INFLUENCE OF IRRIGATION, CROP THINNING AND CANOPY MANIPULATION ON COMPOSITION AND AROMA OF RIESLING GRAPES.

by

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Thesis submitted for the Degree
of Master of Agricultural Science.

April, 1986

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SUMMARY

Variations in the aroma of experimental lots of Riesling grape juice were investigated by subjective and objective means. These methods were used to assess the effect of viticultural practices: irrigation and lighter pruning, crop load, and shoot directioning which are suspected of affecting wine quality. Two years data are presented on the effect of these viticultural practices on fruit yield, vegetative growth and fruit composition during ripening. One seasons data on juice aroma assessment are presented.

Irrigation and lighter pruning resulted in an approximate doubling of fruit yield per vine with only a small delay in ripening. Crop thinning of irrigated and lighter pruned vines caused a halving of yield and a hastening of ripening compared with irrigated; such fruit ripened earlier than unirrigated but with the same yield. Shoot directioning on irrigated and lighter pruned vines had only minor effects.

Monoterpenes, a component of aroma, were extracted from the juice and measured by colour reaction. The concentration of `free volatile terpenes' (FVT) in the juice was not affected by the experimental treatments but significant treatment effects on the concentration of `potential volatile terpenes' (PVT) were observed. Irrigation and lighter pruning caused a significant reduction in PVT while crop thinning of irrigated vines resulted in a significant enhancement compared with irrigated alone in season two.
The concentration of PVT increased as grapes ripened.

Subjective assessment of juice aroma was carried out by a panel of six winemakers with experience in juice assessment. Although there were difficulties in data interpretation, panelists were able to discern differences in aroma intensity associated with fruit ripening and four members of the panel detected differences between

experimental treatments.

Multiple linear regression analysis of aroma score and FVT of all samplings showed a negative correlation for four of the six members of the panel. Regression analysis of aroma score and PVT concentration showed a positive correlation for two of the six members; there was no correlation for the other four members. However, when the data from the four treatments were compared at the same stage of commercial harvest (21 °Brix), the two low-yielding treatments (unirrigated and irrigated plus crop thinned) had higher PVT and aroma scores than the high-yielding treatments.

The significance and implications of these findings are discussed.

STATEMENT

I hereby declare that the thesis here presented is my own work, that it contains no material previously published, except where due reference is made in the text, and that no part of it has been submitted for any other degree.

I consent to this thesis being made available for photocopying and loan if accepted for the award of the degree.

(M.G.McCarthy)

ACKNOWLEDGEMENTS

I wish to express my sincere thanks to Dr.B.G.Coombe for his encouragement to undertake this work and for his guidance during the course of this program, and in the preparation of this thesis.

I thank Dr.P.J.Williams of the Australian Wine Research Institute who as my second superviser provided advice and whose initial work made this project possible.

Thanks are due to Messrs. R.Chapman, R.Day, D.Groom, A.Hoey, C. Hatcher and D.Wardlaw for being willing members of the assessment panel.

I acknowledge the specialist assistance of Mr.P.I.McCloud for help in the statistical interpretation of the voluminous data.

Financial assistance was provided by the S.A. Department of Agriculture which is acknowledged.

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1.0 INTRODUCTION

1.1 Measures of Fruit Quality for Wine

The winemaker assesses grape quality by measuring or judging a number of variables. The physical appearance of the fruit e.g. proportion of cracked or mouldy berries, can be assessed by inspection and the possible effect on quality allowed for. Chemical measures of juice are widely used and the interpretation of the results have been extensively discussed in the literature.

1.1.1 °Brix, pH, acidity and ratios

In cool grape growing regions of Europe sugar is a primary factor in the quality of the vintage and is considered to be the most important measure of grape quality (Huglin 1977). German wines are divided into three main categories based on °Oechsle+ of the must: the higher the °Oechsle the better the quality rating; no other chemical measure is considered necessary. In warm and hot regions quality indices based on °Oechsle or °Brix+ are insufficient determinants of wine quality e.g. Berg (1958) stated that Balling+ was practically useless as a measure of quality. Van Rooyen *et al.* (1984) suggested that °Brix alone was not suitable as an index for segregating high quality wines in South Africa. Amerine and Roessler (1958) noted that the ratio of °Brix to acid was helpful for a preliminary grouping of cultivars. Ough and Alley (1970) claimed that °Brix / % acid was a suitable index for defining optimum maturity of Thompson Seedless grapes.

\+ °Balling : A hydrometer scale expressing per cent soluble solids in an aqueous solution on a w/w basis, calibrated against sucrose solutions. The Balling hydrometer is calibrated at 60°F (15.5°C).

\+ °Brix : A hydrometer scale similar to Balling but calibrated at 20°C (68°F).

\+ °Oechsle : The Oechlse hydrometer gives a measure of the density of grape juice and is calibrated at 15°C.
Degrees Oechsle =[1000 x sp.gr. x(15°/15°)]-1000

However Du Pleissis and Luttich (1982) reported that °Balling/total acid of grapes may be ineffective in defining optimum maturity of grapes in warm irrigated regions. Somers and Evans (1977) stated that pH was probably the most important feature of a red wine. In a survey of young red wines Somers and Evans reported that, despite normal acid values, wines often had pH's greater than 3.7. Somers and Evans (1974) showed significant correlations between wine pH and sensory ratings of young red wines. In an attempt to combine °Brix and pH measures in one index Coombe *et al.*(1980) suggested an index of °Brix x pH^2 for defining ripeness. They claimed this ratio matched well with the data of optimal criteria for high quality Australian dry table wine. Du Pleissis and Roosouw (1978) however claimed that as irrigation may cause marked fluctuations in the otherwise steady rise in must pH, indices which include pH can lead to inaccuracies.

Ough (1969) made the novel proposal that the ammonia concentration of grapes could be an aid with °Brix/acid ratio in predicting optimum harvest. There are numerous other references in the literature to indices for grapes; these have been reviewed most recently by Du Pleissis (1984). But it appears that satisfactory wines can be made from a wide range of °Brix, acid, pH values or other measures suggesting that these analyses are in themselves of limited value as definitive measures of quality for finished wines under most Australian conditions. A more precise physico-chemical measure of quality is required.

1.1.2 Wine colour

Somers and Evans (1974) demonstrated a correlation between wine chemical measures and the order of ranking of two red wine cultivars by three wine judges. The authors were able to show a correlation between quality rating and both wine colour density and degree of ionization of anthocyanins for young 'Cabernet Sauvignon' wines for two successive vintages and for one vintage for young 'Shiraz' wines; the absence of any correlation for 'Shiraz' wines for the second vintage was attributed to some of the wines being "out of condition" and undergoing malo-lactic fermentation. Somers and Evans concluded by stating that "the observed correlation may provide a valuable objective guide to relative assessment of the present, and possibly future, merit of sound young wines of the same variety and style". Somers and Evans (1977) then developed analytical procedures for measuring wine colour density, anthocyanin and phenolic content, and measures of chemical age for young red wines; since that time these measures have been routinely used, especially by Australian researchers, to assess the effects of viticultural practises on red wine quality (e.g. Cirami *et al.* 1984).

Problems have arisen in correlating chemical measures of small wine lots arising from viticultural field experiments to commercial wine quality, often because such measures are not available for commercial wines. Where wines are made from field experiments complications can arise in winemakers' assessment of such wines. Freeman *et al.*(1980), in a four year study at Griffith, N.S.W., found that irrigation and pruning level had significant effects on wine quality. Irrigated vines resulted in a lighter-coloured, early-maturing style of wine with a lower proportion of pigments in the coloured form compared to the more intensly coloured wines from non-irrigated vines. Experienced wine judges could not, however, agree on which style was preferred. McCarthy and Downton (1981) reported significant irrigation effects on wine colour measures and, while individual members of an assessment panel scored wines from the three treatments as being significantly different, there was no overall consensus. Despite these problems in relating objective to the subjective assessment of wine judges or the consumer, the objective methods devised by Somers and Evans have found wide useage for red table wines. Such methods cannot be used for white wine.

1.1.3 Juice and wine aroma

A subjective measure of white wine quality currently being explored is that of juice aroma and flavour. The aroma and flavour of the fruit or must is being used by winemakers for rating grape quality. To this end one South Australian winery has introduced a formalized scheme of grape quality assessment. Cootes *et al.* (1981) demonstrated a high correlation between the rating of clarified grape juice and the score of wine quality of young white wines made from 'Riesling' grapes from three sites in the Barossa Valley. It should be noted that the statistical correlations were calculated from a small number of wines. In the scheme presently used at this winery emphasis is given to the aroma and flavour of the juice rather than measures of sugar, acid, pH, physical condition of the fruit and of vineyard macro-climate.

Du Pleissis (1984) queried the results of Cootes *et al.* (1981) stating that the °Brix and acidity values quoted were not applicable to the same cultivars under South African conditions. He further pointed out that Cootes *et al.* based their findings on only one year's results and suggested that variations could be anticipated. Jordan and Croser (1983) claimed that organoleptic assessment of fruit character may not be relevant for cultivars with high levels of odourless monoterpene forms because "the on-going hydrolysis during juice processing and fermentation could result in a fruit-derived aroma considerably different to that perceived in the fresh grape juice". Notwithstanding, Jordan and Croser stated that, for cultivars such as 'Muscat Gordo Blanco' and 'Riesling', the use of aroma and flavour assessment of juices as an aid in determining harvest date was valid.

1.1.3.1 Aroma and flavour quantification. Although schemes of juice assessment bring a degree of discipline to fruit quality rating, the approach is subjective and therefore relies on the members of the tasting panel. An objective measure of flavour or aroma either of the juice or wine would greatly assist in the determination of wine quality. Ideally such a measure should be capable of defining the degree and character of fruit flavour and aroma qualitatively and quantitatively after characterizing the components important in determining quality. In an extensive review Schreier (1979) listed 398 references to research work on flavour and his list included 39 alcohols now identified in grapes. In the last twenty years there has been a large increase in the number of compounds identified in juice and wine. More than 500 components have been identified, covering many classes of compounds from alcohols, esters, aromatics to oxygen- or nitrogen-containing heterocylic compounds. Continual development in analytical techniques and instrumentation will enable as yet undetected compounds to be identified. However, the mere knowledge of the existence of a compound in juice or wine is no evidence of its importance to wine flavour or overall wine quality.

1.1.3.2 The role of monoterpenes in grape and wine aroma. Over the last decade a combination of analytical and sensory data obtained by several research groups has shown a relationship between grape aroma and the concentration of volatile monoterpenoids. For example, Wagner *et al.* (1977) reported that muscat cultivars generally contain significant quantities of linalool, geraniol, citrol, citronellol and nerol whereas neutral aroma cultivars did not. Comparing samples taken from different regions within Alsace, France they showed that cultivars with a muscat aroma had a higher concentration of terpenes when grown in a favourable mesoclimate (Ribeauville; presumably of superior quality) than when grown in a less favourable mesoclimate

(Bergheim). Previously, Cordonnier and Bayonove (1974) had suggested that, in addition to the floral "free" monoterpenes, there also existed a non-volatile, acid labile, flavour-less form of these compounds. Williams and others at the Australian Wine Research Institute have rationalized and classified the monoterpenes of grapes into two classes (Figure.1.1.3.2) :

class a - odourless, non-volatile, water soluble sugar conjugates.

class b -b1 non-conjugated free volatile odourous compounds
-b2 non-conjugated, non-volatile, non-odourous compounds e.g. polyols.

Williams *et al.* (1983) have suggested that class b1 be called `free volatile terpenes' (FVT) and classes a and b2 `potential volatile terpenes' (PVT) since both conjugates and polyols may be converted to odourous FVT.

Wilson *et al.* (1983) stated that in order to assess the winemaking potential of fruit it is necessary to determine the concentration of both free and potential forms and, that quantification of the levels of free and potential terpenes could be used as a guide for assessing the effects of vineyard management strategies on fruit and subsequent wine quality. To date however the isolation and quantification of free and potential terpenes, whether individually or as a group has involved lengthy liquid extraction, reverse-phase absorbent column separation, hydrolysis and G.L.C. analysis of each sample. This procedure (Williams *et al.* 1982) is clearly only of use for research programmes. However, the development of a simple assay by Dimitriadis and Williams (1984) has enabled the acquisition of a large amount of data on both free and potential monoterpenes in juice and wine from field trials and winery processes.

FIGURE 1.1.3.2

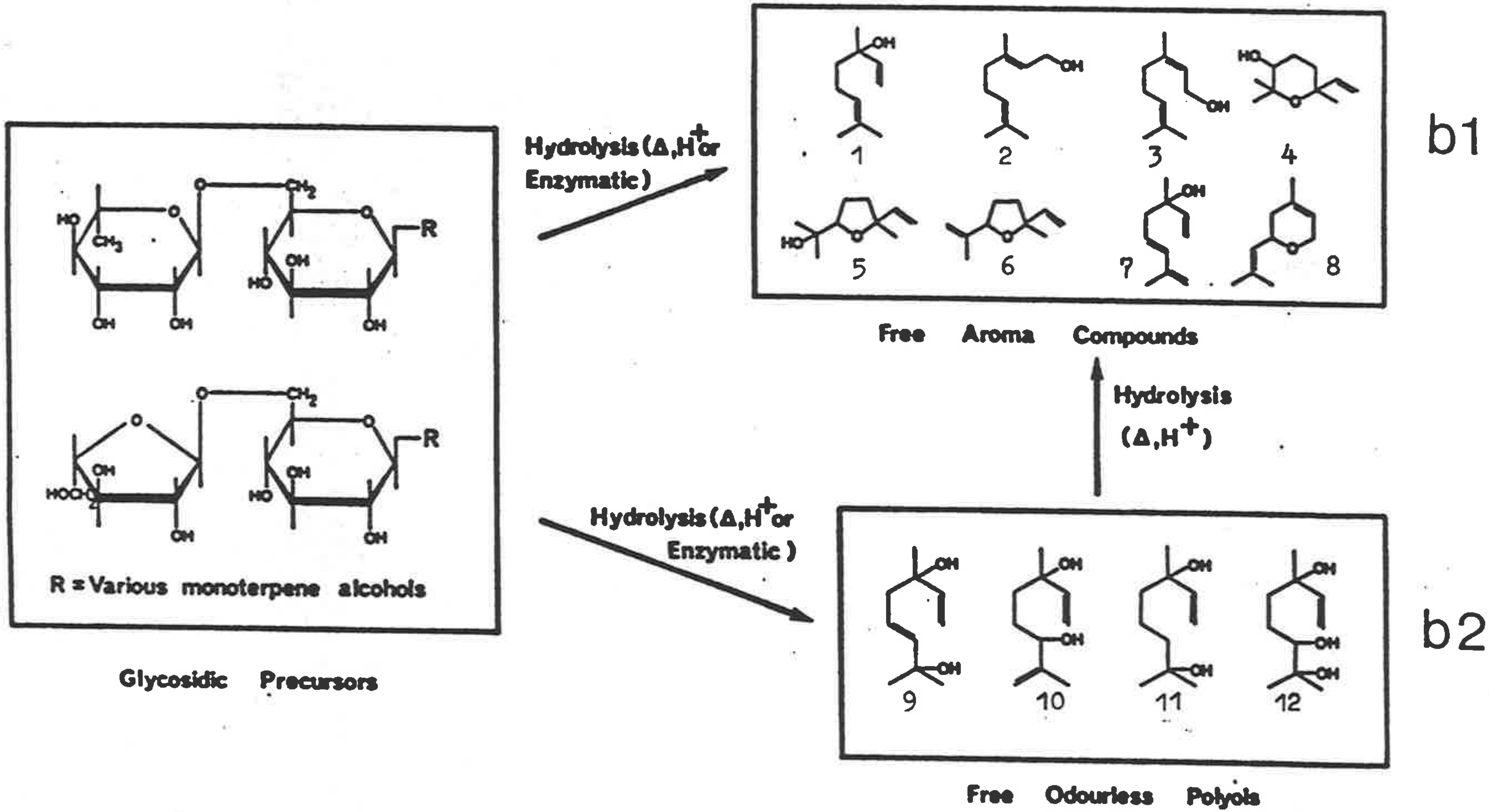
A classification of the monoterpene compounds of grapes. (From Williams *et al.* 1983)

class a - odourless, non-volatile, water soluble sugar conjugates.

class b -b1 non-conjugated free volatile odourous compounds
-b2 non-conjugated, non-volatile, non-odourous compounds e.g. polyols.

Identity of numbered compounds

1 linalool
2 geraniol
3 nerol
4 pyranlinalool oxide
5 furanlinalool oxide
6 anhydrofuranlinalool oxide
7 hotrienol
8 nerol oxide
9 3,7-dimethylocta-1,5-diene-3,7-diol
10 3,7-dimethylocta-1,7-diene-3,6-diol
11 3,7-dimethylocta-1-ene-3,7-diol
12 3,7-dimethylocta-1-ene-3,6,7-triol



Class a. **Class b.**

The assay developed by Dimitriadis and Williams is based on the earlier work of Attaway *et al.* (1967) with citrus juices. The method relies on the oxygen demand of $C_{10}H_{18}O$ compounds in the presence of a strongly acidified vanillin solution; the intensity of the blue-green colour developed in this reaction is directly proportional to the concentration of $C_{10}H_{18}O$ compounds at approximately 600 nm. Since its introduction in 1984 this assay has been employed by both oenologists and viticulturists as a possible measure of grape quality. Ewart *et al.* (1984) for example used the technique to examine geographic influences on monoterpene development in 'Mueller-Thurgau' grapes in New Zealand; Dimitriadis and others (unpub.) followed the development of free and bound terpenes in six cultivars in the Barossa Valley during ripening in 1984, and Nicholas (1984) measured free and bound terpenes in a range of cultivars in the Riverland of South Australia.

However the quantification of free and potential terpenes in the juice of a range of cultivars or viticultural treatments is not in itself sufficient to define an objective measure of grape or wine quality. Although Cootes *et al.* (1981) demonstrated a relationship between juice aroma and final wine quality, satisfactory correlations between objective measures and subjective assessment of juice aroma still have to be demonstrated before the former can be used as an indicator of wine quality. While free terpenes may contribute a significant level of aroma to cultivars such as 'Muscat Gordo Blanco' and related cultivars their role in the aroma of a lesser flavoured cultivar such as 'Riesling' remains to be determined. The role of FVT in determining juice aroma of 'Riesling' grapes was chosen as the objective of this thesis. Investigation of this aspect was considered to be best achieved by imposing a series of treatments on field-grown 'Riesling' grapes known to have significant effects on fruit yield and wine quality.

Choice of treatments for the field experiments

Irrigation and crop thinning

It is alleged that high quality wine can only be achieved by a low yield per vine, long shoots and no irrigation (Branas 1977) and any management practice such as fertilizer, rootstocks and irrigation that increases yield per vine will result in a decrease in wine quality.

The data of Berger (1977) however offer a serious challenge to such assertions. This author reported yield increases of upto 300% without loss of quality. Because of these divergent opinions on the influence of yield per vine on wine quality it was decided to study the influence of yield per vine on the FVT and PVT content of juices.

In the Barossa Valley grape yields are limited by pruning level and water supply. Increasing bud number without irrigation to stimulate additional vigour has no significant effect on yield (author-unpubl.). A combination of lighter pruning and irrigation can result in at least a doubling of yield (McCarthy *et al.* 1983) and accordingly this treatment was chosen to investigate the role of fruit weight per vine on terpene content.

Crop reduction on irrigated (and lighter pruned) vines was identified as a possible means of differentiating between the vigour enhancement effect and the increased yield effect of irrigation. Crop reduction on unirrigated vines was not included since a similar treatment on a different cultivar had no significant effects (author-unpubl.).

Fruit exposure

The role of fruit shading and grapevine canopy micro-climate on wine-grape quality has been reviewed by Smart (1985). Fruit shading has deleterious effects on must and wine composition by reducing must sugar concentration, the tartaric acid, polyphenol and anthocyanin content of the wine as well as wine flavour score. Improved cultural techniques such as irrigation, the use of fertilizers and use of rootstocks which have led to an improvement in vigour have exacerbated fruit shading as the increased vigour has usually not been matched by a change in vineyard design.

