WHERE HAVE ALL THE DROPLETS GONE?

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If you want to know if your neighbours are spraying stand downwind and sniff. What you smell is chemical drift, i.e. the movement of spray outside the target area. However, far too often drift is equated solely with the deposition of spray droplets outside the target area. Drift assessment is thus carried out by measuring off-target deposits. This is superficially attractive but sadly deficient. It ignores the unrelated long distance aspect of drift that causes general contamination of our environment; caused by droplets too small to deposit on any natural object which are lost to the atmosphere - produced both directly by the nozzle and by evaporation of water-based spray droplets in transport.

Whilst damage to local crops or wildlife is of great concern - and more common than is supposed - this latter aspect of drift is ultimately more worrying and hazardous since, while local damage shows the point of deposition of the pesticide, that part of the spray which is lost to the atmosphere is collected or precipitated (as poison rain) in an unknown place at an unknown time - truly uncontrolled drift.

The neglect of this aspect of drift is surprising, given the well known case of DDT crossing the North Atlantic and the acceptance of volatilisation of 'hormone' herbicides as a major cause of drift, although with past measurement of droplet sizes and deposition almost exclusively undertaken by collection techniques, which are biased against smaller droplets and do not even acknowledge the existence of those droplets with insufficient energy to deposit (precisely that part of the spray subject to long distance drift), it is perhaps not surprising that, as Schaefer (1983) notes, "popular theories for the distribution of smaller droplets are conceptually inadequate, scarcely tested and predictively inaccurate".

Only recently have we been able to accurately measure the droplet spectrum actually produced by any nozzle using laser holographic and diffraction analysers. These reveal the billions of tiny droplets produced by the hydraulic nozzle - even when set for herbicide application.

Artificial collectors give artificial results that are inaccurate and misleading, as shown by Uk (1975), with their smooth surfaces and mono-directional orientation never being capable of representing the complex surfaces and movement of a living target. The only way to realistically assess spray distribution is through the addition of a fluorescent tracer to the spray, allowing examination of actual deposits on the target under UV light.

Theories of small droplet transport have nearly all been simple extensions of those for larger droplets. Droplets are viewed as sedimenting out of the sky in a simple streamlined fashion, with wind treated as simple laminar airflow. This views small droplets as projectiles, with droplets that are too small to deposit presumed to have a 'lifetime' which ends in their disappearance with the total evaporation of their water content. None of these assumptions are true.

The use of airfields and wind-tunnels with laminar airflow to determine droplet transport is incapable of simulating the turbulent nature of airflows both above and within the crop. For small droplets sedimentation has little, if any effect with canopy penetration (by eddy diffusion) and deposition (by impaction) determined by predictable laminar airflow.

Canopy penetration is determined by the eddies which form by friction within the boundary layer above the crop surface. The depth of the boundary layer is related to the distance that the wind has travelled over the crop surface, with the ratio of the (vertical) eddy velocity to the (horizontal) mean wind speed modified by air temperature conditions as summarised in a recent BCPC study (Elliott and Wilson, Eds., 1983).

Bache and Sayer (1975) found that peak deposition of small droplets downwind was proportional to the height of the nozzle and inversely proportional to the intensity of turbulence, with a long downwind tail. Their model predicts peak ground deposit further downwind, with a higher droplet density, under stable conditions - showing again the lack of correlation between short and long distance drift.

Once within the canopy smaller droplets deposit primarily by impaction - with the droplet requiring sufficient energy to penetrate the boundary layer of air deflected around obstacles. Although obviously the collection efficiency (the ratio of the number of droplets striking the obstacle to the number which would strike it if the air were not deflected) increases with droplet size and the velocity of the droplet relative to the obstacle, and decreases as the obstacle increases in size, this ignores important features such as the shape, surface characteristics and movement of the obstacle, e.g. fluttering leaves not only increase the relative velocity between themselves and droplets but also present a changing target pattern and disturb the boundary layer at their own surfaces.

There is also the question of retention after impaction, the most important determinant of which for a particular surface is droplet size (Brunskill, 1956), with droplets over a certain size shattering or bouncing.

