Airborne 2,4-D and tomato damage at Geraldton, Western Australia

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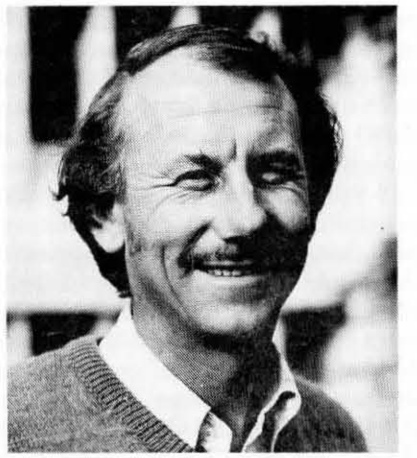


D. J. Gilbey

Summary

2,4-D used for weed control in wheat in the Geraldton area of Western Australia has caused off target damage to tomatoes annually since the early 1950s. Atmospheric monitoring from 1979 to 1982 showed relatively low concentrations of 2,4-D over Geraldton compared to levels recorded in the USA and Canada. The maximum mean weekly level was 0.065 μg 2,4-D m^{-3} in 1980. 2,4-D concentrations varied widely between years, weeks and sites. Tomato crop abnormalities were widespread each year, some of which could be explained by disease. Severe spray drift damage was clearly distinguished from disease in localized situations and occurred when cereal crops were sprayed. Damage was more likely to have been due to short distance droplet drift of low volatile 2,4-D and dicamba than to long distance vapour drift of high volatile 2,4-D esters.

Introduction

Off target 2,4-D damage has been recognized in tomatoes for over 30 years at Geraldton, Western Australia. It occurs each year at any time from late June to late October and affects many of the 50 to 60 tomato gardens there. Wheat is the major crop enterprise in the Geraldton hinterland and is sprayed with 2,4-D for weed control during this period. Pastures in the hills east of the town have been sprayed with 2,4-D to control saffron thistle (*Carthamus lanatus* L.) in September and October. In spite of legislation which restricted the use of high volatile forms of 2,4-D within 19 km of Geraldton until 1979 and within 50 km since 1979, drift of airborne herbicide has continued to damage tomato plants.

Farwell *et al.* (1976) and Robinson and Fox (1978) recognized localized and widespread drift damage patterns in central Washington, USA where airborne 2,4-D has damaged commercial vineyards. They concluded that long distance transport (16 to 80 km) of airborne 2,4-D may account for crop damage, and that localized drift could also cause crop damage when weather patterns do not favour long distance drift. Furthermore, high volatile esters accounted for most of the 2,4-D in years when the most serious and widespread damage occurred in grapevines. Mean monthly 2,4-D concentrations were in the order of 0.21 to 0.38 μg 2,4-D m^{-3}. In similar studies in Saskatchewan, Canada Grover *et al.* (1976) detected mean daily concentrations of 2,4-D up to 23.14 μg 2,4-D m^{-3}. Ninety per cent of the samples were below 1 μg 2,4-D m^{-3} and like Robinson and Fox they also found high volatile esters to be most frequent. Off target spray damage problems are recognized throughout North America and Europe, and considerable research has been carried out in these countries into the effects of meteorological conditions, spraying equipment, method of spraying, spray formulations and additives on spray drift (Yates *et al.*, 1974; Nordby and Skuterud, 1975; Grumbles *et al.*, 1980; Bouse and Leerskov, 1973; Grover *et al.*, 1972, 1978; Maybank *et al.*, 1974; Day *et al.*, 1959; Cooper, 1977). It was not clear how the overseas information could be applied in the Geraldton area because the nature of herbicide drift was not clearly understood, although presumed to be long distance vapour drift. A project was therefore commenced in 1979 to study airborne 2,4-D and herbicide damage to tomatoes. It coincided with a change in restricted spraying regulations, when the use of high volatile 2,4-D esters was prohibited within 50 km of Geraldton instead of the 19 km permitted until 1979.

This paper reports results from each year between 1979 and 1982 together with results of a study on 2,4-D drift from an aerial spraying operation in 1980.

1979 monitoring programme

The method of collection and analysis of 2,4-D was similar to that described by Robinson and Fox (1978). 2,4-D was extracted from a measured volume of air passed through the sampling unit (Figure 1), and adsorbed on to XAD-2 resin. The vertically oriented air inlets to the sampling tubes were 12 mm in diameter and air flow rates were within the range 1.18–1.81 L min^{-1}. Adsorbed 2,4-D was recovered by sequential solvent extraction and analysed by gas chromatography. Results expressed as acid/amine are the sum of 2,4-D as amine and as salt, because the analytical procedure cannot distinguish between these two forms. However, as

