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Australian Government

Grape and Wine Research and Development Corporation

VINE CARBOHYDRATE DYNAMICS AND SOURCE-SINK RELATIONSHIPS

Workshop held on 31 January 2006

at CSIRO Merbein, Victoria

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REPORT to

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Executive Summary

The workshop was convened to review what is known in the broad area of 'vine carbohydrate dynamics and source-sink relationships' and to identify the main gaps in knowledge for further research. Thirty eight participants attended, including two invited guest speakers from the United States. Eight topics were covered by 10 speakers and 'set the scene' for table group discussions. The table groups were asked to consider gaps in knowledge in each of the following areas (a) carbohydrate production (b) fruit initiation, flowering and fruit set (c) root development and cost (d) reserve dynamics and (e) fruit load and development. From the compiled reports of each of the table groups, several themes emerged. These are summarised as follows:-

Within season dynamics between C supply and C reserves. There is a need to quantify the sink demands for carbon, the feed forward and feedback signals, how much carbon is exported to a sink or lost from a sink (turnover) and in what form the carbohydrate exists.

Between season regulation of reserves and relationships with vine performance. This includes the need for whole of vine data on sink carbohydrate levels from one season to the next and assessing the relationship with key parameters of vegetative and reproductive development.

Stress and cultivar impacts. The impact of stresses on whole canopy gas exchange, plus genotype effects and canopy architecture effects.

Better Tools. Use of the latest instrumentation for whole canopy gas exchange, architecture (tomography), root system monitoring (mini-rhizotrons), to obtain data assisting better understanding of carbohydrate dynamics and the application of such data for validation of growth and development models and their use to integrate functional responses with climate.

Drivers and levels of root production. There is a need to better understand 'Below Ground Net Primary Production' (BNPP), specifically the drivers and levels of root production, respiration and distribution, including improved knowledge of root birth rates and death rates.

Carbon supply impacts on fruit initiation, flowering and fruit set. Requires multi-disciplinary, controlled environment studies with model vines to go beyond correlative data to understand function, separate the impact of environment and carbohydrate availability, and to determine the relative impact of C supply on bunch primordial initiation, flower formation, flowering and fruit set.

Links between carbohydrate and nitrogen reserves. Greater emphasis is needed on the link between carbohydrate and nitrogen reserves, their partitioning into various parts of the vine, variety differences, and the impact of size of trunk and main root classes.

Sugar ripeness versus flavour ripeness. What controls the upper limit of berry sugar per vine? Can we uncouple sugar ripeness from flavour ripeness?

The workshop concluded that these themes provide a foundation for determining future research directions and that with the knowledge obtained, the ability of vineyard managers to ensure stability and sustainability of vine performance will be greatly enhanced.

The workshop also concluded that significant benefits were potentially achievable by fostering international collaborations within the broad context of the identified themes.

In conclusion, it is clear that modern tools for monitoring carbohydrate production for the whole canopy or for single shoots with 1 or 2 bunches, the movement of carbohydrate to the sinks (fruit, shoots, wood, roots), the effect of reserves on bunch carbohydrate loading, and on root growth and root health, and the effect of stresses such as heat and soil water supply on bunch carbohydrate status in conjunction with the measurement of tannin or aroma compound evolution in the berries, deserves a focused research project; this should integrate basic carbohydrate research with modelling and quality measurements all the way to small batch wine production and sensory analysis. It is recommended that consideration be given to developing such an initiative.

Introduction

The performance of a grapevine is the net output of the interaction between genotype (rootstock and variety), the environment (climate, soil, water) and the vineyard management practices applied. Carbon assimilation by photosynthesis is central to vine growth and development as it supplies the carbon sources for each of the primary plant functions.

The four major sinks for carbon are shoots (leaves, petioles stems), the extended woody trunk, roots and developing fruit. Due to the perennial nature of the grapevine, it stores surplus carbon in sinks in order to facilitate survival during difficult times e.g. stresses, and to assist early season vine growth in the following season until carbon supply from mature leaves can sustain the vine.

Water and nutrient acquisition by roots is also central to vine growth and development and limitations in either will feed forward to limit carbon assimilation and growth.

