THE CENTRE FOR PESTICIDE APPLICATION AND SAFETY

Assessment of Endosulfan EC based on new risk assessment criteria for Endosulfan ULV

Project 1100/588

THE UNIVERSITY OF QUEENSLAND
GATTON COLLEGE

THE CENTRE FOR PESTICIDE APPLICATION & SAFETY (C-PAS)
School of Agriculture and Horticulture
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A report compiled on behalf of

The Cotton Research and Development Corporation (CRDC)

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The Centre for Pesticide Application and Safety is a national scientific research and training group that provides a wide range of research and consultancy services to industry and government in pesticide application technology

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EXECUTIVE SUMMARY

This report examines available deposition data and assesses the performance of two mathematical models in predicting the relative drift profile of ULV and EC formulations of endosulfan as used in the Australian cotton industry.

Results from algorithms should always be interpreted with care, particularly in the absence of reliable field data, however the findings from the study allow important observations to be made:

- If very small droplets are applied, (eg ULV with VMD of 67 µm) and very low downwind thresholds are required (eg. 0.05% applied rate), significant down wind buffers distances have to be establish within and around crops. Although the size of these areas increases with field source width, greater flexibility in spray drift management (eg in selecting wind direction) can sometimes be conferred as farm size increases.

- Downwind buffer distances can be substantially reduced if droplet size is increased. Assuming a threshold of 0.05% applied rate off target is required, a Gaussian model predicts that buffer distances can be reduced from approximately 2920m, to 600m when ULV (VMD 67µm) is compared to a LDP (VMD 332µm) aerial application. The AgDRIFT model predicts that 0.05% of the applied rate can be contained using a buffer distance of only 428m when an LDP VMD of 332µm is selected.

- When the influence of droplet evaporation is taken in to account, the AgDRIFT model suggests that a water based LV application (eg VMD 162µm at 20 L/ha) can generate significantly greater spray drift than ULV application ULV (VMD 162µm at 3 L/ha)

- Buffer distances could be reduced even further if narrower droplet spectra could be produced at the nozzle and lower release heights adopted, (eg helicopter application).

- Data presented in this report shows that the droplet size generated by an aircraft is highly dependent upon the airspeed surrounding the nozzle. If an aircraft is operated at too high an airspeed for a given hydraulic nozzle type or setting, the potential for spray drift is greatly increased.

- Using existing technology, it is important that aircraft are configured very accurately for operations in cotton growing areas.

- Significant potential exists to utilise the advantages of aerial application if the droplet production process can be refined and spectra narrowed.

- The development of alternative, improved nozzle systems should be supported.

INTRODUCTION

Agricultural aircraft are of great importance to the Australian cotton industry. Specialised aircraft are used to apply selected herbicides and fertilisers prior to planting, insecticides throughout the growing season and defoliants prior to harvest. The use of agricultural aircraft has developed largely as a result of the greater speed, better timing and efficiency of application offered by aerial distribution. Aircraft are able to apply agricultural products rapidly over large areas within narrow optimum application windows. When crop height and irrigated areas restrict the passage of wheeled vehicles, aircraft are able to place pesticides strategically on crops in response to economic thresholds, without contributing to soil compaction and breakdown.

Ultra Low Volume (ULV) application from the air has been used very successfully around the world for nearly three decades. The technique is used to effectively apply insecticides in a range of crops including cotton, field crops and forestry. ULV pesticides formulated in low-volatile oil-based carriers are usually applied 'straight from the can' at total application rates of about 2–5 L/ha. This low rate of carrier is achieved by generating small droplets with a Volume Median Diameter (VMD) of approximately 50–100 μm, usually using rotary cage type atomisers. Such droplet sizes allow large numbers of droplets to be generated resulting in high droplet coverage (expressed in terms of droplet number per square cm) and high efficacy and productivity. This technology is particularly suited to the control of airborne pests (such as locusts and mosquitoes), forestry and broad-acre agriculture. ULV technology has been successfully utilised in the production of cotton in Africa, Asia and Australia.

Restrictions to the application of endosulfan in cotton were implemented by the National Registration Authority for Agricultural and Veterinary Chemicals, (NRA) during 1999. In particular, mandatory buffer distances and nozzle configurations were introduced. Despite the widespread adoption of these management tools and a successful season where an extensive monitoring of 14,000 beef carcases revealed only one carcase that exceeded the ½ MRL export endosulfan level, further restrictions were imposed during July 2000. It is noted that low pest pressure and the low use of endosulfan products may have contributed to this finding.

The new rules for the 2000/2001 season suspended the registration of the ULV formulation of endosulfan but permitted application of existing stocks provided that:

- The protection downwind buffer zone was doubled from 1500 metres to 3000 metres; and
- the maximum allowed rotational speed of Micronair AU5000 nozzles was reduced from 4000 to 2000 rpm.

Based upon data compiled during recent public domain studies undertaken on behalf of the Land & Water Resources Research & Development Corporation (LWRRDC) and the Cotton Research & Development Corporation (CRDC), this report comments on the current practice of establishing down wind buffer distances and nozzle criteria for the aerial application of ULV and EC endosulfan products. The report examines available deposition data and assesses the performance of two mathematical models in predicting the relative drift profile of ULV and EC formulations of endosulfan.

Background

Field Deposition Studies

The off target transport of droplets resulting from the commercial application of endosulfan was monitored during the 1993 to 1998 Australian cotton seasons (Woods, *et al* 1998a). In crop deposition characteristics were assessed by sampling leaves from top, mid and low positions on the cotton plant. Ground deposition was assessed using 1m long chromatography paper covered rulers placed perpendicular to, and alternately half in and half out of the row. Off target transport of droplets was measured using an array of collection surfaces consisting of chromatography paper placed upon horizontal flat plates (usually at 1m height above ground, vertically orientated pipe cleaners and cotton string suspended from 20 metre high towers (Woods, *et al* 2000a). Applications of both endosulfan ULV (applied at a rate of 3 L/ha using Micronair AU5000 equipment), and endosulfan EC (generally applied at a rate of 2.1 L/ha in 30L/ha using CP hydraulic nozzles) were assessed. Endosulfan residue samples were quantified using an ELISA immuno-assay technique developed by CSIRO and the University of Sydney (Lee *et al* 1997, Kennedy *et al* 1998). In addition, some collection devices were analysed by the NSW Agriculture Chemical Residue Laboratory using high performance gas chromatography (GC).

Actual off-target deposition profiles obtained on paper covered flat plates placed 1 metre above the ground and downwind of the field during the monitoring of the commercial field trials are presented in Figures 1 and 2. The data shows the combined results from a number of different trials carried out during the period 1993-98. The data shows the decline in deposit with distance from the edge of the sprayed area when ULV and LV techniques were used. Some data points were corrected to account for variation in wind direction. A high degree of variation in off target deposition values was observed between the trials, which is indicative of the range of meteorological and operating conditions observed. With a coarse average taken across all trials, mean off target deposition values (in g/m^2) at a downwind distance of 500m fell to approximately 2% and 1% of the field applied rate for ULV and LV applications respectively.

Normalising mean figures to a 500m wide field, deposition upon cotton leaves was approximately 60% and 50% for ULV and LV application respectively. Ground deposition was notably higher at approximately 45% for the LV spray compared to 25% for the ULV spray. Of the total amount released per unit crosswind distance over a 500m wide field source width (in g/m), approximately 14% moved across the downwind edge of the field, with approximately half of this depositing within the first 500m downwind. With LV application, this figure was approximately 7%, with most of this (5%) depositing within the first 500m.