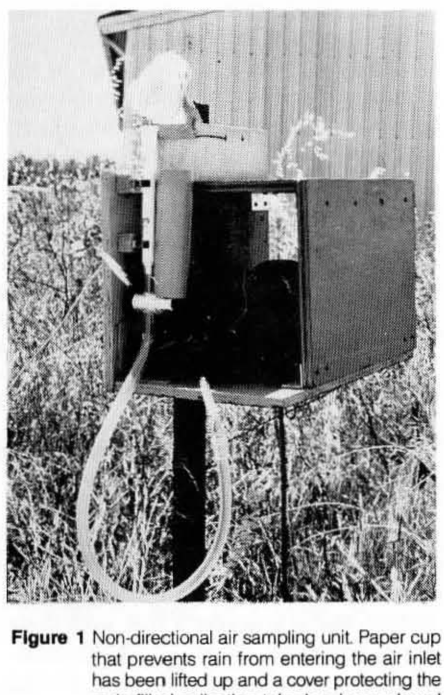


Figure 1 Non-directional air sampling unit. Paper cup that prevents rain from entering the air inlet has been lifted up and a cover protecting the resin filled collecting tube has been placed to one side of the tube.

very little 2,4-D is used or sold in the salt form in Western Australia and most 2,4-D other than ester is sold and used in the amine form, the data for 2,4-D acid/amine can be regarded as mainly amine.

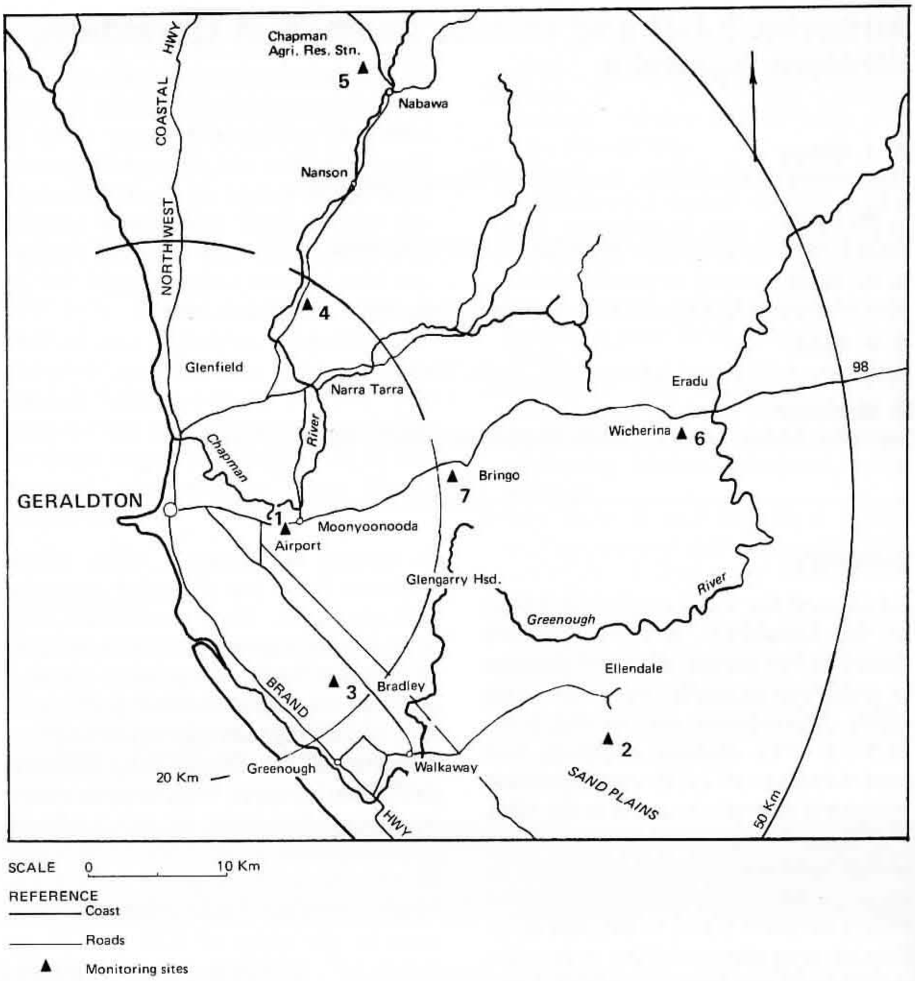
Seven sampling units distributed around Geraldton (Map 1) were operated continuously for 20 weeks from 25 June and the resin tubes changed weekly. Tomato seedlings at the airport were changed each week at the same time as the resin tubes, grown on for at least 4 weeks away from further 2,4-D exposure and visually rated for 2,4-D damage. Thirty commercial tomato gardens distributed throughout the Geraldton district were also inspected for 2,4-D damage during the monitoring period.

The most important result was that non-volatile 2,4-D acid/amine was detected much more frequently than high volatile esters (Table 1). Very little high volatile ester was sprayed on to cereal crops around Geraldton in 1979 because of drought conditions and an aphid infestation that selectively attacked the cruciferous weeds which are the main target of 2,4-D.

