EVALUATION OF SPRAY DRIFT FROM BACKPACK AND UTV SPRAYING

H. W. Thistle, J. A. S. Bonds, G. J. Kees, B. K. Fritz

ABSTRACT. *The objective of these tests was to evaluate pesticide drift from ground applications using a standard manual pump backpack sprayer and a UTV-mounted boomless sprayer. Three deposition sampler types were deployed: Mylar cards, water-sensitive papers, and artificial foliage. This study indicates that drift of pesticide at 20 m downwind of backpack or UTV spraying was about 0.001 of the applied rate. This order of magnitude of drift was similar for both application methods. In the case of the backpack spraying, deposition decreased to about 0.01 of the applied rate just 1.5 m downwind of the swath edge. In the UTV trials, the closest off-swath measurement was 0.5 m downwind of the downwind swath edge, and deposition there ranged from about 0.5 of the applied rate down to less than 0.001. At 2.5 m downwind of the downwind swath edge, these values ranged from about 0.02 down to near 0.0001 of the applied rate. The study concludes that very small amounts of material were deposited at 20 m downwind, but drifted material was present. This conclusion is reached understanding that these trials were conservative by design, as there was almost no intervening vegetation between the release line and the collectors. The study also confirms the dependence of drift on wind speed in these applications.*

Keywords. *Backpack sprayer, Pesticide deposition, Pesticide drift, Pesticide spray drift, UTV sprayer.*

Pesticide spray drift is the off-target movement of pesticides through the atmosphere and can cause unintended human health and environmental consequences (see Felsot et al., 2010, for a summary of pesticide drift studies). The USDA Forest Service (FS) requires data on drift from manual backpack (BP) sprayers and utility vehicle (UTV) mounted boomless sprayers to meet the requirements of the National Environmental Policy Act (NEPA, 1969). Federal land managers are required to assess the risks of any pesticide use on federal lands. The FS chooses to produce formal risk assessments. This study will be used to properly characterize the risks from BP and UTV pesticide spray operations as required by NEPA.

Large datasets are available on drift from aerial applications, tractor boom sprayers, and orchard airblast sprayers. However, there is a paucity of data on the smaller UTV and BP sprayers. The purpose of this field test was to determine the magnitude and spatial distribution of spray drift for both BP and UTV sprayers. Ultimately, UTV and BP sprayers will be incorporated into the spray drift model AgDISP (Teske et al., 2003). Some similar drift studies have been conducted with knapsack and small boom sprayers in the Netherlands. In these studies, a model called IDEFICS was compared to empirical data. The IDEFICS spray drift model is a random-walk model, which describes the trajectories of a large number of individual droplets produced by a single nozzle (Holterman et al., 1998). The primary drivers for drift in the model are the distance of the nozzle from the crop, droplet size, humidity, temperature, and wind speed. The model appeared to overestimate drift in low humidity conditions when compared to empirical data, with <1% of the nominally applied rate (AR) at 12 m from the nozzle. In humid conditions, deposition was <1% AR within 2 m of the nozzle. Empirical drift data from knapsack sprayers showed 12% AR deposition at 0.5 m from the spray line, with 2% AR deposition at 1.5 to 2 m downwind (Snelder et al., 2008). Empirical data from small boom sprayers used in nursery trees was also compared to IDEFICS. In this scenario using a standard sprayer, <3% AR deposition was recorded at 0.5 m, <2% AR deposition was recorded at 1 m, and <1% AR deposition was recorded at >2.5 m (Franke et al., 2010). Ando et al. (2003) measured residues of various common forestry herbicides near backpack application treatments and noted some off-target deposition, but that study was primarily concerned with temporal change in concentration on treated areas over extended periods.

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METHODS

Tests were performed at the Missoula Technology and Development Center (MTDC), a USDA Forest Service facility in Missoula, Montana (46.93° N, 114.10° W, 975 m ASL). The trial site was non-irrigated, relatively flat rangeland with clumped grass. The vegetation in the directly

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sprayed and downwind areas was mowed to a height of 15 cm. The site incorporated two separate grids to increase the likelihood of appropriate wind approach angles. Grid 1 ran in a northwest-southeast direction, and grid 2 ran in a northeast-southwest direction. The grids were laid out to maximize the chance of winds perpendicular to the spray lines based on the climatological wind rose for April at this location. The UTV treatment applied one 7 m wide swath, while the BP treatment applied one 1 m wide swath. The directly sprayed area was 125 m long. Four transects, labeled T1, T2, T3, and T4, ran perpendicular to the length of the directly sprayed area on each grid. Transects T1 and T4 were located 25 m from the start and end of the directly sprayed area, respectively, with 25 m between each transect. All location measurements were made from the centerline of the directly sprayed swath. There were ten spray trials for both the BP and UTV sprayers, and treatments were alternated. The experimental design presented here considers ISO Standard 22866:2005(E) (ISO, 2005).

All BP treatments were conducted with a Solo 425 piston pump sprayer (Solo, Newport News, VA). A controlled flow valve and pressure gauge were attached to the end of the wand to maintain a steady pressure to the spray nozzle of 144.8 kPa (red CFValve, CF Fluid Controls, Houston, Tex.). The nozzle was an XR-11003 low-drift fan nozzle (Spraying Systems Co., Wheaton, Ill.). This configuration produced an ASABE Medium spray ($D_{V0.5}$ = 294 μm). The time required to spray the line was recorded, and the BP sprayer weight was measured before and after each run to determine the application rate. One backpack operator applied all treatments for a consistent steady walking pace, and the application rate and operator gait were monitored with a stopwatch (fig. 1). The spray nozzle height was approximately 80 cm above the ground and angled down at a 45° angle.