Models must also take account of evaporation, which results in droplets shrinking while in the air. Evaporation of water takes place very rapidly, e.g. a 50 µm droplet will lose all its water in 4 seconds; although models of evaporation rates (generally based on single droplets much larger than those employed in pesticide application) are also suspect. However, with only 0.8% of involatile material (material active ingredient plus insoluble formulating agents) a 50 µm droplet from which all the water has evaporated will remain a 10 µm particle of involatile residue which, far from disappearing, can have a lifetime of many days or even months - depending on the chemical - with this 'vaporisation' also slowing chemical degradation (although photochemical degradation will quicken).

The magnitude of the problem is still rarely realised with the hydraulic nozzle producing a very wide spectrum of droplet sizes that can cause local drift under certain conditions, but with a significant proportion of its spray produced in droplets under 30 µm (ignoring the even larger part of the spray which will fall under this size through evaporation) which are bound to remain airborne over long distances. Thus every conventional spraying operation causes long distance drift.

A fan jet nozzle at 1 bar gives over 45% of its droplets under 30 µm (Bals, 1978). In the U.K. alone this means that at least sixteen million gallons of spray liquid applied every year are only contributing to long distance drift, i.e. general environmental contamination. The obvious solution is to produce droplets only of non-driftable sizes. Additives (mainly polymers and macromolecules) to increase the droplet sizes produced by hydraulic nozzles have been increasingly used, but these are both expensive and create mixing problems since viscosity has to be drastically increased to have any effect. It has been demonstrated that droplet sizes produced by a hydraulic nozzle are independent of viscosity up to levels thirty times that of water. Invert emulsions have also been used (mixing the two phases at the nozzle) although specially designed equipment is required and careful formulation is essential.

However, increasing the vmd of a hydraulic spray does nothing to control the droplet size range produced. Droplet formation remains random with increased viscosity resulting in the formation of many huge droplets (many exceeding 1mm in diameter). These droplets will certainly land in the target area (with evaporation not having a significant effect as they plummet to the ground), but this does not mean that they are hitting the target. Droplets over 300 µm will run or bounce off foliage or indeed fall straight to the ground. Not only are these droplets biologically ineffective, but they contain most of the spray volume (remembering that droplet volume, and thus the amount of chemical contained by the droplet, is related to the cube of droplet diameter). Thus most of these large spray droplets are (very expensively) contributing to soil pollution rather than crop protection - with the sheer waste of most of the energy involved in fetching, transporting and atomising the huge quantities of water required for conventional spraying.

Another attempted solution is to lower boom height. However, this is subject to limitations with hydraulic nozzles which, unlike rotary atomisers, require a minimum vertical distance to form their spray pattern and will suffer from increasing unevenness of their already poor spray distribution at lower boom heights, as summarised by Combellack (1984) - of rotary atomisers (Bode and Butler, 1983). In the U.K. farmers have been shifting from 80° to 110° nozzles to try and prevent this worsening of distribution - but this produces more small droplets!

The addition of air to hydraulic nozzles to try and impact small droplets is not only expensive but largely futile, and even counter-productive. Any additional velocity imparted to small droplets will rapidly be dissipated and increasing the force of the downward blast eventually has a negative effect in that leaves will be turned to lie parallel with the airflow and thus present a minimum area to intercept droplets. Moreover, those droplets which do not impact will probably be carried back out of the canopy with the reflected airblast, and this will greatly increase the amount of both short and long distance drift.

However, research shows that droplets under 200 µm are far more biologically effective and better retained. Resulting low volume application rates also greatly increase spraying productivity, with the reduction in spraying costs and loads allowing quick, efficient and timely application. There are thus significant advantages in using these droplets if we can ensure that we do not also produce smaller droplets subject to uncontrolled long distance drift.

The only way to economically control drift is through CDA. CDA should "make it possible to eliminate drift by avoiding completely the drift - generating size and even where this is not possible it can reduce drift by avoiding waste in 'overkill' drops without dispensing unnecessarily small drops" (Hartley and Graham-Bryce, 1980).