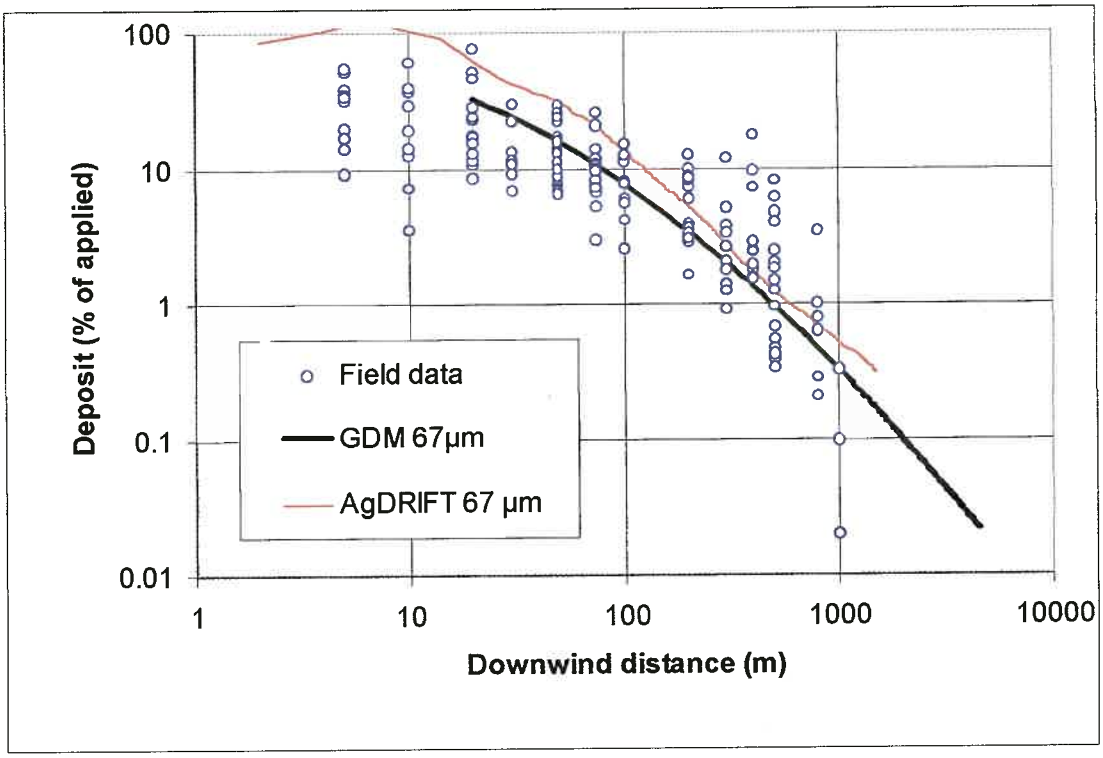


Figure 1. Downwind deposition values obtained on horizontal flat plates for ULV application. Data compared against Gaussian diffusion (GDM) and AgDRIFT ® model outputs.

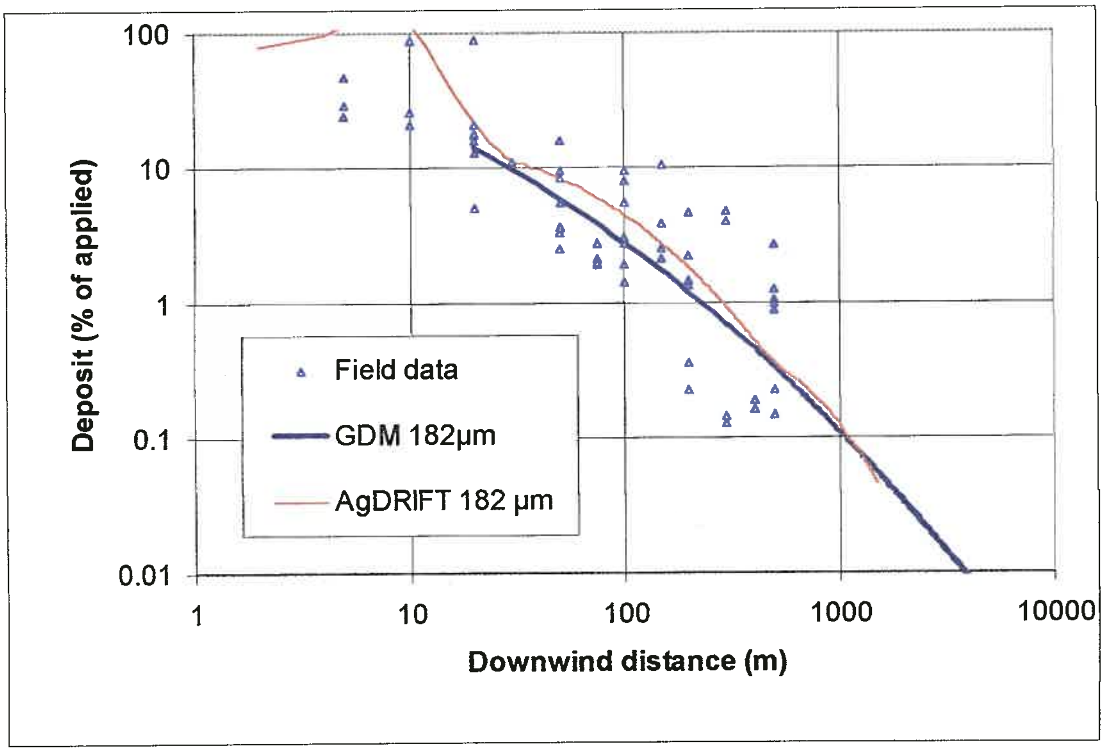


Figure 2. Downwind deposition values obtained on horizontal flat plates for LV application. Data compared against Gaussian diffusion (GDM) and AgDRIFT ® model outputs.

Computer Models

The droplet transportation process can be simulated using a number of mathematical techniques. Three primary methods are employed by researchers, namely Gaussian dispersion theory, Lagrangian wake theory and random walk modelling. The former two approaches have been widely used to simulate the aerial application of pesticides.

Diffusion Models

Diffusion models consider particle assemblies and are thus useful for calculating the environmental impact of pesticide sprays. The Centre for Pesticide Application & Safety has over a number of years reviewed and researched the use of Gaussian diffusion models for spray drift prediction and compared the results with Australian and overseas databases.

When using a diffusion model, a sprayer is assumed to produce an instantaneous line source of droplets as the time taken to release the spray is short compared to the time scale of the atmospheric turbulence that affects the spray dispersal. The cloud of droplets released from such a line source is subject to a number of influences (Lawson, 1989).

1. **Diffusion**. The action of turbulence causes the droplets to move upwards, downwards, forwards and backwards. This increases the vertical and horizontal dimensions of the spray cloud and results in a corresponding decrease in the maximum droplet concentration. It is usual to assume that the concentration of droplets within the cloud follows a Gaussian distribution with standard deviations in the downwind (x) and vertical (z) direction.
2. **Wind**. The spray cloud moves in the direction of the prevailing wind.
3. **Sedimentation**. This is due to droplet mass and causes downwind movement only. This results in a reduction in the height of maximum concentration (initially the release height).
4. **Deposition**. Droplets are removed from the cloud at the crop or ground surface. The transport of droplets into the crop is the sum of the turbulent impaction and sedimentation process.

A downwind moving, sedimenting, diffusing, Gaussian cloud is shown schematically in Figure 3.

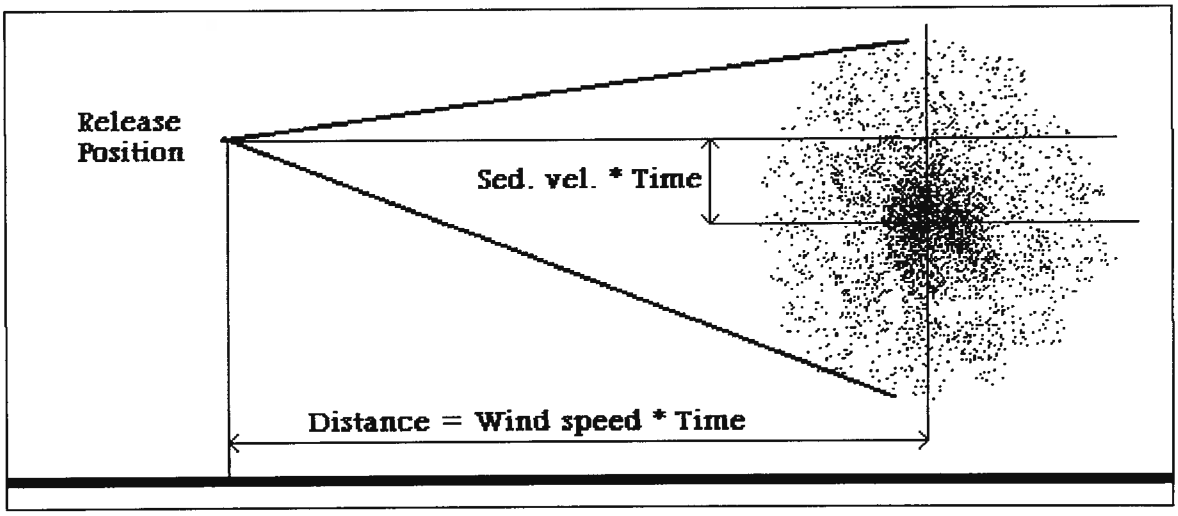


Figure 3. Turbulent dispersal of a spray cloud with a Gaussian concentration distribution (after Lawson, 1989)

