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Growth regulator herbicides such as 2,4-D or MCPA may cause leaves of sunflowers to have parallel vein patterns and abnormal leaf shapes.

Minnesota Extension Service
University of Minnesota

HERBICIDE SPRAY DRIFT

Alan G. Dexter
Sugarbeet Specialist
North Dakota State University and the
University of Minnesota

Herbicide spray drift is the movement of herbicide from the target area to areas where herbicide application was not intended. Herbicide drift generally is caused by movement of spray droplets or herbicide vapors. Herbicide granules or dried particles of herbicide may move from the target area in high winds but are not considered important sources of herbicide drift. While the number of acres damaged and the annual economic loss from spray drift is not large, individuals who are affected can suffer substantial losses.

Herbicide spray drift in high concentrations may injure susceptible crops and could cause prohibited residues in the harvested crops. Spray drift also can damage shelterbelts, gardens and ornamentals, cause water pollution, and damage non-susceptible crops in a vulnerable growth stage (2,4-D drift on wheat in the flowering or seedling stage, for example). Drift also can cause non-uniform application in a field, with possible crop damage and/or poor weed control.

Herbicide drift can occur with any herbicide. However, the risk of damage to non-target plants varies considerably among herbicides. Herbicides which are toxic at low concentrations and widely used cause most of the damage from herbicide drift. Herbicides in this category include 2,4-D, MCPA, dicamba (Banvel), picloram (Tordon), and glyphosate (Roundup).

Even though only a small portion of the applied herbicide drifts, some non-target areas can receive rather high doses. Herbicide drift can accumulate on the downwind side of a field, in a shelterbelt at the edge of a field, or in a portion of an adjacent field. In some cases, herbicide accumulated in downwind areas can exceed the rate applied to the field, with a small portion from each pass of the sprayer drifting to the non-target area. Shelterbelts are particularly susceptible to accumulation of high herbicide rates because the trees intercept the drift.

FACTORS AFFECTING SPRAY DRIFT

Spray particle size: Spray drift can be reduced by increasing droplet size, since a wind will move large droplets less than small droplets (Table 1). Droplet size can be increased by reducing spray pressure, increasing nozzle orifice size, special nozzles such as "Raindrop," additives that increase spray viscosity, and rearward nozzle orientation in aircraft.

Spray pressure with ordinary flat fan nozzles should not be less than 20 pounds per square inch because the spray pattern from the nozzles will not be uniform at lower pressures. The "LP" and "XR" nozzles are designed to give a uniform spray pattern at 15 to 20 psi and this low pressure results in larger spray droplets compared to applications at higher pressure.

Research with ground sprayers (5) indicated that addition of a spray thicker, such as Lo-Drift and Nalco-Trol, reduced spray drift by 66 to 90 percent compared to application without thickener. Research with airplane application (1) indicated that the addition of spray thickener increased the volume mean diameter of spray droplets as compared to applications without thickener. However, the spray thickener also increased the formation of highly driftable small spray droplets less than 122 microns in diameter. The addition of spray thickener should reduce drift from a ground sprayer but may not affect or may even increase drift from airplane application.

Table 1. Influence of Droplet Size on Potential Distance of Drift.

Droplet diameter (microns)	Type of droplet	Time required to fall 10 feet	Lateral distance droplets travel in falling 10 feet in a 3 mph wind
5	Fog	66 minutes	3 miles
20	Very fine spray	4.2 minutes	1,100 feet
100	Fine spray	10 seconds	44 feet
240	Medium spray	6 seconds	28 feet
400	Coarse spray	2 seconds	8.5 feet
1,000	Fine rain	1 second	4.7 feet

Source: Klingman (9), Potts (11) and Akesson and Yates (2)

Some postemergence herbicides such as sethoxydim (Poast) and bentazon (Basagran) require small droplets for optimum performance, so techniques which increase droplet size may reduce weed control. Weed control from herbicides which readily translocate such as 2,4-D, MCPA, dicamba (Banvel), and picloram (Tordon) is affected little by droplet size within a normal droplet size range, so drift control techniques generally will not reduce weed control with these herbicides. Glyphosate (Roundup) is readily translocated, so droplet size generally has minimal effect on weed control. (Small droplets may be retained better than large droplets on hard to wet grasses.) Glyphosate is partially inactivated by increased water volume, so spray volume recommendations on the label should be followed.

