Maximising irrigation savings in grape vines and the effect on yield and wine quality

SFF Project 03/100 and Extension

FINAL SUMMARY OF ALL FOUR YEARS OF THE TRIAL AT NAUTILUS ESTATE, RENWICK VINEYARD

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EXECUTIVE SUMMARY

At the beginning of this trial funding was sought for a three year project looking at sub-optimal levels of irrigation in vineyards. The reasoning behind this was that considerable research work had taken place to establish the optimal levels of irrigation for a grapevine but little seemed to have been done to establish what the consequences were of irrigating at lower levels. These lower levels of irrigation may come about by necessity where water is not available from say drought conditions or it could come about as a matter of choice by winemakers wanting a particular wine style.

A trial was set up on a commercial vineyard to establish the affects of irrigation reductions from around 110mm per year down to around 20mm per year. The results showed that while the vines adapted to the reduced irrigation and produced a crop there were serious consequences on the vines and fruit. Among the results was a reduction in yield of up to 45%. There were also carry over affects for the coming year with reduced cane available to tie down and reduced quality of cane. There was a belief that these negatives may be able to be compensated for by an improvement in wine quality. Small batches of wine were made (around 500 litres per treatment) to establish the affect on wine quality. A number of objective and subjective measures of wine quality were used. The results showed that there was certainly an effect on wine composition. Generally the very low yields, while producing wines of an acceptable standard, were not up to the top quality Sauvignon Blanc that can be grown in the district. Comments from winemakers were that they were of a standard that they would use in the blending process rather than as a selection in its own right.

The conclusion of the trial was that if water was a very scarce resource careful timing of application could result in the production of a useable wine at a yield that should ensure the grower covers enough costs to get through the season. This is an important result as some of the irrigation applications were very small in comparison to the district average and the vines survived the process although they certainly looked stressed for much of the season.

At the end of the first three years the question was asked as to how well the vines would recover from the water stress. A fourth year extension to the project was carried out, to effectively water the block at normal levels for a season and monitor the results.

The results showed that the vines recovered surprisingly easily. Shoot growth was back to normal, yields, bunch weights and berry weights evened out as did the juice composition. These results show the adaptability of grape vines and are encouraging for the grower. Should the grower be restricted in the amount of water they can use in a one year there are likely to be consequences, however the vines quickly adapt, reducing the impact and then when balance is restored they revert to their normal state.

The following are the key points and recommendations from this work:

- Vines are ‘water hogs’ and will consume the water you give them but there is clearly an efficient minimum to get the best result with the least amount of water.
- As irrigation decreases so does Crop Water Use indicating a certain degree of compensation by the vine to reduced water availability
- Irrigation below 40% ETc clearly will reduce yield, mainly because of reduced berry weight and size. This compares to our control at 70 % ETc which we believe is a typical and adequate requirement in Marlborough.
- If you have a limited water resource it is critical to keep soil moisture levels up close to full point during the flowering and fruit set period to obtain the best yields. I.e. timing of the use of what limited water is available can be more important than the total availability.
- Lower irrigation did not improve brix levels, but did tend to increase pH and reduce titrateable acidity.
- The experimentation with Partial Rootzone Drying indicated that it is not a tool for reducing irrigation requirements in Marlborough conditions.
- Vine performance variation increases as water stress is increased. It is unadvisable to reduce irrigation much below the Control level where high levels of soil variability are present within a block.
- Mulch is a useful tool to improve water retention but should not be expected to replace a significant amount of irrigation.
- Use of a Pressure Bomb to measure leaf water potential worked very well when used in conjunction with soil moisture readings. It is a good tool to help set Refill points and determine whether stress symptoms are actually water and not some other factor.
- Measurement of vine sap flow, stomatal conductance and leaf area and use of modelling techniques are all useful tools for researching water stress and the effects of irrigation treatments. A much faster (and subsequently cheaper) method of measuring leaf area is needed to commercially integrate canopy size with soil moisture and irrigation scheduling.

INTRODUCTION

Nationally and internationally water is becoming a limiting resource to the production of quality wine grapes. In New Zealand rapid expansion in this industry has seen growth into previously considered water-short areas and exploitation of previously considered large aquifer reserves. Currently irrigation research is focused on water use in grape vines with the aim to reduce water inputs whilst maintaining or improving wine quality but not adversely affecting yield. As water becomes a more scarce resource then this approach may not give adequate water savings to enable sustainable production.

