Marlborough Crop Water Use Efficiency Report – 2005

Green, S.R., Greven, M., Clothier, B.

September 2005

Report to Marlborough District Council

HortResearch Client Report No. 17385
HortResearch Contract No. 20058

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EXECUTIVE SUMMARY

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The Marlborough District Council (MDC) is currently reviewing the water components of the Proposed Wairau-Awatere Resource Management Plan (PWARMP). They called a meeting of stakeholders (regulators, growers and researchers) with the aim of summarising key findings from the last 15 years of research on grape irrigation in Marlborough. Information gathered from the meeting was targeted to help the MDC decide whether the grape irrigation guidelines in the PWARMP need modification.

As part of the review process, HortResearch Ltd was contracted to complete the following schedule of work:

- summarise the sequence of research activities on grape water requirements in Marlborough since 1992. Provide, in tabular format and chronological order, the key findings associated with each project
- provide concise answers to four key questions that will help identify any knowledge gaps, in order to plan for future research needs.

This report served as a discussion document for stakeholders at the Marlborough Crop Water Use Efficiency Review Meeting, held at the MDC Buildings on September 9 2005. Results from the recent trials (post-1994) on Marlborough vineyards were presented to show that the key factors controlling vine water use are:

- prevailing microclimate
- vine total leaf area
- available soil water.

Over the past 15 years, new measurement techniques (sap flow and time domain reflectometry (TDR)) have been refined to measure transpiration losses from a vineyard. Simple computer models have also been developed to interpret soil moisture measurements and improve irrigation scheduling for subsequent weeks and through until the end of the season. These tools are improving our understanding of vine water use and our assessment of irrigation needs.

Local trials are confirming that significant water savings are possible using carefully managed deficit-irrigation strategies. Much less water is being applied than current allocation permits, and the vines are producing fruit with acceptable yield and juice quality attributes. Clearly, there is some scope for reducing irrigation allocations for grapes, but definitive answers are still required to a number of scientific and practical questions. Long-term trials on different soils (e.g. clay v. sandy v. stones) and in different climates (e.g. the Awatere and the Wairau Plains) may help to identify some of the unknown factors that influence water demand and irrigation need.

Rainfall is a key factor determining irrigation need. Because the recent irrigation trials were carried out during years where rainfall was higher than average, there is value in extending the monitoring, in a reduced capacity, to quantify how low irrigation levels can go in much drier years while maintaining consistent yields and optimum fruit quality.

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INTRODUCTION

Water demand patterns in the Marlborough District have changed dramatically since the early 1970s. Traditional dry-land pastoral farming has been replaced by viticulture, which is reliant upon irrigation through the dry summer months. This changing pattern of land use is set to continue, as new vineyard developments expand into the drier parts of the region. A major limitation to this expansion process is likely to be the provision of sufficient water for irrigation.

Current guidelines for grape irrigation have been shown, through research and water-meter readings, to be very conservative. Some growers are often using much less water than they have been allocated. There is scope for reducing irrigation allocations for grapes. This would help to free up more of the region's scarce water resources to make sure that enough water is available for those viticulturalists, and other users, who want to use it. However, any reduction in irrigation allocation requires better specification of grapevine water needs, and an agreement on the appropriate level of risk. Wise stewardship is needed to manage of the region's scarce water resources now and to protect them in the future.

The Marlborough District Council (MDC) is currently reviewing the water components of the Proposed Wairau-Awatere Resource Management Plan (PWARMP). They called a meeting of stakeholders (regulators, growers and researchers) with the aim of summarising key findings from the last 15 years of research on grape irrigation in Marlborough. Information gathered from the meeting is intended to help the MDC decide whether the grape irrigation guidelines in the PWARMP need modification.

As part of the review process, HortResearch Ltd has been contracted to complete the following schedule of work:

- summarise the sequence of research activities on grape water requirements in Marlborough since 1992. Provide, in tabular format and chronological order, the key findings associated with each project
- provide concise answers to four key questions given below, to help identify any knowledge gaps, in order to plan for future research needs.

1.	The physiological water demand and transpiration rate of a grape plant under Marlborough climatic and soil conditions is now well understood. The key question is not how much water will a grape vine drink but what is the optimum. ***What don't we know about grape plant water use?***
2.	A perennial problem in water allocation is defining quota. The current system is conservative and allows for sufficient water on a daily basis to offset the maximum net transpiration rate observed over the past 30 year period. A consequence of this system for some water resources such as the Wairau Aquifer has been full allocation, but under-utilization in real terms, with water effectively being locked up. Alternatively, an annual quota based on long-term monthly net transpiration rates can be used; however, reliability needs to be factored into this approach.

	What would the revised grape water guidelines be to offset net transpiration 80% of the time since 1970, compared with the current guideline figure of 2.2 mm/day?
3.	Meter records for Southern Valleys Aquifers irrigators since 2001 show actual water use averages 1 mm per day and this figure is supported by other sources. ***Is a rule of thumb of 1 mm per day for grape plants under Marlborough conditions supported by the regulated deficit irrigation trial results and do they suggest a lower limit for irrigation?***
4.	While transpiration is not a function of soil type, it does affect the storage of water and this can have implications over a full irrigation season. ***How important is it to incorporate soil water-holding capacity into an irrigation allocation regime?***

The purpose of this report is to provide a brief summary of research activities over the past 15 years, and provide concise answers to the four key questions presented above. The report served as a discussion document for stakeholders at the Marlborough Crop Water Use Efficiency Review Meeting, held at the MDC Buildings on September 9 2005.

PART 1: SUMMARY OF GRAPE WATER USE RESEARCH SINCE 1992

Project Title:	Crop cover management to enhance deficit irrigation in a humid climate
Research Provider:	Caspari, H. and S. Neal (1998)
Year:	1991-1995
Approach:	A 5-year trial established at Stoneleigh to study the effects of irrigation and cover crop on the yield and juice quality attributes of Sauvignon blanc.
Key findings:	• Crop cover reduced vegetative vigour and resulted in much lower soil moisture levels compared with bare soil. • Floor management had no measurable effect on total yield, while TA was lower and SS was higher in fruit from the chicory and ryegrass treatments. • An early-season water deficit provided control of vegetative growth and had no detrimental effect on fruit growth, yield, and fruitfulness. • Deficit irrigation enhanced the effects induced by crop cover. Cumulative yield after 5 years was about 6% lower, but not significantly different from standard irrigation. • Water stress in 1993 suggested that more careful management of irrigation might be required in hot, dry climates and/or shallow soils.
Comments:	Three key findings came out of this early cover crop / irrigation work. Firstly, the studies confirmed that grapes could get by with much less water than was previously thought (and applied in the vineyards). Secondly, less water could lead to better quality grapes. Thirdly, and in Caspari's view the most important, was the finding that well-managed permanent cover crops did not increase frost problems compared with bare soil. Grape water use was not the focus of this research and the actual irrigation volumes were not reported. Irrigation never exceeded 100 mm per year, and that none was applied in the last 2 seasons (Caspari, pers. comm.). The standard irrigation strategy was to maintain soil moisture levels above 15% [L/L]. This resulted in a moisture deficit (0-1.0 m) of about 150 mm by the end of the 1993/94 season. The trial site had a deep (>1.2 m) loam (FC close to 30%) overlying gravel.