Airborne 2,4-D was detected when cereal crops were being sprayed, with maximum mean weekly levels of 0.06 $\mu g\ m^{-3}$ at Greenough (as acid/amine) and Bringo (as high volatile ester). During the main crop spraying period (weeks 8 to 15), atmospheric 2,4-D levels of 0.01 $\mu g\ m^{-3}$ and above were detected in 50% of the samples.

These results contrast with those from North America with 2,4-D concentrations at Geraldton well below the levels detected in the Washington and Saskatchewan studies where 2,4-D was widely used without restriction. In spite of this, 2,4-D damage occurred in six tomato gardens in the Moonyoonooka area which adjoins the airport. There was no relationship between this damage and 2,4-D levels detected at the airport monitor, nor was any relationship established between seedlings placed near the airport monitor and the levels of atmospheric 2,4-D at that site. Furthermore, wind speed and direction at the airport bore no relationship to either atmospheric 2,4-D levels or crop damage.

The damage to tomatoes at Moonyoonooka was probably due to localized droplet drift. Long distance vapour drift is characterized by a large contaminated air mass that affects an area with dimensions of several kilometres, and it is unlikely that such drift would damage crops at Moonyoonooka without being detected at the airport. Lethal concentrations of short



Map 1 Sampling sites for 2,4-D survey in Geraldton district in 1979

Table 1 Mean weekly aerial 2,4-D concentrations at Geraldton in 1979 ($\mu g\ m^{-3}\ week^{-1}$)

Form of 2,4-D measured	Station	Weeks from start of sampling														
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Non-volatile acid/amine	1 Airport													.02	.02	.01
	2 Walkaway								.02		.03			.02	.01	.01
	3 Greenough			.02						.02	.06				.03	.02[1]
	4 Narra Tarra									.02	.05				.01	.01
	5 Nabawa												.02		.01	.03
	6 Wicherina									.03	.04		.01			.03
	7 Bringo										.03			.01	.01	.02
High volatile esters	1 Airport															
	2 Walkaway															
	3 Greenough														.01	
	4 Narra Tarra														.02	
	5 Nabawa															
	6 Wicherina															
	7 Bringo								.01					.06		
	Weekly tomato damage rating	0	0	0	0	0	0	0	3	2	1	1	0	1	0	0

Rating scale for damage to tomatoes
1 = very slight; minor leaf curling on one or more plants
2 = slight; leaf curling and petiole twisting on several plants
3 = moderate; leaf malformation, petiole twisting, vein clearing on most plants

[1] Monitor malfunction

distance droplet drift may not be detected by monitors for three reasons: a mean weekly value for the concentration of airborne herbicide does not distinguish between a high value for a short time and a constant lower value; wind may carry a contaminated air mass in a plume over a tomato garden but away from a monitor; and airborne herbicide that is being rapidly dispersed as it is carried away from a sprayed field may pass a nearby tomato garden at a lethal concentration and reach a monitor beyond the garden at a much lower concentration or even below the level of detection.

Monitors placed at fixed sites should detect a large contaminated air mass, particularly if it either exists in the area for several days or is replaced each day for several consecutive days. They may not detect relatively small rapidly dispersing plumes of contaminated air that are highly concentrated for short distances and occur infrequently for short periods of time.

In view of the limited use of high volatile 2,4-D esters on cereal crops around Geraldton in 1979, there was a clear need to continue monitoring in 1980.

1980 monitoring programme

The sensitivity of the air monitoring procedure was increased in 1980 enabling results to be reported to a 0.001 $\mu g\ m^{-3}$ limit of detection. Apart from this, the method of collecting and analysing 2,4-D was identical to that used in 1979. Nine sampling units were operated continuously for 21 weeks from June 10, and although air flow rates of less than 1 L min^{-1} were recorded occasionally (for example due to pump wear), all units operated in the range of 1 to 2 L min^{-1}. Seven were within the tomato growing areas and the others due east of Geraldton at distances of 38 km and 50 km (Map 2).

The resin tubes and tomato seedlings at the airport, Moonyoonooka and Eradu monitoring sites were changed weekly and the tomatoes were grown on at Perth for observation as in 1979. Thirty-six commercial tomato gardens distributed throughout the Geraldton district were inspected for 2,4-D damage during the monitoring period.

Atmospheric 2,4-D

Wheat farmers experienced a good start to the growing season in 1980. Record areas were sown around Geraldton and the full range of available herbicides was used.

Most of the 2,4-D was detected during the period (weeks 6–10) which coincided with cereal crop spraying (Table 2). Ninety per cent of the samples collected at this time contained 0.001 $\mu g\ m^{-3}$ or more of 2,4-D, the highest being 0.065 $\mu g\ m^{-3}$ at Moonyoonooka. Some low volatile 2,4-D acid/amine was detected for a further 2 weeks after the main spraying period.

High volatile 2,4-D esters accounted for about 90% of the total 2,4-D detected at Eradu and about 50% at Wicherina (50 km and 38 km due east of Geraldton respectively) and about 40% in the tomato growing areas.