Our experience in both running/using an irrigation scheduling service and an SFF project looking at vine water use (00/294) tells us that vines are basically water hogs and will take almost anything that you can give them. This is not new, it has been known for some time, but gives us an important clue when it comes to the possibilities in this area of water management.

The aim of the first three years of this project was to set up a replicated scientifically sound trial on a commercial vineyard looking at pushing the boundaries of water application to find out what the limits and effects are.

The aim of the fourth year of the trial (extension) was to assess the response of all the deficit treatments when returning irrigation to ‘normal’ levels. This replicated the situation that would likely occur in vineyards where irrigation restrictions have been implemented and then these restrictions removed the following season, e.g. if the Southern Valleys scheme was turned off in a dry year and then back on the following season.

This summary of all four years of the trial undertakes to pull out the key information from the vast amount of data collected and present it in a practical manner and with a focus on the commercial application of the results and conclusions found from this work.

A great amount of detail on all the technology and systems used, the data collected and the individual results obtained can be found in the annual reports for this project and are available from the authors.

SUMMARY OF METHODOLOGY

A 0.76ha block of Sauvignon Blanc on three different rootstocks at Nautilus Estate Renwick Vineyard was selected to conduct the various irrigation treatments. The vineyard is a relatively dry block and consistent with many stony soils in the Marlborough District.

The trial consisted of 18 plots made up of three replicates of the six treatments. Each replicate was completely within one rootstock. The rootstocks were 101/14, 3309 and Riparia Gloire. Please see Figure 1 in the Appendix for a map of the trial layout.
The treatments used the following irrigation strategies

Treatment 1 Control – standard irrigation strategy -70% ET_c less effective rainfall
Treatment 2 50% ET_c less effective rainfall
Treatment 3 40% ET_c less effective rainfall
Treatment 4 30% ET_c less effective rainfall
Treatment 5 PRD* and 60% ET_c less effective rainfall
Treatment 6 Mulch and 30% ET_c less effective rainfall

*PRD is Partial Rootzone Drying, a technique where there are two irrigation lines per row and one side of the vine is kept dry, the other irrigated and then alternated several times during the season to “trick” the vine into thinking it is receiving more water than it actually is.

The major difference between this trial and others previously or currently being carried out is the desire to manage irrigation application under these regimes. This project will not look at merely reducing dripper output to say 40% of the control, but looking at the best use of the total 40% of ET_C available to the vine over the whole season. In effect, there could be times when the 40% treatment receives more than the control and times when it receives nothing. The important part of this approach is practicality. This is the approach that a grape grower would take in a real situation. They would not merely go from say a 4ltr/hr dripper to a 1ltr/hr dripper but rather continue to use 4ltr/hr drippers but manage the irrigation.

In line drip irrigation was installed in early December 2003 with ten separate solenoids to allow individual control of irrigation application on the six irrigation treatments and guard rows. Emitters in the laterals were spaced at 400mm and rated as 1.6 litres per hour. The partial rootzone treatment was set up using 2 litres per hour drippers and two drippers per half vine.

An electromagnetic (EM) survey of the site was completed to determine relative soil moisture differences over the block. Based on this four adjacent bays in relatively similar soil type were selected as monitor bays and one vine in each bay marked as a monitor vine.

Measurements taken at the trial site.

A very comprehensive set of measurements were made particularly during the first three years of the trial with the aim to cover all aspects of vine growth and use as much of the available technology and techniques as possible. Table one lists the measurements taken.

Table one: Measurements taken at the trial site.

Measurement	Sample location	Years
Weekly soil moisture (Neutron Probe)	3 monitor bays per plot	1,2,3,4
Weekly pressure bomb	3 monitor bays per plot	1,2,3
Weekly shoot measurements until trimming	2 shoots from all 4 monitor vines per plot	1,2,3,4
Cordon bud counts	All 4 monitor vines in each plot	1,2,3
Shoot numbers	All 4 monitor vines in each plot	4
Bunch counts	All 4 monitor vines in each plot	2,3
Weekly berry size	4 berries from all 4 monitor vines per plot	1,2,3
Pre-harvest juice analysis	30 berries from all 4 monitor bays per plot	1,2,3,4
Harvest juice analysis	100 berries from all 4 monitor bays per plot	1,2,3,4
Harvest bunch number and bunch weight	4 monitor vines in every plot	1,2,3,4
Point Quadrant		2,3
Sap Flow (Heat Pulse)	Six treatments in one replicate	2,3
Light Interception	Using point quadrant method	2,3
Stomatal Conductance		2,3
Harvest variation data between bays		1,2,3,4
Pruning weights	4 monitor vines in every plot	4
Small batch winemaking	All six treatments had separate wine made	1,2,3

