Symposium on Controlled Drop Application - 12th - 13th April 1978

EFFECTS OF VOLUME RATE AND DROP SIZE ON THE RETENTION OF AN AQUEOUS SOLUTION BY AVENA FATUA L

C.R. Merritt and W.A. Taylor

Agricultural Research Council Weed Research Organization
Begbroke Hill, Yarnton, Oxford, OX5 1PF, England

Summary The retention of aqueous 0.5% v/v 'Agral'*solution by *Avena fatua* was measured at volume rates in the range 20-100 l/ha, with uniform drop sizes between 150 and 350 μm diameter. In general drops of 150 and 250 μm diameter were better retained than 350 μm drops. This effect was most pronounced at the higher volume rates in the case of four-leaf plants.

INTRODUCTION

Interpretation of the biological effectiveness of controlled drop applications has been difficult due to the many factors involved. Changes in volume rates and drop sizes may be accompanied by changes in spray distribution and retention on plant surfaces, as well as in factors affecting the uptake and movement of pesticides within plant tissues, such as the concentration of active ingredients and additives.

Previous work on retention has demonstrated differences which can occur as a result of changes in drop size and volume rate. Brunskill (1956) showed that retention on pea leaves is greater with smaller drops and lower surface tensions. Lake and Taylor (1974), tracing the oil phase of an oil-in-water emulsion of barban, found that drops between 110-440 μm diameter were equally well retained by young wild oat plants, and that retention was linear up to about 150 l/ha. However, when wild oats were sprayed with water or 0.1% v/v 'Agral' solution, Lake (1977) found that 100 μm drops were better retained than drops of 200-600 μm.

A series of experiments have therefore been carried out using drops of 150-350 μm with 0.5% v/v 'Agral' solution to complement previous biological investigations of controlled drop applications of difenzoquat (Wilson, 1976; Merritt and Taylor, 1977).

* Non-ionic wetting agent, Imperial Chemical Industries Ltd, Plant Protection Division

METHODS AND MATERIALS

Seeds of Avena fatua were pre-germinated and sown individually in 9 cm pots. In experiments 1 and 2 the plants were grown outdoors in August to October, whilst in experiments 3 and 4 plants were grown in a glasshouse. Before spraying, plants were selected for uniformity of growth stage. Descriptions of growth stages in this paper are based on the scale of Zadoks, Chang and Konzak (1974).

Plants were sprayed using a spinning disc in a cabinet. An 8 cm plastic disc (the Micron 'Herbi') is shrouded to allow only an arc of spray to be emitted. This spray unit is moved along a track over the material to be sprayed. Volume rate is varied by changes in flow rate of spray liquid on to the disc. Drop size is varied by changing speed of revolution of the spinning disc, and checked by microscopic observation of drops caught in silicone fluid (Zaske, 1970).

A fluorescent dye, Sodium fluorescein (uranin) was added to the spray solution at 0.5% v/v so that application rate and retention could be measured fluorimetrically. Petri dishes (9 cm diameter) were placed on the sprayed area for measurement of application rate by washing out the captured spray.

After spraying, plants were cut at soil level and washed to remove the retained spray solution. Twenty plants were used for each treatment.

In experiments 1 - 3 the plants were washed in 0.1% v/v 'Agral' solution to ensure wetting of the leaves. However, in experiment 4 with smaller plants, 30% iso-propanol was used since it was found that the Agral solution, which partially quenches the fluorescence of uranin, rendered the fluorescence too low for accurate measurement.

The washings were assayed against a series of standards using a Jobin Yvon JY3 spectrofluorimeter at wavelengths of 483 nm excitation and 514 nm fluorescence. Washed plants were dried in an oven at 98° C for 48 hours so that dry weights could be determined as a measure of plant size at spraying.

RESULTS

Experiment 1 Drop sizes of 200 and 300 µm were applied at 25 l/ha. Plants had 3 leaves plus two small tillers at spraying. There was no significant difference in total amount of spray retained between the two drop sizes. (Table 1).

Experiment 2 Drop sizes of 150, 250 and 350 µm were applied at 20 l/ha. Plants had 3-4 leaves and two tillers at spraying. Again, there was no significant difference between the drop sizes. (Table 2).

Experiment 3 Five volume rates were applied in the range 20-100 l/ha and at 3 drop sizes: 150, 250 and 350 µm. Plants had 4 leaves at spraying.

Retention was approximately linear for all three drop sizes (Fig 1). Regression lines were calculated and in each case significance levels were very high $p < 0.01$. The regression lines were compared by significance tests (t tests). There was no significant difference between the regressions lines for 150 and 250 µm drops. The line for 350 µm drops differed from these two, however, with retention at the same level at around 25 l/ha but with the slope decreasing so that at around 100 l/ha retention of 350 µm drops was about half of that with 150 or 250 µm drops.

