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COLLECTION EFFICIENCY OF ACTIVE AND PASSIVE SAMPLERS FOR ULV SPACE SPRAYS

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Abstract

The effectiveness of ULV sprays for vector control depends upon dispersion and mixing of spray droplets within a targeted zone. Variation in spray concentration within an air column (spray flux) is an indicator of spray dispersion. Spray flux is often measured by collecting spray in the sampled air on a variety of samplers and correcting it for collection efficiency (CE). The present study determined CE of a stationary and a rotating ribbon sampler under controlled conditions in a low speed wind tunnel by comparing spray deposition on these samplers with deposition on wire samplers of known CE. Tests were conducted using a spray of 19 µm volume median diameter (Dv0.5) across four wind speeds (0.45, 1.12, 2.24, and 4.47 m/s). For each individual treatment (sampler/airspeed), six replicated measurements were made. The deposition and calculated CE of the wire samplers were used to estimate the spray flux presented to the stationary and rotating ribbon samplers. The test sampler depositions and estimated spray flux were used to determine their CEs. With increasing airspeeds, the CE of stationary ribbon samplers increased (4.2 – 32.0 %) while the CE of rotating ribbon samplers decreased (28.0 – 248.0 %). The stationary ribbon samplers had significantly lower CEs compared to rotating ribbons. However, both samplers maintained similar CEs when airspeed was adjusted for maximum velocity. These results will assist users to correct field measured data to better estimate spray flux.

Key Words: Vector control, spray flux, deposition

Introduction

The efficacy of ultra-low volume (ULV) space spray applications and pesticides has been assessed by measuring insect mortality in holding cages [1 - 6]. However, mortality does not present a complete assessment of a spray application as it will be difficult to differentiate between pesticides and delivery system failure in case of low insect mortality. A measure of the airborne spray material is required to isolate the two effects and to determine the dosages resulting from specific delivery systems and pesticide formulations [7]).

There are methods available to quantify very low chemical concentrations and are used to determine air quality with focus on human exposure risk [8-10]. These assessments have sometimes been done many days after application [11] and air is sampled for days. Also high air concentrations of insecticides from drift of agricultural sprays have been quantified by deposition on natural or artificial targets [12]. However, there are few reports on quantifying pesticides at low concentrations after ULV cold or thermal fog applications that stay in the air for a few minutes. The use of 3 mm slides to determine spray flux after an aerial ULV spray lacked correlation between spray flux and mosquito mortality [13]. Comparison of collection efficiencies (CE) of 3 mm and 25 mm Teflon® coated slides, the rotary collectors used to measure spray flux, resulted in a range of CEs from 19% to 98% [14]. These efficiencies were calculated in comparison with an air sampler assuming that the CE of the air sampler is 100%, which caused overestimation of CEs of both the rotary collectors. Also the droplet spectrum of the sprays the two samplers were subjected to, were remarkably different. Another study [15] also compared the CE of both these samplers and found the CEs in the range of 2.5 to 20% which are remarkably different than the efficiencies determined by [14] for the same samplers. Ground deposition of Naled was collected on filter paper and quantified with gas chromatography in some studies [16, 17]. Drift of Malathion from ground applied ULV spray was monitored by the use of caged mosquito (Culex quinquefasciatus Say) mortality and deposition on filter paper [18]. In each case where bee mortality occurred, spray deposits on filter papers had exceeded 400 ng/cm^2. Although mortality of caged mosquitoes indicated that Malathion drifted through the study areas, little correlation was apparent between mortality and spray deposition on filter paper. Lothrop et al. [19] used filter paper to measure ground deposition of two active ingredients from aerial ULV sprays. They analyzed the samples with high performance liquid chromatography, but could detect only one active ingredient past 60 m from the spray line.

Development of new methodologies, stationary and rotating ribbons have been reported for quantification of airborne spray materials (spray flux) through sites treated with ULV space sprays for control of flying insects [7]. These methods have been used recently to evaluate cold and thermal fogs [20 - 23], to calibrate LIDAR measurements [22] and to compare dispersion of pesticides in a hot environment [23, 24]. However, these studies lacked an estimate of sampler performance and related spray flux. Accurate assessment of spray flux directed to test insects requires knowledge of the collection efficiency (CE) of the samplers used.

