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FLUORIDE TOXICITY IN GRAPE VINES
—a case study

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—a case study

by W. J. Cox and L. T. Jones

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INTRODUCTION

Atmospheric fluoride pollution is commonly associated with the manufacture of bricks, tiles, pipes and other ceramics, the manufacture of glass, enamel, aluminium and steel and the production of phosphatic fertilisers (Marrier and Rose 1971; Quellmalz and Oelschlager 1971; Jones 1976).

The problem of atmospheric fluoride pollution in Western Australia was first raised in 1968 in association with severe leaf scorch in two commercial vineyards located in the vicinity of brickworks in the Swan Valley 16 km north of Perth. Subsequent work identified fluoride toxicity there, as well as in the vicinity of the Armadale, Byford and Cardup brickworks and the Picton and Esperance superphosphate works (Jones, 1978 unpublished report). Severe vegetation damage occurred in the vicinity of each site and a case of fluorosis in cattle was reported in the vicinity of the Cardup works.

Fluoride toxicity was first identified in the study vineyard at Caversham in November 1970 on Pedro Ximenez and Red Emperor grape varieties. A number of monitoring studies have been conducted at this site in the period 1971/72 to 1979/80. these have been summarised here and used to:-

(a) describe the development and symptoms of fluoride toxicity in grapevines and native vegetation;

(b) evaluate the pattern of fluoride accumulation;

(c) develop diagnostic plant analysis criteria relating concentration in the plant to the development of visual symptoms of damage.

MATERIALS AND METHODS

In the majority of field pollution studies it is not possible to use the classical scientific approach of testing hypotheses by imposing treatments and measuring the effects. Where pollution is variable and unpredictable, less exact monitoring techniques are used. Weinstein and McCune (1970) have suggested several criteria for identifying the pollutant. These include identification of symptoms, elimination of other factors such as disease, plant analysis, assessment of meteorological conditions and monitoring of atmospheric levels.

The majority of the monitoring of fluoride concentrations in grape leaves was conducted at a major commercial vineyard at Caversham.

This vineyard is located on the banks of the Swan River approximately 1.5 km to the west of a major brickworks. A smaller brickworks is located 1.5 km to the north east of the vineyard. Late spring and summer easterly winds bring fluoride from either or both sources.

Two sites were sampled, the first was located on a level soil 50 m south of the winery and the second was located in a slight depression 150 m north east of the winery. Details on variety and date of sampling have been summarised in Appendix 1. Native vegetation was sampled as the opportunity arose. Details on species and sampling date have been summarised in Appendix 2.

Sampling

For monitoring in grapevines, 25 leaves were collected by taking one leaf per vine. Recently matured leaves opposite or near the bunch, usually the fourth or fifth leaf from the base of the cane, were sampled. Similar samples are also used for monitoring nutrient status (Beyers 1962).

The leaves were then dried directly at 65° C or after washing to remove surface dust contamination (Leece 1976). Each sample was rinsed in six litres of 0.1 per cent (W/V) detergent

solution for two minutes ensuring complete immersion and continuous agitation. This was followed by three ten-second rinses in separate six litre batches of distilled water. The samples were then oven dried and gristed before analysis for fluorine (Wilson and Plues-Foster 1976).

Equations relating concentration to time of the form $F = a \times bt$ and $F = a \times bt - ct^2$ were fitted to data from sites intensively monitored during the growing season (F is fluorine concentration (ppm), a, b and c are coefficients and t is time in days since first sampling). There was no replication so that statistical comparison of washed vs unwashed, varieties or years was not possible. Any comparisons were based on general trends and correlations.

RESULTS AND DISCUSSION

The results of the monitoring studies and observations on fluoride toxicity symptoms are summarised in Appendix 1 and 2.

Fluoride toxicity symptoms

Although the oldest leaves generally showed the symptoms first (as a result of fluoride accumulation through time), severe symptoms were observed on young foliage affected by direct contact with excessive dosages of atmospheric fluoride. Leaves exposed towards the source of the fluoride generally developed the worst symptoms.

The onset of visual damage depended on fluoride output from the source, wind direction and climatic conditions. In 1976/77 and 1978/79 the symptoms were evident in early November whereas in 1975/76 the first visual symptoms of fluoride damage did not appear until late December. These differences may be related to moisture availability as the effects of humidity on damage have been recorded for a number of species with necrosis more severe on plants exposed to high humidity (MacLean 1973) presumably as a result of increased stomatal pore size. In comparison, water stressed plants are generally less sensitive to pollutants (Heck 1968).

The specific symptoms on grape leaves consist of marginal and tip necrosis in the early stages with the necrotic areas gradually expanding between the veins (Plates 1-3). The injured tissues may also fall off after a few weeks to leave an irregular border (Plate 3). In severe cases the leaves shed. The necrotic tissue has a bronze colouration (Darley *et al* 1966). A separate symptom sometimes observed involves necrotic irregular spots on the leaves and is associated with isolated fluoride-carrying rain drops on days of very high humidity with cloud cover. Severe fluoride toxicity on older leaves resembles premature senescence, potassium deficiency and salt damage and as a consequence late season symptoms on old foliage are unreliable. Young, recently affected foliage can still be used as this is unlikely to be affected by salt excess or potassium deficiency. Plant analysis can also be used to distinguish between fluoride and salt toxicity and potassium deficiency.