Increasingly in Australia, for wine grape production, water deficits are applied particularly in the period between fruit set and veraison, to control vigour and enhance berry composition (1). Despite the availability of numerous soil moisture and other water status monitoring devices, the application of water deficits may not always be consistent from one season to the next as this will be influenced by environment, in particular by rainfall and evaporative demand (2), and by influences of management practice on soil water status (3). The responses of the vine will also be influenced by genotype and other factors (4).

Added to this is the increasing prevalence of one-off events, such as heat waves, periods of drought and consequent restrictions on water availability and potential increases in irrigation water and soil salinity, in combination with diminished root systems under drip irrigation and the need for increased fruit loads to ensure financial viability in the current environment of decreasing grape prices.

We still do not know enough about the role of carbohydrate dynamics under normal conditions let alone under the increasingly more frequent climatic extremes and increased application of resource use efficient and cost effective management practices that are now employed.

Because 'vine carbohydrate dynamics and source-sink relationships' are key issues for sustainable vine performance (5), a workshop was convened to consider what is known within this broad area and to identify the main gaps in knowledge for further research.

References

(1) Kriedemann, P.E. and Goodwin, I. (2003). Regulated deficit irrigation and partial rootzone drying: An overview of principles and applications. Irrigation Insights No 3, Land and Water Australia, Canberra ACT, Australia.

(2) McCarthy, M.G. (1997). The efeect of transient water deficit on berry development of cv. Shiraz *(Vitis vinifera* L.). Australian Journal of Grape and Wine Research 3, 102-108.

(3) Ingels, C.A., Bugg, R.L., McGourty, G.T. and Christensen, L.P. (1998). Cover cropping in vineyards: A growers handbook. University of California, Division of Agriculture and Natural Resources Publication 3338.

(4) Schultz, H.R. (1997) Water relations and photosynthetic responses of two grapevine cultivars of different geographical origin during water stress. Acta Horticulturae 427, 251-266.

(5) Williams, L.E. (1996) Grape. In Photoassimilate distribution in plants and crops: source-sink relationships Eds. E. Zamski and A.R. Schaffer, Marcell Dekker, New York, USA.

Workshop Structure

Funding for the workshop was provided by the Grape and Wine Research and Development Corporation.

The day was opened by Dr. Jim Fortune from GWRDC, convened by Dr. Rob Walker, CSIRO Plant Industry, and facilitated by Dr. Erika Winter of GrapeLinks (**Program see Appendix II**).

The workshop presentations in the morning and early afternoon (**Abstracts see Appendix I**) covered a wide range of topics relevant for the field:

- "VitiSim" – A simplified carbon balance model of a grapevine - A. Lakso
- Carbohydrate reserves and vine productivity – J. Smith, S. Field and B. Holzapfel
- Water stress and carbohydrate partitioning – N. Cooley
- Pruning, rootstock and seasonal impacts on vine carbohydrate status- P. Clingeleffer
- Some effects of crop load and canopy management on bud fertility, inflorescence size and carbohydrate storage – G. Dunn
- Grapevine root dynamics - D. Eissenstat
- From sprinklers to drippers – impacts on grapevine root architecture – C. Soar
- Grapevine root hydraulics: links between root and canopy function - S. Tyerman

In the afternoon five table groups were formed and reported on their results in the plenary session (**see Table Group Summaries below**).

Thirty eight workshop participants (**Appendix III**) were drawn from a broad cross-section of the scientific community and from the wine industry and included two invited participants from the United States, Professor Alan Lakso, Cornell University, and Professor David Eissenstat, Pennsylvania State University.

While in Australia, Professor Lakso visited Wagga Wagga for discussions with staff of the National Wine and Grape Industry Centre, including the presentation of a seminar, and Professor Lakso and Professor Eissenstat visited Adelaide for discussions with staff of the Wine Innovation Cluster and presentation of seminars. A schedule for their visit is attached (**Appendix IV**).