Soil moisture and Irrigation at the trial site

The soil at the trial site is an Awatere series described as a shallow and stony soil with a sandy loam A horizon overlying C horizons of stony loamy sand. As such Permanent Wilting Point (PWP) was estimated as 50% of the FULL points and Readily Available Water (RAW) was estimated at 35% of FULL (approximately 80mm). Full points on all sites are relatively similar with initial estimates of FULL varying between 214mm and 245mm. For the first three years suggested irrigation strategies were put in place at the beginning of the season with the intention of modifying as soil moisture or seasonal influences dictated. A summary of the strategies for the six treatments is shown in Table two. These strategies were essentially the same for the first three years of the trial.

Table two: Irrigation strategy for each treatment, years one to three

Treatment	REFILL	Strategy description
1	65% of FULL	Standard Sauvignon Blanc strategy[1]. Good soil moisture over flowering, slowly drying profile to refill point until Veraison and holding until harvest.
2	54% of FULL	Standard strategy with lower refill point
3	54% of FULL	Lower refill point & lower allowable soil moisture over flowering
4	54% of FULL	Lower refill point, lower allowable soil moisture over flowering & drying to refill by December end.
5 (PRD)	65% of FULL	Standard strategy switching when dry side hit lower strategy line
6	54% of FULL	Same as treatment 4 with mulch applied early November.

[1] See Figure 2, Appendix for graph outlining standard irrigation strategy.

In the fourth year of the trial the aim was to irrigate the whole block to Treatment one levels, i.e. 60% of estimated crop use - (approx) 100 mm per year. The soil moisture readings for Treatment one (original Control plot) were used as the basis of deciding how much irrigation to apply to the whole block.

The Pressure bomb is a scientific instrument widely used in California for irrigation scheduling but has the limitation of requiring consistent sunny days for accurate readings. It measures the osmotic pressure in the vine leaves, a bit like reading the vines "blood pressure", the higher the negative pressure readings the harder the vine is working to extract water from the soil. It was used in the trial to see if there were differences between the different irrigation treatments.

Vine and Yield measurements

Shoot length/number, cordon bud counts, weekly berry size, harvest bunch number/weights, harvest variation data and pruning weights were all measured to record the effect of the different irrigation treatments on growth and yield.

Juice and wine characteristics

Pre-harvest juice analysis and at harvest juice analysis for brix, titrateable acidity and pH were carried out to determine the effect of the irrigation treatments on these parameters.
Small batch wine making was also carried out to see if the effect of the treatments carried through into wine style etc.

Scientific contribution and measurement

As part of this project, Hort Research was contracted to measure actual vine water use, using sap flow sensors in the vine stem. In addition they were also asked to provide measurements of canopy leaf area using point quadrant and light interception techniques and carry out an assessment of the treatment response of leaf stomatal conductance. We have subsequently used a simple model to link water use to the vine's total leaf area and the prevailing microclimate. For this calculation, the local climate data (*i.e.* daily global radiation, air temperature, relative humidity, wind speed and rainfall) were obtained from the NIWA climate station at the Woodbourne airport (station number G13585). Our measurement and modelling approach enables us to compare actual vine water use (from sap flow) against the amount of irrigation applied under the various irrigation treatments. This approach also enables a qualitative measure of plant water stress that can not be obtained from measurements of soil water content alone.

RESULTS AND DISCUSSION

Soil moisture and Irrigation

Table three: Estimated Crop Water Use, Rainfall and Irrigation application from early November (start of irrigation applications) until harvest for the first three years.

