# Maximising irrigation savings in grape vines and the effect on yield and wine quality
# SFF Project 03/100

### Results
### Year Three
### 2005/06

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## 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 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.

This report is for the third year of the trial and should be read in conjunction with the year one and two preliminary results reports where the research method and initial findings are discussed. Table one lists the measurements taken at the trial site this season.

**Table one:** Measurements taken at the trial site.

| Measurement | Sample location |
|---|---|
| Weekly soil moisture | 3 monitor bays per plot |
| Weekly pressure bomb | 3 monitor bays per plot |
| Weekly shoot measurements until trimming | 2 shoots from all 4 monitor vines per plot |
| Cordon bud counts | All 4 monitor vines in each plot |
| Bunch counts | All 4 monitor vines in each plot |
| Weekly berry size | 4 berries from all 4 monitor vines per plot |
| Preharvest juice analysis | 30 berries from all 4 monitor bays per plot |
| Harvest juice analysis | 100 berries from all 4 monitor bays per plot |
| Harvest bunch number and bunch weight | 4 monitor vines in every plot |
| Point Quadrant | |
| Sap Flow (Heat Pulse) | Six treatments in one replicate |
| Light Interception | Using point quadrant method |
| Stomatal Conductance | |

Fruit was harvested from the trial and small batch winemaking carried out to establish differences in wine quality.

## RESULTS AND DISCUSSION

### *Soil moisture and Irrigation*

Full points on all sites are relatively similar with initial estimates of FULL varying between 214mm and 245mm. The soil is an Awatere series soil 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). Irrigation decisions were made based on soil moisture levels and a season long strategy aimed at achieving the total irrigation applications as above. 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 each year of the trial.

**Table two:** Irrigation strategy for each treatment.

| 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 | 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. |

Rainfall over the critical flowering period also ensured good soil moisture levels across all treatments. Graph one shows rainfall and the relative soil moisture levels for the Regulated Deficit Irrigation (RDI) treatments; treatments one, two, three, four and six. Table three shows the irrigation applications for those treatments expressed as litres per vine per week.

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[1] See Appendix One for graphs outlining irrigation strategies.

**Graph one:** Control and Regulated Deficit Irrigation soil moisture readings 2004-05 (relative to FULL point)

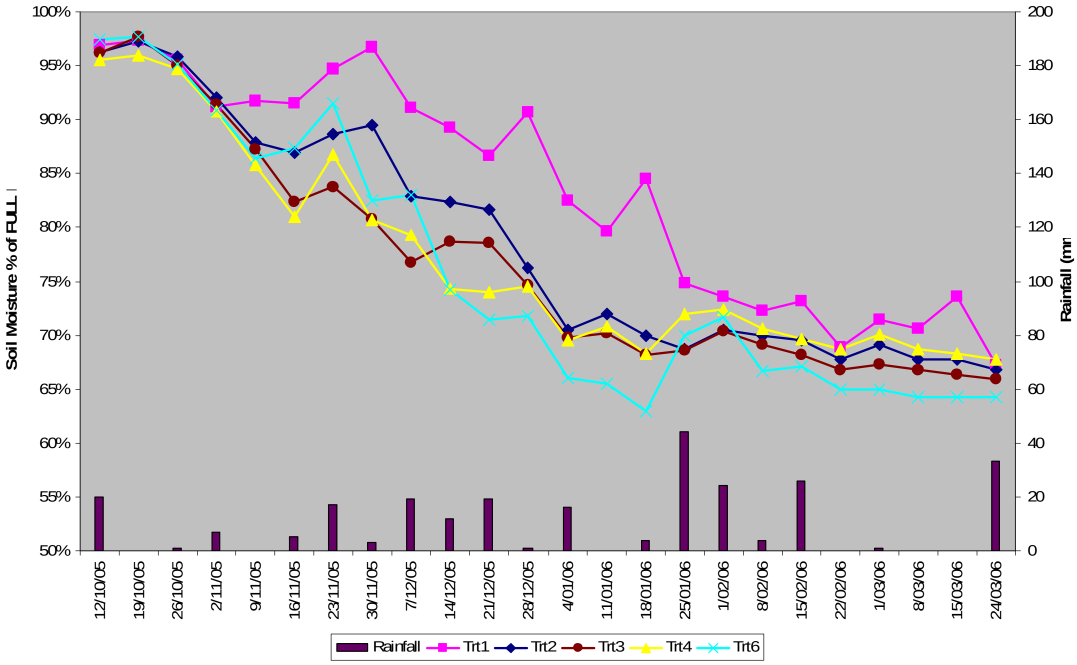


**Table three:** Control and RDI irrigation application 2005-06 (litres per vine for week ending).

| Date | 09/11 | 16/11 | 23/11 | 30/11 | 07/12 | 14/12 | 21/12 | 28/12 | 04/01 | 11/01 | 18/01 | 25/01 | 01/02 | 08/02 | 15/02 | 22/02 | 01/03 | 08/03 | 15/03 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **1** | 26 | 26 | 39 | 38 | 38 | 26 | 26 | 58 | 51 | 53 | 79 | 13 | 0 | 26 | 26 | 26 | 39 | 39 | 39 |
| **2** | 0 | 26 | 39 | 39 | 39 | 26 | 26 | 13 | 15 | 40 | 16 | 13 | 0 | 13 | 13 | 13 | 19 | 20 | 19 |
| **3** | 0 | 0 | 38 | 0 | 39 | 26 | 13 | 26 | 12 | 27 | 13 | 13 | 0 | 0 | 0 | 0 | 13 | 13 | 13 |
| **4** | 0 | 0 | 36 | 0 | 26 | 0 | 0 | 21 | 2 | 27 | 1 | 0 | 0 | 0 | 0 | 0 | 13 | 13 | 13 |
| **6** | 0 | 25 | 35 | 0 | 25 | 0 | 0 | 20 | 2 | 14 | 1 | 0 | 0 | 0 | 0 | 0 | 13 | 13 | 13 |

The early part of the season was relatively dry with the trial site receiving rainfall of 40mm in October, 32mm in November and 54mm in December. While this is only marginally below the long term average it very nearly led to the Southern Valleys Irrigation Scheme being shut off. Irrigation began earlier than either of the previous two seasons and all treatments received irrigation just prior to and at flowering. All treatments also received irrigation late December and early January and again just prior to harvest. Irrigations close to harvest were only small, providing just enough moisture to assist the ripening process. While the mulch treatment received similar amounts of irrigation to treatment four, it’s irrigation was applied less frequently in larger amounts to penetrate the mulch.

Graph two shows rainfall and the relative soil moisture levels for the Partial Rootzone Drying (PRD) treatment, treatment Five. Table four shows the irrigation applications for this treatment. Treatment 5a and 5b refer to alternate sides of the vine as required for PRD treatments.

**Graph two:** Partial Rootzone Drying soil moisture readings 2004-05 (relative to FULL point)

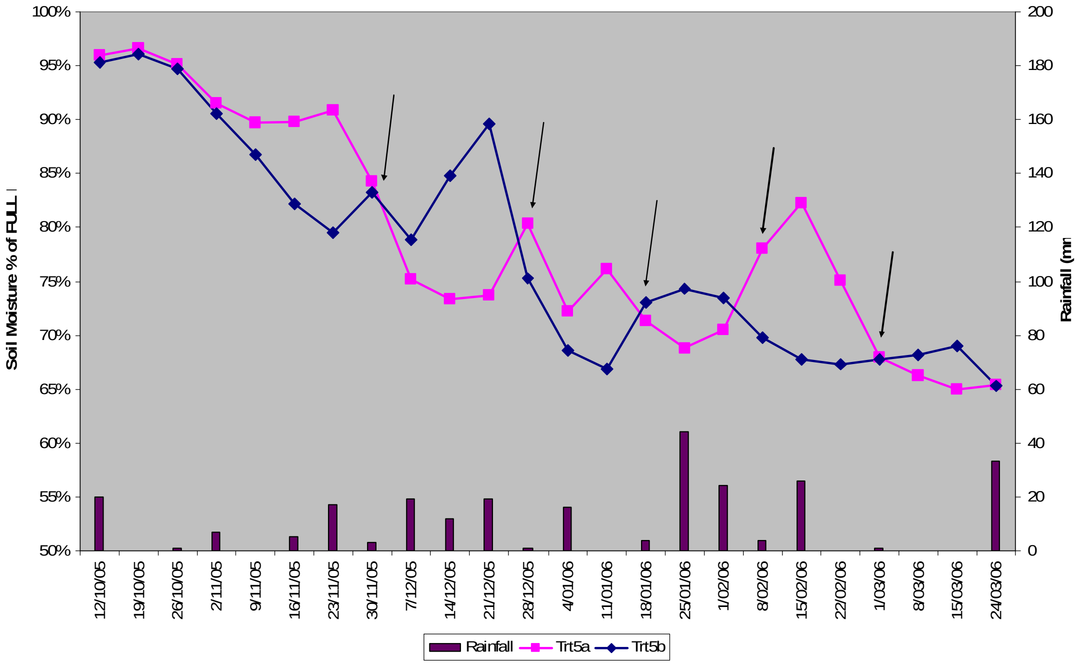


**Table four:** Partial Rootzone Drying irrigation application 2004-05 (litres per vine for week ending).

| 09/11 | 16/11 | 23/11 | 30/11 | 07/12 | 14/12 | 21/12 | 28/12 | 04/01 | 11/01 | 18/01 | 25/01 | 01/02 | 08/02 | 15/02 | 22/02 | 01/03 | 08/03 | 15/03 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 66 | 27 | 25 | 0 | 0 | 0 | 0 | 43 | 30 | 50 | 19 | 0 | 0 | 33 | 33 | 33 | 0 | 0 | 0 |
| 0 | 0 | 0 | 24 | 24 | 32 | 48 | 0 | 1 | 1 | 48 | 40 | 0 | 0 | 0 | 0 | 32 | 45 | 32 |

This season five irrigation switches were necessary and there were clear soil moisture differences between the two sides of the vine. The soil moisture graphs clearly show one side of the vine drying while the other was being wet. For the third season it was not possible to achieve a lower irrigation application than the control treatment. In order to achieve a distinct wetting and drying of the profile, irrigation application had to match or be slightly greater than the control. It appears the wetting and drying of the profile is a key component of partial rootzone drying and given the higher rainfall in the Marlborough district irrigation savings less than a standard deficit irrigation treatment are not possible while achieving this.

