EVALUATION AND MITIGATION OF SPRAY DRIFT

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Definition of Drift

When liquids are forced under pressure through small orifices (like sprayer nozzles) they are sheared into small aerosols or particles having nearly a thousand fold range in spherical diameters. Owing to gravitational forces and the viscosity of air, the rate of fall to ground can be predicted by Stokes Law and is proportional to the radius of the particles. The rate of fall before a particle hits ground (or conversely how long a particle remains in air before it falls a given distance) is modified by entrainment in a mobile air mass. Rate of fall of a spray particle will also be influenced by the rate of evaporation of the liquid constituting the aerosol. The longer the aerosol remains in air before falling to ground (or alternatively striking an object above ground) the greater the opportunity to be carried away from its intended target (e.g., crop canopy). In general, all size classes of spray particles are capable of movement off-target, but the smallest particles would move the farthest before depositing on the ground.

Drift has been historically considered to be the movement of pesticide residues via air masses during and after application. Post application movement of pesticide residues (i.e., after deposition on plants or soil) via volatilization has been distinguished as secondary or indirect drift. Whereas drift is specifically the movement of aerosolized chemical during the application period, volatilization post application can occur over prolonged periods and constitutes mass transfer in the gaseous phase. Although drift has a negative connotation because of its usual association with off-target (or out of field) impacts, sprays drift within the canopy itself during an application swath and serve to increase the potentially bioavailable residues on foliage. On the other hand, off-target or out-of-field drift during application will produce a high concentration of residues that potentially has an immediate or acute effect on nontarget receptors. Volatilization over a prolonged period generates a more dilute concentration of residues but a significantly lower probability of an adverse effect. However, both drift and post-application volatilization movement of residues can produce inadvertent contamination of crops for which the pesticide is not registered. Because the physical principles controlling generation of spray drift and secondary drift are different, distinguishing the two modes of off-target movement as related but distinct phenomena may be logical because measures to mitigate either will necessarily be different.

This paper will provide a historical overview of primary or direct drift and review current status of activities for its evaluation and mitigation. Regulatory assessment and mitigation of agricultural spray drift is currently the subject of an IUPAC technical review project organized by the Advisory Committee for Crop Protection Chemistry.

Historical Overview of the Drift Phenomenon and Its Impact

The first comprehensive review of spray drift phenomena was published in 1964 (Akesson and Yates 1964). In addition to covering the physical principles of drift and its measurement, especially from aerial application equipment, the paper reviewed the historical social and legal ramifications of drift. Prior to the mid-1940's, pesticide formulations were dominated by dusts of arsenate salts. Few synthetic organic active ingredients were commercially available. Application of pesticides was largely made by hand-held or ground sprayers. Aerial application was rare. Spray application nozzles were not engineered as today to precisely control droplet size. The efficiency of pest control was likely far from adequate given the limited availability of insecticides, herbicides, and fungicides and the lack of application equipment that could adequately control deposition on foliage. In this context, little attention was given to movement of chemical residues via runoff, leaching, or drift off-target and away from the sprayed field. Thus, consequences of inaccurate and imprecise application were not an issue amidst the struggle to adequately control pests.

With the advent of DDT in the early 1940's and its subsequent widespread commercialization and intense use by the early 1950's, efficiency of insect pest control greatly improved, largely owing to its high activity against a broad spectrum of insect species at lower application rates than necessary for the inorganic arsenicals. However, even before 1950, studies had shown that DDT could be transferred to milk, suggesting that the chemical might have nontarget impacts not considered before. The ability of DDT to move from one location to another was realized when cows resting in barns sprayed for fly control had residues in their milk. By the mid 1950's DDT was recognized as a persistent and bioaccumulative chemical. Its residues washed off fields, and could subsequently be found in water. However, when residues were found in rainfall in the U.K., the notion arose that residues sprayed on soil or foliage could move via atmospheric transport. At this time, however, the notion that insecticide spray aerosols might be transported in turbulent air was not widely recognized. Not until the 1960's was the atmospheric circulation of DDT widely recognized. While the impact on health and environment of such widespread movement through air has always been open to scrutiny and question, residue monitoring studies had suggested that residues could move off-target during spraying and contaminate either adjacent or distant crops (Ware et al. 1968).