Method of application: Liquid formulations of herbicides are applied by airplane, helicopter, ground sprayer or mist blower applicators. Low pressure ground sprayers are commonly used for herbicide application and are normally operated at 30 to 50 pounds per square inch with 5 to 20 gallons of water per acre.

Herbicide spray drift generally is greater from mist blower and aerial application than from ground application when application is under similar environmental conditions with all sprayers adjusted properly (6). Low pressure ground sprayers generally produce larger spray droplets which are released from the nozzle closer to the target than aerial sprayers or mist blowers.

Distance between nozzle and target (boom height): Less distance between the droplet release point and the target will reduce spray drift. Less distance means less time to travel from nozzle to target and therefore less drift occurs. Small spray droplets have little inertial energy, so a short distance from nozzle to target increases the chance that the small droplets can reach the target. Also, wind velocity often is greater as height above the ground increases, so spray droplets released from a reduced nozzle height are affected by a lower wind velocity (3).

Herbicide volatility: All herbicides can drift as spray droplets, but some herbicides are sufficiently volatile to cause plant injury from drift of vapor (fumes). For example, 2,4-D or MCPA esters may produce damaging vapors, while 2,4-D or MCPA amines are essentially non-volatile and can drift only as droplets or dry particles.

Vapor drift occurs when a volatile herbicide changes from solid or liquid into a gaseous state and moves from the target area. Herbicide vapor may drift farther and over a longer time than spray droplets. However, spray droplets can move over one mile under certain environmental conditions so crop injury for a long distance is not necessarily from vapor drift. A wind blowing away from a susceptible crop during application will prevent damage from droplet drift, but a later wind shift could move damaging vapors from the treated field into the susceptible crop. An experiment conducted in Canada demonstrated that 3 to 4 percent of both 2,4-D amine and high volatile ester drifted as spray droplets. However an additional 25 to 30 percent of the ester drifted as vapor in the first 30 minutes after spraying while no additional movement of the amine was detected (7).

Relative humidity and temperature: Low relative humidity and/or high temperature will cause more rapid evaporation of spray droplets between the spray nozzle and the target than will high relative humidity and/or low temperature. Evaporation reduces droplet size, which in turn increases the potential drift of spray droplets. For example, very fine particles can drift 367 yards to a few miles with only a 3 miles per hour wind (Table 1). However, low humidity may reduce the phytotoxicity of the herbicide because rapid drying of a spray droplet will reduce herbicide penetration into a plant. Also, plants growing in low humidity produce a thicker cuticle than in high humidity, resulting in greater resistance to herbicide penetration. Thus, damage to non-target plants from spray drift may be greater with high humidity than low humidity, even though total drift may be less under high humidity.

Temperature also influences the volatility of herbicides. Research results indicate that the vapor formation from a high volatile ester of 2,4-D approximately tripled with a temperature increase from 60 to 80 degrees F (8). At 80 degrees F, 2,4-D vapor formation was about 24 times greater from a high volatile than a low volatile ester.

Vapor damage to tomato plants from various formulations of 2,4-D at different temperatures showed vapors from high volatile esters caused injury to plants at all temperatures (Table 2). The low volatile esters of 2,4-D did not damage plants at 70 to 75 degrees F but did at 90 and 120 degrees F. Even though low volatile esters of 2,4-D are much less volatile than high volatile esters, vapor drift from low volatile esters can damage susceptible plants. The amine formulation was essentially non-volatile, as no damage-causing vapor was produced even at high temperatures.

Table 2. Relative Damage to Tomatoes by Vapors from 2,4-D Formulations Held at Three Temperatures. Ratings taken 24 hours after exposure, with 1 = no effect and 6 = severe damage.