Experiment 4 Four volume rates were applied in the range 20-100 l/ha and at 3 drop sizes: 150, 250 and 350 μm diameter. Plants had 2 leaves at spraying. In this experiment there appeared to be levelling off in the relationship between retention and volume rate at higher volume rates so regression lines were not calculated. Instead, volume rates were analysed individually (Fig. 2).

As for Experiment 3 retention was poorer with 350 μm drops with no difference between the other drop sizes.

DISCUSSION

Under all conditions examined, 150 μm and 250 μm drops were equally well retained by A. fatua. In experiments 1 and 2 using outdoor grown plants equal retention also occurred with 300 μm and 350 μm drops. In experiments 3 and 4 glasshouse grown plants were used, and here 350 μm drops were not as well retained as smaller drops, except possibly in experiment 3 at volume rates around 25 l/ha. A further difference between the experiments using indoor and outdoor plants is that the outdoor plants retained twice to three times as much spray per unit dry weight than indoor plants at equivalent volume rates. This may be due to the generally more prostrate growth habit and more weathered leaf surfaces of outdoor plants.

Experiments 3 and 4 suggest that the poorer retention of 350 μm drops may become more pronounced as volume rate is increased. In tests in which single drops of this size were applied to leaves of A. fatua at low velocities (well below terminal velocity) drops were observed to bounce only when they impacted on other drops already on the leaves. This phenomenon may best explain the observed differences since it would depend on drop numbers and hence volume rate.

These results have particular relevance to the application of difenzoquat to A. fatua. This is the only wild oat herbicide applied as an aqueous solution. Shafer (1974) showed the need for 0.5% 'Agral' to obtain maximum biological activity of difenzoquat. From our results it would appear that retention in relation to surfactant concentration may be an important factor since Lake (1977) has shown that using 0.1% 'Agral' drops greater than 100 um were poorly retained, although the interaction with volume rate was not studied. Conversely surfactant rate was not a factor studied in our experiments.

References

BRUNSKILL, R.T. (1956) Physical factors affecting the retention of spray droplets on leaf surfaces. Proceedings, Third British Weed Control Conference, 2, 593-603.

LAKE, J.R. (1977) The effect of drop size and velocity on the performance of agricultural sprays. Pesticide Science, 8, 515-520

LAKE, J.R. and TAYLOR, W.A. (1974) Effect of the form of a deposit on the activity of barban applied to Avena fatua L. Weed Research, 14, 13-18.

MERRITT, C.R. and TAYLOR, W.A. (1977) Glasshouse trials with controlled drop application of some foliage-applied herbicides. Weed Research, 17, 241-245.

SHAFER, N.E. (1974) Difenzoquat, a new post-emergence wild oat herbicide for wheat and barley. Proceedings, 12th British Weed Control Conference, 2, 831-838.

WILSON, B.J. (1976) Control of Avena fatua in spring barley by controlled drop application: comparisons of the activity of two herbicides at three doses and four volume rates. Proceedings, 1976 British Crop Protection Conference - Weeds, 3, 905-914.

ZADOKS, J.C., CHANG, T.T. and KONZAK, C.F. (1974) A decimal code for the growth stages of cereals. Weed Research, 14, 415-421.

ZASKE, J. (1970) Determination and assessment of drop size spectra for plant protection nozzles. NachrBl. dt. PflSchutzdienst., Stuttg. 22, 17-24.

Acknowledgements

The authors thank Mr I Clipsham for assistance with the experimental work and Messrs C Marshall and B Bartlett for help with the statistical analysis.

Table 1 **Retention of 0.5% Agral solution in two drop sizes applied at 25 l/ha to Avena fatua with 3 leaves and 2 small tillers**

	Drop size, µm		S.E.
	200	300	
µl/plant	3.30	4.07	± 0.361
µl/g Dry weight	80.5	82.4	± 5.44

Table 2 **Retention of 0.5% Agral solution in three drop sizes applied at 20 l/ha to Avena fatua with 3-4 leaves and 2 tillers**

	Drop size, µm			S.E.
	150	250	350	
µl/plant	15.8	17.0	16.3	± 0.81
µl/g Dry weight	126	137	120	± 5.4

Fig. 1 Retention in µl/g Dry weight for three drop sizes at a range of volume rates. Growth stage of *Avena fatua* - 4 leaves.