Turbulence

Atmospheric turbulence has a significant influence on droplet movement modelled using Gaussian plume equations. Atmospheric turbulence can develop over a crop as a result of the thermal (upward) movement of warm air or the mechanical movement of wind across the ground. A wind or breeze travelling close to the surface of the earth rarely has a smooth flow. Instead the atmosphere is characterised by the turbulent motion of air produced, in part, by the movement of air layers against each other and by frictional losses of energy at the earth's surface. The extent of this turbulence is also determined by the 'roughness' of the surface. For example, a stand of trees or a tall crop would generate greater turbulence for a given wind speed than an area of mown grass. Turbulence intensity, i, may be defined as U*/U where U* is the RMS (root mean square) of the vertical motion of air and U is the mean wind speed.

Turbulence intensity controls the dispersion rate of the spray cloud. It is affected by a combination of lapse dependent stability and mechanical turbulence generated by ground obstacles. Values are approximately 0.1 over most agricultural crops in neutral conditions, but can be less than 0.05 over bare ground in stable conditions and may rise to 0.15 or 0.2 over forest in unstable conditions (Pasquill, 1983). With increasing turbulence intensity, the peak deposit is higher and closer to the source. Far downwind deposition levels, however, are higher at low turbulence intensities. This highlights the dangers of spraying with small droplets in stable conditions. Turbulence however has little effect on large droplet deposition.

The distance to peak deposition may be roughly correlated with HU/U* for small droplets and HU/Vs for large droplets where H is the release height of the spray, U is the mean wind speed and Vs is the sedimentation velocity of the droplet. Table 1 illustrates the importance of turbulence in the transmission of droplets, particularly small droplets. If the effect of turbulence is taken into account (as described by a Gaussian settling plume model (eg. Bache & Sayer, 1975) the dispersive nature of turbulent (mechanically generated) airflow can be shown to bring the peak deposit of sprays down to the ground very rapidly. Unfortunately, the expansive nature of turbulent flow also tends to disperse a low concentration of very small droplets into the atmosphere and at extended distances downwind.

Droplet diameter (μm)	**Wind speed U = 1 m/s**		**Wind speed U = 4 m/s**	
	(S)	**(S+T)**	**(S)**	**(S+T)**
10	166.66m	3.49m	666m	3.52m
25	26.31m	3.31m	105m	3.47m
50	6.94m	2.74m	27.77m	3.31m
100	2.00m	1.59m	8.00m	2.84m
150	1.09m	1.00m	4.35m	2.38m
200	0.71m	0.69m	2.86m	1.97m
300	0.43m	0.43m	1.74m	1.45m
500	0.25m	0.25m	1.00m	0.93m
1000	0.13m	0.14m	0.52m	0.51m

Table 1. Comparison between drift models. The numbers indicate the distance to peak deposition for is sedimentation only (S) and sedimentation plus turbulence (S+T) (Gaussian diffusion model).

Limitations

The Gaussian model does not allow for reduction in droplet size caused by evaporation. Such models are therefore most appropriate for the application of low volatile formulations such as ULV insecticides. Gaussian diffusion models do not incorporate near wake effects caused by airflow around an aircraft or applicator, (Craig.; Woods.; & Dorr, 1998).

FSCBG

In the early 1970's the United States Department of Agriculture (USDA) Forest Service supported development work to adapt a simplified aerial line source model for forestry application that had originally been developed for the US army, (Barry and Ekblad, 1983). The modelling efforts resulted in the production of AgDISP (AGricultural DISPersal) and FSCBG (Forest Service Cramer-Barry-Grim) models in the early 1980's. Both have been updated and improved in the subsequent years and currently AgDISP version 6.3 and FSCBG version 4.3 are commercially available and designed to operate on personal computers.

AgDISP includes subroutines for aircraft wake effects (such as wing tip and rotor tip vortices), vortex decay and droplet evaporation (Barry, 1993). Based on a Lagrangian approach to the solution of the released particle equations of motion, simple models are used to calculate the effect of aircraft and ambient turbulence. The motion of a group of similar sized droplets released into the atmosphere from all release points on the aircraft is tracked (Bilanin *et al.*, 1989).

FSCBG incorporates the near wake effects of AGDISP and predicts downwind dispersion. Once the near wake effects have sufficiently decayed a Gaussian diffusion model is used to predict dispersal at long distance from the aircraft (far wake). FSCBG version 4.3 has an additional feature over previous versions that can alter the change over between the near wake and far wake models. It is possible to use either the near wake model or the far wake (Gaussian) model on their own.

Features of FSCBG include; (Barry, 1993):-

- an analytical dispersion model that handles multiple line sources oriented in any direction to the wind,
- an evaporation model that predicts the change in size of falling spray droplets that are either totally volatile or a mixture of volatile and non-volatile components,
- an analytical canopy penetration model that estimates the fraction of droplets intercepted by a forest canopy,
- a simple user interface,
- presentation of graphics for interpretation of results.

Limitations

- The DOS interface is not easy to use.
- Knowledge is needed to adequately meet input requirements
- Depending on computer configurations and input parameters the program can take a long time to run (up to a couple of hours on Pentium computers).

The model has been used for spray prediction particularly in Forestry situations. It has recently been linked to pesticide and efficacy parameters in New Zealand to assist in the determination of buffer distances and pest response.

AgDRIFT

From 1992-1995, the Spray Drift Task Force (SDTF), a consortium of 40 chemical manufacturing companies, (in response to a directive from the US Environmental Protection Agency [EPA]) conducted a series of field and laboratory studies to develop a database and spray drift model to assist in the registration of agrochemicals. Committing some US$20 million to the project, a model was developed to assist regulatory authorities assess off target risks based on realistic input parameters instead of prescriptive threshold values.

The model, termed AgDRIFT was developed from both FSCBG and AgDISP. AgDRIFT is essentially a Windows™ based version of AgDISP. AgDRIFT version 1 is primarily designed as an aerial predictive model for risk assessment purposes.

AgDRIFT has the facility to introduce a pond or wetland at various downwind distances to determine concentration of deposit in water bodies. Latest versions have also included a stream assessment module for certain applications. These assessments include a dilution and mixing effect in the analysis of down wind deposition.

AgDRIFT utilises a three-tier approach. Tier I is designed to "yield conservative exposure estimates for downwind deposition values … as a preliminary screen for aerial, ground and orchard airblast spraying" (Teske *et al.* 1997, 1). Tier II and Tier III permit increasing access to more model details for aerial spraying only. Input data concerning application, meteorology and the environment can be included. As the level increases, the level of input data required increases.

The USDA Forest Service is currently working with the SDTF and EPA to incorporate forestry applications previously encompassed by the FSCBG model (such as contour plots of deposition) into a modified version of AgDRIFT. Versions of AgDRIFT are also being planned for use by aerial operators.

Limitations

AgDRIFT is limited to a maximum downwind distance of to 304m for Tier I and Tier II and 795m for Tier III. The model will still run for maximum downwind distances between 795m and 1615m but gives a warning. Deposits at downwind distances greater 1615m are not possible.