	Temperature and hours of exposure					
	70-75 F		90 F		120 F	
2,4-D formulation	**2h**	**16h**	**2h**	**16h**	**2h**	**16h**
Butyl ester (high volatile)	3.5	6.0	5.8	6.0	6.0	6.0
Butoxyethanol ester (low volatile)	1.0	1.0	2.3	5.7	5.5	6.0
Dimethylamine (non-volatile)	1.0	1.0	1.0	1.0	1.1	1.2

Source: Baskin and Walker (4)

These results indicate that a low volatile ester would begin to release damaging vapors at a temperature between 75 and 90 degrees F. However, soil surface temperatures are often much warmer than air temperatures, especially on a sunny day. Thus, vapor drift from low volatile esters may occur at air temperatures lower than 75 degrees F.

Wind direction: Herbicides should not be applied when the wind is blowing toward an adjoining susceptible crop or a crop in a vulnerable stage of growth. The wind should be blowing away from the susceptible crop or perhaps the field should not be treated, if weed problems are minor. All feasible drift control techniques should be used if herbicide must be applied while the wind is blowing toward a susceptible crop.

Wind velocity: The amount of herbicide lost from the target area and the distance the herbicide moves will increase as wind velocity increases, so greater wind velocity generally will cause more drift. However, severe drift injury can occur with low wind velocities, especially under temperature inversion situations.

Air stability: Lateral air movement (wind) is generally recognized as an important factor affecting drift, but vertical air movement often is overlooked. In the normal "lapse" situation, air temperature decreases 2.3 degrees F for each 1,000 feet of altitude. Cool air tends to sink, displacing lower warm air and causing vertical mixing. If the "lapse" condition is greater than normal (greater than 3.2 degree F decrease per 1,000 feet), vertical mixing will be greater.

Temperature inversion is the abnormal situation where cool air is near the surface under a layer of warm air. Temperature inversions often occur early in the morning. A temperature inversion allows very little vertical mixing of air, even with wind. Damage from spray drift is most severe with temperature inversion since small spray droplets or vapors will be suspended in the cool air layer at crop or plant height for long periods. Small spray droplets and vapors are carried aloft and dispersed with the normal "lapse" condition. Research has shown that three times more spray drifted 100 to 200 feet and 10 times more drifted 1,000 to 2,000 feet under inversion conditions as compared to "lapse" conditions with a given wind speed (2).

Spray drift under inversion conditions can be reduced by increasing spray droplet size. Herbicides should not be applied near susceptible crops during temperature inversion conditions. Inversions usually can be identified by observing smoke from a smoke bomb or fire. Smoke moving horizontally close to the ground would indicate a temperature inversion.

Spray pressure: Spray pressure influences the size of droplets formed from the spray solution. The spray solution emerges from the nozzle in a sheet, and droplets form at the edge of the sheet. Increased nozzle pressure causes the sheet to be thinner, and this thinner sheet will break into smaller droplets than from a sheet produced at lower pressure. Also, larger orifice nozzles with high delivery rates produce a thicker sheet of spray solution and larger droplets than smaller nozzles.

Nozzle spray angle: Spray angle is the angle formed between the edges of the spray pattern from a single nozzle (Figure 1). Nozzles with wider spray angles will produce a thinner sheet of spray solution, and smaller spray droplets, than a nozzle with the same delivery rate but narrower spray angle.

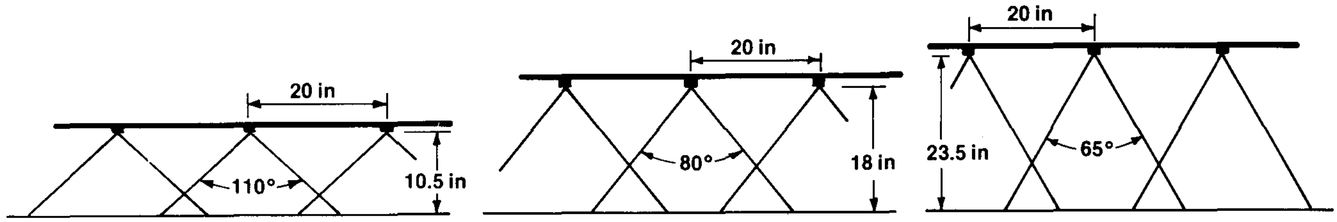

Figure 1. Influence of nozzle spray angle on nozzle height for proper overlap to give uniform spray distribution.

