Regulated Deficit Irrigation (RDI) to save water and improve Sauvignon Blanc quality?


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Abstract
With a fast change of land use in Marlborough from extensive pastoral farming to intensive irrigated viticulture, a need has risen to investigate the sustainable use of the available water. In 2001 a 5 ha irrigation research project was installed in a Marlborough Sauvignon Blanc vineyard. Irrigation treatments installed were control (compensate 100% for crop evapotranspiration (ET₀)), 80%, 70% and 60% of ET₀. During the two years that the Regulated Deficit Irrigation (RDI) trial has run so far, very different climatic conditions created much greater differences in yield and vegetative growth, than up to 40% reduction in irrigation, none of which were significant. The use of sap flow in the vines has been fine-tuned and is now giving reliable results on which to base vine water need.

Keywords
Evapotranspiration; irrigation; leaf water potential; light interception; stem sap flow; Vitis vinifera

Introduction
Over the past three decades there has been a major change in land-use in Marlborough, with vineyards expanding rapidly across the region, replacing traditional dry-land pastoral farms. The Wairau Valley in Marlborough has now become New Zealand’s largest wine producing area with almost 10,000 ha of land planted for grape production. Marlborough is ideal for cool climate viticulture because the weather is typically mild, damaging spring frosts are uncommon, there are ample sunshine hours, and the soils are flat and free draining. However, a major limitation to the expansion of viticulture is likely to be the provision of enough water for irrigation through the dry summer months. A recent survey in Marlborough noted that “...the region is approaching a crossroads in water management, with a growing deficit between natural supply and the demand of water” (Davidson, 2001).

For several years Hort Research has been working together with the local District Council to determine appropriate irrigation allocations for horticultural crops (Green et al., 2002; Greven et al., 2003) and to assess the impact of land use on ground water quality (Green et al., 2003). An efficient irrigation strategy is needed to ensure enough water is available for all users that want it now and in the future. Optimum irrigation for grapes should aim to supply just enough water, at the right time, to achieve the yields and juice composition that is desired by the winemakers. This requires a knowledge of how much water the vines are using and an indication of when irrigation should begin. During mid-summer Marlborough has a high evaporative demand (ET₀ > 7 mm d⁻¹). Vines that have no restriction on water uptake can use as much as 12 L of water per day. However, regular application of that amount of water through the growing season would lead to a “luxury consumption” of water. This not only promotes too much vegetative growth, but will also contribute to leaching of soil nutrients and pesticides below the root-zone, which makes this practice unsustainable in the long run.
A Regulated Deficit Irrigation (RDI) experiment has been established in 2001 to assess how much water the grapevines actually need rather than how much they are able to consume. The experiment is combining experimental methods to measure vine water use and to assess vegetative growth and berry development, with desk-top computer models to calculate transpiration losses and thus provide irrigation scheduling for the vineyard. The aim is to demonstrate that a reduction in irrigation will improve both the economical and ecological sustainability of grape growing in Marlborough, without a detrimental impact on grape yield or quality. In this paper we discuss the preliminary results from the first two years of the RDI trials. The results are intended to support the improvement of irrigation management and hence sustainability of the production of Sauvignon Blanc grapes.

**Methods**

The experiment is being carried out on a 5 ha block of 9-year old Sauvignon Blanc vines (5C root stock) at Montana Wine’s Squire Estate in Marlborough, New Zealand. The soil is a free draining Wairau silt loam of 1 m depth sitting on top of coarse gravel (~85% stones). The vines are on a VSP trellis, planted 1.8 m apart in rows that are approximately North–South oriented and spaced at 2.4 m.

