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Environmental fate model for ultra-low-volume insecticide applications used for adult mosquito management

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HIGHLIGHTS

- ► No model can accurately predict deposition of insecticides applied with ultra-low-volume technology for mosquito management.
- ► We perform field studies to measure actual environmental concentrations of insecticides.
- ► We develop a validated model to predict the deposition of insecticides after ultra-low-volume applications.
- ► The model demonstrated good predictive ability and was validated.

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ABSTRACT

One of the more effective ways of managing high densities of adult mosquitoes that vector human and animal pathogens is ultra-low-volume (ULV) aerosol applications of insecticides. The U.S. Environmental Protection Agency uses models that are not validated for ULV insecticide applications and exposure assumptions to perform their human and ecological risk assessments. Currently, there is no validated model that can accurately predict deposition of insecticides applied using ULV technology for adult mosquito management. In addition, little is known about the deposition and drift of small droplets like those used under conditions encountered during ULV applications. The objective of this study was to perform field studies to measure environmental concentrations of insecticides and to develop a validated model to predict the deposition of ULV insecticides. The final regression model was selected by minimizing the Bayesian Information Criterion and its prediction performance was evaluated using *k*-fold cross validation. Density of the formulation and the density and CMD interaction coefficients were the largest in the model. The results showed that as density of the formulation decreases, deposition increases. The interaction of density and CMD showed that higher density formulations and larger droplets resulted in greater deposition. These results are supported by the aerosol physics literature. A *k*-fold cross validation demonstrated that the mean square error of the selected regression model is not biased, and the mean square error and mean square prediction error indicated good predictive ability.

1. Introduction

West Nile virus (WNV) has now become endemic to North America and disease cases occur throughout the virus transmission season. Since the arrival of WNV, more areas have been experiencing large-scale insecticide applications for mosquito-borne pathogens like WNV. To effectively manage infection rates, morbidity, and mortality due to mosquito-borne pathogens like WNV, there must be a reduction in contact between infected mosquitoes and humans and other virus-impacted animals (Marfin and Gubler, 2001).

One of the more effective ways of managing high densities of adult mosquitoes that vector human and animal pathogens is ultra-low-volume (ULV) aerosol applications of insecticides (Mount, 1998; Mount et al., 1996). Ultra-low-volume applications utilize small droplets from 5 to 25 μm, which are the optimum size to impinge on and cause knock down of flying adult mosquitoes through intoxication (Haile et al., 1982; Lofgren et al., 1973; Weidhaas et al., 1970).

Ground-based ULV applications used for adult mosquito management are very different than agricultural pesticide applications because the nozzles produce an aerosol (droplets <100 μm) and are pointed at a +45° angle from the horizon. Ultra-low-volume applications used for adult mosquito management are most effective when the insecticide remains airborne and moves through the target area; in contrast,

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applications for agricultural pests are designed to minimize the movement of droplets (Hiscox et al., 2006). Droplet spectra for ULV applications used during adult mosquito control operations have a volume median diameter (VMD) between 8 and 30 μm (VMD<30 μm) and 90% of the droplet spectrum should be smaller than 50 μm (VMD 0.9<50 μm). The droplet spectrum used for adult mosquito management is well below those classified as "very fine" to "fine" (VMD<137 μm) by the American Society of Agricultural Engineers, which is considered to be a high drift hazard (Hewitt, 2008; Teske et al., 2000).

Little is currently known about the deposition and drift of small droplets such as those used during ULV applications for adult mosquito management (Teske et al., 2000). Droplets smaller than 50 μm have very low settling velocities, and have similar transport characteristics to those of gaseous mixtures (Thistle, 2000). Currently, there is no validated model that can accurately predict deposition of insecticides applied using ULV technology for adult mosquito management.

Computer models of pesticide drift are widely used tools by regulatory agencies for predicting the deposition of spray particles beyond the intended target area (Felsot et al., 2011). The U.S. Environmental Protection Agency uses different models and assumptions to assess the risks of ULV insecticides (USEPA, 2002, 2006a, 2006b, 2006c, 2006d, 2006e, 2006f). Previous risk and regulatory assessments have used models like ISCST3, AgDrift® (Stewart Agricultural Research Services, Macon, MO, USA) (Teske et al., 2002), and AGDISP (Bilanin et al., 1989) to estimate environmental concentrations of insecticides (Davis et al., 2007; Macedo et al., 2007; Peterson et al., 2006; Schleier et al., 2008, 2009a, 2009b; USEPA, 2008). The ISCST3, AERMOD, AgDrift, and AGDISP models use a steady-state Gaussian plume algorithm, and are applicable for estimating anthropogenic compound concentrations from point, area, and volume sources with coarse droplet sizes and applications that are 10 to 100 m above ground level.

A reliable model that can predict environmental concentrations of ULV insecticides is needed because previous probabilistic risk assessments have shown that the deposition of the insecticide contributes the largest amount of variance to the estimated exposure (Schleier et al., 2009a, 2009b). In addition, a model is needed because of the limited amount of knowledge about which environmental and physicochemical factors have the largest effect on the movement of pesticide aerosols.

Because of public concerns about the safety of adulticides used for the control of adult mosquitoes (Peterson et al., 2006; Roche, 2002; Thier, 2001), the lack of actual environmental concentration data (Schleier and Peterson, 2010), and uncertainties associated with the fate of the ULV insecticides, we conducted environmental fate studies during the summers of 2009 to 2011 in California, Montana, and Louisiana to develop a predictive model for ULV insecticide deposition. For wide applicability, we validate the model with respect to predictive ability and a range of environmental variables.

