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Spray Drift from Agricultural Pesticide Applications

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Pesticide application on the Canadian prairies is primarily by tractor drawn groundrig, with some 5–10% carried out by aircraft. Both types of application have been investigated through field trials to determine the amount of sprayed material leaving the target area at the time of application and the amount of volatilized active ingredient drifting off in the subsequent hour or two following spraying. Variations in this initial off-target drift have been related to meteorological conditions (primarily windspeed), to chemical formulations of the pesticide (generally 2,4-D formulations), and to sprayer parameters such as nozzle type, orientation, and hydraulic pressure. Target deposit masses, off-target deposition, and droplet size distributions of the swath deposits and drift fractions were also measured. Finally, the decrease in drifting droplet mass with increasing downwind travel was investigated under various meteorological conditions. Results to date indicate that some 30–40% of initially deposited butyl ester of 2,4-D evaporates and drifts downwind as vapor in the 2 hr following spraying; the corresponding figure for the octyl ester is 10–15%. Off-target droplet drift at the time of spraying varies between 1 and 8% for ground-rig application, depending on nozzle type and windspeed, and is some 20–35% with aircraft spraying.

Whenever any agricultural pesticide is applied to a field as a spray from either groundrig or aircraft, there is an initial migration of some of the active ingredient away from the target area. This takes the form of droplet drift at the actual time of the spraying, with the smaller size fraction being preferentially wafted downwind rather than depositing out in the target area. Then following the application, and extending over several hours at least, more pesticide may be carried off downwind through evaporation if the active ingredient is at all volatile. Droplet drift is primarily dependent on the mechanical properties of the sprayer that control dissemination and the size spectrum, while vapor drift depends on the pesticide vapor pressure and the soil surface temperature of the target area; in addition, both will vary with wind speed and atmospheric turbulence conditions. Such drift hazards have been the topic of much research interest over the past years.[1-6]

During the crop season on the Canadian prairies some 20 million acres of land are sprayed with pesticides. At an average application of a half pound per acre, this amounts to around 10 million lb of chemical. Most of the total consists of herbicides, primarily various formulations of 2,4-D. These are generally applied to control weeds in emergent crops or on summerfallow during the period of June 1–July 15 each year. Approximately 90% or more is sprayed from tractor-drawn groundrigs, with aircraft spraying accounting for the remainder. The use of insecticides is more variable and is generally limited to specific areas of outbreaks each year; depending on the insect problem most of this may be applied by aircraft. Again, the time of use is more variable but commonly lies between June 15 and August 15.

The drift from these pesticides beyond the confines of the sprayed fields will consist of both spray droplets and the chemical vapor. If only 1% drifts, the total airborne mass would be 100,000 lb or more of material, mostly 2,4-D. This constitutes a reversal of the classic pollution problem, giving an areal source and a point sink. Specific hazards include susceptible crops, tree shelter belts and groves, and vegetable gardens for herbicides, and bees, wildlife, and fish for insecticides. If use of the chemicals could be made more efficient, drift could be reduced and these hazards ameliorated.

From the middle of the 1960s on, the amount of 2,4-D in the air has been monitored at Regina during the spraying season.[7] For several years additional monitoring stations were operated in Saskatoon, Yorkton, and other locations within the province. The results indicated that on roughly one-third of the days in the 6 week period the concentration over a 24 hr sampling period exceeded 0.1 $\mu g/m^3$ and on a few days each year it exceeded 1 $\mu g/m^3$. There was little or no correlation between the high levels at the various stations. Most of the

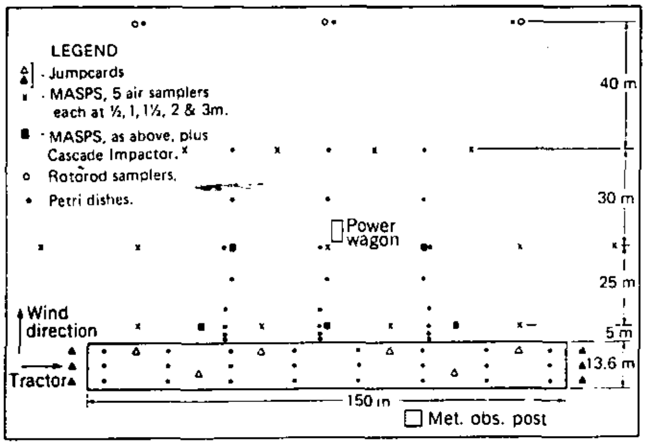

Figure 1. Field trial layout, indicating location and type of sampling equipment as described in the text.

chemical was the butyl ester formulation of 2,4-D, with generally lesser amounts of the lower volatile octyl esters also being detected.