Project Title:	Irrigation Management for Quality Grape Production TBG Contract MGG401
Research Provider:	Caspari, H., Neal, S. and others (1998)
Year:	1995-1998
Approach:	A 3-year project (Gisborne, Hawke's Bay and Marlborough) to improve grape and wine quality using new technologies (Time Domain Reflectometry (TDR) and Regulated Deficit Irrigation (RDI) for soil water management. The project had three broad objectives: 1. develop and test procedures for soil water measurement using time domain reflectometry (TDR) 2. identify management practices for effective control of vine water using irrigation scheduling (with Agriculture New Zealand consultants) and cover crops 3. provide information to growers about the soil water management and the tactical use of irrigation to optimise grape yield and quality.
Key findings:	• TDR gave fast, accurate, and reliable measurements of soil water content, but was difficult to install and operate in very stony soils. The neutron probe was deemed more suitable for those soils. • As with earlier work, cover crops reduced grape vine vigour and helped to suppress disease incidence and severity. Grape composition and wine quality were also enhanced. • Red varieties on very stony soils (Gimblett Gravels, Hawke's Bay) needed frequent irrigation to avoid excessive water stress that would otherwise affect yield and wine quality. A practical guideline for the stony soils was to maintain soil moisture levels under the drip line at 75% of field capacity. Control vines needed 193 L/vine in a wet season (1996/97), and 784 L/vine in a very dry season (1997/98) to maintain adequate soil moisture levels. • Irrigation management affected grape yield and wine quality in both seasons. It was suggested that smart irrigation techniques could be used as a management tools to achieve a desired wine style. • A two-year irrigation trial on Sauvignon blanc was carried out at the Brancott Estate. Full irrigation was applied according to the grower's standard practice (8 L/vine/day). Half- and late-irrigation treatments were also included. • A simple water balance model (no details given, but presumably based on TDR readings) was developed to partition water loss from the vineyard. During mid summer evapotranspiration (ET) from the vines peaked at about 2.5 mm/day. About 25% of the

	total water loss was from the inter-row. • Differences in soil moisture created by irrigation management were rather small compared with those achieved by soil management (crop cover). • Soil moisture levels declined to about 50% of field capacity by the end of the season. Water savings of up to 50% were achieved without loss in yield and improvement of wine quality.
Comments:	As with the earlier trials, grape water use was not the focus of this research and the actual volumes of irrigation were not reported. Thus there is no way of assessing irrigation efficiency. The late irrigation treatment was abandoned in 1997/98 because of very low soil moisture levels and associated symptoms of water stress. HortResearch also ran an extensive field campaign alongside the Brancott trials. Eddy correlation and large-aperture scintillometers were used to measure evaporative losses from the whole vineyard, and a combination of travelling-houmi and sap flow devices was used to quantify the energy balance and transpiration losses from individual vines. This data substantiated the water-balance calculations, and provided parameters for a more detailed model of vineyard water balance (see later).

Project Title:	Determination of the Irrigation Requirements for Olives and Grapes Growing in Marlborough
Research Provider:	Green, S; Caspari, H; Neal, S and Clothier, B
Year:	1998-2000
Approach:	A series of field experiments were set up in Blenheim to study the water balance of olives and grapes. Heat-pulse sensors were installed in the tree stem to monitor transpiration rates and time domain reflectometry (TDR) probes were installed in the root-zone to monitor changes in soil water content. The soil's hydraulic properties were determined using disk permeametry, and a standard weather station located at each site was used to provide supporting meteorological data. Leaf area and leaf stomatal function were also quantified.
Key findings:	• Sap flow measurements in grapevines revealed a daily water use of between 10 to 13 L per vine per day at the height of summer. The values were independently confirmed by TDR measurements of the change in soil water content, and by eddy-correlation measurements of the total evaporation losses from the vineyard. • Field data was used to parameterise a model of the vineyard water balance. The model was then run using a 28-year sequence

	of daily weather from the Marlborough Research Centre. The calculations described the impact of climate variability on the annual distribution of rainfall, water uptake and crop water demand. • For the purpose of modelling, a set amount of irrigation was applied automatically, on basis of crop need, whenever the water deficit in the root-zone exceeded 45% of the available soil water. An aliquot of 2.2 mm was applied during each irrigation event. • Model output revealed that weather and soil type both have a large influence on irrigation need. To meet crop water requirements 80% of the time the following quantity of irrigation was calculated: ➢ 198 mm/year on a Fairhall stony silt loam ➢ 198 mm/year on a Renwick silt loam ➢ 180 mm/year on a Wairau silt loam ➢ 81 mm/year on a Woodbourne deep silt loam. • The model was re-run for a range of Marlborough soils. A statistical summary of the results was then packaged into a decision support tool (SPASMO-DST) for resource planners at the Marlborough District Council. • A number of peer-reviewed scientific papers and popular article were published on the trial results.
Comments:	The field experiments were carried out under a full irrigation regime and so the derived model parameters reflect the 'full potential' water use of the vineyard rather than the actual water 'needs' for optimum grape production. The vine's leaf canopy and daily water use are both maximised under full irrigation. Therefore, the values of irrigation allocation are conservative because water stress has not been factored into the calculations. In practice, the production of quality wine grapes usually requires the use of an irrigation strategy that provides for less than the full potential vine water use. Additional water savings are possible using a targeted irrigation strategy that imposes a managed water deficit to optimise fruit yield and quality.

Project Title:	Predictive water use model for quality wine production SFF project No. 00/294
Research Provider:	Dryden, G. and M. Neal.
Year:	2000-2003
Approach:	Agriculture NZ has been conducting irrigation scheduling services in Marlborough for the past 16 years. During that time they have collected a large quantity of data on vineyard irrigation practices and the yield and quality of wine grapes. The main objective of this SFF project was to develop a predictive model for the irrigation requirements, to improve the water management while enhancing wine quality.
Key findings:	Two software packages were developed to provide a targeted irrigation recommendation: • Probe for Windows® uses the current measurement of soil moisture to provide an assessment of irrigation needs for the coming week. A grower report is generated to show the depth-wise pattern of soil water content, the seasonal development of soil moisture deficit, and the current target irrigation strategy. Totals for irrigation and rainfall are reported along with the likely amount of irrigation required to the end of the season. • WinIR software, provided by HortResearch, determines irrigation need through to the end of the season. The software combines data on vine water use, deduced from the Squire's irrigation trials (see later), with a long-term record of daily weather in Blenheim. Results are presented for a wet, a dry and a normal year. • The 'full potential' water use of the vines is calculated using the formula $ET_C = ET_O K_C$, where ET_O is the reference evapotranspiration and K_C is the appropriate crop factor. The default value for K_C=0.6 at full canopy. • In the 2002/03 season, an applicant group followed the irrigation recommendations and applied, on average, about 109 mm of irrigation. The 'full-potential' water needs were calculated to be 198 mm. The corresponding MDC maximum allowable value was 220 mm per season. • Water savings of between 45 and 51% were achieved using a targeted irrigation approach. A water savings of 1 mm per year, over the whole of the Marlborough grape growing area, represents a savings of 60,000 m^3 and this equates to 50 Olympic-sized swimming pools.
Comments:	In the past, irrigators have been effectively irrigating grape vines based on what they want (largely determined by vine leaf area and prevailing microclimate) as opposed to what they need. There are potentially huge efficiencies to be gained from changing

	management strategies and, e.g., using deficit irrigation at different times of the season. The researchers suggest that the potential may be to reduce the inputs to 25% of $ET_C = ET_O K_C$. Such savings could have a large impact on aquifer levels in the water-limited areas of Marlborough. While this work did not link the impact of irrigation management to grape yield and fruit quality, these links are being explored in the current SFF project being undertaken at Nautilus.