Objectives

The workshop objectives were to:

- **develop a shared understanding of the current state of knowledge** in the broad area of 'vine carbohydrate dynamics and source-sink relationships',
- **identify gaps in knowledge**,
- **propose fields for further research.**

Session Summations

Session I

Models are all imperfect but some are useful, in particular if they deal with essential mechanisms and realistic assumptions. Many models involving carbohydrate dynamics have the aim of integrating carbon assimilation, requirements of carbon in growth and respiration, and carbon demands of the developing crop. However, the sustainability of vine performance from year to year is often neglected. We have a good understanding of photosynthesis, canopy characteristics and light interception but not of reserves and their inter-relationships with crop growth, shoot growth, root and wood growth and respiratory requirements of these organs and tissues throughout a season. Comparison of results from some carbon balance models with actual vine growth and development data have been promising. More work is needed, in particular for roots.

In warm regions of Australia there is almost a 3 month window of opportunity after harvest to replenish reserves. The longer this period and for canopies in good condition the higher the potential crop levels. The effect of this period on nutrient balance and the interaction of nitrogen with carbon balance is also of interest.

Our knowledge of the relationship between carbon reserves and reproductive development is limited. However, with an improved understanding a test for reserve levels could be developed and could lead to targeted vigour and yield management, provided we know varietal and rootstock effects.

Warm roots move more starch to the shoot and trunk, and result in lower leaf stomatal conductance. Lower root dry matter in warmer locations is commensurate with changed hormonal signals. There is a fast response for carbon export to changing root temperatures. Current measurements are too static. Pulse chase studies may improve our knowledge of this area.

Under water stress via prolonged deficit irrigation leaf starch concentration was lower at most times of the day and trunk starch concentration was shown to be decreased in 2 out of 3

seasons. The correlation between carbohydrate production, transformation to starch and the utilization of starch reserves must be dis-entangled if we are to better understand seasonal variations. Berry sugar concentrations were more affected by seasonal effects than by within season water stress treatments.

Pruning decreases vine size and capacity and results in a loss of carbohydrate reserves (10% for spur pruning). The further a node is away from the trunk the less carbon is stored. Cane pruning devigourates a vine due to the removal of carbon reserves with 1 and 2 year old wood. Does the relationship between mass and storage capacity have a 'tip over' point? Does the diameter of scion wood correlate with yield potential (provided there is no bottleneck between rootstock and scion)? Carbohydrate removed as crop is 2-3 times more than carbohydrate stored. On the basis of trunk carbohydrate concentrations, there is little evidence that carbohydrate reserves are limiting performance. With minimal pruning, a significant proportion of buds do not burst, with some bud death occurring, but it is not known whether this is due to deficiencies in bud development e.g. inadequate periderm development or inadequate carbohydrate supply or both. Increased severity of pruning can stimulate branching of inflorescences during budburst leading to higher flower number per inflorescence.

What is a stressed vine and what is the relativity of the within season effects versus the between season effects? What is a balanced vine? Leaf area to fruit weight is an indicator, but what about the level of reserves in key tissues? What is the carryover effect of reserve levels into the next season? When is a vine in homoeostasis? What crop load can be sustainably produced? Photosynthesis can adapt to sink strength but is a vine ever sink- limited? How does sink strength vary over the season in different plant parts? Is there self-regulation like that seen with bud death in minimally pruned vines? Long term self regulation via fertility – is there a self regulation with respect to carbon balance? Should we take fruit off un-harvested vineyards for carbohydrate balance reasons or leave the crop on (vine health and pruning issues are potential concern).

Session II

Vine roots have rarely been studied in detail. Mini-rhizotrons have elucidated the secret life of roots and the seasonal patterns of their activity, being highest between bloom and veraison. Above ground management practices like pruning and high photosynthetic capability (with implications for crop load) had less effect on root growth than soil moisture. Roots live about 100 days; in the first 4 days they absorb much N but slow down and turn brown after 40 days, when respiration drops; the respiration cost of roots may determine their lifespan. It is of great advantage in changing water availability to have many brown mother roots from where small white roots can be quickly generated. In dry soils vines can increase root production in upper soil levels from such mother roots following irrigation. At what temperature do the roots die? Can new growth be driven from reserves? What is the trigger?

Drip irrigation creates pear shaped root architecture with high density at 10-35 cm^3 depth around drippers, whereby distribution is concentrated in the vine row, but with roots also extending into the mid-row area. However root density at increasing depth is affected by soil variability. Vines can draw water from adjacent rows if there is a blocked dripper, this shows horizontal flexibility in response to water supply. What is the effect of different deficit

irrigations on the carbohydrate storage of roots and supply of a vine? Should we devigourate vines via water stress after veraison (a recommendation that followed from times of furrow irrigation)?