However, wide angle nozzles are placed closer to the target for proper overlap than narrow angle nozzles and the benefits of lower nozzle placement outweigh the disadvantage of slightly smaller droplets for drift reduction.

The angle of nozzles relative to direction of travel can influence drift from aerial application. Because of greater wind shearing when nozzles are pointed into the wind, nozzles pointed toward the direction of travel will produce smaller droplets than nozzles pointed back. The smallest droplets are produced from nozzles 45 degrees forward of vertical, while the largest droplets are produced by a straight-back (90 degree) orientation.

Nozzle type: Nozzle types vary in droplet sizes produced at various spray pressures and gallons per minute output (Table 3). "Flat fan," "flood" and "hollow cone" nozzles produce similar-size droplets and a similar volume of small droplets when compared at equal spray pressure. The flood nozzle tends to produce slightly larger droplets than the flat fan, while the flat fan produces slightly larger droplets than the hollow cone.

Two types of Raindrop nozzles have been developed for drift control. The type "RA" is a whirl chamber nozzle with a secondary swirl chamber attached. The type "RD" is a disc-core nozzle with a secondary swirl chamber attached. Compared with

Table 3. Influence of Nozzle Type and Spray Pressure on Droplet Size.

Nozzle type	Delivery rates	Spray pressure	Spray angle	Volume median diameter	Volume with less than 100 micron dia.
	(gal/min)	(lb/sq in)	(degrees)	(microns)	(percent)
Flat fan	0.12	15	65	239	
(LF-2)	0.17	30	76	194	
	0.20	40	80	178	17.5
Flood	0.12	15	90	289	
(D-1)	0.17	30	115	210	
	0.20	40	125	185	15.5
Hollow cone	0.12	15		228	
(HC-12)	0.17	30		185	
	0.20	40	70	170	19.0
Whirl chamber	0.12	15		195	
(WRW-2)	0.17	30		158	
	0.20	40	120	145	23.0
Raindrop	0.11	15		506	
(RD-1)	0.16	30		358	
	0.18	40	90	310	0.8

Source: Delavan Manufacturing Company

the other nozzle types listed in Table 3, the Raindrop nozzles produced the largest droplets and also the lowest volume of small droplets.

Spray pressure with ordinary flat fan nozzles should not be less than 20 psi because the spray pattern from the nozzles will not be uniform at lower pressures. The "LP" and "XR" nozzles are designed to give a uniform spray pattern at 10 to 20 psi and this low pressure results in larger spray droplets compared to applications at high pressure.

Air movement around aircraft: "Vortices" are irregular drifts of air around the fixed wing of airplanes or the rotary blades of helicopters. Updrafts are produced by the fixed wind or rotor tip, while down-drafts are produced by the body of the aircraft. The vortices move spray particles aloft with updrafts and down into the target area with downdrafts (Figure 2). Strength of the vortices is related to the weight and airspeed of a given aircraft. Increased airspeed and increased weight boost the strength of the vortices, thereby raising the chances of drift.

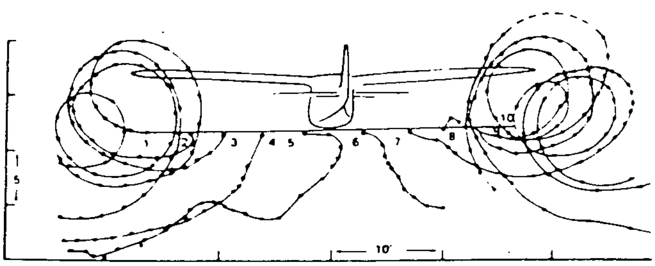

Figure 2. Air Currents in Wake of High Wing Monoplane.