Where berries were exposed to high atmospheric fluoride concentrations, a pinkish skin discolouration occurred. In addition where large leave losses occurred the berries were affected by sunburn.

Native vegetation was also affected by fluoride toxicity with a distinct marginal and tip necrosis (Plates 4 and 5). In severe cases the leaves shed to leave bare branches and a 'staghorn' appearance.

Fluoride concentration in leaves

Effect of washing

Comparisons of washed and unwashed samples indicated there was a significant correlation between the two with unwashed samples having about twice the concentration of fluoride as the comparable washed samples (Table 1).

Table 1.—Comparison between washed and unwashed grapevine leaves.

Variety	Period	Regression Equation	r
Various	Jan 30, 1973	NW (ppm) = 40.7 + 1.12 W	0.66*
Pedro	Oct 14, '75-Nov 19, '76	NW (ppm) = 12.1 + 2.09 W	0.91***
Rhine Riesling	Oct 14, '75-Nov 19, '76	NW (ppm) = 14.7 + 1.80 W	0.95***
Muscat	Nov 10, '76-Mar 19, '76	NW (ppm) = 22.2 + 1.43 W	0.94***
Pedro	Oct 20, '76-Feb 23, '77	NW (ppm) = 5.6 + 2.15 W	0.96***

W = washed NW = not washed

Plants are exposed to fluorides in the soil and water as well as in the air, but the air-borne gaseous fluorides and soluble solids deposited on foliage are the principal contributors to accumulation in tissues. Dust containing fluoride is generally considered to be inactive (Marrier and Rose 1971).

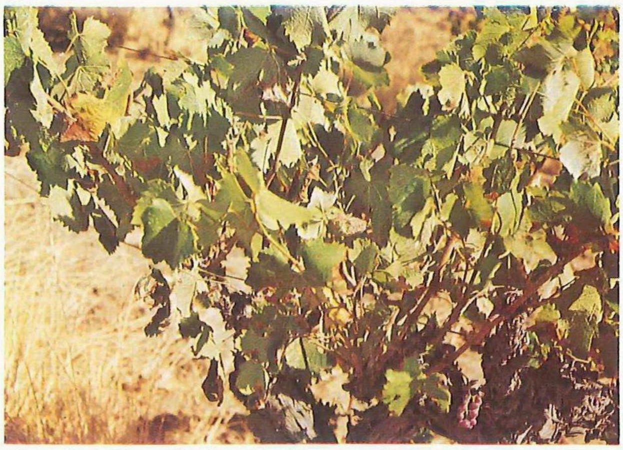

Plate 1. Fluoride damaged grape vine.

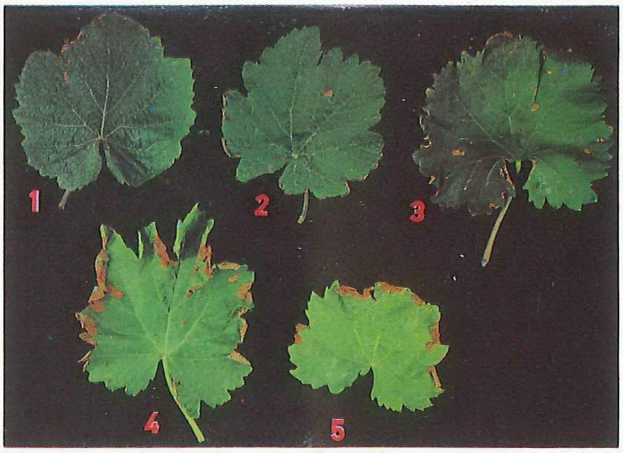

Plate 2. Range of fluoride affected leaves. Healthy top left.

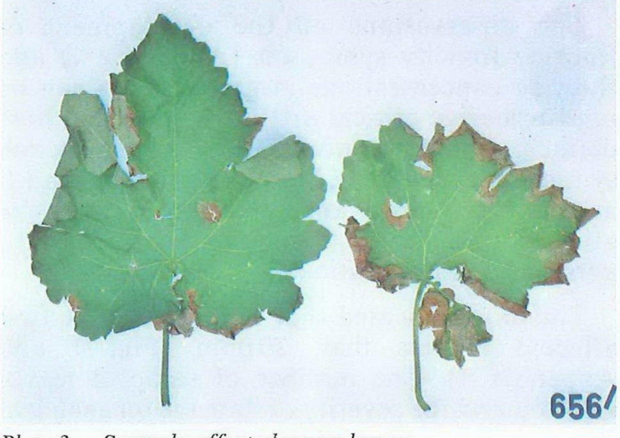

Plate 3. Severely affected grape leaves.

Plate 4. Fluoride affected eucalyptus leaves. Healthy left.

Plate 5. Fluoride affected branch. Note healthy young leaves.

As the ratio of gaseous to particulate forms of fluoride varies with the type of industry and distance from the source (Marrier and Rose 1971) it is likely that the fluoride concentration of washed samples would correlate best with the symptoms of fluoride toxicity and be most applicable under a wide range of environmental conditions.