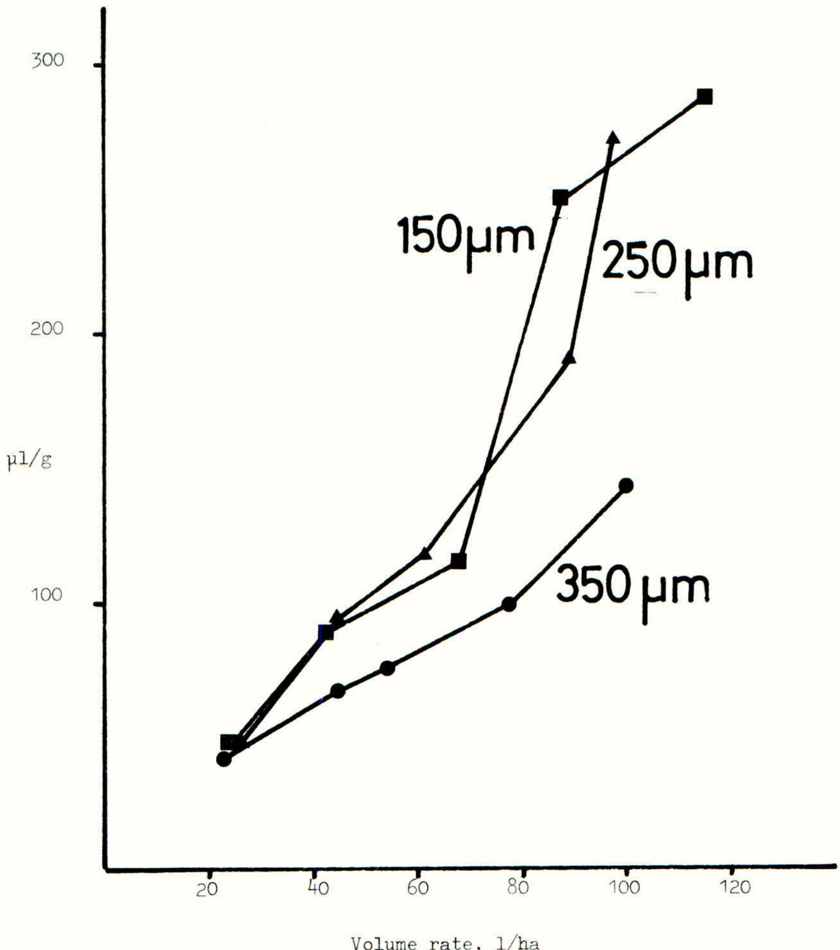
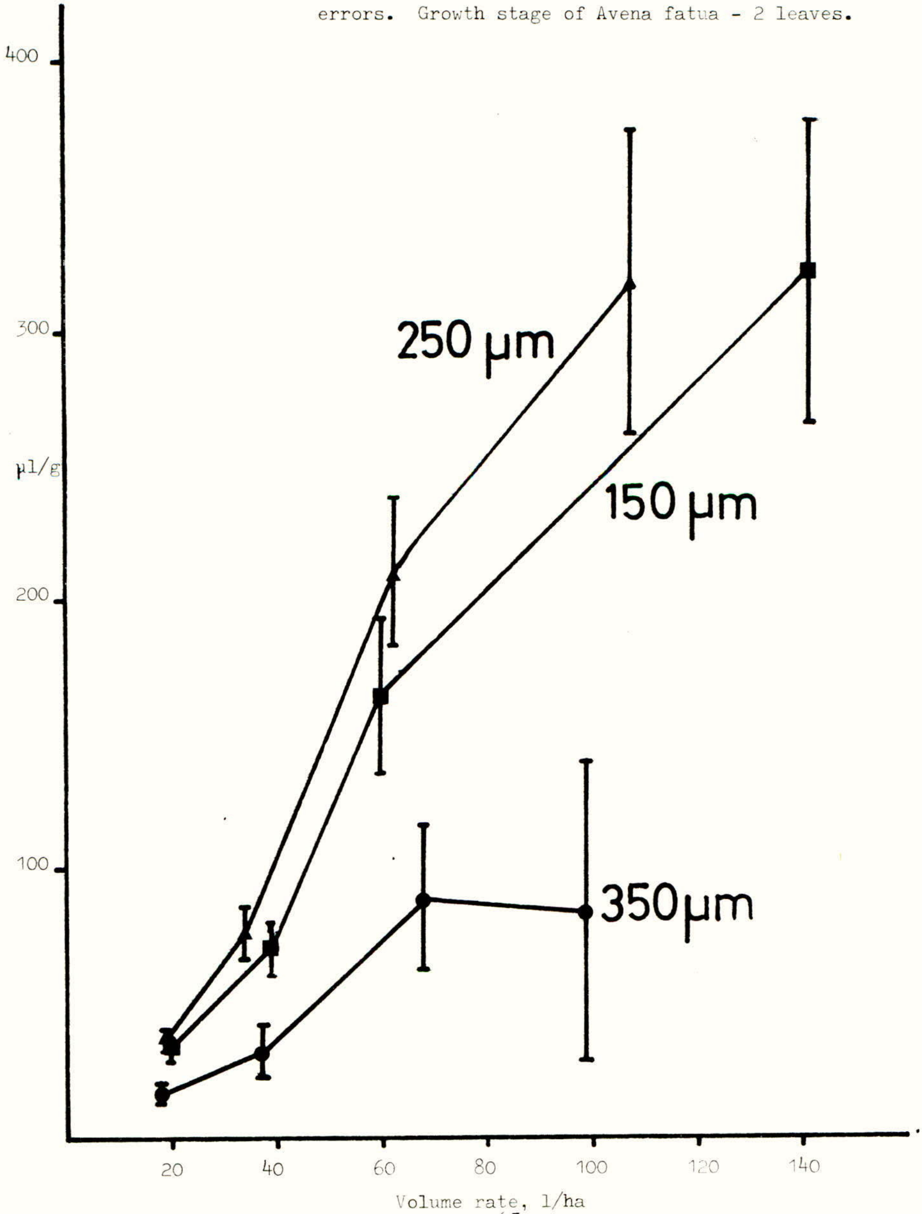