That such amounts can be damaging is apparent in the tree foliage condition during July, as well as on occasion in gardens: crop damage is also regularly the subject of insurance claims and litigation. The problem becomes more acute as crop diversification proceeds and larger areas become planted in rapeseed, mustard, and field peas.

In order to estimate the possible downwind hazard of pesticide drift and in particular to recommend ways in which its magnitude may be reduced in practice, it is essential to distinguish between droplet and vapor migration from the target area. A series of field trials was undertaken to ascertain the relative magnitudes of these two drift components for various 2,4-D formulations.[5] These involved the spraying of a swath of ground immediately upwind of a sampling array. Sequential samples taken during and after the spray application provided a measure of the relative amount of initial droplet drift and of the subsequent vapor loss from the swath. Both volatile esters and nonvolatile amines were used.

The results showed that, for 2,4-D butyl ester, some 35% of the applied chemical evaporated from the ground and migrated downwind. For the less volatile octyl formulation the figure was around 12%. Finally, initial droplet drift from the esters as well as from the nonvolatile amine formulation was of the order of 3–5%.[5]

While the vapor was clearly the major contributor to target loss, it could be eliminated merely by phasing out use of the 2,4-D esters, certainly the butyl one. Droplet hazards, even at 3% drift, can still be significant however, as their pickup by plants is more efficient than is that for vapor. It was considered important to determine how this droplet drift fraction might vary with windspeed, and sprayer characteristics, and how rapidly it might diminish with downwind distance. It was also desired to investigate which of the commonly available nozzle and solution combinations might produce the least initial off-swath droplet drift, while at the same time providing a satisfactorily uniform swath deposit.

Experimental Procedure

The basic field trial layout consisted of a strip of ground (roughly 150 m by 13 m) oriented at right angles to the wind direction and a series of sampling poles and locations downwind of this swath. Surface coverage was typical of that present when regular farm spraying might be carried out. In practice several layouts were staked out at the start of the trial series so that on any given day one of them would be reasonably positioned for the wind on that day. A typical layout is shown in Figure 1. Samplers were placed out to provide a measure of the ground deposit within the swath and downwind of it, and to collect the droplet drift cloud at various heights at several downwind distances. The former consisted of petri dishes 15 cm in diameter and mounted on plywood boards. The latter were small polythene cylinders consisting of sharp edged inlet tube, a ridged, filter disc holder and a critical orifice at the outlet end, set for a flowrate of 10 liters/min. These were mounted every half meter on aluminum poles 3 m in height; the pole served as the suction manifold, to which a pump was attached at the base. A 14 kw power supply, mounted on a trailer was placed in the center of the sampling array, and power lines radiated out from it to each sampling pole. These are designated as MASP's in Figure 1, with the polythene air samplers mounted thereon.

In addition to mass determinations, it was desired to obtain information on the size distribution of the droplets deposited in the swath and of those drifting downwind. For the former samples, small sheets of treated photographic paper were used, on which droplets made sharp edged distinctive stains on landing. Cascade impactors, aspirated at 17 liters/min, provided for size determination of the drifting droplet cloud.

Meteorological observations taken during each trial included wind direction at 2 m height, windspeeds at ½, 1, 2 and 4 m heights, air temperature, temperature difference between ½ and 4 m (to characterize the degree of atmospheric instability), relative humidity and soil surface temperature. All except the last two were continuously recorded, and 5 min averages centered around the actual spraying were taken as the relevant parameter values for each trial. The wind speed at the 2 m height was arbitrarily chosen as the one characterizing the general wind regime. The complete meteorological observation station was located just upwind of the central point of the spray swath.

The groundrig sprayer used in the earlier trials was a standard, tractordrawn farm unit, operating at speeds around 6 km/hr. In the last two years' trials a special twin-boom groundrig was constructed.[8] It permitted the direct comparison of some modification, such as a different spray nozzle, operating pressure, use of a thickening agent, etc., emitted from one of the booms with a standard application technique used in the second boom. As long as the material originating from each could be identified and separately analyzed, the effect of such modification on deposit pattern and droplet drift could be determined directly without the necessity of matching the meteorological parameters for two independent trials.