Project Title:	An assessment of vineyard planting density and the water demand of grapes
Research Provider:	Green, S., Greven, M., Neal, S., and Clothier, B.
Year:	2003
Approach:	A desktop modelling study was carried out to examine the effect of vine spacing, vigour and age, on the irrigation requirements of grapevines: 1. the seasonal development of vine leaf area was determined using data from the irrigation trial at the Squire Estate; 2. transpiration rates at the leaf scale were calculated using a parametric model to describe the leaf response to the aerial environment and the availability of soil moisture; 3. the light environment within the vineyard was simulated using a 3D geometric model to calculate the total amount of light intercepted by the vines and the corresponding rates of transpiration of the whole vine; 4. daily rates of vine transpiration were compared with ET_O to deduce an appropriate 'crop factor' for a range of planting densities, and vine ages; 5. water demand was simulated using a 1D soil water-balance model (SPASMO) that applies irrigation only when the vines are in need of it.
Key findings:	• There is a positive relationship between vine water use and leaf area. The effect of halving the leaf area is an approximate halving in vine transpiration. Vine age and vigour could alter the transpiration rate by a factor of three or more because of different leaf areas. • Mature vines planted at a row spacing of 2.4 m on a Wairau silt loam will need, on average, about 102 mm of irrigation each year. An irrigation allocation of 175 mm per year will meet the vine's water needs at least 80% of the time. • The same vines at a closer spacing of 1.8 m are expected to need about 10 mm per year more irrigation, at the 80% level of

	probability. Increased shading acts to reduce evaporation losses from the grassed inter-row.
Comments:	The main conclusion from this desktop modelling study is that increasing vine density will have only a small influence (< 10%) on vine water demand. Water users are not justified in seeking substantial increases in water allocation on the grounds of an increased planting density. The soil's water holding is likely to have a much greater influence on annual water demand than the effect of different vine densities. Additional water savings may be achievable using smarter irrigation techniques, such as RDI, to impose a mild water stress between veraison and harvest. These strategies were not factored into the calculations.

Project Title:	Regulated deficit irrigation (RDI) to save water and improve Sauvignon blanc quality.
Research Provider:	Green, S., Greven, M., Neal, S, and others
Year:	2001-2005
Approach:	A Regulated Deficit Irrigation (RDI) trial is applying less than the full-irrigation requirement to the grapevines and observing the impact on vine water use and productivity. The aim is to demonstrate that a saving in irrigation can be achieved without a detrimental impact on grape quality. Irrigation treatments of 100% (to compensate for crop evapotranspiration), 80%, 70% and 60%, were installed in a 5 ha block of Sauvignon blanc at the Squire Estate. The 100% treatment followed standard practice by the vineyard manager.
Key findings:	• During the four years of the trial work, the impact of RDI on the yield and vegetative growth of the grape vines was not significant. A 40% savings on irrigation was achieved while maintaining wine quality and having no adverse affect on yield. • The control vines received between 40 mm and 125 mm of irrigation over the growing season. No bunch thinning was carried out and the yields were consistently high (16-20 T/ha) over all irrigation treatments. • Two extreme events occurred during the trial period, and these had a large influence on irrigation need and fruit and production. The first year received the highest spring rainfall on record, so that little irrigation was needed over the summer. The second year was compromised by severe frosts that reduced yields by about 50%. Climate had a greater effect on yield and grape quality than the impacts of RDI.

	• Additional irrigation treatments of 40% and 20% were added to the trial in the 4th year. The impact of these low irrigation treatments on yield and juice quality was not significant. However, with the exception of the second (frost) year, rainfall totals over the growing season (Oct-Mar) were in the upper third with regard to the probability of exceedence. Seasonal rainfall is expected to have a greater influence on irrigation needs in the drier years.
Comments:	The use of sap flow in the vines has been fine-tuned and is now giving reliable results on which to base estimates of vine water need. Sap flow is revealing very low rates of transpiration from vines under the low irrigation treatments. This is symptomatic of a mild water stress. Those vines are conserving their water loss without a significant reduction in grape yield or juice quality, provided the stress is applied post-veraison. The wines at bottling are being tested for differences in flavour and aroma profiles; results will be analysed to determine how irrigation management can influence wine style.

Withholding irrigation from the vines at Squire's did not have a significant effect on yield over the four years of the trial (Table 1). There was a large reduction (~50%) in the 2003 harvest, but this was caused by a severe frost in early November 2002. The following season a 'rebound effect' was observed in vine vigour (increased leaf area) with yields being about 10-20% higher than normal. Most vineyards in Marlborough also reported higher than average yields from the 2004 harvest. Late in the season, sap flow in the low irrigation treatment (20%) was reduced to about 30-50% of the "full potential" (Figure 1). This indicates a reasonable level of water stress occurred in the low irrigation treatment, and yet the vine still produced good yields of grapes.

Year	Treatment	Irrigation [mm/yr]	No bunches per vine	Weight [g/bunch]	Yield [kg/vine]
2002	60	28	82.6	95.8	7.83
2002	70	33	76.0	104.5	7.95
2002	80	38	79.8	98.0	7.84
2002	100	47	74.4	108.1	8.04
Year	Treatment	Irrigation [mm/yr]	No bunches per vine	Weight [g/bunch]	Yield [kg/vine]
2003	60	63	46.3	72.4	3.37
2003	70	74	54.3	80.9	4.44
2003	80	84	48.7	79.8	3.88
2003	100	105	54.9	76.7	4.25
2003	PRD60	63	45.1	72.0	3.21
Year	Treatment	Irrigation [mm/yr]	No bunches per vine	Weight [g/bunch]	Yield [kg/vine]
2004	40	50	74.9	133.9	10.01
2004	60	75	70.0	134.1	9.41
2004	70	88	78.6	129.3	10.29
2004	80	100	64.8	121.5	7.95
2004	100	125	70.0	137.6	9.50
2004	PRD60	75	69.0	145.9	9.72
Year	Treatment	Irrigation [mm/yr]	No bunches per vine	Weight [g/bunch]	Yield [kg/vine]
2005	20	14	84.17	97.83	8.16
2005	40	27	84.67	89.69	7.59
2005	60	41	80.42	83.49	6.72
2005	80	54	82.50	78.87	6.58
2005	100	78	88.08	99.45	8.68
2005	PRD60	41	87.50	106.06	9.37

Table 1. Summary of harvest results from the MDC funded trials at Squires. Irrigation treatments of 100% (to compensate for crop evapotranspiration), 80%, 70% and 60%, 40% and 20% were installed in a 5 ha block of Sauvignon blanc at the Squire Estate. The vine spacing at Squires is 2.7 x 1.8 m → or ~ 2050 vines per hectare. Therefore, a yield of 8 kg/vine translates to about 16 T/ha, and this is high compared with the regional average of about 10 T/ha.