The canopy manipulation treatments used by Smart *et al.* 1985 were at uniform cropping levels; no papers have been seen on the effects of increasing fruit exposure on wine quality of both vines of enhanced vigour and vines of low vigour. Therefore, canopies were manipulated in this experiment to test whether FVT and PVT content could be influenced by increasing fruit exposure.

2.0 MATERIALS & METHODS

2.1 Location of field experiment.

The field experiment was conducted on the Nuriootpa Research and Advisory Centre at Nuriootpa in the Barossa Valley approximately 60 km north-east of Adelaide, South Australia. Some climatic data for the Research Centre are given in Table 2.1. Northcote (1965) defined the soil type as a Light Pass fine sandy loam, Dr 2.23. The trial rows were orientated east-west with a slight slope (less than 1 in 300) towards the western ends of the rows. The level nature of the site simplified the design of the drip irrigation system.

Table 2.1 Selected climatic data for Nuriootpa.
Rainfall and evaporation in mm. and temperature in °C.

	YEAR								40 year average		
	1981		1982		1983		1984				
MONTH	rain	evap.	rain	evap.	rain	evap.	rain	evap.	rain	max.temp.	min.temp.
January	16.2	279.2	18.5	301.5	4.8	282.6	17.2	267.6	17.5	28.7	13.3
February	14.2	236.2	3.6	224.6	3.2	263.2	2.6	246.6	24.7	27.6	13.3
March	37.4	143.8	27.6	189.0	126.0	143.4	21.6	192.8	18.6	25.5	11.3
April	5.8	125.6	73.0	107.6	67.4	71.0	39.2	102.6	39.7	20.9	9.0
May	57.6	63.4	27.0	52.2	56.0	50.0	30.0	71.2	63.7	16.7	6.5
June	95.2	46.0	45.4	38.2	22.2	36.0	32.4	47.0	55.1	14.7	4.9
July	89.8	53.6	18.2	41.4	95.2	38.8	70.0	38.3	65.7	13.3	4.2
August	113.6	66.4	13.0	81.8	63.6	63.8	110.8	62.4	66.4	14.0	4.2
September	43.0	94.8	33.2	113.4	77.6	100.2	61.8	78.9	52.8	16.7	5.8
October	31.2	135.2	18.6	157.4	37.4	142.0	21.6	163.2	54.0	19.8	7.3
November	34.0	183.8	3.6	265.4	36.2	221.2	29.0	233.4	31.9	23.2	9.7
December	4.4	255.2	5.0	263.8	19.8	277.8	11.8	289.8	24.3	25.9	11.7
TOTAL	542.4	1683.2	286.7	1836.3	609.4	1690.0	448.0	1793.8	514.4		

2.2 Planting material.

The vines used in the experiment were planted in 1974 as one year old potted vines. Cuttings had been collected the previous winter and grown under glasshouse/shadehouse conditions at the Research Centre prior to planting out in 1974. Vine spacing was 2.13m in rows 3.65m wide. Rows were ripped before planting and superphosphate applied in the rip line at 2.5 t per ha. Vines were furrow irrigated along the planting row with reticulated "town" water during the first growing season. During winter 1975, the experimental site was trellised and a drip irrigation system installed. The trellis consisted of a single fruiting wire at 1m height. Prior to the start of this experiment vines were cane pruned.

2.3 <u>Experimental site history.</u>

In winter 1977 a drip irrigation trial consisting of three different rates of water application was applied and this trial continued until winter 1981, when the present experiment was begun. There had been sufficient irrigated or unirrigated vines in the previous trial to ensure that in the new experiment vines which had not been irrigated continued to be unirrigated. This constraint however meant that each replicate consisted of a single row of vines.

2.4 <u>Treatments and Experimental Design</u>

The experiment commenced in 1981, however the juices collected for subjective aroma assessment during the 1982 harvest were not considered suitable for assessment even though data on terpene content and yield were collected and some of them are presented here. The 1983 harvest was marred by drought during winter-spring which significantly affected budburst on unirrigated vines. This was followed by above-average summer temperatures and then torrential rain in early March 1983 which resulted in fruit rotting; no data from that year are presented. The results from the 1984 harvest were not subject to the above difficulties and are the major data presented in this thesis. The experimental treatments were :-

Treatment A. Unirrigated.

Treatment B. Irrigated to 0.4 of weekly class A pan evaporation. and lighter pruning.

Treatment C. Trt. B. + crop thinned

Treatment D. Trt. B. + shoot trained.

A randomised block design with three replicates of four treatments was used. Each plot consisted of at least eighteen vines.

2.4.1 Irrigation treatments.

The irrigation treatment was designed to ensure that moisture stress did not limit the potential yield increase as a result of the increased bud number retained but also that excessive vegetative growth did not occur. On the basis of previous experimental work (McCarthy *et al.* 1983) a crop factor of 0.4 was chosen. Irrigation was commenced after berry set in each year and continued on a weekly basis until after the final sampling time. The calculated amounts of water were applied by metering equal periods during four days (Monday, Tuesday, Wednesday and Thursday) in each week, commencing soon after 9.00am on each day.

Calculation of water quantities applied.

The Department of Agriculture maintains for the Bureau of Meteorology a manual weather recording station on the Viticultural Research Centre. Daily readings of Class A Pan evaporation are recorded as well as temperature, wind direction and speed, wet and dry bulb temperature. Weekly evaporation was calculated using readings from Tuesday to Monday (Tuesday's reading is evaporation recorded from 9.00 am Monday). The volume of water to apply was calculated using the formula.

$$I = [(E \times C) - R] \times A$$

I = irrigation requirement in litres per vine

E = pan evaporation (mm)

C = crop factor

R = effective rainfall (mm)

A = area occupied by the vine (m^2)

All rainfall recorded during the irrigation season was assumed to be effective although there is evidence that in such situations summer rainfall is not effective in decreasing soil moisture potential (Van Zyl and Weber 1981). The calculated weekly water requirements per vine for 1984 are shown in Table 2.4.1. It can be seen from the table that little rain was recorded for the growing season except towards the end of the time for which experimental results are reported (i.e. after the week ending 2nd. March)

Table 2.4.1 Selected climatic data and volumes of water applied during the 1983/84 season

Week ending Monday	Evaporation mm	Rainfall mm	Calculated weekly water application L per vine
8/11/83	43.4	8.2	71.4
15/11	43.0	0.8	127.8
22/11	52.2	9.8	86.3
29/11	56.2	17.4	39.6
5/12	49.4	0.0	153.9
12/12	39.6	11.8	31.5
19/12	74.4	0.0	231.8
26/12	79.4	0.8	241.2
2/1/84	57.6	7.2	123.4
9/1	57.4	0.2	177.3
16/1	74.4	8.8	163.3
23/1	52.4	0.2	161.7
30/1	66.2	8.0	144.0
6/2	66.6	0.0	207.5
13/2	61.6	0.2	190.4
20/2	57.2	0.0	178.2
27/2	58.2	0.0	181.4
5/3	40.6	2.4	107.8
12/3	55.0	0.4	168.3
19/3	41.0	3.4	101.3
26/3	38.6	13.0	19.0
2/4	33.6	4.8	67.3
9/4	27.2	12.8	-15.0 *
16/4	34.4	20.0	-48.6 *
TOTAL	1259.6	130.2	2910.7

* no water applied

<u>Irrigation design.</u>

The drip irrigation system installed comprised a single 4L per hour Key-clip (James Hardie Irrigation Pty. Ltd.) dripper attached at each vine position to 13mm water supply lines along each row.

Water applications were controlled by a 7 day Venner time clock operating 12V solenoids situated in the experimental site. A Volumetric Water Meter (Dobbie Dico) was installed to measure the quantity of water applied and thus enable a correction factor to be used for the time clock to ensure that correct water volumes were applied. As the drippers used were designed to operate with water pressures of between 100-110 Kpa, two sets of in-line water pressure reducing valves were installed to adjust the pressure of the reticulated water supply to this range. A pressure gauge was installed in the main water line to the experiment to check the satisfactory operation of the pressure reducing valves.

2.4.2. Crop thinning treatment.

The crop thinning treatment was applied to irrigated vines and consisted of removing whole bunches per shoot. In the 1981/1982 season the distal bunch was removed during December from each fruitful shoot after berry set; this resulted in only a 22 per cent reduction in the number of bunches per vine as the average number of bunches per shoot on irrigated vines was about 3. In the 1983/1984 season a halving of the crop load was aimed for; this was achieved by removing all but the basal bunch on each fruitful shoot.

2.4.3. Canopy management treatment.

The method of M^c^Carthy *et al.* (1983) was used as it increased the number of bunches exposed to direct sunlight and also reduced the number of bunches shaded by one leaf layer. It consisted of training the foliage in a narrow vertical plane above the existing vine trellis (Figure 2.4.3). This was achieved by erecting four equally spaced pairs of wires each 25cm apart above the existing fruiting wires; the pairs were 20, 65, 110 and 155 cm above the fruiting wire. The highest pair was about 2.75 m above ground level. The growing shoots

FIGURE 2.4.3

Vertical trellis used in Trt.D showing dormant shoots trained between paired foliage wires.

were positioned as necessary between these foliage wires, commencing after berry set. Like the thinning treatment, the canopy management treatment was only applied to vines that were also irrigated.

2.5 Pruning levels

A doubling of yield was considered necessary to test adequately the effects of crop load on sugar and aroma measures in the fruit. A doubling in bud number, in addition to irrigation, was judged to be necessary to attain this increase. Hence unirrigated vines were pruned in winter 1981 to 34 buds per vine (as a combination of two canes and two two-bud spurs). Vines to be irrigated were pruned to about 68 buds (as four canes and four two-bud spurs). These pruning levels were maintained for the duration of the trial.

2.6 Estimation of vine leaf area.

Vine leaf area was determined in 1984 using a Li-Cor Portable Leaf area meter (Model L1-3000). From each of five vines per plot in each replicate of either unirrigated or irrigated vines 5 shoots were collected in late March. On each shoot the number of leaves present both on the primary shoot and lateral shoots were recorded. Both primary and lateral leaf blades were removed from all 5 shoots, sealed separately in plastic bags and held at 2^{o}C. From these bags 50 leaves were chosen at random, their area measured, and the areas of primary and lateral leaves per leaf and per shoot were calculated. The average number of shoots per vine was estimated by counting the number of shoots per vine after leaf drop on half of the vines in each plot of each replicate. An estimate of total leaf area per vine was then made.

2.7 Fruit sampling procedure and juice preparation.

Soon after veraison fruit was sampled from two randomly chosen vines in each plot at 7-10 day intervals. Sampling dates are given in Table 2.7. From each selected vine, sufficient bunches chosen at random were harvested to fill a 9 L bucket (2-3kg) and the bunch number and the weight of fruit were recorded. From this the average bunch weight was calculated. Sampled vines were not resampled so as to avoid the possible effects of fruit removal on subsequent ripening and aroma development of the remainder. At the fourth sampling time berry weight was determined from the weight of fifty randomly chosen berries from each of half of the vines in the experiment. After the final sampling the number of bunches remaining on each vine were counted. An estimate of yield per vine was made using the average bunch weight for each sampling and the total number of bunches per vine.

Table 2.7 Sampling dates and elapsed days from 26th January

Sampling date	Elapsed days	Sampling time
27/1/82	1	1
4/2/82	9	2
12/2/82	17	3
22/2/82	27	4
2/3/82	35	5
10/3/82	43	6
19/3/82	52	7
30/3/82	63	8
12/4/82	76	9
7/2/84	12	1
15/2/84	20	2
24/2/84	29	3
6/3/84	40	4
14/3/84	48	5
27/3/84	61	6
9/4/84	74	7
17/4/84	82	8

Harvested fruit was held overnight at 2°C. The two fruit samples taken from each plot were bulked and crushed in a Zambelli crusher-destemmer (Figure 2.7.1). The must was transferred to a water

FIGURE 2.7.1

Zambelli grape crusher-destemmer used for crushing and destemming fruit samples.

bag press (Figure 2.7.2) and the juice expressed at 300-350 Kpa under a cover of CO_2 into a 20 L stainless steel pail. The total volume of juice collected was measured and then transferred to a 4 L glass jar which was sealed and held at 2° C. A 1 L subsample of juice for the determination of FVT and PVT was taken from each 4 L jar, and held in glass stoppered reagent bottles at 2°C. Sodium metabisulphite was not added to this sample as the presence of SO_2 was known to interfere with the terpene assay (Dimitriadis and Williams 1984).A further 50 ml sample of juice was used for determination of °Brix, acid and pH. °Brix was measured with a bench model Abbe refractometer at 20°C. Titratable acidity (as g per L tartaric acid) was determined at an end-point of pH 8.2 using 1.33 N NaOH. Must pH was measured with a calomel electrode. To the remaining juice in the 4 L jar (1.5-2.5 L), sufficient sodium metabisulphite (as a 20g per L solution) was immediately added to give a calculated free SO_2 in the juice of 25 ppm; these juices were used for evaluation of aroma by a "taste" panel (on winemaker advice metabisulphite was not added in 1982 as it was thought at the time that the presence of SO_2 would intefer with aroma assessment but resultant oxidation rendered them unsuitable for panel assessment). As centrifugation or filtration were not practicable both sets of juices were held overnight at 2°C for settling. After settling, the supernatants of both sets of juices were carefully transferred by peristaltic pump into 1 L plastic screw cap bottles and stored at -10°C. Each set of juice for panel evaluation was transferred after two weeks to a -18°C freezer room for longer term storage.

FIGURE 2.7.2

Water-bag press in the open position used for expressing juice from the grape pulp.

2.8 Terpene analysis.

The method of Dimitriadis and Williams (1984) was used.

The 1982 juices were stored at -18°C for approximately 18 months before analysis whereas the 1984 juices were analysed within 12 weeks of harvest. Prior to analysis each 1 L plastic bottle of unsulphured juice was thawed to room temperature using a microwave oven; each sample was shaken by hand at three and six minutes to assist uniformity of thawing which was achieved in about nine minutes. A 550 ml sub-sample was adjusted to pH 6.8 with 20 per cent w/v NaOH. The juice was transferred to a 1 L three-necked flask fitted with a sealed thermometer, an addition funnel and a splash-head steam delivery tube. The juice was heated by means of a water bath slowly to 90-95°C. At this temperature steam was let in from a boiling water flask. Volatiles were collected using a short double-surface condensor cooled with recirculated coolant from a refrigerated water bath at 5-10°C. An initial 100 ml (measured gravimetically, Figure 2.8) for the determination of "free volatile terpenes " was collected in a glass bottle fitted with a plastic screw cap. Without interrupting the steam flow, a 200 ml bottle was placed below the condensor outlet and 15 ml of 40 per cent H_3PO_4 was added to the juice via the addition funnel. A further 200 ml of distillate was collected for the determination of "potential volatile terpenes". The distillate volumes collected were decided after an initial experiment in which 10 ml lots were collected serially and their terpene content assessed (Appendix 1). Distillates were stored at 4°C until analysis.

2.9 Measurement and calculation of terpene concentration.

Samples were analysed in batches of 24 (12 FVT distillates and 12 PVT distillates) with six standards of 0, 10, 25, 50, 75, 100 ug linalool. Ten ml of each distillate was pipetted into 20 x 150 mm pyrex test tubes fitted with silicon rubber seals and screw caps.

FIGURE 2.8

Glassware used to prepare terpene distillates showing steam flask, three necked flask, condensor and electronic balance.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The tubes were placed in a water bath at 2-4°C for 30 mins. 5 ml of vanillin/H_2SO_4 reagent was added slowly while the contents were constantly agitated in a beaker of cold water. Tubes were sealed, shaken and replaced in the 2-4°C water bath. When all tubes had been thus prepared they were transferred to a 60°C waterbath for 20 mins, then cooled to 5°C for 5 minutes. The optical density of all the samples was measured within 30 minutes at 608 nm (no filters, 3.0 nm band width) using 10mm disposable cuvettes. The water blank reading was subtracted from that of all the standards and unknowns. A regression equation was derived for each set of standards and used to calculate concentration (as mg linalool eqivalents per L) in the juice samples. An example of the standard curve and regression equation used is given in Appendix 2.

2.10 Juice preparation for panel assessment.

Juices were thawed in a microwave oven in batches of eight. A batch took about 55 minutes to thaw during which individual samples were shaken three or more times to ensure uniform thawing. Sodium erythorbate (50mg per L) was added to each litre container of juice (10ml of a stock solution of 5g sodium erythorbate per litre water). Free sulphur dioxide was measured by the Ripper method and adjusted to 20-25 mg per L where necessary. Each batch of eight juices was then placed in a refrigerator at 4-5°C. The preparation of a batch of juices took about 30 mins by which time the next batch from a second microwave oven was ready. A set of 48 juices took about 4 hours to prepare. Juice samples were chosen for an assessment session such that each treatment was present for each of the 8 sampling times (32 juices). An additional 2 juices from each sampling time were similarly chosen at random (16 juices). The juices were then numbered at random from 1 to 48 for a set. Approximately half an hour before the panel assessment six sets of juices were poured into numbered glasses. The juice assessment was carried out in a winery tasting room in which external noise and colour interferences were minimised (Figure 2.10).

2.11 <u>Panel assessment.</u>

The assessment panel comprised six winemakers from local wineries with experience in both white wine production and juice assessment. The panel met on two consecutive afternoons and assessed 48 juices on each occasion. Each panel member was asked to assess the intensity of the aroma of each juice and assign a score between 0 and 10; they did not taste the samples. There was no discussion between the panelists during the evaluation except when glasses with odd taints were noticed; these taints were caused by the glasses, not the juice, and in such cases new glasses were used. Each panelist assessed the juices at his own pace, some only taking half an hour, others longer.

2.12 <u>Analysis of results.</u>

Where applicable, results were analysed by analysis of variance. Comparison of the data for each sampling time is valid since vines were not resampled, i.e. each set of data can be considered sufficiently discrete to be treated separately. Mr. P.I. McCloud of the Mathematics and Computing Services unit of the Department of Agriculture carried out the statistical analyses of juice score and regression analyses. The analyses of variance of wine scores were derived from Brien (1983) using Genstat. Barlett's test (Johnson and Leone 1976 page 257) was used to test for homogeneity of variance between each panelist. Correlations of score with FVT and PVT was by multiple linear regression modelling. Non-orthogonality was tested for by changing the order in which terms were included in the model.

FIGURE 2.10

Winery tasting room used for juice assessment showing two members of the panel assessing juices.

33 b

3.0 RESULTS

3.1 1984 harvest

3.1.1 Fruit yield and its components.

Irrigation resulted in an approximate doubling of fruit weight per vine when averaged for all sampling times (compare Trts.A and B in Table 3.1.1). The increase in fruit weight on vines with vertically trained shoots (Trt.D) compared with irrigated alone was of the order of 10%. Crop thinning of irrigated vines (Trt.C) caused a large significant reduction in crop compared with irrigated only (Trt.B); the yield was only half that of Trt.B and was not significantly different from unirrigated (Trt.A). The increase in fruit weight per vine was primarily due to more bunches per vine on irrigated vines as a consequence of lighter pruning. Treatments had no significant effect on berry weight determined at the fourth sampling. Differences in the number of berries per bunch were significant but small, there being small increases attributable to irrigation.

Pruning weights were not different.

3.1.2 Vine Leaf Area

Irrigation resulted in an increase in total vine leaf area compared with unirrigated (Table 3.1.2). The increased leaf area was a result of more shoots per vine. Irrigation resulted in a small decrease in lateral leaf area.