Table five shows seasonal crop water use, rainfall and irrigation application for the six treatments. Crop water use has been calculated using the soil based model developed during the previous Sustainable Farming Fund project 00/294.

**Table five:** Estimated Crop Water Use, Rainfall and Irrigation application from 1st November 2005 until harvest.

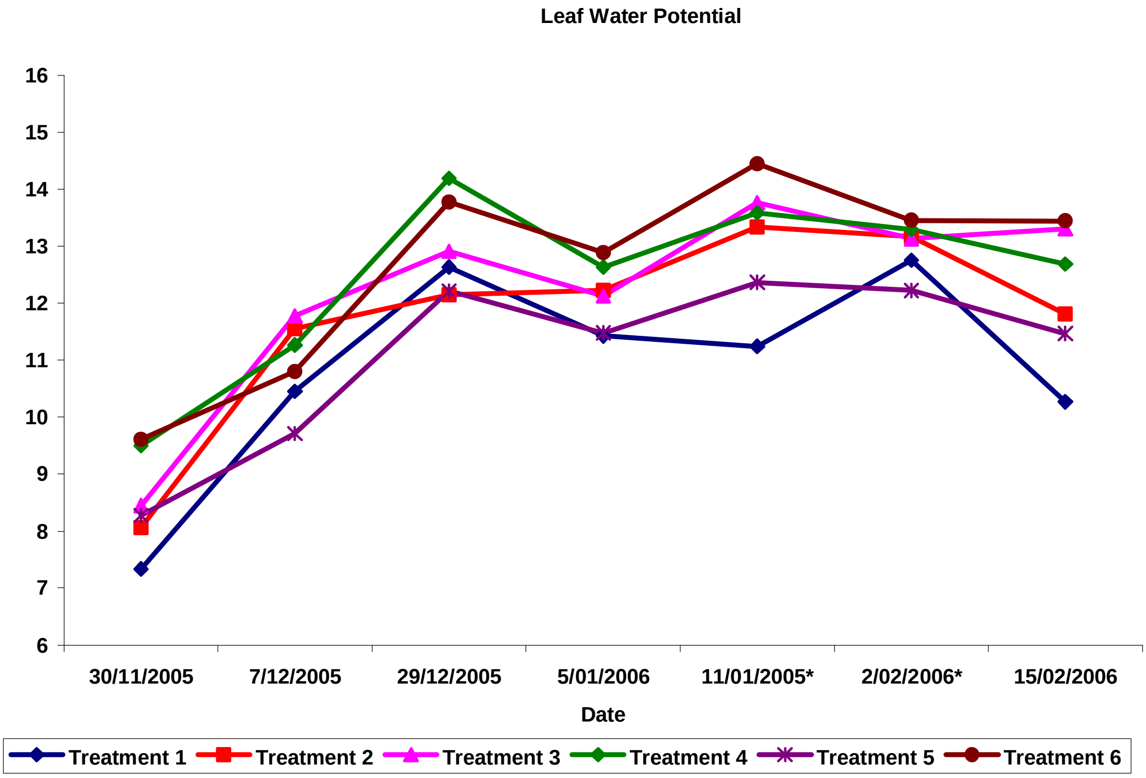
| **Treatment** | **CWU** | **Rainfall** | **Irrigation (L/vine)** | **Irrigation (mm)** | **% of CWU less effective rainfall** |
|---|---|---|---|---|---|
| 1 | 312 | 235 | 666 | 124 | 86 |
| 2 | 271 | 235 | 389 | 71 | 68 |
| 3 | 247 | 235 | 245 | 43 | 53 |
| 4 | 222 | 235 | 152 | 27 | 49 |
| 6 | 243 | 235 | 161 | 30 | 39 |
| 5a | 275 | 235 | 358 | 66 | |
| 5b | 305 | 235 | 328 | 61 | |
| PRD Ave | 290 | 235 | 686 | 127 | 103 |

Table five shows that as irrigation application decreased actual crop water use also declined. Average crop water use for the PRD treatment was slightly less than the control but more than treatment two. This pattern has been the same for all three seasons and shows that a PRD treatment despite receiving similar amounts of irrigation to the control makes better use of that water as crop use (transpiration) is lower. Treatment six again had higher crop use compared to treatment four, despite receiving similar amounts of irrigation. The mulch appears to ensure moisture retention in the soil which is available to the vine for use.

### *Pressure Bomb*

Midday pressure bomb readings were taken each week on the same day as the soil moisture readings. Unbagged (leaf water potential) leaves were sampled between 11am and 1pm. Whenever overcast conditions were present readings were not taken. This was due to the fact that the previous year’s data showed very low (no stress) readings on overcast days and this was consistent with previous researcher’s experiences. Weather conditions on eleven of the possible twenty five days allowed a full set of readings to be taken. Graph three shows all pressure bomb readings from the unbagged leaves. Values on the y-axis are increasingly negative.

**Graph Three:** Midday leaf water potential (unbagged).

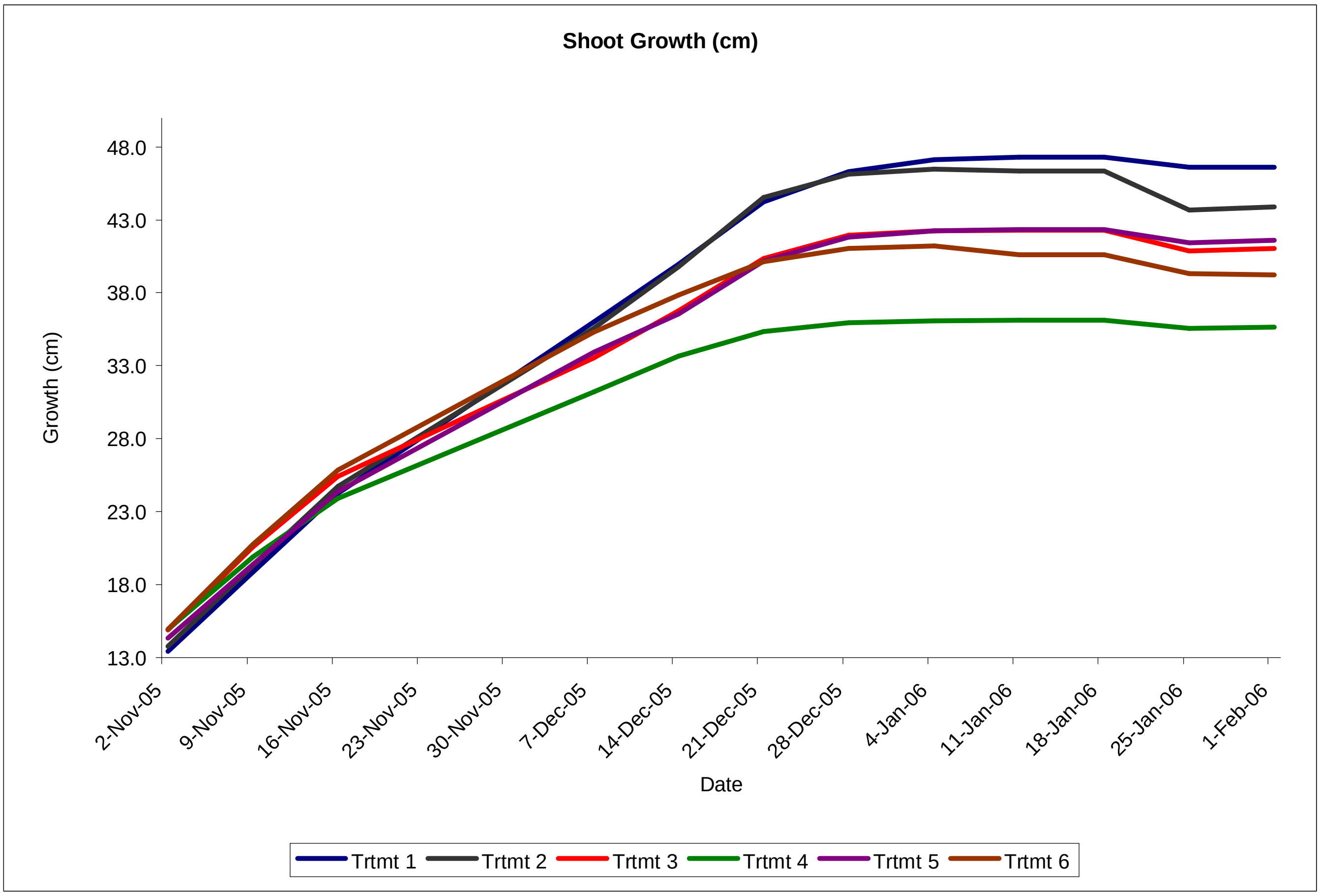


Pressure bomb readings this season again appear to be in line with soil moisture readings. Pressure bomb readings of -12 to -14 appeared to correspond with the lowest soil moisture readings. Treatments 1 and 5 showed the least water stress while treatments 4 and 6 showed the most. This is a very encouraging result as it is in line with last season and shows the potential of this technology in setting target soil moisture levels based on vine stress.