We know root to shoot signals via ABA, cytokinins, sap pH but shoots also communicate with roots, to down-regulate water uptake in response to decreased need eg after shoot topping or leaf darkness. This response is fast and acts on aquaporins (proteinaceous water pores) which mediate the root’s hydraulic resistance. The signal travels in the phloem and may have large implications on root reserve status as well as their activity in water uptake. We have much to learn with respect to root-shoot signalling.

Table Group Summaries of 'Knowledge Gaps'

1. Carbohydrate Production

- Insufficient knowledge of sink demands for carbon and the respiratory requirements of the sinks; what are the feed forward and feedback signals?
- Carry-over effects of the level of carbon reserves on plant function from season to season are not well characterized.
- Much of our knowledge is based on single leaves; we do not have adequate knowledge of the scaling effect from single leaves to the whole canopy, especially under stress conditions.
- We have limited knowledge of the impact of weather extremes, in particular, of temperature (e.g. heat stress) and vapour pressure deficit.
- We have limited information on the physiological recovery of single leaves following water deficits; what is the response of exposed versus shaded leaves?
- What is the impact of cultivar and stresses on whole canopy gas exchange?

Priorities

- Whole canopy gas exchange studies and use of the data to validate models
- Comparison of stressed and unstressed situations
- Cultivar effects.

2. Fruit initiation, flowering and fruit set

- It was noted that there are four distinct processes:
  - Initiation of bunch primordia
  - Flower formation
  - Flowering
  - Fruit Set
  - And that the impact of carbon supply is potentially least at initiation of bunch primordia and highest at fruit set. Confirmation is required.

- Our knowledge of the dynamics between carbon supply and reserves is poor; moreover, we cannot simply look at carbohydrates in isolation of other factors such as nutrition and hormones.

- Much of our existing knowledge is based on correlative data; we need to go further and identify the physiological causes behind the specific responses.

- Some of the available data is from what we might call 'extreme' experimental treatments; we should not lose sight of the responses that occur in what we might call 'normal' management treatments.

- Overall, we have insufficient knowledge of the role of carbohydrates in the chain of reproductive processes from bunch primordia initiation to first set. There is a need to integrate and interpolate; modelling can assist this process.

Priorities

- Understanding the role of carbohydrates in the key physiological processes from bunch primordia initiation to fruit set is most important.

- Notwithstanding the limitations of model vine studies e.g the inabilibty to assess old wood as a sink for reserves, controlled environment studies should be conducted (with model vines) to understand the processes involved; this will enable the impact of environment and carbohydrate availability to be separated. A collaborative approach involving molecular scientists, whole plant physiologists and modellers would be a pre-requisite to allow the transfer knowledge back to studies with the grapevine.

3. Root development and cost

- The regulation of 'Below Ground Net Primary Production and respiration' (BNPPR) is poorly understood. Specifically, our knowledge of the drivers and levels of root production and root respiration is limited.

- What are the consequences of stresses e.g. high temperature and water deficits on root production and respiration? What shoot-root signaling processes are initiated and what are the recovery times?

- Our knowledge of grapevine root development and distribution patterns is also limited. Research needs to be expanded to cover a wider range of irrigation systems and schedules, soil types, genotypes etc. Mini-rhizotrons should be used to study root morphology, root 'birth' rates and 'death' rates etc.

- Methodology for quantifying the level of first, second and third order roots should be investigated. For example, it may be possible to develop molecular probes specific to each root type.

Priorities

- The order of priority is dot points 1, 2 and then 3 above.

- Consideration should be given to developing an intensively instrumented site with appropriate above and below ground instrumentation.

4. Reserve dynamics

- The grapevine carbohydrate pool is influenced more by vine size than the concentration of carbohydrate in any one part of the vine. Because the carbohydrate pools are dynamic, our knowledge of how much is going in relative to going out and in what form the carbohydrate exists is limited. We need better measures of carbohydrate turnover. We also need to be cautious of looking at carbohydrates in isolation of other key reserve components, in particular nitrogen.