The most interesting results were that non-volatile acid/amine 2,4-D accounted for over half the atmospheric 2,4-D over the Geraldton tomato garden area (i.e. all sites except site 6, Wicherina and site 7, Eradu) and the maximum level detected was much higher than that of any other form (Table 3). Even though the levels are low compared to the Washington and Saskatchewan studies, 2,4-D acid/amine is more likely to have damaged tomatoes than 2,4-D

Table 2 Mean weekly aerial 2,4-D concentrations at Geraldton in 1980 ($\mu g\ m^{-3}\ week^{-1}$)

Form of 2,4-D measured	Station	Weeks from start of sampling												
		1	2	3	4	5	6	7	8	9	10	11	12	21[2]
Total 2,4-D[1]	1 Narngulu						0.003	0.004	0.003	0.012	0.027			
	2 Utakarra		0.008				0.002	0.002		0.012	0.017			
	3 Moonyoonooka			0.002			0.004	0.008	0.003	0.033	0.065			
	4 Airport					0.002	0.003	0.003		0.011	0.011			
	5 Wonthella						0.004	0.002		0.011	0.023			
	6 Wicherina						0.003	0.011	0.003	0.014	0.018	0.001	0.002	
	7 Eradu		0.003	0.003	0.007	0.003	0.009	0.021	0.029	0.020	0.045			0.002
	8 Glenfield						0.005	0.005	0.040	0.025	0.016	0.001	0.005	
	9 Waggrakine						0.002	0.007	0.002	0.021	0.013	0.002	0.003	
Low volatile 2,4-D acid/ amine	1 Narngulu							0.002		0.007	0.013			
	2 Utakarra		0.008					0.002		0.007	0.010			
	3 Moonyoonooka						0.002	0.001		0.022	0.052			
	4 Airport					0.002		0.001		0.007	0.005			
	5 Wonthella									0.004	0.009			
	6 Wicherina							0.008		0.006	0.009	0.001	0.002	
	7 Eradu						0.003	0.003	0.004		0.002			
	8 Glenfield						0.002	0.003	0.040	0.011	0.010	0.001	0.005	
	9 Waggrakine						0.001	0.002	0.002	0.014	0.005	0.002	0.003	
High volatile 2,4-D ester	1 Naragulu						0.003	0.002	0.003	0.005	0.014			
	2 Utakarra						0.002			0.005	0.007			
	3 Moonyoonooka			0.002			0.002		0.007	0.011	0.013			
	4 Airport						0.003	0.002		0.004	0.006			
	5 Wonthella						0.004	0.002		0.007	0.014			
	6 Wicherina						0.003	0.003	0.003	0.008	0.009			
	7 Eradu		0.003	0.003	0.007	0.002	0.006	0.018	0.025	0.020	0.031			0.002
	8 Glenfield						0.003	0.002		0.014	0.006			
	9 Waggrakine						0.001	0.002		0.007	0.008			

[1] Means of each form of 2,4-D had been summed to give the figures shown for 'Total 2,4-D'.
[2] Tables are shortened because no 2,4-D was detected between weeks 12 and 21.
☐ Indicates sampling unit malfunction, and 2,4-D levels where shown are estimated from predicted airflow through the unit.

Table 3 Atmospheric 2,4-D at Geraldton in 1980[1]

Form	Percentage of total 2,4-D detected	Highest level detected ($\mu g\ m^{-3}$)
High volatile ethyl ester	40	0.014
Low volatile butoxy ethanol ester	1	0.003
Non-volatile acid/amine	59	0.052

[1] Only data from sites in Geraldton tomato garden area are used (i.e. site 6, Wicherina and site 7, Eradu are excluded).

ester. The maximum atmospheric level of high volatile ester at Geraldton represents 0.1% to 1.0% of the North American figures and for this reason it is not regarded as a likely source of significant damage. Low volatile butoxy ethanol esters are of even less significance, but it is important to note that restrictions on the use of both forms of the ester did not prevent them from entering the tomato growing area.

Considering that wheat growers are not permitted to spray 2,4-D ester within 50 km of Geraldton, an explanation for the presence of this compound near the township is required. Both short and long distance transport may have occurred, since the monitoring procedure cannot distinguish droplets from vapour.

Maximum concentrations of high volatile ester (0.014 $\mu g\ m^{-3}$) were detected within the tomato garden area (Map 2) in weeks 9 and 10 with concentrations at Eradu of 0.02 to 0.031 $\mu g\ m^{-3}$. If no 2,4-D ester was sprayed within the restricted area and Eradu data reasonably represents atmospheric concentrations in unrestricted spraying areas around Geraldton, then the rate of dispersion is exceptionally low and contrary to the results of other drift studies which showed that airborne herbicide dispersed to less than 50% of the initial concentration within 1 km of the source (Grover *et al.*, 1972; Grumbles *et al.*, 1980; Yates *et al.*, 1974). It is extremely unlikely that herbicide drift from a specific spraying activity in the unrestricted area could contribute significantly to the monitors near the tomato gardens and more likely that 2,4-D esters sprayed within the restricted area account for its presence near Geraldton township.

