Investigations in to Vine Nutrition and Water Status on Grape and Wine Quality



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Abstract

The objective of this study was to investigate the links between late season leaf health and wine quality, using distinct vigour zones within a vineyard that gave rise to leaf health gradients, and by manipulating leaf health with nitrogen fertilisers. Increased leaf health was linked to greater overall canopy growth and density, and higher leaf and must nitrogen levels. Fruit sugars ware unaffected, although acids tended to rise and tannins decrease in fruit and wines from vines with improved late season leaf health. Sensory preference was found for wines made from fruit from low vigour vines with less healthy leaves, while there was little sensory difference from nitrogen addition.

Executive Summary

Investigations into late season leaf health included study of distinct vigour zones within a vineyard that gave rise to leaf health gradients, and manipulation of leaf health using nitrogen fertilisers.

It was demonstrated, through study of distinct vigour zones, that leaf health had a strong positive relationship with the extent of canopy growth. Leaf health was assessed by chlorophyll content, and by leaf counts, since leaf senescence leads initially to reduced chlorophyll, and finally to leaf abscission. Vines that had increased late season leaf health also had greater pruning and shoot weights, a higher level of lateral shoot growth, and an increase in bud burst percentage, all indicative of an increase in shoot and canopy vigour. This led to an increase in canopy shading of the fruit zone.

The vigour areas were investigated using remote sensing, and the remote sensing index of plant cell density (PCD) was very strongly positively correlated to pruning weights.

Yield was not consistently linked to vigour in this trial. Although yield did rise with vigour in all trials on Sauvignon blanc, results in Pinot Noir were variable. We found increased yield with increased vigour in one block, while the other block showed no relationship, even though both blocks represented comparable ranges of overall canopy vigour and comprised the same clone.

Fruit sugar levels in Pinot noir were not affected by vine vigour associated with the differences in leaf health in this trial. It may be concluded that photosynthates were not limiting fruit ripening in Pinot Noir. Fruit sugar level of Sauvignon blanc tended to decrease as vigour increased, although not when the value was converted to sugar per berry, when there was no difference. Malic acids were increased in vines with increased vigour, that in turn served to significantly increase juice pH of fruit from high vigour vines.

Juice yeast assimilable nitrogen (YAN) content increased with vigour. Wine fermentation rate was strongly linked to the juice YAN, nonetheless all wines were able to ferment to dryness.

Pinot noir wines made from fruit of increasing vigour zones tended to decrease in colour density, and consistently showed strong decreases in phenolics. It should be noted that this was not related to yield, since the yield and vigour relationship was not consistent.

Sensory analysis indicated that the wines made from fruit of each vigour level were all clearly distinguishable. Wines of low vigour fruit tended to have more tannin and darker fruit characters, while high vigour fruit was more herbaceous.

Manipulating leaf health, through addition of nitrogen fertiliser to soils, confirmed results that were associated with different vigour zones, including increased leaf chlorophyll content, delayed abscission and, increased lateral and main shoot growth. Varying the timing of nitrogen application conferred greater understanding of the developmental responses of the vines and how that may be reflected in the chemistry of the grapes and wine.

Nitrogen addition early in the season underpinned increased vine canopy growth, however nitrogen later in the season was more important at influencing late season leaf health. Therefore, in the first year of application nitrogen timing could be used to enhance leaf health but not cause any change in vine canopy characteristics.

The effects of nitrogen applications tended to be carried over from one season to the next. As a result, late season nitrogen from the previous season led to a higher rate of nitrogen early in the following season. The importance of timing was less in the subsequent season, and instead rate became more of an influence on the canopy growth. However, nitrogen added pre bloom still made less difference to late season leaf health than other timings, although it was still higher than the unfertilised control.

Nitrogen addition in all seasons led to an increase in the percentage bud break the following season.

The increase in canopy density as a result of nitrogen addition was observed as a decrease in light in the fruit zone.

Fruit sugars were increased in one season due to nitrogen addition pre bloom, although this may have been associated with an increase in berry shrivel. The berry shrivel appeared to be linked to improve fruit set – again, this was only evident in one year of the trial. Nitrogen addition tended to increase titratable acidity.