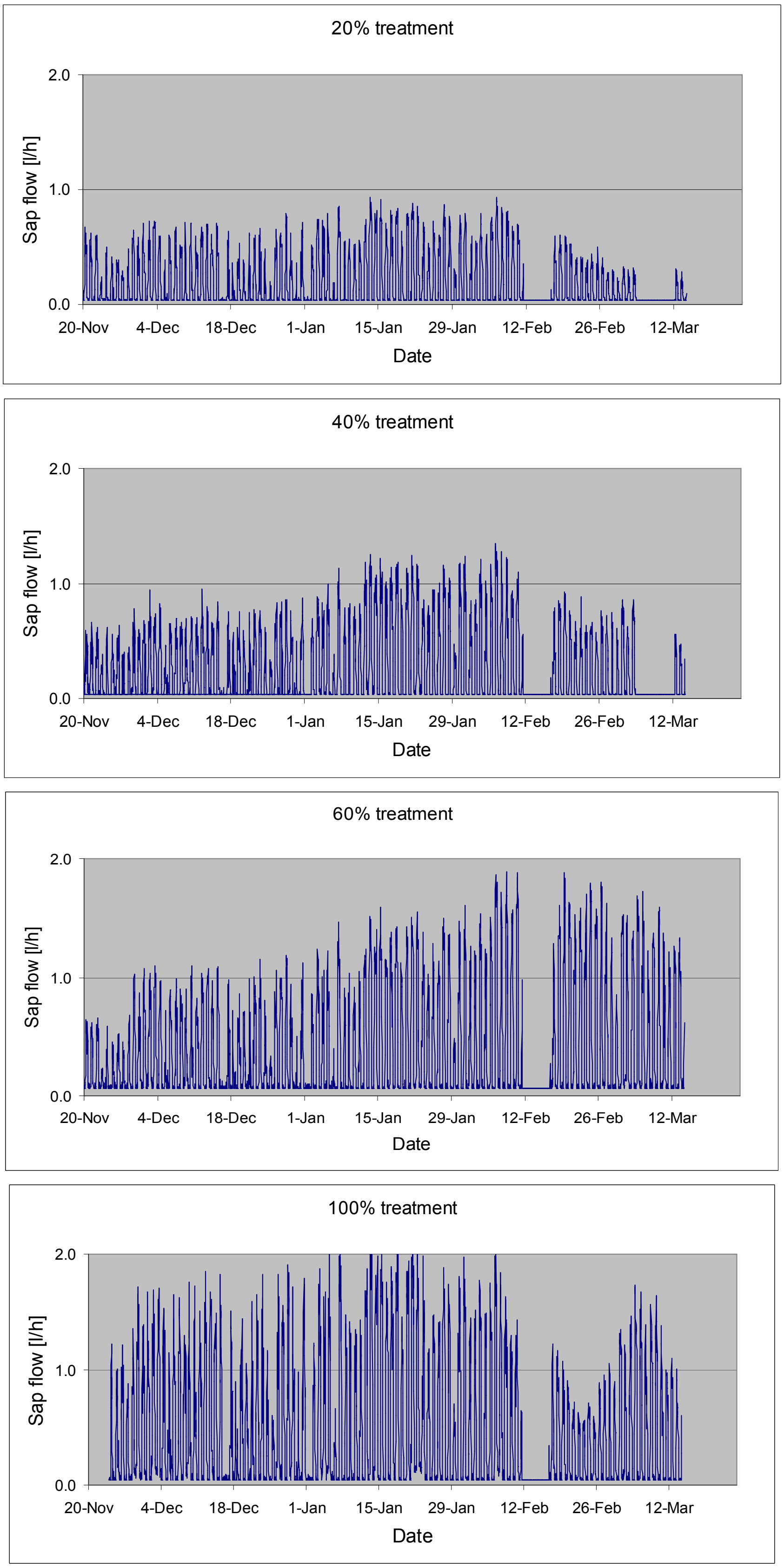

Figure 1. The impact of irrigation on sap flow in vines from Squires (2004/05 season). Late in the season, sap flow in the low irrigation treatment (20%) was about 30-50% of the "full potential". Irrigation on the 100% treatment was temporarily halted in mid February (a power failure) and this resulted in a drop in vine sap flow (bottom panel).

Project Title:	Maximising irrigation savings in grape vines and the effect on yield and wine quality SFF Project 03/100
Research Provider:	Dryden, G., and M. Neal.
Year:	2004-2006 (in progress)
Approach:	A replicated irrigation trial has been set up on a commercial vineyard (Nautilus) to push the boundaries of water application, in order to find out what the limits and effects are. The block is relatively dry and on a stony soil. Treatments of 70% (Control), 50%, 40% and 30% of ET_C have been applied. The irrigation scheduling service is looking at the best way to use the annual irrigation total over the whole season. The refill point for irrigation is set between 55% and 65% of field capacity.
Key findings:	• Preliminary results (Years 1 and 2) report the control vines (70% ET_C) receiving ~ 100 mm of irrigation and the low water treatments (30% ETC) receiving just 17 mm of irrigation. Late rainfalls in February and March (~125 mm) meant that little irrigation was needed from veraison through to harvest. • Rainfall late in the season (Year 1) increased the level of splitting (~25% on the low water treatment) on the trial block. • Smaller berries and lighter bunches led to lower yields for the lower irrigation treatments. Yields on the 30% ET_C treatment were just 41% of the control. However, it should be noted that there was no bunch thinning on any treatments,; the control vines had a very high yield (~20.3 t/ha; Year 1) that was also found across the region (attributed to large rainfall late in the season). • Vine vigour, as determined by shoot length and leaf area, was reduced by 30-40% in the low water treatment. Low water treatments (Year 1) had significant shrivel and the while Brix targets were reached, TAs were elevated partly because of dehydration. • Sap flow measurements showed vines under the low water treatment consistently used less water that the control. Daily water use in late February was 4-5 L per vine. This equates to an ET_C ~ 1 mm per day being consumed by the vines. • The wines at bottling showed significant differences in flavour and aroma profiles; results are being analysed to show how irrigation management can influence wine style.
Comments:	This study parallels the RDI trials at Squire's. A similar measurement and modelling approach is being adopted, and there is commonality in the yield and quality attributes being recorded. The main differences between the two trials are: the soil at Nautilus is very stony with a full point of about 230 mm/m; the Nautilus vines

	are less vigorous (~65% lower leaf area); soil moisture content is monitored using a neutron probe (TDR is difficult to install in stony soils); the irrigation scheduling service is setting the irrigation regime in a way that optimises water use through the season. Trial results are confirming that lower irrigation rates can produce the desired grape yields. Conclusions about the wine quality are yet to be made. Very low irrigation, followed by late summer rainfall (Year 1), did cause a large drop in yield and led to an increase in splitting; these are both less desirable effects of RDI.

Some key results from the Nautilus trial are presented below (from a draft of the annual report prepared for SFF, Greg Dryden, pers comm.). In the first two years of the trial, the control treatment (#1) received between 100-107 mm of irrigation while the reduced irrigation treatments (#2-4) received <50 mm per year. Generally, vines receiving less irrigation water had reduced leaf area and sap flow measurements indicated lower rates of crop water use.

Table 1: Estimated Crop Water Use, Rainfall and Irrigation application from 19th November 2003 until harvest.

Treatment	CWU	Rainfall	Irrigation (L)	Irrigation (mm)	% of CWU less effective rainfall
1	310	241	577	107	74
2	268	241	291	55	61
3	245	241	163	30	42
4	225	241	96	17	34
6	245	241	162	30	42
5a	250	241	83	15	
5b	319	241	450	84	
PRD Ave	284	241	533	99	86

Table 2: : Total yield per hectare for each treatment.

Treatment	1	2	3	4	5	6
yield. (t/ha)	20.3	12.7	10.3	8.4	18.2	7.3
Yield % control	100%	63%	51%	41%	90%	36%

Table 3: Estimated Crop Water Use, Rainfall and Irrigation application from 10th November 2004 until harvest.

Treatment	CWU	Rainfall	Irrigation (L)	Irrigation (mm)	% of CWU less effective rainfall
1	380	307	540	100	57%
2	327	307	252	47	41%
3	310	307	118	22	24%
4	290	307	89	16	21%
6	316	307	142	26	23%
5a	347	307	268	50	
5b	335	307	330	61	
PRD Ave	341	307	599	111	81%

Table 4: **ıe:** Total yield per hectare for each treatment.

Treatment	**1**	**2**	**3**	**4**	**5**	**6**
Yield. (t/ha)	17.7	13.5	12.5	11.5	18.1	10.3
Yield % control	100%	76%	71%	65%	103%	58%

Yield data from the Nautilus trial are presented for the 2004 and 2005 harvests (Tables 1 to 4; Greg Dryden, pers. comm.). As no bunch thinning was carried out, yields on the control and PRD treatments were higher than desired. Overall, the yields from this block were also high compared with the district average. Vines at Nautilus received much less that the current irrigation allocation (220 mm per year). Even the lowest irrigation treatments achieved very acceptable yields for Sauvignon Blanc in Marlborough.

PART 2: SPECIFIC QUESTIONS FROM MDC.

Q1: What we don't know about grape plant water use?

There are many environmental (e.g. light, temperature, humidity, wind speed, soil water) and management factors (e.g. vineyard planting, canopy management, irrigation, fertilization) that influence plant water use. In some cases it is relatively straightforward to predict their influence (e.g. potential water use is proportional to leaf area, all other factors being equal). However, it is more difficult to be precise about environmental and management effects on irrigation need and, more importantly, what influences there may be on the yield and juice quality of the grapes. This is because environmental and management factors are often linked, so that changing one factor can result in both a direct and an indirect response by the vine and the vineyard manager e.g. wet spring → increased vigour → greater leaf area → greater vine water use → more thinning and leaf plucking → reduced transpiration → less irrigation need. Furthermore, reducing leaf area → greater light exposure to fruit → changes in flavour and aroma profiles of the grape juice at harvest. Efficient irrigation management could account for some, or all, of these factors, yet our understanding is incomplete because quantitative measurements are seldom made.