Sampler CE is defined as the ratio (presented in %) of material collected by the sampler to the amount of material that would pass through the space occupied by the sampler [25]. Collection efficiency of samplers for airborne spray materials is dependent upon the droplet size, sampler shape as well as local wind speed and direction [25]. It has been determined that the CE of flat cards decreased with increasing wind speed, but the CE of spheres was not affected [26]. Additionally, they observed that the CE of spheres was generally higher compared to flat cards. Another study also found higher CE for round shaped samplers than that of flat surfaces [27].

Errors in quantifying spray flux are errors associated with collection of spray from the air onto the ribbons and errors associated with extraction of deposits on the ribbons [7]. The methodology used to determine CE in this study includes both these errors and results in a more accurate CE of the spray flux measurement system. This study was designed to determine the CE of active and passive ribbon sampler systems for ULV space sprays under varying ambient airspeeds.

Materials and methods

The work was conducted in a low speed dispersion wind tunnel at the USDA-ARS-Area-wide Pest Management Unit in College Station, TX. The low speed tunnel (1.2 x 1.2 x 12.2 m) had an operational airspeed range of 0.45 to 6.5 m/sec. CEs of rotating and stationary ribbon samplers were determined at 0.45, 1.12, 2.24, and 4.47 m/s airspeeds with six replications for each sampler/airspeed combination. The spray was generated using an air shear nozzle (ADAPCO, Inc., Sanford, FL) at the upwind end of the tunnel and spray liquid comprised of BVA 13 mineral oil and Uvitex OB (Ciba Corporation, Newport, DE) fluorescent dye mixed at 4000 ppm.

Droplet size was measured upwind of the spray samplers using a Sympatec Helos laser diffraction droplet sizing system (Sympatec Inc., Clausthal, Germany) (Fig. 1). The Helos system uses a 623-nm He-Ne laser and was operated with an R5 lens, providing a dynamic range from 0.5 to 875 µm divided across 32 sizing bins. Droplet size data was recorded as DV0.1, DV0.5, and DV0.9; where 10, 50, and 90 % of volume is contributed by droplets smaller than these diameters, respectively. The nozzle produced a droplet spectrum with a DV0.5 of 19 µm.

Rotating and stationary ribbons were test samplers and a small steel wire was used as the standard sampler. The standard and test samplers were placed downwind of the nozzle (Fig 1). The nozzle and all test samplers were centered horizontally and vertically inside the wind tunnel.

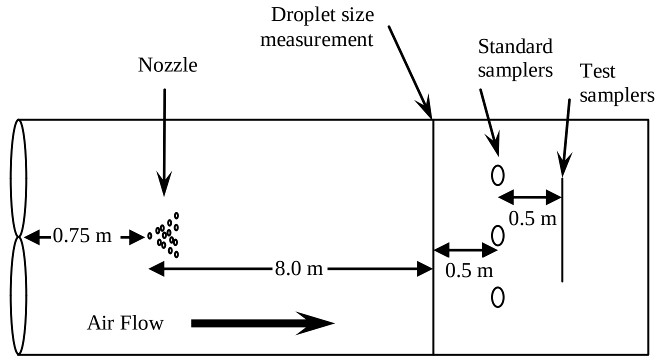

Figure 1. A cross sectional view of the wind tunnel depicting nozzle location, air flow, droplet size measurement and samplers

Three standard wire samplers (0.56 mm diameter and 149 mm long) were used to determine spray flux through the wind tunnel. Wire samplers were vertically centered and secured to a post in the tunnel using hemostats. The rotating ribbon sampler was mounted on the drive of an aerosol droplet sampler (Model 212, John W. Hock Company, Gainesville, FL) and is described by [7]. The sampler uses a 46.8 x 2.54 cm cotton ribbon stretched horizontally and clamped to a bracket rotating at 510 rpm (Fig 2). For the stationary ribbon, the motor of the rotating ribbon was locked such that the ribbon is stretched perpendicular to the air flow. The rotating ribbon and stationary ribbon samplers represented active and passive samplers, respectively.

Before each application, new wires were loaded as standard samplers and a new ribbon was clamped to the bracket. After the spray cloud dispersed through the wind tunnel, wires and ribbons were removed, placed in pre-labeled plastic bags and stored in an ice chest for laboratory analysis. The samples were then stored in the refrigerator at 4°C and were analyzed within three days.