Effect of plant part and leaf age

A specific comparison of the effect of leaf age on fluoride concentration was made on mid-season samples (December 23, 1975) and the effect of leaf age and plant part on late season samples (April 6, 1976) of Pedro, Muscat and Rhine Riesling (Table 2).

At the first sampling the concentration of fluoride in washed and unwashed leaves increased with age in all varieties. Pedro was consistently higher than Muscat and Rhine Riesling for washed samples (Table 2). When sampled in April there appeared to be an effect of

Table 2.—Effect of leaf age and plant part on fluoride concentration (ppm).

Plant part	Age	Treatment	Variety		
			Pedro	Muscat	Rhine Riesling
			ppm	ppm	ppm
December 23, 1975					
Leaf Blade incl. petioles	Young	W	9	5	1
		NW	26	28	35
	Mature	W	18	16	14
		NW	78	61	64
	Old	W	37	23	26
		NW	160	110	110
April 6, 1976					
Leaf Blade	Young	W	170	160	100
		NW	300	310	219
	Mature	W	180	160	130
		NW	310	260	220
	Old	W	170	170	150
		NW	330	280	330
Petioles	Young	W	8	10	7
	Mature	W	6	7	8
	Old	W	7	6	6

W = washed NW = not washed

leaf age in Rhine Riesling but no effect in the other two varieties. There was no effect of leaf age on the fluoride content of petioles. There was, however, a marked difference between petioles and blades (Table 2). Although the effect of leaf age was inconsistent it is obviously desirable for reproducibility to sample leaves of the same age particularly early in the season.

The low concentration in the petioles suggests that fluoride is not readily translocated from the leaves. Fluoride has been shown to enter the plant mainly in the gaseous form through the stomates and is transported to the leaf tips and margins (Thomas 1951). Because of the low concentration in petioles, whole leaves or leaf blades only should be used for diagnostic use.

Fluoride accumulation

Monitoring of fluoride levels in grape leaves in the period 1970/71-1979/80 indicated fluctuating levels of accumulation (Table 3 and Appendix 1). In each season fluoride concentrations in leaf tissues increased steadily as indicated by the positive b coefficient in the regression equations. The rate of increase was indicated by the magnitude of the b coefficient and this varied with both season and location (Table 3). Site 2 was consistently higher than site 1 and this was probably due to the closer location to the fluoride pollution source.

The flouride concentrations of the leaves indicated atmospheric pollution from fluoride as vines located on similar soil types in non-affected areas contained only 4-20 ppm (Anon 1972). The contribution from soil is unlikely to be significant because of the low total soil fluoride concentration (60 ppm) and the low solubility of soil calcium and aluminium fluorides (Marrier and Rose 1971).

The seasonal differences could be associated with the amount of fluoride output as well as climatic factors, particularly the incidence of south east winds and humidity. The rate of accumulation in the variety Pedro was considerably higher in 1975/76 and 1978/79 than in other years (Table 3). In the latter year it was particularly noticeable that the onset of severe damage coincided with prolonged periods of south easterly winds which carried fluoride from the source to this vineyard.

Fluoride concentration vs toxicity symptoms

The observations on the development of fluoride toxicity symptoms (Appendix 1) and fluoride concentrations in grape leaves can be used to derive critical or threshold levels; here defined as the concentration above which symptoms are evident. Metabolic processes such as photosynthesis and respiration may be affected at lower concentrations (Doley, personal communication).

The data indicated that old leaves were first affected at less than 20 ppm (Fig. 1 and Appendix 1). The number of sampled leaves affected and the severity of damage on each leaf increased until the concentration reached

Table 3.—Seasonal fluoride accumulation in grape leaves (ppm).

Variety	Period	Equation			
		Linear	R^2	Quadratic	R^2
Pedro[1]	14/10/75-19/3/76	W = -23.3 + 1.04 t	0.80***	5.2 - 0.24 t + 0.0009 t^2	0.96***
		NW = -20.1 + 1.69 t	0.81***	-6.3 + 1.07 t + 0.004 t^2	0.83***
Rhine Riesling		W = -19.7 + 0.85 t	0.80***	4.0 + 0.21 t + 0.007 t^2	0.98***
		NW = -25.1 + 1.61 t	0.82***	1.4 + 0.42 t + 0.008 t^2	0.88**
Muscat[1]	10/11/75-19/3/76	W = -20.5 + 1.22 t	0.91***	-1.9 + 0.18 t + 0.008 t^2	0.99***
		NW = -9.9 + 1.81 t	0.87***	0.0 + 1.26 t + 0.004 t^2	0.88**
Pedro[2]	27/1/76-8/3/76	W = 97.7 + 1.32 t	0.96***		
		NW = 223.0 + 1.06 t	0.20^{NS}		
Rhine Riesling[2]	8/3/76	W = 67.8 + 1.98 t	0.99**		
		NW = 181.8 + 2.44 t	0.58^{NS}		
Pedro[1]	20/10/76-23/2/77	W = 4.4 + 0.56 t	0.97**	6.0 + 0.45 t + 0.0009 t^2	0.97*
		NW = 2.4 + 1.42 t	0.96**	12.3 + 0.45 t + 0.008 t^2	1.00**
Pedro[2]		W = 0.7 + 0.74 t	0.87*	15.5 - 0.24 t + 0.008 t^2	1.00**
		NW = 12.6 + 1.58 t	0.96**	25.4 + 0.75 t + 0.007 t^2	0.99**
Pedro[1]	27/10/78-2/3/79	W = 29.1 + 1.05 t	0.97**	22.6 + 1.54 t - 0.004 t^2	0.99**
Pedro[2]		W = 48.7 + 1.51 t	0.98***	48.9 + 1.50 t+ 0.0001 t^2	0.98**