By the early 1950's, the herbicide 2,4-D was commercially introduced and quickly adopted by cereal farmers. Its mode of toxic action was specific to plants but selectively toxic to broadleaf species. Throughout the 1950's engineering of application equipment had improved the precision of delivery and foliar coverage. Ground rigs, airplanes, and helicopters supplanted hand-application equipment in the industrialized countries. While 2,4-D was hailed as a great breakthrough for adequately controlling weeds in cereal crops, its side effects on nontarget crops were soon noted. Specifically, in California, USA, where cereal crops were grown in proximity to vineyards, grape growers complained of foliar injury and yield loss (Akesson and Yates 1963). The symptomology was characteristic of 2,4-D injury. Court records of the time document civil actions taken as a result of drift movement of the herbicide from target to nontarget crops. Pertinently, movement of 2,4-D was recognized both during spraying through drift and after spraying through volatilization losses (Sherwood et al. 1970; Grover et al. 1972). In contrast to experiences with DDT movement, where residues could only be detected following chemical analysis of tissues, 2,4-D residues were easily surmised by the easily recognizable morphological changes in foliage (Zimmerman et al. 1953; Greenshields et al. 1958).

The early history of DDT and 2,4-D were harbingers of the evolving knowledge that chemicals could move easily form target to nontarget areas both during application as well as post application. Only as analytical chemistry improved sufficiently to easily analyze trace residues did awareness come of the side effects of pesticide spraying. Similarly, the realization that movement of chemicals during spraying created a potential hazard occurred only because susceptible plants exposed to 2,4-D developed unique morphological symptoms.

With the change in insecticidal active ingredients from moderately acutely toxic chemicals (DDT, chlorinated cyclodienes) to the acutely toxic organophosphorus compounds (e.g., ethyl parathion) came the realization that spray drift could be hazardous to bystanders or aquatic habitats analogously to herbicides drifting on nontarget crops. In contrast to a growing concern about off-target impacts of active ingredients with high acute toxicity, the concern over widespread nontarget impacts of herbicides became somewhat muted. As herbicide chemistry diversified and was developed more specifically for field crops, especially throughout the Midwestern U.S. and the cereal growing regions of Europe and Australia, farmers could begin to apply herbicides directly to the soil prior to plant emergence in the spring. Thus, throughout the 1970's and 1980's, herbicides were most frequently applied at a time of year when nontarget foliage would be absent. But, with the development of herbicides in the mid-1980s that were better suited for post emergence applications, the potential of spray drift to damage susceptible plants became a more widespread problem. Indeed, the potential problems associated with spray drift have likely grown as widespread use of glyphosate has increased in conjunction with the planting of biotechnology-derived soybean and corn in the U.S.

Over the last three decades, worldwide concern has focused on contamination of water resources. Runoff and subsurface flow are likely the most important pathways for chronic contamination of surface water habitats with pesticide residues at ng/L concentrations (Dabrowski and Shulz 2003). Intense rainstorms in close proximity to application can cause "catastrophic" runoff events with in-stream concentrations (low µg/L) that are acutely toxic to invertebrates and occasionally fish kills. Over the long term, direct contamination of water bodies by spray drift has been associated with only about 10% of the contaminant loads caused by surface runoff. However, pesticide residues concentrations resulting from spray drift (i.e., µg/L levels) can be similar to those following heavy rainfalls and thus also constitute acutely toxic exposures (Dabrowski and Shulz 2003). No-spray buffer zones and the encouragement of riparian strips between agricultural land and water bodies have been recommended to simultaneously reduce the likelihood of toxicologically significant spray drift and reduce runoff loading. Recent U.S. court rulings in the Pacific Northwest have superseded regulatory law to mandate no-spray buffers that protect endangered aquatic species like salmon (Felsot 2004a).

A historical review of spray drift and its potential for nontarget injury shows the phenomenon, although widely discussed, has not been satisfactorily mitigated despite the many years of training pesticide applicators. Part of the problem is the realization that zero movement is an impossible goal to achieve. At best, we can aim to reduce movement rather than ideally eliminate it. However, the most efficient and efficacious mitigation techniques can only be developed following a thorough understanding of the phenomenon and how changes in equipment, chemical adjuvants, and physical practices change aerosol (particle) movement and subsequent deposition.

