II.7 Factors Affecting Application and Chemical Deposition

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Control of spray deposition is vital if pesticides are to be delivered safely and effectively to the intended target. Numerous studies have shown that drift (off-target movement of material) and deposition of pesticides are affected by application equipment, release height, windspeed, air turbulence, air temperature, humidity, and formulation characteristics. It is important for pest managers and applicators to understand the factors that influence the movement of spray droplets on their journey to the target. Drift can become a critical factor when environmentally sensitive areas are in or near spray operations.

Droplet Size

Droplet size is recognized as the major factor in the transport to and the collection of spray by the target. Agricultural sprays contain droplets of varying sizes, but the selection of proper equipment, spray delivery pressure, and nozzle selection play important roles in maintaining a reasonably uniform droplet size. In agricultural sprays, droplets are usually measured in micrometers (µm)—units that are often referred to as microns. Large droplets are influenced primarily by gravity and tend to fall within the target area, whereas small droplets, falling more slowly, are susceptible to wind or turbulence effects and can be moved off target.

A 200-µm droplet would require only 5.4 seconds to fall a distance of 3 m while a 20-µm droplet would take 230 seconds. With only a 1.5-m/second wind, the 20-µm droplet could drift 338 m while the 200-µm droplet would drift only a few meters. Droplets below 100–150µm are generally considered to be the primary driftable portion of the spray. The following table describes droplet characteristics.

Although drift potential may be reduced by increasing the size of droplets, spray coverage on target surfaces may not be as effective at a given volume application rate if most of the liquid volume is contained in very large droplets. Good spray coverage on the target is necessary for efficient insect or weed control. The number of droplets per unit area is a function of droplet size. The relationship between droplet volume and diameter (d) is expressed by the equation

$$\text{Volume} = \Pi d^3/6.$$

Doubling a droplet's diameter will increase its volume by a factor of eight. Therefore a 400-µm droplet has a volume eight times that of a 200-µm droplet. Alternatively, eight 200-µm droplets contain the same volume of spray as a single 400-µm droplet. This formula is an important consideration when determining or assessing deposits on target surfaces.

If thorough coverage is required for pest control, small droplets will be more effective than large droplets, but small ones will be more susceptible to off-target movement by the wind. The droplet size selected for a particular application is often a compromise between coverage with smaller droplets and reduced drift with larger droplets.

Nozzles

Application equipment is very important in determining the droplet sizes contained in the spray. Most agricultural nozzles produce a spray containing a range of droplet sizes, referred to as the droplet size spectrum. The droplet size spectrum is often described by the volume median diameter (vmd or $D_{v0.5}$), which is the droplet size at which one-half of the total spray is in larger droplets and one-half is in droplets smaller than the vmd. A parameter often used to express the range of droplet sizes in the spray is the relative span and is given by the expression $(D_{v0.9}–D_{v0.1})/D_{v0.5}$. Large relative span values indicate wide range of droplet sizes. Typical relative span values for agricultural sprays are in the range 0.8–1.2.

The main types of nozzles used in agriculture are hydraulic, which uses pressure to atomize; gaseous, which uses shear between two fluids; and rotary, which uses centrifugal force. When they are used at practical field application rates, all nozzles produce a range of droplet sizes. Under certain conditions, rotary atomizers can produce a reasonably narrow droplet size spectrum, giving rise to the term "controlled droplet application."

The hydraulic or pressure nozzle is the type most often used in aerial and ground application of pesticides. Droplets are produced by forcing liquid through a small opening, or orifice, under pressure. The size and type of the nozzle tip determine the flow rate and to some extent the droplet size produced. The fan tip produces a flat fan of spray; the disc-core nozzle produces a hollow cone pattern.

In general, a larger nozzle orifice will produce a spray with a larger mean droplet size. Increasing the operating pressure for a given nozzle will increase the flow rate, decrease the mean droplet size, and generally increase the proportion of small droplets. Nozzles on aircraft tend to produce sprays with smaller mean droplet size at similar pressures because of additional shear forces due to the high-speed movement of the aircraft through the air. Increased flying speed or directing the orientation of nozzles forward into the airstream will produce sprays with a smaller droplet size.

As nozzles are used, abrasion and erosion will increase the orifice size and alter the flow rate and droplet size. Nozzles should be checked frequently for calibration and discarded if the flow rate has increased by more than 10 percent.

Examples of rotary atomizers are the Micronair and the Beecomist. The droplet size produced by rotary atomizers is dependent on rotational speed. Higher rotational speeds produce smaller droplets. Rotary nozzles can produce sprays with a smaller mean droplet size than those pressure nozzles can.

Evaporation

Droplets can become smaller as they move toward the target due to evaporation of the spray material. Evaporation, especially in the low-humidity conditions of the Southwest, results in rapid reduction in the size of water droplets. The evaporation rate increases as temperature rises or humidity decreases. At a temperature of 86 °F and relative humidity of 50 percent, a 50-µm droplet of water will completely evaporate in 4 seconds while only falling 15 cm. Spray deposition within the target area can drastically decrease as the temperature increases during the day, an important factor to take into account during a spray operation. Table II.7–2 describes evaporation characteristics.