For each application, 10 ml of spray mixture was metered using a syringe pump at 25 ml/min and sprayed for 24 second with the nozzle operating at 552 kPa inside the wind tunnel for varying wind speeds. Spray flux is defined as the flow of spray material per unit cross-sectional area of the tunnel per unit time [28] and remains constant for each application due to consistency of sprayed mixture. When the spray flux is integrated over time, it is referred to as the integrated spray flux or integrated flux. During this study, the spray was collected on the sampling media from the start time, until the entire spray plume exited the wind tunnel. By definition, the spray deposition (µl/cm^2) on the collection media is a function of integrated flux and CE.

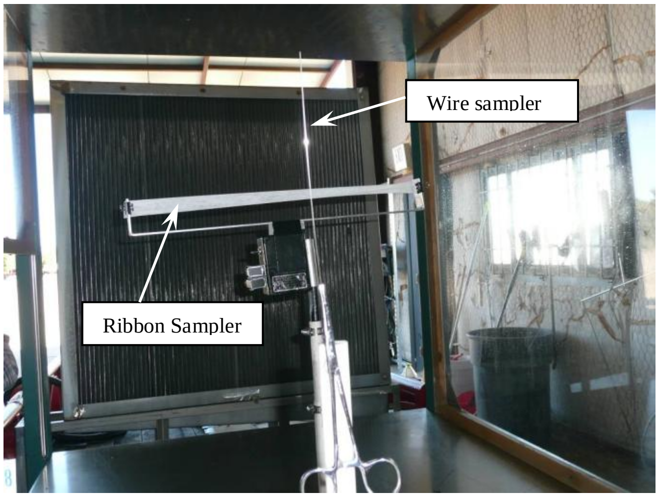

Figure 2. View of two samplers in a wind tunnel at College Station, TX

Deposition on all samplers was measured by washing dye off the ribbon/wire using a fluorescent analysis [29]. The samples were washed inside an individual plastic bag using 15 ml hexane. Fluorescence readings of the solution were determined using a spectrofluorophotometer (Shimadzu, Model RF5000U, Kyoto, Japan) and converted to a spray volume using calibrations developed from a set of standardized fluorescence concentrations. The spray volumes for each sample were then divided by the effective sampling area of that particular sampler to calculate a spray deposition (µL/cm^2). The area sampled by the fine wire samplers was 2.504 cm^2 (0.559 mm dia. x 149.3 mm length x 3 wires) while area for which the test samplers could collect was measured at 118.9 cm2 (46.8 cm x 2.54 cm).

The CE of the wire samplers was calculated for each application using droplet size data, wind speed in the wind tunnel, relative humidity and temperature in the room [28]. The integrated flux for each replication was determined by dividing the measured spray deposition on wire samplers with their CE. The CEs of the test samplers were then determined by dividing the deposition on test samplers with integrated flux. The effect of wind speed and sampler types on deposition, integrated flux and CE was analyzed using Analysis of Variance procedure of JMP statistical software version 5 (JMP, Cary NC). The means were compared using the t-test at 95% confidence.

Results and Discussion

For constant spray flux, as discussed earlier, the deposition is directly related to the CE of the samplers. The analysis of variance indicated that the sampler type, wind speed and their interaction affected the deposition significantly ($P < 0.0001$). The deposition on the rotary ribbon was significantly higher compared to that on stationary ribbon at wind speeds of 0.45, 1.12, and 2.24 m/s (Table 1). Deposition on rotary ribbon samplers was significantly higher than that on wire samplers at 0.45 m/s, while it was significantly lower than that on wire samplers at 2.24 and 4.47 m/s winds.

Table 1. Mean deposition of BVA-13 oil on different samplers at four wind speeds

Sampler	Mean deposition (µl/cm^2) at wind speeds, m/s			
	0.45	1.12	2.24	4.47
Rotating Ribbon	0.50 Aa*	0.19 Ba	0.12 BCb	0.09 Cb
Stationary Ribbon	0.01 Dc	0.02 Cb	0.04 B c	0.10 Ab
Wire with rotary ribbon	0.10 Cb	0.18 Ba	0.23 ABa	0.29 Aa
Wire with stationary ribbon	0.11 Cb	0.19 Ba	0.22 ABa	0.27 Aa

*Means followed by the same capital letter in a row and same small letter in a column are not significantly different ($\alpha = 0.05$).