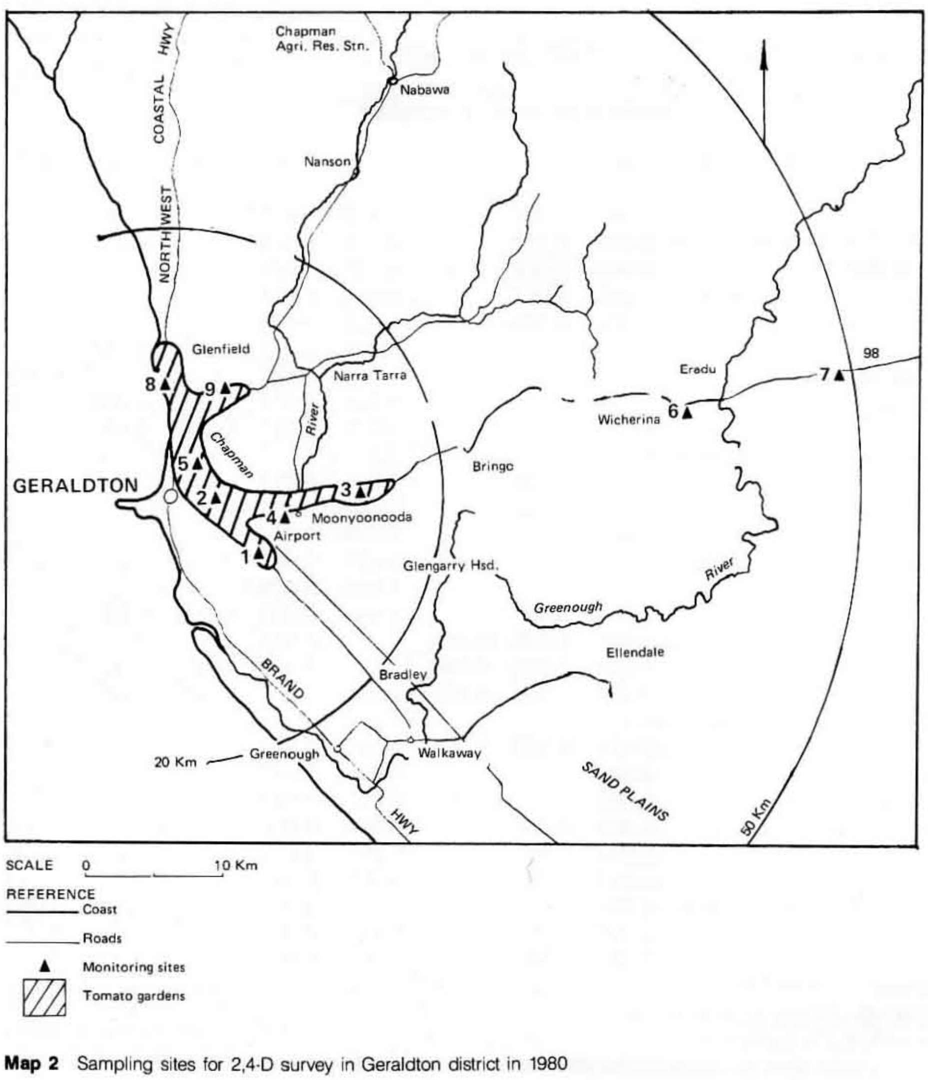
Damage to tomatoes

The survey of commercial gardens revealed that slight distortions of tomatoes were widespread throughout the whole area. Electron microscopic examination of leaf tissue showed that tobacco mosaic virus (TMV) infections were also widespread. 2,4-D damage could only be distinguished from TMV when tomatoes were moderately to severely distorted.

Severe 2,4-D damage occurred in commercial gardens at Moonyoonooka and moderate damage occurred in several other gardens. All were located near cereal crops, in some instances separated only by a corrugated iron or open wire fence. In these situations direct droplet drift from any spraying would inevitably affect the tomatoes. Another explanation for the high atmospheric 2,4-D levels and crop damage at Moonyoonooka is that dispersion of 2,4-D may be restricted by the hilly terrain during inversion conditions. Moonyoonooka is located in an old eroded area typified by steeply sloped flat-topped hills rising to 250 m. Cereals are grown in the broad valleys, two of which join in the Moonyoonooka airport area and 2,4-D drift could be funnelled to this location.

Tomato seedlings that were placed near monitors at Moonyoonooka and the airport each week frequently developed herbicide damage symptoms in the glasshouse. Damage was rated for severity but no relationship was established with the mean weekly 2,4-D concentrations detected at the same monitoring station for the same week. Seedlings were damaged on several occasions when no 2,4-D was detected for the corresponding site and week, and on other occasions no damage was recognized when a relatively high level of 2,4-D was detected for the same site and week.