Fig. 2. Retention in µl/g dry weight for three drop sizes at a range of volume rates, with standard errors. Growth stage of Avena fatua - 2 leaves.



NOTES

THE EFFECT OF WIND TURBULENCE AND CROP CHARACTERISTICS ON THE DISPERSAL OF AERIAL SPRAYS

T. J. Lawson & S. Uk

CIBA-GEIGY, Agricultural Aviation Research Unit,
c/o Cranfield Institute of Technology,
Bedford, England

Summary The results are presented from ULV aerial spray field trials designed to measure how the total amount of airborne spray varies with spray release height, drop size, downwind distance, turbulent airflow conditions and the type of underlying surface. It was found that due to aircraft wake effects, flying very close to the ground did not reduce the airborne drift of drops in the range 10 to 64 µm compared with flying at 5 m. The underlying surface exerted an important influence on the removal of airborne drops. A mature wheat crop was about 70% more efficient in removing 50 µm drops than was a ploughed fallow field. For 150 µm drops this fell to about 20%. At distances away from the influence of the aircraft wake, a theoretical model gave adequate predictions of the variation of drop dispersal with turbulence, provided that the lowering of the effective spray release height by the aircraft wake was considered.

INTRODUCTION

Increasing evidence from a variety of sources (e.g. Himel, 1969, Uk, 1977; Lake 1977) shows that improved drop retention on the crop target is obtained when the drop diameter is smaller than 100 µm. Although the question of spray drift out of a field has always been a problem with LV and HV applications, the use of sub-100 µm drops reinforces the need for further understanding of drift and its relation to such factors as wind speed, spray release height and crop characteristics.

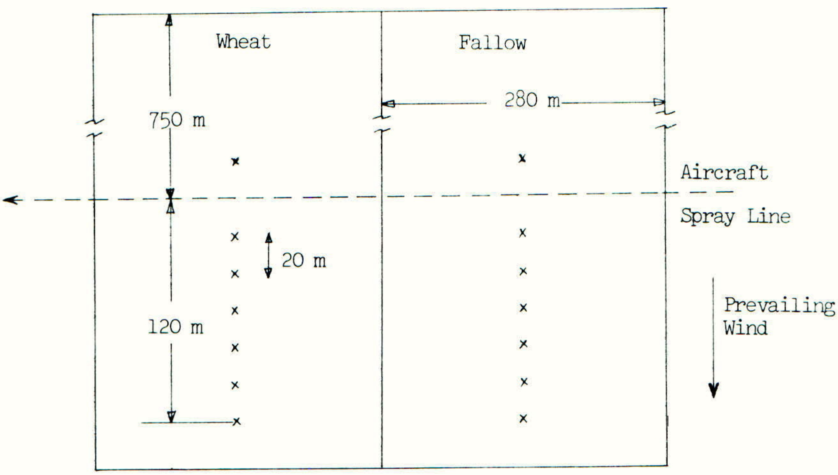
Most approaches to assess spray drift from aerial applications have involved ground level measurements of spray deposits at various distances downwind from the sprayed field (e.g. Akesson & Yates, 1974; Yates, et al, 1974; Yeo & Thompson, 1954). Measurements have either been made on artificial collecting surfaces to yield drop size and number, or on natural surfaces in which case only chemical quantity is obtained. In both cases with only measurements near ground level it can be difficult to interpret the results to establish the effect of the crop on removing drops of different sizes in different meteorological conditions. This paper describes experiments designed to measure the total quantity and spectrum of spray remaining airborne up to 120 m downwind from a single spray line, and to see how this airborne drift varies with meteorological conditions, spray release height and the nature of the underlying crop surface. In order to maximise the different effects between crop surfaces, experiments were carried out over both wheat and fallow fields.