All UTV treatments were applied with a gas engine powered, 189 L, high-volume turf and tree sprayer skid (KS50P6, Kings Sprayers, Orlando, Fla.) mounted on a John Deere Gator (Deere & Co., Moline, Ill.) equipped with a Boominator 1400FM (UDOR USA, Inc., Lino Lakes, Minn.) boomless spray nozzle (Kees, 2008). The nozzle was mounted approximately 80 cm above the ground and pointed down at a 45° angle from horizontal. The swath width of the boomless nozzle is approximately 7 m. The spray pressure was set at 206.8 to 275.8 kPa. The manufacturer describes the spray as "heavy," and we estimate that it is in the ultra-coarse size range ($D_{V0.5}$ > 650 μm). The sprayer incorporates a SprayLogger system (AgTerra Technologies, Inc., Sheridan, Wyo.) with a flow valve to document flow rates and spray time (Throop, 2014).

Figure 1b. UTV spraying using a King's KS50P6, 189 L high-volume turf and tree sprayer skid mounted on a John Deere Gator.

Figure 1a. BP spraying using a Solo 425 piston pump sprayer.

The actual application rates as measured in the field are shown in the box-and-whisker plots in figure 2. The central line in the box is the median value, while the two outer lines are the upper and lower quartiles. The whiskers extend to 1.5 times the box width (relative to the ordinate). An asterisk outside the whiskers denote a close outlier, while an open circle denotes a far outlier (see SYSTAT, 2009, for outlier definitions). AR was calculated from the log file for the UTV sprayer and gravimetrically for the BP sprayer.

The tracer Brilliant Sulphoflavine (BSF) at a concentration of 0.5% w/v with no adjuvants or surfactants was used for volumetric measurements of drift on Mylar sheets and artificial foliage. Water-sensitive papers were also placed alongside the Mylar sheets to measure percentage cover. In the field, a central nurse tank with 50 L of agitated premixed tracer solution fed the experimental sprayers. During each

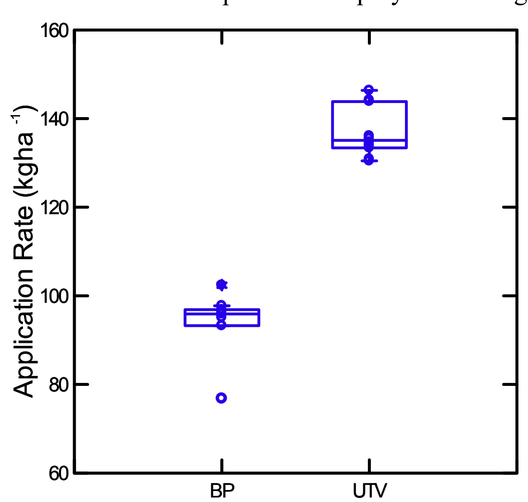

Figure 2. Variation in application rate for BP and UTV spray trials.

treatment, a tank sample was taken for calibration and quality control purposes in the laboratory. The artificial targets (Mylar and artificial foliage) were collected into labeled plastic bags and transported to the USDA-ARS in College Station, Texas, for volumetric analysis. Samples were processed by pipetting an appropriate amount (depending on collected volume) of distilled water and 10% isopropyl alcohol into each bag, agitating the samples for approximately 15 s, and decanting 6 mL of the effluent into a cuvette. This method has proven to recover 90% or greater of deposited material for typical spray mixtures (Fritz et al., 2011).

The cuvettes were placed into a spectrofluorophotometer (model RF5000U, Shimadzu, Kyoto, Japan) with an excitation wavelength of 430 nm, an emission at 520 nm, and a minimum detection level of 0.00007 mg cm^{-2}. Fluorometric readings were converted to concentrations of spray material per area sampled using comparative analysis with fluorometric standards of known tracer deposition volumes (µL cm^{-2}). All fluorescent tracers are subject to UV degradation. The potential tracer degradation and the recovery for each treatment were measured using four additional Mylar targets spiked with 100 µL of tracer solution. These degradation standards were placed an appropriate distance upwind of the treatment site and exposed for the duration of the test. Image analysis for the water-sensitive papers for percentage cover readings was conducted using DropVision Ag (Leading Edge Associates, Asheville, N.C.).

Samplers were located upwind, downwind, and in the direct spray zone areas of transects 1 to 4, as shown in figure 3. For the BP treatments, five water-sensitive papers were used to document the spray pattern and percentage cover. Ten Mylar cards were deployed along each transect for volumetric deposition assessment, and eight pieces of artificial foliage (AF, described by Thistle et al., 2009) were used. For the UTV sprayer, eight water-sensitive papers, eleven Mylar cards, and eight pieces of AF were used. AF was located 20 cm off the ground. At 10 m downwind, two additional pieces of AF were located 1 and 1.5 m above the ground. The AF was cut to a length approximately three times its diameter (approx. 15 cm long) with a projected area of 65 cm^2. An air sampler (Air metric PM-10) with a Teflon filter was located at the far downwind end of each transect, 25 m from the sprayer centerline. Due to concerns regarding the PM-10 data, these are not discussed.

Two portable meteorological stations were used to sample weather conditions. These stations were located 30 m upwind of the spray grid, one for each grid orientation, and measured temperature and humidity (model 41372/43372,