As already discussed, the most likely explanation for this is the inability of the monitors to distinguish lethal concentrations of airborne 2,4-D for very short periods of time from sublethal concentrations that may have been



Map 2 Sampling sites for 2,4-D survey in Geraldton district in 1980

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constant for most of the weekly sampling time. If tomatoes tolerate a constant atmosphere of 0.01 $\mu g\ m^{-3}$ of 2,4-D but 1.7 $\mu g\ m^{-3}$ for one hour is lethal, the monitors will still detect both as a mean concentration of 0.01 $\mu g\ m^{-3}$ 2,4-D for one week.

Aerial spraying study

This study was carried out because aerial spraying with high volatile 2,4-D ester some distance from the tomato gardens was thought to be the main source of 2,4-D damage.

On 25 July 1980 a 600 ha paddock of wheat at Mullewa (100 km east of Geraldton) was aerially sprayed with 448 g a.i. 2,4-D isopropyl ester ha^{-1}. The aircraft was fitted with nine 0.004 Spraying Systems fan jet nozzles and the herbicide was applied at a pressure of 200 kPa from a height of 7.6 m at 177 km h^{-1}, in a cross wind of 23.5 km h^{-1}. The carrier was distillate and total output was 1.12 L ha^{-1}.

Isopropyl ester has a similar vapour pressure to ethyl ester (0.19 Pa and 0.15 Pa respectively); it was used so that drift from the test paddock could be distinguished from ethyl esters being used elsewhere in the district, but isopropyl ester would produce data which could be extrapolated to that for ethyl esters.

Air sampling monitors were placed in a line along the wind direction 0, 0.5, 1, 2, 5, 10 and 35 km from the edge of the sprayed paddock and at a height above ground of 1.5 m. Silica gel coated glass plates were placed on the ground at each of the monitoring stations and were also located within the crop during spraying.

The wind direction was from the north west at 1.00 p.m. when the sampler positions were decided. Spraying commenced at 1.25 p.m. but by 2.00 p.m. the wind had changed to west north west. Spraying was completed at 2.25 p.m. Sampling at all stations except 35 km commenced at the same time as spraying, the 35 km sampler was started 30 minutes later, and all samplers operated for 4 hours. The samplers at distances of 2 km and 5 km were moved to positions closer to the plume centre line at 3.35 p.m. and 2.50 p.m. respectively.

Subsequent analysis of wind data from a continuous recording Wolfle anemometer showed that the initial siting of the samplers at and beyond 2 km was significantly removed from the plume centre line because of the change of wind direction. This meant that only the southernmost section of the sprayed area would have contributed to the samples gathered at 2, 5 and 10 km during the actual spray period.

On the day after the spraying the samplers were placed at the same distances (except 35 km) away from the paddock in line with the wind direction (which was from the south west at about 25 km h^{-1}), and again run for 4 hours during the afternoon.

Atmospheric 2,4-D was detected up to 10 km from the sprayed area during the 4 hour period after the commencement of spraying (Table 4) and ground deposits were detected up to a distance of 5 km. Because the samplers at and beyond 2 km were significantly off the plume centre line during the spraying period it was not possible to assess the highest concentrations at and beyond 2 km. The data shows, however, that rapid dispersion of airborne 2,4-D occurred within 1 km of the sprayed paddock, with the concentration being reduced by over 50% within this distance. This supports the results of Grover *et al.* (1972), Grumbles *et al.* (1980) and Yates *et al.* (1974) and the statement earlier in this paper explaining the presence of 2,4-D ester near Geraldton township.

Many interacting factors affect drift (Maybank *et al.*, 1974; Nordby and Skuterud, 1975; Yates *et al.*, 1974), and the data presented here apply only to the meteorological conditions and spraying method at the time of the study. Although the conclusion that drift was reduced by over 50% within 1 km allows for considerable variability in weather and spraying method, this would not necessarily apply to calm or temperature inversion conditions. Herbicide drift under these conditions is unpredictable (J. Maybank personal communication, 1981) and requires further study.

Low concentrations of 2,4-D were detected only within 0.5 km of the field on the day after spraying, and it is concluded that vapour drift 24 hours after spraying was of little significance.

Table 4 Magnitude of 2,4-D drift from aerial spraying in 1980

Distance from sprayed paddock (km)	Mean 2,4-D concentration ($\mu g\ m^{-3}$) Day 1	Day 2	2,4-D deposited on the soil surface (silica gel plates) (gm ha^{-1})
0	7.000	0.012	31.0
0.5	3.600	0.007	14.0
1	2.000	<0.004	3.5
2	0.140	<0.004	0.17
5	0.070	<0.004	0.05
10	0.008	<0.004	—
35	<0.002	—	—

1981 and 1982 monitoring programmes

In 1981 the study was confined to one air sampling unit stationed at the airport for 15 weeks from mid-July, with 39 commercial tomato gardens also being inspected for 2,4-D damage.