YAN content was increased by nitrogen fertiliser addition to the soil up until veraison in the first year of its addition. With nitrogen applications at or post-veraison, there was either no difference or even a reduction in YAN. Ferment rates were driven by the YAN. In the first season of application, early additions led to increased YAN, however in the second year there was no effect from timing of application.

Wine tannins appeared to be reduced by high rates of nitrogen, and there was evidence to suggest that nitrogen addition led to sun exposure decreasing tannin content.

The outcomes of this trial underline the importance that nitrogen has on the growth of the grape vine. Additions of nitrogen post harvest in true cool climates is considered unlikely to work, due to the poor leaf health and low temperatures at this time limiting the uptake of soil nitrogen. In contrast, additions post veraison were shown to be effective at boosting nitrogen in the following season.

In summary, leaf health had many potential links to wine quality. Particularly important were increases in shading from higher canopy vigour, and changes in fruit nitrogen content. A scorecard, developed for vigour characterisation, proved to be as accurate as many other measures of canopy attributes, and had the advantages of being rapid and non-destructive.

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Background

Vine canopy attributes have a profound effect on wine quality. This project investigated late season leaf health given empirical observations of differences between vigour zones and differences in wine quality between vigour zones.
Grapevines lose leaves at the end of every summer growing season. Increased stresses upon a leaf will lead to early senescence, a process involving a decrease in plant chlorophyll content and remobilisation of nutrients from the leaf to other areas of the vine, and ending in the abscission of the leaf from the vine. Nutrient, disease and water stress may all accelerate senescence, as may increased shading.
Measures of late season leaf health are effectively assessments of the degree of leaf senescence. They will reflect the stresses faced by a vine over the growing season.
Late season leaf health may then be linked directly to wine quality through changes in shading later in the season, or indirectly as an indicator for stress (be it chemical, nutritional or otherwise), or as a factor associated with other vine canopy attributes that also reflect vine stress.
This study sought to increase the understanding of these linkages and the impact on wine quality. Studies were also made into managing leaf health through nutrition, and the best way to control vine nutrition for maximum wine quality outcomes.

Materials and Methods

The project tackled its examination of leaf health and wine quality links in two separate ways. One group of trials involved the examination of areas in the vineyard with a leaf health gradient, which was identified as a change in overall vine vigour. The second group of trials manipulated leaf health with nitrogen fertiliser application in a relatively uniform block of vines.

All trials were conducted at the Tamar Ridge Estate's vineyards in Kayena, in Tasmania's Tamar Valley. This area is a cool climate region, at a latitude of 41.2°S.

The vigour gradient trials examined two blocks of own-rooted Pinot Noir clone G5V15, and two sites within one block of Sauvignon blanc of unknown clone. All vines were spaced 1.5m apart within the rows, and rows 2.25 m from each other. Both Pinot Noir trials were cane pruned to a Scott Henry trellis. The Sauvignon blanc trial sites in 2005-06 covered one area that was trained to a Scott Henry trellis, and the other to a vertically shoot positioned trellis. In the second year of this trial, it was trained to a Scott Henry trellis.

Links were established between various canopy attributes, with measurements including remote sensing imagery, point quadrat, leaf chlorophyll, pruning weights, and the development of a vigour scorecard for rapid vigour characterisation. This scorecard proved to be as accurate as many other measures of canopy attributes, and was rapid and non-destructive.

Fruit development was assessed by monitoring veraison progression, and measurements of fruit yield and the factors that contribute to yield. Fruit

chemical components were assessed, including juice sugars, titratable acids (TA) and pH, along with yeast assimilable nitrogen (YAN), malic acids, and phenolic compounds.

Small-lot winemaking was carried out to examine the impact of these factors on wine quality. This involved developing standard protocols for winemaking, which allowed for a cost effective and consistent process. The consistency was confirmed by replicated winemaking trials. These protocols have since been used in other trials, and will be of use to future researchers.

Wines were assessed by an examination of spectral characteristics of the wine, by Enose analysis, and by a tasting panel.

As well as investigating leaf health and wine quality links, this project allowed correlations to be drawn between various aspects of the canopies of different vigour zones. In particular, correlations between remote sensing data and ground-based measurements were assessed.

