Drift Filtration By Natural and Artificial Collectors:
A Literature Review

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Summary

The Spray Drift Task Force field studies were aimed at including reasonable worst-case conditions that would tend to favor relatively high drift rates for U.S. agricultural spraying. The field trials were therefore conducted in areas where there was only very low stubble or bare ground, which would minimize the opportunity for drifting droplets to be intercepted by collection surfaces in the target and downwind areas. The AgDRIFT® model (Teske et al, 1997) does not include interception factors for filtration of drift by natural or artificial collectors, with the exception of the *Stream Assessment Screen*, where riparian interception factors can be specified. If appropriate interception values were known, it would be valuable to include spray interception to facilitate the model use for real-world spray applications where such drift mitigation measures are sometimes possible. The purpose of the present report is to review literature sources for suggested interception factors that could be considered for inclusion in future releases of the AgDRIFT® model. The literature cited in this report shows that drift reduction of up to 90 % can typically be achieved using appropriate vegetative or natural barriers downwind of a spray area. However, caution should be noted in drift mitigation using such approaches, since careful attention needs to be given to the characteristics of such a barrier, to optimize porosity and other characteristics if such drift mitigation is to be effective.

1.0 Introduction

This report discusses the effects of natural (e.g. vegetation, hedges, trees) and artificial (e.g. netting) structures in removing drift from spray applications under field conditions. Various literature reports are cited with a view to making decisions on appropriate interception factors for different types of structures. The section of the report on “Spray Interception” explains the theory behind spray collection on different surfaces. The report then cites specific references to practical application of vegetative filtration in reducing pesticide drift exposure. The section on “Drift Filtration by Natural and Artificial Collectors” includes references from Europe and Australia where credit is given to such barriers in reducing drift exposure, and recommendations are provided for some of the designs of such barriers for maximum effectiveness in reducing drift.

2.0 Spray Interception

Following release from a sprayer, droplets will tend to travel with their initial trajectory and velocity, and then be carried by the ambient wind until deposition. If vegetation or other structures are in the path of the spray, droplets may be intercepted and thereby not tend to drift as far. Studies conducted by the SDTF and others (e.g. Holland et al, 1997; Praat et al, 2000) have shown that in orchard spraying, canopy development and sprayer position relative to the canopy can have a major influence on spray drift.

The ability of natural or artificial structures to intercept and retain droplets is determined largely by the collection efficiency of the structures. Collection efficiency is assessed as the droplet mass fraction deposited on the surface from the bulk air volume (Parkin and Merritt, 1980; Matthews, 1992). In other words, it expresses the percentage of the spray cloud that is collected by the structure. Since most objects cause a change in air flow patterns, air is deflected by collectors, causing typically less than 100 % of the spray cloud to be collected. It should also be noted that leaf structures can have a large impact on collection efficiency. Fuzzy strings and filamentous leaves can have collection efficiency rates that exceed 100%. If the collector is moving (i.e. active rather than passive), collection efficiency may exceed 100 % as the collector sweeps droplets from a larger air volume than it would if it were static.

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May and Clifford (1967) studied the collection efficiency of spheres, ribbons and discs for sampling aerosol sprays. They plotted collection efficiency against the impaction parameter P, where:

$$P = f[(p.V_o.d^2)/(18V.l)]$$

P = impaction parameter
p = droplet density (kg/m^3)
V_0 = droplet velocity (m/s)
d = droplet diameter (m)
mu = absolute viscosity (kg/m/s)
l = target collector dimension (m)
f = function (mathematical symbol)

Collection efficiency is sensitive to droplet diameter, collector geometry, droplet and collector velocities and wind speed.

Zhu et al (1994) showed that collection efficiency also decreases with higher wind turbulence intensity, based on research using computer modeling.

Equations such as those of May and Clifford (1967) are useful for estimating collection efficiency rates. However, providing input values for such calculations can be complex. For example, in natural environments, there may be frequent changes in wind speed, direction and collector orientation and geometry. These changes are often unpredictable. Agricultural and biological sprays typically include a range of droplet sizes, which can provide a range in collection efficiencies.