In 1982 air sampling units were stationed north and west of Geraldton airport, with a directional sampling unit (Figure 2) at the airport Bureau of Meteorology base. This unit incorporated an anemometer which directed the air sample to specific XAD-2 resin-filled glass tubes according to the wind speed and direction. Providing the wind speed exceeded 0.6 m sec^{-1}, the monitor sampled from six equal segments between 0-360° as shown in Table 6 and on Map 3. Air sampled while the wind speed was 0.6 m sec^{-1} or less was directed to specific resin tubes for calm conditions. The air sampling units were operated for 16 weeks from 6 July, and 29 commercial tomato gardens were inspected for 2,4-D damage during the sampling

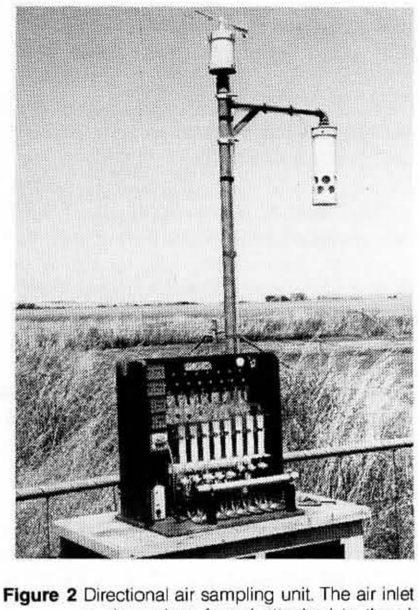


Figure 2 Directional air sampling unit. The air inlet is a clear glass funnel attached to the side arm carrying a wind movement detector.

Table 5 Maximum mean weekly herbicide concentrations in the atmosphere at Geraldton in 1981 and 1982 ($\mu g\ m^{-3}$)

Herbicide	1981	1982
2,4-D ester	0.003	0.005
2,4-D acid/amine	not detected	0.015
dicamba	0.002	0.005

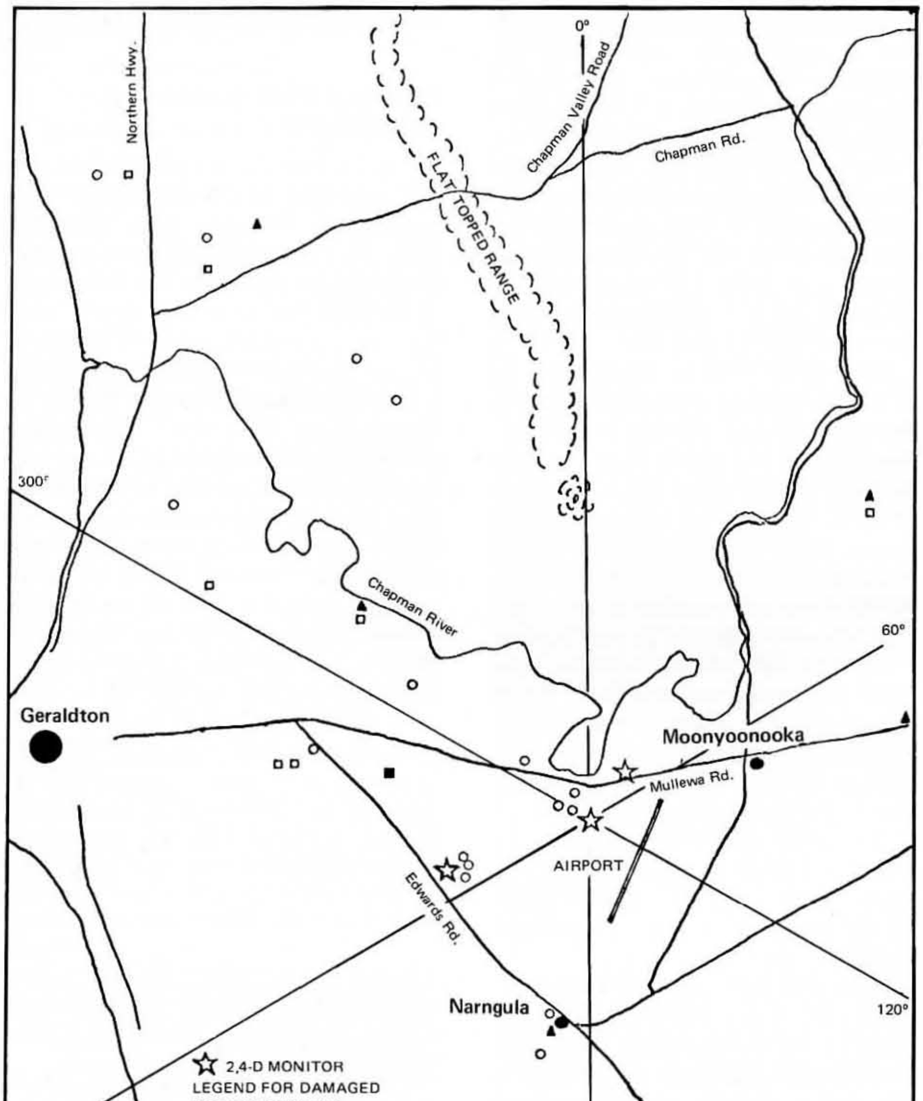
period. As in previous years, the air flow rate through the non-directional units was 1-2 L min^{-1}. That for the directional unit was 10.5 L min^{-1}, which was achieved by inserting a critical orifice to the pump inlet.