Under a similar microclimate with a similar level of water availability, vine water use will depends on the vine's total leaf area and the stomatal function of the leaves. Each year the vines grow under different temperature and rainfall regimes, and there may be catastrophic events such as floods, droughts, hail or frost, that have indirect influence on vine water use if leaf area or leaf function is altered. There are few trials that can provide definitive answers about climate impacts on leaf-area development. This is because most of the research has been done on different grape varieties growing overseas. Knowledge needs to come from vines growing in the soils and microclimates around the Marlborough region.

Currently, there is no quick way to obtain an accurate measure of the leaf canopy. Point quadrat methods, promoted since the early 1970s, use a simple hand-held tool to monitor the grape canopy (e.g. a leaf-layer number of 1-2, and a leaf-to-fruit ratio of 12-15 are good rules of thumb for a balanced vine). Yet few growers are using point quadrat, probably because the measurements are time-consuming and cumbersome. As part of their evaluation of precision viticulture, Lincoln Environment Ltd is developing an alternative system for remote sensing of the leaf canopy. Simple ways that better define the vine's leaf area are useful to evaluate variability in the vineyard.

Current knowledge gaps surrounding leaf area include the impact of vine age and vigour, grape variety and root-stock, canopy management (trimming, hedging and leaf-plucking), irrigation and fertilizer regimes (timing and amount), and the water and nutrient status of the soil. There are also unexplained differences across the region (e.g. phenological dates of bud burst and harvest are consistently different between the Awatere and the Wairau valleys). Explaining these differences would improve our understanding of actual vine water use under stressed and non-stressed conditions.

Data from current trials is leading to new models of leaf stomatal response (SB vines only) to the aerial environment. Stomata are the small pores on the underside of grape leaves. These pores open during daytime to take in the carbon required for new biomass production (root-shoot-leaf-berry) and they transpire water that evaporates from the leaf surface to the surrounding air. Water stress will cause a partial closure of the stomata, thereby reducing transpiration losses, having an impact on photosynthesis (carbon uptake decreases), and possibly altering the balance between leaves and fruit on the vine. A knowledge gap exists in our understanding of how stomata respond to different levels of available water and how the carbon balance is altered during stress at different times of the growing season. To date, there is little research data to quantify the drought tolerance of other grape varieties, and almost no reported studies of stomatal response of grapevines in Marlborough.

We have yet to determine exactly how irrigation (and other factors) influence berry development and affect final juice quality. Different stresses, occurring at different times, will alter the flavour and aroma profile of the grape juice, and these relationships may change as the vines age. There is probably no one way to produce fruit of the quality desired by the winemaker. However, there are opportunities to influence juice quality, and consistency, through better understanding that leads to improved management practices. Long-term trials on different soils (e.g. clay v. sandy v. stones) and in different climates (e.g. the Awatere and the Wairau Plains) may help unravel some of the connections between water demand and irrigation need.

At the moment it is difficult to quantify the level of water stress. This is because there are very few plant-based measurements that are practicable for the growers and irrigation consultants. Sap flow and leaf-to-air temperature differences are being evaluated, and 'rules of thumb' to interpret midday values of leaf water potential are being tested at the irrigation trial sites. However, these tools are still in the research domain and it may be some time before they are available to vineyard managers. In the meanwhile, soil moisture monitoring remains a common tool to make decisions about irrigation need. A wide range of soil moisture sensors (e.g. TDR, neutron probe, capacitance probe, gypsum block, and tensiometers) has been trialled in local vineyards. However, there are practical issues surrounding how and where to measure soil moisture, and there are uncertainties about how to interpret the data. Figure 2 illustrates the problem of soil moisture readings.

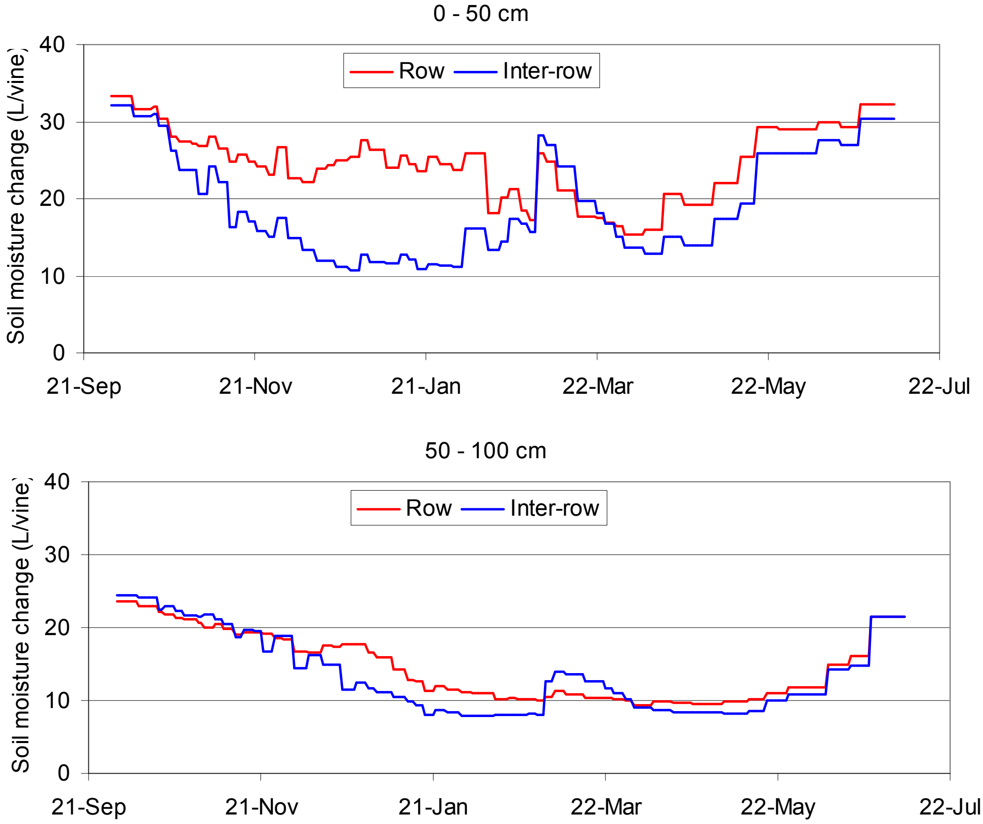

Figure 2: Seasonal development of soil moisture under the control vines (2003/04) as measured by TDR at depths of 0 - 50 cm and 50-100 cm.

Once the irrigation is turned on, the soil measurements reveal plenty of water in the wetted strip under the drippers (row) but there is much less water in the inter-row. Readings taken in the wetted strip will probably overestimate the amount of water that is available, and they may overestimate vine water use. As the season progresses, vine roots extract much more water from deeper parts of the root-zone, including the inter-row. Thus, it is difficult to calculate vine water use from measurements of soil moisture alone, unless the measurements are deep enough (to the bottom of the root-zone) and include the inter-row soil.

Trial results from Squire's and Nautilus are beginning to quantify the effect of soil water deficit on vine water use. In both trials there has been a reduction in leaf area and a decline in the leaf stomatal conductance of grapevines under water stress. A questions remains about how low a managed water deficit in the root zone can go. Past trials in Marlborough sought to maintain a water deficit of about 100-150 mm in the top metre of soil. Obviously, vines on deeper soils that have deeper root systems will tolerate a much bigger water deficit. Conversely, vines on lighter soils of limited depth (e.g. < 0.5 m) may not even hold 100 mm/m of water in the root-zone soil water. In the latter case, simple 'rules of thumb' gleaned from the early trials will not translate across other soil types.