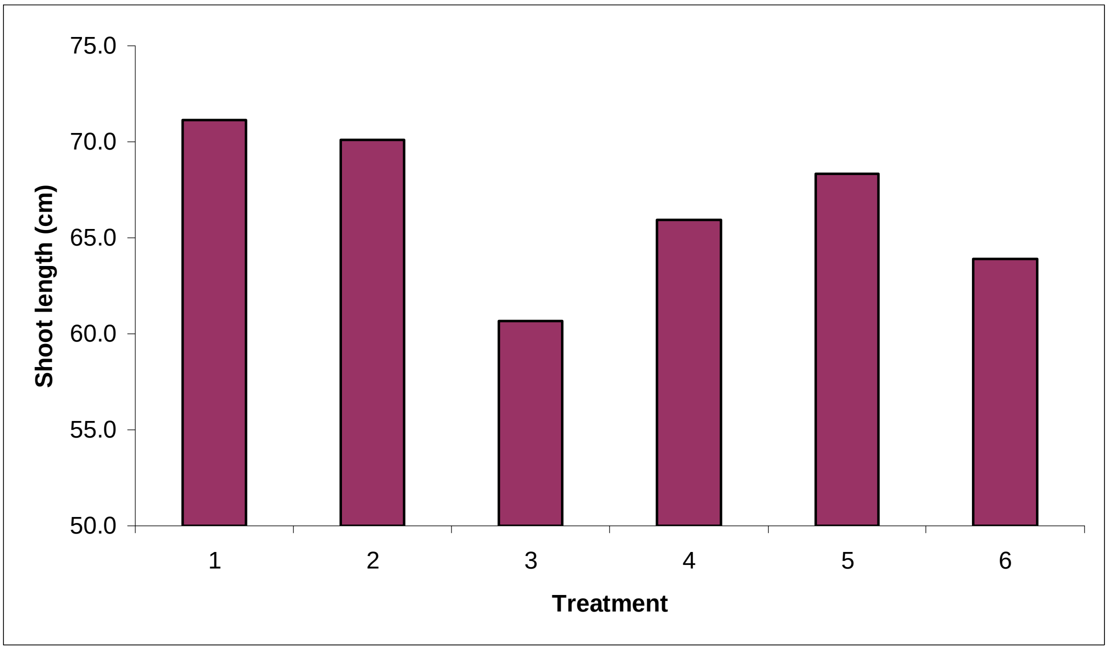
*Shoot Measurements*

Shoot measurements were taken from four shoots from four vines in each plot making a total of 54 measurements per treatment. These measurements were taken from 2nd November until the 1st February. Shoot growth is shown in Graph four and the trends suggest the lower irrigation treatments had lower growth rates however the only significant difference was between treatment 1 and 4.

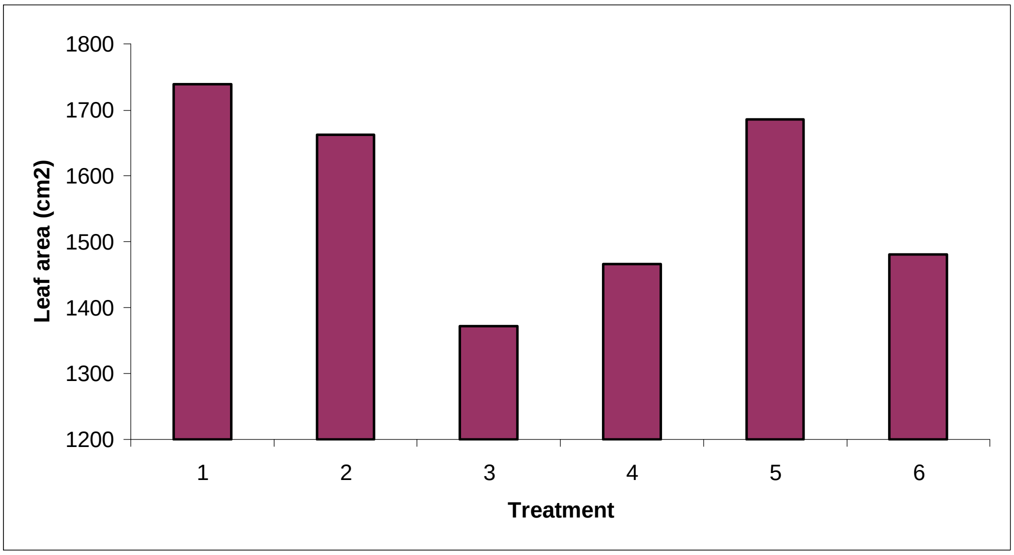
**Graph four:** Shoot growth curves.



**Graph five:** Shoot lengths on 9th January.



**Graph six:** Leaf area of main and lateral leaves on 9th January 2006.



On 9th January 15 shoots per replicate (45 per treatment) were collected and measured. All leaves and laterals were stripped, counted and leaf area measured. The length of all shoots is shown in Graph five and the total leaf area is shown in Graph six. The shoot lengths show a similar result to the shoot growth data that was measured on a weekly basis, with little difference between the treatments and few statistically significant differences. However, the leaf area for the drier treatments is lower than the control treatment but also not significantly so. This appears to suggest that the vines have adapted somewhat to the drier conditions as statistically different shoot growth was achieved in the first year of the trial.

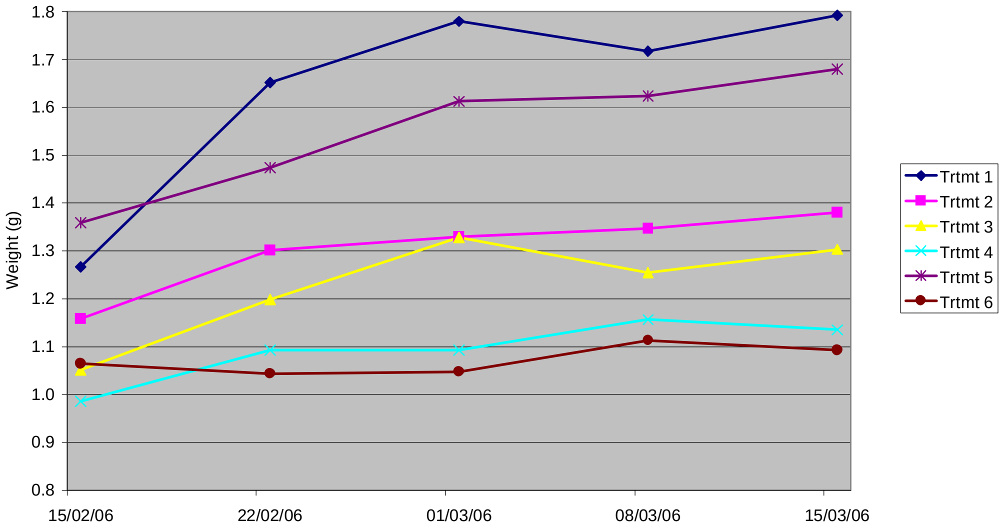
*Berry Weight*

Berry weight was measured weekly from 15th February to harvest via a 100 berry destructive sample and is shown in Graph seven. Berry size was also measured on the vine from 19th January onwards and is shown in Graph eight.

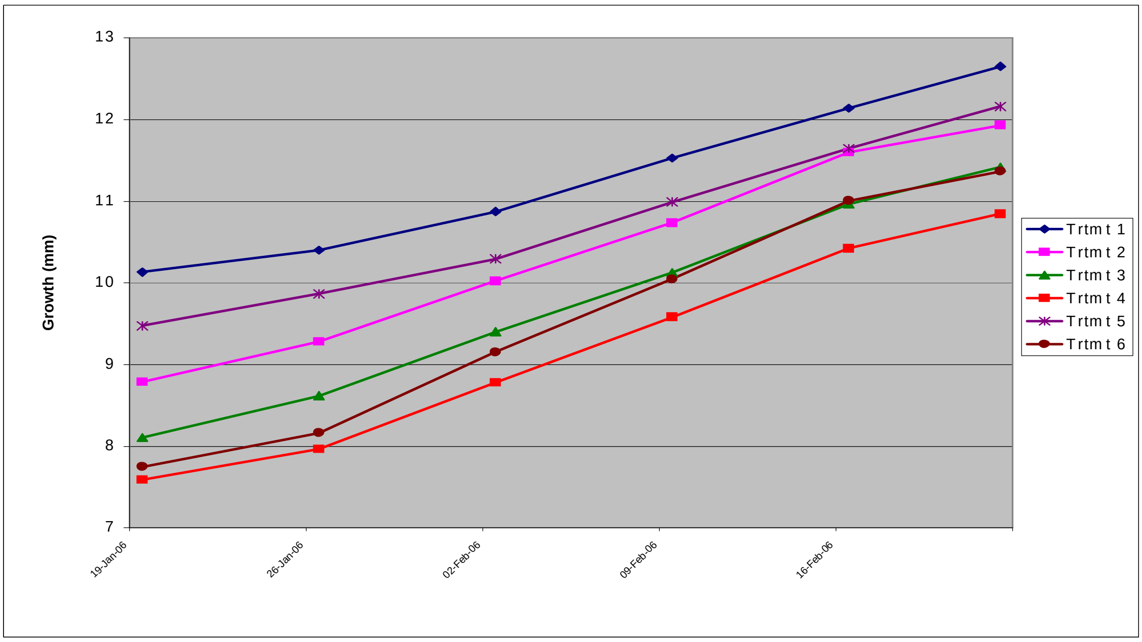
Despite irrigating all vines at flowering there were significant (p=0.05) differences in berry weight and berry diameter when samples began and this trend held at harvest. The final berry weights at harvest showed that the higher irrigation treatments (including PRD) had the highest berry weights. The lower treatments had the lowest berry weights and diameters.

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.