Sensitivity Analysis

The results of a sensitivity analysis using AgDRIFT to assess the effect of windspeed, temperature relative humidity, boom length, aircraft speed, droplet size (using BCPC curves) and flying height are presented in Figure 4. For the sake of completeness, Figure 4 (top right) includes a similar analysis for turbulence intensity using a pure Gaussian Diffusion Model (Craig;, Woods;, Dorr, 1998a&b). Constants used for the analysis are shown in Table 2.

The y-axis for each graph shows the percentage (0-5%) of the applied rate that is deposited 500m downwind of the sprayed area. Trends that increase droplet transport downwind are clearly indicated namely:

- A reduction in droplet size.
- Increasing release height.

- Increasing boom length.
- Increasing aircraft airspeed.
- Increasing wind speed.
- Increasing temperature.
- Decreasing relative humidity.
- Low turbulence intensity.

Table 2. Constants used in AgDRIFT ™ sensitivity analysis

Droplet size	**Medium** **VMD = 216 µm** **Dv 0.1 = 95** **Dv 0.9 = 369**
Material	Water
Windspeed	3 m/s
Direction	-90 deg
Temperature	30° C
Relative Humidity	50 %
Aircraft	AT 502
Aircraft speed	60 m/s (115 knots)
Boom height	3m
No. of flight lines	20
Swath width	25
Surface Roughness	.0075

Comparison of Models with LWRRDC Field Data

Gaussian Diffusion and AgDRIFT computer models (using droplet size data from laser diffraction studies) were compared with the LWRRDC field data, (Figures 1 & 2). Parameters were entered into the models (Table 2) which represented the most typical conditions experienced during the field trial program. Droplet size data was incorporated from the laser diffraction studies. Computer modelling and mass balance mean figures were derived by normalising data to correspond to spray application over a theoretical 500 metre field source width. Some data points were corrected to account for variation in wind direction.

Calculations generated downwind drift profiles which compared favourably with the experimental data. The slight elevation of the AgDRIFT curve at mid-distance (Figure 2) compared to the GDM curve for water based spray drift may be due to the ability of the AgDRIFT model to predict the effect of droplet evaporation. There was however, very good agreement between the models at distances greater than 500m downwind. Some of the data was appreciably (up to 10 times) higher than levels predicted by the models. This may be because some of the trials were carried out in stable or dusk surface temperature inversion atmospheric conditions. Both the models assume a neutral atmosphere (i = 0.1).

Both models have been validated against data by several researchers including Dorr, (1996), Bird, (1996) and Woods,: Craig., & Dorr, (1998).

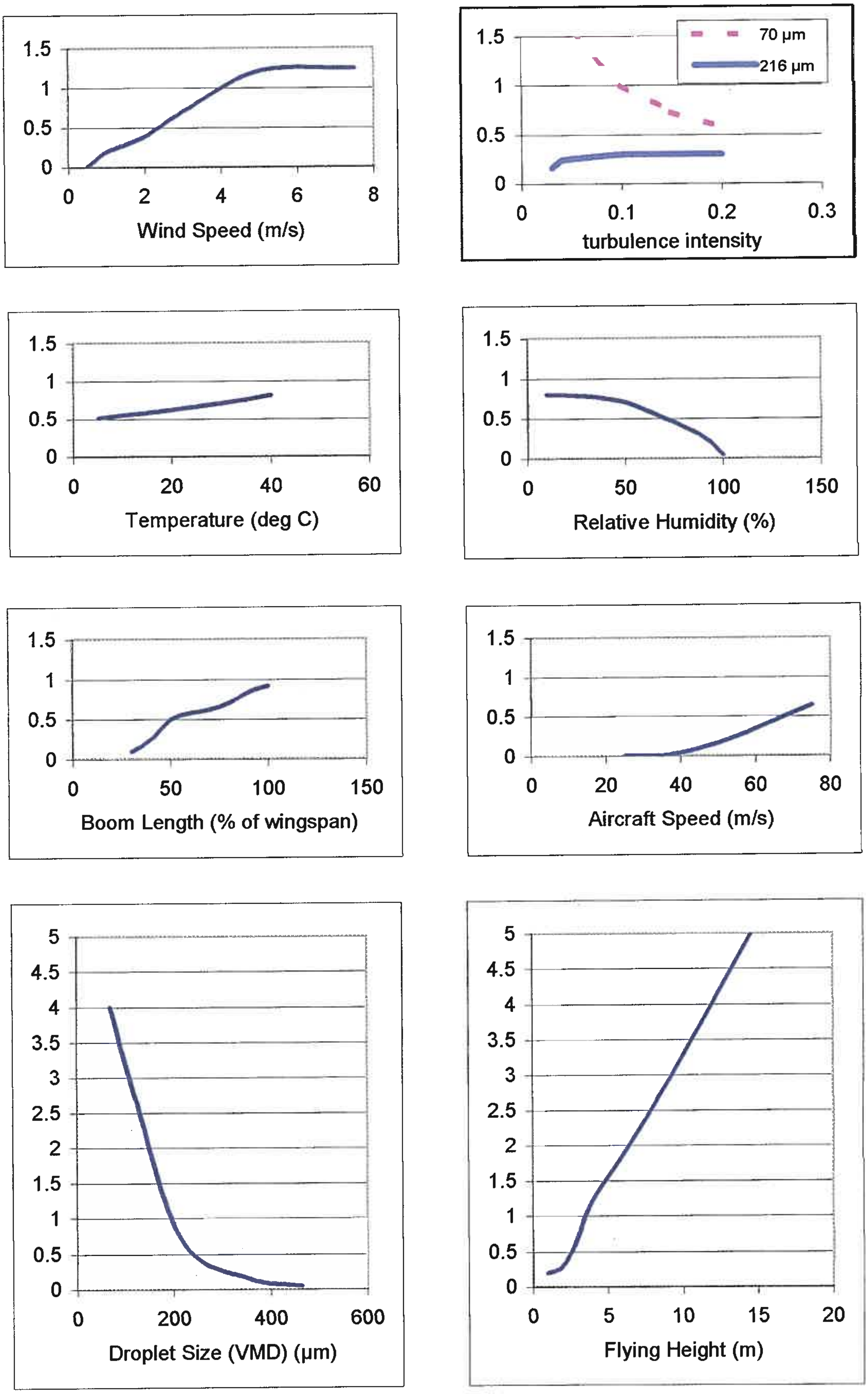


Figure 4. **Summary of application parameters on aircraft spray drift. Drift expressed as percentage of applied rate deposited 500 metres downwind of field. (all apart from turbulence intensity were carried out using AgDRIFT ^{TM}).**

PREVIOUS STUDIES

Downwind Buffers

During 1999, an analysis was conducted on behalf of the NRA to examine the influence of application parameters on the establishment of protective downwind buffer distances for the aerial application of Endosulfan. This work was undertaken under the auspices of CRDC research project UQ23C.

Data from the LWRRDC studies, output from AgDRIFT (v 1.04) and the results from a Gaussian Diffusion model were compared and averaged, (Table 4). A field width of 500 metres was assumed and the downwind threshold of endosulfan set at a value (<0.1% of the applied dose) computed by the University of Sydney to represent a deposit level that would generate residues below the maximum residue limit (< 0.4 ppm). A summary of the analysis is shown below in Table 3

Table 3. Analysis of Buffer Distances for the Aerial Application of Endosulfan – Summary

	Buffer Distances (m) to achieve deposit on pasture < 0.4 ppm			
	low	high	suggested	conservative
ULV	800	1500	1500	3000
LDP	300	1000	750	1500
Ground	150	300	200	400

NB. Pasture levels based on average paddock containing 200g/m² of material.(Uni of Sydney). Spray release height, 3m (aerial) and 0.5 metres (ground) application.

The studies showed that increasing field width increased the downwind deposit. It was also postulated that poor meteorology, eg the presence of stable atmospheric conditions, (therefore reduced turbulence levels), could also change the analysis and lead to higher deposit values. However it was also recognised that appropriate withholding periods could reduce the buffer distances and large droplet sizes (>250 μm) would also significantly reduce the concentration of the downwind off target deposit.

It is noted that the NRA elected to follow the suggested buffer distances of 1500m for ULV, 750m for large droplet application (LDP) and 200m for ground application in cotton.