For the aircraft trials, two different spray planes were used, one a Callair, the other a more modern Cessna Agtruck. Only a single nozzle system was used on each, the standard approved version used in routine operations.

In all trials 2,4-D amine in aqueous solution was used as the basic application; the rate was 55 mg/m^2 (8 oz/acre). It was applied as a 0.5 or 1% solution for the groundrig and as a 10% solution for the aircraft. This meant the total emission along the swath of some 100 g of 2,4-D in each trial. The solution volume and hence the amount of 2,4-D applied could be carefully measured with the groundrig, but for the aircraft it had to be estimated from the nozzle delivery rate and flight time. To improve on the sensitivity level available for sample analysis a dye tracer (brilliant sulfoflavine, BSF) was added to the spray solution. For the twin-boom trials the use of a second dye tracer (rhodamine B, RhB) was essential for the partitioning of the sample between the two systems. It was ascertained at the outset that neither dye significantly altered the solution properties or spray characteristics, nor did they interfere with one another at the analysis stage.

The procedure for the field trials followed generally similar lines in all cases. Once the samplers were in place, and flow rates of the aspirated ones checked, the spray solution was mixed and loaded into the tank and the nozzles checked. A set of blank air samplers was aspirated just prior to the trial to provide a correction for possible background contamination levels. For groundrig trials, spraying commenced just prior to the tractor entering the test swath and its speed along the swath, the hydraulic pressure in the tank and the fluid flowrate to the booms were carefully monitored during the course of the 1-2 min run. The pumps were started at the commencement of spraying, and the air samplers aspirated for a 3 min period, long enough to ensure full passage of the droplet drift cloud. The samplers were then collected and transported back to the laboratory for analysis.

Extraction of the petri dishes, air samplers, and cascade impactor slides was with highly purified ethanol solvent. The samples were then analyzed for dye content in a fluorometer, corrected for blank sample levels and for any photolytic decay of the dye and converted to mass of 2,4-D/sample. For the ground deposit samples, both in the swath and those at various downwind distances, these masses divided by the petri dish area gave deposit densities. Average deposit density and standard deviation within the swath was calculated from the 24 sample dishes present, from which total deposit in grams and swath recovery in percent of mass emitted were readily found. Ground deposits in various downwind strips were analogously determined.

The mass of 2,4-D in each air sample was divided by the sampler flow rate and multiplied by the wind speed for the relevant height to yield a droplet drift density value in mg/m^2. When appropriately averaged and multiplied by the vertical and crosswind dimensions the total drift mass and recovery at each downwind distance were obtained.

The mass of dye found for each stage within the cascade impactors permitted a size distribution to be drawn and the volume median diameter to be obtained. For the swath deposits, it was necessary to size microscopically the stains on the paper surface, correct these for spread factor and plot the volume percentages for each size range. This yielded a volume median diameter value for the spray that landed within the swath. The data could also be used as a check on the total deposit mass as found from the petri dish samples.

Experimental Results

The meteorological conditions for all the trials were generally those that could be expected to pertain to routine farm spraying conditions on the Canadian prairies in June. Air temperatures were between 15°C and 32°C, with soil temperatures some 10–20°C higher, and relative humidities around 30–50%. Most of the trials were carried out under positive lapse rates in midafternoon; a few were conducted in the early morning or evening when the temperature gradient indicated inversion conditions were present. A wide range of wind speeds was involved, from 5 to 35 km/hr so that the behavior of various spray nozzles and sprayer settings and the initial drift they produced could be examined over the range of winds likely to be experienced in farm operations.

For groundrig application the initial drift, i.e., that observed at the sampling line 5 m downwind varied between <0.5% and 8% of the spray emitted, depending on spray nozzle used.