**Graph seven:** Berry weight 15 February 2006 to harvest



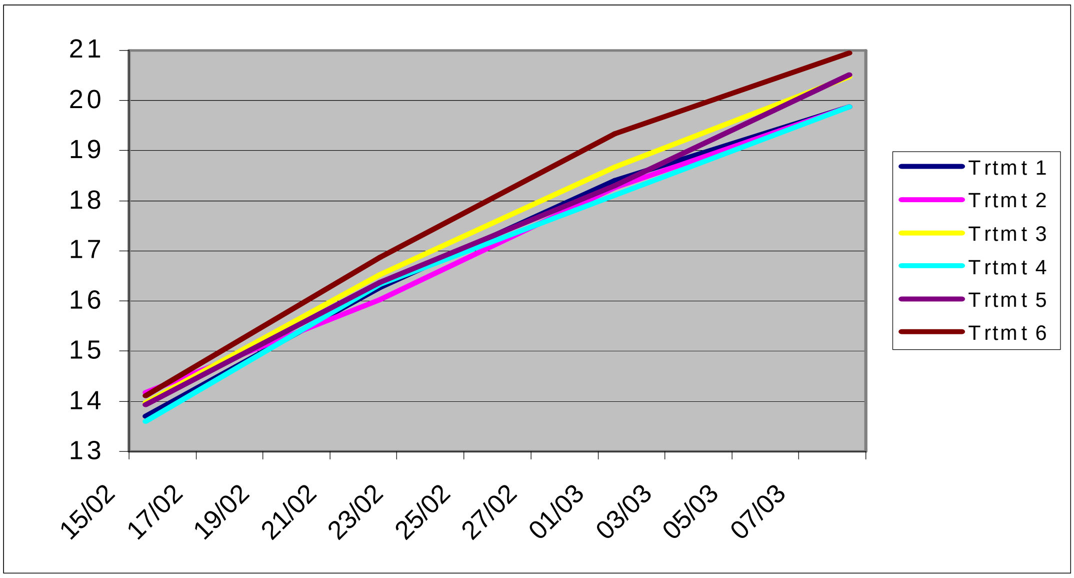
**Graph eight:** Berry growth over the growing season



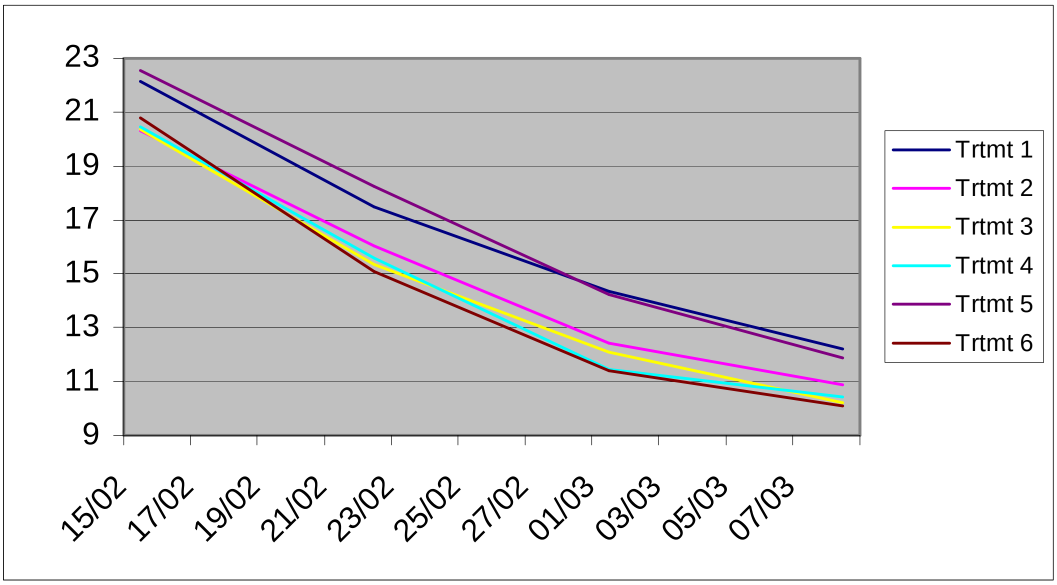
*Pre Harvest Juice analysis*

Berry samples were taken from 15th February through to harvest and analysed by Hortresearch. For each treatment 360 berry samples were taken (120 from each replicate). These were selected from vines in the same bay as the monitor vines. Graphs nine, ten and eleven show the brix, titratable acidity and pH of the pre harvest berry samples.

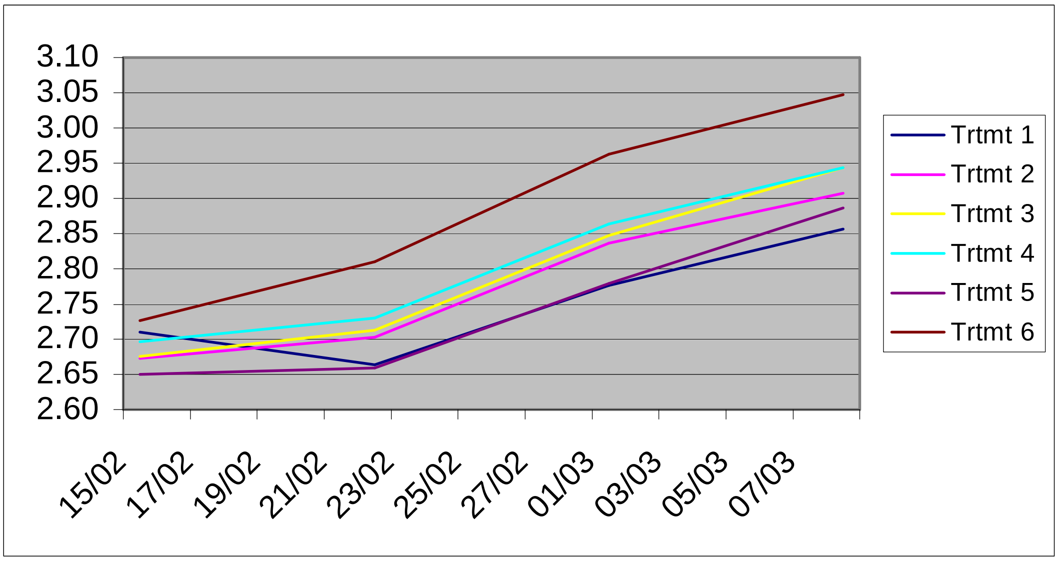
**Graph nine:** Brix levels of sampled fruit



**Graph ten:** Titratable acidity levels of sampled fruit.



**Graph eleven:** pH levels of sampled fruit



In summary the lower irrigation treatments tended to have lower titratable acidity and higher pH. There were significant difference between the lowest and highest irrigation treatments for both titratable acidity and pH.

*Harvest*

The intention of this trial is to determine the best management practice when water availability is limiting, therefore it was determined to try to harvest the treatments as close to a desired level of ripeness as possible rather than harvesting on one date and monitoring the resulting juice analysis. The following criteria were set to determine harvest date:

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

For each treatment a 1200 berry sample (400 from the monitor vines in each replicate) was analysed at harvest as well as analysis of the pressed juice. Table six shows the harvest date and juice analysis of the 1200 berry sample and Table seven shows the actual juice analysis of the pressed juice.

**Table six:** Harvest date and analysis of the berry sample at harvest.

| Treatment | Harvest Date | Brix | T/A | PH |
|---|---|---|---|---|
| 1 | 17/03/2006 | 20.6 | 11.1 | 2.93 |
| 2 | 17/03/2006 | 20.5 | 9.2 | 3.00 |
| 3 | 16/03/2006 | 20.9 | 8.9 | 3.02 |
| 4 | 16/03/2006 | 20.2 | 8.1 | 3.04 |
| 5 | 17/03/2006 | 20.6 | 10.2 | 2.96 |
| 6 | 16/03/2006 | 21.8 | 8.9 | 3.12 |

There was no significant difference between the Brix levels at harvest, however there were significant ($p=0.05$) differences between the lowest and highest irrigation treatments for titratable acidity. The pH of the mulch treatment was significantly different from the other treatments.

**Table seven:** Analysis of pressed juice.

| Treatment | Brix | T/A | pH |
|---|---|---|---|
| 1 | 22.0 | 10.4 | 2.91 |
| 2 | 21.4 | 9.7 | 3.01 |
| 3 | 20.5 | 9.9 | 2.98 |
| 4 | 22.4 | 9.3 | 3.01 |
| 5 | 21.9 | 10.4 | 2.88 |
| 6 | 20.9 | 9.0 | 3.08 |

*Splitting*

The level of splitting this year was virtually non-existent and not measured as a specific parameter. This is the result of better water availability at cell division and less rainfall over harvest.

*Bunch weight/ Bunch number*

The number of bunches and their weight for each of the monitor vines was recorded. This is shown in Table eight.

**Table eight:** Bunch number and weight for monitor vines.

| **Treatment** | **1** | **2** | **3** | **4** | **5** | **6** |
|---|---|---|---|---|---|---|
| Bunches per vine monitor vines | 71 | 74 | 64 | 76 | 78 | 71 |
| Ave bunch weight monitor vines (g) | 94 | 86 | 75 | 70 | 97 | 59 |
| Average berries per bunch | 52 | 61 | 57 | 59 | 58 | 55 |
| Average berry weight (g) | 1.82 | 1.41 | 1.32 | 1.20 | 1.67 | 1.07 |

Bunches numbers per vine showed little difference between the treatments however bunch weight was significantly (p=0.05) lower for the lower irrigation treatments. The reason for the reduced bunch weight was primarily due to a decreased berry size.

*Yield Analysis*

Table nine shows the yields on a per hectare basis for all irrigation treatment.