Field Source Width

During July 2000, in response to a request from the NRA, a further small study was conducted to simulate the effect of increasing field source width and reducing the deposit threshold. For this analysis, computer generated droplet spectra, (not endosulfan wind tunnel data), were used in conjunction with a Gaussian plume model to simulate the effect of increasing field source width. This model was selected so that theoretical deposit data could be generated several kilometres downwind of a source point. No other analytical tools were used.

Results from this study are summarised in Figures 5 and 6.This simple computational analysis shows that, as expected, downwind deposit values increase as droplet size is reduced, field source width is increased and the allowable downwind threshold is reduced. Figure 6 shows that a Gaussian plume model will predict that 0.05% of the applied rate will be deposited 3000meters downwind if a VMD of about 115μm is selected in conjunction with a field source width of 1500 metres. Under the same criteria a 250 μm spectra would require a downwind buffer distance of about 1500-1600 metres.

Table 4. Analysis of Buffer Distances for the Aerial Application of Endosulfan

ULV

downwind distance (m)	Deposit Levels (% applied rate)									
	ULV AU5000 2300 rpm 162µm					ULV AU5000 7000 rpm 67µm				
	Data mean	AgDRIFT mean	GDM mean	avg (%)	pasture ppm	Data mean	AgDRIFT mean	GDM mean	avg (%)	pasture ppm
100		2.23	2.66	2.45	8.80	8.5	12	6	8.83	31.80
200		0.58	1.16	0.87	3.13	5.8	4.5	2.7	4.33	15.60
300		0.27	0.68	0.48	1.71	3.4	2.4	1.6	2.47	8.88
400		0.16	0.45	0.31	1.10	3.3	1.5	1.1	1.97	7.08
500		0.095	0.33	0.21	0.77	2.1	1	0.77	1.29	4.64
600		0.056	0.25	0.15	0.55	1.8	0.67	0.59	1.00	3.61
800		0.023	0.16	0.09	0.33	1.4	0.31	0.38	0.70	2.51
1000		0.014	0.11	0.06	0.22		0.22	0.26	0.24	0.86
1200		0.009	0.08	0.04	0.16		0.14	0.19	0.17	0.59
1500		0.004	0.05	0.03	0.10		0.06	0.13	0.10	0.34
2000			0.03	0.03	0.11			0.079	0.08	0.28
2500			0.02	0.02	0.07			0.053	0.05	0.19
3000			0.01	0.01	0.04			0.037	0.04	0.13

LDP

downwind distance (m)	Deposit Levels (% applied rate)									
	LDP (9510 - 100 knots) 332 µm					LDP (CP coarse - 130 knots) 182 µm				
	Data mean	AgDRIFT mean	GDM mean	avg (%)	pasture ppm	Data mean	AgDRIFT mean	GDM mean	avg (%)	pasture ppm
100		0.6	0.44	0.52	1.91	5.4	4.3	2.2	3.97	14.58
200		0.18	0.19	0.19	0.68	2.6	1.6	1.93	2.04	7.51
300		0.087	0.108	0.10	0.36	1.7	0.85	0.55	1.03	3.80
400		0.054	0.072	0.06	0.23	1.2	0.55	0.36	0.70	2.58
500		0.036	0.051	0.04	0.16	0.87	0.39	0.26	0.51	1.86
600		0.025	0.039	0.03	0.12		0.28	0.2	0.24	0.88
800		0.013	0.024	0.02	0.07		0.15	0.13	0.14	0.51
1000		0.007	0.015	0.01	0.04		0.086	0.087	0.09	0.32
1200		0.005	0.013	0.01	0.03		0.062	0.064	0.06	0.23
1500		0.003	0.008	0.01	0.02		0.04	0.044	0.04	0.15
2000			0.005	0.01	0.02			0.026	0.03	0.10
2500			0.003	0.00	0.01			0.017	0.02	0.06
3000			0.002	0.00	0.01			0.012	0.01	0.04

Ground

downwind distance (m)	Deposit Levels (% applied rate)									
	Ground low (SD 03-F110) 360 µm					Ground high (110015) 204 µm				
	Data mean	AgDRIFT mean	GDM mean	avg (%)	pasture ppm	Data mean	AgDRIFT mean	GDM mean	avg (%)	pasture ppm
50	0.183	0.4	0.193	0.26	0.95		2.05	0.581	1.32	4.83
100	0.119	0.229	0.097	0.15	0.55		0.895	0.295	0.60	2.19
150	0.087	0.16	0.062	0.10	0.38		0.489	0.188	0.34	1.24
200	0.054	0.121	0.044	0.07	0.27		0.313	0.133	0.22	0.82
250	0.046	0.096	0.033	0.06	0.21		0.211	0.101	0.16	0.57
300	0.038	0.079	0.026	0.05	0.18		0.151	0.079	0.12	0.42
400	0.026		0.017	0.02	0.08			0.054	0.05	0.20
500	0.013		0.012	0.01	0.05			0.039	0.04	0.14
600			0.01	0.01	0.04			0.029	0.03	0.11
800			0.006	0.01	0.02			0.019	0.02	0.07
1000			0.004	0.00	0.01			0.013	0.01	0.05

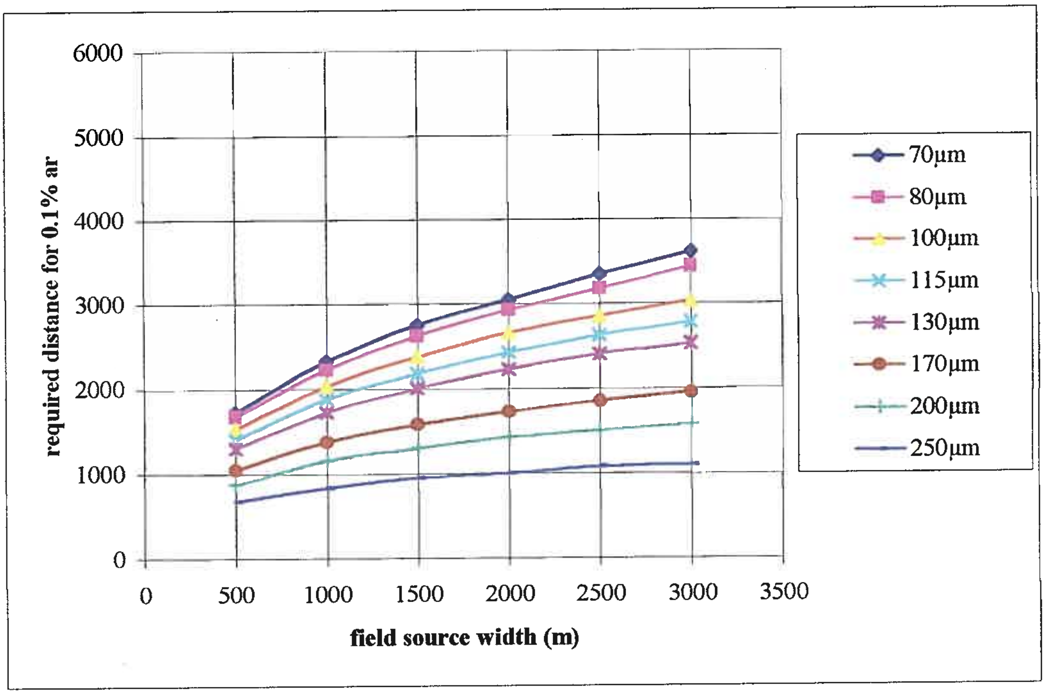


Figure 5. Effect of field source width on spray drift buffer distance required to reach 0.1% field applied rate