Table I. Summary of deposit and initial drift recoveries for various wind speeds and sprayer characteristics

Trial Type[a] nozzle, and pressure (kPa)	Windspeed at 2 meter height (km/h)	Recoveries per 100g of emission[b]			Volume median diameter	
		Swath deposit + S.D. (g)	Initial off-swath deposit (g)	Initial drift (g)	swath μ	drift μ
Groundrig, 8002, 210	8.5	90 ± 19	0.4	0.6	600	13
	13.7	104 ± 17	0.9	1.2	590	15
	22.0	83 ± 15	1.1	1.6	650	15
Groundrig, 65015, 170	9.4	106 ± 19	0.7	0.9	600	14
	35.5	99 ± 27	3.5	4.7	580	20
Groundrig, 650067, 280	16.5	94 ± 25	2.4	4.8	440	15
Groundrig, 8002LP, 100	16.4	106 ± 22	0.7	0.6	860	17
Groundrig, thickener	16.6	107 ± 50	0.5	0.2	1400	11
Spracoupe	3.9	93 ± 25	3.4	5.0	240	20
	21.6	82 ± 31	4.1	15.1	260	10
Aircraft	7.9	61 ± 30	6.1	14.8	280	70
	14.8	54 ± 22	8.0	31.3	220	100

[a] The groundrig sprayer is basically the standard tractor drawn device used by farmers on the Canadian prairies; the Spracoupe is a specialized, wheeled sprayer vehicle; the aircraft results are preliminary average values from tests on both a Callair and Agtruck planes. For the groundrig data, the first number is the designation of the flatfan, Teejet-type nozzle used (i.e. the 8002 is an 80° one, high flowrate, the 650067 is a 65°, low flowrate nozzle etc.) The second number is the hydraulic pressure under which the nozzle was operated (100 kPa = 15 psi). The numbers for each device and windspeed combination are averages of at least four separate trials.

[b] These recovery figures are the following:

(i) swath deposit: for each trial, the average deposit density value of the 24 samples collected in the swath times the swath area and divided by the amount of herbicide emitted (× 100). The S.D. value is the standard deviation of the 24 individual dish values about this mean, again expressed in terms of grams of 2,4-D found per 100 g of emission.

(ii) initial off-swath deposit: the average deposit density found from the 9 samples in the 5 meter wide downwind strip beside the swath (out to the first air sampling line) times the area of this strip and again divided by the amount of herbicide emitted (and again times 100).

(iii) initial drift: the average of all the 35 air sampler amounts found on the 5 meter sampling line converted to mg/m^2 of 2,4-D passing this line in the air, multiplied by the cross wind vertical area enclosed by these sampling poles (and multiplied by 100/emission amount as before).

hydraulic pressure, and of course wind speed. Values of this quantity, together with swath deposit and initial off-swath deposit recoveries are given in Table I for some of the nozzle and solution combinations tested. The curves in Figure 2 illustrate how the initial droplet drift fraction was found to vary with wind speed at the 2 m height.

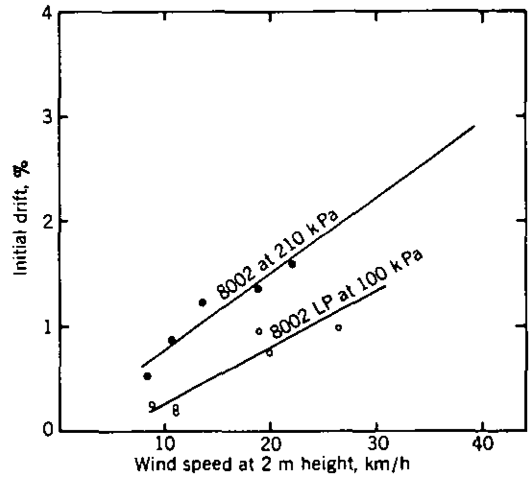

Figure 2. *Variation of initial droplet drift with wind speed.* The solid circles are for an 80° flat fan nozzle (Teejet type 8002) operated at 210 kPa hydraulic pressure, the open circles for a special low pressure version of this nozzle operated at 100 kPa.

Also in Table I is a droplet size measure for the deposit and drift material, as characterized by the volume median diameter.

It is apparent from these last two columns of Table I that the initial off-swath drift from groundrig application consists generally of smaller droplets than that from aircraft spraying, despite the overall smaller sizes produced by the latter. This is understandable inasmuch as the greater release height, and the greater mechanical turbulence accompanying their release from aircraft spraying would tend to enhance the drift tendency over the entire droplet spectrum, compared to that pertaining to ground rig application. It might therefore be expected that the subsequent downwind behavior of the drift cloud would be somewhat different in the two cases. The