The trials manipulating late season leaf health utilised a single Pinot Noir vineyard block (own rooted, clone 114), with relatively uniform vine canopy growth and relatively poor late season leaf health. An initial trial was established to determine the impact of adding nitrogen and altering irrigation levels from veraison through to the finish of the growing season on leaf health.

The results of this trial indicated that nitrogen levels were more powerful at influencing late season leaf health than irrigation in this block, so in subsequent seasons the trial focussed on nitrogen fertilisation as a tool to manipulate leaf health.

Major trials looked at various rates of nitrogen application, applied at four different dates (pre bloom (PrB), post bloom (PoB), pre veraison (PrV) and post veraison (PoV)). Further trials were established to investigate the impact of bunch sunlight exposure and its interaction with nitrogen, and to look at the difference between altering must YAN using either field applied nitrogen, or DAP directly to the must.

Nitrogen impacts on canopy growth were assessed by pruning weight measurement, shoot node counts and shoot tip growth activity. Leaf chlorophyll estimates using a chlorophyll meter and leaf retention counts were used to gain understand the impact of nitrogen on leaf health. Fruit zone light penetration was recorded using a light meter.

Leaf nitrogen content was also measured, which involved building a model using chemometrics for leaf nitrogen content assessment by near infrared spectrometry. This model significantly reduced the costs of analysis, and may be useful to both researchers and industry.

Results and Discussion

Vigour trials

Vine leaf health was linked to a range of canopy characteristics in the sites with naturally occurring vigour gradients, where greater late season leaf health occurring in vines with higher canopy growth. These vines had a greater number of leaves in total, with more extensive lateral shoot growth. Late season leaf

counts were higher, both because of the greater number of nodes and a higher percentage of leaves per node. Leaf chlorophyll estimates rose as vigour zone rose also, and photosynthetic efficiency also rose slightly as vigour increased.

Vine vigour is primarily a reflection of average shoot vigour, and the links demonstrated in these trials indicate that shoot growth and leaf health will be influenced by common factors. Leaf health assessments then may be indicators for a general state of canopy growth, which previous research has demonstrated can have a range of influences on grapes and wine. The increased vine vigour was evident from all the different methods used in canopy assessment.

Leaf and canopy changes may influence fruit development by changing the light interception in the fruit zone, altering carbohydrate supply to grapes, changing fruit zone air movement. While also modifying canopies, alterations in vine nutrient status can have direct effects on fruit composition also.

Vine yield can also be altered by vine vigour, with other studies linking increasing vigour with increased yield. An increasing yield with vigour was observed in the sauvignon blanc trial sites, and one of the Pinot Noir trial sites. However, in the second Pinot Noir trial, vigour did not show any increase with yield. Both Pinot Noir blocks were the same clone and trellised to a Scott Henry system, and also covered a similar range of vigour level. Further illustrating the potential complexity of yield and vigour relationships was the observed different yield components responsible for total vine yield, between the sauvignon blanc and the Pinot Noir. Increase in yield in the Pinot Noir was primarily as a result of increased bunches per shoot and therefore overall bunch counts. Conversely, the higher vigour sauvignon blanc vines had more bunches per shoot, higher bunch weights, higher berry weights, and more shoots per vine. Therefore, no consistent relationship with yield and vigour could be determined. This underscores the benefit of block history in the implementation of yield forecasting systems.

One factor that was higher in higher vigour vines was an increased percentage bud break. While this increased the number of shoots per cane node, it did not translate into an increase in vine shoot counts (which might also have impacted yield). The reason for this was that the number of nodes per cane decreased with vigour, caused by increasing internode length while pruning to similar length canes.

While berry sugar concentration did not change in the Pinot noir trials, in the sauvignon blanc trials increasing vigour invariably led to a decreased Brix. However, the high vigour zone berries were also larger, and dividing the total soluble solids by the berry weight indicated that the sugar per berry showed no difference between the zones.

The juice pH and particularly the juice TA consistently rose in the highest vigour zones in all trials and in all years. Malic acid assessment of one of the Pinot noir blocks indicated that this was responsible for much of the rise in TA, which would explain the corresponding rise in pH. The sauvignon blanc vines however did not differ in malic acid levels, therefore some other factor was leading to the higher pH. Raised levels of potassium can have this effect, and, while leaf potassium levels did not appear raised, soil potassium levels were significantly

higher in the higher vigour zones in this trial. This may have led to increased berry potassium concentration.