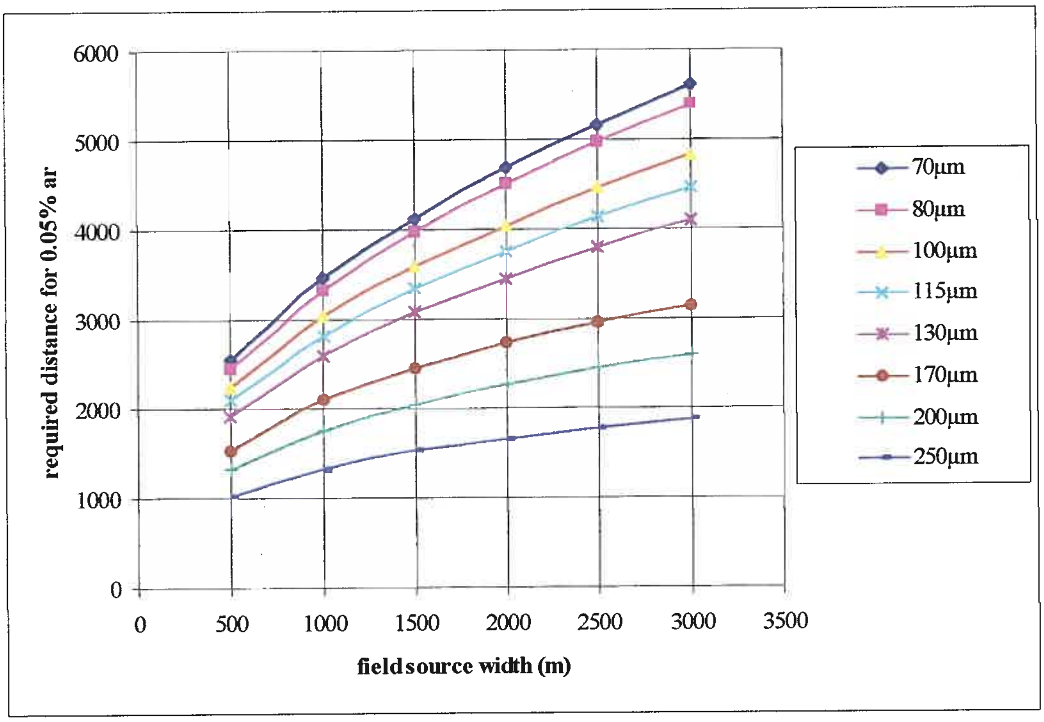


Figure 6. Effect of field source width on spray drift buffer distance required to reach 0.05% field applied rate

A BROADER ANALYSIS

To explore these issues in more depth, a further analysis was conducted using actual endosulfan droplet size data sourced from Malvern 2600 laser wind tunnel studies, (Woods,; Dorr,; and Craig, (2000b). A variety of nozzle combinations were selected as illustrated in Table 5.

Nozzle details	*VMD*
Micronair® AU 5000 20# cage, 45° blade angle, 7250 RPM, 2.3 L/min, 51 m/s	67 µm
Micronair® AU 5000 14# cage, 85° blade angle, 1950 RPM, 2.6 L/min, 67 m/s	119 µm
Micronair® AU 5000 20# cage, ~80° blade angle, ~2000 RPM, 2.3 L/min, 51 m/s	162 µm
Micronair® AU 5000 20# cage, 75° blade angle, 2300 RPM, 15.4 L/min, 51 m/s	162 µm
CP® hydraulic nozzle, 0.125 orifice, 30° deflector, 85 kPa, 4.9 L/min, 67 m/s	182 µm
FF 8006vs hydraulic nozzle, 320 kPa, 2.5 L/min, 67 m/s	244 µm
FF 9510 hydraulic nozzle, 280kPa, 3.7 L/min, 51 m/s	332 µm
Narrow spectrum with a standard deviation of size = 0.1	250 µm

Table 5. Range of Volume Median Diameters chosen for input into GDM.

Only one spectra (250 µm), was selected based on a computer generated spectra, Craig;, Woods;, and Dorr, (1998a). This spectrum was modified to illustrate the theoretical effect of reducing the number of small droplets generated by a nozzle system. All the spectra are shown in graphical form in Figures 7 & 8.

Gaussian Dispersion Model

The chosen droplet size distributions were run through the Gaussian diffusion model. The spreadsheet model was configured to perform an overlap based upon a 20 metre flight lane separation for field source widths of 500m and 3000m. The distances downwind of the sprayed paddock at which off target downwind deposition reached less than 1%, 0.1 % and 0.05% of the field applied rate were calculated.

AgDRIFT

Similarly similar input values were entered into AgDRIFT (v 1.07) and downwind deposition values determined.

The results of both analyses are summarised in Table 6.

Droplet Spectra Modification

The modified 250 µm (VMD) droplet spectrum shown in Figure 8 was also evaluated using the Gaussian model. By reducing the volume of material contained in both small and large droplets, the narrower spectrum significantly reduced predicted downwind buffer zones. Compared against the 244 µm (VMD) LV spectrum generated by hydraulic flat fan nozzles, the 250 µm spectrum allowed the 0.05% applied rate threshold to be significantly reduced from 980m to

400m, (Table 6). Such an analysis demonstrates the great gains in drift management that can be obtained by making small improvements in the performance of spray nozzles fitted to aircraft.

The AgDRIFT sensitivity analysis illustrated in Figure 4 demonstrates the importance of flying height in determining spray drift potential. The computer generated 250 µm (VMD) droplet spectrum was also evaluated using the Gaussian diffusion model using a theoretical release height of 1 metre instead of 3 metres. This reduced the buffer distance required to achieve a downwind threshold of 0.05% of the applied dose a further 220m to 180m. This analysis demonstrates advantages that could perhaps be conferred by rotary wing application, (Table 6). Small helicopters can usually be operated at lower flying heights, (boom heights) than larger fixed wing aircraft.