[1] = Site 1 [2] = Site 2 W = Washed leaves NW = Unwashed leaves t = Time in days from first sampling

150 ppm (Fig. 1). In the majority of cases the leaves shed at higher concentrations. Comparison of these results with those obtained in 1976/77 suggests that damage may occur at even lower leaf concentrations. The suggested tolerance level is comparable to the 12-30 ppm obtained for a range of varieties in an independent study in the Swan Valley (Anon 1972). Comparison with other studies is confounded by lack of washing although if a factor of 2 is allowed, the data of Quellmalz and Oelschlager 1971 who recorded damage on unwashed leaves in the range 41 (July 1) to 321 (October 31) ppm, would also suggest a figure of approximately 20 ppm.

The threshold level may vary with varieties because of inherent differences in plant susceptibility although our data is not detailed enough to detect these differences. On the basis of visual symptoms alone local varieties have been ranked on the scale:—

Severe — Black Malaga, Red Emperor, Ohanez, Pedro, Semillon

Mildly Affected — Currants, Grenache, Shiraz, Cabernet, Chenin Blanc

All varieties were affected at high atmospheric fluoride concentrations. Analysis of grape leaves is a useful tool in diagnosing fluoride toxicity and the presence of fluoride pollution. However the measurement of fluoride accumulation through time can be assessed by an alternative simple and reliable method based on the use of lime impregnated filter papers (Wilson and Plues-Foster 1978). Results obtained with lime filter papers correlate well with *F* accumulation in grape leaves (Wilson and Plues-Foster 1978).

Although the development of leaf symptoms and fluoride concentrations in the leaves were highly correlated (Fig. 1) the symptoms could be the result, partly or wholly, of potasium deficiency and/or salt toxicity. Leaf and soil analysis for potassium indicated that the potassium status was adequate (Jones unpublished data) and in fact no potassium fertiliser is recommended for these soils. The chloride concentration in leaves at the majority of sampling times was sufficiently low (Appendix 1) to suggest that the leaf scorch was not due to salt. The desirable chloride level is less than 0.25 per cent with toxicity at levels greater than 0.5 per cent (Beyers 1962).

Native vegetation

As the opportunity arose, native vegetation in the vicinity of a brickworks was sampled and analysed for fluoride. The concentrations ranged from 63 to 3 400 ppm in washed leaf samples