Must was also assessed for yeast assimilable nitrogen levels, which did consistently showed an increase with increasing vigour. Must nitrogen levels tend to reflect the nitrogen available to the vine, and indeed there was a strong correlation between leaf nitrogen and vine nitrogen in the sauvignon blanc trial (leaf nitrogen was not assessed in the Pinot noir trial). YAN levels were also shown to have a major impact on the rate of fermentation. In these trials, all wines were able to ferment to dryness, even though the YAN levels of some low vigour panels was below the 140 mg/L level published as a minimum for healthy ferments.

Both berry and wine phenolic compound levels were altered by the vine vigour. Increasing vigour led to decreased phenolic compounds in the wines in all Pinot Noir trials, and also a decrease in berry extract tannins at the highest vigour level. In contrast to this, anthocyanin content did not change in any vigour zone. It did, however, change in terms of the level of anthocyanin ionization, which was much higher in lower vigour wines.

Wine colour density tended to drop as vigour increased, although this was not significant in all years. The higher phenolic component also led to a decrease in pigmented polymers as vigour increased, in all years, which would indicate that the colour of the lower vigour wines was more stable.

As noted above, the two Pinot Noir blocks examined showed different relationships between yield and vigour. This means that the effects of the vigour level on wine acids and phenolic content cannot be attributed to vine yield.

Pinot Noir wines were tested using Enose analysis, which discriminated between vigour zones. This was backed up by sensory analysis, where principle component analysis was able to clearly discriminate between the different vigour zones. In general, wines from the high vigour zone were characterised as having more earth, herbaceous and reductive characteristics, while wines from the lowest vigour zone had greater scores for dark fruit character, spice and overall fruitiness, as well as tannin quantity. The identity of reductive characteristics with the highest vigour zone wines is interesting, since low YAN has been associated with hydrogen sulfide build up in wines in the past, however these wines had the highest YAN of all zones.

The range of canopy characteristics that were measured in the course of the trial provided a data set that was used to help correlate the remote sensing images to actual vine canopy measures. A very strong correlation was found between the plant cell density (PCD) value and pruning weight (up to R^2=0.95), which was also found to be robust between different blocks. From this data, it is considered that the PCD maps may be used for estimating pruning weights across large areas of vineyard, as long as they are trellised similarly.

Therefore, it was seen that leaf health could be used as an indicator of vine vigour, which had a range of impacts on wine quality. This was potentially through canopy structural changes, but may have been related to other factors also.

Nitrogen fertilisation trials

The nitrogen trials that were established were useful in understanding more about the relative contributions to wine quality caused by leaf health, canopy and the underlying drivers of growth. They also provided information on how nitrogen nutrition impacted the leaf health over the course of the season, and how it altered berry chemistry. By adjusting the timing of application, leaf health and vine growth could, to a certain extent, be decoupled, to allow the identification of their relative importance.

This was evident in the first year of the project, when a trial to examine the relative impact from additional nitrogen and additional irrigation was established, at veraison. Nitrogen addition at this date was successful at delaying abscission of leaves, with green leaves maintained in the canopy for a longer period. While leaf health was improved, canopy growth was not altered, having effectively ceased by veraison.

The nitrogen rate by application date trial was established to examine, amongst other effects, the impact of nitrogen at different growth stages.

Nitrogen addition pre bloom in the first year of this trial led to a clear increase in overall vine growth, with more lateral shoot growth and increased pruning weight measurements. However, late season leaf health was not improved by this early addition, and late season leaf counts were no different to the control panels. Conversely, all additions made post bloom were able to improve the leaf retention, while not altering the overall vine growth to a significant degree.

The reaction to nitrogen timing in the second consecutive season of addition also indicated that pre bloom additions had less leaves later in the season than all other treatments that received nitrogen. However, the previous season's nitrogen additions caused an overall increase in vine nitrogen, so all treatments had better leaf retention than the controls. They also all had increased leaf chlorophyll content and pruning weights compared to the control vines.

All vines showed a similar pattern of chlorophyll distribution. It was higher in lower leaves early in the season, but as the season progressed leaves higher in the canopy became those with the highest estimated chlorophyll content. Nitrogen addition invariably led to an increase in chlorophyll content estimates.