3.1.3 Changes in °Brix

Sugar concentration increased by about 10 °Brix over the 70 days between the first and last sampling. Significant differences in °Brix were apparent between treatments for all but the seventh sampling time (Figure 3.1.3). At each sampling time except the sixth, Trt.C fruit had the highest °Brix (often significantly) and Trt.B and Trt.D the lowest. Figure 3.1.3 shows that after the second to fourth sampling

FIGURE 3.1.3

Change in °Brix with time during 1984 vintage

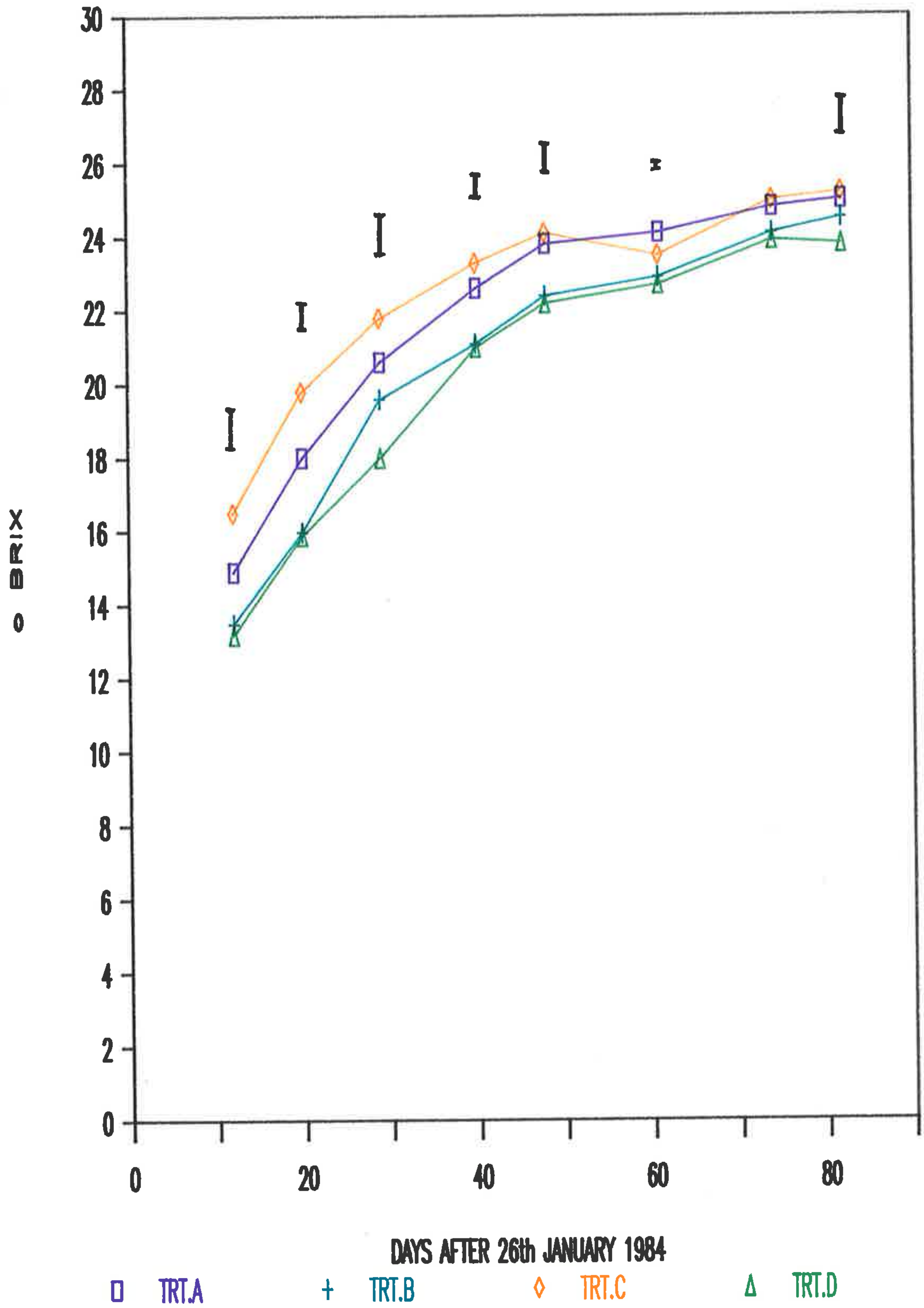
● Treatment A : Unirrigated

● Treatment B : Irrigated

● Treatment C : Trt.B + crop thinned

● Treatment D : Trt.B + shoot trained

Vertical bars indicate least significant difference ($P < 0.05$) between treatments at each sampling time. No bar = treatments do not differ significantly.



30
28
26
24
22
20
18
16
14
12
10
8
6
4
2
0
o BRIX
0
20
40
60
80
DAYS AFTER 26th JANUARY 1984
TRT.A
TRT.B
TRT.C
TRT.D

Table 3.1.1 Yield and its components for 1984 (average of all sampling times except berry weight and number of berries per bunch which was determined at time 4).

Treatment	Fruit wt. kg.per vine	No. bunches per vine	Berry wt g	No.berries per bunch	Pruning wt kg.per vine	Yield/pruning wt. ratio
A - Unirrigated	7.6	54	1.20	113	1.1	7.2
B - Irrigated	14.8	115	1.03	122	1.2	12.8
C - Irrigated & thinned	7.8	56	1.09	118	1.2	7.5
D - Irrigated & shoot trained	16.5	112	1.10	124	1.2	14.2
L.S.D 5%	1.5	20	N.S.	7	N.S.	Not determined

Table 3.1.2 Leaf variables of unirrigated and irrigated vines (Treatments A and B) estimated at sample time six.

	Unirrigated	Std.dev.	Irrigated	Std.dev.
No. of primary shoots per vine.	35	7.7	49	5.4
No. of primary leaves per shoot.	18	4.2	19	5.2
No. of lateral leaves per shoot.	34	8.5	31	7.0
Area of primary leaves (cm^2 per leaf).	70.2	9.2	75.1	7.1
Area of lateral leaves (cm^2 per leaf).	36.3	4.1	29.9	3.8
Total area of primary leaves(m^2 per vine).	4.4		6.9	
Total area of lateral leaves(m^2 per vine).	4.3		4.5	
Total leaf area per vine(m^2).	8.7		11.4	

there was a slowing in the rate of accumulation and a levelling by the eighth sampling. °Brix of Trt.B. and D, the high yielders, were similarly low throughout, while those for Trt.A and C were higher, especially until sampling time six. Quadratic computer modelling was done on °Brix (quadratic equations were not derived) (Table 3.1.3) : all treatments had similar quadratic coefficients but significantly different intercepts and linear coefficients; Trt.A had a significantly higher Y intercept than Trt.B while Trt.C had a significantly higher Y intercept than Trt.A.

Table 3.1.3 Summary of quadratic curve modelling of °Brix versus time for 1984 vintage.

Model term.	SSQ.	d.f.	MSQ.	Level of Significance.
Constant	360.75	2	180.38	***
+T.	27.07	3	9.023	***
+T.D.	5.262	3	1.754	***
+T.D_2	.269	3	.0897	NS
Residual	7.049	20	.3525	
Total	400.4	31		

+T Tested for difference in intercepts.
+T.D Tested for the difference in linear coefficient.
+T.D_2 Tested for the difference in quadratic coefficient.

NS = not significant.

*** = $P < 0.001$

3.1.4 Titratable acidity and pH.

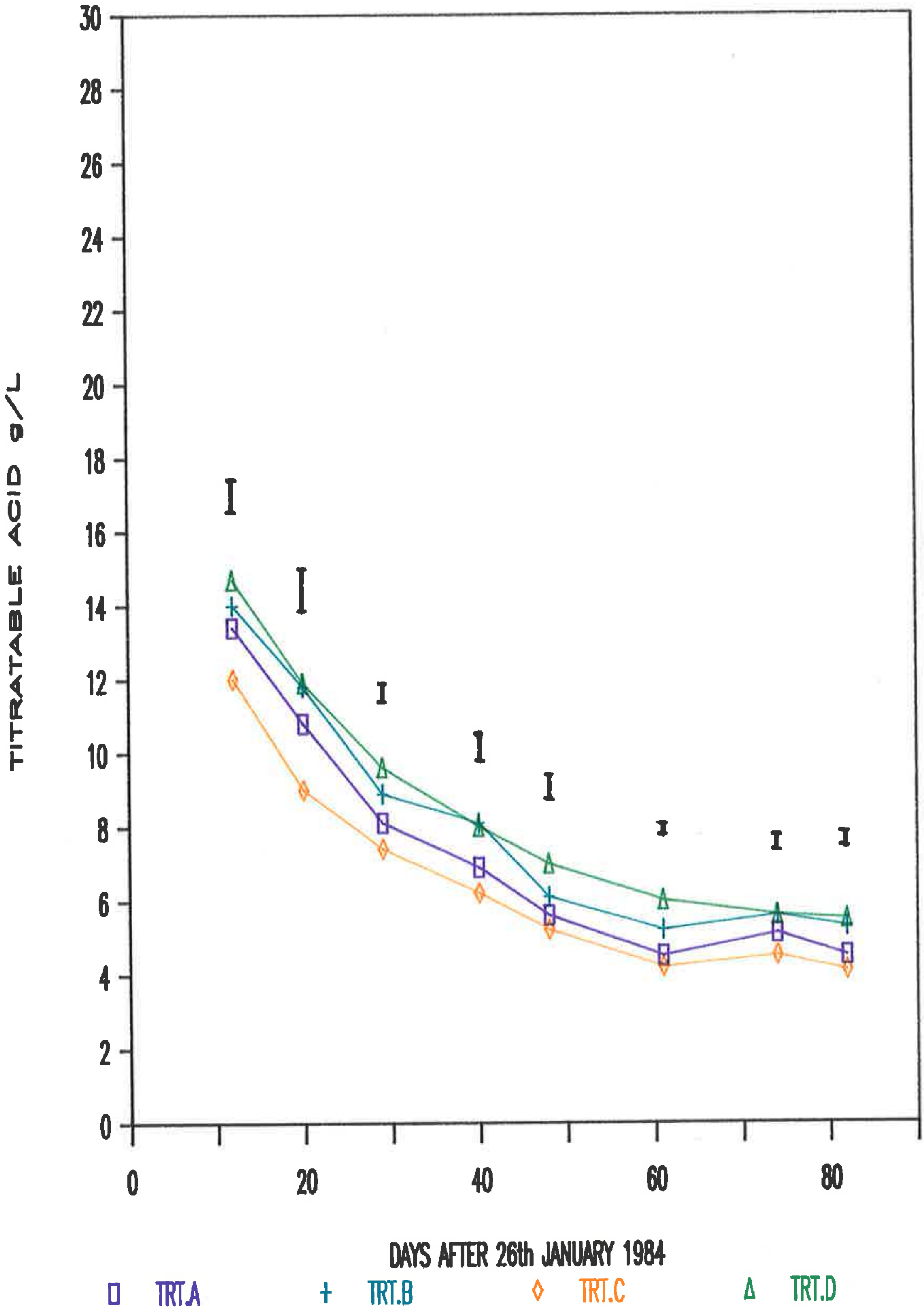
All treatments exhibited a similar decline in titratable acidity between the first and sixth sampling time after which there was a levelling (Figure 3.1.4.1). Titratable acid ranged from 14.7 (Trt.D at the first sampling) to 4.1 (Trt.C at time eight). At each sampling time Trt.C had the lowest acidity, significant at four times, and similar to Trt.A at other times. Irrigated and shoot trained vines (Trt.D) had the highest acid, significant at three samplings, and similar to Trt.B at other times. On the date when treatments attained 22 °Brix all had a titratable acidity of about 7.5 g per L.

FIGURE 3.1.4.1

Change in titratable acid with time during 1984 vintage

- ● Treatment A : Unirrigated
- ● Treatment B : Irrigated
- ● Treatment C : Trt.B + crop thinned
- ● Treatment D : Trt.B + shoot trained

Vertical bars indicate least significant difference ($P < 0.05$) between treatments at each sampling time.


TITRATABLE ACID g/L
30
28
26
24
22
20
18
16
14
12
10
8
6
4
2
0
0
20
40
60
80
DAYS AFTER 26th JANUARY 1984
TRT.A
TRT.B
TRT.C
TRT.D

There was an increase in must pH with time upto sampling time seven after which there was a decrease. Some of the differences in must pH (Figure 3.1.4.2) appear to be accounted for by ripeness differences; the ripest fruit had the highest pH. Comparison of Figures 3.1.3 and 3.1.4.2 shows that at six of the eight samplings Trt.C (irrigated and thinned) was riper than Trt.A (unirrigated) and at the other times of similar ripeness, yet Trt.A had a higher must pH than Trt.C at seven sampling times (significant at three).

3.1.5 Free terpenes (FVT)

The concentration of FVT of Trts.A and C was relatively constant from sampling times one to six and increased at seven and eight. The FVT content of Trts.B and D rose after sample time 5. The highest concentration was 0.62 mg per L for Trt.A (unirrigated) at sample time seven. There was no significant effect of treatment on the concentration of FVT in the juice at any sampling time (Figure 3.1.5).

3.1.6 Potential terpenes (PVT)

The concentration of PVT increased steadily during the ripening of the fruit for all treatments although there was a trend for a levelling off at later dates (Figure 3.1.6). The concentrations of PVT were higher than FVT starting at 0.56 to 0.83 and rising to 1-2 mg per L. Irrigation (Trt.B) caused a significant lowering of the concentration of potential terpenes in the juice compared with unirrigated (Trt.A). The addition of shoot training to irrigation (Trt.D) caused a small but non-significant reduction in PVT. At all times irrigated and crop thinned (Trt.C) was significantly greater than irrigated only (Trt.B) and at three sampling times was significantly higher than unirrigated (Trt.A).

3.1.7 FVT + PVT content per vine

The sum of FVT and PVT per vine was calculated using yield data and

FIGURE 3.1.4.2

Change in must pH with time during 1984 vintage

● Treatment A : Unirrigated

● Treatment B : Irrigated

● Treatment C : Trt.B + crop thinned

● Treatment D : Trt.B + shoot trained

Vertical bars indicate least significant difference ($P < 0.05$) between treatments at each sampling time. No bar = treatments do not differ significantly.

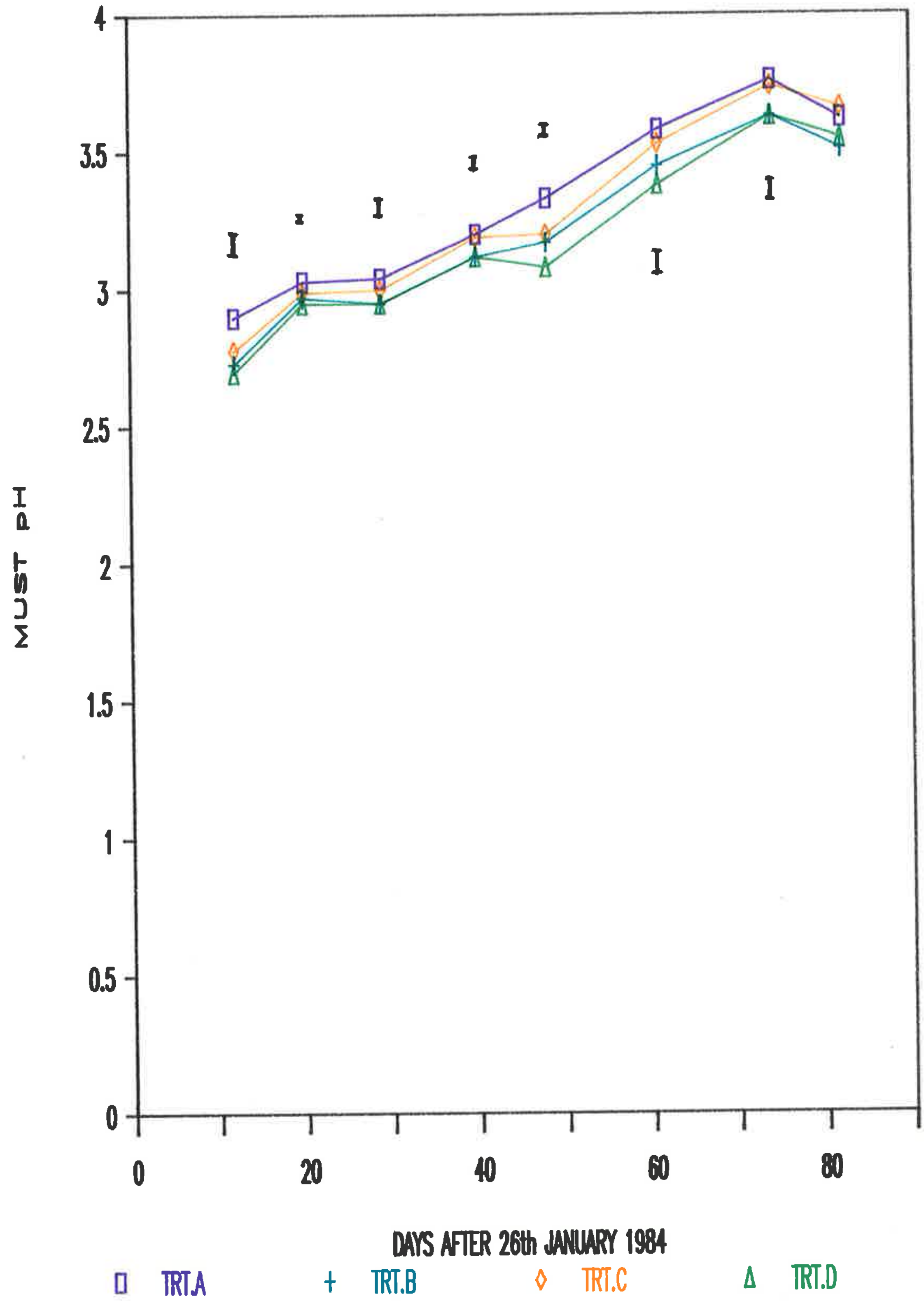

4
3.5
3
2.5
2
1.5
1
0.5
0
MUST PH
0
20
40
60
80
DAYS AFTER 26th JANUARY 1984
TRT.A
TRT.B
TRT.C
TRT.D

FIGURE 3.1.5

Change in FVT with time during 1984 vintage.

● Treatment A : Unirrigated

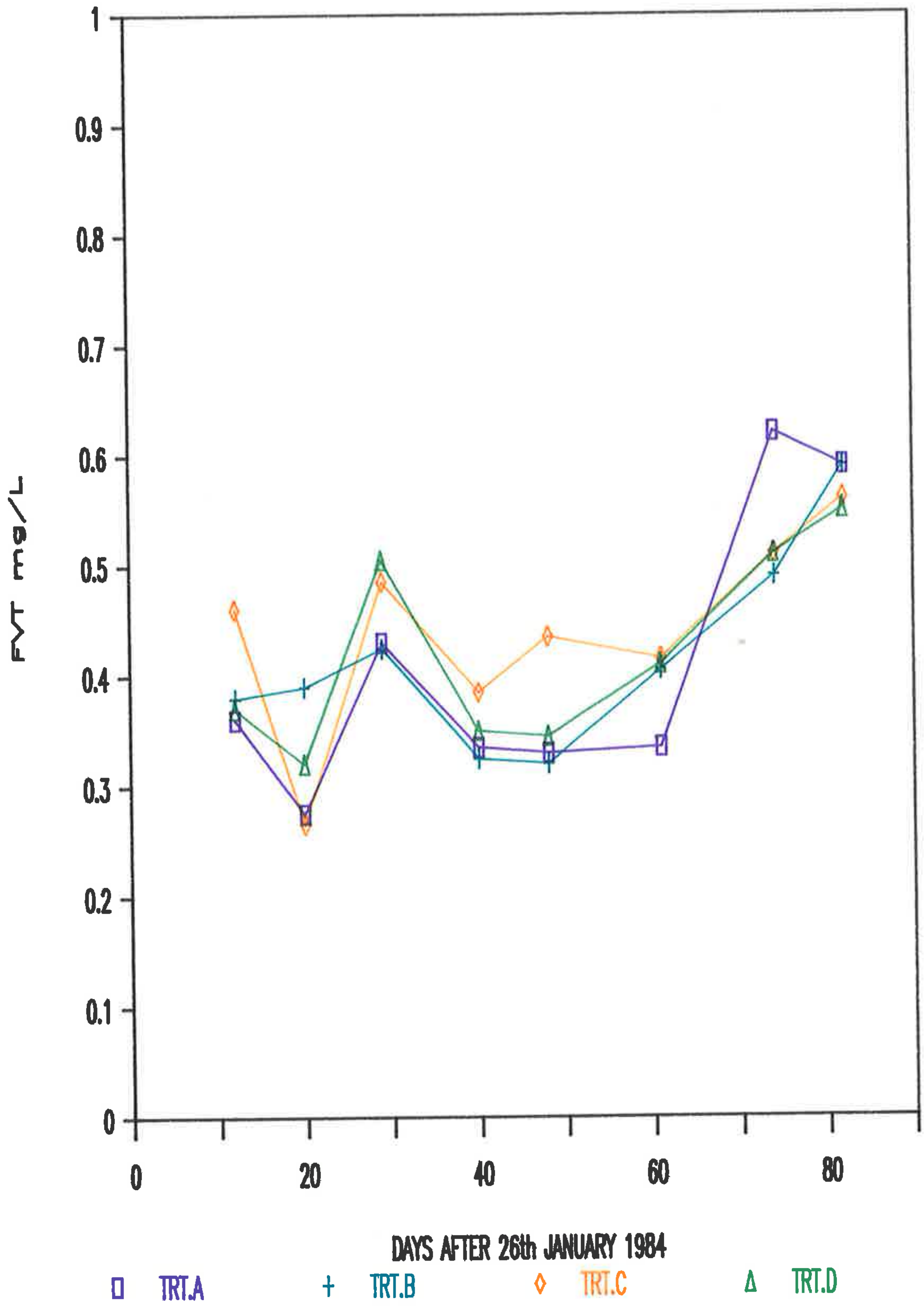
● Treatment B : Irrigated

● Treatment C : Trt.B + crop thinned

● Treatment D : Trt.B + shoot trained

There was no significant treatment effect ($P < 0.05$) at any sampling time.