Current Needs for Spray Drift Assessment in Risk Assessment

Highly concentrated agrochemical residues generated during spray application can move (drift) beyond target foliage (or in some cases soil if a pre-emergent herbicide or fumigant is used) to nontarget receptors including water, plants, and animals. Nontarget receptors may be acutely exposed and therefore face the greatest risk of adverse effects during and immediately after spray application. In addition to movement of agrochemical residues in turbulent air masses downwind of application, residues can also become concentrated in inversions or stable air masses and be transported long distances. Similarly, agrochemicals can volatilize from plant and soil surfaces in comparatively high concentrations for several days after application. These secondary drift residues also pose a hazard to nearby nontarget receptors.

The likelihood or risk of an adverse impact will depend directly on the magnitude of exposure. Spray drift can be quantified as a function of surface area deposition relative to downwind distance. The resulting function can be empirically obtained or estimated using both deterministic and stochastic models. Exposure assessment is combined with dose-response functions (or singular toxicity benchmarks like No Observable Adverse Effects Levels [NOAELs]) to characterize the risk of toxicity.

Regulatory authorities currently use the output from drift models as one input along with surface runoff to estimate the risk of adverse effects in aquatic systems. These same models, however, can also be used to estimate exposure to nontarget people or livestock and/or nontarget plants, assuming that appropriate toxicity endpoints have been developed. In the latter case, the risk may be characterized as the downwind distance where exposure of a nontarget receptor (for example, a child) would have a reasonable certainty of causing no harm (see Figure 1 for an example).

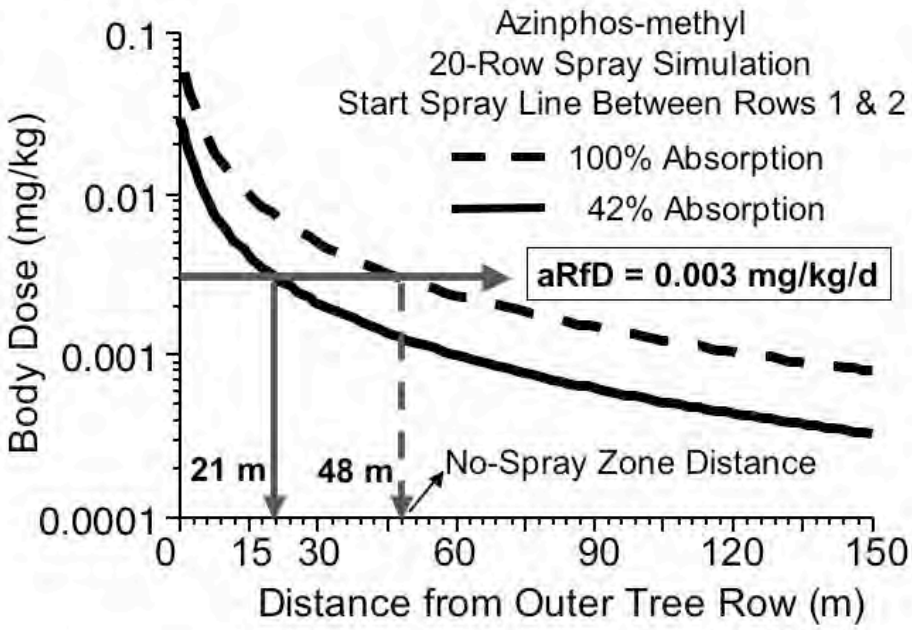

Figure 1. Estimation of no-spray zones for protection of a 10-kg child according to the standard of "reasonable certainty of no harm" (Felsot 2004b). Downwind drift of the OP insecticide azinphos-methyl from an orchard was estimating using the model AgDrift. The deposition data were transformed from percentage of spray application rate to a whole body dose by normalizing the mass of pesticide to the body surface area. Note that the body dose deposition data were scaled logarithmically to facilitate overlaying the acute reference dose (aRfD) benchmarks. The distances of 21 m and 48 m represent the downwind distance where a whole body dose to a child (assuming dermal absorption efficiency of 100% and 42%, respectively) would be reasonably certain to cause no harm. For mitigation of the impact of spray drift, these distances could be considered reasonable no-spray zones if application was taking place in an orchard adjacent to residential housing.