An unexpected response to nitrogen addition was a late season build up of anthocyanin in leaves. This was higher with higher rates of nitrogen, confined to pre bloom nitrogen applications in the first season of the nitrogen rate by date trial, but common to all applications in the second season of this trial. Anthocyanin build up may be caused by nitrogen:carbon imbalances in the plant, produced either to shield photosynthetic cells from light when there is no effective method of using harvested energy, or as a way of using excess carbon compounds. While current science is still being debated on the function of anthocyanin, it is clear that it is indicative of a certain state of the vine's metabolism. A greater understanding of this may be useful in interpreting the phenomenon in other field scenarios.

The carryover effect from nitrogen in the preceding season was observed also in an increased percentage of buds burst, reflecting the result observed in the

vigour trial. This was observed in the second and subsequent years of all nitrogen application trials in the study.

No irrigation treatments affected bud burst, although increased irrigation had led to a reduced leaf loss early in the season. The magnitude of the improvement in leaf retention was equivalent to the impact from adding low rates of nitrogen. However, low rates of nitrogen were as effective as high rates at inducing bud burst in this trial, while irrigation did not increase bud burst percentage at all. This suggests the effects were not caused by the improved leaf health providing higher carbohydrate accumulation, but were more closely tied to the nitrogen itself. Cytokinins may be stored in plant tissue for release in spring, which may then impact bud burst. Since nitrogen can increase cytokinins, this may have influenced the bud burst on these vines.

Pre bloom shoot growth was increased by nitrogen added at any timing in the previous season. Leaf counts were higher, leading to higher average shoot Modified Eichorn Lohrenz scale (E-L) levels. An analysis of the increase in average growth stage indicated that this was primarily due to a wider range of growth stages of the shoots on vines with no nitrogen fertilisation, but a similar maximum E-L. Therefore, nitrogen was not accelerating vine growth, but it was leading to more shoots growing near to the maximum potential growth rate.

The impact of previous season's nitrogen application was also evident in flowering development, where higher rates of nitrogen led to more developed flowering at the time of monitoring. The exception to this was post veraison applications in the second season of growth, which appeared to have a similar level of capfall development as the control vines. The tissue analysis (see below) indicated these vines had the higher bloom time leaf nitrogen, therefore it is unlikely that this is linked to reduced tissue nitrogen.

Bloom time leaf lamina sampling showed that the later nitrogen additions led to more carryover to the following season. In fact the tissue nitrogen levels from the pre bloom additions the previous season did not have an impact on plant nitrogen 12 months later, although they had still prompted an increase in bud burst. They had also increased average shoot E-L stage, implying an increase in overall plant growth. Since plant nitrogen concentrations remained the same in pre bloom treatments as in the controls, the increase in growth would indicate greater total nitrogen content per vine.

Veraison laminae nitrogen contents showed that the current season nitrogen applications were now more important at influencing vine nitrogen content, although post veraison applications from the preceding season still led to an increase in vine nitrogen when compared to the control. They were also about the same as the pre bloom additions, even though these vines had received their nitrogen in the current season.

All nitrogen values at bloom and veraison were still below those listed in (Robinson, 1992) as being adequate for healthy vine growth.

The leaf lamina nitrogen contents were well correlated with leaf chlorophyll content estimates, with the strength of the correlation increasing when chlorophyll assessment date and leaf nutrient sampling date were close.

Point quadrat data confirmed that the increased growth and leaf retention was leading to an increase in canopy density. The nitrogen also increased leaf size. Light meter readings from the fruit zone showed that this was leading to less light reaching the interior of the canopy of nitrogen fertilised vines. This was expected because of the increase in leaf layers, but increased chlorophyll content was also shown to decrease transmission of light through a leaf, thereby increasing its ability to cause shade.

To summarise the canopy effects, nitrogen addition was able to recreate a number of the factors seen in the vigour trial, such as increased canopy density, pruning weight and leaf retention. However, timing of nitrogen addition was able to influence this to some degree, where earlier additions were able to stimulate growth, while later additions were better at improving leaf retention.

Fruit development

The nitrogen addition did not only impact the canopy, but the fruit development as well, although the impact was not consistent between seasons.

