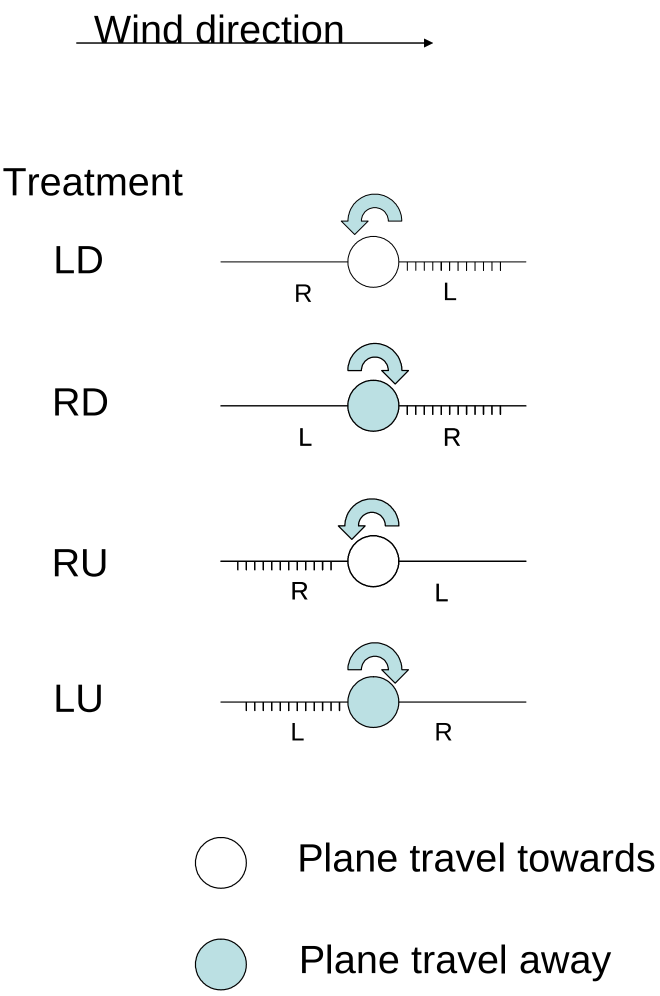
The study presented herein was conducted to quantify spray drift differences between right and left booms and determine the influence of propeller direction under the same conditions. Weather variables of air temperature, relative humidity, wind speed, and wind direction were measured.

Methods

The spray tests were conducted over an early cotton crop, and layout of samplers is illustrated in Figure 1. The cotton was planted in 1-m rows and was generally 0.2- to 0.3-m tall across the 60-ha rectangular test area. The spray area with cotton rows was oriented so that the prevailing wind was blowing at nearly 90° to the direction of sprayer travel. Nine horizontal 25.4 by 25.4-cm alpha cellulose spray sampling sheets were placed 3-m apart on same-sized boards in the swath to collect in-swath deposit and at three sample lines to collect drift fallout 104, 134, 195, and 317 meters downwind, perpendicular to the flight path. At each sample line, the alpha cellulose samplers were placed 30-m apart and mounted in a horizontal plane 0.5-m above the ground surface. High volume (Hi-Vol) vacuum motor air samplers with 10.2-cm diameter (81-cm^2 surface area) TFA2133 glass fiber filters collected airborne drift and were placed at the same intervals downwind as the alpha cellulose samplers. These high volume air samplers were utilized to measure the air-entrained off-target drift that was likely to be moving across a downwind crop head-high. Droplet drift at this height provides an indication of how much material might be inhaled by a human downwind from the spray zone. The high volume samplers were mounted at a height of 1.8-m above ground level and were set to a flow rate of 0.68 m^3 of air per minute through the filter.

An aqueous mixture of malathion at a spray rate of 19 L/ha was applied from an Air Tractor 402B aircraft through fifty D6-46 hollow cone tips at a release height of 3.7-m. Each replication had four treatment combinations of boom switch (left or right, on or off) and airplane direction as illustrated in Figure 2. For each treatment, four passes were made applying 0.11 kg chemical/ha on each pass. Swath width was 23-m and tips were directed straight down to induce measurable drift at an aircraft speed of 56 m/s. All tests were conducted under environmental conditions that would be considered conducive to off-target drift. Weather conditions were measured on-site at 1.8-, 3-, and 9-m heights using a Campbell Scientific 21X logger. During the tests, temperature varied between 28°C and 33°C and relative humidity varied between 65% and 85%. Average wind speed during the test for Day 1 (reps 1 and 2) was 4.80 m/s (Standard Deviation, S.D. = 0.96 m/s) and for Day 2 (reps 3, 4, and 5) was 3.84 m/s (S.D. = 0.97 m/s). Wind deviated from 90^{o} by 2^{o} west, with a S.D. of 12^{o} for Day 1. During the second day of testing, wind deviated from 90^{o} by 16^{o} west, with a S.D. of 17^{o}. Calculated atmospheric stability ratios indicated turbulent, unstable air during both days of testing.