There is little data from Marlborough vineyards to demonstrate how the timing and the degree of water stress influences leaf area development and vine water use. Literature suggests that water stress around flowering has a greater effect on final yields that does water stress after veraison. In addition, there are few data sets to quantify how much the vine's water needs change because of differences in soil type, soil depth, root depth, water and nutrient stresses, pest and disease pressures, and crop load. There is likely to be no single answer to the question 'how much water does a grapevine need?', because the needs depends on the environmental and management factors discussed above. However, recent trial results, and water-meter records, are confirming that an allocation of 220 mm/year is likely to be generous, most years, for mature vines on the deep soils.

Q2: What is the grape water allocation required to offset net transpiration 80% of the time, and how does this value compare with the current guideline value of 2.2 mm/day?

On a daily basis SB vines at Squires have a peak water use of about 4 mm per day during the middle of the summer (Figure 3). There are tails at each end of the growing season resulting from reduced evaporative demand and smaller leaf areas. The need for irrigation will be much less than 4 mm per day because summer rainfall often occurs and this helps to replenish moisture levels in the root-zone soil. Some years (e.g. 2001/02) very little irrigation may be needed because of adequate rainfall while on other years (e.g. 1996/97) more frequent irrigation may be needed to avoid water stress at key development times.

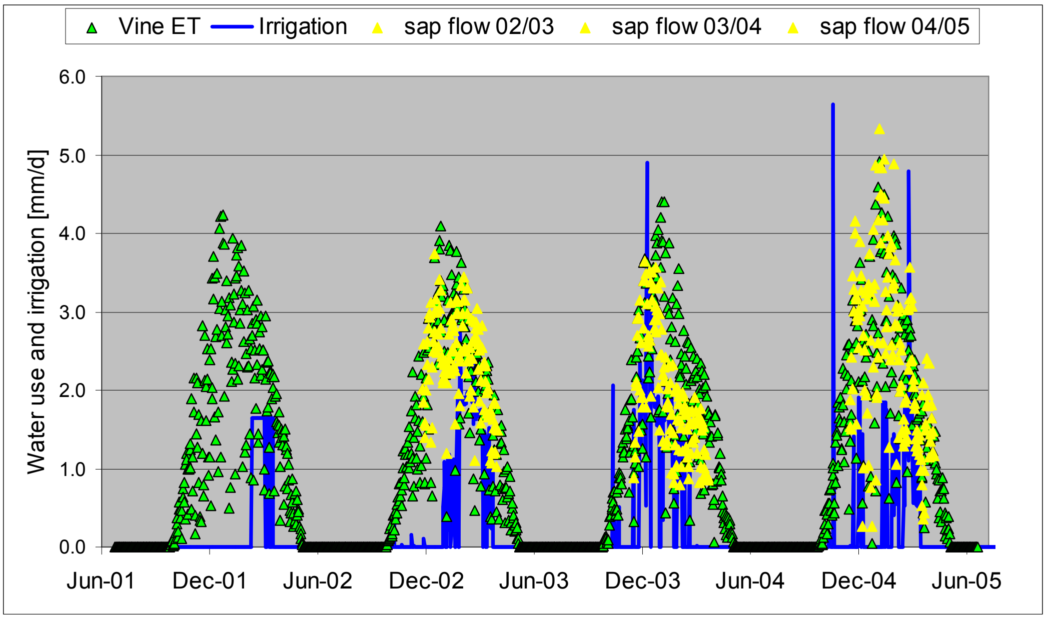

Figure 3. Seasonal water use of grape vines under the 100% irrigation treatment at the Squire's trial site, predicted from climate and leaf area measurements and measured by sap flow. The vine's daily water use, ET_C [mm/day] was calculated as the product of a crop factor, K_C, times a reference potential ET_O. Vines under the 100% irrigation treatment were transpiring at close to their "full potential" as defined by ET_C.

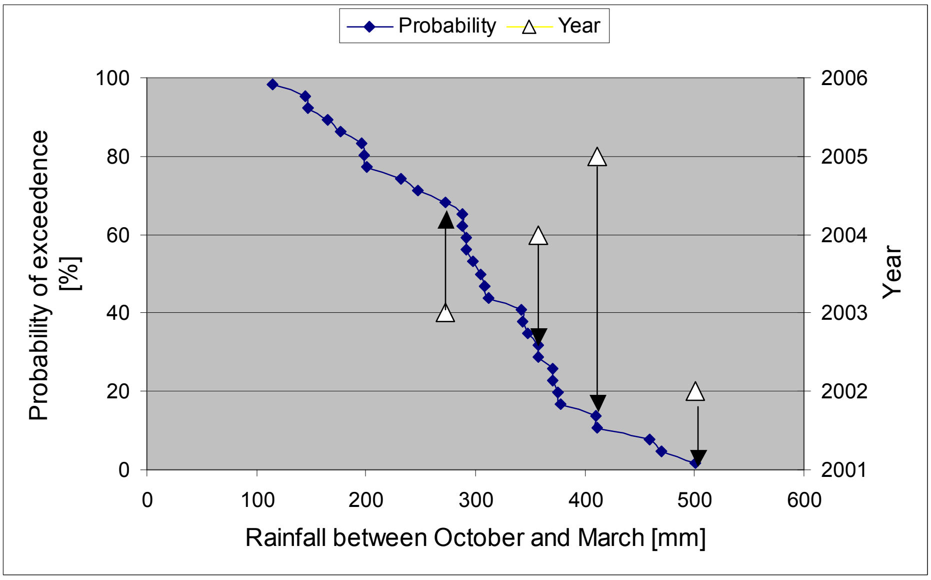

Figure 4. Rainfall distribution over the irrigation season (Oct-Mar) compiled from long-term records (1972-2005) at the Marlborough Research Centre. The average rainfall is about 300 mm per season. The open symbols highlight the years of the Squire's trial. With the exception of the 2003 harvest (the frost year), all years were wetter than average.

The long-term rainfall distribution (1972-2005) over the irrigation season (October-March) is shown in Figure 4. Each year of the Squire's trial has been highlighted, for comparison, to show that the trial data has come from years of average to high seasonal rainfall. The erratic and uncertain nature of rainfall, at critical times, is the main driver for irrigation, all other factors being equal.

Previously, we have provided conservative answers to *Q2* in our risk assessment of irrigation needs by olives and grapes in Marlborough (Green *et al.*, 2000). That study used data from field experiments at the Brancott Estate to parameterise a mechanistic model of the soil water balance. Sap flow measurements indicated an average daily water use of 10 to 13 L per vine per day (2-2.5 mm per day) towards the end of summer. These values were independently confirmed using TDR measurements of the change in soil water content, and using eddy-correlation measurements of the total evaporation from the vineyard. So the model calculations were based on sound experimental data, and they factored in real soil and climate data. However, because the vineyard was under a full irrigation regime, the derived model parameters tended to reflect the 'full potential' water use of the vineyard rather than the actual water 'needs' for optimum grape production.

For the purpose of modelling, we used a set amount of irrigation, some 2.2 mm per day, and this was applied automatically whenever 45% of the available soil water was depleted from the root-zone (Green *et al.*, 2000). The model was run using a 28-year sequence of daily weather from the Marlborough Research Centre (1972-2000). Hydraulic properties of 4 local soils, taken from data in the New Zealand Soils database (Landcare Research), were factored into the calculations. The desk-top modelling study concluded that grape water requirements would be met 80% of the time, by providing:

- 198 mm of irrigation per year on a Fairhall stony silt loam
- 189 mm of irrigation per year on a Renwick silt loam
- 180 mm of irrigation per year on a Wairau silt loam
- 81 mm of irrigation per year on a Woodbourne deep silt loam.