The calculated integrated flux through the wind tunnel cross section was similar ($P = 0.83$) during all tests. Further, the difference in deposition on wire samplers during the tests for stationary and ribbon samplers was non-significant ($P = 0.94$, table 1). These observations suggest that the CE of the two test samplers was determined under similar conditions.

The analysis of variance indicated that the sampler type, wind speed and their interaction significantly affected the CE of the spray sampling ($P < 0.0001$) (Table 2). Overall, the rotating ribbon (active) sampler had a higher mean CE (97.2 %) compared to the stationary ribbon (passive) sampler (14.3 %). The CE of the stationary ribbon samplers (CE_{SR}, %) increased with wind speed (U, m/s), which is consistent with previous studies [30, 31]). An empirical positive linear relationship was observed for CE of the stationary cotton ribbon with increasing wind speed ($CE_{SR} = 9.98$ U).

Table 2. Mean collection efficiency of different samplers at four wind speeds

Sampler	Mean collection efficiency (%) at wind speeds, m/s			
	0.45	1.12	2.24	4.47
Rotating Ribbon	248.3 Aa*	68.1Ba	44.4 Ba	28.1 Ba
Stationary Ribbon	4.2 Cb	6.6 Cb	14.6 Bb	31.9 Aa
Wire (Calculated)	44.4	63.1	73.2	80.6

*Means followed by the same capital letter in a row and same small letter in a column are not significantly different ($\alpha = 0.05$). The collection efficiencies of wire samplers are presented for reference.

The CE of the rotating ribbon samplers (CERR, %) decreased with the increasing wind speed exponentially, which is consistent with the results from [15] for other rotating samplers. The CE of rotating ribbon samplers can be represented as an empirical function of wind speed as CERR = 98.5 U-0.931. With increasing wind speed, the deposition and CE decreased on the rotary ribbons while it increased on the stationary ribbons and wire samplers (Tables 1 & 2). The rotating ribbon sampler had higher CE compared to the stationary ribbon sampler for wind speeds of 2.24 m/s or lower. However, no significant differences in CEs were observed at winds of 4.47 m/s. Comparison of the two empirical equations above indicated that either of the two samplers could be used in wind speeds above 3.9 m/s while the rotary ribbon is more suitable at lower wind speeds.

The collection efficiency of the commonly used Hock and FLB samplers (J. W. Hock, Gainesville, FL), which collect spray on slides, has been reported in the range of 19% to 98% by [14]at wind speeds of 1.0 to 3.5 m/s. For the same samplers, another study [15] has reported collection efficiency in the range of 2.5 to 20% at wind speeds of 0.5 to 4.0 m/s. Collection efficiency of the samplers in this study at wind speeds of 0.5 to 4.5 m/s is compared with the data reported by [15] on the grounds that same procedure was used in this study and [15] while [14] used different procedures which has some apparent complications as discussed above. The results of this study show that the collection efficiency of stationary and rotating ribbon samplers is higher than both slide samplers at upper end of the permissible wind speed range (0.5 to 4.5 m/s) for ULV space sprays. This means that these samplers can more effectively be used for lower concentrations of pesticides. At lower end of the permissible wind speed rage, the rotary ribbon have much higher collection efficiency than other samplers and can prove to be a better flux measurement tool, especially when concentrations are very low. However, these samplers do not provide droplet size information and slide samplers have to be utilized if the droplet size measurements are required.

We measured rotating ribbon sampler CEs above 100% indicating higher than the expected amounts of spray collected. We suspect that the rotating samplers collected spray material from the space larger than what they occupy. To test this theory, air movement around a rotating sampler was measured in still air with a hot-wire anemometer and determined that there was a 0.15 – 0.30 m/s upward air movement at 30.5 -7.6 cm below the rotating ribbon. With slow moving spray clouds under lower wind speeds, this air movement pushes spray material from outside into the sampling zone. Also the rotation of the ribbon increases the relative velocity between the droplets and the sampler resulting in a higher collection rate. At higher wind speed, the upward movement of the air is suppressed by the kinetic energy of the oncoming wind and the effect of rotation is diminished.

Results reported in this study describe the operational performance of two alternative sampling devices as well as how concentration data measured using these devices can be corrected to estimate the actual spray flux through a sprayed area. This will assist researchers and operators in providing a better estimate of the actual spray concentrations during bioassay experiments or spray application studies.

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