A control irrigation treatment ($I_{100}$) has been established where irrigation is applied to fully (100%) compensate for crop evapotranspiration losses. Neighbouring RDI treatments have been set up to deliver 80% ($I_{80}$), 70% ($I_{70}$) and 60% ($I_{60}$) of the control irrigation. Vine water status is being monitored once a week using pre-dawn measurements of leaf water potential ($\Psi_{PD}$). The irrigation strategy is to apply water as soon as $\Psi_{PD}$ drops below a threshold value. Prior to veraison, the vines are irrigated whenever $\Psi_{PD} < -0.2$ MPa. For the period between veraison and harvest, irrigation is applied whenever $\Psi_{PD} < -0.4$ MPa. The irrigation system comprises inline drippers (Dripline 2000, Netafim, Australia) that were purpose built for this experiment. The drippers are arranged at different spacings and flow rates so the irrigation can be turned on at the same time for the whole block, and deliver the target irrigation rates for each of the treatments. Each irrigation treatment is replicated three times using four rows of vines for each replicate.

Prior to the start of the experiment soil pits were dug to a depth of 1.0 m to establish the depthwise distribution of the soil’s hydraulic and physical properties as well as the carbon and nitrogen content. Additional soil samples were also taken to a depth 1.0 m to determine the vertical profile of fine roots (kg m$^{-3}$). This data is used to determine the field capacity of the soil and the amount of readily-available soil moisture in the root-zone. Several automatic TDR probes (model CS615, Campbell Scientific Inc., USA) are being used to log the changes in soil moisture both under the drippers and in non-irrigated parts of the root-zone. Soil moisture in the $I_{100}$, and $I_{60}$ is also being measured three times per week using an array of 48 TDR probes in each treatment, with probes installed both under the dripper line and in between the vine rows. The measurements of soil moisture are at 15 cm depth intervals over the range 0 to 1.05 m.

Supporting weather data is obtained from an automatic weather station in the vineyard. The weather station records a half hour average for the global short-wave radiation ($R_{S,g},$ W m$^{-2}$), global and diffuse PAR radiation ($R_{P,g}$ and $R_{P,d},$ µmol m$^{-2}$ s$^{-1}$), air temperature ($T_A,$ °C), relative humidity ($RH,$ %), wind speed ($U,$ m s$^{-1}$), and rainfall ($P,$ mm). The through fall of rain and the amount of irrigation water applied to the $I_{100}$ vines is monitored using a number of tipping bucket rain gauges. An array of 48 short-wave sensors mounted in the inter-row and close to the ground is used to measure the amount of solar radiation absorbed by the grape vines (Figure 1A). The weather data is used to calculate the daily vine water use by combining the Penman–Monteith equation to determine a reference potential...
evapo-transpiration, $ET_o$ (Allen et al., 1998), and using the % light interception as a surrogate for the crop factor of the vines (Figure 1B). Regular measurements of vine leaf area, leaf stomatal conductance and stem sap flow by the heat pulse method (Green et al., 2004) are used to validate these calculations.

During the course of the experiment an assessment of the vine’s physiological development is made at 7–14 day intervals. Targeted vines with an average bud-count of between 45 and 50 are being monitored for shoot growth and berry development. In addition, vegetative growth is also assessed every 2–3 weeks on neighbouring vines, by measuring the shoot length and leaf area of 21 destructively harvested shoots. The total dry weight of summer and winter prunings (kg DM/vine) is also used to assess the total vegetative growth. From mid-season through to harvest the canopy density is measured once per month using the Point Quadrat technique (Smart, 1992). The last Point Quadrat measurement is then compared against a measure of the total leaf area on targeted vines at harvest.

Berry development is assessed weekly from veraison until harvest, by measuring berry diameter and measuring bunch dry weight (DW). Fruit quality (°Brix, titratable acidity (TA) and juice pH) is also monitored weekly from the five weeks before harvest. At harvest the mean weight per bunch is determined from the number of bunches per vine, and the total weight of fruit per vine. A total of 50 kg of grapes per plot are set aside for micro-vinification.

Results and discussion
Weather conditions during the first two years of this trial were quite different. The first season (2001/02) began with a very wet spring, with total rainfall (Oct–Mar) well above the long-term average (Figure 2). Air temperatures and solar radiation totals were also higher than normal. Over the course of a day, the vines were found to intercept about half as much solar radiation, per unit ground area, compared to a horizontal grass surface (Figure 1A).