- We are lacking in data on whole vine carbohydrate reserves and the location of such reserves within the vine during the course of a season and also the season to season effects, which appear to be significant but poorly understood. We need better tools to study the dynamics of carbohydrates in specific plant parts. Is there a winter value (based on vine size and carbohydrate concentration in e.g. the trunk) that might be used as an indicator of cropping potential? This research could be linked with routine winter bud dissections for fruitfulness estimates. Improved tools are required for the study of source-sink interactions and respiration in wood and roots.

- Most studies have tended to focus on either carbohydrate or nitrogen reserves. More research is needed on the link between carbohydrate and nitrogen reserves, in particular the partitioning of such reserves into various parts of the vine, variety differences and the impact of size of the trunk and classes of roots.

Priorities

➢ The order of priority is dot prints 1, 2 and 3 above.

- Almost all studies on vine carbohydrate reserves to date have been only correlation studies with normal conditions or with strong treatments that give responses equally validly related to potential reductions in root growth, nitrogen reserves, bud development etc. There is a need for attempts to more directly affect reserves e.g. through CO_2 enrichment studies or through identification of mutants with altered reserve characteristics.

5. Fruit load and development

Productivity per unit area is a key factor, along with grape composition, in vine performance. However, this output represents the net integration of numerous factors, hence the efforts by modellers to link them together and to understand which are the most important drivers. While we have developed an improved understanding, there is still much that we don't know. Key gaps in knowledge with respect to productivity per unit area are:

Genotype: what are the genetic factors that determine differences between varieties with respect to productivity per unit area? What determines the upper limit for a variety? What are sustainable high yields? What is the required yield for optimum quality? What form of low input crop control is feasible?

Climate: while we have a good basic understanding of climatic impacts e.g. warm versus cool climate physiology, we have a poor understanding of the impact of transient stresses, especially heat, within a season. Is heat stress early in the season more damaging than later in the season? Do we fully understand the consequences of combinations of stress e.g. heat plus water deficit? What are the consequences with respect to photosynthesis, the plants ability to utilize stored reserves, fruitfulness etc. How can we better understand this without good climate data and models that integrate weather with other key factors? Such information is crucial if we wish to fully understand the potential impacts of climate change.

Canopy architecture: much of our knowledge is based on observations of single leaves, yet a canopy consists of leaves of different sun exposures and shading, transient and long term, and different leaf ages and health. We lack information on whole canopy performance that is fully linked with the changes that occur within the rest of the vine e.g. impacts on root growth and reserves.

Sugar ripeness versus flavour ripeness: In general, we do not have a good understanding of these important fruit development characteristics. In some seasons, they appear to be linked, in other seasons it is clear sugar ripeness occurs at a different time to flavour ripeness. While crop load, variety and vine health are obvious influencing factors, what other factors influence sugar loading and final concentration? A better understanding of these factors is required before we can seriously look at uncoupling sugar ripeness from flavour ripeness.

Priorities

- Develop better tools for studying whole of vine carbohydrate dynamics. This should include whole canopy gas exchange studies, changes in sink size and carbon partitioning to the sinks, spatially and temporally.

- Integrate use of vine tomography to better characterize vine architecture and relative sink sizes.

- Link whole of vine studies with attempts to better characterize upper limits for quality in terms of yield-quality relationships.

- Develop simple tools.