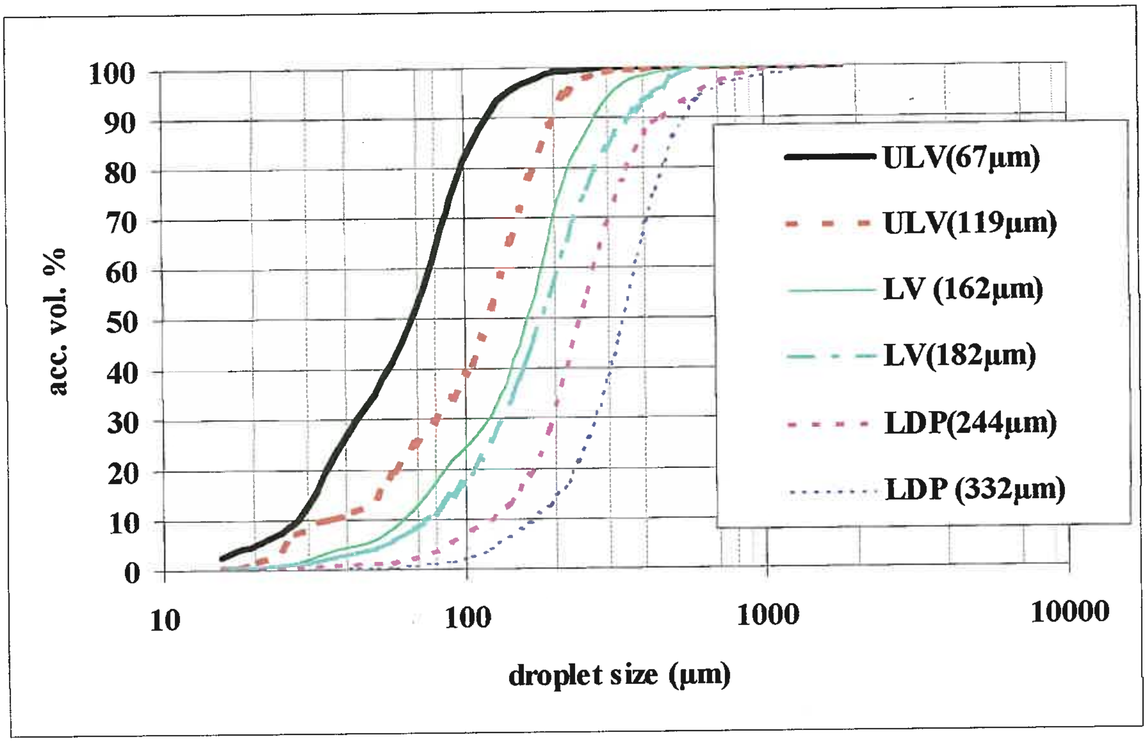


Figure 7. Malvern laser droplet size distributions used in the analysis

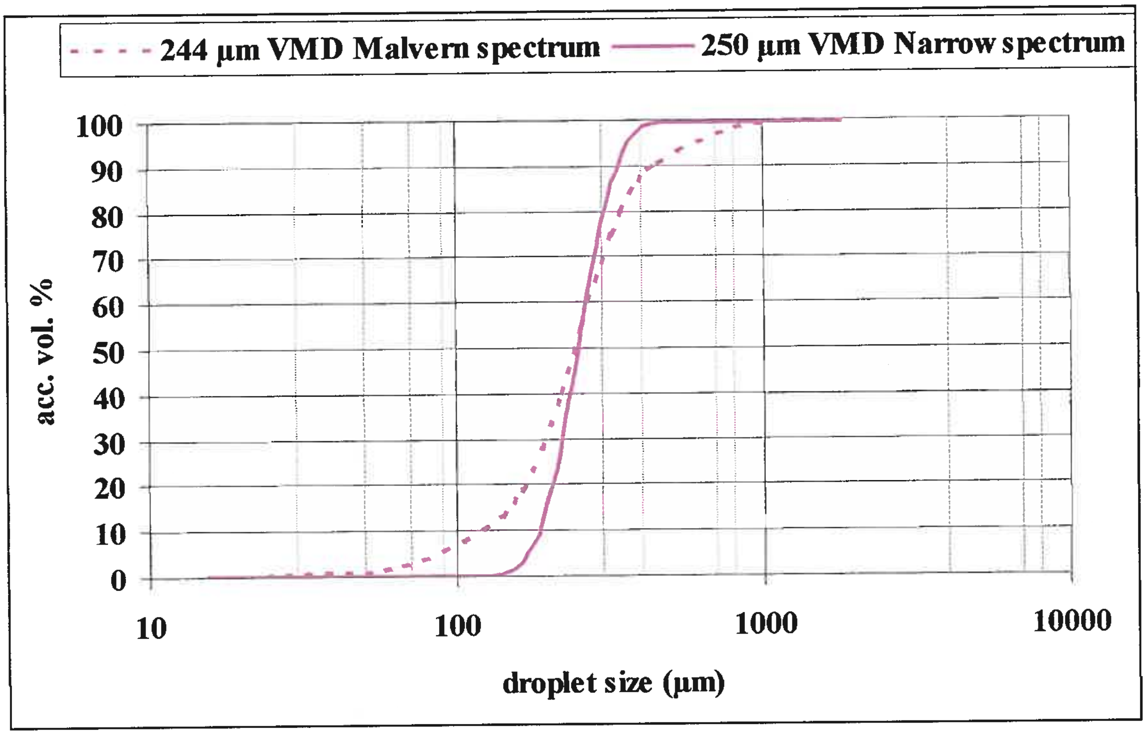


Figure 8. Computer generated 250µm VMD narrow spectrum compared to 244µm VMD Malvern data

	ULV	ULV	ULV	LV	LV CP	LV FF	LDP	Model	Model
Droplet VMD (µm)	**67µm**	**119µm**	**162µm**	**162µm**	**182µm**	**244µm**	**332µm**	**250µm**	**250µm**
release height	3m	3m	3m	3m	3m	3m	3m	3m	1m
Wind speed	3m/s	3m/s	3m/s	3m/s	3m/s	3m/s	3m/s	3m/s	3m/s
GDM									
turbulence intensity	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
500m wide field source									
1% applied rate at	500m	380m	280m	280m	240m	120m	80m	60m	20m
0.1% applied rate at	2000m	1560m	1220m	1220m	1060m	640m	380m	260m	100m
0.05% applied rate at	2920m	2300m	1800m	1800m	1600m	980m	600m	400m	180m
3000m wide field source									
1% applied rate at	1067m	760m	530m	530m	443m	205m	122m	102m	34m
0.1% applied rate at	4268m	3119m	2311m	2311m	1958m	1094m	582m	441m	170m
0.05% applied rate at	6232m	4599m	3410m	3410m	2956m	1675m	918m	679m	305m
AgDRIFT									
Formulation	ULV	ULV	ULV	EC	EC	EC	EC	EC	EC
Total rate	3L/ha	3L/ha	3L/ha	20L/ha	30L/ha	30L/ha	30L/ha	30L/ha	30L/ha
500m wide field source									
1% applied rate at	472m	356m	159m	352m	271m	127m	67m	-	-
0.1% applied rate at	>1500m	927m	516m	1421m	1053m	501m	277m	-	-
0.05% applied rate at	>1500m	1191m	658m	>1500m	>1500m	764m	428m	-	-

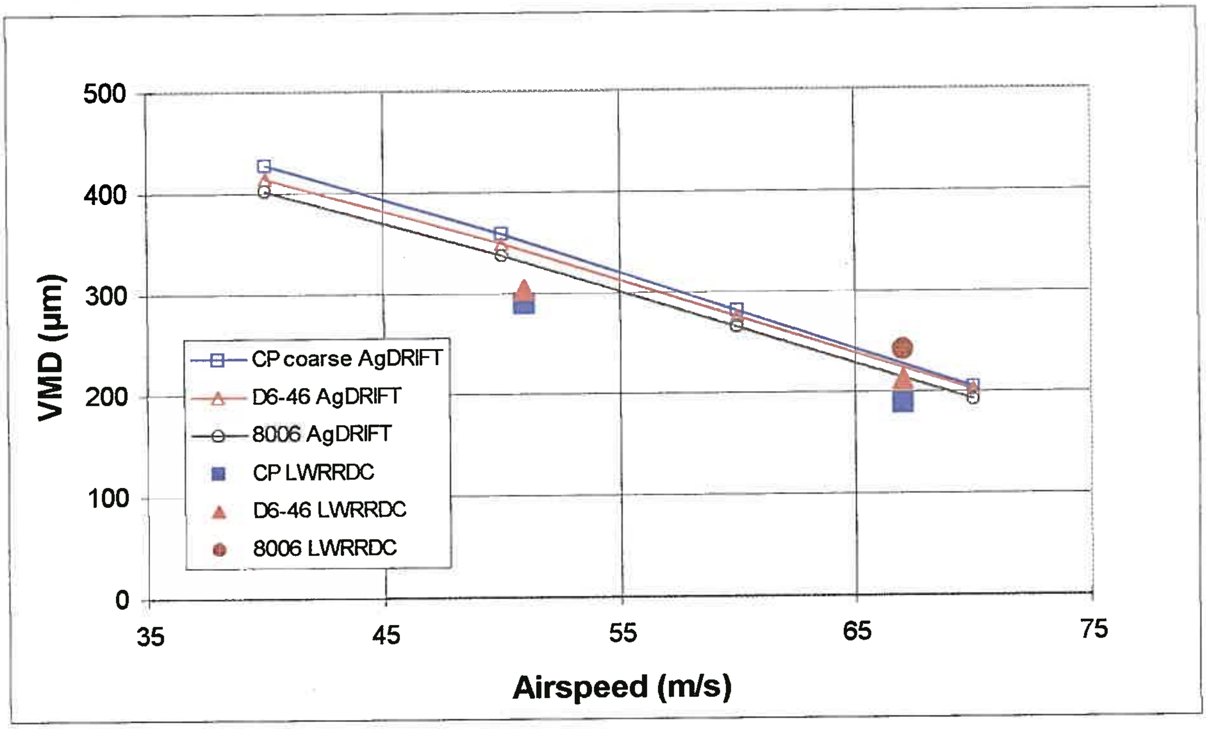
Table 6. Results of Gaussian diffusion and AgDRIFT computer modelling runs

Airspeed and Evaporation

The effect of two parameters was investigated in more detail, namely, the influence of airspeed and droplet evaporation on droplet size and drift profiles.

The influence of airspeed was assessed using measured wind tunnel data (LWRRDC dataset) and the AgDRIFT computer model. The results are summarised in Figure 9.