The second season (2002/03) was characterised by a severe spring frost which caused damage to about 90% of the vines within the trial site. Many of the young shoots and leaves were desiccated and their inflorescences lost. Following this severe frost event, all equipment had to be moved to another part of the vineyard, where frost damage was negligible. New vines were selected for monitoring. In general, weather conditions during this second season (2002/03) were much drier than normal, with total rainfall at about 60% of long-term average (Figure 2). Air temperatures were also slightly lower than average during the second season, which resulted in 1370 growing degree-days (GDD, base 10 °C) in the first season compared to 1257 GDD in the second season. Both years, potential evapotranspiration rates were similar to the long-term average at around 1000 mm.
The seasonal pattern of soil moisture reflects the contrast in rainfall during the two seasons and the different water holding capacities of the soils at the two sites (Figure 3). In the first season the TDR measurements were taken on the south side of the vineyard where the field capacity was about 320 mm/m. There was enough rainfall early in the season to maintain the root-zone moisture level close to field capacity almost through until veraison. Thus irrigation did not commence until about mid-February, as soon as the pre-dawn leaf water potential for the $I_{100}$ treatment dropped below about $-0.2$ MPa. Thereafter, the control vines ($I_{100}$) each received 85 mm of irrigation to supplement the 36 mm of rain that fell from veraison through until harvest. There appeared to be very little difference in soil moisture among the irrigation treatments.

In the second season, the TDR measurements were moved to the north side of the vineyard following the frost event. There the silt loam is shallower (i.e. the gravel layer is

Figure 3 Total stored water in the soil, from 0–1.05 m for irrigation at 100% compensation for crop evapotranspiration ($I_{100}$) and for 60% compensation ($I_{60}$) for the wet 2001/02 season and the dry 2002/03 season
about 0.95 m deep) and the soil profile has a slightly higher sand content. The field capacity on the north side is only 200 mm/m, yet it was much drier than that at the start of the second season because of a low rainfall over the winter period. Because the dry spell continued throughout most of the second season, irrigation commenced about 5 weeks earlier. In total, the control vines received about 125 mm of irrigation to supplement the 85 mm of rain that fell from veraison through until harvest. In the much drier second season there was a clear difference in soil moisture level across the irrigation treatments. Irrigation on the \( I_{100} \) treatment was sufficient to maintain the soil moisture around 50% of field capacity whereas the \( I_{60} \) treatment dropped to about 33% of field capacity.

As expected, there was a large spatial variability in soil moisture. Large diurnal changes were observed under the drippers; the soil moisture content exhibited a clear wetting, draining and drying pattern. Away from the dripper zone, in the dry soil, the moisture content was similar for all treatments. Thus, the vines received almost all of their water from within the dripper zone and there was very little water uptake from the surrounding dry soil zones. During the course of both seasons root uptake tended to switch from the surface roots to deeper in the soil profile where soil moisture was more readily available. However, root uptake activity quickly switched back to the surface roots as soon as irrigation commenced (data not shown).

The impact of irrigation on vine vigour was assessed by way of a leaf area measurement just after harvest. In the first season the control vines (\( I_{100} \)) reached a final leaf area of 9.6 m\(^2\) while vines from the \( I_{60} \) treatment supported a canopy leaf area of just 7.3 m\(^2\) (Table 1). Good bud initiation combined with high spring rainfall and elevated summer temperatures, resulted in exceptionally high yields (~50% up on average years) and vigorous vegetative growth. There was a clear linear trend between irrigation amount and leaf area yet there did not appear to be any significant difference in the yield or juice composition of the grapes (Table 1).

Results from the second season are more difficult to interpret. Across the irrigation treatments we recorded similar results in terms of vine productivity and juice component analysis despite the large differences in irrigation volumes and soil moistures (Table 2).