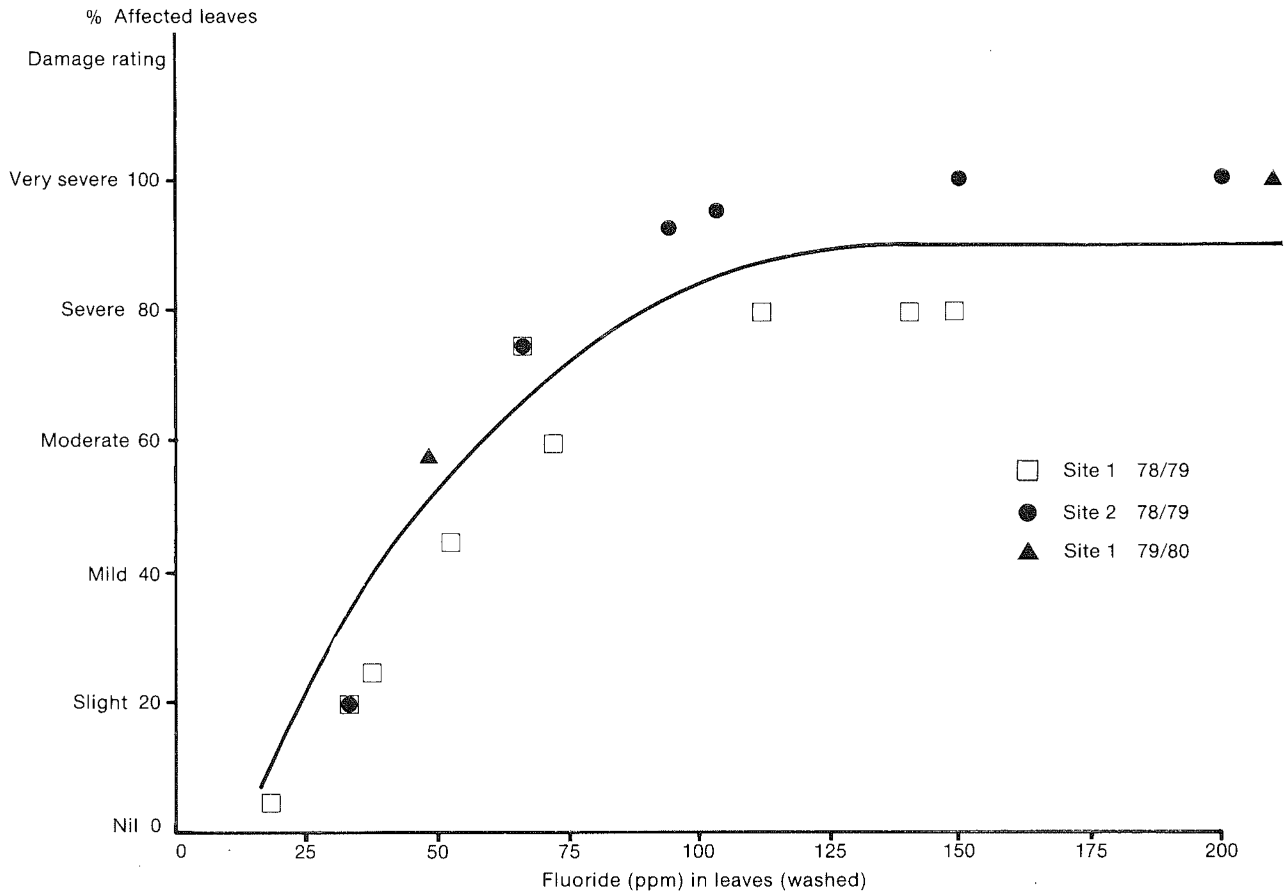

Fig. 1. Relationship between fluoride concentration in leaves and damage (variety Pedro 1978/79, 1979/80).

(Appendix 2). Comparable samples in the absence of noticeable fluoride pollution contained 9-19 ppm (Anon 1972). These concentrations are considerably higher than those found in grape leaves (Appendix 1) probably as a result of longer leaf life.

There was no sequential sampling to attempt to relate symptoms to leaf concentrations but observation of visual symptoms suggested that red gum was very sensitive while flooded gum, wandoo and sheoak were relatively tolerant. Olives grown in the area also appeared relatively resistant.

Economic considerations

The location of a number of brick and tile works in the Swan Valley has resulted in foliar fluoride damage to a number of vineyards. Unless fluoride output is controlled by pollution control equipment it is likely that more vineyards will be affected as brick and tile production expands.

In this study there was no attempt to assess the effect of fluoride toxicity on grape yield, quality and vine vigour. It is likely that leaf scorch and leaf fall could significantly reduce yield, quality and vine vigour depending on the severity and occurrence during the growing season. In addition there may be specific effects on photosynthesis (apart from leaf area) and on fruit set (Maclean *et al* 1977). During bunch formation (November-December), decreases in yield are related to the percentage of foliage removed whereas defoliation at veraison (first sign of colour in the grape berry [mid January-mid February]) had little effect on yield but reduced the final sugar content (Jones personal communication). Towards the end of the season when leaves become inactive, leaf loss would be relatively unimportant except for some disruption in the translocation of metabolites as a result of reduced leaf area.

Apart from the indirect effects of reduced leaf area there may be effects on fruit set. Observations of vines affected by prolonged fluoride toxicity indicated lower grape yields as a result of fewer bunches per vine and reduced grapes per bunch. There is little quantitative information about the effects of gaseous hydrogen fluoride on fruit or vegetable crop yields. Studies with beans found significant

reductions in pod number and weight although tomatoes grown at the same concentration showed no effect. The depression in yield in beans occurred despite the absence of any effect on leaf dry matter (Maclean *et al* 1977). Increased soil and litter fluoride through prolonged fluoride pollution may also reduce fruit yield. This has been reported to increase soil organic matter possibly as a result of reduced microbial activity (Rao and Pal 1978). This may increase fertiliser requirement because of reduced nutrient recycling.

CONCLUSIONS

Atmospheric fluoride pollution affects grape vines as a result of fluoride accumulation in older leaves or short term exposure of younger foliage to higher concentrations. Affected foliage becomes necrotic and under severe conditions the leaves shed.

Leaf analysis can be used both as a diagnostic tool to identify fluoride toxicity and to distinguish it from potassium deficiency or salt toxicity. Affected mature leaves (fourth and fifth from the base of the cane and adjacent to the fruiting bunch) contained greater than 20 ppm fluoride.

Seasonal monitoring of grape vines also provides a useful tool for assessing fluoride pollution although the lime impregnated filter paper technique would be simpler (Wilson and Plues-Foster 1978).

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REFERENCES

Anon (1972). An ecological appraisal of the effects of gaseous emission from clay brick manufacture on adjacent agriculture. Environmental Resources of Australia. Perth, Western Australia.

Beyers, E. (1962). Diagnostic leaf analysis for deciduous fruit. South African J. of Agric. Science. 5(2) : 315-329.

Brewer, R. F., Crevelling, R. K., Guillemet, F. B. and Sutherland, F. H. (1960). The effects of hydrogen fluoride gas on seven citrus varieties. Proc. Amer. Soc. Hort. Sci. 75 : 236-243

Darley, I. A., Nichols, A. and Middleton, P. (1966). Identification of air pollution damage to agricultural crops. Department of Agriculture, California. Bulletin 55.

Heck, W. W. (1968). Factors influencing expression of oxidant damage to plants. Annual Review of Phytopathology 6 : 165-88.