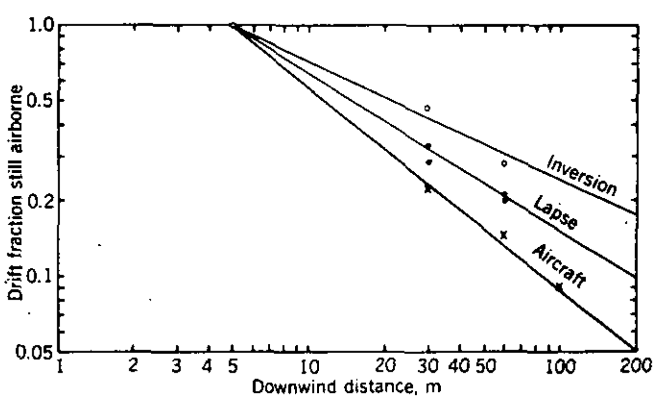

Figure 3. Decrease in droplet drift with downwind distance. Assuming unit magnitude drift at the first sampling line 5 m downwind from the swath edge, these curves give the relative drift magnitudes observed from the samplers on the further downwind lines; each point is the average of at least four separate trials.

diminution of the cloud can be determined from the drift densities observed at the air sampling lines 30 and 60 m downwind of the spray swath. The average values, expressed as a fraction of the initial drift density on the 5 m line are plotted in Figure 3. While a separate decay curve would be appropriate to each wind speed value and hence trial, these have been averaged in the figure for simplicity. However, two different rates are shown for the groundrig application, relevant to turbulent (lapse) and stable (inversion) air conditions.

It is possible to use these drift cloud decay curves to estimate the amount of droplet drift that might be expected to escape from an entire farm field spray operation. The data plotted in Figure 2 are for drift fractions from a single swath; if a second swath had been sprayed immediately upwind of it, drift amounts could be expected at each of the sampling line distances commensurate with the fractional values given in Figure 3 for distances 13 m greater in each case. A third swath further upwind would provide drift amounts as found for distances 26 m out, and so forth. As these drift fractions are purely additive a composite total may be derived; it must, of course, be considered a rough estimate only and conclusions based on it treated with great caution. Table II illustrates this process for the spraying of an entire section (mile square) field. Now for each 1% of drift the average initial drift density will be 2 mg/m^2 (assuming the cloud extends only up to 4 m in height and the desired application rate onto the ground is 55 mg/m^2). It can be seen that drift density levels exceeding the ground application can be produced in a full field operation, particularly if the drift cloud is confined in its vertical diffusion.

As can be seen from summation of the three recovery values in Table I, it was generally possible to obtain a near total accountancy of the 2,4-D emitted, with the greatest fraction being found in the swath. More important than the total amount found here, however, was its variability; the production of as uniform a deposit pattern as possible is after all the primary goal of the farm sprayer application. The variability was calculated for each trial as the standard deviation of the 24 individual values for the sample dish array. The actual densities could also be plotted and isopleths drawn.

A few trials were carried out with a randomly placed set of sampler dishes; the results gave roughly the same standard deviation for their average as for the regular grid, indicating the latter did provide a reasonable measure of the pattern obtained.

The degree of swath deposit uniformity, as characterized by the standard deviation, was frequently quite different, even under quite similar trial conditions. However, it did not appear to be affected by wind speed unless this was quite high (>30 km/hr), whereupon the standard deviation showed some increase.

The implications of swath pattern variability may be seen from Figure 4, and Table III which is based on it, for the series of trials on the 65° Teejet nozzle. Given a particular type of weed, its surface area and its susceptibility to a particular herbicide, an effective deposit rate (in mg/m^2) may be set. If spraying produced a perfectly uniform deposit, this would also be the necessary emission rate for the spray, in mg/m^2. The greater the variability, the larger has to be the latter to ensure a desired degree of weed control. Using the curves of Figure 3, it is possible to calculate emission rates that would be needed to achieve 80 and 95% weed control for various levels of susceptibility, as set by assumed deposit rates. As certain factors such as tractor speed, nozzle pressure, and terrain condition were more carefully controlled in the trials than would be possible in routine farm field operations, it must be admitted that even the worst case may not represent the extreme for such operations.

Another feature that appears in Table I regarding the swath standard deviation is that it tended to be much higher for some of the sprayer modifications that effectively reduced drift. This was most noticeable from the twin-boom type of trial, for which the simultaneously obtained samples provided the most direct comparison of drift control and deposit uniformity for any proposed modification. Thus for instance, the considerable improvement in the former factor when thickeners were added to the spray solution has been purchased at the expense of a significant worsening of the latter characteristic. It should be noted that the relatively high swath deposit standard deviations found for Spracoupe and aircraft operations will be reduced through downwind deposition of drifting droplets when multiple swath application takes place.