Source: Yates and Akesson (15)

A spray boom which covers no more than three-fourths of the distance from the center of the aircraft to the end of the wing or rotor tip will limit the spray released into the updrafts and reduce drift (14). Lowering the spray boom a foot or more below the wing of fixed-wing aircraft or moving the boom as far forward as possible on helicopters also reduces the exposure of spray droplets to vortices.

Proper spacing of nozzles to reduce drift and achieve uniform application varies with the type of airplane. Nozzles generally should be closer together near the end of the boom, with three- to four-foot gaps on the left of center and three or four nozzles grouped to the right of center. Air drawn by the propeller will spread the spray from the clustered nozzles into the area lacking nozzles to form a uniform pattern. Spray distribution should be regularly tested and the nozzle spacing adjusted to produce a uniform spray pattern.

A summary of the influences of various factors on spray drift is given in Table 4.

Table 4. Summary of Influences of Various Factors on Spray Drift.

Factor	More drift	Less drift
Spray particle size	smaller	larger
Release height	higher	lower
Wind speed	higher	lower
Spray pressure	higher	lower
Nozzle size	smaller	larger
Nozzle orientation (aircraft)	forward	backward
Nozzle location (aircraft)	beyond ¾ wing span	¾ or less wing span
Air temperature	higher	lower
Relative humidity	lower	higher
Nozzle type	produce small droplets	produce larger droplets
Air stability	inversion	lapse
Herbicide volatility	volatile	non-volatile

SIMULATED HERBICIDE DRIFT ON SUNFLOWER AND SUGARBEETS

Research has demonstrated that sunflower yield loss from simulated spray drift of 2,4-D and dicamba (Banvel) was influenced by the growth stage of sunflower when the herbicide was applied (13). Sunflower yield loss varied from 25 to 82 percent as compared to an untreated check (Figure 3). Yield loss was greatest when the herbicides were applied in the bud stage and least when applied during flowering. Sunflowers with two to four true leaves were affected less than larger pre-flowering sunflower. The growth stage response of sunflower to 2,4-D and dicamba was similar so the results with the two herbicides are combined in Figure 3.

The amount of herbicide which contacted the sunflower and the environment during and following application influenced yield loss caused by simulated herbicide drift (10, 13). For example, 2,4-D at 0.5 ounces active ingredient (a.i.) per acre applied to 12 to 14-leaf sunflower caused a 5 percent yield loss in 1973, but the same treatment caused a 93 percent loss in 1978. Equal amounts of drift may cause very different effects on sunflower yield depending

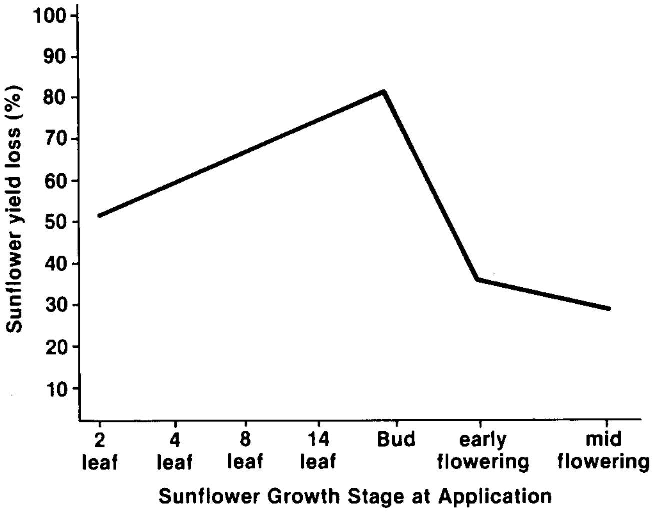

Figure 3. Sunflower yield loss from simulated herbicide drift applied at various growth stages averaged over 2,4-D at 0.5, 1.0 and 2 oz/A and dicamba (Banvel) at 0.1, 0.5 and 1.0 oz/A as compared to an untreated check.