METHODS AND MATERIALS

The experiments were conducted in the Sudan Gezira - a large irrigated area adjacent to the Blue Nile, with a regular layout of rectangular fields each approximately 1300 m by 280 m (90 acres). Two adjacent fields were selected with their long axis aligned parallel to the prevailing wind direction of 020°. One field contained wheat (variety Giza 155) to a height of approximately 0.6 m, while the other was fallow, with ploughed furrows 0.25 m deep (peak-to-trough) aligned cross-wind.

One set of sampling poles was erected in each field, with an upwind fetch of 750 m. The poles were 13 m high and spaced at 20 m intervals downwind to a maximum of 120 m (Figure 1). The aircraft spray line was perpendicular to the sampling line, and 20 m upwind of the first pole. A further pole was erected 20 m upwind of the spray line. Spray was sampled on vertical cylinders 2 cm in diameter and 20 cm long on which was wrapped spray sensitive paper(i). A chain of seven such cylinders, regularly spaced every 2 m, hung from each pole.

Figure 1. Spray Sampling Layout



The spray liquid was Dimecron ULVAIR 250 (a low volatility CIBA-GEIGY formulation containing 25% phosphamidon) with 0.5% w/v of fluorescent tracer(ii) added to increase drop visibility. Drops were counted and sized under UV light using a microscope attached to a Fleming Particle Analyser. To avoid cylinder edge effects, only drops within a 1 cm central band were analysed. True drop diameters were obtained from stain diameters using spread factors determined under field conditions.

Wind and temperature profiles were derived from a 7.5 m mast instrumented at six levels with miniature cup anemometers and thermistor probes. Wind speeds at the

---

(i) Type HN 380, Reed Charts Limited, Clydevale, London

(ii) Neon Red M.F. or Saturn Yellow M.F., Swada (London) Limited spray sampling heights were calculated using the log-linear profile (e.g. Webb, 1970) and an assumed zero-plane displacement of 0.7 x crop height. These wind speeds were used to apply corrections to the spray samples to allow for the collection efficiency of the cylinders (May & Clifford, 1967). In order to characterise the airflow two further parameters were calculated, namely the friction velocity, u_*, and the Richardson Number. The friction velocity is a measure of the strength of the turbulent eddies within the mean airflow, while the Richardson Number indicates the thermal stability. All meteorological parameters were derived separately for the wheat and fallow fields.

The spray was released from a single Micronair AU 3000 fitted to a Pilatus Turbo-Porter. With an impeller angle of 45^o, aircraft speed of 48 ms^{-1} (95 kts) and liquid flowrate of 7 l min^{-1}, the Micronair was rotating at about 4000 rev/min while emitting spray either 1.5 m or 5 m above the underlying surface.

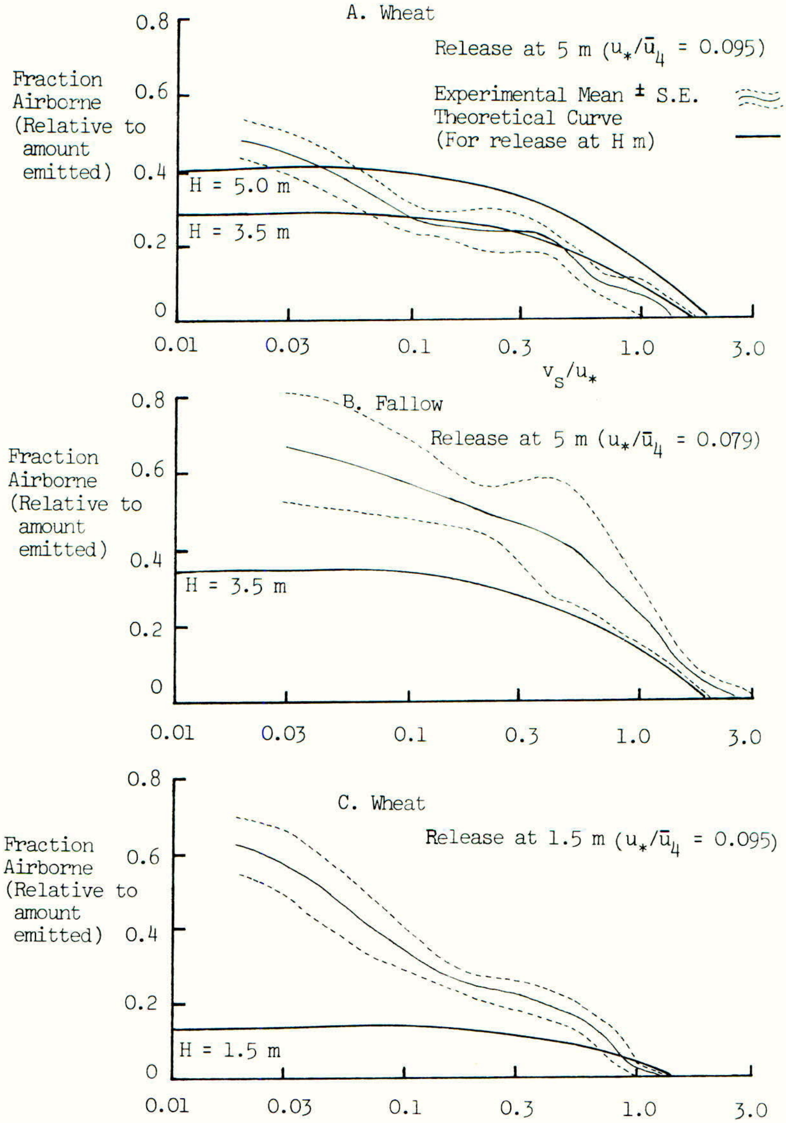
The drop spectrum was measured from the deposits on the first downwind pole, when it was known that no spray had reached the ground in the intervening distance. The mean spectrum from 10 trials had a VMD of 104 $\pm$ 3 (S.E.) μm. The spectrum was divided into five size classes based on the $\sqrt{2}$ progression covering the range 10 μm to 230 μm, and the amount of chemical in a given size class passing each pole was calculated relative to the amount of chemical emitted in that class by integrating over the seven sampling heights. At each flying height in neutral conditions, a total of 17 experiments was carried out over wheat and 8 experiments over fallow, i.e. a total of 50 experiments.