Conclusions

It is apparent that, due to the additive nature of the droplet drift coming off successive swaths, even a small fraction of initially drifting material may be hazardous to susceptible plants when herbicides are applied to farm fields. Due to the small size of the drift droplets once the water component has evaporated, ground deposition rates are low, and if vertical diffusion and dilution are moderate, the drift density at the downwind field edge may well exceed the deposit density within the field, even when only 1% initially moves off from each swath.

Over the range of windspeeds commonly encountered during farm spraying operations, the amount of initial, off swath droplet drift increased roughly linearly with the speed,

Table II. Estimates of mass flux from the spraying of a section of land at a rate of 55 mg/m^2 (i.e. 8 oz/acre).[a]

Relative contribution to drift from:	Downwind field edge			500 m further downwind		
	Aircraft, lapse	Groundrig, lapse	Groundrig, inversion	Aircraft, lapse	Groundrig, lapse	Groundrig, inversion
first swath	1.0	1.0	1.0	0.1	0.2	0.3
2nd–5th swaths	1.3	2.0	2.4	0.3	0.7	1.1
6th–10th swaths	0.9	1.7	2.2	0.4	0.9	1.3
11th–30th swaths	2.1	5.0	6.8	2.3	3.4	5.1
31–120th swaths	4.4	14.7	25.4	3.5	12.5	22.3
Total	9.7	24.4	37.8	5.5	17.7	30.1
If initial drift is:	30%	3%	3%			
Average initial drift density (1 swath) to 4 m height (mg/m^2):[b]	60	5.4	5.4			
Total drift (all swaths), averaged to 4 m height (mg/m^2):	580	130	200	330	95	160
averaged to 10 m height (mg/m^2):	230	50	80	130	35	65

[a] In this table it is assumed that the closest swath to the downwind field edge contributes unit drift at that edge; the relative contribution of each subsequent upwind swath is then found from the decay curves of Figure 3 (eg. the next four swaths contribute in total 1.3 times as much as the first swath in the case of the aircraft, the next 5 together contribute 0.9 times as much as the first, etc.). At 500 m these relative contributions from all swaths are reduced by this further travel according to the relevant decay curves of Figure 3. Thus, the off-field drift from all 120 aircraft swaths, initially 9.7 times that from the closest swath, decreases by nearly half (to 5.5 times the initial, one swath drift) after a further 500 m of downwind travel, etc.

[b] These figures are found from multiplying the swath deposit density (50–60 mg/m^2) by the drift percentages in the above row and by the ratio of swath width to drift cloud height (16m/4m for aircraft, 13 m/4 m for groundrig). The figures in the last two rows are then obtained by multiplying these one-swath drift amounts by the total contributions of all swaths as found above (eg. 9.7, 24.4 etc.). Both the initial drift density and the total drift figures here refer to the mass of chemical passing through a unit vertical cross-section at right angles to the wind direction.

Table III. Emission rates of herbicide necessary to ensure that at least 80 or 95% of the area sprayed receives enough deposit to control the weeds, given three different swath variability levels.[a]

Assumed effective deposit density (mg/m^2)	Fraction of area to receive at least amount in previous column (%)	Necessary emission rate (mg/m^2)		
		Average	Best case	Worst case
20	80	28	23	40
20	95	49	25	120
35	80	47	40	75
35	95	85	45	200

[a] Here it is assumed that either 20 or 35 mg/m^2 is sufficient herbicide for weed control and that one wishes to ensure that either 80 or 95% of the weeds receive at least this amount. The emission rates necessary to achieve these various levels are then found from one of the three lines shown in Figure 4. For instance, if the sprayer is behaving as shown by the "average" curve of Figure 4, an application rate of 28 mg/m^2 will ensure that 80% of the area receives at least 20 mg/m^2; on the other hand if it was behaving more erratically and producing a very uneven deposit as illustrated by the "worst" case, it would be necessary to apply the chemical at a rate of 40 mg/m^2 to ensure that 80% of the area received at least 20 mg/m^2, or at a rate of 120 mg/m^2 if one wanted 95% effective coverage and control.