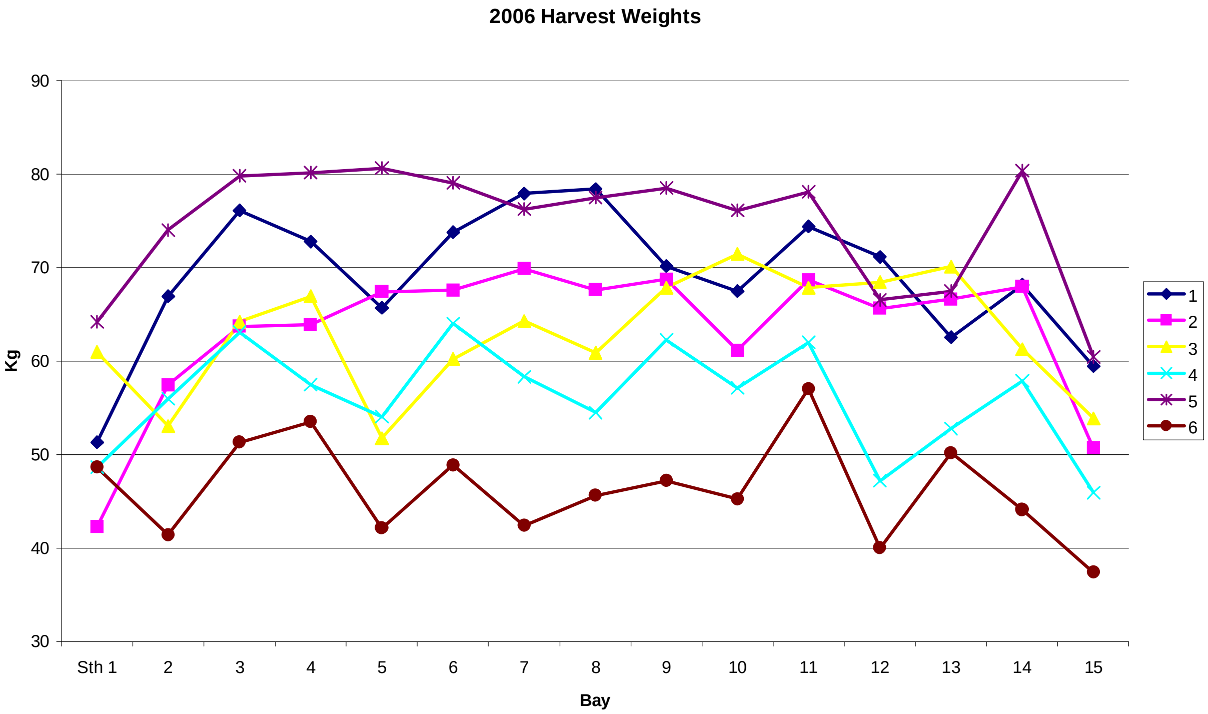
**Table nine:** Total yield per hectare for each treatment.

| **Treatment** | **1** | **2** | **3** | **4** | **5** | **6** |
|---|---|---|---|---|---|---|
| Yield. (t/ha) | 11.9 | 10.8 | 10.8 | 9.6 | 12.8 | 8.1 |
| Yield % control | 100% | 91% | 91% | 81% | 108% | 68% |

The yield for treatments one and five was significantly different from treatments four and six. This is consistent with expectations and confirms that reducing irrigation below 40% of ETc will reduce yield.

The weight of fruit from each bay was also recorded to determine if soil type variability down rows was significantly affecting yield. Graph twelve shows bay fruit weights for each of the treatments.

**Graph twelve**:  Weight of fruit per bay.



There is consistency with last two seasons with the bay weights.  There is more variation in those treatments with lower irrigation levels.  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*

As part of this project, Hort Research was contracted to measure actual vine water use, using sap flow sensors in the vine stem, as well as providing measurements of canopy leaf area and 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.

## Measurement details

### *Sap flow in the vine trunk*

For Year 3 of this trial, the Project Management Committee requested Hort Research to expand the sap flow measurements to include three vines from each of the irrigation treatments. To achieve this task, a total of 18 new sets of heat-pulse sensors and associated electronic controllers were constructed. The probes were installed in the vines in early January, and they were operated continuously up until mid-March (about one week before harvest). As with previous years of the trial, we used the T-max method (Green et al, 2003) to measure vine sap flow.

For the Tmax method, one temperature probe (1.2 mm diam.) is placed 12.5 mm downstream from a linear heater, and a second reference probe is placed a further 30 mm downstream (Figure 1). A brief pulse of heat (100 W over 2 s) is applied to the heater probes. The heat pulse travels along with the moving sap stream, and the time for a maximum temperature rise at the first temperature probe is used to calculate the sap velocity (= a distance over a time). This velocity is then integrated over the conducting sapwood area to yield a measure of the volume flow rate, expressed in litres per hour. The second 'reference' probe compensates for any background changes in stem temperature that might otherwise affect the measurement. Once the probes were installed, the stem section of each vine was wrapped in aluminium foil, in the vicinity of the probes, to minimise the effects of radiant heating on stem temperatures.

Signals from the sensors were measured using two dedicated data loggers (Campbell CR10X), equipped with solar panels (12 V, 5 W) and multiplexers (model AM25T). Raw data from the loggers was manually downloaded, once every 7-10 days, before being processed and archived. All measurements were converted into units of litres of water per vine per hour. The data were then summed to estimate daily and cumulative vine water use from mid-January through until about a week before grape harvest.

Figure 1. A total of 18 sets of sap flow probes were installed into the vines at the trial site at Nautilus Estate. Sap flow was measured once every 30 minutes using the T-max heat-pulse method (Green et al., 2003).

### *Vine leaf area*

Two methods were used to assess canopy leaf area. Firstly, whole shoots were sampled in mid-January to determine shoot length and leaf area. A total of 15 shoots were destructively sampled from each row of vines, giving a total of 45 shoots from each irrigation treatment. These shoot samples were then brought back to the lab and separated into their respective leaf, shoot and fruit material. A sub-sample was taken to determine leaf area as well as the oven-dried weight of each shoot component. Destructive sampling of whole shoots and a determination of vines' leaf areas took about ½ a day to complete for each treatment. Destructive sampling allows for a precise measure of canopy leaf area and biomass allocation, yet it is very time consuming.

A quicker alternative was provided by the point quadrat (PQ) method which is based on a non-destructive measure the leaf layer number (LLN). 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 the following equation

$$A_T = LLN\left(\frac{W\ h}{k}\right) \qquad \text{[Eq 1]}$$

where W and h are the width and height of the canopy (m), respectively, and the parameter k is the canopy extinction coefficient. The appropriate value of k = 0.6 has been determined from PQ measurements on grapevines (Green et al, 2006). The PQ measurements take about ½ an hour to complete (for a total of 8-10 vines) and the results are comparable to shoot data (Green et al (2006) report an accuracy of +/- 10% compared with destructive sampling).

*Leaf stomatal conductance*

Transpiration losses are controlled by leaf stomata (tiny pores on the leaf surface through which CO2 enters and water vapour escapes). During the daytime the stomata are open and the plants photosynthesise (absorb CO2) and transpire (lose water). Leaf stomata open to a lesser degree under levels of low light and/or increasing temperature and vapour pressure deficit (Jarvis, 1976). Leaf stomata also partially close in dry soils. This action will reduce evaporative losses and curtail productivity. At night the stomata are normally closed so that nocturnal transpiration losses are negligible.

Leaf stomatal conductance and leaf transpiration was measured using a CIRAS-2 portable photosynthesis system (PP Systems, Hertfordshire, UK). Measurements were made on six sunlit and six shaded leaves from each treatment, at 5-7 day intervals and between the hours of 0900-1100. This is the time when maximum conductance often occurs. The effect of irrigation on leaf function can be assessed directly, in a matter of minutes, by taking the ratio of conductance's in the treatment and control vines. A 50% reduction in leaf transpiration means a 50% reduction in vine transpiration, all other factors being equal. Measurements were been done on sunlit and shaded leaves to examine whether they behave differently to water stress.

*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). Measured values of global radiation, air temperature, relative humidity and wind speed are used to calculate a reference evaporation rate, $ET_O$ [mm $d^{-1}$] as

$$ET_0 = \frac{\frac{s}{\lambda}(R_N - G) + \gamma \frac{900}{(T+273)} u_2 (e_s - e_a)}{s + \gamma(1 + 0.34u_2)} \qquad \text{Eq. [2]}$$

where $R_N$ [MJ m$^{-2}$ d$^{-1}$] is the net radiation, G [MJ m$^{-2}$ d$^{-1}$] is the ground heat flux, T [$^{o}$C] is the mean air temperature, es [kPa] is the saturation vapour pressure at the mean air temperature, ea (kPa) is the mean actual vapour pressure of the air, $u_2$ [m s-1] is the mean wind speed at 2 m height, s [Pa $^{o}$C$^{-1}$] is the slope of the saturation vapour-pressure versus temperature curve, $\gamma$ [66.1 Pa] is the psychometric constant, and $\lambda$ [2.45 MJ kg-1] is the latent heat of vaporisation for water. Climate data for this calculation were obtained from the Woodbourne airport (NIWA station number G13585).

Equation [2] defines the rate of evaporation expected from an extensive surface of green grass cover, of a short, uniform height, that is actively growing, completely shading the ground, and not short of water. To account for the effect of the plant-physiological characteristics of the grape vines, we define a crop-coefficient, $K_C$, which relates the reference evaporation rate, $ET_O$, to the actual crop water use, $ET_C$. For routine calculations of vine transpiration, the following equation was used:

$$ET_C = K_C.ET_O \qquad \text{Eq. [3]}$$

where $K_C$ is a dimensionless number that could varies between about 0.1 (young vines) and about 0.7 (vigorous grape canopies with large leaf area). The particular value of $K_C$ defines the maximum rate of water use expected under optimum (or non-limiting) soil water and fertility conditions and achieving full production potential in a given growing environment. For simplicity, the following equation was used here to estimate a value for the vine crop factor as

$$K_C = 1 - \exp\left( -kA_T \big/ 2A_G \right) \qquad \text{Eq. [4]}$$

Thus, the crop factor $K_C$ depends on the total leaf area ($A_T$ from Eq. [2]) and the corresponding vine density (here Ag = 4.05 m$^2$ of ground area per vine). Treatment effects on vine water status can then be determined from the ratio of measured sap flows (i.e. actual transpiration loss) in each treatment relative to the values of $ET_C$ determined via Eq. [3].