Evaluation of Spray Drift: Experimental

Long before spray drift was incorporated into quantifications of exposure for risk assessment, hundreds of studies examined drift experimentally. The most prominent examinations of physical principles, empirical studies, and impacts of drift remain the early seminal review by Akesson and Yates (1964) and the monograph by Elliott and Wilson (1983). Akesson and Yates (1964) focused on the general principles of drift from aerial application equipment and discussed tracers and collection devices for measurement of drift deposition. Elliott and Wilson (1983 thoroughly reviewed ground applications in the U.K., especially of the auxin agonist herbicides (i.e., chlorinated benzoic acids and phenoxyacetates).

The objective of the experimental studies has been to understand the mechanisms of spray movement and deposition. The operator controllable independent variables of these experiments have included mode of application (ground vs. aerial), sprayer parameters (nozzle type and pressure; sprayer speed), volume rate and active ingredient rate, and spray mixture adjuvants. The uncontrollable independent variables include meteorological conditions (wind speed and direction; humidity) and atmospheric stability (inversions and mixing).

The measured dependent variable in the plethora of published experiments is typically the amount of chemical (either pesticide active ingredient or fluorescent tracer) depositing on the ground downwind of a crop row, the line of sprayer travel, or the edge of a spray swath. Ground collectors have included mylar sheets, glass plates, filer papers, silica gel plates, and pans of water. Some studies have incorporated bioassays as drift measures by using the gradient in response of caged insects or potted plants. Some studies measure the residues in air during drift by employing low or high volume samplers.

Airborne spray particles during application have been measured through the use of passive samplers or active air sampling. The passive samplers have included string collectors to heights of ~10 m or spheres sitting on a mast. Low and high volume air samplers have been used to characterise the quantity of pesticide active ingredient in the "drift cloud". Details regarding independent and dependent variables have been tabulated for several experimental drift studies to illustrate the myriad factors and measurements that must be considered in drift studies (Table 1).

In addition to measuring the mass of active ingredient (or the surrogate tracer chemical) depositing or remaining in the air at some downwind distance from a field or orchard, experimental studies have focused on characterizing and quantifying the distribution of spray particle sizes. These studies serve two purposes. Because particle size is the most influential factor on the proportion of spray that is likely to drift off-target, then its characterization can lead to recommendations for deploying or operating equipment that produces the largest spray particles without affecting efficacy. The second use of particle size distribution methods has been to build drift models or validate their predictions.

Evaluation of Spray Drift: Regulatory Risk Assessment

Drift Assessment in the U.S. By the early 1990's, an industry group in the U.S. known as the Spray Drift Task Force (STDF) had formed in the U.S. to generate a bibliographic database of spray drift studies and to empirically test spray drift (Hewitt et al. 2002). The objective of the Task Force was to develop a set of models that could be used to predict drift, and thereby alleviate the cost of doing empirical studies required for pesticide registration risk assessments. The Task Force has published a number of pamphlets

Table 1. Examples of experiments that have evaluated variables affecting drift and details regarding methods deployed.