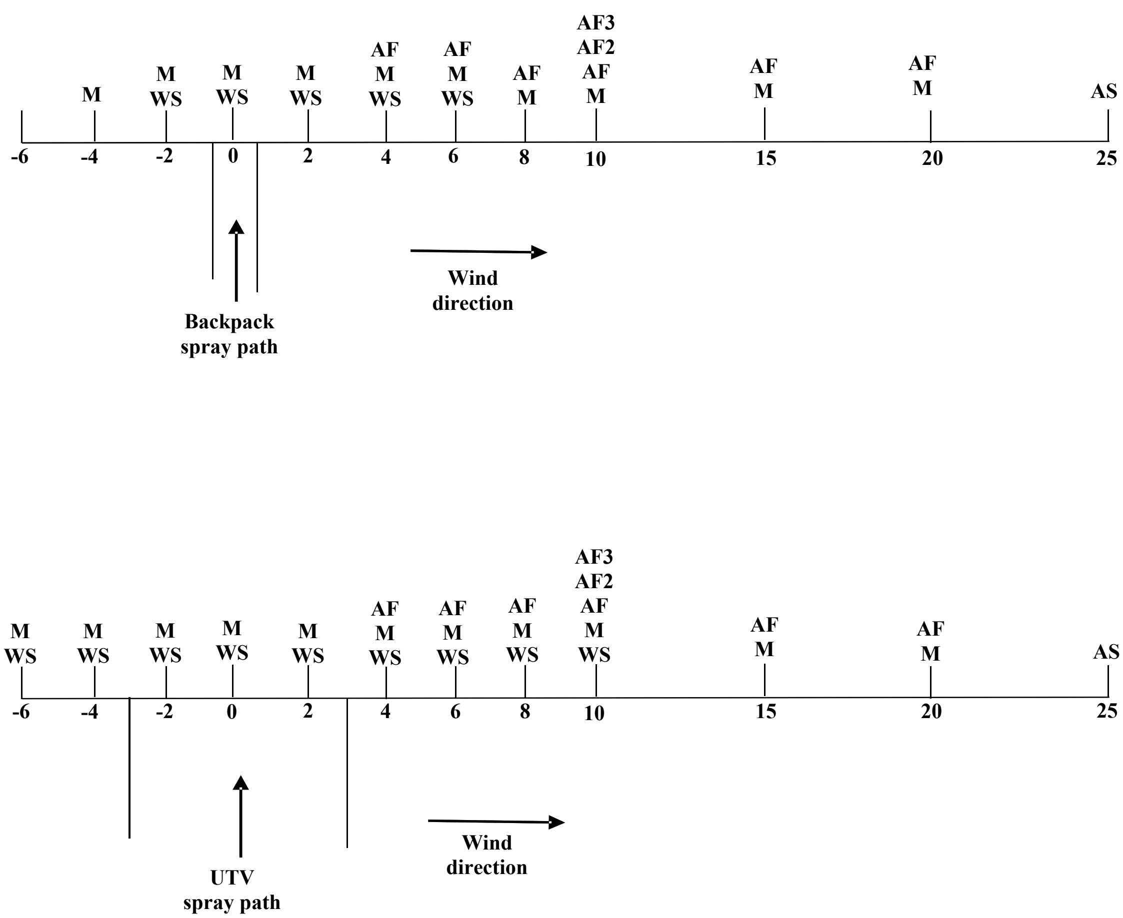

Figure 3. Sampler layout for spray trials: M = Mylar card, WS = water-sensitive paper, AF = artificial foliage at 0.2 m height, AF2 = artificial foliage at 1 m height, AF3 = artificial foliage at 1.5 m height, and AS = air sampler.

Table 1. Spraying trials.

Sprayer	Date (2014)	Time	Trial	AR (μL cm^{-2})	u (m s^{-1})	RH (%)	Ri	u/x (s)	MB
Backpack	April 21	10:20	1	9.7	0.6	43.5	-10.6	37.7	.76
		12:59	3	9.2	0.9	25.7	-22.6	28.7	1.23
		15:01	5	9.5	3.0	17.9	-0.8	15.8	.89
		16:41	7	7.7	2.2	12.9	-0.1	12.2	1.28
		18:06	9	8.2	2.6	11.7	-0.1	7.6	NA
	April 22	8:02	11	8.2	1.5	49.0	-0.2	13.3	1.09
		10:00	13	9.4	2.5	43.7	-0.8	10.8	1.19
		11:27	15	9.6	3.1	35.2	-0.4	6.5	1.06
		12:42	17	9.6	3.1	39.6	-0.6	7.1	1.33
		15:20	19	10.2	1.5	50.5	-11.7	13.3	0.80
UTV	April 21	12:00	2	13.0	0.5	34.1	-4.3	43.1	1.21
		13:54	4	13.4	1.1	21.3	-0.9	24.5	1.58
		15:46	6	14.4	2.0	14.4	-0.4	13.4	1.48
		17:20	8	13.6	3.0	12.3	-0.1	8.1	1.72
		18:58	10	13.4	2.3	13.2	0.0	10.9	1.82
	April 22	9:08	12	13.7	0.8	56.0	-15.5	31.2	1.76
		10:50	14	13.5	1.8	32.8	-5.9	11.1	2.02
		12:02	16	13.2	5	35.8	-0.1	4.4	2.12
		14:06	18	13.3	4.2	53.0	-0.0	4.8	1.73
		14:47	20	13.4	2.4	52.9	-0.4	9.2	2.25

R.M. Young Co., Traverse City, Mich.) and wind speed and direction (model 5431, 024, 010C, Met One Instruments, Inc., Traverse City, Mich.) at two heights (2 and 7 m). These data were collected at 1 Hz and averaged across the length of each trial. The anemometers have an accuracy of 0.07 m s^{-1} and stall at 0.22 m s^{-1}. A ΔT temperature system (Climatronics, Inc., Bohemia, N.Y.) composed of matched thermistors with differential accuracy of 0.05°C was deployed on the main tower with six ΔT sensors deployed at 2.0, 4.0, 5.9, 7.9, 9.9, and 11.9 m heights. These data were stored every minute. Two three-axis, 15 cm path-length, Vx probe sonic anemometers (ATI, Longmont, Colo.) were deployed at 2.3 and 12.8 m heights, and data were recorded at 10 Hz. The main tower was positioned 20 m southeast of the grid. Due to technical issues with the sonic system, wind speed data (shown in table 1) are from the sonic system through trial 10 and from the cup system thereafter. The meteorological data were used to calculate the Richardson number as a measure of atmospheric stability, defined as Ri = $g/T\,(\Delta T/\Delta Z)/(\Delta u/\Delta z)^2$, where g is gravity (m s^{-2}), and T is temperature (K).

Results and Discussion

Backpack Sprayer

Results of the sampled deposition are discussed and plotted on both linear and log-linear axes due to the decadal change in values moving away from the sprayer. This approach graphically emphasizes the generally small amounts of total drift off-target on a percentage basis while also allowing evaluation of trends in the small amounts of spray material deposited farther downwind. Trial conditions and mass balances (MB) are summarized in table 1.

Near-field deposition from the BP sprayer is concentrated in the 1 m swath (fig. 4a). Figure 4b indicates that deposition has already decreased to 0.01 of the applied rate at 2 m downwind and generally decreases a further order of magnitude by 10 m. Note that in both backpack and UTV spraying with a boomless nozzle, deposition is expected to exceed the nominal AR at the swath centerline and drop below it at the swath edge.