RESULTS

The upper boundary of the spray cloud increased as it drifted until at 120 m it was just grazing the topmost sampling point. Thus it could be assumed that all the airborne fraction of the cloud was being sampled. The volume of airborne spray in each drop size class as a fraction of the volume emitted in that class was plotted against the ratio of the mean sedimentation velocity, v_s, of the size class to the friction velocity u_*. This produced graphs similar to Figure 2A, which shows the airborne fraction at 120 m downwind over wheat in neutral conditions for a spray release height of 5 m. The ratio v_s/u_* was chosen for the abscissa as it indicates the relative importance on spray dispersal of gravitational settling compared with turbulent dispersal. In neutral conditions over wheat, u_* was related to the mean wind speed, $\bar{u}$, at 4 m by $u_* = 0.097\ \bar{u}_4$. Thus for example, from Figure 2, it was found that in a wind of 3 ms^{-1} ($u_* \approx 0.3$ ms^{-1}) roughly 25% of drops of 45 μm diameter (v_s = 0.06 ms^{-1}, v_s/u_* = 0.2) remained airborne at 120m.

Also shown in Figure 2A is the theoretical prediction of the airborne fraction for a release height of 5 m derived from the model of spray dispersal by Bache & Sayer (1975). Although the model assumes 100% retention of all drops reaching the surface, it still predicts a larger airborne fraction than that observed, and thus there must be other factors that act to reduce the airborne fraction below this theoretical minimum. It is likely that such factors are connected with the aircraft wake effect, which lowers the effective spray release height (Smith, 1972; Trayford & Welch, 1972). Reducing the release height to 3.5 m would bring close agreement between theory and experiment for $v_s/u_* > 0.05$. Visual observation of the spray cloud leaving the atomiser shows that it loses height rapidly within several aircraft lengths.

Figure 2. Fraction airborne after 120 m over various surfaces in near neutral stability (wind speeds 2 - 7 ms^{-1})



For smaller drops with $v_s/u_* < 0.05$ (i.e. drops < 30 μm in a wind of 5 ms^{-1}), the airborne fraction was above that predicted. The movement of drops with v_s/u_* < 0.3 is determined almost completely by the turbulent airflow, and thus they are brought down to the surface with equal efficiency. However, the lower collection efficiency of the smaller drops by the underlying surface leads to their having larger airborne fractions than predicted by the theory which assumes perfect removal at the surface. It would appear that drops > 40 μm ($v_s/u_* > 0.1$ in a wind of 5 ms^{-1}) were removed from the airflow by the wheat field with nearly 100% efficiency, but that for drops of 20 μm the removal efficiency fell to about 75%. It should be emphasised that this refers to the bulk removal efficiency of both the crop and ground surface as a whole, and does not imply anything about the collection efficiency of individual foliage elements.

The effect of spray dispersal in neutral conditions over fallow ground is shown in Figure 2B. Here, the lower surface roughness resulted in the friction velocity being a smaller fraction of the wind speed ($u_* = 0.079\ \bar{u}_4$) than over wheat. The airborne fraction was more than that predicted by theory using an effective release height of 3.5 m for all drop sizes, indicating a removal efficiency of less than 100%. Table 1 contrasts the removal efficiencies of wheat and fallow fields for different drop sizes, based on the assumption that the efficiency of wheat is 100% for droplets of 40 μm and larger.