T/ment	Crop water use			Rainfall			Irrigation mm			% of CWU less effective rainfall		
Year	1	2	3	1	2	3	1	2	3	1	2	3
1	310	380	312	241	307	235	107	100	124	74	57	86
2	268	327	271	241	307	235	55	47	71	61	41	68
3	245	310	247	241	307	235	30	22	43	42	24	53
4	225	290	222	241	307	235	17	16	27	34	21	49
6	245	316	243	241	307	235	30	26	30	42	23	39
5a (PRD)	250	347	275	241	307	235	15	50	66			
5b (PRD)	319	335	305	241	307	235	84	61	61			
PRD ave	284	341	290	241	307	235	109	111	127	86	81	103

Year 1 = 2003/04, Year 2 = 2004/05 and Year 3 = 2005/06. Crop water use has been calculated using the soil based model developed during the previous SFF project 00/294.

Table three shows that as irrigation application decreased actual crop water use also declined across all three seasons. The PRD treatment's average CWU was slightly less than the control (despite receiving similar amounts of irrigation) but more than treatment two across the three years and this shows that the PRD treatment made better use of that water as crop use (transpiration) is lower. However over all three years it was not possible to apply less irrigation on the PRD treatment compared to the control. In order to achieve a distinct wetting and drying of the profile, irrigation had to match or be slightly greater than the control. This is accentuated in Marlborough by the higher average rainfall compared to where PRD has been used in Australia.

The mulch in treatment six has higher crop use compared to treatment four despite receiving similar amounts of irrigation. The mulch appears to improve moisture retention in the soil - exactly as growers hope for when they apply mulch.

In year four all the treatments had virtually the same amount of irrigation as can be seen in table four. The small variation with treatment 3 is not significant.

Table four: Estimated Crop Water Use, Rainfall and Irrigation application from 1st November until harvest in year four.

Treatment	CWU	Rainfall	Irrigation (L/vine)	Irrigation (mm)
1	309	245	423	82
2	281	245	423	82
3	302	245	510	94
4	234	245	423	82
5	325	245	423	82
6	360	245	423	82

Pressure bomb- leaf water potential

Pressure bomb readings were generally in line with soil moisture readings across the first three years of the project. Pressure bomb readings of -12 to -14 appeared to correspond with the lowest soil moisture readings. Treatments 1 and 5 showed the least water stress while treatments 4 and 6 showed the most. This is a very encouraging result as it shows the potential of this technology in setting target soil moisture levels based on vine stress and its role in helping set Refill points.

Vine and berry measurements

In general the shoot and leaf measurements over the first three years of the project were not conclusive as to the effect of reduced irrigation on vine growth. In the first year the treatments with the lower irrigation had distinctly shorter shoots and lower leaf area but in the second and third years the differences became more marginal and the mulch in treatment six definitely helped counteract the lower irrigation application. Timing and quantity of rainfall also had a significant effect on these results. The results indicate that after the first year the vines adapted somewhat to drier conditions in terms of shoot and leaf growth although the trends were still for the lower irrigation treatments to have slightly lower shoot growth rates. However there was a significant improvement in growth rates of the original lower irrigation treatments in year four once more "normal" irrigation returned as can be seen in Table five.

Table five: Average shoot growth rates (cm/day) for 2003-2006 and 2006/07.

Treatment	1	2	3	4	5	6
Average	0.69	0.64	0.58	0.58	0.76	0.65
2006/07	0.48	0.46	0.54	0.62	0.50	0.62

In the case of berry weights and size significant differences were recorded across all the first three seasons, with the higher irrigation treatments (including PRD) consistently achieving higher weight/size than the lower irrigation ones, and this was the main factor where higher yields were obtained. Table six shows these results for all four years in the case of weight and the first three years for berry size.

Table six : Berry weight and size at harvest

Treatment	Berry Weight				Berry size		
Year	1	2	3	4	1	2	3
1	1.81	1.65	1.82	1.84	12.3	12.1	13.8
2	1.50	1.41	1.41	1.87	11.1	11.6	13
3	1.22	1.40	1.32	1.99	10.7	11	11.8
4	1.11	1.42	1.20	2.03	11.8	10.4	11.7
5	1.63	1.76	1.67	2.06	12	11.6	13.1
6	1.14	1.31	1.07	2.02	11.1	11	12.2

The highlighted column in year four clearly indicates how berry weight became very similar between all treatments once a "normal' irrigation regime was re-introduced.