Jones, L. T. (1976). Air pollution damage to plants in the Perth region—Local Case Study in "Air Pollution and Plants" Symposium. Western Australian Institute of Technology.

Leece, D. R. (1976). Diagnosis of nutritional disorders of fruit trees by leaf and soil analyses and biochemical indices. J. Aust. Inst. Agric. Sci. 34 : 146-153.

Maclean, D. C. (1973). Fluoride phytotoxicity as affected by relative humidity. Proc. 3rd Int. Clean Air Congr. p. A 143-145.

Maclean, D. C., Schneider, R. E. and McCune, D. C. (1977). Effects of chronic exposure to gaseous fluoride on yield of field-grown bean and tomato plants. J. Amer. Soc. Hort. Sci. 102(3) : 297-299.

Marrier, J. R. and Rose D. (1971). Environmental fluoride. NRC (Canada) Publication No. 12, 226.

Quellmalz, E. and Oelschlager, W. (1971). Fluoride contents of air and plants in the vicinity of a brickworks. Staub-Reinhalt Luft. 31 : 29-31.

Rao, D. N. and Pal, D. (1978). Effect of fluoride pollution on the organic matter content of soil. Plant and soil. 49 : 653-656.

Thomas, M. D. (1951). Gas damage to plants. Annual Review of Plant Physiology. 2 : 293-322.

Weinstein, L. H. and McCune, D. C. (1970). Field surveys, vegetation sampling, and air and vegetation monitoring. In Jacobson, J. S. and Hill, A.C. (ed.). Recognition of air pollution injury to vegetation : a pictorial atlas. Air Pollution Control Assoc., Pittsburgh, P.A.

Wilson, P. E. and Plues-Foster, L. A. (1976). Report on fluoride uptake by grapevine leaves and limed filter papers from brickwork emissions. Part 1. Government Chemical Laboratories, Perth.

Wilson, P. E. and Plues-Foster, L. A. (1978). Report on fluoride uptake by grapevine leaves and limed filter papers from brickwork emissions. Part 2. Government Chemical Laboratories, Perth.

Appendix 1.—Concentration of fluoride in leaves.

Location	Species (Cultivar)	Date	F ppm W+	F ppm NW	Cl % W	Cl % NW	Symptoms
Four rows near winery	V. vinifera cv. Pedro	14.10.75	4	12	0.08	0.08	
		20.10.75	7	9	0.06	0.06	
		27.10.75	4	10	0.11	0.09	
		3.11.75	4	14	0.09	0.09	
		10.11.75	13	46	0.11	0.15	
		17.11.75	16	24	0.13	0.11	
		24.11.75	2	9	0.09	0.09	
		1.12.75	2	9	0.11	0.11	
		7.12.75	22	59	0.21	0.20	
		15.12.75	6	27	0.10	0.08	
		22.12.75	37	160	0.23	0.21	
		29.12.75	31	120	0.20	0.20	
		13.1.76	58	110	0.27	0.25	Some leaf scorch on exposed leaves.
		27.1.76	100	200	0.33	0.29	Some leaf scorch on exposed leaves.
		24.2.76	—	—	—	—	50% of leaves affected. Mainly exposed leaves.
		19.3.76	180	250	0.35	0.35	
	V. vinifera cv. Rhine Riesling	14.10.75	6	17	0.11	0.15	
		20.10.75	3	14	0.19	0.15	
		27.10.75	2	10	0.13	0.15	
		3.11.75	<1	4	0.04	0.08	
		10.11.75	10	33	0.34	0.30	
		17.11.75	11	21	0.28	0.23	
		21.11.75	1	4	0.08	0.08	
		1.12.75	1	10	0.11	0.11	
		7.12.75	17	22	0.29	0.29	
		15.12.75	6	24	0.08	0.12	
		22.12.78	26	110	0.29	0.27	
		29.12.78	39	140	0.35	0.29	
		13.1.78	50	100	0.31	0.27	Some leaf scorch on windward exposed leaves. Random aged.
		27.1.76	66	150	0.39	0.35	Slight amount of leaf scorch.
		24.2.76	—	—	—	—	Small amount of leaf scorch.
		19.3.76	150	260	0.49	0.45	
	V. vinifera cv. Muscat	10.11.75	2	16	0.05	0.04	
		17.11.75	1	3	0.04	0.06	
		24.11.75	1	3	0.06	0.06	
		1.12.75	2	9	0.04	0.04	
		7.12.75	9	47	0.06	0.06	
		15.12.75	9	23	0.08	0.04	
		22.12.75	23	110	0.06	0.06	
		29.12.75	28	100	0.06	0.06	
		13.1.76	36	57	0.08	0.08	No leaf scorch.
		27.1.76	74	130	0.12	0.12	Slight amount of leaf scorch.
		19.3.76	160	240	0.20	0.20	
150m west of east boundary of winery	V. vinifera cv. Pedro	12.11.75	—	24	—	0.07	Severe symptoms.
		13.1.76	—	—	—	—	Severe leaf scorch in random pattern.
		27.1.76	100	200	0.33	0.29	Severe leaf scorch on 50% of leaves
		10.2.76	110	250	0.31	0.27	
		24.2.76	140	300	0.33	0.29	
		8.3.76	150	230	—	—	
	V. vinifera cv. Rhine Riesling	12.11.76	—	—	—	—	
		13.1.76	—	—	—	—	
		27.1.76	66	150	0.39	0.33	
		10.2.76	100	250	0.39	0.35	
		24.2.76	120	280	0.47	0.43	
		8.3.76	150	250	0.49	0.47	
	V. vinifera cv. Muscat	12.11.75	—	—	—	—	
		13.1.75	—	—	—	—	Some leaf scorch in random pattern.
		27.1.76	66	150	0.39	0.35	Severe leaf scorch on 30% leaves.
		10.2.76	100	250	0.39	0.35	
		24.2.76	120	280	0.47	0.43	
		8.3.76	150	250	0.49	0.47	