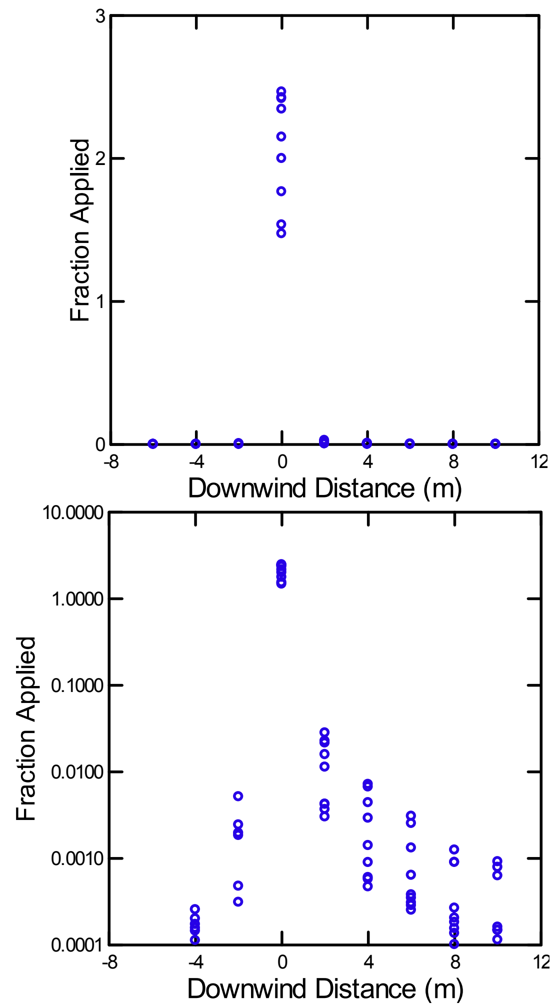

Figure 4. Near-field deposition from BP sprayer applications as measured on Mylar cards: (a) linear axis and (b) log-linear axis. Upwind is designated as negative distance.

Figure 5 shows deposition on AF out to 20 m downwind.

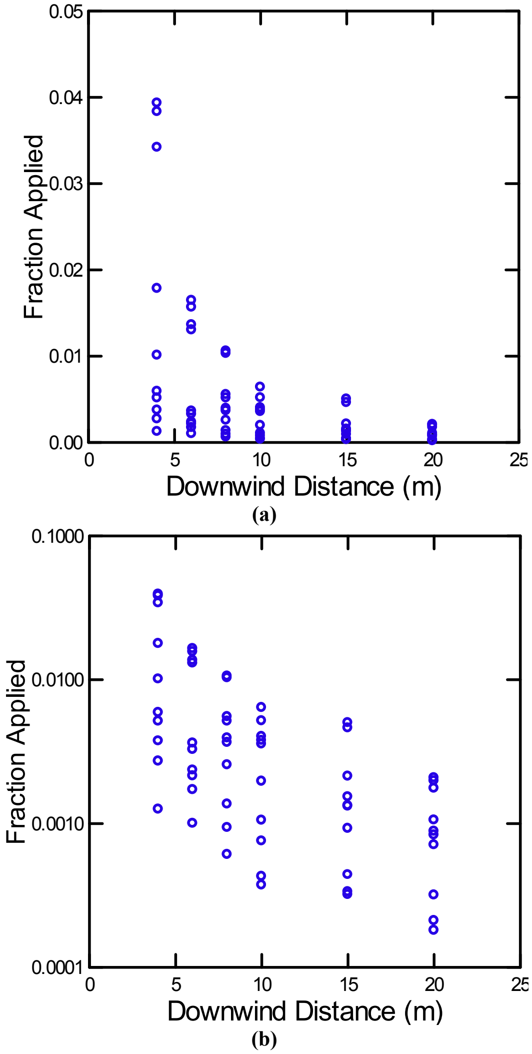

Figure 5. Farther-field deposition from BP sprayer trials as measured on artificial foliage: (a) linear axis and (b) log-linear axis.

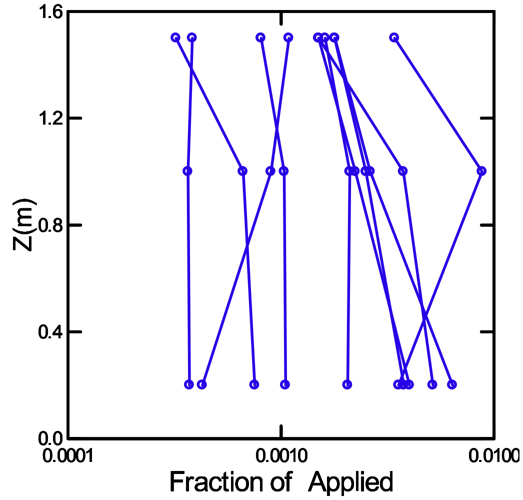

Figure 6. Profiles of deposition measured on AF collectors 10 m downwind of BP sprayer application.

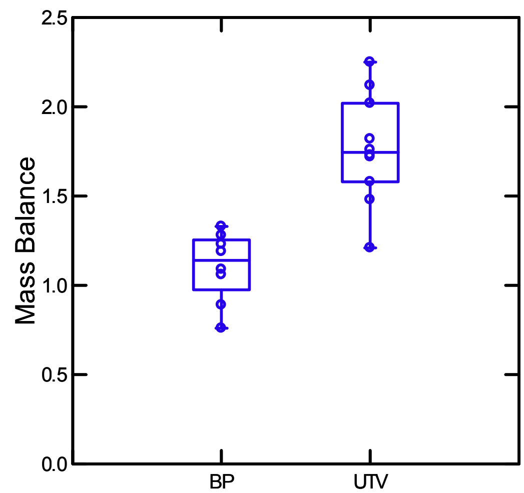

Figure 7. Distribution of trial mass balance for BP and UTV sprayers.