## Results

### *Vine transpiration determined from sap flow*

Figure 2 shows the rates of sap flow measured in the control vines (T1 averaged over three vines) compared with corresponding rates of sap flow measured in vines from the lowest irrigation treatment (T4 received 30% of the water given to the control vines). The effect of withholding irrigation water is quite obvious in these diurnal traces of sap flow. Transpiration from the T4 vines dropped to about 20-25% of the control vines. The T4 vines received only a small amount of irrigation leading up to early January (Table 1). As a result, soil moisture levels for the T4 vines were quite low compared with the other irrigation treatments. Neutron probe measurements under the wetted strip revealed a difference of about 50 mm in root zone soil moisture under the drippers (Table 2). This equates to about 20 days of vine water use, on average.

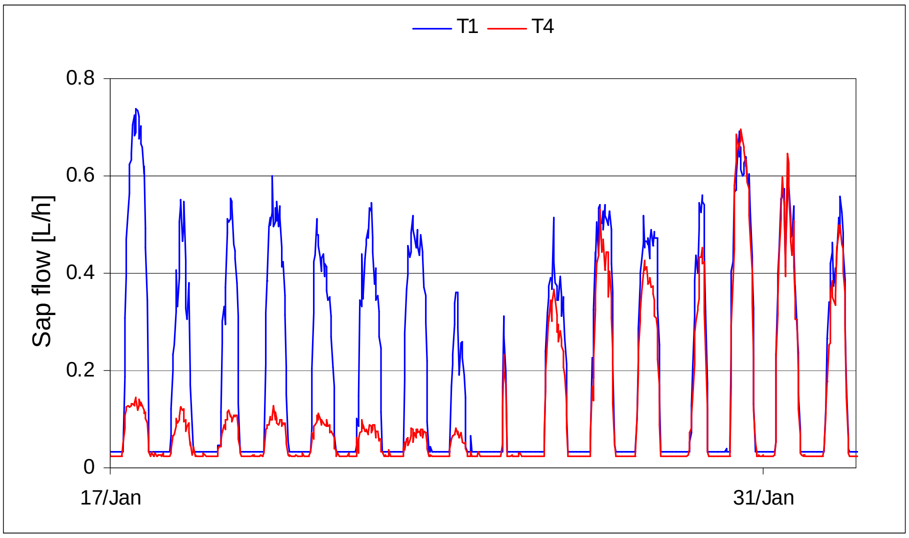


Figure 2. The diurnal pattern of sap flow in the grapevine stem was measured using the Tmax heat-pulse method of Green et al. (2003). Here T1 represents the control (100%) irrigation treatment and T4 represents the 30%DI treatments. A large rainfall of 55 mm was recorded around 25th January.

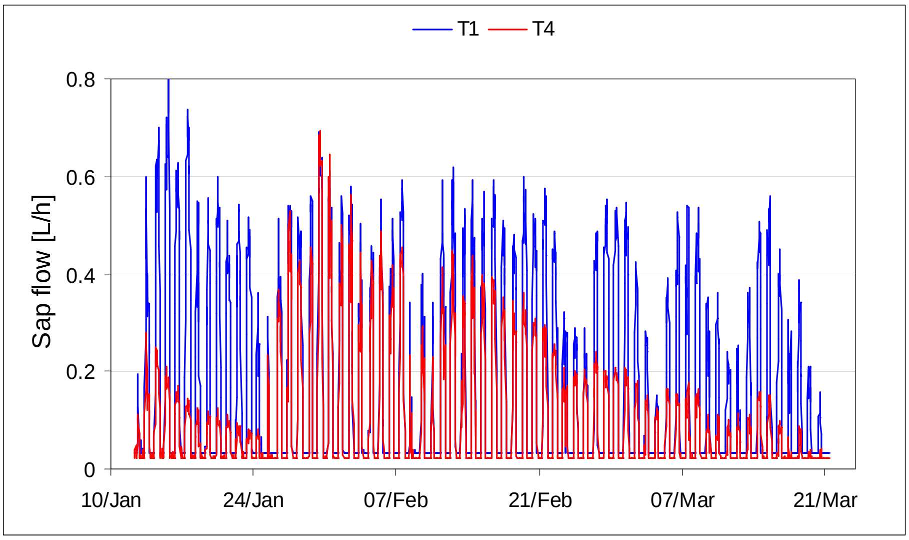


Figure 3. As for Figure 2, showing the diurnal pattern of actual vine water use in the control vines (T1) compared with vines from the T4 treatment that received only 30% of the control, on average.

Any reduction in sap flow relative to the control is indicative of a mild water stress – all other factors being equal. A large rainfall of about 55 mm occurred between 24-25 January. Sap flow in vines from the T4 treatment increased significantly following this rainfall. Sap flow on all vines was very low on those two rainy days. A few days later sap flow in the previously stressed T4 vines had recovered to be almost the same as in the control vines (Figure 2). The late January rainfall was quickly consumed by the vines. In the absence of further irrigation the T4 vines became progressively more stressed through until final harvest (Figure3).

### *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. This was measured on six sunlit leaves and six shaded leaves at weekly intervals from flowering until harvest.

The leaf stomatal conductance results are in quantitative agreement with the sap flow measurements, with conductance's of the deficit irrigated vines being reduced by between 45 to 75% relative to the control vines (Figures 4 & 5). Otherwise the seasonal pattern of leaf conductance was similar in all treatments and reflected different weather patterns on each day. The vines 'normal response' to environmental conditions is reasonably well understood (Green et al., 2004). These data could be used to determine the vines response to water stress, providing the soil's moisture content and water retention properties are known.

Leaves from the control vines (T1) 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). We were surprised to see the leaf stomatal conductance of the PRD vines remained similar to the control (data not shown). This result indicates that the PRD vines had a similar water status, yet they were reported as receiving only 30% of the irrigation water.

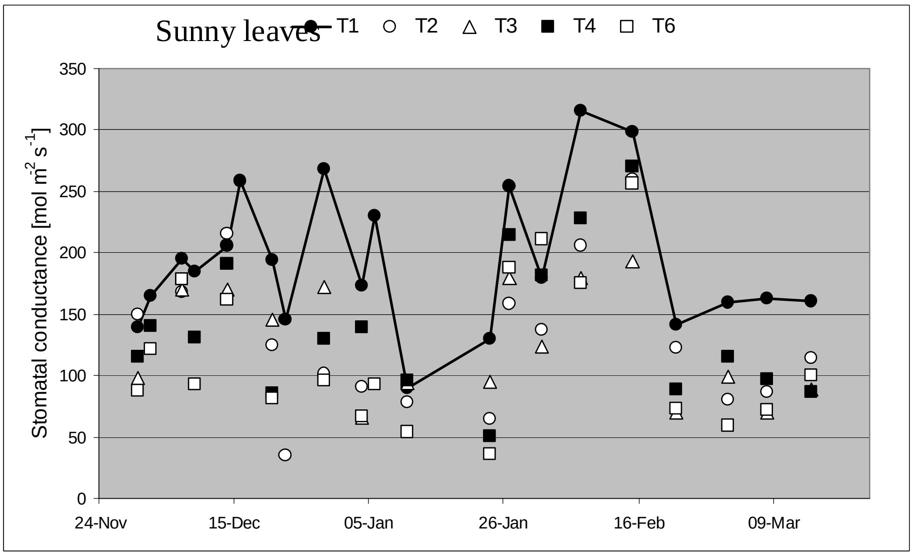


Figure 4. The effect of irrigation treatment (T1-T6) on the average leaf stomatal conductance measured on 6 sunlit leaves between the hours 0900 to 1100.

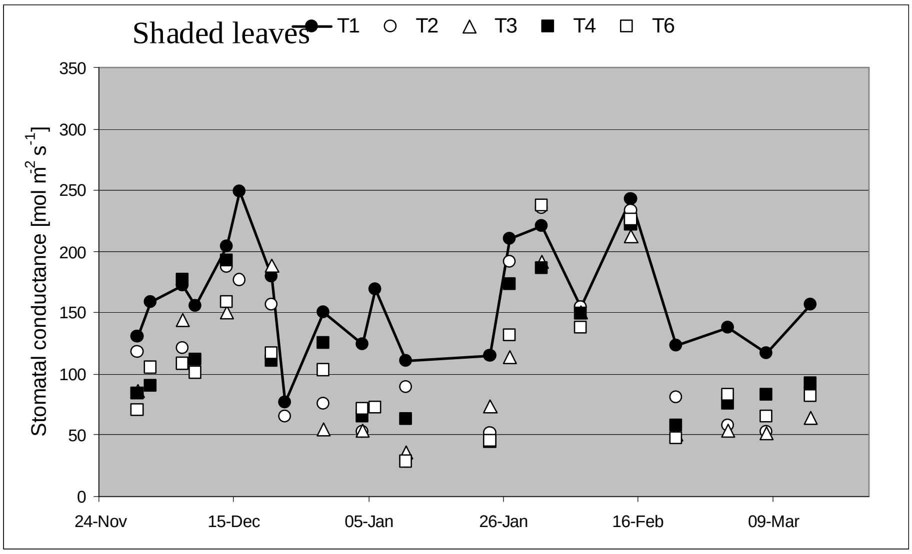


Figure 5. The effect of irrigation treatment (T1-T6) on the average leaf stomatal conductance measured on 6 shaded leaves between the hours 0900 to 1100.

### *Treatment effects on vine leaf area*

The control vines received almost twice the irrigation, over the whole growing season, compared with the other deficit irrigated vines (Table 2). 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 (Figure 5). 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. For example, 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.