Natural collectors include an almost infinite variety of different shapes, sizes, orientations, movement rates and other characteristics that will affect their tendency to collect agricultural chemical particles. The apparent height of natural surfaces can be described using a variable referred to as "**surface roughness**". This is typically assumed to be 1/30 the height of the actual surface cover. The AgDRIFT® model (Teske et al, 1997) includes input of different surface roughness values. Typical values included in the model are as follows:

0.0001 m smooth ice
0.0001 to 0.001 m water
0.0001 to 0.02 m snow
0.0003 m desert sand
0.001 to 0.01 m bare soil (higher if plowed)
0.003 to 0.01 m grass 0.02 to 0.1 m high
0.04 to 0.10 m grass 0.25 to 1 m high
0.04 to 0.20 m crops
0.02 to 0.10 m typical rural farmland
0.5 to 1.0 m orchards
1.0 to 6.0 m forests
0.4 to 2.0 m suburban/towns
1.0 to 10.0 m city centers

As shown above, and as explained in the literature (Holloway, 1970), there is considerable variation between the roughness of different surface types. It is difficult to represent the other characteristics of natural collectors (e.g. orientation, shape, movement rate, etc.). Leaf area index has been widely used to describe leaf canopy density - for example for tree canopies.

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Terrestrial environments include vegetation, animals and bare ground. Each has different collection characteristics. Within a type, the collection characteristics can vary in space and time. For example, the orientation of leaves often changes due to phototropism as they attempt to expose a maximum surface area to the sun (Morton, 1977). When subjected to dehydration, or as a water-retention mechanism at hot, dry times of the day, many plant species exhibit wilted leaves. These may have a different collection efficiency than when the same leaves are more rigid at cooler times of the day.

Working with drift spraying for the control of migrant pests in Africa, Courshee (1959) and Symonns et al (1989) observed that sprays with $D_{v0.5}$ values of 70 to 90 µm are selectively collected by the vertical surfaces of sparse desert vegetation, and only a small proportion of the spray is deposited on the ground. Studies conducted with the aerial spraying of cotton in the Sudan showed that as the $D_{v0.5}$ of the spray was increased from 80 to 130 µm, the spray recovery rate on cotton leaves increased from 30 to 80 % (Anon, 1978).

Sundaram (1988) monitored fenitrothion deposits on simulated and live surfaces during an aerial spray. The results showed that the simulated surfaces had better collection efficiency than natural fir needles, birch leaves and flowers. The simulated materials were aluminum coil clusters (intended to mimic mature balsam fir needles) and kromekote cards with various orientations. In contrast, Spillman (1984) reported that artificial cylinders and ribbons were less efficient at catching drops than natural surfaces. He felt that natural surfaces may be better at capturing droplets due to their roughness, and in some tissues, the presences of hairs. The ease of residue extraction with different plants and vegetative tissues may vary - thus each situation can be different when evaluating vegetative collection efficiency.

Makarov et al (1996) studied the collection efficiency of different vegetation surfaces. They observed higher collection efficiency values for pine needles than birch leaves. This would be expected due to the narrower diameter of the pine needles. They gave an equation for predicting droplet collection on vegetation as follows:

$$v = I_c . u . \Omega . \mathrm{Eff}(u, d)$$

where:

v = residue on vegetation (mg residue per kg of leaves)
I_c = dosage of material in cloud that went past the vegetation (mg.s/m^3)
u = wind velocity (m/s)
Ω = plant area density (m^2/kg)
Eff = collection efficiency
d = droplet diameter

Experimental measurements of deposition rates within a thick wheat grass canopy gave close agreement with the predicted rates using the above equation.

Clearly, droplet size is an important parameter affecting collection efficiency. Bache (1980) demonstrated that collection efficiency for large particles (diameter >150 µm) is affected mainly by foliage structure, and droplets size and wind speed are less important.

The U.S. Dept. of Agriculture Forest Service has assessed foliage for the presence of pesticide droplets and tracers following application in the field (Barry, 1984). Most droplets collected by the conifer foliage had diameter below 60 µm.

Barry et al (1977) found very different collection for different droplet size ranges on three types of collector: artificial collector (impaction plates), natural larvae (Western spruce budworm larvae), and natural foliage (Douglas-fir needles). The study showed that Douglas fir needles were an excellent collector for 6-20 µm droplets.

Hislop et al (1983) observed that deposition rates were higher at the tip of winter barley and wheat leaves than at the base. Tu et al (1986) conducted laboratory and field studies of spray deposition rates on rice leaves. Droplet size was not accurately measured; however, estimates based on sampling with magnesium oxide coated slides and spray collection on paper collectors, gave $D_{v0.5}$ values between 100 and 220 µm. Deposition rates were always higher at the tips of the rice leaves than at the bases, due to the narrower width for collection of small droplets.