### Table 1

Total irrigation, final leaf area, and juice composition results from the first season (2001/02). Juice analysis included soluble solids [SS], juice pH and titratable acidity [TA] determined from a 100 berry sample

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Irrigation (L/vine)</th>
<th>Leaf area (m(^2)/vine)</th>
<th>SS (°Brix)</th>
<th>Juice pH</th>
<th>TA (g/L)</th>
<th>berry weight (g)</th>
<th>bunch weight (g)</th>
<th>FW/vine (g)</th>
</tr>
</thead>
<tbody>
<tr>
<td>( I_{100} )</td>
<td>360</td>
<td>9.6</td>
<td>22.9</td>
<td>3.05</td>
<td>11.54</td>
<td>1.82</td>
<td>108</td>
<td>8040</td>
</tr>
<tr>
<td>( I_{80} )</td>
<td>288</td>
<td>8.8</td>
<td>22.5</td>
<td>3.04</td>
<td>13.20</td>
<td>1.84</td>
<td>89</td>
<td>7835</td>
</tr>
<tr>
<td>( I_{70} )</td>
<td>252</td>
<td>8.4</td>
<td>22.8</td>
<td>3.08</td>
<td>11.90</td>
<td>1.78</td>
<td>104</td>
<td>7945</td>
</tr>
<tr>
<td>( I_{60} )</td>
<td>216</td>
<td>7.3</td>
<td>22.6</td>
<td>3.07</td>
<td>11.20</td>
<td>1.87</td>
<td>96</td>
<td>7828</td>
</tr>
<tr>
<td>P</td>
<td>ns</td>
<td>ns</td>
<td>ns</td>
<td>ns</td>
<td>ns</td>
<td>ns</td>
<td>ns</td>
<td>ns</td>
</tr>
</tbody>
</table>

### Table 2

Yield results for the second season (2002/03) as per Table 1

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Irrigation (L/vine)</th>
<th>Leaf area (m(^2)/vine)</th>
<th>Yellow leaf (%)</th>
<th>SS (°Brix)</th>
<th>Juice pH</th>
<th>TA (g/L)</th>
<th>Berry weight (g)</th>
<th>Bunch weight (g)</th>
<th>FW/vine (g)</th>
</tr>
</thead>
<tbody>
<tr>
<td>( I_{100} )</td>
<td>690</td>
<td>16.8</td>
<td>8.3</td>
<td>21.53</td>
<td>3.05</td>
<td>9.30</td>
<td>1.58</td>
<td>77</td>
<td>4254</td>
</tr>
<tr>
<td>( I_{80} )</td>
<td>550</td>
<td>18.9</td>
<td>9.7</td>
<td>21.47</td>
<td>3.04</td>
<td>9.85</td>
<td>1.54</td>
<td>80</td>
<td>3878</td>
</tr>
<tr>
<td>( I_{70} )</td>
<td>480</td>
<td>22.8</td>
<td>25.7</td>
<td>21.53</td>
<td>3.07</td>
<td>9.30</td>
<td>1.61</td>
<td>81</td>
<td>4439</td>
</tr>
<tr>
<td>( I_{60} )</td>
<td>410</td>
<td>16.4</td>
<td>23.9</td>
<td>21.30</td>
<td>3.09</td>
<td>9.11</td>
<td>1.60</td>
<td>72</td>
<td>3368</td>
</tr>
<tr>
<td>P</td>
<td>ns</td>
<td>0.001</td>
<td>ns</td>
<td>ns</td>
<td>ns</td>
<td>ns</td>
<td>ns</td>
<td>ns</td>
<td>ns</td>
</tr>
</tbody>
</table>
There was no simple relationship between yield at harvest and the amount of water applied. The variation in crop load between the vines proved it difficult to derive statistically significant trends among the treatments. A comparison between Tables 1 and 2 confirms much larger differences between years rather than between treatments. The second season exhibited a doubling of leaf area and a reduction in bunch size so that the final yield per vine was almost halved. At harvest time the berry juice also had lower SS and TA in the second season. We attribute the change in vigour and productivity of the vines to the spring frost that probably reduced fruit set, although there were no visible signs of damage at the time, and promoted an increased growth of lateral shoots.