The only herbicides detected in 1981 were 2,4-D ester and dicamba, and the maximum concentrations of each were near the limit of detection, 0.001 $\mu g\ m^{-3}$ (Table 5). Twenty-three gardens were found to contain moderately or severely malformed tomato plants even though the monitor failed to detect any significant airborne herbicide. As discussed previously, the most likely explanation is the limitations of a fixed monitor to detect short distance droplet drift of 2,4-D acid/amine which may have caused the observed malformations.

In 1982 the maximum concentration of 2,4-D acid/amine was higher than 2,4-D ester and dicamba (Table 5). Only six gardens were moderately or severely affected by herbicide and at three locations moderately damaged gardens were close to undamaged gardens, which provides circumstantial evidence of short distance droplet drift being responsible.

The objective of collecting air samples separately from each sector by the directional monitor was to further test the hypothesis that 2,4-D ester being sprayed on to the large area of cereals grown more than 50 km to the east of Geraldton is the main source of airborne 2,4-D at the township. Data from this monitor (Table 6) show that 2,4-D ester was detected coming from two sectors, 60–120° and 120–180° (east and south east), in each case during one week out of 16. It was not detected by one of the nearby non-directional monitors during the same weeks, which suggests that it arose from droplet drift of a rapidly dispersing plume from nearby sources.

Both 2,4-D acid/amine and dicamba were detected coming from all directions, and the highest concentration of each was detected from the west sector over a period of 4 hours during the same week. Furthermore 2,4-D acid/amine was detected during 8 weeks and dicamba during 5 weeks of the 16-week sampling period. Thus 2,4-D ester was detected less frequently, from fewer directions and at lower maximum concentrations than the other products, which does not support the hypothesis that 2,4-D ester sprayed 50 km or more to the east of Geraldton is the main source of airborne herbicide at the town. The data gives more support to the results of previous years when it was concluded that short distance droplet drift from localized spraying with 2,4-D amine and dicamba is now the most likely cause of herbicide damage to tomatoes at Geraldton.



Map 3 2,4-D survey in Geraldton District in 1982

Table 6 Mean maximum herbicide concentration from six directions at Geraldton in 1982 ($\mu g\ m^{-3}$ for stated number of hours)

	Direction					
Herbicide	**0–60°**	**60–120°**	**120–180°**	**180–240°**	**240–300°**	**300–0°**
2,4-D ester	0	0.003/14 h	0.004/43 h	0	0	0
2,4-D acid/amine	0.006/50 h	0.04/13 h	0.04/26 h	0.04/37 h	0.12/4 h	0.06/20 h
dicamba	0.004/40 h	0.009/7 h	0.002/36 h	0.006/37 h	0.04/4 h	0.02/7 h

Conclusions

This project has enabled a better understanding of the nature of atmospheric 2,4-D in the Geraldton area, which can be related to the characteristics of long distance and short dis-

Figure 3 A tomato garden at Geraldton with undulating cereal growing land in the background. Cereals are grown right up to the fence surrounding the garden.

tance herbicide drift. While vapour drift of high volatile 2,4-D ester sprayed within 50 km of Geraldton may have contributed substantially to tomato crop damage before restrictions were introduced, the problem is now more probably due to short distance droplet drift of 2,4-D amine and dicamba, and to a lesser extent droplet and vapour drift of 2,4-D ester sprayed within the prohibited area.

It has been established that crop damage coincides with cereal crop spraying but it has not been possible to relate particular spraying activities with crop damage because individual spraying events could not be identified by the monitors.

Important aspects of the project were the surveys of tomato gardens in conjunction with air monitoring, which revealed possible causes of crop damage other than herbicide drift and the localized distribution of crop damage. Before this project, it was believed that crop damage was evenly distributed throughout the district each year and thus characteristic of long distance vapour drift. The surveys showed that crop damage was unevenly distributed and thus more characteristic of short distance droplet drift.

While the atmospheric concentrations of 2,4-D detected at Geraldton were low compared to North America, the monitors could not distinguish between a high concentration for a short time and a constant low level during the weekly monitoring interval. The same constraint would apply to the North American data so there is some basis for comparison, but a much shorter monitoring interval, such as one hour, is required to detect peak concentrations. Further research is needed to establish the critical levels of atmospheric 2,4-D concentrations and exposure time that cause tomato crop damage, because published information only records the effect of 2,4-D applied as a single dose in the form of a spray.

It is expected that 2,4-D damage to tomatoes at Geraldton could be further reduced by attempting to reduce short distance droplet drift from cereal spraying operations within the restricted area around the town.

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