Summary of table group discussions

Carbohydrate Production	Fruit Initiation, Flowering and Fruit set	Root Development and Cost	Reserve Dynamics	Fruit Load and Fruit Development
●Sink demands for C, what are the feed forward and feed back signals? ●Regulation of reserve carry-over from season to season. ●Stress impacts on whole canopy gas exchange and time to recovery. ●Cultivar differences and their stress responses. ●Use of whole canopy and whole of vine data to validate models.	●Relative impact of C supply on bunch primordia initiation, flower formation, flowering and fruit set. ●Limited knowledge of dynamics between C supply and reserves. ●Avoid looking at carbohydrates in isolation of other factors. ●Go beyond correlative data to understand function. ●Need for multi-disciplinary, controlled environment studies with a model plant. ●Include modelling to integrate function and responses with climate.	●Better understanding needed of 'Below Ground Net Primary Production'; drivers and levels of root production and respiration. ●Stress impacts e.g. heat on root production and respiration; shoot-root signaling processes and recovery times. ●Limited knowledge of root development and distribution patterns; root birth rates, death rates etc. ●Intensively instrumented site, with above and below ground instrumentation.	●Carbohydrate turnover; limited knowledge of how much is exported to a sink, lost from a sink and in what form the carbohydrate exists. ●Lack data on whole vine carbohydrate reserves, during a season and from season to season. ● Improved tools needed for monitoring changes in reserve dynamics. ●More emphasis needed on the link between carbohydrate and nitrogen reserves, their partitioning into various parts of the vine, variety differences, and impact of the size of trunk and main root classes.	●Productivity per unit area, an output representing the net integration of numerous factors. More information is needed on genotype effects, stress effects, climate impacts and canopy architecture effects. ●Sugar ripeness versus flavour ripeness; what controls the upper limit of berry sugar per variety? Can we uncouple sugar ripeness from flavour ripeness. ●Better tools needed. Whole canopy gas exchange and whole of vine systems. Application of vine tomography.

●- Within season dynamics between C supply and C reserves
● - Between season regulation of reserves and relationships with vine performance
● - Stress and cultivar impacts
● - Better tools
● - Carbon supply impacts on fruit initiation, flowering and fruit set
● - Drivers and levels of root production

● - Links between carbohydrate and nitrogen reserves
● - Sugar ripeness versus flavour ripeness

Ref: Users on 'Sultana-mb'/WAL350/Forums, seminars, workshops/Vine carbohydrate dynamics & source-sink relationships January 2006.

Recommendations for future research and possible outcomes for Australian viticulture

Sustainable viticulture requires **perennial stability** in our production systems.

1. **Carbohydrate reserves** play a role in perennial stability. Carbohydrate dynamics are currently under- investigated.
   - Their production may be enhanced by viticultural practice.
   - Their utilization in times of adverse seasonal conditions or by poorly executed management practice needs to be known to be counteracted by appropriate management practice.
   - The timing, amount and location of their deposit for use in the current and subsequent seasons should be investigated as a possible indicator to predict vigour and yield.

2. The links between **water availability and carbohydrate dynamics** have not been fully elucidated.
   - Water use efficient irrigation practices that ensure perennial stability irrespective of climate events must be determined and extended.
   - Root health and effectiveness must be secured under irrigation practice

3. The links between **carbohydrate reserves and nitrogen reserves** are not well known.
   - These links can be manipulated by fertilizer and water management
   - These links may play a role in fruit quality (nitrogen related fruit and wine quality)

4. The frequently cited need for an **uncoupling of carbohydrate deposition into fruit from the formation of aroma and flavour compounds** is a worthy goal, but the main obstacle is our poor understanding of the factors and potential linkages.
   - Knowing what drives the slow down or changes in carbohydrate loading of fruit around ripening would be of great merit for balanced wine production.
   - Varietal and climatic differences must be elaborated and tested.

The challenge will be to produce a minimum dataset for a model which can simulate management practices that ensure carbohydrate balance in vines during various climatic events of a season and ensuring perennial stability.

Interestingly, most Industry Representatives chose the tablegroup "Fruit load and fruit development". The best accepted test for a model on carbohydrate dynamics would thus include Point 4 from above.

In conclusion, it is clear that modern tools for monitoring carbohydrate production for the whole canopy or for single shoots with 1 or 2 bunches, the movement of carbohydrate to the sinks (fruit, shoots, wood, roots), the effect of reserves on bunch carbohydrate loading,

and on root growth and root health, and the effect of stresses such as heat and soil water supply on bunch carbohydrate status in conjunction with the measurement of tannin or aroma compound evolution in the berries, deserves a focused research project; this should integrate basic carbohydrate research with modelling and quality measurements all the way to small batch wine production and sensory analysis. It is recommended that consideration be given to developing such an initiative.

Appendix I : Abstracts of presented papers

As submitted by the speakers

"VitiSim" – A simplified carbon balance model of a grapevine

Alan Lakso[1] and Stefano Poni[2]

[1]Cornell University, NY State Agricultural Experiment Station, Geneva, NY 14456, USA; [2] Istituto di Frutti-Viticultura, Universita` Cattolica del Sacro Cuore, 29100 Piacenza, Italy.