During the project it also became clear as to how important the timing of irrigation application is to berry size, its not just how much water is applied but when it is applied that also counts. Irrigation at flowering is critical to ensuring adequate fruit set and reduced irrigation and or rainfall in the weeks following set will reduce berry size. This is an important consideration for growers wishing to maximise yield with reduced irrigation availability.

Juice and wine characteristics

As harvest date was dictated by a target brix level there were no significant differences in the brix levels recorded between the treatments either with the harvest or post harvest analysis. Preharvest brix levels were only different in the first year of the trial where lower irrigation treatments had higher brix earlier than higher irrigation treatments.

There was a trend noted where the lower irrigation treatments tended to have lower titratable acidity and higher pH compared to the higher irrigation treatments. These were significant ($p=0.05$) differences.

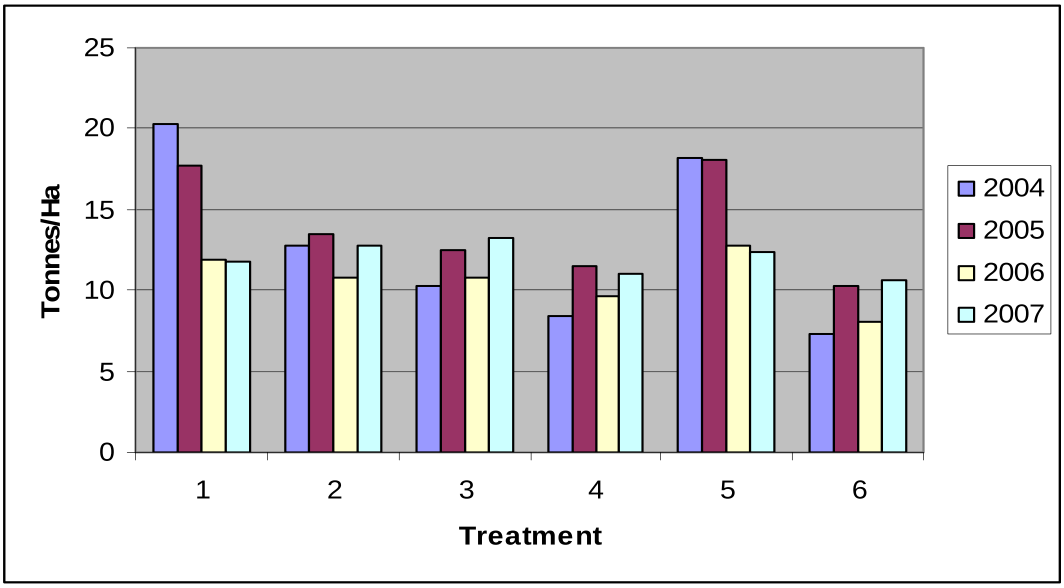
There was a belief that the negative effects of the low irrigation treatments may be able to be compensated for by an improvement in wine quality. Small batches of wine were made (around 500 litres per treatment) to establish the affect on wine quality. A number of objective and subjective measures of wine quality were used. The results showed that there was certainly an effect on wine composition. Generally the very low yields, while producing wines of an acceptable standard, were not up to the traditional 'Marlborough Sauvignon Blanc' that can be grown in the district. Comments from winemakers were that they were of a standard that they would use in the blending process rather than as a selection in its own right. The lower irrigation wines tended to exhibit flavours more at the tropical end of the spectrum.

Harvest and yield results

The target parameters to decide the start of harvest for all four years were set as:

> *Brix - approx 21*
> *TA - < 10g/L*
> *Flavours - mix of herbaceous and tropical characters but without excessive greenness*

Graph one: All four years yield results.



As can be seen from graph one there were significant differences in yield in the first three years, in particular with treatments one and five (high irrigation) compared to treatments four and six. This is consistent with expectations and confirms that reducing irrigation below 40% of ETc will reduce yield.

In year four yields were similar between treatments although treatments four and six show a slightly reduced yield due to lower bunch numbers. This could be an effect of the more limited cane growth in the previous year. However it is clear that the return to “normal” irrigation has gone a long way towards achieving a similar yield across the treatments, and this is because of the improved berry weight and size on the original low irrigation treatments.