.41 b



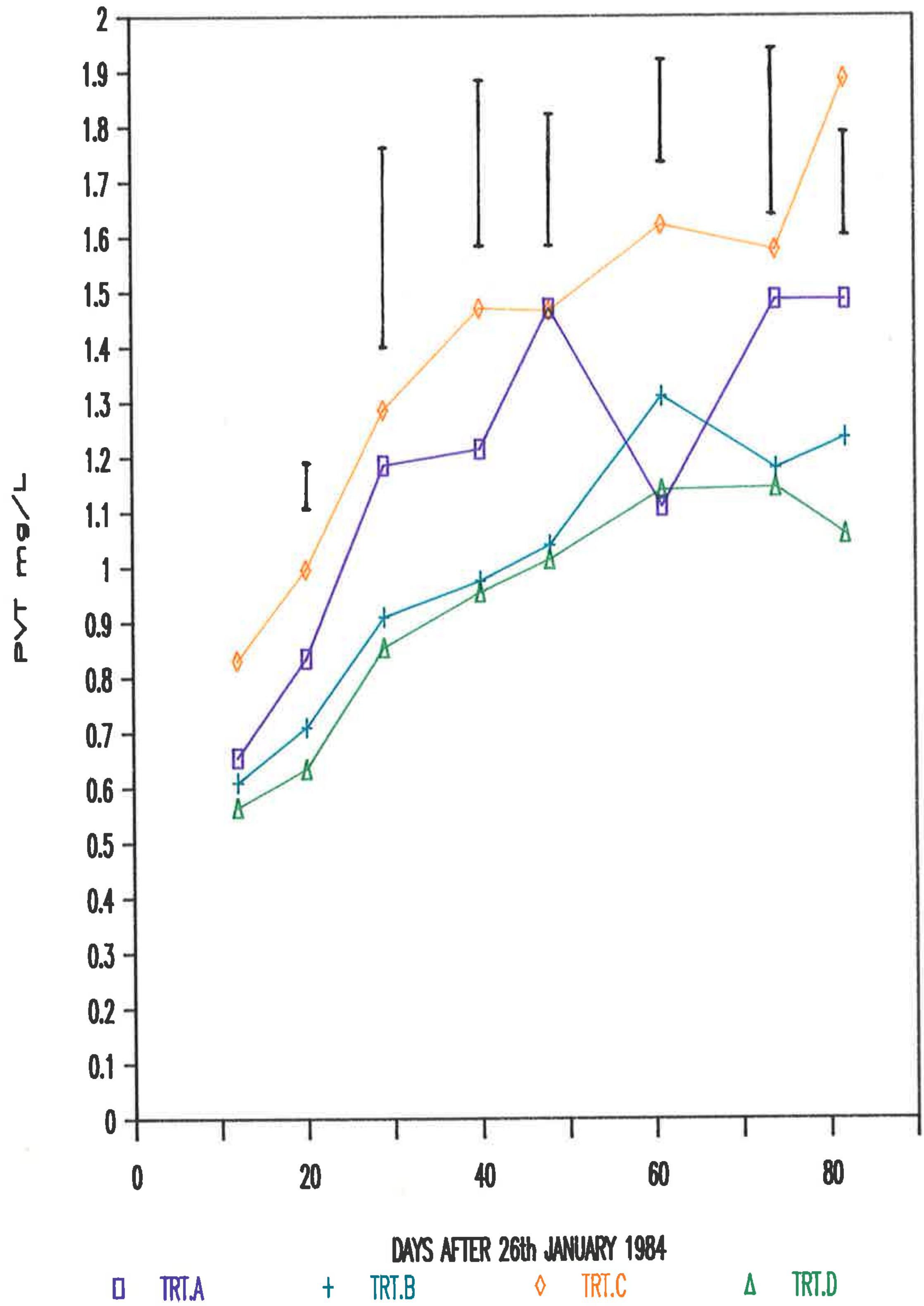
FVT mg/L
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
20
40
60
80
DAYS AFTER 26th JANUARY 1984
TRT.A
TRT.B
TRT.C
TRT.D

FIGURE 3.1.6

Change in PVT with time during 1984 vintage.

- Treatment A : Unirrigated
- Treatment B : Irrigated
- Treatment C : Trt.B + crop thinned
- Treatment D : Trt.B + shoot trained

Vertical bars indicate least significant difference ($P < 0.05$) between treatments at each sampling time. No bar = treatments do not differ significantly.


2
1.9
1.8
1.7
1.6
1.5
1.4
1.3
1.2
1.1
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
PVT mg/L
0
20
40
60
80
DAYS AFTER 26th JANUARY 1984
TRT.A
TRT.B
TRT.C
TRT.D

that of litres of juice per kg fruit. These values (Figure 3.1.7) show that high yielding vines (Trt.B & D) contained higher total terpene content than low yielding (Trt.A & C). Regression analysis of the data for treatments A and B (not week 6 for treatment A) shows there was no difference in the rate of increase in total terpene content.

3.1.8 Panel juice scores.

Juices were scored on a 0-10 scale although some members refrained from using the limit values of 0 and 10. Data from all juice assessments are given in Table 3.1.8.1.

Barlett's test for homogeneity of variance of each of the residual mean squares associated with the three error terms in the analysis of variance on each panelist (Table 3.1.8.2) confirmed that analysis of variance over all panelists was justified.

Table 3.1.8.2 Analysis of variance table for each panelist for test of homogeneity of variance.

		Mean squares for Panelist					
Source of variation	d.f.	1	2	3	4	5	6
Dayno(sample time)	7	25.833	14.494	47.368	30.390	6.010	32.475
Day(assessment day)	1	0.167	16.667	0.094	46.871	2.344	11.344
Residual	7	6.262	1.548	3.308	5.491	1.153	2.249
Replicate	2	0.080	0.620	1.305	7.956	4.317	1.929
Day.Replicate	2	3.305	1.555	1.918	3.089	2.342	0.687
Residual	28	2.532	1.553	2.198	3.306	1.852	2.763
Treatment	3	2.890	0.959	16.029	3.382	2.095	4.753
Dayno.Treatment	20	2.223	0.969	4.361	5.120	1.529	3.099
Day.Treatment	3	3.568	1.003	2.044	1.274	1.416	2.346
Residual	19	1.372	3.178	1.563	1.823	1.237	1.950

FIGURE 3.1.7

Change in FVT + PVT content per vine
with time during 1984 vintage.

● Treatment A : Unirrigated

● Treatment B : Irrigated

● Treatment C : Trt.B + crop thinned

● Treatment D : Trt.B + shoot trained

Vertical bars indicate least significant difference
(P < 0.05) between treatments at each sampling time.

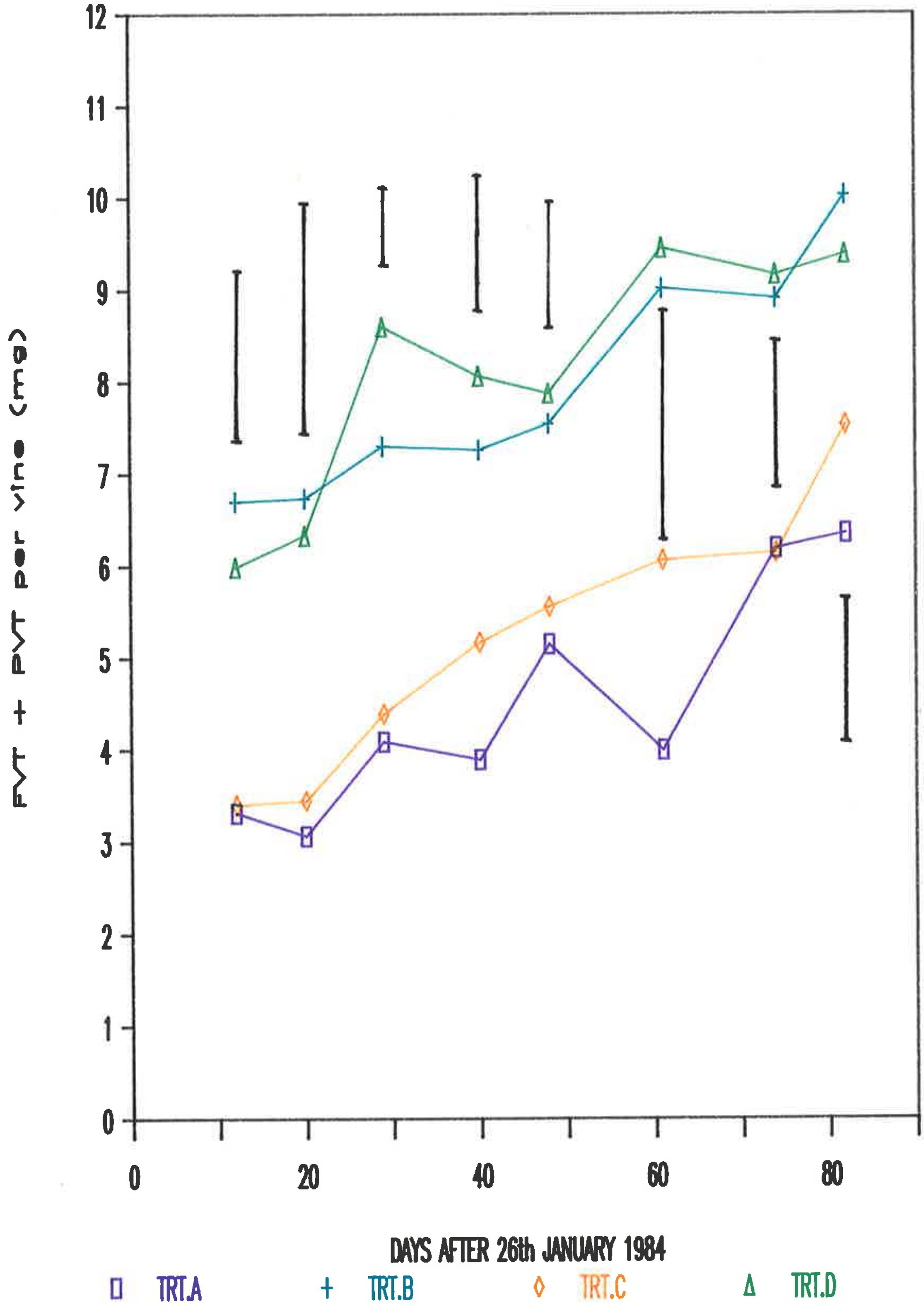

FVT + PVT per vine (mg)
12
11
10
9
8
7
6
5
4
3
2
1
0
0
20
40
60
80
DAYS AFTER 26th JANUARY 1984
TRT.A
TRT.B
TRT.C
TRT.D

Table 3.1.8.1 Complete set of juice aroma scores

DATE	TRT	REP	PANELIST 1	2	3	4	5	6	DATE	TRT	REP	PANELIST 1	2	3	4	5	6
7-FEB-84	A	1	1	1	1	0	3	2	14-MAR-84	A	1	9	8	9	7	6	7
		2	5	5	1	1	4	5			2	7	7	8	8	6	8
		3	5	6	2	4	5	4			3	5	5	5	7	6	4
	B	1	4	5	1	2	6	3		B	1	9	6	7	8	8	8
		2	2	4	2	1	3	4			2	7	3	8	8	6	6
		3	3	4	2	0	6	3			3	8	7	7	7	4	8
	C	1	3	4	1	1	4	4		C	1	6	8	7	6	6	6
		2	5	5	2	4	6	4			2	9	4	8	7	5	6
		3	3	5	2	1	8	4			3	7	7	7	7	6	5
	D	1	2	3	1	1	5	2		D	1	9	8	9	7	8	9
		2	4	3	2	0	6	2			2	9	7	7	9	6	7
		3	5	5	2	1	5	2			3	9	6	8	7	8	6
15-FEB-84	A	1	10	6	8	10	8	6	27-MAR-84	A	1	8	9	7	7	5	9
		2	8	7	7	7	8	8			2	7	7	6	8	9	10
		3	2	4	1	2	8	3			3	9	6	6	5	6	9
	B	1	4	5	3	3	7	2		B	1	6	4	7	5	4	10
		2	5	5	2	2	8	2			2	8	8	6	5	6	7
		3	6	6	2	4	8	4			3	8	7	6	6	8	8
	C	1	10	8	9	9	6	7		C	1	9	3	6	9	6	8
		2	9	8	8	8	7	9			2	7	7	6	5	7	7
		3	9	5	9	9	8	7			3	7	7	7	5	4	7
	D	1	4	6	2	5	5	5		D	1	8	7	8	8	5	7
		2	6	4	2	7	8	3			2	9	6	5	7	7	6
		3	4	6	3	1	7	5			3	9	7	9	7	7	7
24-FEB-84	A	1	8	8	7	7	6	8	9-APR-84	A	1	7	8	4	6	8	7
		2	10	3	9	9	7	8			2	8	7	7	6	3	9
		3	6	7	5	3	6	5			3	8	4	5	3	8	6
	B	1	5	6	5	3	6	5		B	1	6	5	7	6	6	8
		2	5	7	4	7	8	5			2	7	8	9	6	7	9
		3	6	6	5	2	8	5			3	10	8	8	9	5	8
	C	1	6	6	5	5	5	5		C	1	8	9	7	8	4	8
		2	10	5	7	8	4	10			2	8	7	7	5	5	6
		3	9	8	6	5	9	9			3	7	7	8	7	5	7
	D	1	4	6	3	8	7	4		D	1	10	7	7	9	5	9
		2	5	6	4	6	5	6			2	7	8	6	9	5	9
		3	7	4	4	3	7	3			3	8	7	6	9	6	6
6-MAR-84	A	1	9	8	9	10	6	8	17-APR-84	A	1	7	9	9	6	7	10
		2	8	7	7	10	8	7			2	7	9	8	6	7	9
		3	7	5	7	8	8	6			3	8	6	10	4	6	9
	B	1	7	9	5	9	5	8		B	1	7	6	5	5	6	4
		2	6	6	6	3	7	4			2	6	8	7	6	7	6
		3	6	6	5	3	6	5			3	8	7	5	5	6	9
	C	1	7	8	8	6	6	5		C	1	9	8	6	4	4	7
		2	7	7	10	5	7	7			2	8	8	9	6	6	10
		3	9	6	9	10	7	7			3	8	9	8	4	5	9
	D	1	7	7	7	6	7	5		D	1	8	9	10	9	6	8
		2	7	8	5	6	7	6			2	6	7	7	4	4	7
		3	7	8	4	8	7	5			3	8	8	6	7	5	10

Analysis of variance of juice aroma score for all panelists (Table 3.1.8.3) showed significant treatment, dayno. and day effects and significant two and three-way interactions.

Table 3.1.8.3 Analysis of scores of all panelists

Source of Variation	SSQ	df	MSQ	F	Significance
Panelist	68.769	5	13.754		
Dayno	806.965	7	115.281	13.96	***
Residual	289.022	35	8.258		
Day	41.821	1	41.821	16.39	***
Panelist.Day	35.664	5	7.133	2.80	*
Dayno.Day	50.793	7	7.256	2.84	*
Residual	89.277	35	2.551		
Replicate	5.085	2	2.543	1.59	n.s.
Day.Replicate	3.707	2	1.853	1.16	n.s.
Dayno.Day.Replicate	179.587	28	6.414	4.02	***
Panelist.Replicate	25.915	10	2.591	1.62	n.s.
Panelist.Day.Replicate	21.079	10	2.108	1.32	n.s.
Residual	223.627	140	1.597		
Treatment	45.909	3	15.303	8.606	***
Panelist.Treatment	44.418	15	2.961	1.665	n.s.
Dayno.Treatment	168.788	20	8.439	7.746	***
Day.Treatment	17.530	3	5.843	3.286	*
Residual	433.855	244	1.778		

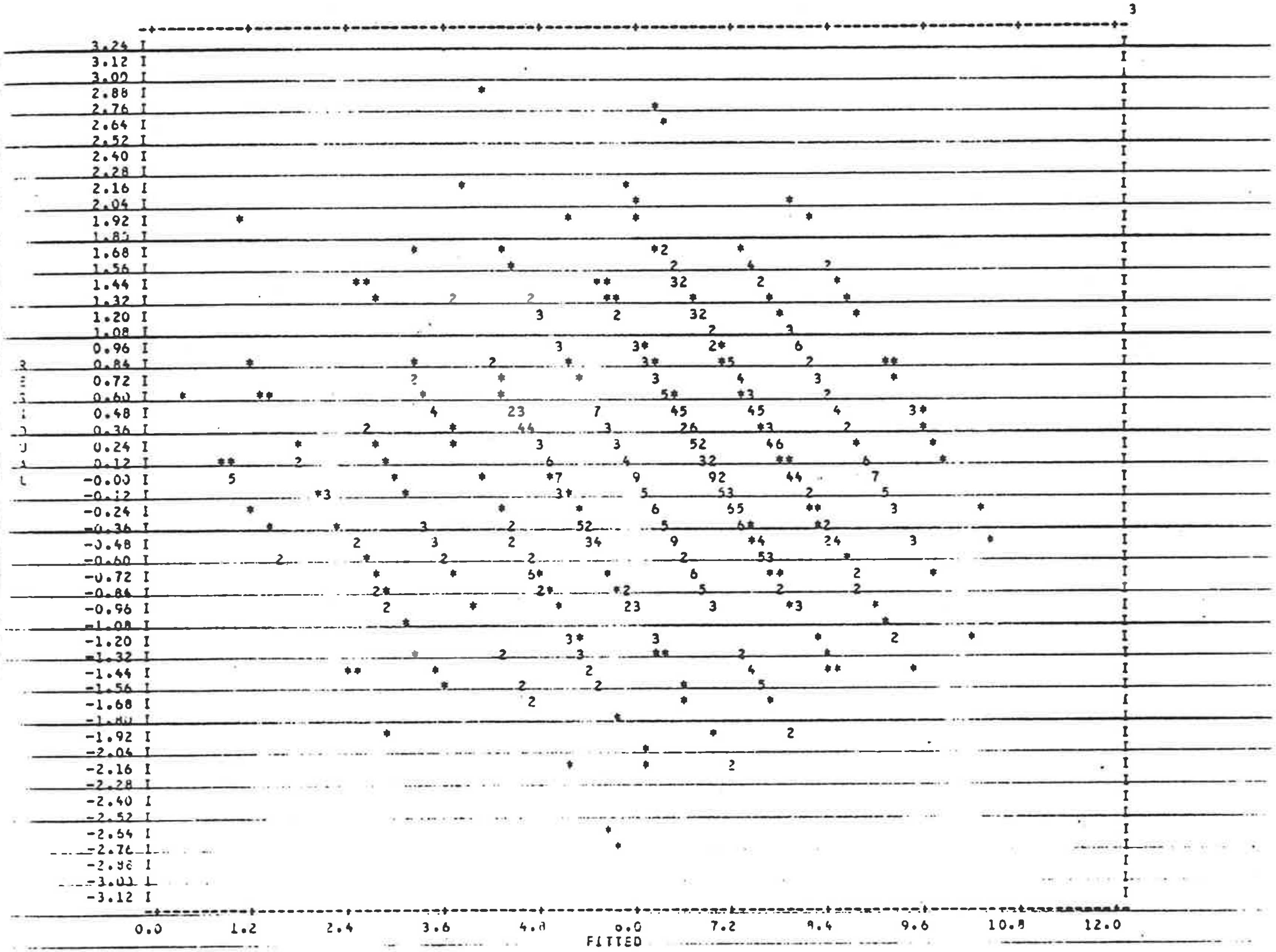
* = p < 0.5
** = p < 0.01
*** = p < 0.001
n.s.= non-significant

The plot of residuals versus fitted values showed a random distribution although there was some bounding due to the discrete nature of the data (Figure 3.1.8.1). Data transformation was not considered necessary.