As grape production systems evolve and require refined management for highest quality, there is a need to be able to compare and understand the performance of these systems and to compare performance across the variations of yearly weather and different climates. A key parameter to express vine balance is "crop load", an expression that normally implies the carbohydrate supply/demand balance. Growth analyses by excavating vines are very difficult to do on cropping vines in the field. So, a general carbon balance model, developed initially for apple trees, was adapted for grapevines using an auto-programming software, STELLA®, that requires few programming skills. The model uses a daily time step to simulate seasonal leaf area development, canopy light interception, canopy photosynthesis, canopy respiration, and dry matter accumulation. The initial results for comparison of the model simulations to measurements of seasonal gas exchange and to growth analyses have been encouraging. Comparisons of seasonal root development patterns in Concord vines to simulated patterns of carbon availability to the roots suggest that in NY conditions, the great majority of new root production occurs between bloom and veraison. Future efforts will focus on incorporating and modeling interactions of canopy form and radiation, root system requirements, carbon reserves, carbon partitioning priorities, and environmental or pest stress effects.

Carbohydrate reserves and vine productivity

Jason Smith, Stewart Field and **Bruno Holzapfel**.

National Wine and Grape Industry Centre (NWGIC), Locked Bag 588, Wagga Wagga, New South Wales 2678.

Background.
Stored carbohydrates play an essential role in supporting canopy growth in spring until sufficient leaf area is attained to meet carbon demands from photosynthesis. It has also been demonstrated that reserves can be used later in the season to assist with fruit ripening if the supply from photosynthesis is insufficient. However, the replenishment of reserves can in turn be modified by crop load, photosynthetic capacity or any environmental or management factor that influences whole vine carbon balance or seasonal capacity for carbon assimilation. The objective of this presentation, which has been drawn together from several different research projects, is to provide examples of some of the factors that influence carbohydrate reserve accumulation. The relationship between carbohydrate reserves and reproductive development, and the use of a reserve test as an indicator of yield potential in the following season, will also be discussed. An important question that remains to be answered is whether the carbohydrate reserve status of the vine has a direct controlling influence over vine productivity.

Post-harvest and for reserve accumulation and vine productivity.
In the warmer irrigated grape growing regions of Australia vines may retain a functional canopy for up three months after harvest. It often assumed that this post-harvest period is important for maintaining vine productivity by allowing time for replenishment of carbohydrate reserves, renewed root growth, and nutrient uptake before leaf-fall. In a study conducted in four Semillon vineyards in the Riverina and Hilltops regions of NSW, early harvest and post-harvest defoliation treatments were used to alter the length and effectiveness of the post-harvest period over two consecutive growing seasons. Complete defoliation (100%) at harvest caused a significant reduction in root and wood starch concentrations at all sites when determined at leaf-fall after two seasons of treatment. Partial defoliation (50%) reduced wood starch concentrations at both of the Riverina sites, but to a lesser degree than after complete defoliation. Harvesting the fruit four to six weeks prior to commercial harvest significantly increased starch reserves in the roots and wood. Across all sites, treatments induced a range of starch concentrations of 4.3-11.6%DW for wood tissue and 7.2-33.4%DW for the roots. The treatments generally had the opposite effect on soluble sugar concentrations, and for the wood in particular, induced large changes in the starch:soluble ratio. In the third season of the study, where more detailed measurements of reproductive development were made, yield was significantly increased by the previous early harvesting treatment, and reduced