Type of Applicator	Crop, Pesticide, Tracer	Sprayer Parameter Variables	Environmental Variables	Monitoring Collectors	Results: Maximum Downwind Distance/Distance Sampled & Effect of Variables	Reference
Ground sprayer (dual boom); Aerial: Callair; Cessna Agtruck	None; 2,4-D amine; brilliant sulfoflavine	Pressure & nozzle variable; thickeners	Meteorological observations: wind speed at 0.5, 2, 2, 4 m; temperature difference between two elevations, 0.5 & 4 m; 40 m; inversion vs. lapse	Ground deposition: 15 cm diam Petri dishes; particle size assessment using photographic papers Drift cloud: polyethylene cylinders with air pumps at 10 L/min; particle size assessment using Cascade impactors (17 L/min)	100 m/100m; drift percent varied by nozzle type; drift ↑ with incr. pressure; drift ↑ in inversion; drift ↓with ↓ pressure, ↑ volume, use of thickeners, use of low pressure type nozzle; suggested improving spray deposit homogeneity to reduce application rate	Maybank et al. 1978
Myers A36 orchard airblast	Apples; none; fluorescent tracer (Uvitex)	D4-25 nozzles; 931 kPa; 468 L/ha	Meteorological observations: wind at 5.7 m; temperature gradient 10 cm – 4.3 m	Ground deposition: 10-mil plastic, 10 x 25 cm; Drift Cloud: string & bottle collectors mounted 1-5 m vertical; Air: Staplex Hi-volume, 1 & 3 m elevation; 0.57-0.74 m^3/s	152 m/152 m (0.05% of spray); 3.5% airborne @ 122 m	Fox et al. 1990
Ground field sprayer	Cereal stubble; aminotriazole; Fluoresceine L.T.S.;	2.5 & 10 Bars pressure Boom heights: 40 & 80 cm	Wind measured 2 m above ground level; 1.5 –4 m/sec	Ground: sentinel barley plants (bioassay) Drift Cloud: plastic rods, 55 cm high	200 m; deposition ↑out to 25 m with ↑ in boom ht., pressure, wind speed; phytotoxicity @ 10% estimate: 50 m low boom, 75 m high boom	Nordby & Skuterud 1975
Ground sprayer: Hi-Boy Aerial: Stearman biplane	Cotton, methoxychlor	Ground: T-jet nozzle, 40 psi; Aerial: no. 8 nozzle, 30 psi	Morning (lapse) vs. evening (inversion) spray	Ground: 10x25 cm glass plates on ground and at 24 in; Air: Andersen air samplers & Cascade impact samplers placed at ground level	Evening: 2640 ft/2640 ft Morning: 660 ft/660 ft; aerial application↑compared to ground; no difference in deposition relative to ht of plates; ground deposition µg in agreement with mass recovered in Andersen air samplers; included mass/volume measure	Ware et al. 1969

describing their studies and implications of the results along with an Internet accessible model called AgDrift (http://www.agdrift.com/).

AgDrift consists of three application modules (Teske et al. 2001). Two of the modules are applicable for downwind drift predictions from ground applications with either a horizontal boom sprayer or an orchard airblast sprayer. The modules are Tier I deterministic models based on the 50th percentile distribution of downwind drift deposits (as percentage of application rate). A recent update to AgDrift was released that allows the boom sprayer module to make downwind deposit predictions at the 90th percentile. The boom sprayer module allows predictions based on fine-medium and coarse sprays, and allows predictions for booms set at 0.61 m or 1.2 m from the top of the canopy. The orchard airblast sprayer is segmented into orchards or vineyards at full canopy or during dormancy. No other parameters can be changed except the number of rows for both modules can be varied from 1-20, and spraying can be initiated from any row (i.e., the outside *n* rows do not have to be sprayed). The model estimates drift to 1000 ft downwind of the outermost target row.

The aerial application module of AgDrift is a semi-stochastic model that relies on droplet size distributions (Teske et al. 2002). The droplet size distributions are calculated for nozzle types and nozzle parameters resident in several libraries compiled by the SDTF and the USDA. Users can also input their own drop size distributions. Several tiers of the aerial module are available, and fixed wing and rotary (helicopter) aircraft can be simulated. Each tier allows an increased number of parameters to be modified. Major alterable parameters include air speed, swath displacement, boom length and position relative to the wings (or rotor), nozzle configuration along the boom, wind direction and speed, and relative humidity.

Results from aerial application trials to assess the validity of the aerial module of AgDrift have been published (Bird et al. 1996, Teske et al. 2002). Many of these trials are limited in scope and not commercial scale applications. To date few commercial applications by ground sprayers have been tested to determine model validity.

The U.S. EPA occasionally but not consistently uses AgDrift for ecotoxicological risk characterization as part of the determinations for registration or re-registration eligibility of active ingredients. When EPA does not use the model, they will often assume that 1-5% of the applied active ingredient drifts from a 10-ha field into an adjacent 2-m deep body of water with a surface area of 1 ha.

AgDrift does have a stream simulator model wherein pesticide spray from aerial or ground applications drifts into a stream of user defined dimensions. The flow rate of the stream and no-spray buffer distances from the outside crop row to the edge of the water can be varied.