AF is a much better collector of fine droplets than flat cards, so it was used farther downwind where only fine drops remain airborne under most circumstances. These graphs illustrate that even though deposition at 20 m downwind of BP spraying is extremely low, it is measurable, with values centered on 0.001 at 20 m downwind from the swath centerline. Although 0.001 of the applied rate is a very small amount, it indicates that some minor drift may occur from these operations.

Figure 6 shows deposition profiles for the BP spray operation measured at 10 m downwind of the spray line. These data clearly indicate that some mixing occurred over the shallow layer measured here, as deposition values range around 0.001 at 1.6 m height at this distance downwind. Most of the profiles show a decrease in deposition with height, although not all (one profile shows deposition increasing across the three levels measured). A number of the profiles show deposition fairly constant between the 0.2 and 1 m levels, which is not unexpected given the release height. The logarithmic *x*-axis must be kept in mind when inspecting the vertical gradients.

UTV Sprayer

The UTV trials were characterized by deposition that appeared marginally too high. This is borne out by the trial mass balances shown in figure 7. Mass balance (MB) was calculated for each trial by summing the deposition numerically along the transect. Each sampler was assigned a representative area, and the total was compared to the amount released over a corresponding length of the spray line. This analysis shows that while the BP sprayer averaged very close to 1 (well within the expected error of this technique), the UTV trials averaged about 1.7 (ranging from 1.21 to 2.25; table 1), indicating a systematic error in the UTV data. The UTV tank was agitated during the spraying, but build-up of dye was observed near the tank outlet. Therefore, the most likely explanation for this error is that BSF dye was coming out of solution and concentrating near the tank outlet, causing the spray to have a higher dye concentration than calculated for the tank mix.

Given that the results of this study are generally stated as order-of-magnitude drift values, the problem with the UTV data was addressed by scaling the fraction applied values by the mass balance. Thus, if the mass balance was near 1 (as expected), then there was only minor adjustment, and so forth. Graphs of scaled and unscaled data are shown for comparison.

Figure 8 shows the deposition data from the Mylar cards for the UTV spray trials to 10 m downwind of the spray line expressed as fraction applied. The data fairly clearly delineate the 7 m spray swath (negative distance denotes upwind). It is clear that there is wide variance in deposition at 0.5 m downwind of the spray swath (distance of 4 m from the centerline) but that the deposition is generally less than 0.001 at 6.5 m off the swath (10 m downwind of the centerline).

Figure 9 shows deposition on AF out to 20 m downwind (referenced from the swath centerline) for the UTV spray trials. At 20 m, the deposition is generally slightly less than 0.001 of applied. Note that figures 8 and 9 match reasonably well at 10 m, with the figure 9 graphs reflecting the higher collection efficiency of the AF collectors for fine drops.

Figure 10 shows profiles of deposition on the AF collectors at 10 m downwind of the UTV swath centerline for these trials. These profiles (with one strong exception) are notable for being so well mixed at this distance. Even considering the logarithmic axis, the vertical gradients appear shallow over this near-surface layer.

Meteorological Influences

As stated earlier, this article does not attempt to explain the complexities of the interactions between all the possible variables in these spray trials, and a separate modeling exercise will be undertaken. However, basic meteorological correlations are shown.

Figure 11 shows the relationship between wind speed and deposition at 10 and 20 m downwind of the swath centerline for the BP spray trials. This relationship is surprisingly weak for these trials, with R^2 values of 0.40 and 0.42, respectively. Although comprehensive data are not available for BP sprayers, the relationship between wind speed and drift has been strongly established for other ground sprayers (Hewitt et al., 2001; Teske et al., 2009). To investigate further, figure 12 incorporates the measured approach angle of the wind. The wind direction during the trial was used to calculate the distance to the sampler from the spray line considering the wind direction, which is typically off perpendicular by some amount. This distance was then divided by the wind speed, resulting in a transit time (x/u, s) for the air to move from the spray centerline to the sampler. This relationship shows substantially higher R^2 values of 0.71 and 0.73, respectively, when compared to figure 11.

The wind speed and transit time relationships to downwind deposition are slightly different for the UTV trials as compared to the BP sprayer trials. Figure 13 shows wind speed explaining 0.78 and 0.64 of the variance at 10 and 20 m, respectively. In contrast with the BP trials, figure 14 shows lower R^2 values for the deposition versus transit time relationship, with values of 0.70 and 0.60 at downwind distances of 10 and 20 m, respectively.

It is interesting to note that we did not find a significant correlation with relative humidity (RH) in this study. Some correlation is expected, and there was a range of humidity during the trials. The climate in Missoula can be generally described as high steppe and is dry. Table 1 shows that RH ranged from a very dry 11.7% to a moderate 56.0% over the course of the trials. The low release height and large drops used in these application scenarios caused the vast majority