Figure 9. The effect of airspeed on droplet size



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The graph shows dramatically that increasing the flying speed of aircraft reduces the droplet size produced by all current hydraulic nozzles systems. Importantly, increasing the airspeed from 40 m/s (78kt) to 70 m/s (136 kt) whilst keeping all other parameters constant, decreases the droplet diameter (VMD) by 50%. It is interesting to note that in this analysis, the droplet sizes measured during the LWRRDC project compared well with the AgDRIFT (Dropkick™) prediction for the nozzle types used. The same wind tunnel was used to generate the droplet spectra for both the model and the LWRRDC database.

The effect of evaporation of water based sprays and the influence of carrier volume was assessed using the AgDRIFT model, (Figure 10). This figure shows the effect of droplet size (VMD) on downwind buffer distances required for the deposition to fall to 1% of the applied rate (AR). The curves show the effect of increasing the volume application rate whilst maintaining a constant product rate of 2.1 L/ha.

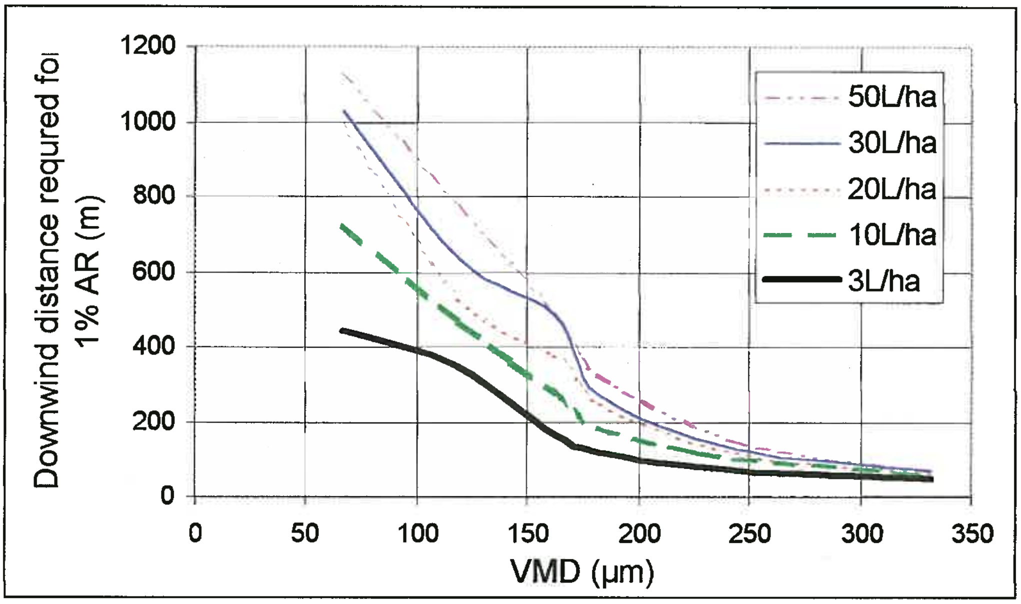

Figure 10. Effect of droplet size (VMD) on downwind buffer distances required for deposition to fall to 1% of applied rate (AR) for various total application rates (constant product rate of 2.1 L/ha)

Figure 10 shows that, as expected, the distance required for the downwind deposition to reach 1% of the applied rate decreases as droplet size is increased. However, if droplet size is kept constant and the total application rate is increased by adding more water (while keeping the rate of active applied per hectare constant), then the drift from the spray event increases. This increase in drift is caused by the evaporation of the water component of the droplet. The graph shows clearly that this effect is greater with small droplet sizes than with larger droplet sizes. Large droplets fall more quickly to the ground, (have a high sedimentation velocity) and evaporate less as less of their volume is exposed at the surface of the droplet. For droplet diameters above about 330 µm (VMD) the effect of water volume is negligible.

This analysis also shows that both an LDP application of pesticide at 2.1 L/ha in 30 L/ha of water, (VMD of 250µm) and an ULV application rate of 3 L/ha (VMD of 180 µm), 70% oil, require similar buffer distances to reduce the downwind deposit to 1% (and 0.1%) of applied rate. In other words, EC formulations can generate significantly more drift than ULV when applied through nozzle systems that produce small droplets.

This effect may be offset by the addition of adjuvants that reduce the rate of droplet evaporation. To reduce drift, such adjuvants may not have to increase the initial droplet size if the evaporative process can be slowed. These effects are currently being studied in CRDC project UQ27C.

DISCUSSION

Previous research sponsored by the LWRRDC and CRDC has shown that both Gaussian diffusion models and AgDRIFT, can be used with some confidence to predict the movement of ULV and LV cotton sprays up to about 800m downwind, (Figure 1 & 2,), (Woods *et al.* 2000c.) The analysis presented above however, has pushed the models beyond these limits in an attempt to compare the relative drift arising from ULV and LV application at distances up to several kilometres downwind.

It cannot be overstated that models are models! As the envelope is extended and limits pushed back, results from algorithms should always be interpreted with care, particularly in the absence of reliable field data.

However the findings allow some observations to be made.

The AgDRIFT sensitivity analysis described in Figure 4 shows the importance of droplet size and release height in determining the magnitude of pesticide drift.

It is clear that if very small droplets are applied, (eg. ULV 67 μm) <u>and very low</u> downwind thresholds are required (eg. 0.05% applied rate), significant down wind buffers distances have to be establish within and around crops. Although the size of these areas increases with field source width, greater flexibility in spray drift management (eg in selecting wind direction) can sometimes be conferred as farm size increases.

The downwind buffer distance can be substantially reduced if droplet size is increased. Assuming a threshold of 0.05% applied rate off target is required, the Gaussian model predicts that buffer distances can be reduced from approximately 2920m, to 600m when ULV (67μm) is compared to a LDP (332μm) aerial application. This assumes that a field 500m wide is sprayed at a wind speed of 3m/s, release height of 3m, and with a turbulence intensity of 0.1, (Table 6). AgDRIFT predicts that 0.05% of the applied rate can be contained using a buffer distance of only 428m when an LDP VMD of 332μm is selected.

When the influence of droplet evaporation is taken in to account, the AgDRIFT model suggests that a water based LV application (eg VMD 162μm at 20 L/ha) can generate significantly <u>greater</u> spray drift than ULV application. The model predicts that a buffer of 1421m is required for LV application compared with only a 516m buffer for an oil based ULV (VMD 162μm at 3 L/ha), assuming a 0.1% applied rate downwind threshold.

These buffer distances could be reduced even further if narrower droplet spectra could be produced at the nozzle and lower release heights adopted, (eg. helicopter application), Table 6. These parameters are currently under investigation in CRDC project UQ 27C. The new (CRDC/UQ) wind tunnel facility is being used to investigate the relationship between nozzle design, formulation, airspeed, flowrate and droplet size.

Data presented in this report also shows that the droplet size generated by an aircraft is highly dependent upon the airspeed surrounding the nozzle. If an aircraft is operated at too high a speed for a given hydraulic nozzle type or setting, the potential for spray drift is greatly increased.

Although regulators, in the case of endosulfan ULV, have set large downwind buffer distances (3 km) for ULV application, these distances only appear necessary for very small droplet application, extended field source widths and very low downwind thresholds. Models predict that these distances may be conservative where larger ULV droplets are used and smaller field source widths sprayed. These findings enhance the need for Micronair nozzle systems to be fitted with on-board transducers to measure rotational rpm and thus droplet size.

LDP application can effectively reduce the need for large downwind buffer distances. However there is considerable risk in applying pesticides using the incorrect combination of hydraulic nozzle, flying height and airspeed. For example, a CP nozzle, (30° coarse setting) fitted to an aircraft travelling at 67 m/s (130 kt), requires a buffer distance of 1053m, double that of an aircraft set up to spray a ULV at 162 μm, (516m). This analysis assumes a 0.1% applied rate downwind threshold is required.

Significant potential exists to manage pesticides within envelopes set by regulators, however as off target thresholds are reduced, greater buffer distances have to be employed.

Using existing technology, it is important that aircraft are now configured very accurately for operations in cotton growing areas.

Significant potential exists to utilise the advantages of aerial application if the droplet production process can be refined and spectra narrowed. The development of alternative, improved nozzle systems should be supported.

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