Drift Assessment in Europe. European Commission Council Directive 91/414/EEC dictates data requirements for authorization of plant protection products in the Member States. Experimental data on environmental fate and exposure is required and modeling data may also be used. Protection of water quality is one of the primary agendas for product authorization, so effort is spent developing PECs (predicted environmental concentrations) to determine the likelihood of harm to aquatic organisms for which NOECs (No Observable Adverse Effect Levels) have been developed. To coordinate the use of models, the EU Commission authorized the formation of FOCUS (FOrum for the Co-ordination of pesticide fate models and their USe) to assess the models and develop a scheme for risk assessment to protect water. The source inputs necessary for predicting concentrations of pesticides in surface water are surface runoff and erosion and drift. Four tiers of exposure assessment are used to estimate PECs for surface water. The data in each tier for drift come from a combination of the Tier I module for aerial application in the model AgDrift and "drift tables" developed by the BBA in Germany for ground applications to various cereal, vegetable, and fruit crops.

From 1989-1992, the BBA (Federal Biological Research Center for Agriculture and Forestry) in Germany conducted drift experiments for a variety of ground application scenarios in different field and orchard crops. The results of the many studies were assembled into tables and statistically analyzed to produce 95th percentile distributions of percentage residue deposits relative to downwind distance from a crop row (Ganzelmeier et al. 1995). The maximum distance of drift measured in most of the experiments was 25 m or less. Further studies were conducted during 1996-1999 with improved analytical methods and the maximum distances of measured drift were extended to 100 m. Based on the new BBA studies the Ganzelmeier tables were revised (Rautmann et al. 2001).

Although other European countries have developed empirical drift tables, the FOCUS process still uses the Ganzelmeier tables as the key source for drift into water bodies (FOCUS 2001). In the lower tiers of the FOCUS scheme for estimating PECs, no-spray buffer zones are assumed to be 1 m for arable crops (cereals or grains) and 3 m for vines, orchards, and hops. Tier 1 analysis assumes a single application under worst-case conditions, and Tier 2 analysis allows sequential applications (under worst case conditions).

For the tier 3 and higher exposure assessments, the drift tables were developed by FOCUS into a drift calculator. The drift calculator is actually one module of FOCUS' tier 3 assessment tool called SWASH (Surface Water Scenarios Help) (http://viso.ei.jrc.it/focus/sw/index.html). In addition to containing the drift calculator, SWASH is a shell that also contains the models (like PRZM and MACRO) necessary to predict pesticide movement in surface runoff.

The drift calculator in SWASH is simply the regression function that describes the 90th percentile ground deposition of spray particles relative to the distance from the last sprayed crop row. Each algorithm describing the regression is different (i.e., modified) by specific input parameters depending on the crop scenario. Parameters that can be input include crop type, application rate, number of applications, and water body type. SWASH links the drift and runoff models together and inputs the data into TOXSWA, a model for simulating the fate of the pesticide residue in a receiving water body and thus predicting the resulting concentration (i.e., PEC).

Mitigation of Spray Drift Impacts

Owing to the physical principles governing the formation and movement of aerosols or spray particles, drift of pesticides is inevitable. At best, pesticide applicators can only adopt practices (best management practices or BMPs) that will minimize drift itself or at least its impacts in a comparison to spraying without adoption of BMPs. How much mitigation is necessary can be partially quantified by making the objective of BMPs reduction of spray drift sufficiently so that any nontarget receptor exposure will be below a reasonable certainty of no harm. The reasonable-certainty-of-no-harm standard is employed presently by the U.S. EPA under the Congressional mandates inherent in the Federal Insecticide Fungicide and Rodenticide Act. One way to achieve a reasonable certainty of no harm is to apply a benchmark margin of exposure (MOE) or safety factor to the ratio of the predicted environmental concentration (PEC) and the toxicological endpoint (usually the LC50 for acute toxicity and the NOAEC for reproductive/developmental toxicity).

In the U.S. and elsewhere regulatory authorities use drift assessments in conjunction with run-off modeling to estimate exposures of aquatic systems to pesticide residues. When drift assessments indicate unacceptable risks of adverse effects to aquatic organisms, mitigation is implemented through several mechanisms. First, specific equipment parameters may be explicitly stated on formulated product labels. Sprayer equipment and operational practices that reduce overall drift are based on extensive empirical studies. The most important factor that will influence the magnitude of drift generally includes practices that will bias the distribution of particle sizes to the higher spherical diameters. The distribution can be characterized by measuring the volume median diameter (VMD), or the spherical diameter that demarcates half the spray volume containing larger particles than the VMD and half containing smaller particles. Extensive research shows that increasing the VMD of particle can be accomplished through specific nozzle types, operating pressures, spray volumes per ha, and tractor speed. Revised U.S. product labels for some pesticides now include statements recommending that applicators use nozzle types that will produce medium to coarse particles (Table 2). In Germany, the Ganzelmeier tables have been developed using different types of sprayers and nozzles so that applicators can make a choice to use equipment that will minimize drift. The U.K. Pesticide Safety Directorate offers a website to applicators that allows them to examine the drift reduction ratings of many types of equipment (http://www.pesticides.gov.uk/PSD_Databases/products/spray-fp.cfm).