Appendix 1.—Concentration of fluoride in leaves.—*Continued.*

Location	Species (Cultivar)	Date	F ppm W+	F ppm NW	Cl % W	Cl % NW	Symptoms
Four rows near winery	V. vinifera cv. Pedro	20.10.76	6	12	0.08	0.06	No leaf scorch.
		15.11.76	20	31	0.20	0.20	Considerable leaf scorch on old leaves.
		21.12.76	31	66	0.26	0.30	Medium amount of leaf scorch on older leaves. No new damage.
		19.1.77	60	120	0.35	0.35	Old scorched leaves have fallen off.
		23.2.77	74	190	0.51	0.51	New scorch on younger leaves in exposed situations.
150m west of east boundary of winery	V. vinifera cv. Pedro	20.10.76	16	28	0.08	0.08	Fair amount of leaf scorch on older leaves.
		15.11.76	13	48	0.18	0.22	Large amounts of leaf scorch.
		21.12.76	34	86	0.22	0.28	As above. Leaves now fully mature.
		19.1.77	56	160	0.33	0.33	Severe leaf scorch. Large per cent of old leaves shed. Also new damage.
		23.2.77	110	220	0.37	0.35	
Four rows near winery	V. vinifera cv. Pedro	27.10.78	17	—	—	—	Little damage. 5% of leaves affected.
		3.11.78	38	—	—	—	25% affected.
		13.11.78	54	—	—	—	44% affected
		8.12.78	72	—	—	—	60% affected
		5.1.79	110	—	—	—	80% affected. Extensive new damage of younger leaves. Older leaves shed.
		2.2.79	140	—	—	—	80% affected.
		2.3.79	150	—	—	—	86% affected.
150m west of east boundary of winery	V. vinifera cv. Pedro	27.10.78	34	—	—	—	Moderate damage.
		3.11.78	65	—	—	—	75% affected
		13.11.78	94	—	—	—	93% affected.
		8.12.78	103	—	—	—	96% affected.
		5.1.79	150	—	—	—	100% lower leaves shed. Extensive new damage. Fewer bunches. Less grapes/bunch, liable to sunburn.
		2.2.79	200	—	—	—	100% affected.
		2.3.79	240	—	—	—	95% affected.
Four rows near winery	V. vinifera cv. Pedro	15.11.79	47	—	—	—	57% affected. Mild damage, not as severe as 1978/79.
		14.2.80	260	—	—	—	100% affected. Badly affected by new damage on youngest leaves.
		8.12.78	—	42	—	—	Old mature leaves affected
	Red Emperor	8.12.78	—	480	—	—	Very badly affected.
Middle Swan	Various	Nov 1971	(26-100)	—	—	—	Severe scorch.
	Currant	Nov 1971	4-7	—	—	—	Unaffected 2km from source.
	Various	Feb 1972	(32-300)	—	—	—	Severely affected.
	Pedro	20.3.72	—	230	—	—	Leaf scorch on young and old leaves.
	Canon Hall	28.11.72	30	60	0.08	0.10	Medium scorch. 1.6km W of kiln.
	Pedro	28.11.72	40	81	0.18	0.22	Medium scorch. 1.6km W of kiln.
	Ohanez	28.11.72	37	130	0.03	0.10	Medium to severe leaf scorch.
	Red Emperor	28.11.72	36	110	0.17	0.16	1km NW of kiln. Medium to severe scorch.
	Shiraz	28.11.72	39	90	0.16	0.17	1km NW of kiln. Medium leaf scorch.
	Pedro	28.11.72	48	90	0.12	0.14	2.1km NW of kiln. Severe scorch.
	Verdelho	28.11.72	43	91	0.13	0.14	1km NW of kiln. Medium scorch.
	Ohanez	28.11.72	37	90	0.10	0.12	Medium amount of scorch.
	Red Emperor	28.11.72	32	97	0.24	0.28	Winery. Medium scorch.