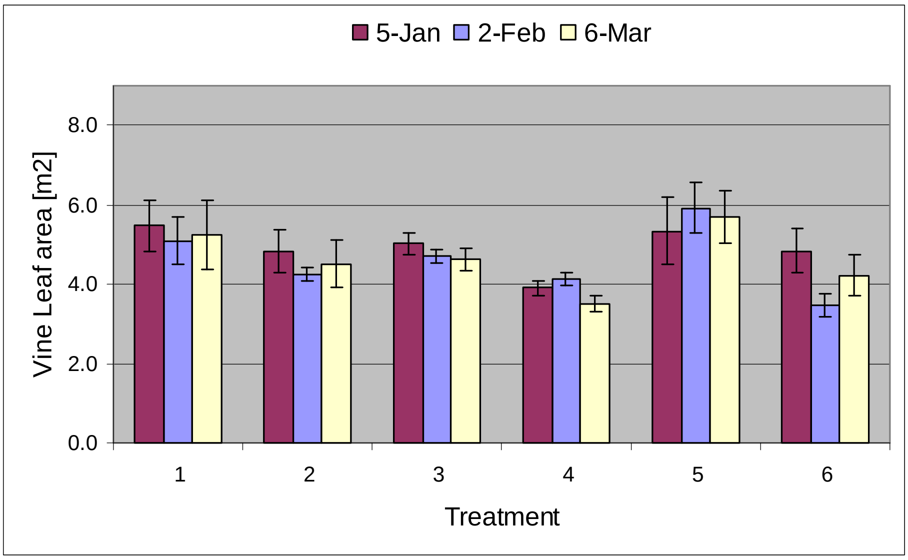


Figure 5. Treatment effects on the late-season development of vine leaf area as calculated from the point quadrat methods. Control vines are Treatment 1; deficit irrigation treatments 2-4 receive between 50 and 30% of the control, respectively; PRD vines are Treatment 5; and the vines in Treatment 6 are mulched and get 30% of control.

A similar reduction in leaf area was observed in the mulched vines (T6) that also received about 30% of the irrigation given to the control vine. This implies that the mulching treatment (at least in this third year) was not very effective at reducing water stress under the low irrigation regime. In contrast, the PRD vines (treatment T5) were given about ½ the irrigation of the control vines (359 L/vine *c.f.* 665 L/vine) yet they actually ended the season with slightly higher leaf area (5.7 $m^2$ *c.f.* 5.3 $m^2$). This result is not consistent with the other reduced-irrigation treatments that all showed a reduction in leaf area corresponding with the lower irrigation volumes. While it is possible that root signalling may have enhanced the water use efficiency of these PRD vines, we have no additional measurements to confirm this possibility. The volumes of irrigation delivered to the PRD vines should be re-checked for accuracy before this result is examined further.

*Measurement and modelling to quantify vine water use*

The potential water use of the vines was calculated via Equations [1-3] on the basis of measured canopy leaf area and daily climate data from the Woodbourne airport located some 1-2 km away. The results are shown as the red line in Figures 6-11 for the various irrigation treatments. This calculation reflects the expected water use for a “well watered vine” of a given leaf area. For comparison, the actual water use of the vines, as determined by the total daily sap flow through the vine stem, is shown by the blue lines of Figures 6-11. The ratio between the actual and the potential water use provides a direct measure of water stress ‘felt’ by the vines. We also plot 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 (Figure 6). The actual water use of the control vines (T1; Figure 6) and the PRD vines (T5; Figure 10) was also found to be very similar to the potential rates of water use calculated via Equations [1-3]. 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.

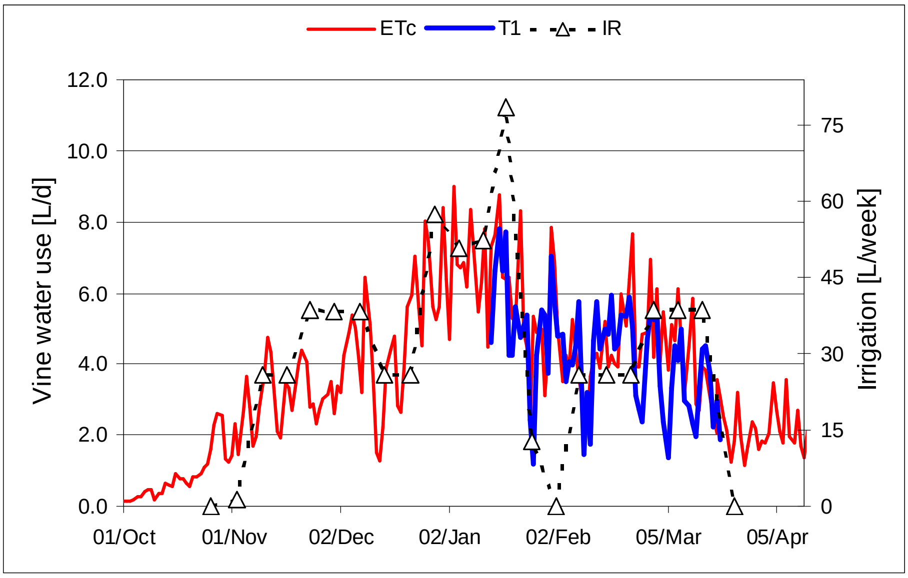


Figure 6. Daily vine water use as measured with sap flow sensors (blue line) and modelled on the basis of prevailing microclimate and vine leaf area (red line). Results are for the control irrigation treatment where the vines receive 100% to match their water use (symbols).

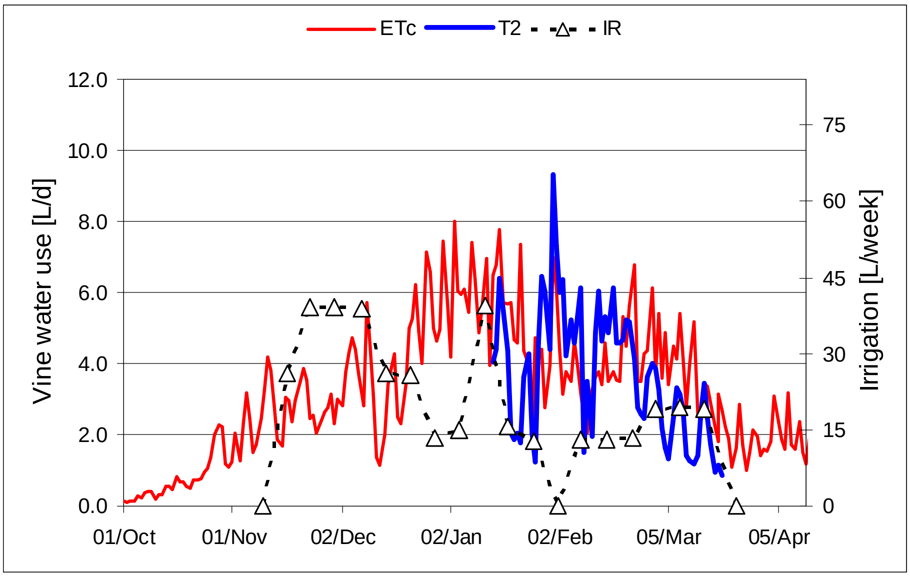


Figure 7. Daily vine water use as measured with sap flow sensors (blue line) and modelled on the basis of prevailing microclimate and vine leaf area (red line). Results are for the T2 treatment where the vines receive 50% of the irrigation needed to match their water use (symbols).

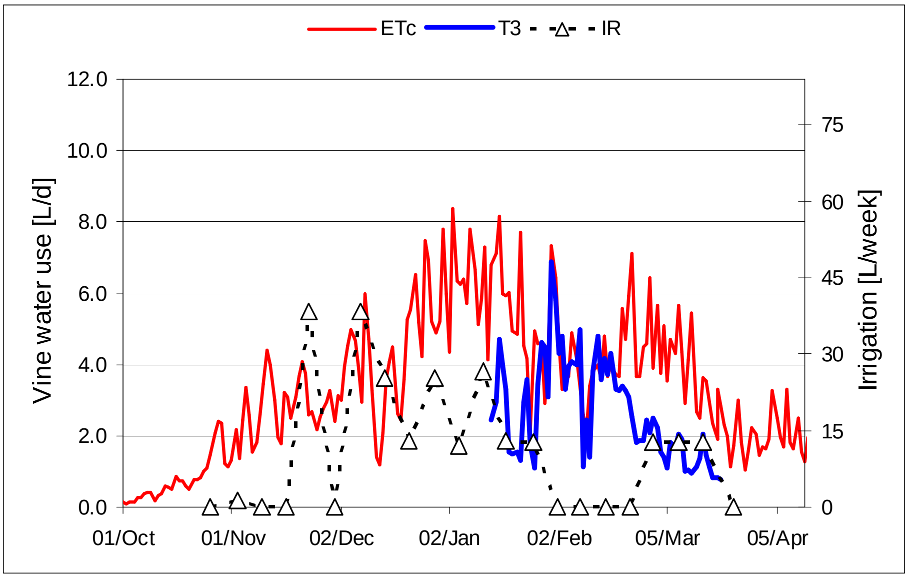


Figure 8. Daily vine water use as measured with sap flow sensors (blue line) and modelled on the basis of prevailing microclimate and vine leaf area (red line). Results are for the T3 treatment where the vines receive 40% of the irrigation needed to match their water use (symbols).