Harvest variation between bays

In all four years of the project bay weights were recorded for each treatment to assess the effect of low irrigation levels on yield variation. There is more information regarding this subject in the year four report including a separate industry/literature review. In summary it was clear that the trend is reduced irrigation increases vine yield variation and that on the return to “normal” irrigation this phenomena was reduced. The reasoning is that as the soil becomes lighter there is less buffering capacity within the soil to combat the lower irrigation regimes. Hence the effect on variation is more dramatic on the lower irrigation treatments.

__Scientific contribution and measurement__

Hort Research were contracted in the first three years of the project to measure actual vine water use, using sap flow sensors in the vine stem. In addition they were also asked to provide measurements of canopy leaf area using point quadrant and light interception techniques and carry out an assessment of the treatment response of leaf stomatal conductance.

Sap flow in the vine trunk

Heat pulse sensors using the Tmax method (Green et al, 2003) were used to measure vine sap flow. In the third year of the trial these sensors were set up in three vines per irrigation treatment. The measurements taken are converted into litres of water per vine per hour and then summed to estimate cumulative vine water use. Figure 1 is an example of vine sap flow results taken from year three of the project. The effect of rainfall on January 25th can be seen with both the control (T1) and dry irrigation treatment (T4) returning to similar crop use for a period.

Figure 1: Sap flow for treatments one and four 17th January to 2nd February.

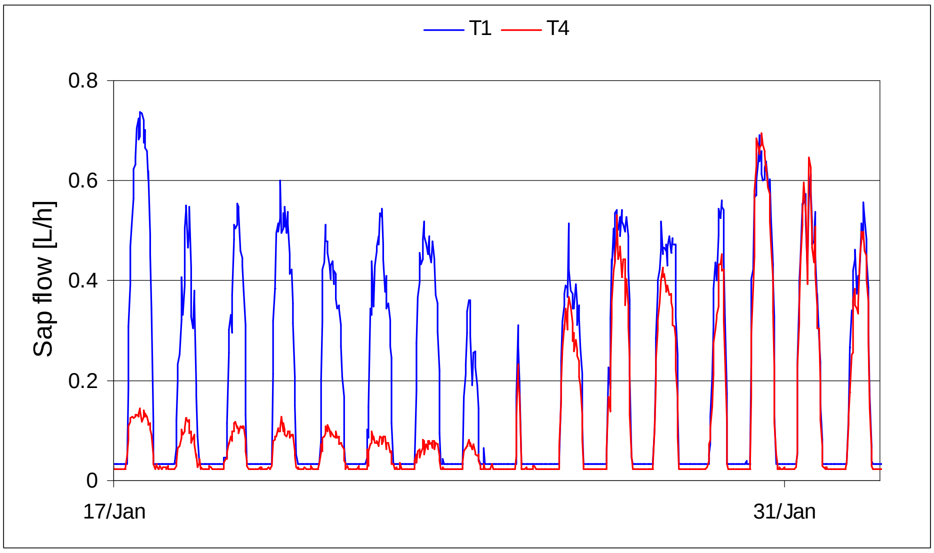


Figure 1 shows the diurnal pattern of sap flow in the grapevine stem. Here T1 represents the control (100%) irrigation treatment and T4 represents the 30%DI treatments. A large rainfall of 55 mm was recorded around 25th January.

Sap flow measurements as shown in the example clearly indicate the differences in sap flow when water availability is restricted by reduced irrigation and lack of rainfall. The rainfall event of 25th January had an immediate effect, increasing sap flow in the low irrigation treatment to similar levels to the control treatment.

Leaf stomatal conductance

Vine water use is determined by a number of factors including vine leaf area, prevailing microclimate (expressed as the potential evaporative demand, mm/d), and the availability of soil water. Grape leaves can exercise mild control over their

transpiration loss via stomata on the under side of the leaf surface. The degree of control is characterized by the leaf stomatal conductance.
Leaves from the control vines tended to have higher stomatal conductance compared to the deficit irrigated vines, and this implies a greater transpiration loss for those vines, and a lower level of water stress. As expected, the shaded leaves tended to have a lower stomatal conductance compared with the sunlit leaves. This is because stomata tend to be less open in the shade. A similar 45%-75% reduction in conductance was observed in the shaded leaves under the lowest irrigation volumes (i.e. T4 and T6) compared with the control (i.e. T1).

Sap flow and stomatal conductance are ideal research tools to quantify the degree of water stress induced by the various irrigation treatments.