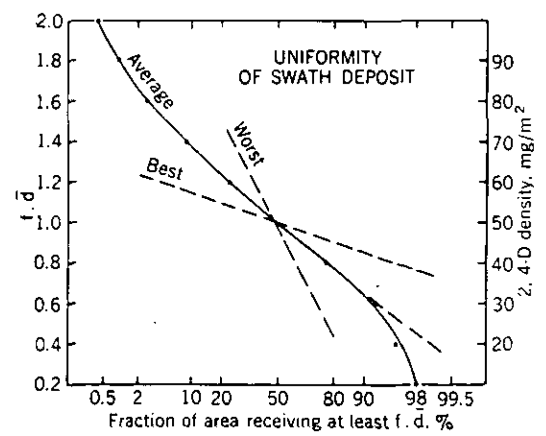

Figure 4. Variation of swath deposit uniformity with standard deviation of the sampler array. Based on the standard deviation about the mean deposit density as found from the 24 petri dish samples, it is possible to calculate what fraction of the test swath area received at least *f* times the average density, and what this fraction means in terms of actual deposit density. The "average" curve is the mean of 14 separate trial results, one of which is represented by the "best" curve and one by the "worst".

at least for groundrig application. This was not obvious for the initial droplet drift from aircraft spraying but became established at greater downwind distances. Clearly, spraying under the lightest winds possible is advisable, particularly when near susceptible plants, trees, and crops. Spraying under inversion conditions, when upward dilution of the drift cloud is much reduced, is disadvantageous, except insofar as the winds may be very light at such times.

Tests on various modifications to groundrig sprayers indicated that reducing the hydraulic pressure, applying more total solution volume, using thickeners, or low pressure nozzles, resulted in every case in a reduced level of initial drift. All achieved this through a coarsening of the droplet size spectrum, with a resultant reduction in the volume of small droplets produced. This improvement, however, was frequently accompanied by an unacceptable worsening of the swath deposit uniformity. In one or two of the modifications, reduction in the initial droplet drift fraction could be attributed as well to a lowered boom height. Again this might be accompanied by a greater variability of the pattern, at least over rough terrain, or where boom whiplash occurred.

In surveying these results of drift control modifications it appears that a more promising approach would be to work towards improving the homogeneity of the swath deposit.[8] If this were achieved, the chemical emission rate that is necessary to produce a desired level of weed control could be reduced. This in turn would result in a decrease of the off-swath drift for any given combination of sprayer parameters.

It should be noted that while these studies have been carried out on 2,4-D, the findings are basically applicable to any herbicide. The physical properties of the solution, rather than the biological effects of the active ingredient, are involved and once known, may be used to identify any divergence in quantitative values of deposit and drift features. The same generalization may be made for the consideration of insecticide application, except for the proviso that the desired interaction of droplet and target will be different.

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References

1. H. F. Johnstone, W. E. Winsche, and L. W. Smith, "Droplet migration in the atmosphere," *Chem. Rev.* **44**: 353 (1949).
2. R. J. Courshee, "Investigations on spray drift, 1. the small droplet component of sprays," *J. Agric. Eng. Res* **4**: 144 (1959).
3. N. B. Akesson and W. E. Yates, "Problems relating to application of agriculture chemicals and resulting residues," *Ann. Rev. Entom.* **9**: 285 (1964).
4. J. Maybank and K. Yoshida, "Delineation of herbicide drift hazards on the Canadian prairies," *Trans. A.S.A.E.* **12**: 759 (1969).
5. R. Grover, J. Maybank, and K. Yoshida, "Droplet and vapour drift from butyl ester and dimethylamine salt of 2,4-D," *Weed Sci.* **20**: 320 (1972).
6. C. E. Goering and B. J. Butler, "Paired Field Studies of Herbicide Drift," paper no. 73-1575, A.S.A.E. conference, Chicago, Dec. 1973.
7. R. Grover, L. A. Kerr, K. Wallace, K. Yoshida and J. Maybank, "Residues of 2,4-D in air samples from Saskatchewan: (1965–1975)," *J. Environ. Sci. Health* **B11**(4): 331 (1976).
8. J. Maybank, K. Yoshida, S. R. Shewchuck, and R. Grover, "Spray Drift and Swath Deposit Pattern from Agricultural pesticide application: Report of the 1976 field trial program. SRC Report no P77-1, Jan. 1977.

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