Even with CDA evaporation can reduce droplets in size and thus an anti-evaporant should always be used when using droplets under a certain size, or in hot, dry or calm conditions with, as previous examples illustrate, the addition of 12½% of an anti-evaporant preventing any droplet becoming less than half its size at emission and improving deposition (Wodageneh and Matthews, 1981). The low volume application rates make the effective addition of anti-evaporants an economic possibility, or even the use of oil-based formulations (used very successfully already with insecticides and fungicides in many parts of the world). In one of the few direct large scale comparisons between oil-based CDA (at 1 L ha^{-1}) and water-based LV (at 20 L ha^{-1}) the U.K. Forestry Commission showed far greater deposition within the target area, and on target surfaces, with CDA from the air (Holden and Bevan, Eds., 1978), with this further demonstrating effective turbulent transport of small droplets.

A development which promises greater control of drift with small droplets is the electrostatic charging of sprays. Electrostatics has the huge advantage of providing droplets with their own internal force for deposition rather than applying an external force to them, thus allowing them to deposit on any surface (Bals, 1982).

However, electrostatics as the sole force for spray atomisation, dispersion and deposition can hinder spray distribution; decreasing penetration and swath width and thus effectiveness and work rate (Morton, 1982; Pascoe and Jackson, 1983; Sherman and Sullivan, 1983). The application of electrostatics to spinning discs is also a possibility we are investigating (with lower charge levels and a less intensive electrostatic field), but after five years of research by ourselves and others on electrostatics much basic work still needs to be done - with the spray transport of charged droplets (which will have velocities and trajectories modified by mutual repulsion and the development of space charges) still little understood.

Thus much more work is needed on droplet transport, as I hope this paper illustrates, requiring a complete re-assessment of our current analytical and measurement techniques which rest on, and thus can only reinforce, mistaken preconceptions about transport of smaller droplets, especially with respect to drift.

By being able to predict droplet transport realistically, and with means already existing to produce desired droplet sizes within a very narrow size band, the application of pesticides can become far more accurate than the random process that it remains at present. As the U.K. Royal Commission on Environmental Pollution concluded:

"The time may come when pesticides will not be cleared for present day 'conventional' spraying if other techniques such as ULV/CDA have proved equally safe, more efficient and preferable on environmental grounds".

LITERATURE CITED

Bache, D.H. & W.J.D. Sayer (1975). Transport of aerial spray: I. A model of aerial dispersion. Agric. Met., 15, 257.

Bals, E.J. (1978). The reasons for C.D.A., Proc. 14th Br. Weed Control Conf., 659.

Bals, E.J. (1982). The principles of an new developments in ULV spraying: some reflections. Proc. 16th Br. Weed Control Conf., 1033.

Bode, L.E. & B.J. Butler (1983). Spray characteristics of rotary atomisers. In: Pesticide Formulations and Application Systems: Second Conference, ASTM STP 795, K.G. Seymour (Ed), American Society for Testing and Materials, 89.

Brunskill, R.T. (1956). Factors affecting the retention of spray droplets on leaves. Proc. 3rd Br. Weed Control Conf., 593.

Combellack, J.H. (1984). Herbicide application: A review of ground application techniques. Crop Protection, 3, 9.

Elliott, J.G. & B.J. Wilson (Eds.) (1983). The drift of herbicides. BCPC Occasional Publication, 3.

Hartley, G.S. & I.J. Graham-Bryce (1980). Physical principles of pesticide behaviour. Academic Press, London.

Holden, A.V. & D. Bevan (Eds) (1978). Control of Pine Beauty Moth by fenitrothion in Scotland 1978. Forestry Commission.

Morton, N. (1982). The Electrodyn sprayer: First studies of spray coverage on cotton. Crop Protection, 1, 27.

Pascoe, R. & A.J. Jackson (1983). Progress on developing Electrodyn sprayers for use in rice. 10th International Congress of Plant Protection, 499.

Schaefer, G.W. & K. Allsopp (1983). Spray droplet behaviour above and within the crop. 10th International Congress of Plant Protection, 1057.

Sherman, M.E. & J.G. Sullivan (1983). Vehicle-mounted Electrodyn sprayer application in cotton and soybeans. 10th International Congress of Plant Protection, 500.

Uk, S. (1975). Spray collection by cotton plants: The contribution of small droplets and their production by airborne atomisers. Seminar on the strategy for cotton pest control in the Sudan, Ciba-Geigy.

Wodageneh, A. & G.A. Matthews (1981). The addition of oil to pesticide sprays - downwind movement of droplets. Tropical Pest Management, 27.