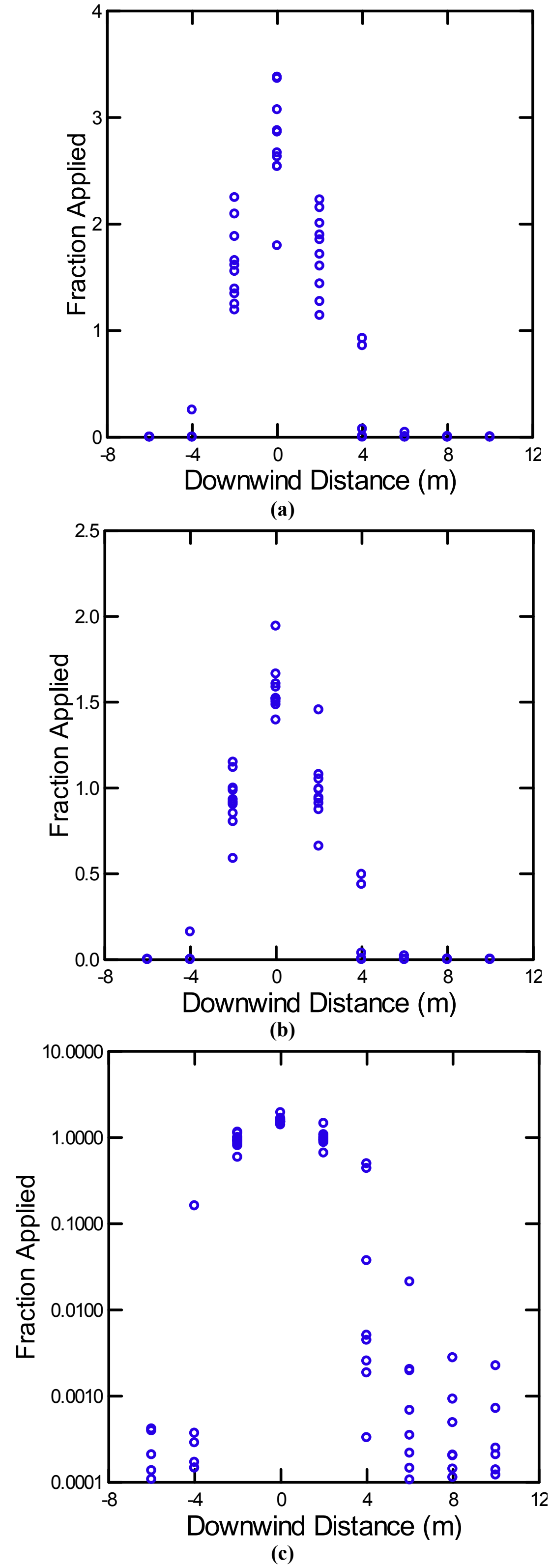

Figure 8. Near-field deposition measured on Mylar cards: (a) fraction applied versus distance for UTV spray trials, (b) with fraction applied scaled by mass balance, and (c) scaled fraction applied on a log-linear axis. Distance is from swath centerline with upwind negative.

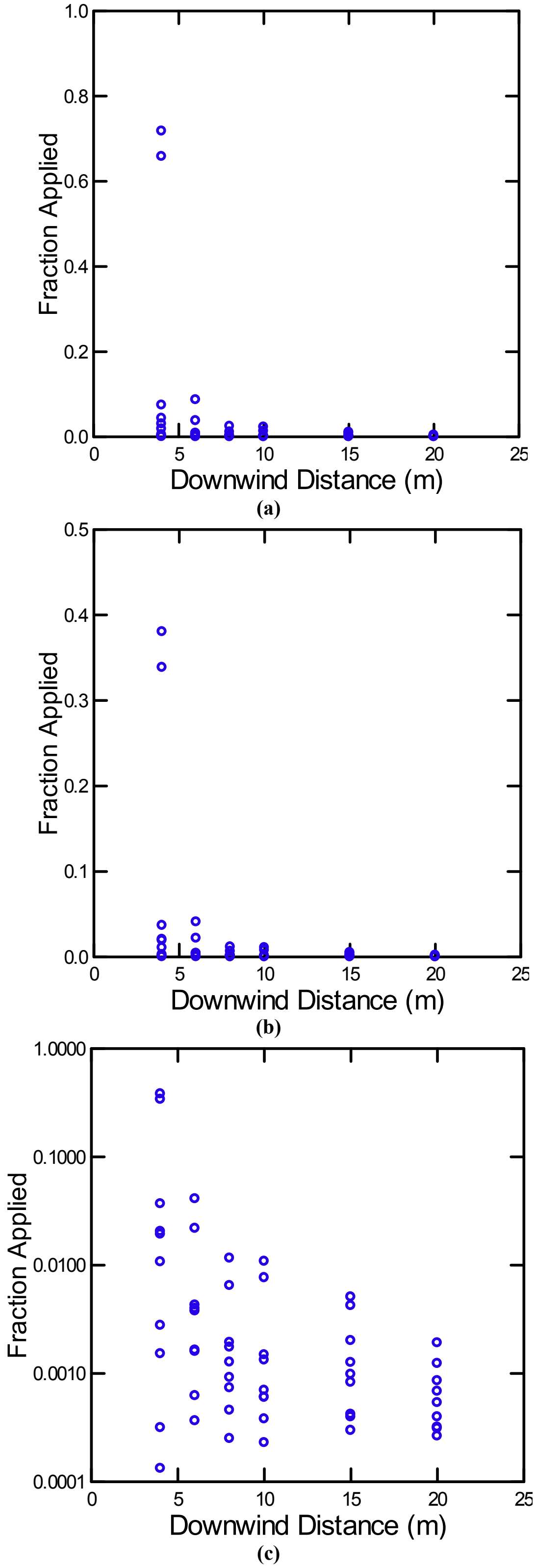

Figure 9. Drift measured on artificial foliage: (a) fraction applied versus distance for UTV spray trials, (b) with fraction applied scaled by mass balance, and (c) scaled fraction applied on a log-linear axis. Distance is from swath centerline.

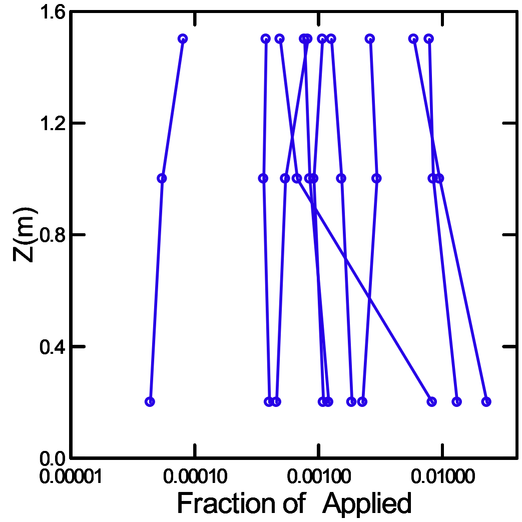

Figure 10. Profiles of deposition on AF with height 10 m downwind of swath centerline for the UTV sprayer trials.