Figure 2. Experimental treatments



Sample Deployment and Collection

Sample deployment and collection procedures were similar to those described by Gaultney et al. (1996) and will be summarized here. For deployment of samplers, clean rubber gloves were put on, and sealed plastic bags containing fresh drift collectors were taken out to the collection site. Alpha-cellulose collectors were placed on collection boards and attached with new spring clips. High volume collectors were placed into mounting brackets and clamped into place. The same people who deployed fresh collectors also collected the samples. Pre-labeled, plastic zip-lock bags were placed at the side of the field in alignment with the three replicate collectors at each distance from the spray area and nine in the spray swath. Field personnel used new rubber gloves to pick up the collector bags. Alpha-cellulose samples were detached from the backing board by removing the spring clips and discarding them. Each alpha-cellulose sample was immediately put into the proper pre-labeled large collection bag. This procedure was repeated for each of the nine alpha-cellulose samples in the swath and three alpha-cellulose samples at each downwind distance. The high volume collectors were each removed from their mounts and placed in small pre-labeled bags. The samples were returned to the edge of the field and immediately placed into ice chests where they were protected from light.

Sample Analysis

Pesticide was extracted from the horizontal alpha-cellulose collectors by first cutting the alpha-cellulose into five strips measuring 5.08 cm long. The five strips were cut in half and placed in a 946-mL wide-mouth glass jar with 300 mL of ethanol. The jars were placed on their sides in a laboratory platform reciprocating shaker and were shaken for 30 min. The alpha-cellulose was then squeezed and removed from the jar, and the effluent left in the jar was placed in a rotary evaporator and evaporated down to 10 mL.

The sample was then ready for gas chromatograph (GC) analysis of malathion tracer. The GC used for the sample analysis was a Hewlett-Packard (HP) gas chromatograph Model 5890 equipped with a HP Model 7673 autosampler with an autoinjector, and a HP Model 19256A flame photometric detector in the phosphorous mode. The operation of the GC was through the HP Chemstation software. Analysis of the hi-volume air sampler filters followed as similar procedure as the alpha-cellulose. The only difference between the two procedures was that the air sampler filters were cut into thirds and placed in a 946-mL wide-mouth glass jar with 100 mL of ethanol instead of the 300 mL used with the larger collectors. Residue data were analyzed using PROC Mixed (SAS, 2000).

Results

In-swath fallout samples were analyzed to give an indication of spray distribution in the swath due to propwash. Preliminary residue analysis of in-swath fallout showed no discernable patterns between treatments. Downwind samples were then analyzed to determine the effect of boom switching and propeller wash effects on drift measured as concentration at each sampler.

Tables 1 and 2 illustrate SAS outputs for both sampling methods downwind. Wind effects did not contribute to differences in initial SAS runs, so they were removed for final analyses. Covariance parameter estimates showing little effect were progressively removed from the model.

Neither active boom nor boom location was statistically significant for either sampling method at the 0.05 level. Although not statistically significant at p=0.05, there appeared to be weak interaction between the active boom and horizontal sampler location (Boom*Loc, p=0.0751) for fallout sheets. Likewise, spray concentration at a downwind distance seemed to be weakly influenced by sampler location (Ldist*Loc, p=0.0904). Overall, there seemed to be involvement of horizontal sampler location at each downwind distance for both sampling methods, although involvement was weaker for the Hi-Vol samplers.

Interesting results can be observed by limiting analysis to the second day of testing (three replications), shown in Tables 3 and 4. Although active boom (Boom) and Boom Location (UD, upwind or downwind) were still not significant (p=0.1722 and p= 0.2143, respectively), Boom*UD interaction was significant at the 0.10 level (p=0.0604) for fallout sheets. There was also a Boom*UD interaction with distance (Ldist*Boom*UD, p=0.0735). Wind direction (Windir, p=0.0963) and Ldist*Windir (p= 0.0838) showed significance at the 0.10 level, but as indicated, these variables were not significant when all replications were counted over both days. Wind factors were not significant when using the Hi-Vol samplers, although UD and Ldist*UD showed developing trends (p=0.1388 and p=0.1406, respectively).