Table 1

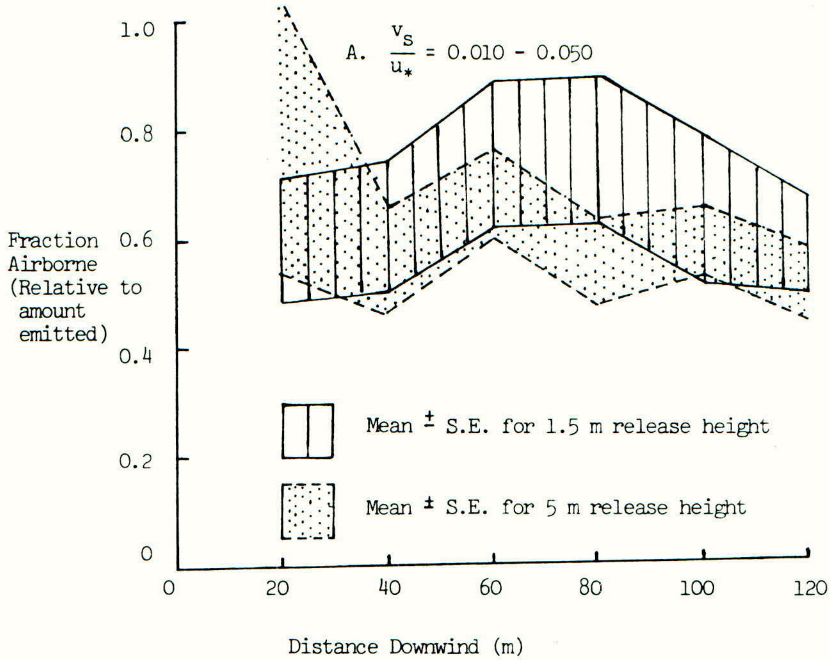
Bulk removal efficiencies of wheat and fallow fields for various drop sizes (wind speeds 2-7 ms^{-1})

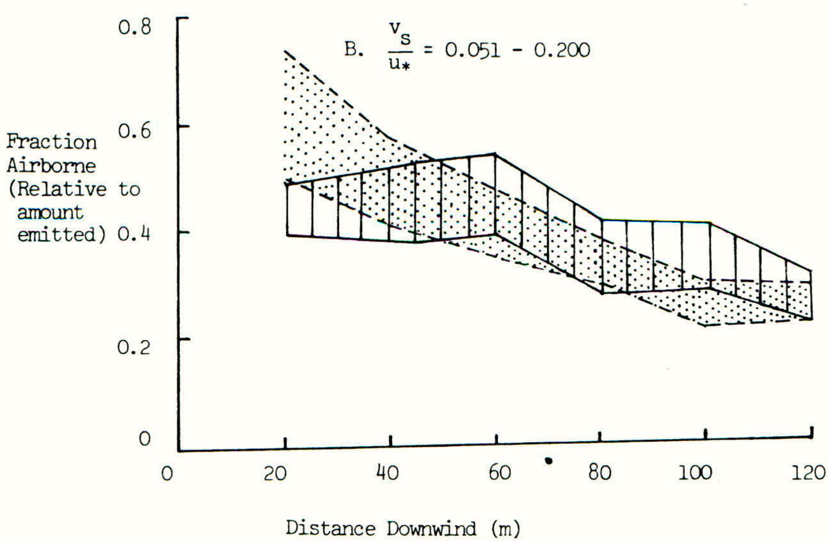
Drop diameter (μm)	Wheat (%)	Fallow (%)
20	75	43
50	100	60
90	100	69
150	100	84

The relation between spray removal and flying height is illustrated with reference to Figure 2C which shows the airborne fraction for a spray release height of 1.5 m. In other respects the experimental conditions were similar to Figure 2A. The airborne fraction of 120 m downwind is several times greater than the theoretical prediction for all drops except those where gravitational settling is beginning to dominate turbulent dispersal.

The effect of spray release height is further illustrated in Figure 3, which presents the airborne fraction at all downwind distances from the spray line for two categories of v_s/u_*. In the typical wind speeds encountered during the experiments these correspond to two drop size classes (10-32 μm) and (32-64 μm). It is clear that for these drop sizes, the airborne fraction of spray passing above a given downwind point is not reduced by flying very close to the ground. This is due to the ground effect on the aircraft wake which acts to raise the effective release height of these small drops (Smith, 1972 and Trayford & Welch, 1972).

Figure 3. Fraction airborne against distance downwind from spray line for two categories of v_s/u_*





Despite the size of the standard errors in Figure 3, it would appear that the measured airborne fraction tended to increase up to 40 m downwind for drops in both size classes, when the aircraft was flying close to the ground. If this effect is real, it may be due to a reduction in the spray collection efficiency of the sampling cylinders. One possibility is that the airflow was not perpendicular to the cylinders, thus leading to an increase in the effective sampling area and hence a decrease in the deposit per unit area. An airflow incidence angle of 45° would lead to a true deposit density over 40% greater than that measured. It is possible that the ground/wake interaction could lead to spray travelling at such angles, and that the effect would be most marked with the aircraft close to the ground.