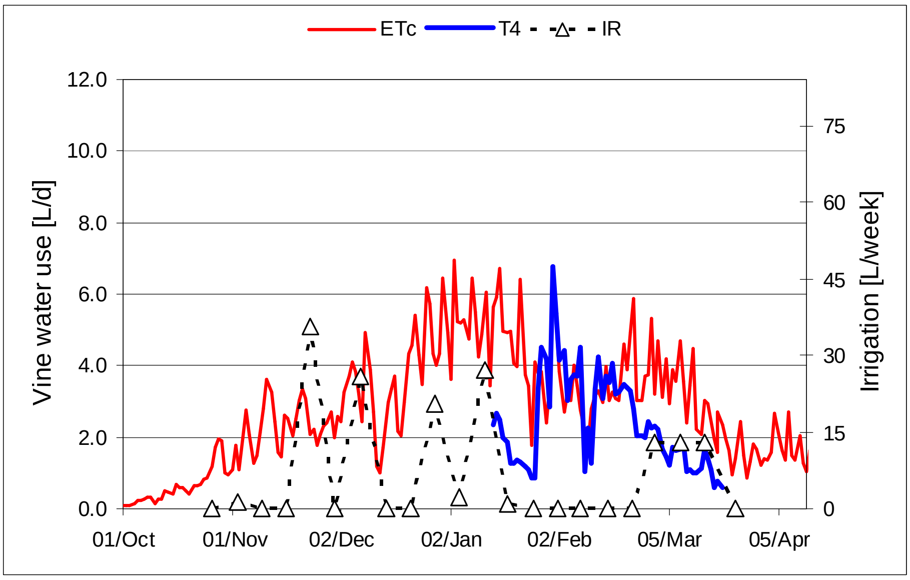


Figure 9. Daily vine water use as measured with sap flow sensors (blue line) and modelled on the basis of prevailing microclimate and vine leaf area (red line). Results are for the T4 treatment where the vines receive 30% of the irrigation needed to match their water use (symbols).

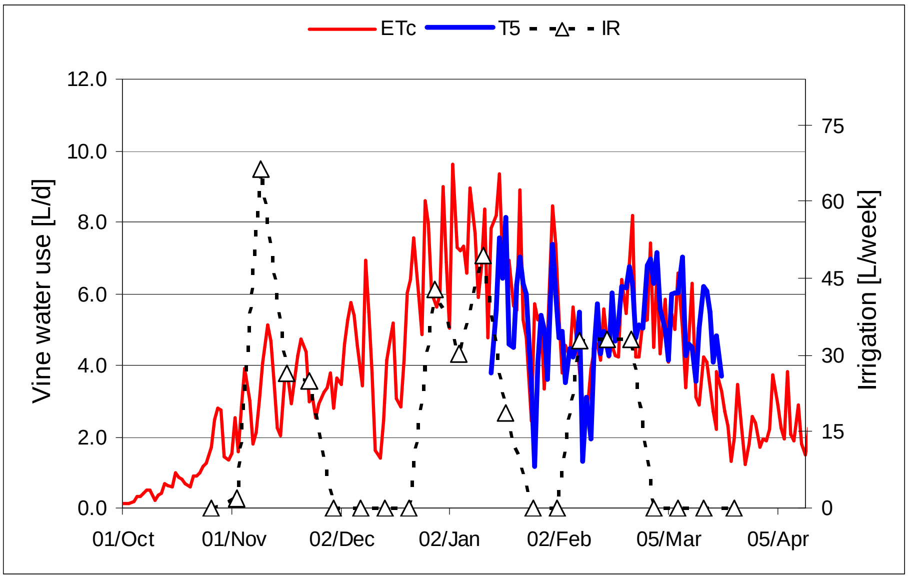


Figure 10. Daily vine water use as measured with sap flow sensors (blue line) and modelled on the basis of prevailing microclimate and vine leaf area (red line). Results are for the RPD treatment (T5) where the vines receive 30% of the irrigation needed to match their water use (symbols).

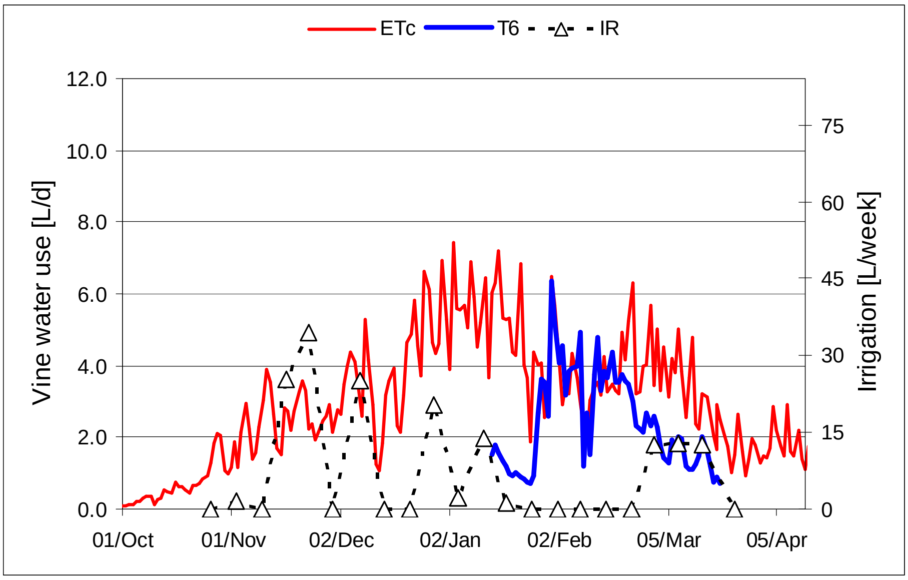


Figure 11. Daily vine water use as measured with sap flow sensors (blue line) and modelled on the basis of prevailing microclimate and vine leaf area (red line). Results are for the T6 treatment where the vines are mulched, and they receive 30% of the irrigation needed to match their water use (symbols).

On the other hand, there were times during the growing season when the vines from the reduced irrigation treatments did exhibit water stress. For example, vines from both the T4 and T6 treatments, that each received only 30% of the control irrigation volume, had measured sap flows that were < 50% of $ET_C$ during mid January, just prior to the large rainfall of the 25th. Thereafter, all vines recovered their water status back to the point where measured sap flows matched $ET_C$ throughout the month of February. However, by early March the reduced irrigation treatments once again exhibited symptoms of water stress with actual transpiration rates declining through until harvest.

## Discussion and Conclusions.

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.

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.

Sap flow and stomatal conductance are ideal research tools to quantify the degree of water stress induced by the various irrigation treatments i.e. this can be expressed via the respective ratios between control and treatment values. Results presented in Figures 4 & 5 show large difference in stomatal conductance under the different irrigation treatments. Similarly, Figures 6-11 show large differences (50% or more) in daily sap flow (water loss of whole vines) compared to the potential transpiration losses. 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.

## *Winemaking Summary*

### *Method*

The fruit was hand harvested and whole bunch pressed using a Diemme AR40 airbag press with a target recovery of 600 litres per tonne. Hard pressings were not recovered. Due to the high variability of the harvest weights we did not believe we would get meaningful juice extraction rates and therefore did not take the pressing to completion. Sixty grams/tonne of PMS was added as the press was loaded. The juice was chilled with dry ice and settled in tank using pectolytic enzyme. Juice analysis was completed.

Chaptalisation and de-acidification were not needed this year

After 24 hours settling the clear juice was racked to a 1000 litre “fermenta-bag” and inoculated with EC1118 yeast. Two standard additions of DAP were made, 150 ppm on day 2 and 100 ppm on day 4 of ferment. Brix and temperature were monitored daily. The wines were fermented using chilled water as a cooling medium and good temperature control was achieved.
Once the wines were dry 60 ppm SO2 was added along with 1000 ppm of Bentonite. Fifty litres of each wine was then racked off and chilled for 2 weeks at <5 oC to partially cold stabilise. The wines were then filtered through a pad filter to bottle. Treatments 4 and 6 were not filtered to clarity due to the filter blocking.

A summary of the harvest/wine data follows:

| **Trial Number** | **1** | **2** | **3** | **4** | **5** | **6** |
|---|---|---|---|---|---|---|
| **Harvest data** | | | | | | |
| Harvest date | 21/4 | 18/4 | 18/4 | 17/4 | 21/4 | 17/4 |
| Brix | 22.0 | 21.4 | 20.5 | 22.4 | 21.9 | 20.9 |
| Titratable acidity (g/L) | 10.4 | 9.7 | 9.9 | 9.3 | 10.4 | 9.0 |
| pH | 2.91 | 3.01 | 2.98 | 3.01 | 2.88 | 3.08 |
| **Additions** | | | | | | |
| Potassium bicarbonate (g/L) | - | - | - | - | - | - |
| Sugar (g/L) | - | - | - | - | - | - |
| DAP (ppm) | 250 | 250 | 250 | 250 | 250 | 250 |
| Superfood (ppm) | | | | | | |
| **Wine analysis** | | | | | | |
| Titratable acidity (g/L) | 9.9 | 8.9 | 9.6 | 8.3 | 9.5 | 8.9 |
| PH | 2.90 | 2.98 | 2.95 | 3.03 | 2.94 | 2.94 |
| Residual sugar | 1.9 | 6.7 | 3.8 | 3.1 | 2.6 | 3.5 |

### Harvest

The trials were picked over a 5 day period in the later part of what was an early season. Juice analysis was in the range we were looking for with the exception of Trail 3 where the brix was below target.

### Fermentation

The ‘white ferment-a-bags’ used for fermentation have a double skin and allow external cooling.  Trial 2 required re-inoculation as it did not ferment initially.  It also ended up with the highest level of residual sugar

## *Results*

The wines at bottling showed less significant differences in flavour and aroma profiles than the previous year.  The later picked, higher crops tended to show greener characters even though they were sugar ripe (particularly the control – treatment 1).  The lowest cropped, treatment 6 seemed to have marginally more palate weight with a slightly ripe fruit spectrum.  The differences in flavour profile seemed lees apparent than may be expected due to the yield differences.  The early season and relatively short picking window between treatments may have resulted in a more narrow spectrum of flavours.

**References:**

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