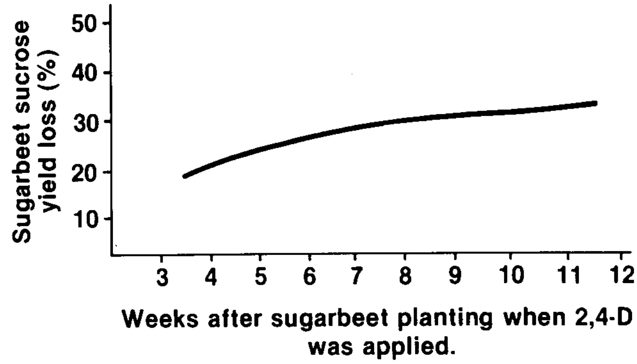

Figure 4. Loss of extractable sucrose in sugarbeets treated with 2,4-D to simulate drift at various growth stages averaged over two years and rates of 0.5, 2 and 4 oz/A as compared to an untreated check.

on environment. Sunflower injury from herbicide drift will be greatest with warm temperatures and high soil moisture.

Sunflower yield loss from 2,4-D at 0.5, 1.0 and 2.0 ounces a.i. per acre was 67, 81 and 98 percent, respectively, while dicamba (Banvel) at 0.1, 0.5 and 1.0 ounces a.i. per acre caused sunflower yield loss of 19, 34 and 58 percent, respectively, as compared to an untreated check when the herbicides were applied to eight-leaf sunflower in 1979.

Sunflower height reduction, as compared to undamaged sunflower, caused by 2,4-D, MCPA, or dicamba (Banvel) was significantly correlated with sunflower yield loss (10). Drift of 2,4-D, MCPA, or dicamba which causes a sunflower height reduction also would be expected to reduce yield. However, typical injury symptoms may be observed on sunflower from low amounts of drift without sunflower height reduction. Yield loss would not be expected from spray drift unless height reduction occurs.

Sugarbeet yield loss from simulated 2,4-D drift was influenced by the size of the sugarbeets at application (12). Sugarbeet yield loss generally increased as size of the sugarbeets at application increased (Figure 4). Loss in extractable sucrose per acre was 20 percent when the 2,4-D was applied four weeks after planting and loss increased to 32 percent when the 2,4-D was applied 11 weeks after planting, as compared to an untreated check.

Early season 2,4-D applications reduced yield in tons per acre but had little effect on percent sucrose while 2,4-D applied late in the growing season reduced percent sucrose but did not reduce tons per acre, as compared to an untreated check (12). Occasionally, late season applications of 2,4-D actually increased yield in tons per acre, but the reduction in percent sucrose was large enough to cause a loss in extractable sucrose per acre.

Simulated drift of 2,4-D also caused increased loss of extractable sucrose during storage (12). Sugarbeets normally lose some sucrose during storage and sugarbeets that were not treated with 2,4-D lost 20 percent of their extractable sucrose during storage averaged over two experiments (Table 5). However, sugarbeets treated with 2,4-D lost from 27 to 36 percent of their extractable sucrose. Sugarbeets which are damaged by spray drift of a growth regulator herbicide such as 2,4-D should be

Table 5. Influence of simulated 2,4-D drift on loss of extractable sucrose during sugarbeet storage, averaged over five application dates and two years.

Herbicide	Rate	Extractable sucrose loss during storage[a]
	(oz/A)	(%)
2,4-D	0.5	27
2,4-D	2.0	34
2,4-D	4.0	36
Untreated check	—	20

[a]Stored at 41 F and 95% relative humidity for 150 days in 1978-1979 and 110 days in 1979-1980.

processed as soon as possible after harvest. Post-harvest storage of sugarbeets damaged by spray drift would result in storage of lower quality sugarbeets and in greater sucrose losses in the storage piles.

Sugarbeets may exhibit visible symptoms of herbicide injury from spray drift without yield loss (12). Sugarbeets can recover completely from low levels of damage so the presence of symptoms does not necessarily indicate that a yield loss will result from the drift.

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