2. Materials and methods

Ground-based ULV field experiments were conducted near Elk Grove, California (38°27′17.27″N, 121°27′9.25″W), Bozeman, Montana (45°38′ 47.09″N, 111°24′8.18″W), and Baton Rouge, Louisiana (30°31′1.57″N, 91° 9′20.32″W) during the summers of 2009 to 2011. Sites with little vegetative structure and a flat topography were chosen for all experiments because vegetation affects air movement and subsequent deposition of insecticides and we were interested in high depositions for conservative estimates of exposure. Sites were 200 m long with two lines of horizontal drift collectors positioned 25 m to the left and right of the center of the plot to capture any variability of deposition within the spray plot (Fig. 1). Because the two lines of deposition samplers are sub-samples they were averaged together at each distance from the spray source for statistical analysis. During each spray event, 11 receptors on the two sampling lines were placed in the field at different distances from the spray source (Fig. 1). Sampling occurred at distances of 5, 10, 15, 20, 30, 35, 40, 50, 60, 65, 70, 75, 80, 90, 95, 100, 110, 120, 125, 130, 135, 140, 155, 160, and 180 m from the spray source.

During all applications, the truck speed was 16.1 km/h. Applications occurred when the prevailing wind was blowing perpendicular to the collection site (Fig. 1). Sprays were conducted using a Guardian 95 ES (ADAPCO, Sanford, FL, USA) in Montana and a London Fogger model 18 (London Fog Inc., Long Lake, MN, USA) in California and Louisiana. Nozzle orientation of the sprayers was a +45° angle compared to the horizon which is the most commonly used angle for mosquito management. Between each spray replication the nozzle, pump, and hoses were rinsed with 300 ml of D.I. H_2O followed by 300 ml of a 1:1 mixture of high pressure liquid chromatography acetone (99.7% purity; EMD Chemicals, Gibbstown, NJ, USA) and American Chemical Society (ACS) grade toluene (99.5% purity, Mallinckrodt Baker, Inc., Phillipsburg, NJ, USA) (Schleier et al., 2010).

The oil-based insecticides Permanone® 30–30 (30% permethrin), Scourge® 18 + 54 (18% resmethrin), Permanone® 31–66 (31% permethrin) (Bayer Environmental Science, Research Triangle Park, NC, USA), Zenivex® E20 (20% etofenprox) (Central Life Sciences®, Schaumburg, IL, USA), and Pyronyl™ Crop Spray (6% pyrethrins) (Prentiss Inc., Alpharetta, GA, USA) were used. The water-based formulations Aqua-Reslin® (20% permethrin) (Bayer Environmental Science, Research Triangle Park, NC, USA) and Aqua-Kontrol (20% permethrin) (Univar®, Redmond, WA, USA) were used. The active ingredients were applied at the maximum rate of 7.85 g/ha of active ingredient according to label for all insecticides, except for Pyronyl Crop Spray which was applied at the maximum rate of 2.8 g/ha of active ingredient.

The experimental design was completely randomized with each formulation randomly selected for the order it was sprayed. Replications were performed over time within the same night and over different nights with a total of 96 spray events occurring during the three field seasons. Applications began no earlier than 18:00 h at all locations, but most applications occurred after 20:00 h.

Between June 21 and 26, 2009 a total of nine and eight sprays of Aqua-Reslin and Permanone 31–66 occurred in California, respectively. Aqua-Reslin was mixed 1:1.5 with deionized (D.I.) H_2O and applied at the flow rate of 240 ml/min. Permanone 31–66 was mixed 1:0.25 with ACS grade toluene and applied at a flow rate of 74 ml/min.

Between July 16 and August 5, 2009, a total of 13, 12, and 4 sprays of Aqua-Reslin, Permanone 30–30, and Scourge 18 + 54 occurred in Montana, respectively. Aqua-Reslin was mixed 1:1 with D.I. H_2O and applied at a flow rate of 192 ml/min. Permanone 30–30 was mixed 1:2:1 with Crystal Plus 70 T light mineral oil (STE Oil Company, Inc., San Marcos, TX, USA) and ACS grade toluene and applied at a flow rate of 192 ml/min. Scourge 18 + 54 was mixed at 1:0.4:0.4 with Crystal Plus 70 T light mineral oil and ACS grade toluene and applied at a flow rate of 192 ml/min.

Between June 7 and 22, 2010 a total of seven sprays of Aqua-Reslin and Pyronyl Crop Spray occurred in California, respectively. Aqua-Reslin was mixed 1:1 with D.I. H_2O and applied at a flow rate of 192 ml/min. Pyronyl Crop Spray was mixed at 1:0.2 with ACS grade toluene and applied at a flow rate of 163 ml/min.

Between July 19 and August 12, 2010, a total of eight, seven, two, seven, and six sprays of Aqua-Reslin, Permanone 30–30, Scourge 18 + 54, Zenivex E20, and Aqua-Kontrol occurred in Montana, respectively. Aqua-Reslin was mixed 1:1 with D.I. H_2O and applied at a flow rate of 192 ml/min. Permanone 30–30 was mixed 1:2:1 with Crystal Plus 70 T light mineral oil and ACS grade toluene and applied at a flow rate of 192 ml/min. Scourge 18 + 54 mixed at 1:0.4:0.4 to Crystal Plus 70 T light mineral oil and ACS grade toluene and applied at a flow rate of 192 ml/min. Zenivex E20 was mixed 1:0.4:0.4 with Crystal Plus 70 T light mineral oil and ACS grade toluene and applied at a flow rate of 192 ml/min. Aqua-Kontrol was mixed 1:1 with D.I. H_2O and applied at a flow rate of 192 ml/min.