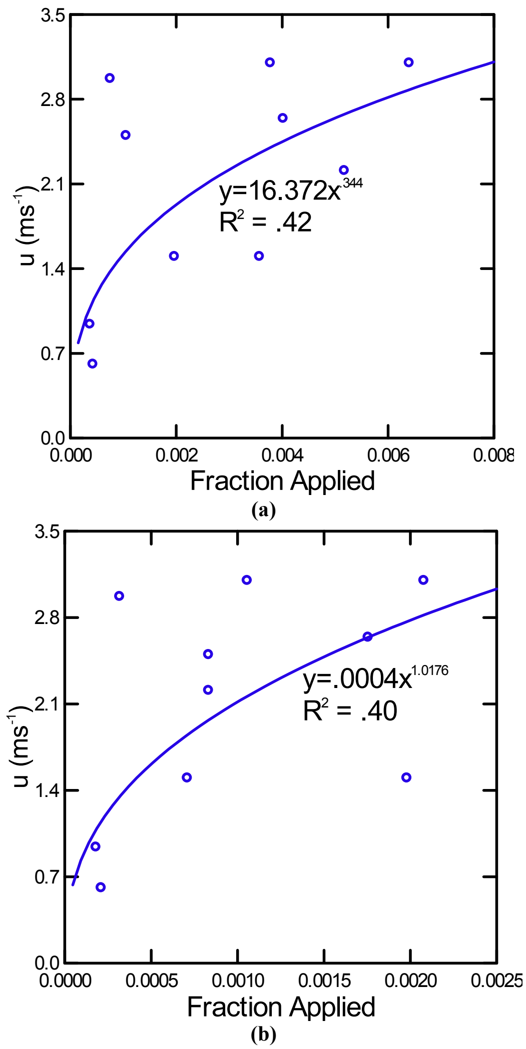

Figure 11. Relationship between wind speed and fraction applied at (a) 10 m and (b) 20 m downwind of swath centerline for BP spray trials.

of the material to reach the ground quickly, thereby reducing evaporative effects on droplet size and thus transport. These trials may not have been sensitive enough to detect evaporative effects on the small fraction of material (composed of fine drops) that drifted.

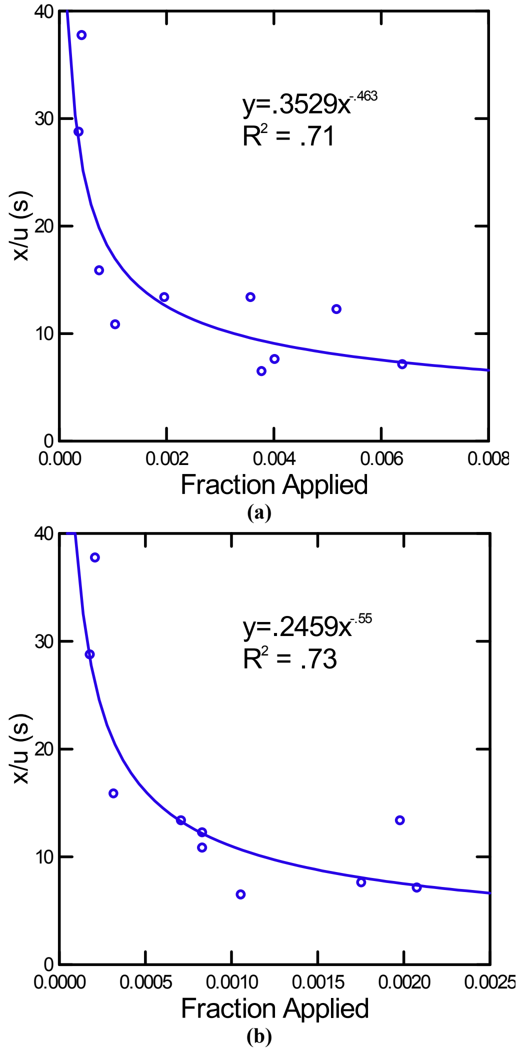

Figure 12. Relationship between transit time and fraction applied at (a) 10 m and (b) 20 m downwind of swath centerline for BP spray trials.

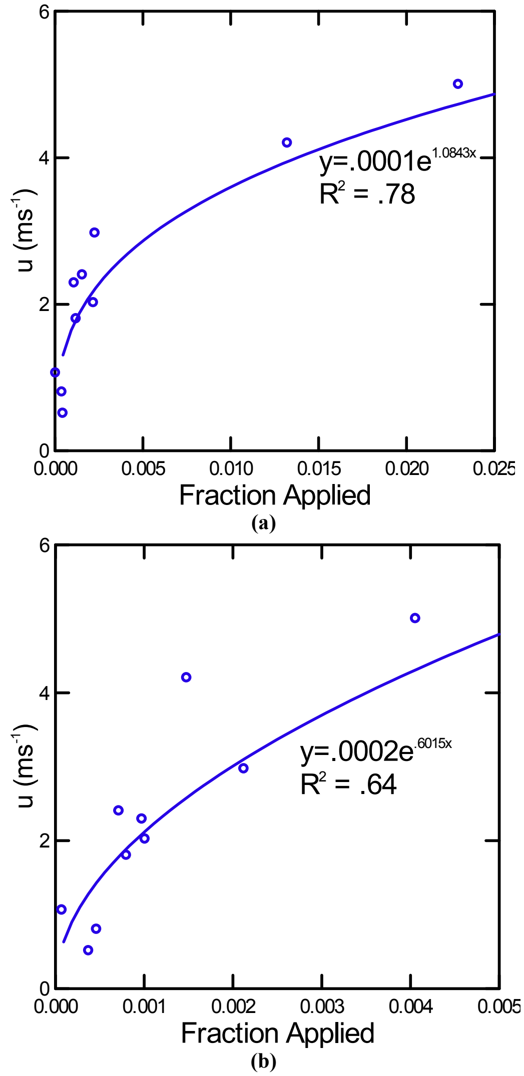

Figure 13. Relationship between wind speed and fraction applied at (a) 10 m and (b) 20 m downwind of swath centerline for UTV spray trials.