Research has been conducted studying the deposition of airborne microbes and other solid particles on different artificial and natural surfaces. Although liquid droplets may adhere better to such surfaces than solid particles of similar size, many of the issues affecting collection are similar for liquid and solid particles. Chamberlain (1967) notes that the flow of air over the earth's surface is normally turbulent, and the components of the turbulent velocities in all directions above the ground are usually large compared to the sedimentation velocities of particles with diameter <50 µm. Chamberlain measured the velocity of deposition (the sum of particle transport velocities due to sedimentation and impaction) for *Lycopodium* spores with $D_{v0.5}$ = 2 µm for different friction velocities. Friction velocity (measured in cm/sec) is related to the shearing stress of the wind on the ground. The ratio of velocity of deposition to wind speed was found to be about 0.01 for the *Lycopodium* spores. Using tables generated by Gregory (1961), Chamberlain (1967) illustrated that 50 % of these light, very small particles could travel at least 200 m downwind if released at a height of 10 cm above the ground (with no canopy) in "average" weather conditions.

Chamberlain (1966) compared deposition of *Lycopodium* spores in a wind tunnel using 6 cm tall grass and sticky artificial grass. In both cases, there was a linear increase in the velocity of deposition with higher friction velocity; however, the rate of increase and the measured values were greater for the sticky artificial grass. The higher values were attributed to greater retention by reduced bounce-off for the sticky grass. Similar effects were observed using wet grass compared to dry grass.

In the context of designing vegetative buffers for interception of spray drift in pesticide application scenarios, Dorr et al (1998) suggested that 40 – 50 % porosity was the optimum level for spray interception. They also proposed that several rows of low porosity vegetation would be more effective at spray drift interception than a single row of dense vegetation. This issue has also been researched by Naegali (1941) and others.

3.0 Drift Filtration by Natural and Artificial Collectors

The previous section of this report described studies investigating collection efficiency of different structures with particular emphasis on general trends rather than specific assessments of drift reduction. The present section provides a review of literature references that include specific drift reduction benefits from natural and artificial collectors.

Several governments have recognized the value of vegetative buffers for reducing drift potential onto sensitive terrestrial and aquatic areas. In the U.K., such buffers are important for such protection (Tooby, 1997). Van de Zande et al (2000a) described a government project in the Netherlands associated with the Dutch Pesticide Act for assessing drift reduction options by various means including the use of windbreaks. It was noted that a wind break on the outer-edge of a field can reduce spray drift by 70 to 90 % in the zone 0 – 3 m downwind of the wind break (Porskamp et al, 1994, VROM, 1998). Dutch regulations encourage the use of natural or artificial barriers to reduce drift. Many studies have been made in the Netherlands to support such interests (Heijne, 2000). Porskamp et al (1994) observed an 85 % reduction in drift from using an alder windbreak downwind of fields being sprayed. The research involved a series of field trials at different times of the year. Reductions were greater in summer and early fall (at least 90% reduction in drift when a hedge was present) than in April (68-79% reduction in drift with the hedge). The authors concluded that reductions in drift of 68% to >90% could be obtained using a wind break around an orchard being sprayed. The range reflects differences in leaf density of the wind breaks and the wind speeds during the studies.

The studies reported above were for orchard airblast applications. Other studies have been conducted in the Netherlands to investigate the effect of wind break height and ground air-assisted versus conventional spraying on drift (Van de Zande, 2000b). The field trials were extensive, involving at least nine replicate measurements for each scenario. The crop being sprayed (sugar beet) had a mean height of 0.5 m. The windbreak (Elephant grass, *Miscanthus*), located at 1 m from the edge of the crop, was cut to different heights to determine the effect of relative crop: windbreak height on drift. The windbreak heights were 0.5, 1.0 and 1.5 m. Deposition (drift) was measured at distances up to 16 m from the last downwind nozzle. Spray applications were made using a sprayer with and without air-assistance (Hardi Twin sprayer). The results showed that without air-assistance in the application, drift decreased with greater ratio of windbreak to crop height. With air-assistance, drift was lower (with a 0.5 m crop height) than the conventional application, and drift decreased further with taller windbreaks. These data are summarized in the following table which shows deposition as a percent of the application dose at distances up to 2 m downwind of the application area:

Buffer	Conventional	Air Assistance
No buffer	2.4	0.46
2m crop free	1.5	0.20
Miscanthus, equal height	1.1	0.20
Miscanthus, +0.5 m height	0.4	0.11
Miscanthus, +1.0 m height	0.28	0.05

The above studies showed that vegetation can significantly reduce drift from spray applications to orchards and row crops. Other studies have shown that man-made materials can also be used to intercept drift and thereby reduce deposition rates in the field. Artificial netting provided a 68 – 88 % reduction in drift in studies conducted with ornamental spraying by Smidt et al (1998), and 45 – 80 % reduction in drift from fruit orchard spraying (Heijne et al, 1999).