Three members of the panel scored juices on day 2 higher than day 1; (Table 3.1.8.4) there was no significant difference between scores on day 1 or day 2 for the other three panelists. Juices from sample times two, four and eight were scored higher on day two than day one (Table 3.1.8.5). For the other sample times there was no significant difference in scores between day one and day two.

FIGURE 3.1.8.1

Plot of residual versus fitted values for the combined analysis of juice aroma score for all panelists.


FITTED
0.0 1.2 2.4 3.6 4.8 6.0 7.2 8.4 9.6 10.8 12.0
3.24 3.12 3.00 2.88 2.76 2.64 2.52 2.40 2.28 2.16 2.04 1.92 1.80 1.68 1.56 1.44 1.32 1.20 1.08 0.96 0.84 0.72 0.60 0.48 0.36 0.24 0.12 -0.00 -0.12 -0.24 -0.36 -0.48 -0.60 -0.72 -0.84 -0.96 -1.08 -1.20 -1.32 -1.44 -1.56 -1.68 -1.80 -1.92 -2.04 -2.16 -2.28 -2.40 -2.52 -2.64 -2.76 -2.88 -3.00 -3.12

47 b

Table 3.1.8.4 Juice aroma score for each panelist on each assessment day for all treatments and sampling times

Panelist	day 1	day 2
1	6.8	6.9
2	5.9	6.8
3	5.9	5.8
4	5.3	6.4
5	6.0	6.3
6	6.0	6.7

L.S.D. $(p < 0.5) = 0.66$
$(p < 0.1) = 0.89$
$(p < 0.01) = 1.17$

L.S.D's apply only for day 1 versus day 2 for each panelist

Table 3.1.8.5 Analysis ofjuice aroma mean score for day one and day two of assessment.

Sample week	day one	day two	mean score
1	2.9	3.6	3.3
2	5.2	6.4	5.8
3	5.9	6.2	6.0
4	6.3	7.4	6.8
5	7.3	6.7	7.0
6	6.8	7.1	6.9
7	7.0	7.0	7.0
8	6.5	7.6	7.0

L.S.D.(1)	$(p < 0.5) = 0.77$	1.0
	$(p < 0.1) = 1.04$	1.3
	$(p < 0.01) = 1.37$	1.7

L.S.D(1) applies only for day 1 versus day 2 for each sample week

Aggregate data show that panelists perceived an increase in juice aroma score for all treatments between the first and third sampling times; there was no further significant increase in the mean aroma score for all panelits for all treatments after sample time three.

When scores from all sampling times were pooled Treatments A, B and D were scored higher on day two than day one. Trt.C (irrigated + thinned), which was scored highest of all treatments on day one, was similar to Trt.A (unirrigated) on day two of assessment.

Table 3.1.8.6 Juice aroma score of each treatment for all sampling times and panelists.

Treatment	Juice aroma score day 1	day 2	mean score
Treatment A (Unirrigated)	6.3	6.8	6.5
Treatment B (Irrigated)	5.3	6.4	5.8
Treatment C (Trt.B + crop thinned)	6.6	6.6	6.6
Treatment D (Trt.B + shoot trained)	5.9	6.3	6.1
L.S.D. (p < 0.5) =	0.29	0.37	0.22
(p < 0.1) =	0.39	0.49	0.28
(p < 0.01) =	0.50	0.63	0.36

A majority of the members of the panel (five of the six) scored Trt.C (irrigated and crop thinned) significantly higher than Trt.B (irrigated) (Figure 3.1.8.2) and four scored Trt.A (unirrigated) significantly higher than Trt.B. Two panelists scored Trt.C significantly higher than Trt.A and one scored Trt.C lower than Trt A. Four panelists did not distinguish between Trt.B and D (irrigated and shoot trained); two scored Trt.D higher than B. Four panelists did not distinguish between Trt.A and Trt.D while two scored Trt.A higher than Trt.D.

Comparing the scores for each of the four treatments at all sampling times (Figure 3.1.8.3) the main result was the sharp rise

FIGURE 3.1.8.2

Mean juice aroma score for each treatment for each panelist for all sampling times.

Treatment A : Unirrigated

Treatment B : Irrigated

Treatment C : Trt.B + crop thinned

Treatment D : Trt.B + shoot trained

Vertical line indicates least significant difference ($P < 0.05$) between treatments for each panelist.

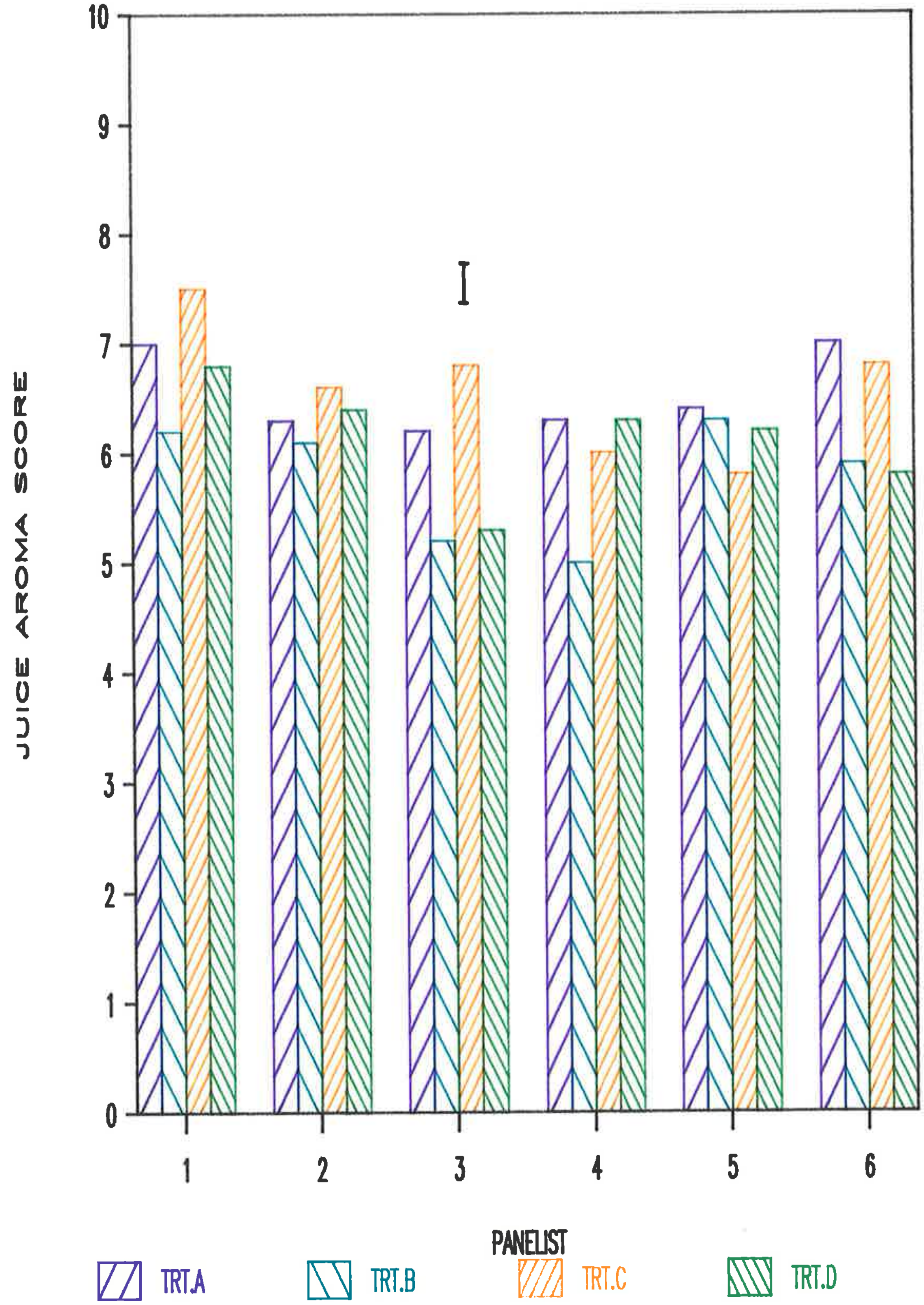

JUICE AROMA SCORE
0
1
2
3
4
5
6
7
8
9
10
1
2
3
4
5
6
PANELIST
TRT.A
TRT.B
TRT.C
TRT.D

FIGURE 3.1.8.3

Mean juice aroma score for each treatment at each sampling time for all panelists.

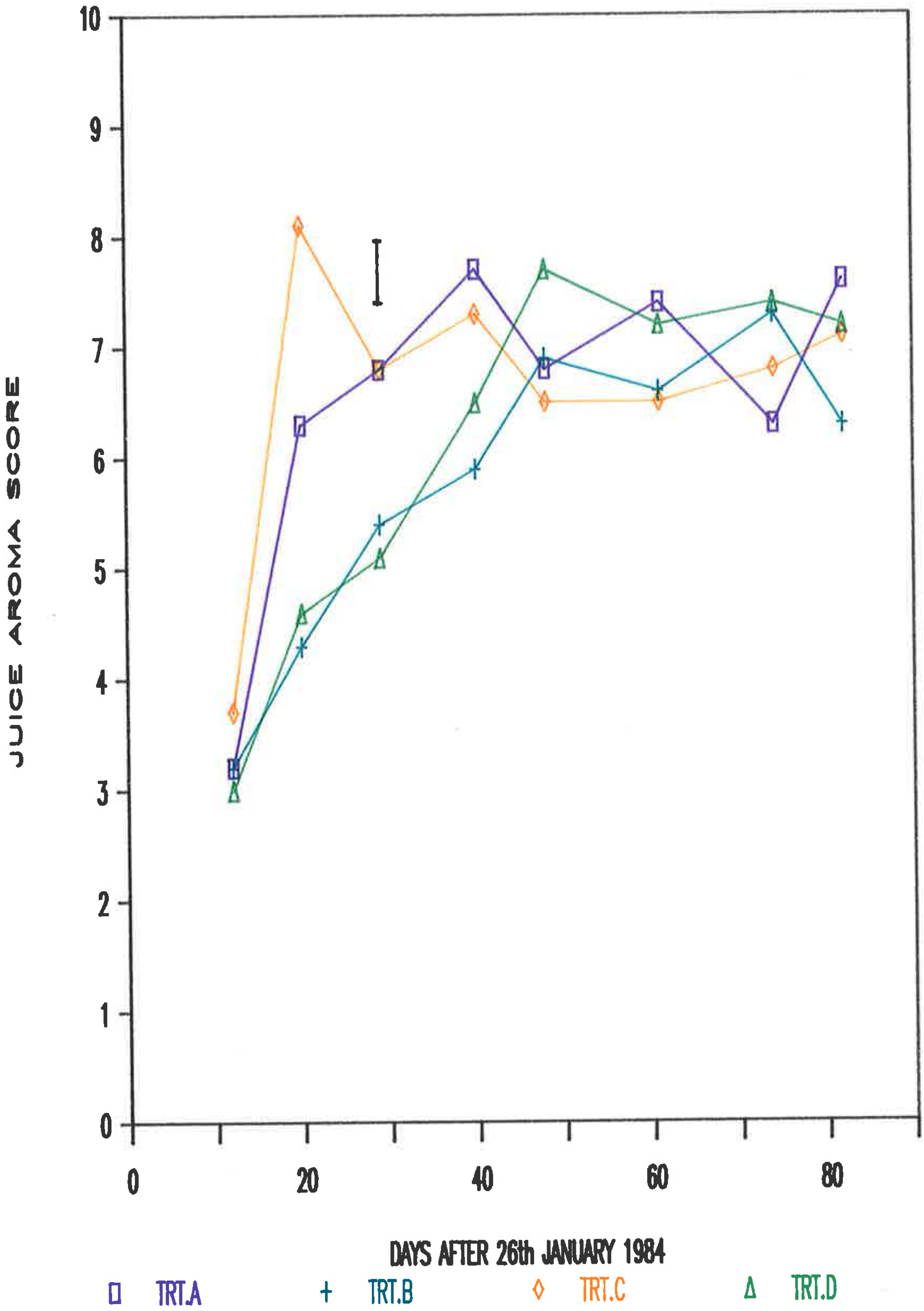
● Treatment A : Unirrigated

● Treatment B : Irrigated

● Treatment C : Trt.B + crop thinned

● Treatment D : Trt.B + shoot trained

Vertical line indicates least significant difference ($P < 0.05$) between treatments for each sampling time.


10
9
8
7
6
5
4
3
2
1
0
JUICE AROMA SCORE
0
20
40
60
80
DAYS AFTER 26th JANUARY 1984
TRT.A
TRT.B
TRT.C
TRT.D

after the first sample and the higher scores at times two to four for the two low yielding treatments (A and C) compared with the higher yielding treatments (B and D). After the fourth sampling time there was no increase in juice aroma score and treatment differences were not consistent.

3.1.9 Regression analyses of aroma score versus terpenes

The relation between score and terpene content was described by two multiple - linear regression models. The first model assumed the same slope for all four treatments and allowed for different Y intercepts while the second model allowed for different slopes and intercepts for each treatment.

The models were descibed by the following :

$$y_{ijkl} = \mu + \alpha_i + \beta_j + \gamma_k + \tau_l + \lambda x_{ijkl}$$

y = score

μ = overall mean

α_i = replicate effect (allowed for different intercepts for each replicate)

β_j = treatment effect (allowed for different intercepts for each treatment)

γ_k = day number effect (sampling time)

τ_l = day effect (day 1 or day 2 of assessment)

x = terpenes (FVT or PVT)

λ = slope (model 1 did not include this variable, model 2 did. If this was non-significant in model 2, model 1 was used.)

As sample time, assessment day and replicates were confounded in the juice assessment procedure the regression model data was tested for non-orthogonality to verify that these terms could be included separately. The test for non-orthogonality was performed by changing the order in which the 'Day' and 'Replicate' terms were added. When the 'Day' term was added before the 'Replicate' term (Table 3.1.8.6), the sums of squares associated with sampling day and replicate changed but were similar to the alternative order and at no time was any significance level at 5% affected. This procedure demonstrated the validity of the model.

Table 3.1.8. Test of non-orthogonality by modification to model for those panelists for whom model(1) could be used for FVT versus juice aroma score

	Method 1			Method 2	
	Change in sums of squares.	Significance		Change in sums of squares	Significance
Panelist 1					
Replicate	0.219	n.s.	Day	0.167	n.s.
Treatment	7.028	*	Replicate	0.233	n.s.
Dayno	25.833	***	Treatment	6.982	*
Day	0.056	n.s.	Dayno	25.833	**
Panelist 2					
Replicate	1.073	n.s.	Day	16.667	**
Treatment	1.181	n.s.	Replicate	0.861	n.s.
Dayno	14.494	***	Treatment	0.901	n.s.
Day	15.404	**	Dayno	14.494	***
Panelist 3					
Replicate	1.531	n.s.	Day	0.094	n.s.
Treatment	13.510	**	Replicate	1.528	n.s.
Dayno	47.368	***	Treatment	13.546	**
Day	0.194	n.s.	Dayno	47.368	***
Panelist 5					
Replicate	3.823	n.s.	Day	2.344	n.s.
Treatment	1.510	n.s.	Replicate	3.957	n.s.
Dayno	6.010	**	Treatment	1.681	n.s.
Day	3.122	n.s.	Dayno	6.010	***
Panelist 6					
Replicate	2.260	n.s.	Day	11.344	*
Treatment	9.122	**	Replicate	2.449	n.s.
Dayno	32.475	***	Treatment	9.247	**
Day	12.098	*	Dayno	32.475	***

3.1.9.1 Score and Free terpenes (FVT). The first model could be used to best describe the relationship between score and FVT for members 1,2,3, 5 and 6 of the panel (Table 3.1.9). Three claimed a significant negative correlation while for the other two panelists there was no significant correlation, positive or negative, between score and FVT.

There was a significant negative correlation between score and FVT for the single panelist for whom the second model could be used to best describe the relationship.

Table 3.1.9 Summary of multiple linear regression analysis of juice score with free and potential terpenes.

	Free terpenes						Potential terpenes					
	Panelist						Panelist					
	1	2	3	4	5	6	1	2	3	4	5	6
Model (1)												
Constant(mean)	***	***	***	***	***	***	NS	**	NS	NS	***	NS
Replicate	NS	NS	NS	*	NS	NS	NS	NS	NS	NS	NS	NS
Treatment	*	NS	**	*	NS	**	*	NS	**	*	NS	*
Day number	***	***	***	***	**	***	**	***	***	***	***	***
Day	NS	**	NS	**	NS	*	NS	**	NS	***	NS	*
Terpenes	(**)	NS	(***)	(***)	NS	(*)	NS	NS	NS	NS	NS	*
Model (2)												
Constant (mean)	***	***	***	***	**	***	NS	NS	NS	NS	*	NS
Replicate	NS	NS	NS	*	NS	NS	NS	NS	NS	NS	NS	NS
Treatment	*	NS	**	*	NS	**	*	NS	**	*	NS	**
Day number	***	***	***	***	**	***	***	***	***	***	**	***
Day	NS	**	NS	***	NS	*	NS	**	NS	***	NS	*
Terpenes	**	NS	***	(***)	NS	*	NS	NS	NS	NS	NS	*
Terpenes.Trt.(slope)	NS	NS	NS	*	NS	NS	NS	NS	NS	*	NS	*

* = P < 0.5
** = P < 0.01
*** = P < 0.001

( ) = Negative correlation.

3.1.9.2 Score and Potential terpenes (PVT). There was no significant correlation between juice score and PVT for four members of the panel using either regression model. The second model could be used to describe the correlation for two panelists (4 and 6), the correlation being significant at 5 per cent and 7 per cent when different slopes and intercepts were allowed for. This correlation was positive.

3.2 1982 Harvest

3.2.1 Fruit yield and its components

Irrigation resulted in an approximate doubling of fruit weight per vine when averaged for all sampling times (compare Trt.A and B in Table 3.2.1). Thinning fruit on irrigated vines (Trt.C) resulted in a significant reduction in fruit weight compared with irrigated (Trt.B) but it was still significantly greater than Trt.A (unirrigated). Vertical training of shoots on irrigated vines (Trt.D) had no significant effect on fruit weight compared to irrigated alone. The increase in fruit weight on irrigated (Trt.B) and irrigated and shoot trained (Trt.D) was primarily due to more bunches per vine as a consequence of lighter pruning but also due to heavier bunches. There was an increase in the weight of prunings from irrigated vines, significant for Trt. C and D but not for B, in comparison with unirrigated (Trt.A). There was no significant difference between any of the irrigated treatments.