Figure 3 illustrates trends indicated by the LSMEANS analysis of SAS for fallout samplers on the last three replicates. The LU and RD treatments show a slightly lower concentration when compared with the other two treatments at the 104-m downwind distance. These two treatments had different booms spraying (right boom downwind and left boom upwind, respectively), but propeller wash rotation was in the same direction. Further statistical analysis confirms that there was some influence. A new variable indicating propwash direction (PW) had the same effect as the Boom*UD interaction discussed above. When introduced into the statistical mix, PW indicated the same significance as Boom*UD at the 0.10 level (p=0.0604). PW effect also depended on distance (Ldist*PW, p=0.0735).

Table 1. SAS output for Alpha Cellulose fallout sheets

```
                Type 3 Tests of Fixed Effects

                      Num     Den
 Effect                DF      DF    F Value    Pr > F

 REP                    4    15.6       4.96    0.0090
 BOOM                   1      12       0.55    0.4724
 UD                     1    44.3       0.82    0.3707
 BOOM*UD                1      12       0.47    0.5050
 LOC                    2     144       2.46    0.0889
 BOOM*LOC               2     144       2.64    0.0751
 UD*LOC                 2     144       1.20    0.3035
 BOOM*UD*LOC            2     144       0.90    0.4076
 ldist                  1    14.7     116.62    <.0001
 ldist*LOC              2     144       2.44    0.0904
 ldist*UD               1    43.1       0.73    0.3987
```

Table 2. SAS output for Hi-Vol samplers

```
                      Num     Den
 Effect                DF      DF    F Value    Pr > F

 REP                    4    13.9      10.25    0.0004
 BOOM                   1      12       0.00    0.9532
 UD                     1     191       0.40    0.5295
 BOOM*UD                1      12       0.39    0.5464
 LOC                    2     182       2.10    0.1253
 BOOM*LOC               2     179       0.29    0.7493
 UD*LOC                 2     179       2.39    0.0946
 BOOM*UD*LOC            2     179       0.34    0.7097
 ldist                  1    13.7     403.46    <.0001
 ldist*UD               1     185       0.50    0.4820
 ldist*LOC              2     182       1.81    0.1666
```

Variables:
REP = Replication (5)
BOOM = Boom Spraying (Left or Right)
UD = Boom Location (Upwind or Downwind)
LOC = Sampler number at each sample line distance (3)
Ldist = Distance downwind (log transformed)

Table 3. SAS output for fallout sheets. Analysis limited to second day of testing

```
                            Num     Den
 Effect                      DF      DF    F Value    Pr > F

 REP                          2    7.79       1.29    0.3293
 BOOM                         1    24.1       1.98    0.1722
 UD                           1    22.7       1.63    0.2143
 BOOM*UD                      1    23.8       3.89    0.0604
 LOC                          2      74       1.36    0.2642
 BOOM*LOC                     2      74       0.24    0.7900
 UD*LOC                       2      74       0.65    0.5265
 BOOM*UD*LOC                  2      74       0.06    0.9382
 ldist                        1    15.4      40.82    <.0001
 ldist*BOOM                   1    23.4       1.86    0.1852
 ldist*UD                     1      22       1.57    0.2233
 ldist*BOOM*UD                1    22.8       3.52    0.0735
 ldist*LOC                    2      74       1.28    0.2838
 ldist*BOOM*LOC               2      74       0.21    0.8104
 ldist*UD*LOC                 2      74       0.56    0.5757
 ldist*BOOM*UD*LOC            2      74       0.07    0.9311
 WINDIR                       1    28.1       2.96    0.0963
 ldist*WINDIR                 1    27.3       3.22    0.0838
```

Table 4. SAS output for Hi-Vol samplers. Analysis limited to second day of testing

```
                              Num      Den
Effect                         DF       DF     F Value     Pr > F

REP                             2     5.03        5.17     0.0604
BOOM                            1      106        0.49     0.4850
UD                              1      106        2.22     0.1388
BOOM*UD                         1      106        0.68     0.4098
LOC                             2      102        0.80     0.4500
BOOM*LOC                        2      102        0.15     0.8606
UD*LOC                          2      102        0.28     0.7593
BOOM*UD*LOC                     2      102        1.09     0.3403
ldist                           1      102      245.04     <.0001
ldist*BOOM                      1      103        0.69     0.4085
ldist*UD                        1      103        2.21     0.1406
ldist*BOOM*UD                   1      102        0.76     0.3857
ldist*LOC                       2      102        0.70     0.4975
ldist*BOOM*LOC                  2      102        0.15     0.8639
ldist*UD*LOC                    2      102        0.29     0.7485
ldist*BOOM*UD*LOC               2      102        1.17     0.3160
WINDIR                          1      106        0.65     0.4222
ldist*WINDIR                    1      102        1.26     0.2646
```

```
Variables:
REP = Replication (3)
BOOM = Boom Spraying (Left or Right)
UD = Boom Location (Upwind or Downwind)
LOC = Sampler number at each sample line distance (3)
Ldist = Distance downwind (log transformed)
```