Appendix 1.—Concentration of fluoride in leaves.—*Continued.*

Location	Species (Cultivar)	Date	F ppm W+	F ppm NW	Cl % W	Cl % NW	Symptoms
Sites as for 28.11.72	Canon Hall Muscat	30.1.73	43	86	0.13	0.13	Slight scorch.
	Pedro	30.1.73	56	87	0.21	0.21	Medium to severe leaf scorch.
	Ohanez	30.1.73	48	140	0.26	0.29	Medium scorch.
	Red Emperor	30.1.73	74	140	0.40	0.49	Medium to severe scorch.
	Shiraz	30.1.73	86	140	0.23	0.27	Very slight scorch.
	Pedro	30.1.73	81	120	0.18	0.19	Severe leaf scorch.
	Verdelho	30.1.73	50	60	0.15	0.14	Medium leaf scorch.
	Pedro A	30.1.73	66	130	0.21	0.19	Very severe scorch. 1km WNW.
	Muscat B	30.1.73	50	110	0.14	0.18	Severe leaf scorch on young and old leaves.
	Ohanez	30.1.73	28	79	0.14	0.16	Medium scorch.
	Red Emperor	30.1.73	55	66	0.34	0.30	Leaf scorch on old leaves.
2.1 km West of kiln	Pedro	3.12.73	—	106	—	0.18	Severe leaf scorch.
		1.2.73	240	—	—	—	Severe leaf scorch.
Caversham	Ohanez	1.2.73	18	—	—	—	Slight marginal scorch.
2.1 km West of kiln	Pedro	1.2.73	200	—	—	—	Severe leaf scorch
		23.10.74	—	12	—	—	Slight marginal leaf scorch
		23.10.74	—	8	—	—	Slight marginal leaf scorch
		23.10.74	—	10	—	—	Very slight only on oldest leaves.
		28.11.74	25	—	—	—	Healthy recently matured leaves.
		28.11.74	19	—	—	—	Marginal leaf scorch.
		28.11.74	18	—	—	—	Healthy.
		28.11.74	12	—	—	—	Slight leaf scorch
		28.11.74	12	—	—	—	Healthy.
		28.11.74	7	—	—	—	Slight scorch.
	Pedro	6.3.75	—	260	—	—	Severe scorch.
		6.3.75	—	390	—	—	No scorch.
		6.3.75	—	290	—	—	Severe scorch.
		6.3.75	—	380	—	—	No scorch.
	Muscat	6.3.75	—	370	—	—	No scorch.
	Pedro	6.3.75	—	220	—	—	Scorch.
Middle Swan	Grenache	27.11.72	94	180	0.22	0.29	Medium to severe leaf scorch.
	Gallop's Black	27.11.72	68	100	0.20	0.20	Very severe leaf scorch.
	Canon Hall	27.11.72	53	98	0.16	0.16	Very severe leaf scorch.
		27.11.72	51	92	0.14	0.18	Very severe leaf scorch.
	Grenache	30.1.73	120	150	0.38	0.38	Severe leaf scorch.
	Gallop's Black	30.1.73	100	110	0.37	0.29	Severe leaf scorch.
	Canon Hall	30.1.73	76	98	0.25	0.27	Very severe leaf scorch.
		30.1.73	77	110	0.27	0.27	Very severe leaf scorch.
Caversham	Malbec	30.1.73	16	31	0.75	0.77	Bad scorch. Like salt.
	Cabernet	30.1.73	15	37	1.06	1.06	Bad scorch. Like salt.

Appendix 2.—Fluoride concentration in trees

Location	Species (Cultivar)	Date	F ppm W	F ppm NW	Cl % W	Cl % NW	Comments
Middle Swan Primary School	Redgum	28.11.72	220	300	0.83	1.00	Severe marginal scorch and mottle.
De La Salle College,	E. botryoides	28.11.72	270	300	0.59	0.63	Severe marginal
Middle Swan	E. botryoides	28.11.72	120	120	1.10	1.14	leaf scorch and tipping.
Nedlands Park,	Apricot	23.3.73	19	—	—	—	Healthy.
Middle Swan	Flooded gum	17.10.73	170	140	0.33	0.30	0.7 km N or kiln.
	Sheoak	17.10.73	63	97	1.77	1.90	Older leaves tipped 0.7 km NW kiln.
Swan River, Middle Swan	Flooded gum	17.10.73	1 250	1 300	0.85	0.83	Severe scorch. 0.15 km N kiln
Middle Swan	Sheoak	17.10.73	1 100	1 450	1.41	1.69	Some leaf tipping.
Middle Swan	Flooded gum	17.10.73	3 400	3 750	0.52	0.54	0.06 km N of kiln. Severe scorch.
Middle Swan	Sheaoak	17.10.73	890	960	0.97	1.02	Leaf mottling and slight tipping.
Middle Swan	Olive	17.10.73	1 400	1 400	0.23	0.24	Leaf mottling and yellow tipping.
Middle Swan	Flooded gum	17.10.73	1 100	1 000	0.16	0.15	0.13 km SE kiln. Severe scorch.
Middle Swan	Olive	17.10.73	1 250	1 250	0.31	0.30	Healthy tree located as above.
Middle Swan	Flooded gum	17.10.73	610	610	0.32	0.33	0.16 km W slight scorch.
Middle Swan	Olive	17.10.73	570	440	0.20	0.18	Older leaves yellow with some tipping.
Middle Swan	Flooded gum	17.10.73	310	330	0.72	0.68	0.4 km SE marginal leaf scorch.
Middle Swan	Red gum	17.10.73	130	120	0.24	0.28	Very severe marginal leaf scorch.
M. L. Whiteman	Flooded gum	4.5.80	150	180	—	—	Slight scorch.
Middle Swan	Sheoak	4.5.80	150	170	—	—	Healthy

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