The current MDC guideline assumes 100 days of irrigation, and has an annual allocation set at some 220 mm per year. This allocation would appear to be very generous for vines on a Woodbourne deep silt loam and is expected to provide more than enough water to meet the vine's water needs some 80% of the time on the other soil types. The model calculations are conservative, however, because they assume the vines are transpiring at their full potential. No account has been made for a managed water stress and the likely impact this has on vine water demand. Some real irrigation data are presented in Figure 5.

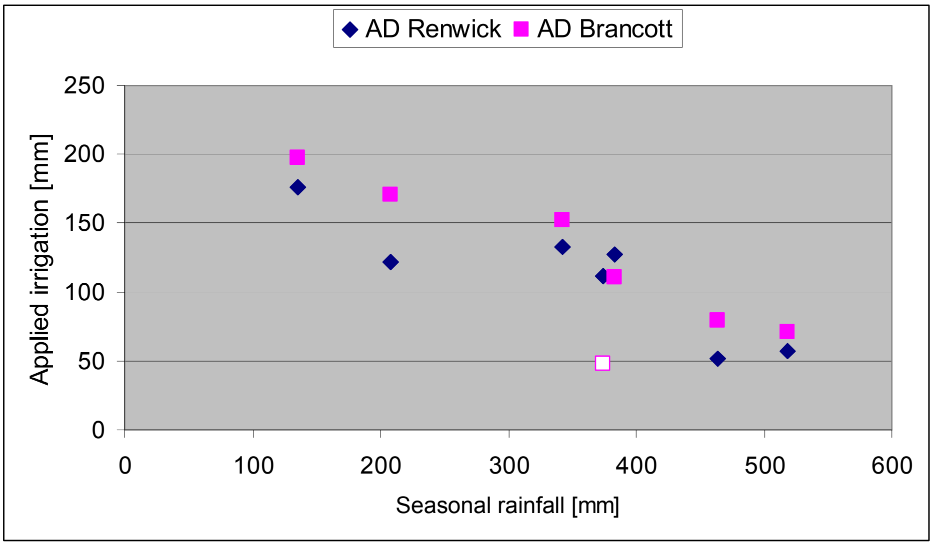

Figure 5. The relationship between annual amount of irrigation (October-April) and the seasonal rainfall recorded on vineyards at the Renwick and Brancott Estates. Here, irrigation totals were calculated from weekly records of pumping from the well. During 1999 the well ran dry (open symbol) and so irrigation was not possible (data provided by Victoria Raw, Allied Domecq Wines).

In practice, vineyard managers at Allied Domecq Wines are applying more irrigation during the drier years (Figure 5). The average amount of irrigation over the last eight years has been about 110 mm/yr at Renwick (mostly red grape varieties) about 120 mm/yr at Brancott (mostly white varieties). These two vineyards are often using less than the current allocation of 220 mm/year. On average they are using about half their allocated amount, but 1 year in 8 they have applied almost 200 mm of irrigation.

Q3: Is a rule of thumb of 1 mm per day for grape plants under Marlborough conditions supported by the regulated deficit irrigation trial results and do they suggest a lower limit for irrigation?

For a vineyard that is not short of water, and has healthy mature vines in full canopy, transpiration losses from the vines will easily exceed 1 mm per day through most of the growing season (Figure 3). At the Squire's trial site, vine water consumption was calculated to be 390 - 420 mm per year, assuming a maximum K_C of about 0.6 (Figure 6). Vine water consumption at Nautilus was similarly calculated at 310-380 mm per year (control vines – Greg Dryden, pers. comm.). The difference in vine water use at Nautilus is explained by the lower leaf areas. The annual amount of irrigation applied to the control vines at Squire's varied between 40 mm/year (2001) to 125 mm per year (2003). Vines under the low irrigation treatment (20%) consumed considerably less water (see Figure 1) because of a mild water stress. They received just 25 mm or irrigation during 2002/03.

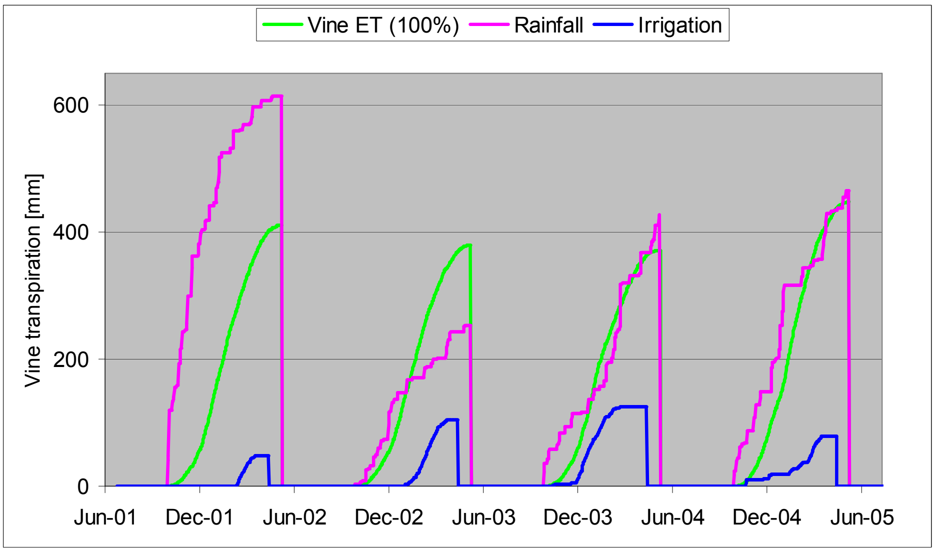

Figure 6 Water balance calculations for the control vines at the Squires trial site, as represented by the seasonal vine water use (ET), and the accumulated totals of rainfall (pink line) and irrigation (blue line). Except for the frost year (2002/03), total rainfall exceeded total vine water use. There will be additional evaporative losses from the vineyard floor.

The reduction in irrigation had no significant effect on harvest yields and fruit quality (Table 2). Similar water savings are also being imposed on the Nautilus trial. In Years 1 & 2, between 100-107 mm of irrigation was applied to the control vines. Yields were generally very high (~20 T/ha) under the control and PRD treatments, and they were acceptable (~10 T/ha) under the RDI treatments that received <50 mm irrigation per year. Results from these two trials are confirming that grape vines receiving less that the current irrigation allocation (220 mm per year) are able to produce fruit with acceptable yield and juice quality attributes. Both trials have shown that a much lower irrigation rate, of ~100 mm per year is adequate, at least on these soils during growing seasons that were wetter than average.

Q4: How important is it to incorporate soil water holding capacity into an irrigation allocation regime?

Soil scientists use several terms to define the water storage capacity of soils under different conditions.

- Field capacity is defined as "the amount of water held in soil after excess water has drained away and the rate of downward movement has materially decreased". This usually takes place within 2 or 3 days after rain or irrigation in free draining soils. Typical suction values associated with the field capacity are -10 to -33 kPa (-0.1 to -0.33 bars).
- Wilting point is defined as "the soil water content at which plants have extracted all the water they can from a soil". There is no sharply defined lower limit for water availability, but –1500 kPa (-15 bars) is commonly used as an estimate of the permanent wilting point.
- Available water is defined as "the amount of water between field capacity and the permanent wilting point". Plant roots cannot extract all of the water stored in the root-zone soil. There is always some water in the soil below the permanent wilting point but it is too strongly bound to the solid particles of the soil. This is called hygroscopic water.

Like water content, the soil's field capacity and permanent wilting point are defined on a volume of water per volume of soil basis. The difference between these two values provides a definition of the amount of water available for plant uptake after any excess water has drained away. Table 2 presents typical values for a range of soil textures. It should be noted that the available water is very small in sandy soils and much larger in loams and clays.