DISCUSSION

Data has been presented on the fraction of an aerial spray that remains airborne at downwind distances up to 120 m as a function of the drop size, the level of turbulence and the characteristics of the underlying surface. The difference in the airborne fraction obtained over wheat and fallow surfaces emphasises the point that in order to make a realistic assessment of the likely loss of spray from a particular field, measurements must be made over a field containing the crop of interest. Due to the fact that it had been recently ploughed and the soil was loosely piled, the fallow field probably had higher removal efficiencies than many surfaces over which drift assessments are often made (airstrip runways, deserts, etc.).

It is generally considered that loss of spray from a field is reduced by flying lower. Although this is true in general, it does not hold when the aircraft is flying very close to the ground. In these circumstances the interaction of the contra-rotating wing tip vortices with the ground causes the aircraft wake to rise. This is in contrast to flying 5 m above the ground where the initial movement of the wake is towards the ground. It appears that, at least for a high wing aircraft, no advantages in terms of the reduction of airborne drift of drops from 10-64 μm are derived by flying closer than several metres to the ground.

The relation between wind speed and airborne drift is illustrated in Figure 2A. For a given drop size with a 100% removal efficiency, there will be no drops remaining airborne beyond 120 m if v_s/u_* is greater than about 1.5. As the wind speed increases (v_s/u_* decreases), so the airborne fraction increases until when $v_s/u_* \approx 0.3$, it levels out at about 0.25. Any further increase in wind speed would cause only a slight rise in the airborne fraction, as indicated by the theoretical curve. (N.B. The rise in the experimental curve for $v_s/u_* \leq 0.1$ is due to a drop in the removal efficiency of the small drops). Thus for 50 μm drops with $v_s = 0.07$ ms^{-1}, very little increase in airborne drift occurs for an increase in wind speed above about 2 ms^{-1} ($u_* \approx 0.2$ ms^{-1}).

The development of theoretical models of spray dispersal requires a realistic treatment of the interaction of drops with the underlying surface. In the standard Gaussian plume approach, this is usually handled by assuming 100% removal of the plume as it reaches the underlying surface, although recently, Dumbauld et al (1976) have introduced drop size dependant removal efficiencies into their model. An assumption of 100% removal appears reasonable for drops larger than about 50 μm dispersing over a mature wheat crop. However, measurements of removal efficiencies that are more sensitive to drop size, surface type and wind speed are clearly required.

Acknowledgements

The authors wish to thank all members of the CIBA-GEIGY Sudan Project Team especially the Aviation Group for their help during the one-month experiment. Thanks are also due to the Sudan Gezira Board for providing fields for the trials. We are indebted to CIBA-GEIGY Limited for permission to publish this work.

References

AKESSON, N. B. & YATES, W. E. (1974) The use of aircraft in agriculture, F. A. O. Rome, 92 - 98

BACHE, D. H. & SAYER, W. J. D. (1975) Transport of aerial spray, I. A model of aerial dispersion, Agricultural Meteorology, 15, 257 - 271

DUMBAULD, R. K. et al (1976) Dispersion - deposition from aerial spray release, Third symposium on atmospheric turbulence, diffusion and air quality, American Meteorological Society, Boston, Massachusetts

HIMEL, C. M. (1969) The optimum size for insecticide spray droplets, Journal of Economic Entomology, 62, (4), 919 - 925

LAKE, J. R. (1977) The effect of drop size and velocity on the performance of agricultural sprays, Pesticide Science, 8, 512 - 520

MAY, K. R. & CLIFFORD, R. (1967) The impaction of aerosol particles on cylinders, spheres, ribbons and discs, Annals of occupational hygiene, 10, 83 - 95

SMITH, M. R. (1972) Agricultural Research at Mississippi State, University Progress Report, Mississippi State University, State College, Mississippi

TRAYFORD, R. S. & WELCH, L. W. (1972) The simulation of aerial spray trajectories, CSIRO Division of Mechanical Engineering Internal Report No. 110

UK, S. (1977) Tracing insecticide spray droplets by sizes on natural surfaces. The state of the art and its value, Pesticide Science, 8, 501 - 509

WEBB, E. K. (1970) Profile relationships: the log-linear range and extension to strong stability, Quarterly Journal of the Royal Meteorological Society, 96, 67 - 90

YATES, W. E. et al (1974) Criteria for minimising drift residues on crops downwind from aerial applications, Transaction of the American Society of Agricultural Engineers, 17 (4), 627 - 632

YEO, D. & THOMPSON, B. W. (1954) Aircraft applications of insecticides in East Africa. V The deposition in open country of a coarse aerosol released from an aircraft, Bulletin of Entomological Research, 45 (1), 79 - 92