Evaporation rate is affected by formulation properties as well as air temperature and relative humidity. An oil droplet is less volatile than a water droplet and would not decrease in size so rapidly. Suppliers of a number of spray additives claim their products reduce evaporation. In most cases, these claims lack scientific validation, but the addition of a nonvolatile substance may provide some drift control by preventing the droplet from evaporating to extinction. For example, a 400-µm droplet with 12.5-percent nonvolatile composition would stabilize at 200 µm because of the nonvolatile fraction.

Effects of Formulation Properties

Properties of the pesticide formulation or mixture can influence droplet size. Formulations with low viscosity (thickness) or surface tension generally produce sprays with slightly smaller mean droplet size because less energy is required to break up and atomize the material. Formulations that contain emulsifiers usually have low surface tension and tend to produce sprays with smaller mean droplet size. Also, many of the solvents used in pesticide formulations are highly volatile. Their incorporation into the spray mix can accelerate the decrease in droplet size due to evaporation, and using these volatile additives may increase the drift potential of certain formulations.

Numerous adjuvants (additives) are available for mixing with pesticide sprays as “spray modifiers.” For example, spray thickeners are often added to pesticide sprays in an attempt to reduce the proportion of small, driftable droplets. These adjuvants generally increase the viscosity of the spray mixture, resulting in the production of large droplets; however, studies have shown that adjuvants can also increase the number of very fine droplets. The diverse functions, chemistry, concentrations, and interactions of thickeners, surfactants, and surface active agents make it difficult to predict the effect of these products on droplet size and spray deposition.

Dispersal of Spray

Weather plays an important role in spray dispersal and deposition. Wind displaces spray material, and the distance spray material moves depends on droplet size, the strength of the wind, and the spray release height. Strong winds and higher spray release heights will cause droplets to move a greater distance. Strong winds can cause even large droplets to move off target and become a hazard. Spray operations should be shut down if windspeeds increase excessively. As an example, the U.S. Department of Agriculture's Animal and Plant Health Inspection Service normally stops spraying with ultra-low-volume pesticides when the windspeed reaches 10 miles per hour. Other conditions and State laws may dictate even lower windspeeds.

There is always some downwind displacement of spray droplets, even in light winds. If spray applications are made by moving into the wind, this displacement will move spray back behind the sprayer. If applications are made in a crosswind, the spray will be moved slightly downwind from the sprayer. This occurrence is known as swath displacement and should be taken into account when switching on and off the sprayer. With crosswind swath displacement, multiple spray passes are needed to obtain the desired deposition.

Table II.7–1—Selected characteristics of various size spray droplets of water

Droplet diameter	Terminal velocity	Fall time from 3 m	Drift distance (3-m fall with 5-km/h wind)	Drops/cm^2 from 10 a/ha application
(µm)	*(M/sec)*	*(Sec)*	*(M)*	*(No./cm^2)*
10	0.003	1,020	1,372	190,990
50	0.075	40	54	1,530
100	0.279	11	15	192
200	0.721	5.4	5	24
500	2.139	1.6	2	1.5

Table II.7–2—Evaporation characteristics for water droplets under two environmental conditions

Droplet size	Time to extinction	Fall distance	Time to extinction	Fall distance
(µm)	*(Sec)*	*(M)*	*(Sec)*	*(M)*
50	14	0.5	4	0.15
100	57	8.5	16	24
200	227	136.5	65	39

Air Temperature

In strong winds, frictional turbulence produces mechanical stirring of the air and promotes strong mixing in the atmosphere that tends to lessen the effects caused by any localized temperature differences. In lighter winds, especially where there is intense radiation, temperature can vary significantly with height. Temperature variations are caused by solar radiation and heat exchange between air, soil, and vegetation. The change in temperature with height is called the vertical temperature gradient. The temperature gradient has an important effect on atmospheric stability because it can increase or decrease air mixing. Under normal atmospheric conditions, the air is warmer at ground level and gets cooler with an increase in height due to the decrease in air pressure with height. Under these conditions, the temperature decrease is approximately 1.8 °F for every 100-m height increase. This factor is known as the adiabatic lapse rate.

If the temperature decreases more rapidly, there is a superadiabatic lapse rate, characterized by strong convection currents and turbulence. Under these conditions, the air layer is said to be unstable. High levels of spray drift can occur when a large number of small droplets are caught in the convection currents and fall out of the target zone.

If the temperature change is less than the adiabatic lapse rate, the air layer is considered stable. Under certain conditions, temperature can increase with height. This condition, known as inversion, is extremely stable. Inversions can occur only over a limited height range because there must be an overall drop in temperature with increase in height. Inversions usually occur when the wind is zero or very slight and may develop by the "sinking" of cold, dense air pushed in by weather fronts, or by radiational cooling of the surface, especially on clear nights. Off-target spray drift can occur under these condition because the inhibited mixing permits the formation of a mass or cloud of small droplets that can move great distances with little dispersal.