Vine leaf area

The potential productivity of grapevines in a given climatic region is largely determined by their total leaf area and by the fraction of leaves that are exposed to full sunlight, provided that other factors (e.g. water and nutrient stresses, insect and disease pressures) are not limiting vine growth and fruit development. Simple means to assess canopy leaf area may prove helpful, in the future, as the grape industry seeks to improve the efficiency of irrigation management regimes.
Two methods were used to assess canopy leaf area;

a) Destructive sampling – accurate but very time consuming

b) Point quadrant method. (PQ) In this case a slender rod is pushed through the leaf canopy and the number of leaf contacts with the rod is recorded by a data logger. The vines total leaf area, A_T (m^2), is calculated using a mathematical equation.

For example in year three the control vines received almost twice the irrigation, over the whole growing season, compared with the other deficit irrigated vines. They tended to be more vigorous, presumably because of this greater water supply, and they ended the season with a slightly greater leaf area compared to the deficit irrigation vines. There was a reasonable correspondence between trends in vine leaf area (i.e. vigour) and the total amount of irrigation water applied over the growing season. Measured just before harvest, the total leaf area of the control vines reached about 5.3 m^2 per vine. The corresponding leaf area of the T4 vines (30% of control) was about 3.5 m^2 per vine, on average. This represents a reduction in leaf area by a factor of about 1/3 as a result of the reduced irrigation.

An undeniable asset of the PQ method for leaf area determination is that it does not involve the cutting and destruction of shoots. This non-destructive method allows for repeated measurements in the same place during the entire growing season. Furthermore, the PQ method provides additional information about the leaf canopy (e.g. canopy density and the number of internal/external leaves) that is not possible from shoot sampling alone. However, the method may not be practical for routine measurements by vineyard staff since it still takes too long, especially towards the end of the growing season when canopy areas and leaf densities are at their highest.

Modelling potential vine water use

In general, vine water consumption depends on three factors: the atmospheric demand for water that is defined by the local microclimate; the vine leaf area that is determined by the number of shoots and the leaf area per shoot; and the response of the leaves to their aerial and soil environment. A standard crop-factor approach is used to relate the water use to the prevailing weather and time of year. The procedure is based on guidelines given by the Food and Agriculture Administration (FAO) of the United Nations (Allen et al, 1999). Equations were used to calculate a reference evaporation rate and then calculate a crop factor that could be used for grape vines to estimate crop water use for a 'well watered vine'

The potential water use of the vines was calculated using these equations on the basis of measured canopy leaf area and daily climate data from the Woodbourne airport located some 1-2 km away. They were graphed and compared to the vine sap flow measurements. The ratio between the actual and the potential water use provides a direct measure of water stress 'felt' by the vines. We also plotted the seasonal volumes of irrigation on the same graphs, using scales that match (i.e. by a factor of 7), to enable a comparison between daily water use and the weekly irrigation volumes.

Seasonal irrigation volumes closely matched potential water use of the control vines. The actual water use of the control vines and the PRD vines was also found to be very similar to the potential rates of water use calculated via the model. This result implies vines from these two treatments were supplied with adequate levels of soil moisture in their root zones (via irrigation and rainfall) thereby limiting symptoms of water stress that could otherwise affect transpiration and productivity.

Both leaf area and climate data are needed to calculate, with certainty, the potential water of grape vines. Stomatal conductance may well be a useful tool for irrigation consultants to rapidly assess the water status of vines. However, the consultant would also need to measure, or be able to calculate leaf stomatal conductance under 'non-stressed' conditions, in order to confirm the degree of water stress.

Further research effort, and additional analysis of experimental data from this trial, including fruit growth and soil moisture, is needed in order to unravel the link between plant and soil water status, irrigation demand and fruit quality using both a measurement and modelling approach.

APPENDICES

Figure One: Trial design.

Treatment 1 Control – standard irrigation strategy (approx 70% ET_c less eff. rainfall)
Treatment 2 50% ET_c less effective rainfall
Treatment 3 40% ET_c less effective rainfall
Treatment 4 30% ET_c less effective rainfall
Treatment 5 PRD and 60% ET_c less effective rainfall
Treatment 6 Mulch and 30% ET_c less effective rainfall

Figure 2: **Standard Sauvignon Blanc grape strategy**