Leaves sampled in the second season showed clear signs of early senescence that may be attributable to irrigation because there was more yellowing of leaves in treatments that received less water (Table 2). With hindsight we also attribute the reduced leaf area in the first year to an early leaf drop rather than a reduced leaf production since those leaves were collected several weeks after harvest. Point Quadrat measurements during the first year indicated similar results across all treatments in terms of the number of leaves, the number of clusters, the percentage of internal leaves, and the percentage of exposed clusters (data not shown). We postulate that early leaf senescence will have an effect on vine performance in subsequent seasons. This is something that will be followed in future years.

Winter pruning weights provide an additional assessment of vine vigour. For both years there were only small differences in shoot length and pruning weights among the different RDI treatments (Table 3). However, the total dry matter of pruned shoots in the first year was about twice that of the second year; the variation between years in pruning weights correlates well with the fruit yield but not with leaf area. In other words, the shoot to fruit ratio was conserved between year and between treatments while the shoot to leaf ratio was not. An abundance of spring rain in the first season caused a vigorous growth of heavy bull canes with long internodes and relatively few leaves. Although not visible at the time of trial installation it was probably due to the frost that in the second season the apical dominance of the young shoots was severely reduced. In combination with the much drier and cooler weather, this is likely to have caused an abundance of thin laterals with short internodes, dramatically increasing the number of leaves.

The value of $\Psi_{PD}$ indicates the amount of water available to the vines and should also reflect the amount of irrigation given to them. Figure 4 shows that $\Psi_{PD}$ of $I_{60}$ and $I_{70}$ treatments was consistently lower than the other treatments for seven of the nine measurement dates. However, the differences in $\Psi_{PD}$ are actually very small in terms of vine water stress. Thus, it is not surprising that the yields and juice quality components were similar across the different irrigation treatments. Deloire et al. (2003) suggested that the acceptable level of stress for a grapevine depends on the phenological stage of development. Prior to flowering $\Psi_{PD}$ should remain above $-0.2$ MPa to avoid symptoms of water stress. $\Psi_{PD}$ can then be lowered to about $-0.3$ MPa between fruit set and veraison. After veraison $\Psi_{PD}$ can be lowered even further e.g. down to $-0.4$ or even $-0.6$ MPa, depending on what

### Table 3 Sauvignon Blanc pruning weights 2001/02 and 2002/03

<table>
<thead>
<tr>
<th>Treatment</th>
<th>2001/02</th>
<th>2002/03</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Pruning weight (g)</td>
<td>Shoot length /vine (m)</td>
</tr>
<tr>
<td>I$_{100}$</td>
<td>2,078</td>
<td>42.8</td>
</tr>
<tr>
<td>I$_{80}$</td>
<td>2,289</td>
<td>44.7</td>
</tr>
<tr>
<td>I$_{70}$</td>
<td>2,087</td>
<td>46.6</td>
</tr>
<tr>
<td>I$_{60}$</td>
<td>2,168</td>
<td>47.6</td>
</tr>
<tr>
<td>P</td>
<td>ns</td>
<td>ns</td>
</tr>
</tbody>
</table>
characteristics the wine maker wants to achieve. In this trial we have endeavoured to follow the same irrigation strategy. However, the first season was much wetter than normal, and the excess rainfall made it difficult to achieve the desired stress levels across the irrigation treatments. Commercial pressures in the second year, brought about by the frost-induced yield losses, were such that severe water stresses could not be imposed. Further research is being done this season, on a smaller scale, to try and avoid such experimental problems of the past.