In the first season of the nitrogen date by rate trial, pre bloom additions significantly increased the percentage of berries that had commenced veraison at the sampling date. Nitrogen addition in the irrigation by nitrogen trial in 2005-06 also led to increased veraison development in 2006-07 at the time of assessment.

In 2007-08, there was no increase in veraison that could be attributed to nitrogen addition. Instead, the only impact of nitrogen timing was seen in a delay in veraison from the post bloom addition. This reflected a non-significant trend that had been apparent in the previous season. There are a number of reasons that this may have occurred, including an increase in cytokinin content resulting from the vine's reaction to nitrogen. Cytokinin application is known to delay veraison.

In 2006-07, the more developed veraison level of vines where nitrogen was applied pre bloom was reflected in juice chemistry at harvest, which had significantly higher sugar levels than all other treatments. Fruit from post bloom and pre veraison treatments also had a higher sugar concentration than the post veraison application and the control.

However, another reaction to the early nitrogen addition in 2006-07 was a greater number of berries being dislodged from their pedicels during ripening, and either falling to the ground, or being present as shrivelled berries in the bunch. Inclusion of higher numbers of shrivelled berries in the must may well have increased the sugar levels in the fruit of the pre bloom nitrogen treatment also. Veraison progression only reflects the vine history up until that time, while fruit sugars at harvest reflect the whole ripening period. Factors such as improved leaf health post veraison in the post bloom and pre veraison nitrogen timing treatments may also have improved their sugar levels.

Counts from the rachis taken from vines fertilised pre bloom and unfertilised vines showed that there were more pedicels per each branching of the rachis from the fertilised vines. This led to a greater number of pedicels per mm of rachis length. Since the nitrogen treatments were applied just prior to bloom,

flower number would not have been influenced by nitrogen. Therefore, this result implies that nitrogen was increasing fruit set.

Fruit set assessment in the following season did not show any differences, however there was also no increase in berry shrivel and fall as a result of nitrogen in this year. Fruit set has many potential influences, and this result indicates that nitrogen may have been a limiting factor in the first year, but other limitations were more important in the second season.

Yield components

Yield could be influenced by nitrogen application. Bud burst was increased in all years of the trial, and fruit set in the second, both factors that may increase yield. Average bunch weight was significantly higher comparing unfertilised to fertilised vines in 2006-07 (the same season as the increased fruit set). Although pre bloom addition had the highest average bunch weight of all dates, this was not statistically significant. Overall yield was also not altered by nitrogen application in this season of the date by rate trial.

Bunch weight was significantly increased by the 17 g N/vine in the irrigation by nitrogen trial in the 2006-07 season. Nonetheless, overall yield was not significantly different.

In the 2007-08 season the bunch weight was again higher in the 20 g N/vine treatment vines, although not significantly so. Bunch counts were significantly higher on this treatment, and the resulting harvested yield was also significantly higher at this treatment level. The control vines had a yield that was equivalent to 9.2 tonnes per hectare, compared to 11.0 tonnes per hectare for the 20 g N/vine. Berry weight did not vary in any treatment in any year, and nitrogen date did not appear to have any impact on yield components.

The highest levels of nitrogen did not maintain the same yields as the 20 g N/vine treatments. Excessive shading has been known to decrease bud fruitfulness, and the bunch counts from the 50 g N/vine were lower than the 20 g N/vine, although not significantly so.

The major cause of reduced yield in the 50 g N/vine treatments however, was fruit lost to botrytis. Bunches that had botrytis were not included in the total harvest weights, and in 2007-08 the level of botrytis rose with each increase in added nitrogen. This was particularly prevalent in the vines with pre bloom additions of nitrogen. It is not clear whether this is due to increased canopy densities, or higher nitrogen levels themselves.

Grape chemistry

As noted above, pre bloom applications of nitrogen in 2006-07, the first year of the date by rate trial, led to increased sugars at harvest, and there was a similar effect from nitrogen carried over from the irrigation by nitrogen trial in that season. The pH of the fruit was higher in the treatments with the higher sugar level in the irrigation by fertilisation trial also. However, although pH was higher, titratable acidity rose in the fruit from vines that received higher doses of nitrogen, reflecting what was seen in the vigour trials.