Table 2. Comparison of narrative particle size classifications and corresponding VMD (volume median diameter) developed by the American Society of Agricultural Engineers (ASAE S572 standard) and the British Crop Protection Council.

Am. Soc. Agric. Engineers S-572		**British Crop Protection Council**	
Classification	**VMD (µm)**	**Classification**	**VMD (µm)**
Very fine	<150	Very fine	100
Fine	150-250	Very fine/fine	154
Medium	250-350	Fine/medium	241
Coarse	350-425	Medium/coarse	356
Very Coarse	425-500	Coarse/very coarse	451
Extremely Coarse	>500		

A second method of mitigating pesticide drift is the specification of sprayer operational parameters on product labels. For example, research shows that greater drift occurs as wind speed increases; thus, product labels tend to state maximum levels of wind for spraying. Boom height of ground sprayers will change the time between spray emission and droplet impact on the canopy and thus influence drift. Labels may specify that the outer row or two of orchards only be sprayed from one side (outside to inside of orchard) and that outer nozzles are turned off.

Mandating no-spray buffer zones on product labels or via a code of practice is a third mechanism for mitigating spray drift. In the U.S. new product labels for pesticides deemed to have a concern for endangered species now have specific no-spray zones between the edge of a water body and the last sprayed row. The assessments of spray drift in Germany and the resulting tables used in the FOCUS modeling efforts assume certain minimal no-spray buffers. However, these buffer zones can be increased or decreased depending on the type of equipment chosen by the applicator or other field-specific situations. In the U.K. applicators can engage in the LERAP (Local Environment Risk Assessment) process to estimate the size of no-spray buffer zones that would cause minimal drift and thus protect surface waters. Also, as part of the LERAP process, pesticide applicators can choose specific pesticides that are likely to have the least impact on aquatic organisms, and therefore they can decrease the size of required no-spray buffer zones.

Education is a fourth method of spray drift mitigation. Educational programs worldwide are based on explanations of the physical principles of drift, equipment, and operational factors, including the influence of meteorology. Finally, educational efforts provide information about other practices not mandated by regulations that could minimize drift. For example, shields or hoods on boom sprayers and drift control adjuvants have been shown at least minimally effective in empirical studies, but these practices do not seem to have been made as regulatory mandates yet.

Needs for Harmonization of Spray Drift Evaluation and Mitigation

Similar pesticides are registered throughout the world, but dissimilar methods are employed to estimate both the magnitude of spray drift and its potential impact. Especially lacking are common procedures for estimating the residues depositing in a body of water or on a nontarget organism. For example, different countries use different volumes of water as a nontarget receptor. Thus, residue concentrations in water resulting from spray drift can vary by several orders of magnitude, and such wide variation leads to divergent perspectives on spray drift hazards.

Risk assessment procedures for estimating exposure would benefit by a critical assessment of spray drift studies worldwide. Although several models have been developed for estimating chemical movement downwind during application, a comparative analysis is lacking for model adequacy in estimating spray drift (especially from ground sprayers), movement post application (secondary drift), and movement of spray aerosols in inversions. Presently, the models are used by regulatory agencies to estimate mass transfer into water bodies as an addition to movement via runoff. Improving the accuracy of such models and validating them will require more field studies using commercial scale applications.

Finally, agrochemical product labels include warnings such as avoid spray drift, but comparatively little attention has been paid to mitigating such drift. In some cases, certain physical parameters (pressure and water volume) and nozzle technology are recommended. In other cases, no-spray buffers may be recommended between the sprayer and the nontarget receptor. However, critical analysis of all of the mitigation recommendations is lacking, nor is there a universal consensus for how to assess mitigation. Risk managers would benefit by a comprehensive review of mitigation practices worldwide and recommendations for harmonizing procedures to assess mitigation.

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