Table 3.2.1 Yield and its components for 1982 (average of all sampling times)

Treatment	Fruit wt. kg.per vine	No.bunches per vine	Pruning wt kg.per vine	Yield/pruning wt. ratio
A - Unirrigated	7.3	83	1.9	3.8
B - Irrigated	13.8	137	2.6	5.4
C - Irrigated & thinned	11.1	107	3.0	3.7
D - Irrigated & shoot trained	14.3	140	3.1	4.6
L.S.D. 5%	1.4	9	0.8	Not determined

3.2.2 Changes in °Brix, titratable acidity and pH

There was a slowing in the rate of increase in °Brix after the sixth sampling time (Figure 3.2.2.1). There was no consistent treatment effect on °Brix. There were no significant differences between treatments at five of the nine sampling times; at two sampling times irrigated and shoot trained (Trt.D) was significantly lower than unirrigated (Trt.A) and at sampling times two and four Trt.D was only significantly lower than Trt.C (irrigated and thinned). The differences in must acidity and pH (Figures 3.2.2.2 and 3.2.2.3) appear to be accounted for by °Brix differences; fruit with the highest °Brix had the highest pH and lowest acidity, Trts A and C (the low yielders) tending to be higher in pH and lower in acidity than Trts.B and D.

3.2.3 Free terpenes (FVT)

Treatments A, B and C increased steadily to sampling time eight and declined at time nine (Figure 3.2.3). Trt.D (irrigated and shoot trained) attained maximum concentration at time six and steadily declined to about the same level as Trt's.B and C at time nine. There was no significant effect of treatment on the concentration of FVT in the juice at any sampling time.

3.2.4 Potential terpenes (PVT)

The concentration of PVT increased during fruit ripening (Figure 3.2.4) and continued to increase after the slowing in the rate of increase in °Brix. Trt.B (irrigated) had significantly lower PVT concentrations than unirrigated (Trt.A) at sampling times five and eight. Compared with Trt.B (irrigated) there was no significant effect on PVT of crop thinning (Trt.C) or the addition of vertical shoot training (Trt.D).

3.2.5 FVT + PVT content per vine

Treatment effects on the fruit terpene content were non-significant at six of the nine sampling times (Figure 3.2.5). At times six, seven and eight Trt.A (unirrigated) was significantly lower than the three irrigated treatments.

FIGURE 3.2.2.1

Change in °Brix with time during 1982 vintage

● Treatment A : Unirrigated

● Treatment B : Irrigated

● Treatment C : Trt.B + crop thinned

● Treatment D : Trt.B + shoot trained

Vertical bars indicate least significant difference ($P < 0.05$) between treatments at each sampling time. No bar = treatments do not differ significantly.

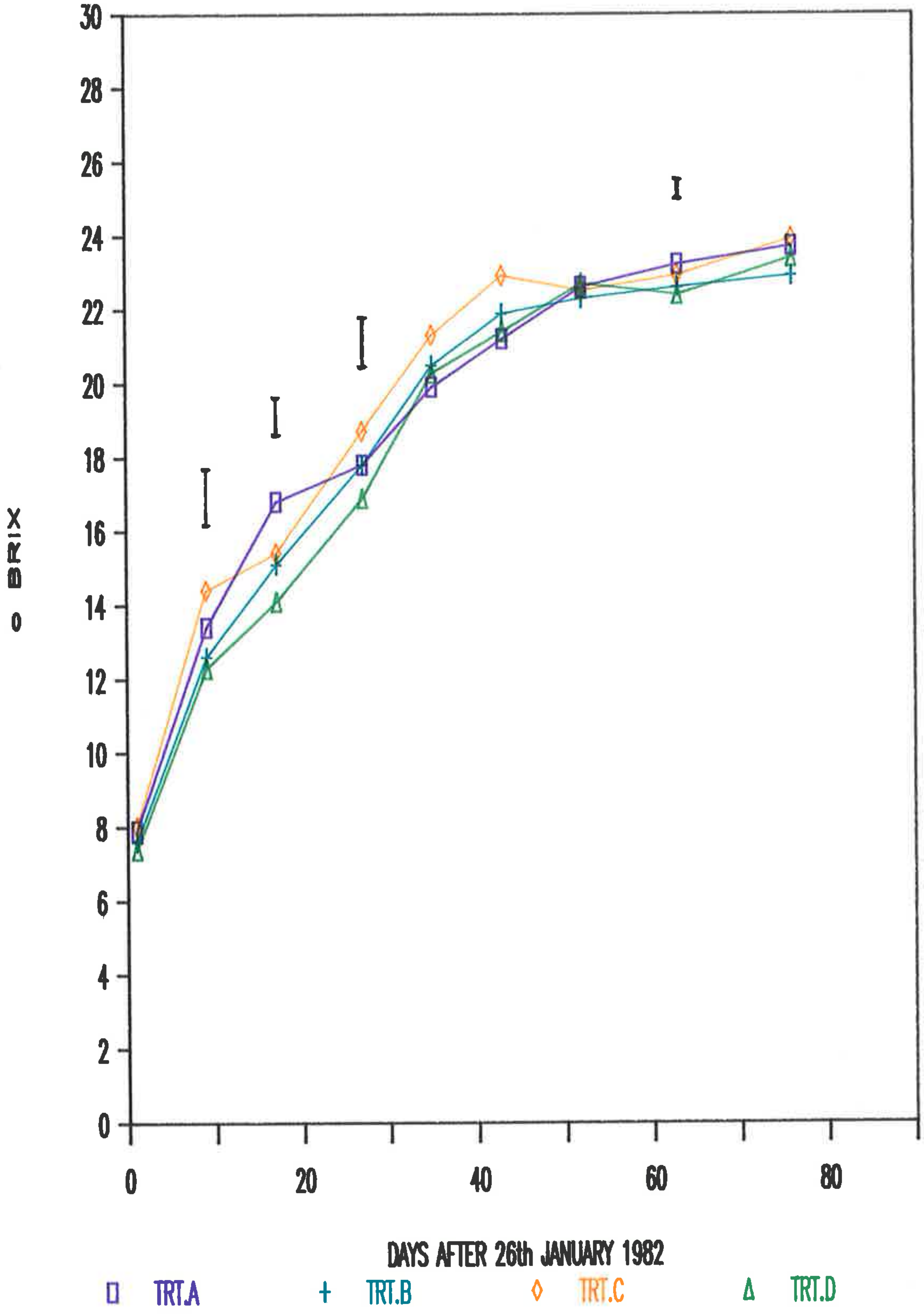

30
28
26
24
22
20
18
16
14
12
10
8
6
4
2
0
o BRIX
0
20
40
60
80
DAYS AFTER 26th JANUARY 1982
TRT.A
TRT.B
TRT.C
TRT.D

FIGURE 3.2.2.2

Change in titratable acid with time during 1982 vintage.

- Treatment A : Unirrigated
- Treatment B : Irrigated
- Treatment C : Trt.B + crop thinned
- Treatment D : Trt.B + shoot trained

Vertical bars indicate least significant difference ($P < 0.05$) between treatments at each sampling time. No bar = treatments do not differ significantly.

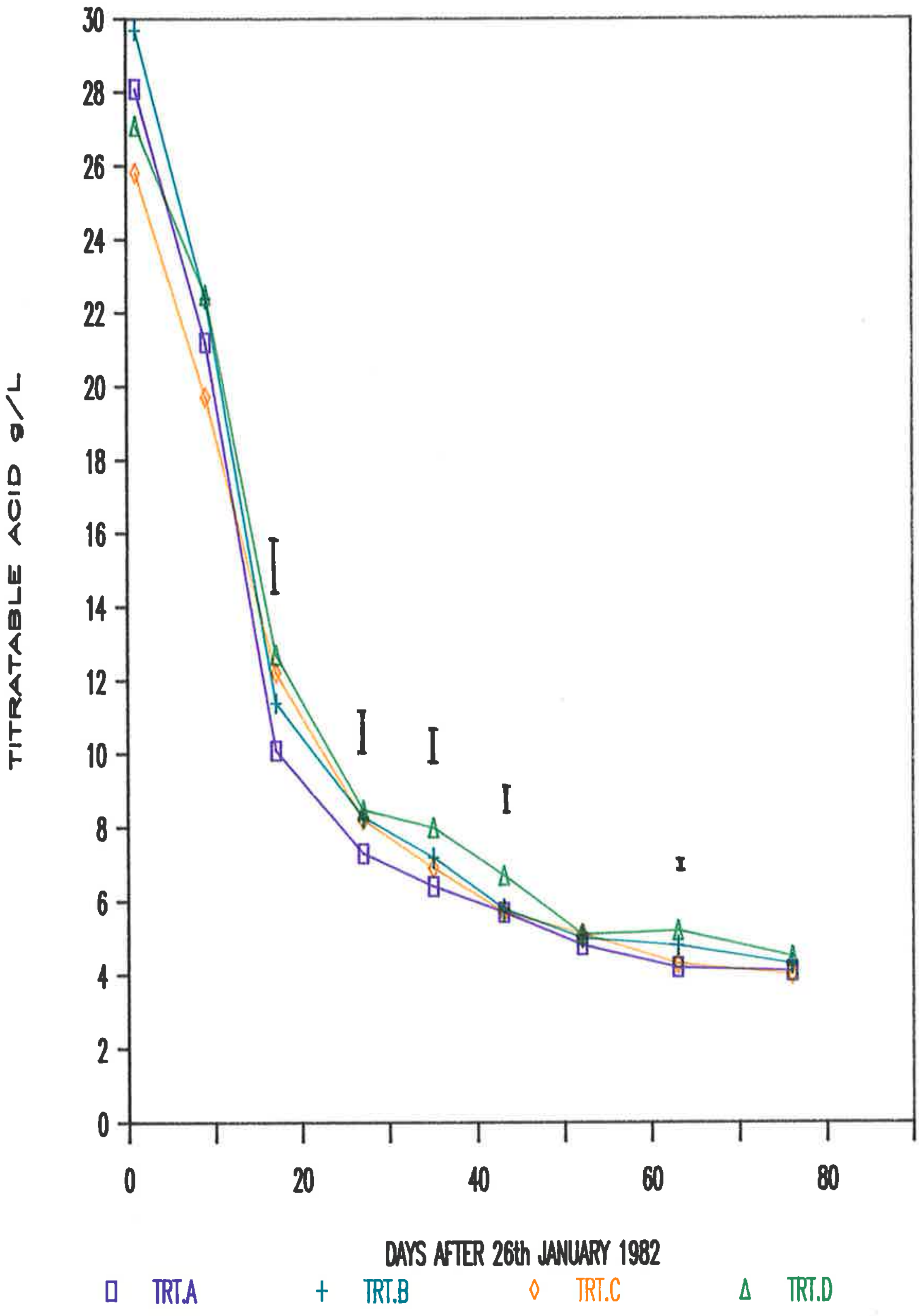
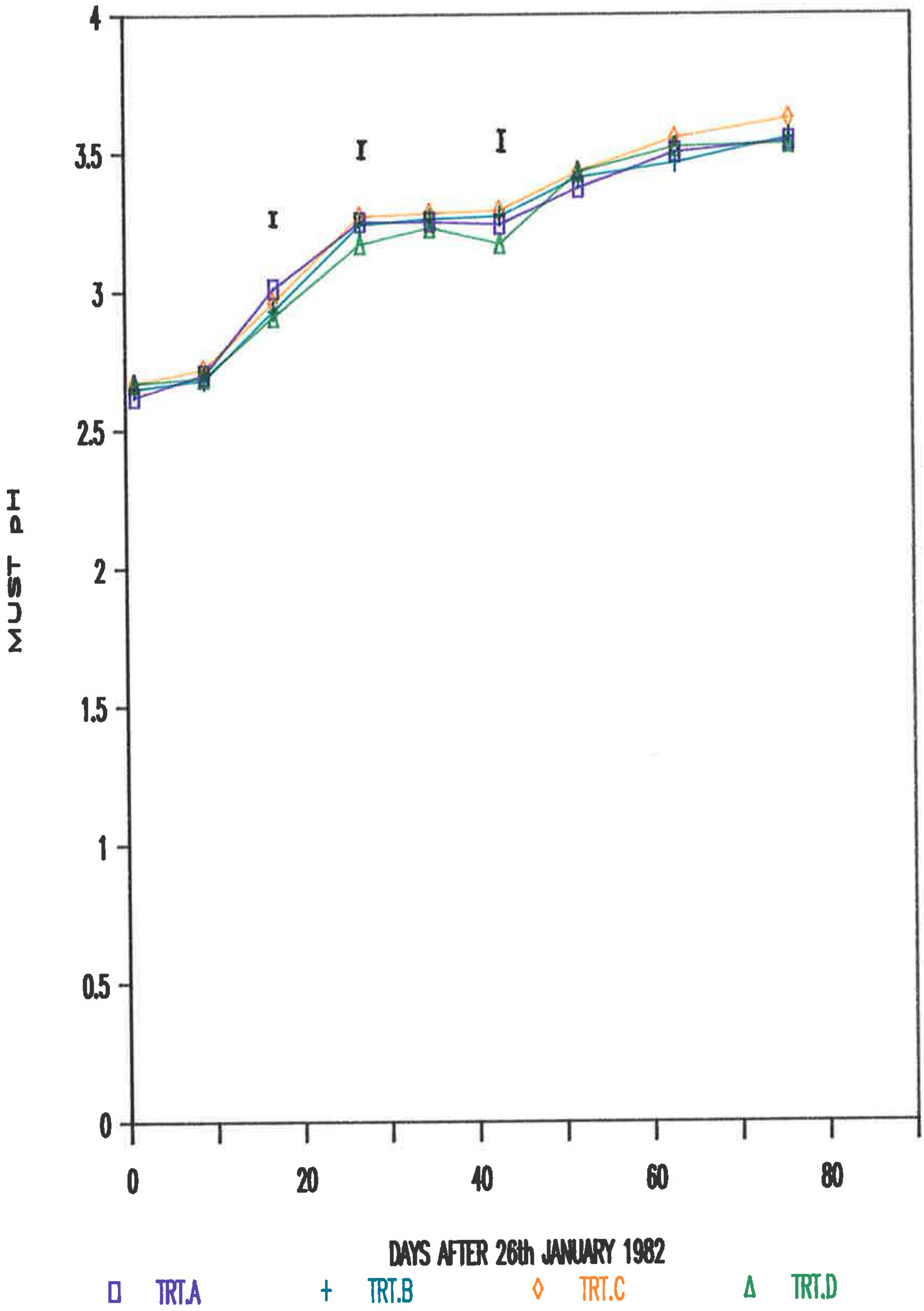

TITRATABLE ACID g/L
30
28
26
24
22
20
18
16
14
12
10
8
6
4
2
0
0
20
40
60
80
DAYS AFTER 26th JANUARY 1982
TRT.A
TRT.B
TRT.C
TRT.D

FIGURE 3.2.2.3

Change in must pH with time during 1982 vintage

- Treatment A : Unirrigated
- Treatment B : Irrigated
- Treatment C : Trt.B + crop thinned
- Treatment D : Trt.B + shoot trained

Vertical bars indicate least significant difference ($P < 0.05$) between treatments at each sampling time. No bar = treatments do not differ significantly.


4
3.5
3
2.5
2
1.5
1
0.5
0
MUST PH
0
20
40
60
80
DAYS AFTER 26th JANUARY 1982
TRT.A
TRT.B
TRT.C
TRT.D

<u>FIGURE 3.2.3</u>

Change in FVT with time during 1982 vintage.

● Treatment A : Unirrigated

● Treatment B : Irrigated

● Treatment C : Trt.B + crop thinned

● Treatment D : Trt.B + shoot trained

There was no significant treatment effect (P < 0.05) at any sampling time.

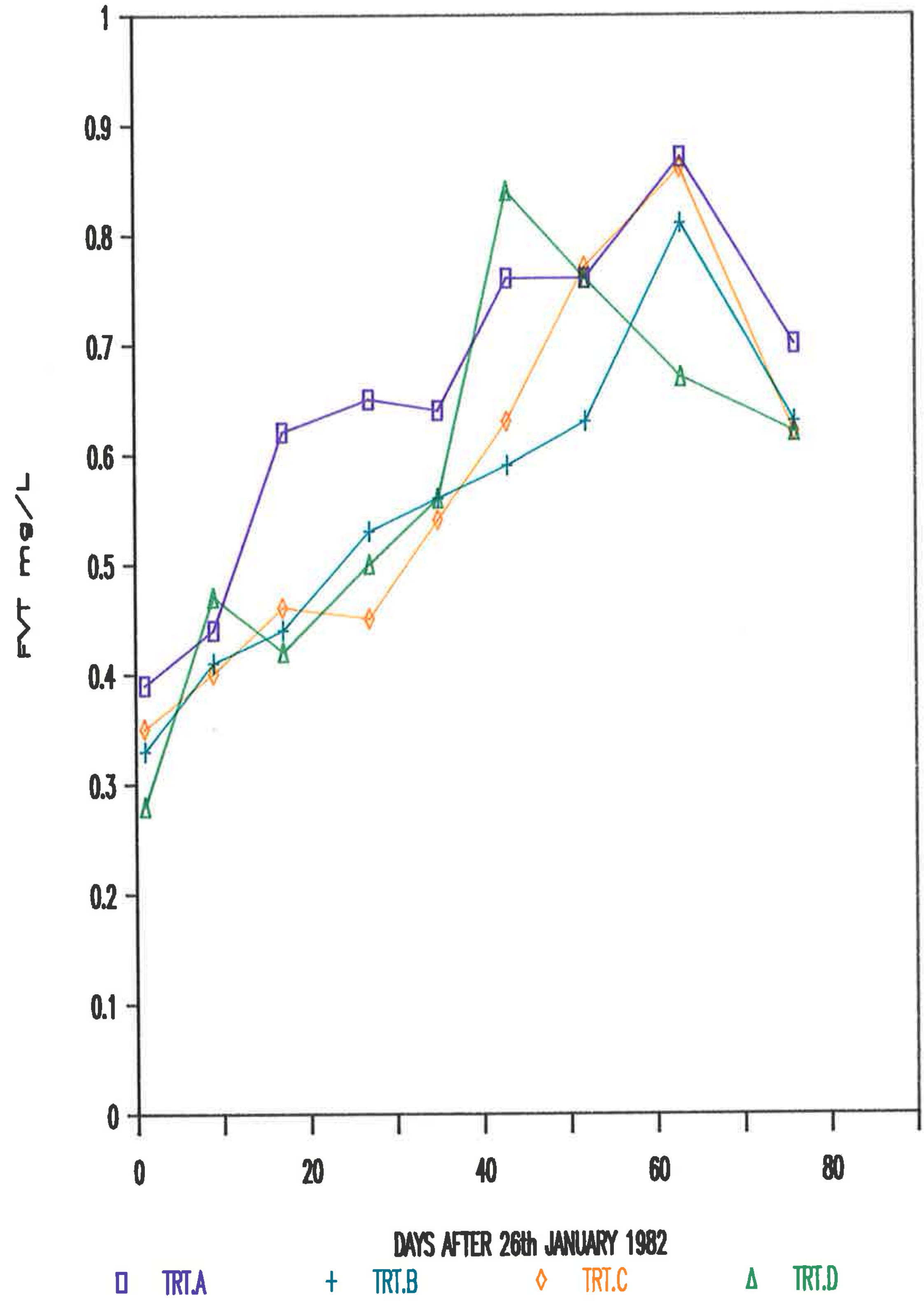
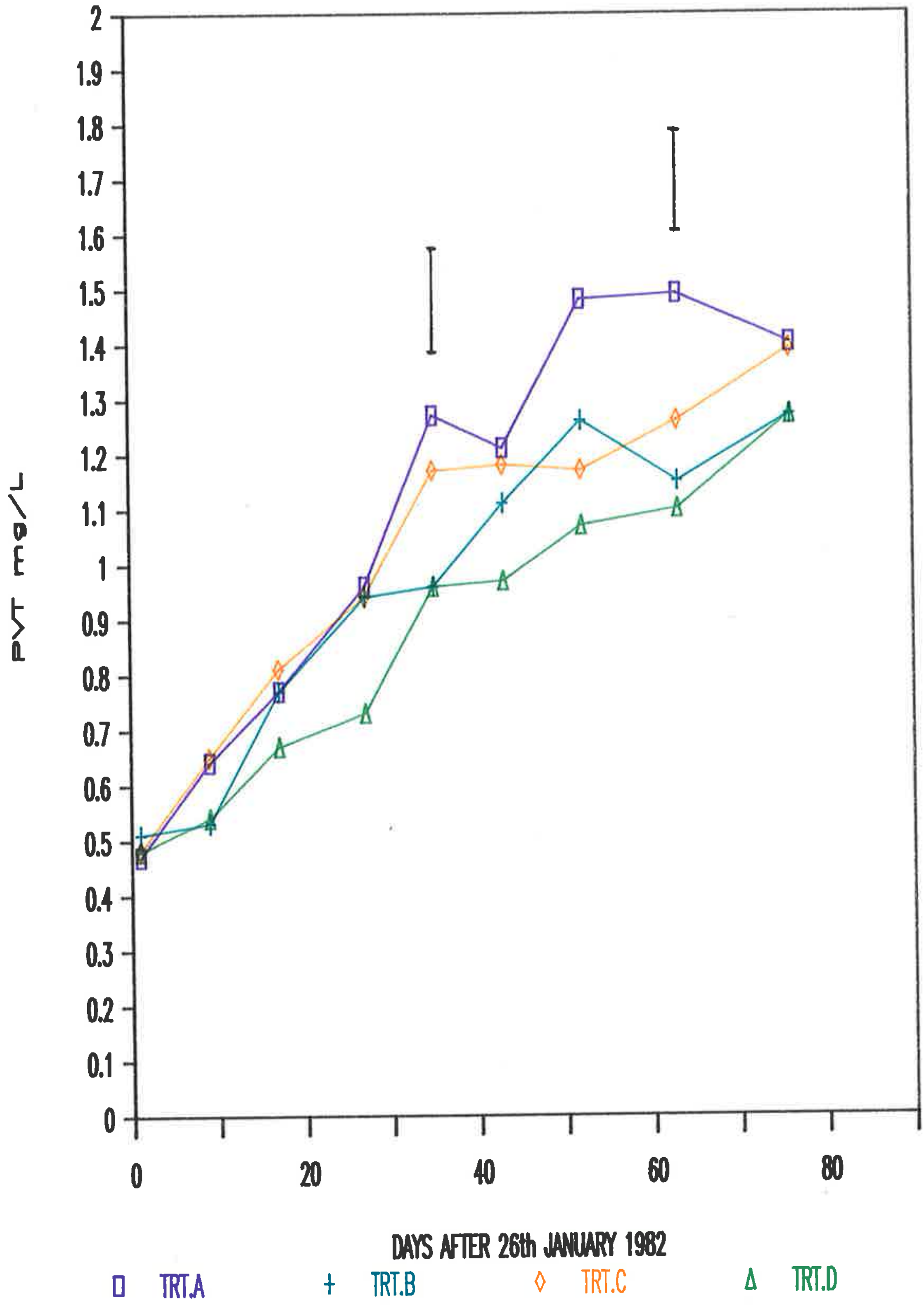