The rise in TA with increasing nitrogen was also seen in the date by rate trial. Not only did increasing rates of nitrogen lead to higher TA, but adding nitrogen

post bloom seemed to lead to the highest TA of any other timing. This was highly significant in 2006-07, but was not significantly higher than other treatments in 2007-08.

There were no significant differences in sugars at harvest in 2007-08.

Yeast assimilable nitrogen content was generally raised with increasing nitrogen applied. In the first year of the date by rate trial, pre bloom and post bloom applications had the highest YAN content, followed by pre veraison additions. Post veraison additions did not impact YAN at all.

In the second year of this trial, date made no difference to the YAN content of the fruit, but YAN did increase as the nitrogen rates increased.

An exception to this pattern was observed in the nitrogen by irrigation trial, where 17g N/vine depressed YAN levels, and 51g N/vine led to YAN's that were equivalent to the control level. It is postulated that the lower rate may have been enough to reduce the remobilisation of nitrogen that results from leaf senescence, but not enough to increase phloem nitrogen content itself. This would lead to less nitrogen being available for the fruit to use than may otherwise have existed.

Berry phenolics were assessed in one year of the trial, and showed very little difference in the date by rate trial. A further trial was examined where fruit from vines that received high rates of nitrogen or none at all was separated into exposed and shaded fruit. This found that unfertilised fruit had similar amounts of tannin on both internal and external bunches. Vines that had received nitrogen had similar phenolic levels on the internal fruit to that of the unfertilised vines, but the external fruit had substantially reduced tannin content.

Wine making and wine quality

Fermentation rates were shown to correlate well with the YAN levels in all trials. In the DAP versus field nitrogen trial, it was very clearly associated, and the timing of DAP additions could be clearly seen on fermentation curves. This reflects most other trials looking at YAN and fermentation in the ranges that were encountered in this study.

While rates did vary, all wines were able to ferment fully.

Somers analysis revealed that the highest rate of nitrogen added in the nitrogen by irrigation trial had led to wines with a greater total anthocyanin content, and increased colour density. Irrigation, however, had led to a decrease in colour density, phenolics and anthocyanin ionization.

The wines from first year of the date by rate trial appeared to vary mostly as a result of the increased maturity of the fruit from the pre bloom additions. These wines had a higher level of anthocyanin ionization and colour density than all other wines.

Wines from the fertilisation by exposure trial indicated that wines from external bunches had a higher level of anthocyanin than those made from internal bunches. Nitrogen addition led to wines with a higher hue value, indicating a greater degree of oxidation. The Somers phenolics measurements indicated that the internal fruit had a slightly lower phenolics content than external fruit, but

the major impact on tannins and phenolics being nitrogen. Nitrogen addition led to wines that showed significantly decreased Somers analysis and Dambergs analysis.

In the second season of the date by rate trial, when harvest sugars had been similar, no wines varied in their Somers analyses. Tannin content however did decrease with increasing nitrogen addition.

The tannin decreases observed here are similar in pattern to the tannin levels across the vigour zones. Both nitrogen and shading have previously been linked to phenolic compound content, and the results from the nitrogen by exposure trial indicate that there may be an interaction between the two factors.

The trial looking at field nitrogen versus DAP as a means to supplement YAN showed that field applications of nitrogen had very little impact on wine extractible components, compared to adding DAP. The treatment with the largest impact on wine spectral characteristics was DAP added pre inoculation. This led to an increase in anthocyanin ionization, as well as a (non-significant) increase in anthocyanins present. The result was wines with a significantly increased colour density compared to all other treatments. The reasons for this are unclear, but it may be due to an early increase in yeast biomass. This could increase the activity of yeast on releasing anthocyanins from their complexes, better allowing them to be available for wine colour formation.

Enose analysis of the wines from this trial indicated that there were significant sensory differences between the DAP supplemented wines and the field fertilised. There also appeared to be differences based on the DAP timing, however this was less clear. A sensory assessment of these wines did not reveal major differences. The factors clearly separated were 'forest floor', which was less in wines that received early DAP (either full or split), and 'sweet spice', which appeared to be higher in the control wines.