Studies were conducted by the Natural Environmental Research Council Institute for Terrestrial Ecology in the U.K. to assess the value of hedges in reducing spray drift from agricultural fields (Davis et al, 1994). They found that a 1.6 m tall by 1.2 m wide hedge provided reduced damage levels in animal bio-indicators (lower larval mortality levels) but mixed results with vegetative bio-indicators (tomato plants) and tracer extraction from collectors. They concluded that drift reductions using hedges were not effective when wind speeds were greater than 3 m/s, but were reasonably effective at lower wind speeds.

Initial research in New Zealand by May et al (1994) did not yield conclusive results on the effects of shelter on drift because the shelter vegetation was modified considerably by the grower during the course of the study. Other orchard spraying studies in New Zealand (AEI, 1987) have provided more conclusive information on the effect of shelter vegetation on drift. In six field trials, live shelter was found to be more effective than artificial shelter at reducing drift, with respective reduction factors of 88 and 75%. Holland and Maber (1991) noted that these findings are consistent with other (not always published) research in New Zealand.

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Miller et al (2000) studied the effect of vegetative buffers on reducing drift. They found that tall grass was 30 % more effective than a cut grass/ flower mixture at reducing drift. Their field results agreed with previous wind tunnel testing (Miller and Lane, 1999) supporting the concept that establishing a field margin with some tall vegetation gives the potential to reduce the risk of drift beyond a sprayed field. They noted that the vegetation acts as a filter for airborne droplets and impedes air flow. They added that very dense vegetation will not allow adequate air flow through the canopy and the main flow could be above the filter strip such that the filtering effect is substantially reduced and the overall effect on drift dispersal is negative.

Similar ideas have been presented elsewhere, for example guidelines are provided in Queensland, Australia for planting vegetative buffer zones for maximum drift reduction (Voller, 1999). The guidelines note that trees and shrubs with small needle-like leaves or stems are more efficient at removing small drifting droplets from the air than broad relatively smooth eucalyptus trees. Large leaves which are covered in small hairs are also stated as being efficient at removing droplets. Buffer strips are recommended to be carefully planned for maximum drift interception. The density of the buffer should be 30 to 50 %, consisting of more than one row of vegetation with tree spacing of 5 – 6 m. The minimum height should be 1.5 times the spray release height, and of length that exceeds the length of the spray passes. Buffer widths should be around 20 m. The report carefully distinguishes between drift buffers and wind breaks. The former are more open (less dense) and contain specialized species with better filtering capacity. They are also usually placed in different locations on a property, with wind breaks being needed upwind from the field for protection of the crop from wind, and drift buffers on the downwind side to protect sensitive areas from spray drift.

Spillman and Woods (1989) studied the effects of trees as buffer zones for drift interception in the U.K. They found that dense barriers tend to cause the wind to flow up and over the barrier, while porous barriers allow some air to pass through the barrier and deflect some air over the top. The study showed that the minimum height of a barrier should be 1.5 times that of the release height of the spray for a 50 % porous barrier. If the porosity is reduced to 40 %, the minimum height becomes 2 times that of the spray release height. A further study by Spillman (1990) showed that using multiple rows, it was possible to increase the amount of spray catching surfaces within the buffer while minimizing the air flow deviation (Dorr et al, 1998).

Following on from the work by Spillman, Dorr et al (1998) studied drift reductions from vegetated buffer zones. Through a research program with 26 field trials between 1991 and 1993, they found that spray drift could be reduced by approximately 50 % using a row of trees downwind of the spray application area. The porosity of the vegetation was only 10 to 20 %, and more effective drift reduction was inferred for canopies with higher porosity of around 40 to 50 %. These and other data were used to develop a model for predicting droplet capture by wind breaks (Raupach et al, 2001).

Finally, studies by the SDTF and others have shown that trees are very effective at intercepting droplets from spray applications within the canopy (Johnson, 1995a) in orchard airblast applications, and that a crop may reduce drift compared to applications over bare ground/ stubble (Johnson, 1995b). The SDTF orchard airblast studies showed that drift was significantly reduced behind each successive row of trees that were sprayed within different types of orchard canopy. The order of magnitude of reduction varied with the crop type and sprayer type/ setup.

In conclusion, reductions in drift from natural and artificial barriers depends on the structure and location of the barrier, as well as the wind speed and droplet size spectrum of the spray. There is general agreement in the literature that a drift reduction of 45 to 90 % can be achieved through appropriate barriers.

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