The guideline of using “100% compensation of crop evapotranspiration (ET\textsubscript{C})” for the control treatment appears to be more definite than it actually is. While potential evapotranspiration (ET\textsubscript{O}) is well defined by the weather data, the appropriate crop factor \( K\textsubscript{C} \) (\( ET\textsubscript{C} = K\textsubscript{C} \times ET\textsubscript{O} \)) for grapes is less well defined since it varies with development stage and canopy vigour, and is likely to be influenced by the availability of soil moisture. This raises the question about how much irrigation the vines received: it is possible that the \( I\textsubscript{100} \) treatment may somehow have applied too much water. If this were the case then we might expect the \( I\textsubscript{60} \) treatment to provide at least some treatment difference, especially in the second season when monitoring was done on the north side of the vineyard where the soil has a much lower water holding capacity. However, this was not the case. In the second season soil moisture under the \( I\textsubscript{100} \) treatment was maintained at 50% of field capacity whereas the \( I\textsubscript{60} \) treatment showed a steady decline in soil water (Figure 3). This soil-based result partly confirms the \( I\textsubscript{100} \) treatment was not over-irrigating.

The irrigation volume for the \( I\textsubscript{100} \) treatment was chosen on the basis of a \( K\textsubscript{C} \) value of 0.5 at full canopy in accordance with the percentage of light interception (Figure 1A). Heat-pulse measurements of stem sap flow confirmed a similar crop factor from the ratio of daily vine water use per unit ground area and ET\textsubscript{O}. Figure 5 illustrates how vine transpiration responds

![Figure 4](image4.png) **Figure 4** Leaf water potential measured pre-dawn over a period of almost four months during 2003

![Figure 5](image5.png) **Figure 5** A comparison between sap flow in the vine trunk and incoming short-wave radiation (average from 4 vines). The vines were trimming around mid-day on 11 January
to the light environment in the vineyard. It should be noted that the two axes have been re-scaled to give a good match for the first couple of days (Jan 8–10). Thereafter, about 1/3rd of the leaf area was removed when the vines were hedged and trimmed. The leaf removal caused a significant reduction in the vine water use, with the maximum peak rates declining from 1.2 L h\(^{-1}\) to about 0.8 L d\(^{-1}\) after the trimming. Point Quadrat measurements around this time indicated the leaf layer number was reduced by about 30% yet the size of the canopy was not affected (data not shown).

We now have sufficient confidence in the stem sap flow measurement to use the heat-pulse technique to schedule the irrigation amount. The measurements are reliable, use inexpensive technology, provide a good time resolution of sap flow, and are well suited to automatic data collection and storage (Green et al., 2004). However, supporting observations of soil moisture and leaf water potential are still required to decide when to start irrigating, and observations of rainfall are still needed to decide when to pause the irrigation.

Smarter irrigation management such as RDI may yet induce small changes in vegetative growth, yield and quality of grapes. There is an opportunity to improve water use efficiency, as defined by the litres of water used per kg of fruit produced. In this trial we have managed to achieve a 40% reduction in irrigation without a detrimental impact on vine productivity. Thus, irrigation efficiency has improved. A 40% savings in vine irrigation would represent a significant savings in water demand if the results were applied across the whole of the Marlborough region.

This trial still has several years to run. The research is aimed at the development of simple and accurate tools to help growers improve their irrigation management and hence the sustainable use of a valuable resource. The research should also help improve our understanding of those factors that impart grapes with the characteristics of yield and quality desired by the winemakers. With such information the grower has the opportunity to adapt his irrigation management to meet the market demand, whether that means a reduced yield of high quality grapes or simply a maximum production per ha.

**Conclusions**

- Water use in Sauvignon Blanc grapes in Marlborough, could be reduced by 40% without causing differences in yield or quality parameters.
- In an area like Marlborough where irrigation is additional rather than essential, seasonal differences are likely to be greater than irrigation treatment differences.
- Cutting the amount of irrigation reduced leaf area but none of the yield parameters. Reduction came from both a reduced leaf growth as well as earlier senescence.
- Stem sap flow measurements were found to accurately reflecting the vine canopy size and transpiration.

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