Conclusions

- Leaf health is linked to wine quality directly through increased shading and ability to photosynthesise sugars, and indirectly as an indicator of vine nutrient status and overall canopy growth.
- Nitrogen readily manipulated leaf health in this trial, indicating that it is the limiting factor for leaf health in the vines used this trial. This was consistent with the nitrogen analysis, indicating sup-optimal levels even when high rates of nitrogen were applied.
- As well as increasing leaf health, nitrogen increased overall vine growth. However, this is not always desirable, and adding nitrogen later in the growth cycle (pre or post veraison) led to improved leaf health, but minimal excess growth. Carryover effects reduced the impact of this to a certain degree.
- Many of the benefits to leaf health of nitrogen could be achieved by low rates (17 to 20 g N/vine), which further reduces the potential negative effect of excess growth associated with higher rates of nitrogen.
- Increasing nitrogen may increase botrytis risk, however this was not the sole cause of disease, since the highest vigour levels did not equal the highest botrytis levels.

- Pre bloom applications of nitrogen led to increased canopy growth but no improvement on late season leaf health, however was associated with increasing fruit sugar levels in one year of the trial. Adding nitrogen post bloom may lead to a delayed veraison.
- Nitrogen addition led to improved bud break, and potentially in one season improved fruit set. It may also have increased the vine fruitfulness when added at low levels.
- The effects of nitrogen addition were similar to the effect of increasing vigour, although the control that is available over timing of addition did lead to differences compared to a permanent soil-based driver of growth.

Tasmania may be considered a marginal climate for ripening grapes, as are most great Pinot noir producing regions. Therefore, small changes in growing season temperature and environmental conditions may have large impacts on the maturation of the fruit. Seasonal effects may explain why nitrogen addition in 2006-07 appeared to increase the progression of veraison and the accumulation of sugars into the fruit, however no increase in rate of ripening was observed as a result of nitrogen in the 2007-08 season. It may also explain the impact of nitrogen on fruit set in 2006-07 but not in 2007-08. A longer term trial would be required to further clarify this.

Appendix 1 – Communication

Wells, R (2008) Late Season Leaf health and Wine Quality. *Presentation to the WIT (Wine Industry Tasmania) Annual Field Day*, 21st November 2008, Swansea Town Hall

Wells, R. (2008) Correlation of Vineyard Imagery with Pinot Noir Yield and Vigour and Fruit and Wine Composition. *Presentation to a Remote Sensing Field Day*, 11th June 2008

Wells, R. (2008) Nitrogen Fertilisation and Pinot Noir Wine Quality. *Presentation to the TIAR Tamar Ridge Estates Field Day,* 23rd January 2008, Tamar Ridge Estates, Tasmania

Wells, R., Smart, R.E., and Wilson, S. (2007) Correlation of Vineyard Imagery with Pinot Noir Yield and Vigour and Fruit and Wine Composition. *Presented as part of the workshop "Using some new (and old) technologies to rationalise vineyard management and wine grape pricing". Australian Wine Industry Technical Conference*, 28th July to 2nd August, 2007, Adelaide, South Australia

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Wells, R., Wilson. S., and Smart, R.E. (2007) Investigation into the relationship of late-season Pinot Noir leaf health to grape and wine composition. *Proceedings of the Australian Wine Industry Technical Conference,* 28th July to 2nd August, 2007, Adelaide, South Australia, p. 360

Wells, R. (2007) Tamar Ridge Estates Vine Nutrition Program. *Presentation to the Vineyard of the Year Field Day*, 21st May 2007, Kayena, Tasmania

Wells, R., Smart, R.E., and Wilson, S. (2006) Grapevine Leaf Health Links to Wine Quality. *Presentation as part of TIAR 10th Anniversary Seminars,* 28th November, 2006, Newnham, Tasmania

Wells, R. (2006) Vigour and Wine Quality. *Presentation to the Tasmanian Farmers and Graziers Association*, 8th August, 2006 George Town, Tasmania

Wells, R. (2006) Impacts of Vine Health and Vigour on Grape and Wine Quality in a Cool Climate Viticultural Setting. *Presentation as part of TIAR/DPIWE Seminar Series* 19th May 2006

Appendix 2 – Intellectual Property

Nil

Appendix 3 - References

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Appendix 4 – Staff

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- Mrs Dorothy Humphery Vineyard Manager, Tamar Ridge Estates
- Dr Stephen Wilson Former PhD Supervisor

Appendix 5 – Budget reconciliation