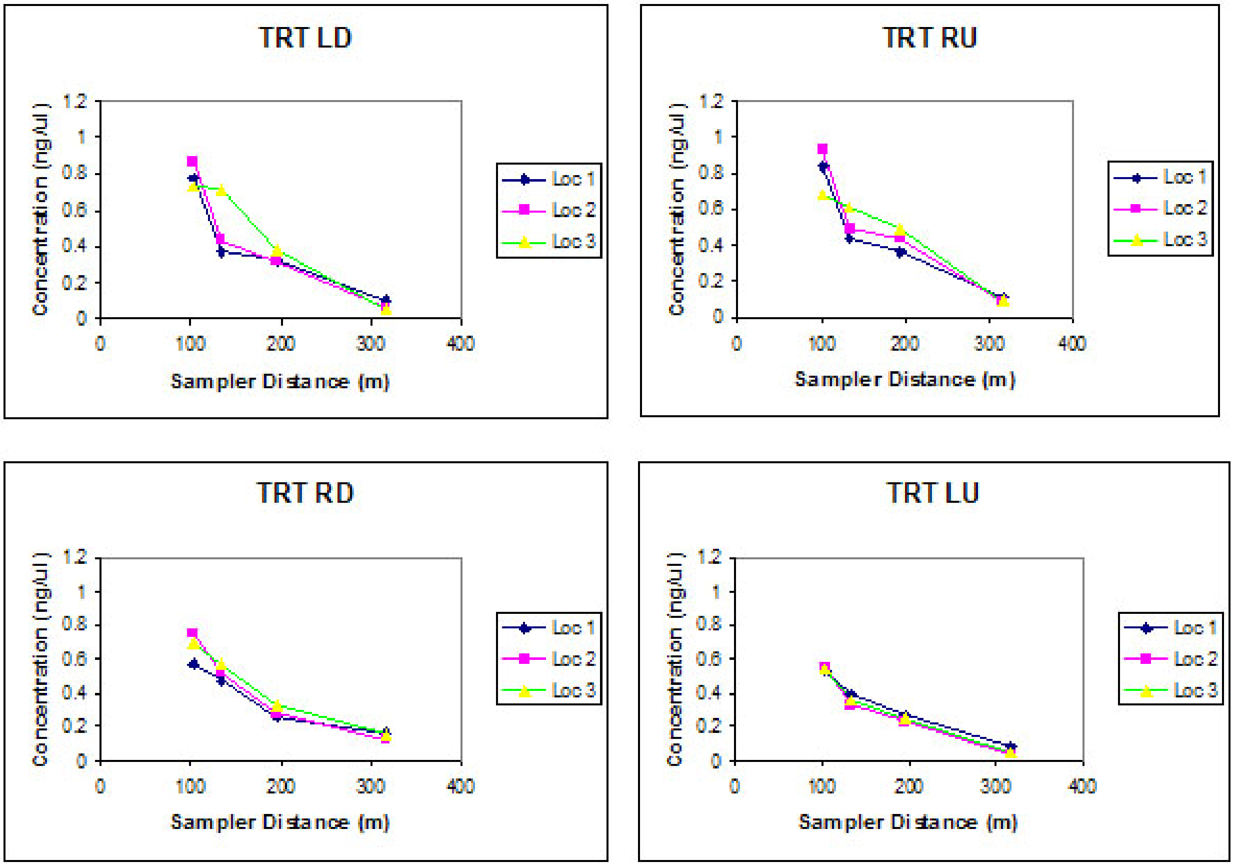


Figure 3. Trends indicated by LSMEANS for fallout samplers over three replications on day 2 of testing