1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
FVT mg/L
0
20
40
60
80
DAYS AFTER 26th JANUARY 1982
TRT.A
TRT.B
TRT.C
TRT.D

FIGURE 3.2.4

Change in PVT with time during 1982 vintage.

- ● Treatment A : Unirrigated
- ● Treatment B : Irrigated
- ● Treatment C : Trt.B + crop thinned
- ● Treatment D : Trt.B + shoot trained

Vertical bars indicate least significant difference
(P < 0.05) between treatments at each sampling time.
No bar = treatments do not differ significantly.



PVT mg/L
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
1.1
1.2
1.3
1.4
1.5
1.6
1.7
1.8
1.9
2
0
20
40
60
80
DAYS AFTER 26th JANUARY 1982
TRT.A
TRT.B
TRT.C
TRT.D

FIGURE 3.2.5

Change in FVT +PVT content per vine
with time during 1982 vintage.

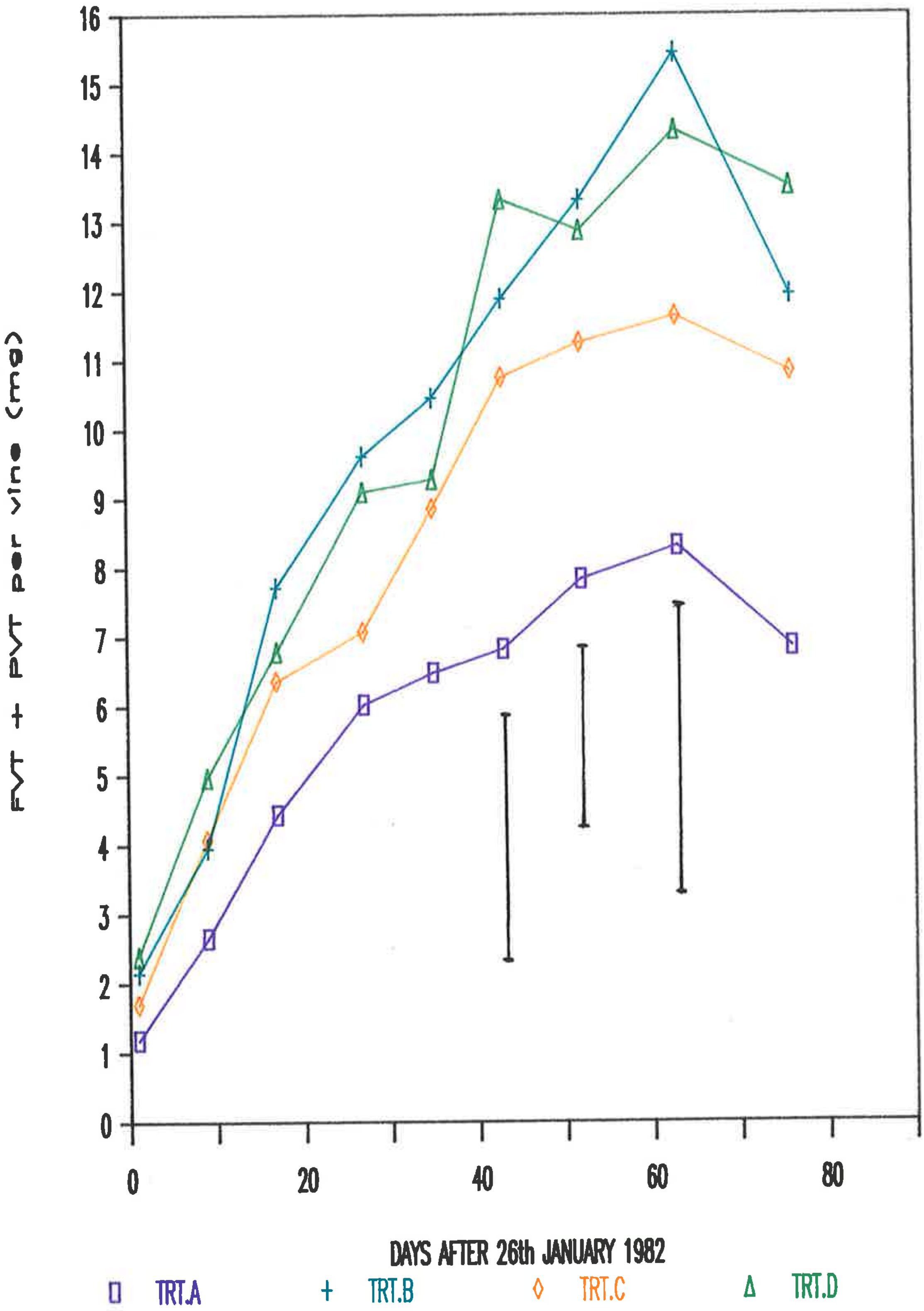
● Treatment A : Unirrigated

● Treatment B : Irrigated

● Treatment C : Trt.B + crop thinned

● Treatment D : Trt.B + shoot trained

Vertical bars indicate least significant difference ($P < 0.05$) between treatments at each sampling time.
No bar = treatments do not differ significantly.


FVT + PVT per vine (mg)
16
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1
0
0
20
40
60
80
DAYS AFTER 26th JANUARY 1982
TRT.A
TRT.B
TRT.C
TRT.D

4.0 DISCUSSION

4.1 Yield and its components

The response in fruit weight to irrigation and lighter pruning was similar in both years with Trt.B (irrigated) and Trt.D (irrigated and shoot trained) yielding about double that of unirrigated Trt.A and is similar to that previously reported (McCarthy *et al.* 1983). The increase in yield on irrigated vines was due to more bunches per vine which was a function of the increased number of buds retained at pruning time.

Removal of one bunch per shoot on irrigated vines (Trt.C) in 1982 (which only reduced the number of bunches per vine by 22 percent) resulted in about a 20 per cent reduction in yield while in 1984, when all but one bunch was removed (a 49 per cent reduction in the number of bunches per vine) the yield reduction was about 50 per cent. The significant reduction in crop due to crop thinning is in contrast to Bravdo *et al.* (1984) who reported a non-significant reduction when 36 per cent of the bunches were removed and only a 15 per cent reduction when half the bunches were removed. Bravdo *et al.* (1984) found this was due to a compensatory increase in berry weight and also to improved bud fruitfulness; he also reported a significant increase in pruning weight in response to bunch removal. In the experiment reported here there was no consistent effect of bunch removal on berry weight nor increase in pruning weight.

4.2 Increased crop effects on ripening.

The significant increase in fruit weight as a result of irrigation and lighter pruning reported here is similar to that reported in other vine irrigation experiments in summer drought regions. In common with these experiments is the small effect on °Brix in comparison with the large differences in fruit weight.

In the Barossa Valley drip irrigation resulted in about a doubling of fruit weight (McCarthy and Staniford 1983) but there was no significant treatment effect on °Brix at harvest. Moisture stress during ripening resulted in enhancement in °Brix (Hardie *et al.* 1981) although by harvest there were no significant irrigation treatment effects.

In an irrigation experiment with 'Chenin blanc' grapes in South Africa (Van Zyl and Weber 1977), no significant differences in the mean total soluble solids values were noted; all treatments attained 20 °Brix simultaneously despite yield increases of up to 50 per cent. The authors felt that this lack of difference was due to the similar fruit:vegetative growth ratio of irrigated and unirrigated vines.

An alternative ratio that has also been used is that of leaf area to fruit weight. May *et al.* (1969) found that, through controlled defoliation of 'Sultana' grapes at Merbein, Victoria, approximately 7 cm^2 per g fruit was needed to ripen the crop. 'Flame Tokay' grapes required approximately 12 cm^2 per g fruit without any significant delay in maturity date (Kliewer and Weaver 1971) and Kliewer and Antcliff (1970) found that approximately 10 cm^2 per g fruit was required to mature the crop fully without decreasing the total soluble solids. In the experiment reported here both irrigated and unirrigated vines had leaf areas in the range reported; the absence of a treatment effect on this ratio may explain the minor effects of increased crop on ripening.

The higher pH of Trt.C (irrigated and crop thinned) compared with Trt.A (unirrigated) at similar °Brix may be a response to irrigation *per se*. Freeman and Kliewer (1983) found that crop thinning had no effect on wine pH as did Bravdo *et al.* (1984) but Freeman and Kliewer (1983) reported that irrigation raised wine pH and potassium concentration. McCarthy and Staniford (1983) reported that drip irrigation of 'Shiraz' vines in the Barossa Valley increased wine potassium concentration and pH. Somers (1977) demonstrated a positive relationship between wine potassium and pH. While not measured in this experiment it is possible that the higher pH of Trt.C in comparison with Trt.A at similar °Brix (and fruit yield) was a result of a higher potassium content.

4.3 Thinning effects on ripening.

The enhancement in ripening as a result of crop thinning on irrigated vines in 1984 is in contrast to the non-significant treatment effect in 1982 and appears to be correlated with the crop reduction achieved. In the 1982 experiment crop thinning which resulted in a 20 per cent reduction in yield had no effect on °Brix; in 1984 the crop reduction was 47 per cent and there was a significant enhancement in °Brix.

Unpublished data of the author show that for 'Shiraz' a 34 per cent yield reduction resulted in a significant increase in °Brix at harvest. A 22 per cent crop reduction on 'Carignane' had no significant effect on °Brix (Freeman and Kliewer 1983) and Kliewer and Weaver (1971) reported that a 53 per cent reduction in crop resulted in a significant improvement in °Brix of grape must and grape skin colour.

Kliewer and Weaver (1971) suggested that the enhancement in °Brix was in response to the increase in leaf area per g fruit (unthinned vines had approximately 5.0 cm^2 per g and thinned vines approximately 14 cm^2 per g).

Irrigated vines in this experiment had about 8 cm^2 per g fruit yet thinning fruit on irrigated vines, which doubled this ratio to about 15, resulted in a significant enhancement in ripening. As no crop thinning treatment was applied to unirrigated vines it is not possible to determine why °Brix was significantly enhanced by thinning on irrigated vines.

Conflicting data on fruit ripening in response to thinning was presented by Bravdo (1983) who found that bunch removal on irrigated 'Cabernet Sauvignon' resulted in a delay in harvest date. He claimed that this delay was due to excessive vegetative growth following crop removal as a similar treatment on less vigorous vines resulted in a significant enhancement in ripening. Bravdo *et al.* (1984) found that moderate crop thinning on vigorous 'Carignane' vines resulted in a significant enhancement in °Brix and suggested that this improvement was a consequence of a more favourable fruit weight : pruning weight ratio. For the cultivar 'Carignane' overcropping effects appeared at ratios above ten to twelve. Data presented here suggest that 'Riesling' may be overcropped at ratios greater than about eight.

In 1982 when there was no significant treatment effect on °Brix : unirrigated vines (Trt.A) had a ratio of 3.8, irrigated (Trt.B) 5.4 and irrigated/thinned (Trt.C) 3.7. In 1984 the ratio for unirrigated vines was 7.2, irrigated (Trt.B) 12.8 and Trt.D (irrigated and shoot trained) 14.2. Thinning of irrigated vines (Trt.C), which resulted in a significant increase in °Brix compared with irrigated (Trt.B), lowered the ratio to 7.5.

The lower pruning weights in 1984 compared with 1982 may have been a result of the intervening drought. Data from an irrigation experiment (author-unpubl.) show a similar decline in pruning weights for all treatments however, in contrast to the results reported here, there was a difference in pruning weights between unirrigated and irrigated vines. The small but non-significant increase in pruning weight in 1984 for treatments B, C and D, despite a doubling of fruit weight on treatments B and D, suggests these vines were overcropped; the significant responses to thinning are also indicative of overcropping.

4.4 Free and potential terpenes.

Data presented here show that potential volatile terpene content (PVT) is sensitive to crop load even though free volatile terpene content (FVT) is not. The effect of crop load and shoot training on the concentration of FVT was small and mostly non-significant at each sampling time. The lack of significance was no doubt associated with the large variation between replicates even though 2-3 kg per vine was collected at each sampling time. Similar variation has been found in other experiments (author-unpubl.) where berry samples have been taken for terpene determination and up to fifteen replicates sampled. As reported here, large variation between sampling times has been observed for other varieties and does not appear to be due to analytical technique or sampling method. The range of FVT concentration within berries of a single bunch and between bunches is yet to be quantified, as are environmental influences.

The contribution of PVT to wine aroma has yet to be resolved. If hydrolysis and enzymatic breakdown caused significant conversion of potential to free forms during fermentation, processing and storage then PVT content could contribute to wine aroma. The decrease in PVT as a result of irrigation in 1984 agrees with winemaker opinion that irrigation at the level used in this experiment and the resultant increase in yield does result in a decrease in wine quality. If this proposition is correct then determination of PVT at harvest may be used as a suitable measure of wine quality in the longer term. Additional work is necessary to resolve the role of PVT and wine quality. Also to be clarified is whether irrigation results in a decrease of other aroma components which may also contribute to wine aroma.

The sensitivity of PVT content of unirrigated vines (Trt.A) to rain was apparent during ripening in both years. In 1984, rain (16.4

mm) between the fifth and sixth sampling resulted in a decrease in PVT at time six; in 1982 rain between the fifth and sixth sampling times resulted in a decrease in PVT but further rain between times seven and eight did not change PVT. The PVT content of irrigated vines (Trts.B, C and D) did not show such sensitivity to rain. Berry dehydration may account for some of the increase but the rise in PVT of irrigated vines is unlikely to be a result of berry dehydration as irrigation continued to the onset of autumn rain.

A possible cause of the enhancement in PVT content of irrigated + thinned vines (Trt.C) compared with Trt.B may be the significant increase in leaf area per g. fruit. For irrigated vines this ratio was about 8, unirrigated, 11 and irrigated + thinned about 16; this ranking is similar to that for PVT and °Brix. Kliewer and Weaver (1971) demonstrated that fruit colouration of 'Flame Tokay' grapes was maximal when this ratio was about the same as that required for maximum total soluble solids (about 14 cm^2 per g). Data presented here demonstrate that a ratio greater than 11 resulted in increased °Brix; a similar ratio may be necessary for optimum PVT.

Vertical shoot training to increase fruit exposure had no significant effect on PVT although there was a trend for Trt.D (irrigated and shoot trained) to be lower in PVT than irrigated alone (Trt.B) in both years. The absence of a significant treatment effect on FVT or PVT suggests that fruit exposure may not be an important determinant of terpene content of 'Riesling' grapes. In an assessment of the experiments in this thesis, R.E. Smart (pers. comm.) suggested that although vertical shoot positioning increased fruit exposure compared with irrigated alone (Trt.B), shoot density and shading were still excessive on both irrigated and irrigated + shoot trained; this would explain the absence of a treatment effect. Smart claimed that optimum shoot densities were not possible at the shoot numbers and vine row widths used in this experiment.

4.5 Potential volatile terpenes versus °Brix

Comparison of PVT and °Brix figures for each year highlight the different rate of increase of these harvest components (compare Figures 3.1.3 with 3.1.6 and 3.2.2.1 with 3.2.4). Hardy (1969) found that development of muscat aroma compounds was most rapid during the final stages of ripening. The analytical technique used by Hardy (1969) gave a measure of FVT and some PVT but he showed that acceptable °Brix occurred before maximum volatile monoterpene content. Verisini *et al.*(1981) found that maximum volatile terpene content was reached in ripening 'Riesling' grapes prior to the cessation of the rise in sugar. This is in contrast to data presented here; although there were fluctuations in PVT with increasing ripeness, the slowing of the rate of increase in °Brix preceded a similar slowing in terpene content. There were however similarities in the rate of increase of PVT and °Brix. The ratio PVT x 100/°Brix gave a consistent value of between 4.8 and 6.1 when averaged for all sampling times for both years. In each year irrigation (Trt.B) lowered the ratio compared with unirrigated (Table 4.5), the ratio being lower in 1984 than 1982. Crop thinning of irrigated vines (Trt.C) had no effect in 1982 but increased the ratio in 1984.

Table 4.5 PVT x 100/°Brix for Treatments A, B and C for harvest years 1982 and 1984

Year	Trt.A (unirrigated)	Trt.B (irrigated)	Trt.C (irrigated + crop thinned)
1982	5.7	5.3	5.3
1984	5.4	4.8	6.1

To exploit the flavour potential of muscat-like grapes Wagner *et al.* (1977) suggested they should be harvested before maximum °Brix (certainly prior to the over-ripe stage) and that terpene concentration (in particular linalool and geraniol) should be able to predict more accurately the quality of the vintage than °Brix. Di Stefano (1981) noted that berry terpenol content of ripening 'Moscato Bianco' grapes closely followed the curve of sugar accumulation. The influence of temperature on the rate of increase in °Brix may account for this conflicting data. In cool regions the rise in °Brix may follow terpene accumulation; in warm and hot regions where sugar accumulation is rapid, this rise may occur prior to maximum terpene concentration.

4.6 FVT + PVT content per vine

Increased crop had a significant effect on the fruit terpene content (Trts B & D in Figure 3.2.5) in 1982. The increase for Trt.B (irrigated) was about 1.7 times that of non-irrigated (Trt.A) when averaged for all sampling times. In 1984 the increase was about 1.8 times which was similar to the increase in °Brix and leaf area. Kliewer and Weaver (1971) found a correlation between leaf area and solute production (as Total Soluble Solids); data presented here also indicates that leaf area may play a role determining fruit terpene content.