Figure 15 shows the relationship between fraction applied and Richardson number (Ri) in these data. Ri is an indicator of atmospheric stability, with values near zero indicating a neutral atmosphere, while negative Ri indicates an unstable atmosphere and positive Ri indicates a stable atmosphere. The relationship between pesticide droplet drift and stability is theoretically known (Thistle, 2000) but is often difficult to identify in deposition data. The graphs in figure 15 illustrate this issue. Ri can be pulled toward neutral by either a low temperature gradient or high wind speed. Thus, on a cloudy day without strong surface heating and low wind speed, drift may be low, and the atmosphere is neutral. On a day with high wind speeds, du/dz will be large near the surface, so Ri will again be neutral even though the drift values will be large due to the high winds. Figures 15a and 15b both show this tendency, as fraction applied ranges from high to low when Ri is near zero. Prior work (Thistle et al., 2012) showed a relationship between mass balance and stability. This relationship was investigated with these data, but the correlations were low and are therefore not shown.

Conclusions

This study indicates that drift of pesticide at 20 m downwind of BP or UTV spraying was about 0.001 of the applied rate. This order of magnitude of drift seems to apply to both application methods. In the case of BP spraying, deposition decreased to about 0.01 of the applied rate just 1.5 m downwind of the swath edge. In the UTV trials, the closest off-swath measurement was just 0.5 m downwind of the downwind swath edge, and deposition there ranged from about 0.5 of the applied rate down to less than 0.001. At 2.5 m downwind of the downwind swath edge, these values ranged from about 0.02 down to near 0.0001 of the applied rate. It is interesting that, although the deposition values decreased rapidly immediately adjacent to the spraying path, this rapid rate of decrease did not continue farther downwind. The maximum values at a given distance continued to rapidly decrease, but the minimum values remained non-zero. Thus, this study concludes that very small amounts of material were deposited at 20 m downwind, but drifted material was present. This conclusion is reached understanding that these

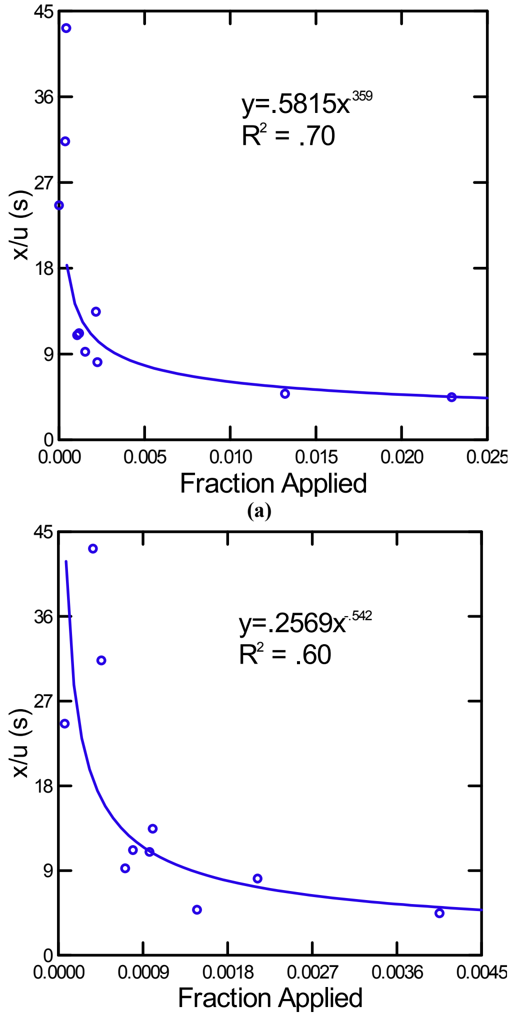

Figure 14. Relationship between transit time and fraction applied at (a) 10 m and (b) 20 m downwind of swath centerline for UTV spray trials.

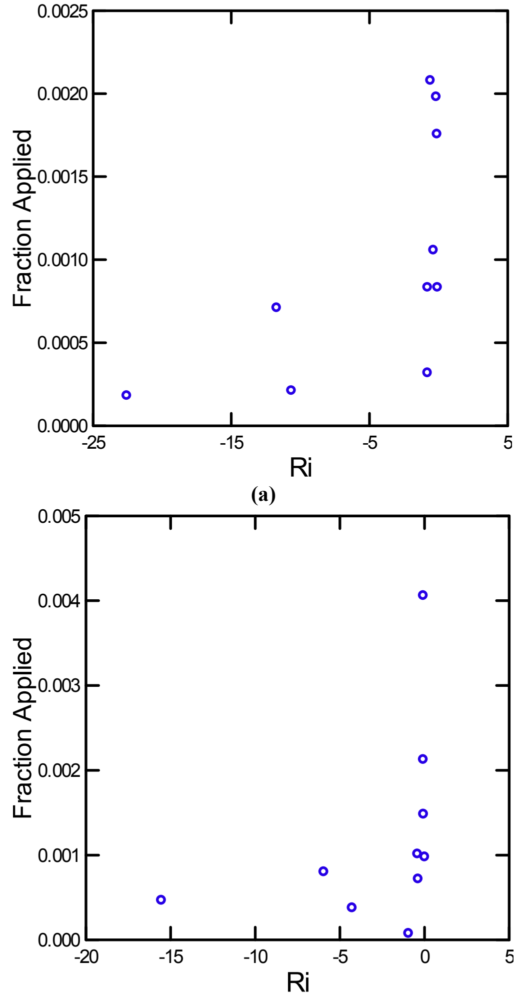

Figure 15. Richardson number (Ri) versus fraction applied at 20 m downwind of swath centerline in (a) BP and (b) UTV spray trials.

trials were conservative by design, as there was almost no intervening vegetation between the release line and the collectors. It is assumed that intervening vegetation would have scavenged spray and lowered the drift fractions shown here.

A second article will attempt to develop a mechanistically oriented model, but basic relationships with meteorology were investigated here. The influence of wind speed on drift was examined in this article and was well demonstrated in the UTV trials, as expected, based on previous drift work with other application methods. The influence of wind speed in the BP trials was less apparent until the wind speed was transformed to transit time using the approach angle of the wind to calculate the along-wind distance to the samplers. Deposition at 10 and 20 m downwind correlated reasonably strongly with transit time for both the BP and UTV trials, although the R^2 values were higher for the direct wind speed versus deposition relationships for the UTV trials.

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