Discussion of Results

The last three replications on day two were broken out for analysis since wind speed and direction were different for both days. As indicated, statistical results were quite different than the case where all replications were analyzed. Although wind speed and direction were measured every minute, it was still difficult to ascertain exact wind conditions at a sampling point. A reference spray applied simultaneously with every treatment could be used to remove environmental effects. Most noticed trends involved the fallout samplers. Hi-Vol samplers were set at a fixed volumetric flow rate corresponding to a wind speed of about 1.4 m/s. This was much less than the wind speeds observed for our study, which would tend to deflate readings of actual concentration of malathion due to anisokinetic conditions (Hinds, 1982). Although wind was not highly variable, any change in wind speed would cause sample concentration to be biased up or down, requiring compensation by measuring wind at each sampler or use of an isokinetic sampler such as one described by Thomson and Smith (2000). Filters used in the Hi-Vol samplers probably did not collect all malathion going through them. Additional polyurethane foam (PUF) filters placed behind the primary filter have been shown to collect additional spray (Amin et al., 1999). Differences in spray release height can have a marked effect on spray drift. Spray release height was not monitored, although a highly experienced and steady agricultural pilot was used to aid uniformity in release height. Methods for measuring spray release height using ultrasonic methods in the airplane and laser from the ground are being investigated. Real-time determination of aircraft spray release height was previously investigated by Koo et al. (1994).

Results indicated herein differed slightly from a short study previously reported (Huddleston et al., 1994). Their study used vertically placed string samplers at two downwind distances. The authors indicated that the right boom probably contributed more to drift than the left boom. For our study, the boom effect was greater when analysis was limited to three replications on the second day of testing (p=0.1722), although not statistically significant. Propeller wash effects depending on distance were seen on the second day, but these were weakly tied to which boom was spraying.

Conclusions

Based on results, the following conclusions can be made:

1. For the entire test (over two days, five replications):
    a. Residue analysis of in-swath fallout showed no discernable patterns between treatments.
    b. Neither active boom nor boom location were statistically significant for either sampling method.
    c. There appeared to be weak interaction between the active boom and horizontal sampler location.
    d. Spray concentration at a downwind distance seemed to be weakly influenced by horizontal sampler location at each distance.

2. For analysis limited to the second day of testing (three replications):
    a. Boom (actively spraying)*UD (upwind /downwind) interaction, propwash direction (PW), Boom*UD interaction with distance (Ldist), and PW interaction with distance were all significant at P=0.10 for fallout sheets.
    b. Wind direction (Windir, p=0.0963) and Ldist*Windir (p= 0.0838) showed significance at the 0.10 level for fallout sheets.
    c. For Hi-Vol samplers, UD and Ldist*UD were not statistically significant but showed developing trends (p=0.1388 and p=0.1406, respectively).
    d. Plots of least-squared means indicated possible propwash direction effects at the shortest downwind distance (104-m).

Treatments applied with the direction of propeller wash rotation that rolled on the ground surface in the upwind direction tended to reduce drift. The interaction of the propeller wash with the ground surface may be as important as the slipstream effects on released droplet trajectories, and should be investigated further.

References

Amin, M.K., A.R.Womac, Q.D. Bui, T.C. Mueller, and J.E. Mulrooney. 1999. Air sampling of aerosol and gaseous pesticides. Transactions of the ASAE 42(3):593-600.

Gaultney, L. D., K.D. Howard, and J. E. Mulrooney. 1996. Off-Target Drift with Air-Assisted Agricultural Sprayers. Pesticide Formulations and Application Systems: 16th Volume, ASTM STP 1312; Herbert M. Collins, G. Robert Goss, and Michael Hopkinson, Eds., American Society for Testing and Materials.

Hinds, W.C. 1982. Aerosol technology: properties, behavior, and measurement of airborne particles. Sec. 10.1, Isokinetic Sampling. John Wiley and Sons, NY: pp.187-194.

Huddleston, E.W., J.B. Ross, T.M. Ledson, R. Sanderson, G.M. Kilgore, and D.L. Clason. 1994. Right Wing-Left Wing Difference in Drift. Technical paper AA94-004, St Joseph, MI: ASAE; Washington D.C.: NAAA.

Koo, Y.M., A.R. Womac, and J.A. Eppstein. 1994. Laser altimetry for low-flying agricultural aircraft. Transactions of the ASAE 37(2):395-400.

SAS, 2000. The SAS system, Version 8. SAS Institute, Cary, NC.

Thomson, S.J. and L.A Smith. 2000. Evaluation of a control system for isokinetic hi-volume sampling of airborne spray. Applied Engineering in Agriculture 16(3): 309-314.

Univ. of Nebraska. 2004. Aerial Pest Control, Chapter 3, Calibration. Pesticide Education Resources. University of Nebraska, Lincoln, NE.

URL: http://pested.unl.edu/catmans/aerial.skp/aerch3.htm. Accessed September 12, 2004.

Disclaimer

Mention of a trade name, proprietary product, or specific equipment does not constitute a guarantee or warranty by the U.S. Department of Agriculture or the University of Tennessee and does not imply approval of the product to the exclusion of others that may be available.