Crop load per vine may also influence terpene content per vine. Crop thinning on irrigated vines, which about doubled leaf area per g fruit, did not result in a doubling of terpene content; in 1984 fruit thinning resulted in a reduction in terpene content (significant at most times) compared with irrigated alone (Trt.B).

4.7 Organoleptic assessment of aroma.

Interpretation of the juice aroma scores is complex. The absence of a test of reliability of judges both within each assessment day and between days was unfortunate but for the latter unavoidable. As only one juice sample was prepared it was not possible to present the same sample on different days; the thawed juice could not be held for twenty four hours without deterioration or alternatively refrozen and thawed without possible changes in juice aroma. C.J. Brien (pers. comm.) suggested, that in the absence of repetitive assessment of the same sample on different sessions, scores from similar treatments of different replicates could be used as some measure of judge reliability between sessions. Interpretation of data using this method is however confounded by the significant Dayno x Day x Replicate interactions (Table 3.1.8.3, page 46) and the significant Day effect although there was no replicate or Day x Replicate effect.

The higher scores for day two of assessment compared with day one for three of the six panelists was unexpected. Panelists were asked to score the juices 0 to 10 on each day on the basis of the juices presented on that day so that possible differences due to preparation would be avoided. The higher score for some members of the panel on day two suggested day two juices may have been of higher aroma but were scored relative to day one. This result indicates that an assessment of judge reliability and possibly pretraining of the panel should have been done.

Notwithstanding the presence of significant interactions panelists were able to discern a significant treatment and sampling time effect (Table 3.1.8.3 page 46). Differences were discernible despite the method used to prepare the juices : members of the panel normally assess freshly prepared juices with uniform sulphur dioxide and sodium erythorbate concentration, not samples that had been frozen for up to 12 weeks and thawed, often with sub-optimal sulphur dioxide content and no erythorbate until after thawing. Five of the six members of the panel scored Trt.C higher than Trt.B and four of the six scored Trt.A higher than B demonstrating that under the experimental conditions reported here, a doubling of crop resulted in a significant decrease in juice aroma score.

Panelists discerned treatment effects between sampling times two and six; at the seventh and eighth sampling times consistent differences were less apparent. The large increase in juice aroma score for Trt.C (irrigated + thinned) between the first and second samplings is in contrast to other treatments which showed a slower increase in juice aroma score. This difference highlights a possible conflict in determining the timing of the vintage; Trt.C was scored highest at time two when its °Brix was about 20. A delay in harvest date to achieve riper fruit may have resulted in lower wine aroma. In contrast, Trt.B (irrigated) did not achieve maximum juice aroma until the seventh sampling (day 74) although the fruit was sufficiently ripe for processing (about 22 °Brix) by the fifth sampling. After that time there was an undesirable increase in must pH and decline in titratable acid.

Although significant, the overall reduction in aroma score as a result of a large increase in yield was only 0.7 units from a level of 6.5. The ability of winemakers to detect aroma differences where the increase in yield is not as great remains to be determined i.e. the magnitude of the yield increase needs to be considered in assessing the relative effects of yield on juice aroma.

The conclusion by the majority of the members of the panel that fruit from high yielding irrigated vines had less aroma than fruit from low yielding unirrigated vines suggests that juice assesssment might be a useful method of assessing viticultural treatment effects, perhaps better than small-scale wine lots. The interpretation of data from small-scale wine lot assessment can often lead to inconclusive findings. McCarthy and Downton (1981) found that eight winemakers asked to assess small-scale wine lots made from a drip irrigation trial could not agree : five could not detect a difference and three claimed wine made from unirrigated fruit was of higher quality than wine made from irrigated vines. The absence of a significant treatment effect for five of the eight tasters was surprising in view of significant reductions in wine spectral measures which Somers and Evans (1977) had shown to be an index of wine quality.

4.8 <u>Juice score and terpene content.</u>

FVT concentration predicted juice aroma score for the majority of the members of the panel but the correlation was negative! By contrast PVT predicted aroma score (positive correlation) for two members of the panel although the correlation was not as statistically significant as with FVT (probabilities of +5 and +7 per cent for the latter compared with -0.1 per cent for the former).

Williams (1982) warned that statistical correlations between analytical and sensory data need careful interpretation. It seems unlikely that members of the panel reacted negatively to terpene aroma : the increase in aroma found here, despite a lack of increase in FVT, is more likley to be due to the increase in concentration of other aroma compounds. Williams *et al.* (1983) suggested that, while the flavour of non-muscat cultivars (such as 'Riesling') was controlled by monoterpenoids (although data presented here suggest it is not), the thirteen-carbon nor-isoprenoid compounds such as damascenone and vitispirane may be responsible for individual varietal flavours. Wagner *et al.* (1977) stated other grape aroma constituents needed to be identified in those cultivars for which monoterpene content did not correlate with aroma. It was unfortunate that juices prepared in 1982 were not suitable for assessment. Unlike 1984, in 1982 there was a steady rise in FVT which may have positively correlated with aroma score.

The positive correlation between PVT concentration and score for two members of the panel was unexpected. Williams *et al.* (1983)

stated that PVT are odourless, non-volatile, water soluble derivatives that may undergo hydrolysis to 'free' aromatic forms. Williams *et al.* (1983) demonstrated that hydrolysis from glycosidic conjugates or polyols to FVT could be achieved by acid and heat or enzymes but under laboratory conditions temperatures upto 70°C or pH lower than normal juice pH were necessary to accomplish this. Current indications are that endogenous glycosidases are not very active at juice pH or under juice storage conditions of low temp and high SO_2. (P.J. Williams - pers. comm.). However, the large 'pool' of PVT may undergo some conversion to FVT under juice assessment conditions (room temp. and 20-25 ppm free SO_2) sufficient for this pool to contribute to aroma, as found here.

4.9 Harvest components at 'winemaking' maturity.

The previous discussion of the relationships between juice aroma, terpene concentration and other constituents took into account the whole range of berry sugar concentration. Conclusions made on this basis may not apply to the narrower range which would be regarded as normal ripeness by winemakers. Thus the effects of treatments on harvest components were examined at sampling time four (day 40) which was taken as indicative of normal harvest time for unirrigated vines. This method permitted the calculation of significance of differences between treatments. Irrigation and lighter pruning (Trts.B & D) resulted in a doubling of yield (Table 4.9.1) while thinning of irrigated vines (Trt.C) gave about the same yield as unirrigated (Trt.A). Irrigation (Trts.B & D) resulted in a 15-21 day delay in harvest; thinning of irrigated vines (Trt.C) resulted in a 5 day enhancement in maturity compared with unirrigated. The PVT content of irrigated vines (Trts.B & D) was about 20 per cent lower than unirrigated while Trt.C (irrigated and crop thinned) was 20 per cent higher than unirrigated. There was no significant difference in FVT content between any treatment but the juice aroma score of Trts.B & D was significantly lower than unirrigated (Trt.A) and Trt.C (irrigated + thinned) which were similar.

Table 4.9.1 Analyses of fruit on day 40 (March 6th 1984)

Harvest component	Treatment A (unirrigated)	Treatment B (irrigated)	Treatment C (irrigated & crop thinned)	Treatment D (irrigated & shoot trained)	L.S.D. (P < 0.05)
°Brix	22.6	21.1	23.3	21.0	0.6
Change in harvest date * (from Fig.3.1.3)	0	15 days delay	5 days enhancement	21 days delay	
pH	3.20	3.12	3.19	3.12	0.05
Acid (g/L)	6.9	8.1	6.2	8.0	0.8
FVT (mg/L)	0.34	0.33	0.39	0.35	N.S.
PVT (mg/L)	1.22	0.98	1.47	0.96	0.3
Percent change compared with A	-	-20%	+20%	-21%	
Juice aroma score	7.7	5.9	7.3	6.5	0.6
Yield (kg/vine)	7.6	14.8	7.8	16.5	1.5
Percent change compared with A	-	+94%	+3%	+117%	
Number of bunches	54	116	56	112	20
Berry weight (g)	1.20	1.03	1.09	1.10	N.S.

N.S. = non-significant

* i.e. the day on which the °Brix of Trt.A (unirrigated) was reached.

The choice of the fourth sampling time as a standard harvest time could be criticised since, as Table 4.9.1 shows, there were significant differences in the sugar and acid contents. In an attempt to remove this difference the date on which grapes from each treatment attained a specified °Brix level was interpolated from Figure 3.1.3; the Brix chosen for this purpose was 21°. The values for many of the measures at each of the interpolated times are presented in Table 4.9.2. Statistical comparisons are not possible but the order of difference required for significance in Table 4.9.1 could be used as a guide.

Table 4.9.2 Analyses of grapes at 21 °Brix
(found by interpolation at the dates indicated)

	Treatment A (unirrigated)	Treatment B (irrigated)	Treatment C (irrigated & crop thinned)	Treatment D (irrigated & shoot trained)
Days after 26th Jan.	31	39	25	40
°Brix	21	21	21	21
pH	3.09	3.10	3.00	3.10
Acid (g/L)	8.0	8.2	8.0	8.0
FVT (mg/L)	0.41	0.33	0.39	0.35
PVT (mg/L)	1.19	0.96	1.15	0.93
Juice aroma score	6.9	5.8	7.4	6.5

Irrigation and lighter pruning (Trts.B and D) delayed the attainment of 21 °Brix by 8-9 days compared with unirrigated whereas thinning of irrigated and lighter pruned vines enhanced ripeness by 6 days compared with unirrigated, and 14 days compared with Trt.B. All treatments had similar acid content but Trt.C had a lower pH which is in contrast to previous results. The FVT content of unirrigated (Trt.A) was higher than the other treatments, but like the data from the common harvest date, the differences are likely to be non-significant. The PVT contents of unirrigated (Trt.A) and irrigated and crop thinned (Trt.C) were higher than those for Trts.B and D; this was the same trend as for day 40 data. The juice aroma score of Trts.C and A were higher than Trt.B (irrigated) and Trt.D (irrigated and shoot trained) was between A and B.

5.0 CONCLUSION

a. Irrigation and lighter pruning of 'Riesling' doubled yield, delayed the rise in sugar accumulation slightly, reduced the concentration of potential volatile terpenes (PVT) in the juice, and lowered the juice aroma score.

b. Thinning of fruit from irrigated vines, to the same crop level as that on unirrigated vines, produced earliest ripening, highest PVT and highest juice aroma score; this suggests that many of the effects of irrigation on grape quality are due to its effects on crop load.

c. Positioning of shoots on irrigated vines caused little effect; most results were the same as irrigated.

d. Treatments had no effect on the concentration of free volatile terpenes (FVT) and FVT did not correlate positively with aroma score.

e. PVT increased as grapes ripened, as did aroma score, but there were poor positive correlations between these values both within treatments and for each panelist. However the PVT and aroma score values, interpolated when grapes reached 21 °Brix, were highest in the two low yielding treatments and lowest in the two high yielding treatments.

f. Analysis of PVT would appear to be moderately useful as a guide to the timing of harvest for high wine quality. The discrepancies noted between aroma score and terpene content suggest that analysis of other aroma compounds should be sought for 'Riesling' grapes.

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APPENDIX 1

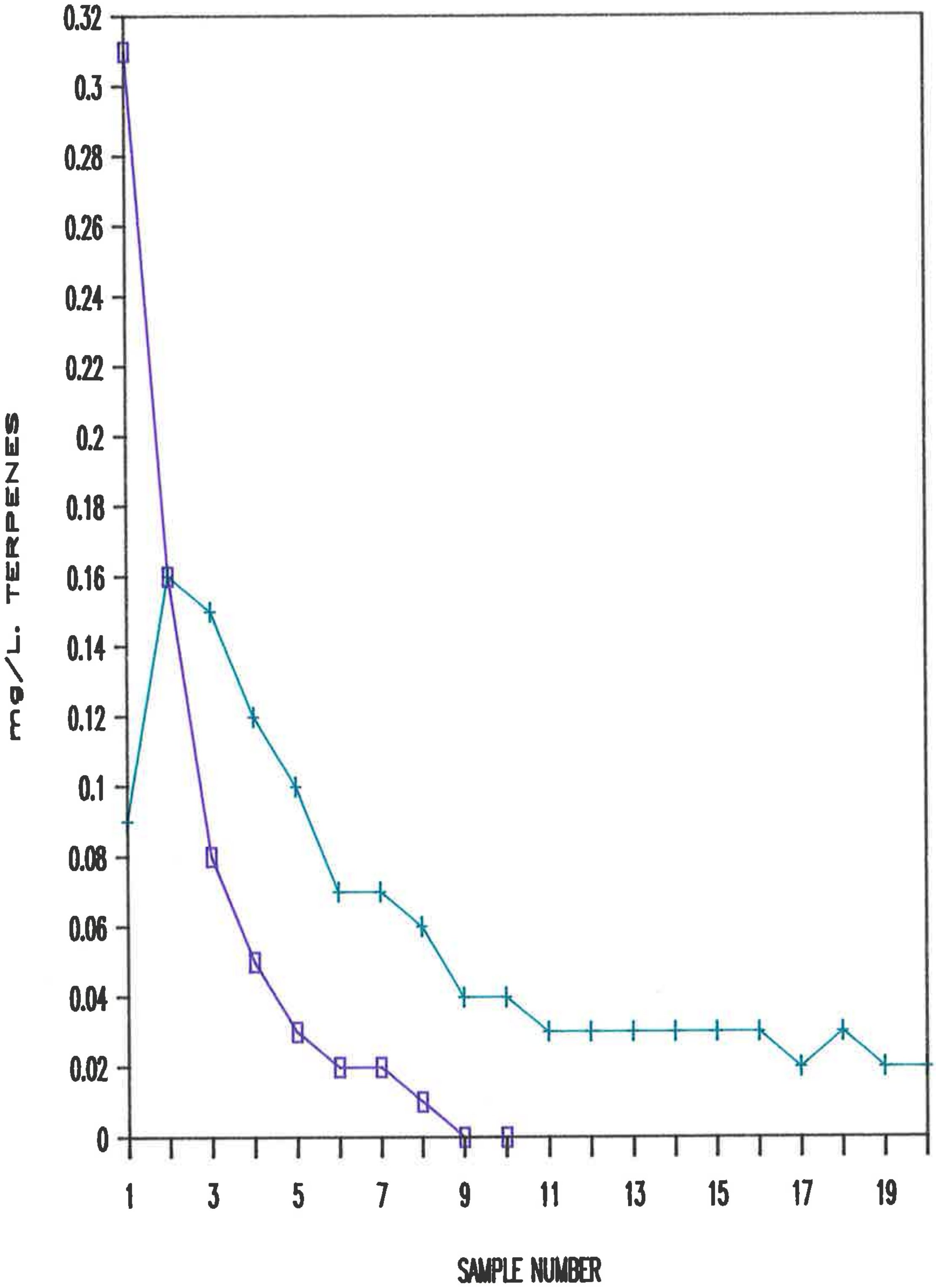
Results of serially collected distillates of Free and Potential terpenes to determine distillate volumes required.

Figure A.1

Concentration of free and potential terpenes in serially collected distillates (10 ml. per sample).

0 Free terpenes

+ Potential terpenes

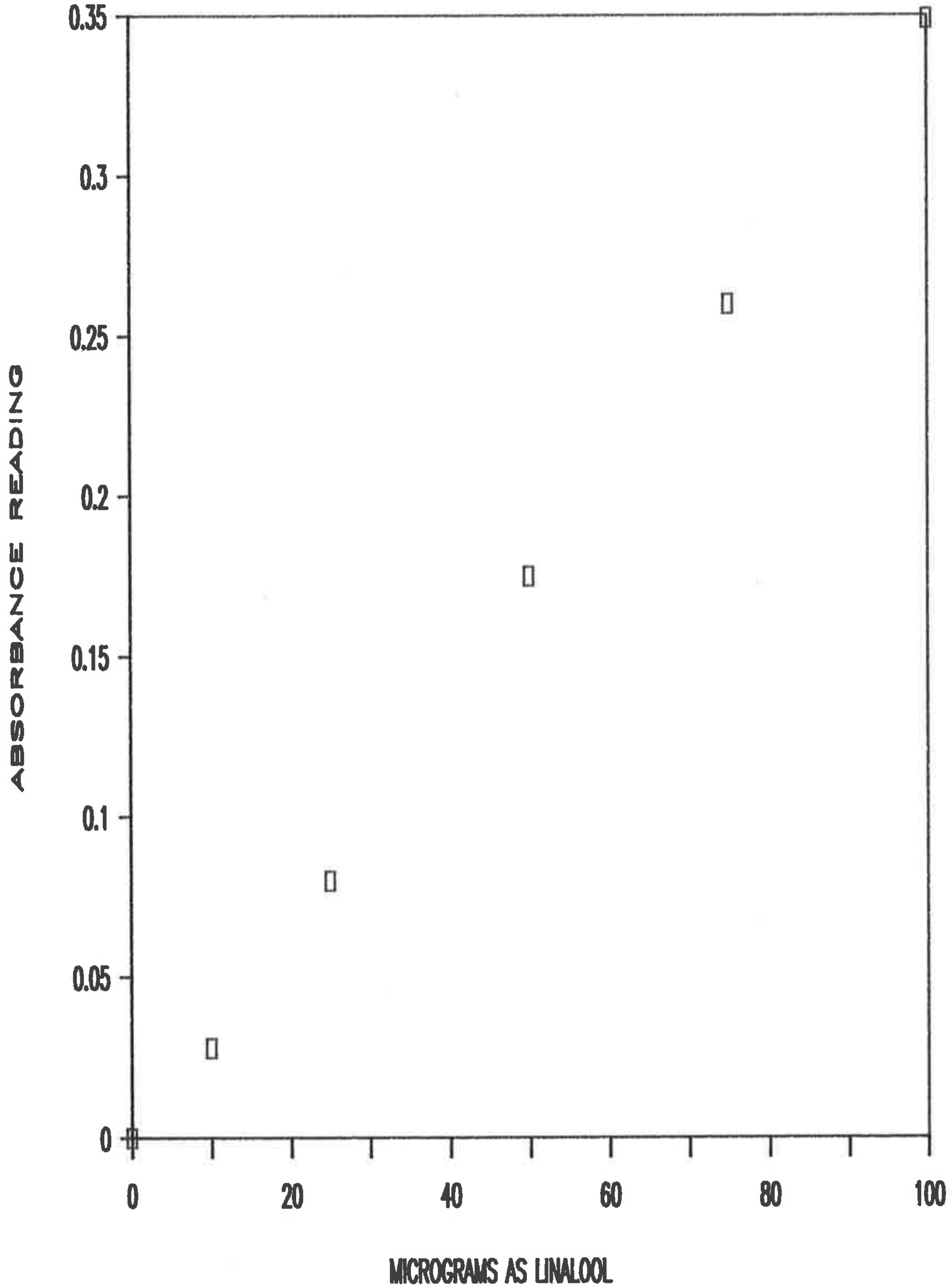

mg/L. TERPENES
0.32
0.3
0.28
0.26
0.24
0.22
0.2
0.18
0.16
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
1
3
5
7
9
11
13
15
17
19
SAMPLE NUMBER

APPENDIX 2

An example of a standard curve and regression analysis used to determine the regression equation for each set of terpene distillates.

Figure A.2

The relationship between micrograms terpenes as linalool and absorbance reading.



0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
ABSORBANCE READING
0
20
40
60
80
100
MICROGRAMS AS LINALOOL

Table A.2 An example of linear regression analysis used to determine the regression equation for terpene distillates.

ANALYSIS OF VARIANCE

SOURCE	SS	DF	MS	VR
REGRESSION	+.7579+04	1	+.7579+04	7631.669
RESIDUAL	+.3973+01	4	+.9932+00	
TOTAL	+.7583+04	5		

$r^2 = .9995$

REGRESSION COEFFICIENTS		STANDARD ERROR	T VALUE
Const.	+.8467+00	+.6341+00	1.336
ABS	+.2842+03	+.3253+01	87.359

The regression equation derived from this analysis is :

Terpene concentration = 284.2 x absorbance reading + 0.85