Texture Class	Field Capacity FC	Wilting Point WP	Available Capacity AC
Sand	0.12	0.04	0.08
Loamy Sand	0.14	0.06	0.08
Sandy Loam	0.23	0.1	0.13
Loam	0.26	0.12	0.15
Silt Loam	0.3	0.15	0.15
Silt	0.32	0.15	0.17
Silty Clay Loam	0.34	0.19	0.15
Silty Clay	0.36	0.21	0.15
Clay	0.36	0.21	0.15

Table 2. Water Retention Properties for Agricultural Soils (Values Taken from ASCE, 1990, Table 2.6, p. 21)

For budgeting calculations, it is useful to know the available water-holding capacity in a soil profile. This value is typically expressed in mm and can be obtained by integrating the available water-holding capacity over the effective depth of the soil layer. Some simple calculations are presented below for a uniform soil profile:

- A silt loam of 1 m depth typically has a total available water-holding capacity of 150 mm. If the vine roots extend to a depth of 1 m, then approximately 150 mm of water can be withdrawn from the soil before symptoms of water stress will occur.
- By comparison, a sand of 1 m depth typically has a total available water holding capacity of just 80 mm. This means that the same vines can extract just 80 mm of water from the top 1 m of sandy soil before they start to become water stressed.

The difference in available water between sand and a silt loam is typically about 70 mm of water per meter of soil depth. This represents about three weeks of water use assuming the average transpiration loss is 3 mm per day. Such differences will have an impact on the irrigation needs of the vines. Figure 6 illustrates how the depth and stone fraction of a gravel layer might alter the amount of readily available water in the soil profile. Stones are an important in Marlborough since many vineyard soils are shallow alluvium on top of a gravel layer. Here we consider the following hypothetical case: when the gravels are deep (>100 cm) the profile holds about 115 mm/m of soil depth; when the gravels are shallow (90% stones to the soil surface) the profile holds just 20 mm/m of soil depth; in the intermediate case (50% stones below a depth of 50 cm) the profile holds about 75 mm/m of soil depth. Vines on a shallow stony soil need to be irrigated much sooner, all other factors being equal. Over the course of a single season those vines on soils with lower water holding capacities will require more irrigation to sustain them over the dry summer months.

Agriculture New Zealand Ltd has provided us with their irrigation and soil monitoring data from a number of vineyards operated by Allied Domecq Wines (Greg Dryden, pers. comm.). Their data emphasise the facts that:

- deeper soils, with fewer stones, tend to have a higher field capacity,

- vines on the deeper soils tend to be given less irrigation over the course of the growing season (Figure 7).

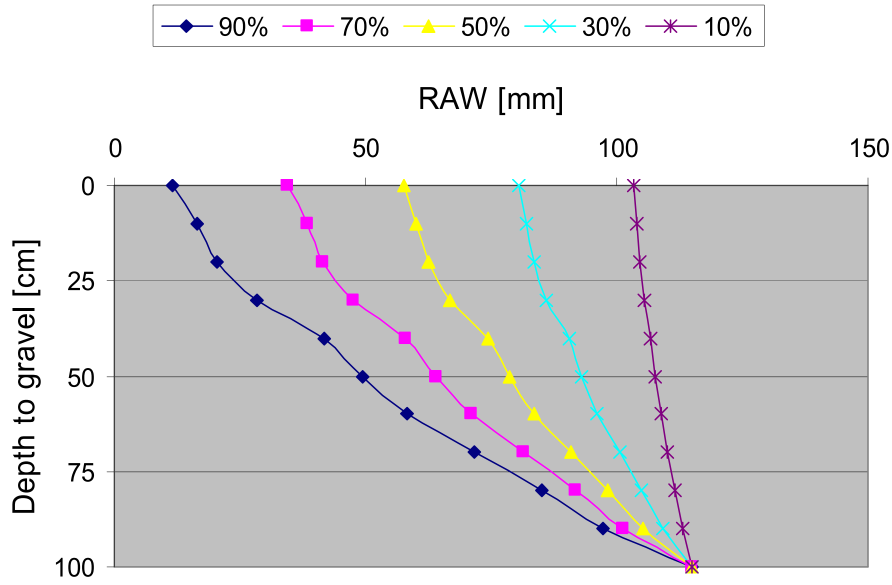

Figure 6. Stone fraction [%] and depth to gravel [cm] has a direct influence on the amount of readily available water (RAW). Results here are for a hypothetical Wairau sandy loam soil that has a maximum RAW of 115 mm/m.

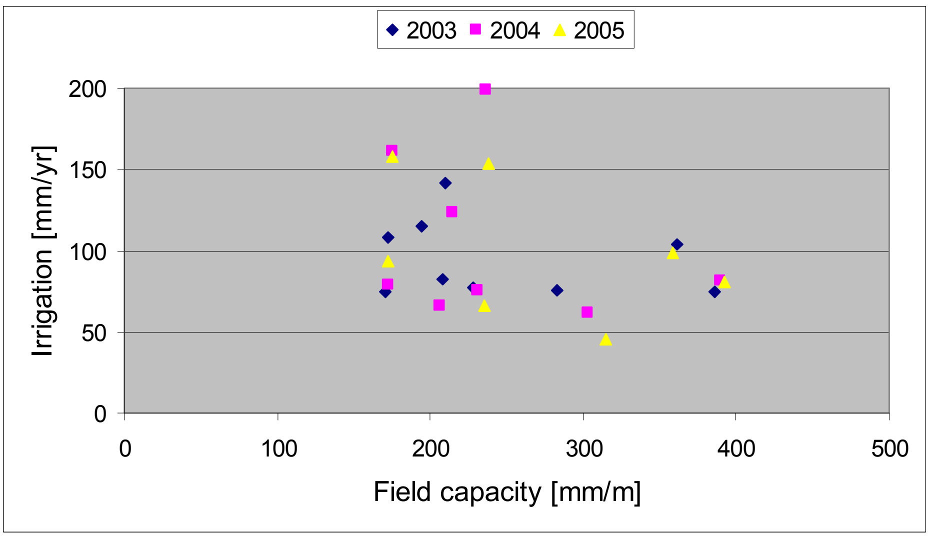

Figure 7. The relationship between total seasonal irrigation (October-April) and the soil's field capacity, as monitored on Allied Domecq vineyards in Marlborough. The data includes a range of grape varieties and was supplied by Greg Dryden (Agriculture New Zealand) in consultation with Victoria Raw (Allied Domecq Wines).

Current irrigation at Allied Domecq Wines (ADW) is applying about 100 mm/yr to vines on the deeper soils, and up to 200 mm/yr to vines on the shallow soils. ADW have yet to impose any deficit irrigation strategies, so further water savings are achievable.

SUMMARY

Results from the recent trials (post-1994) on Marlborough vineyards have confirmed the key factors controlling vine water use are:

- prevailing microclimate
- vine total leaf area
- available soil water.

Rainfall is a key factor determining irrigation need. HortResearch and NIWA maintain a number of climate stations around the region. Long-term records are available and they can be used for a risk assessment of rainfall reliability.

Over the past 15 years, new measurement techniques (sap flow and TDR) have been refined to measure transpiration losses from a vineyard. Simple computer models have also been developed to interpret soil moisture measurements and improve irrigation scheduling for subsequent weeks and through until the end of the season. These tools are improving our understanding of vine water use and our assessment of irrigation needs.

Local trials are confirming that significant water savings are possible using carefully managed deficit-irrigation strategies. Much less water is being applied than current allocation permits, and the vines are producing fruit with acceptable yield and juice quality attributes.

Clearly, there is some scope for reducing irrigation allocations for grapes, but definitive answers are still required to a number of scientific and practical questions. Long-term trials on different soils (e.g. clay v. sandy v. stones) and in different climates (e.g. the Awatere and the Wairau Plains) may help to identify some of the unknown factors that influence water demand and irrigation need.

Because the recent irrigation trials were carried out during years where rainfall was higher than average, there is value in extending the monitoring, in a reduced capacity, to quantify how low irrigation levels can go in much drier years while maintaining consistent yields and optimum fruit quality.

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