by the complete defoliation treatment. The partial defoliation treatment, which was intended to simulate the effects of severe machine harvester damage, had minimal effect on yield. At the Riverina sites where the treatments effects were largest, about 60-70% of the variation in yield was attributed to differences in bunch weight. The differences in bunch weight were in turn attributed largely to inflorescence flower numbers, which were increased by the early harvest treatment and decreased by complete defoliation. Bunch numbers were also reduced by complete defoliation and increased by early harvest, suggesting that one season of post-harvest treatment was sufficient in alter bunch initiation. However, initiation in the third year of the study (which followed two seasons of post-harvest treatments) did not differ significantly between treatments. A possible explanation for differing fruitfulness response to one or two seasons of post-harvest treatment is that any direct effects on initiation were progressively offset by treatment effects on shoot growth and canopy development. The differences in yield induced by the post-harvest treatment also altered carbohydrate reserve accumulation in the third year of the study, with the high yielding early harvest treatment having the lowest reserves at harvest, and the low yielding complete defoliation treatment having the highest reserves. These results demonstrate the dynamic nature of the relationship between yield and the accumulation of carbohydrate reserves, but also its complexity when interactions between the two (such as bunch initiation) may span two or more seasons. With respect carbohydrate reserves and vine productivity, the differences observed between the Riverina and Hilltops sites suggests that post-harvest period becomes increasingly important for reserve accumulation as cropping levels increase, and that this in turn is one of the reason vines in warmer climates can carry heavy crop loads year after year. However, it was also apparent that the treatments also influenced nutrient uptake and the growth of the perennial parts of the vine. These are issues that need further consideration in relation to interactions with carbon availability, and the relative importance of carbohydrate and nutrient reserves for vine productivity.

Variability in reserve accumulation and use as indicator of vine yield potential.
The previous study with Semillon demonstrated that post-harvest vine management can alter both carbohydrate reserve accumulation and vine productivity in the following season. If the amount of carbohydrate reserves stored by the vine at leaf-fall does have a direct influence vegetative growth and reproductive development in the following season, then deliberate manipulation of reserve accumulation may provide an alternative method of vigour and yield management. Testing of reserve levels may also improve our capacity to meet crop load targets. To provide more information on how management, variety and climatic conditions influence carbohydrate reserve accumulation, and also what the typical range of reserve concentrations might be expected, a survey of 34 commercial Shiraz and Chardonnay vineyards was undertaken just prior to pruning in 2005. Starch concentrations ranged from 9.1-41.4, 3.4-11.7, and 4.7-9.6 %DW for the roots, wood (combined cordon/trunk sample) and spurs respectively. This vineyard-vineyard variation in starch concentrations is of approximately the same magnitude as the differences induced by the post-harvest treatments imposed on Semillon in the

earlier study. Preliminary results show that average starch concentrations at leaf-fall are similar in cool, warm and hot-climate vineyards. In the Hilltops region, where a number of drip/rainfall dependant vineyards experienced several consecutive years of water stress, average root starch concentrations were lower. However, drip irrigated vineyards with reliable water supply did not differ from furrow irrigated vineyards. Information from growers is currently being compiled to determine if factors such as crop load or harvest date may explain more of the observed variability in reserve concentrations. To test the potential for a carbohydrate test to be used in conjunction with bud-dissections as tool for crop load forecasting and regulation, bud-fruitfulness assessments were made on the first four nodes of 20 canes from all survey sites. Retained bunch numbers were then calculated from counts of retained buds in spring, and were found to strongly correlate with actual bunch numbers ($r=0.90$). We are currently looking at the extent to the reserve status of the vine may explain differences between predicted and actual bunch numbers. However, based on the positive correlation between leaf-fall reserves and bunch weight that was observed in the earlier Semillon project, we are particularly interested to determine if reserve levels can be used to refine bunch weight estimates. Bunch weight measurements will be made prior to harvest this year, and repeated for an additional season, to determine if any relationship exists between reserves and bunch weight at the 34 survey sites.

Rootstock effects on biomass partitioning and reserve accumulation.

The growth and biomass accumulation of Shiraz grapevines grafted on Shiraz, Ramsey, Ru140, Schwarzmann, 101-14, 5BB, and 420A was measured for three years following grafting. Vines in each graft combination were grown either under full irrigation, or a reduced irrigation treatment imposed between fruit-set and leaf-fall in the second and third year of the study. Total biomass production during the three years was reduced by the water stress treatment, but was not influenced by rootstock within irrigation treatment. For the first two years, when the vines were grown without fruit, water stress did not change the allocation of biomass between the root system and shoot. However, the presence of fruit, which was retained in the third year, strongly influenced the allocation of biomass between root system and shoot. Ramsey induced the highest yield (819g) in the Shiraz scion, but fruit growth and sugar accumulation was at the expense of root growth and carbohydrate reserve accumulation. Under reduced irrigation, the combination of reduced carbon assimilation and high crop load was sufficient to prevent any new accumulation of root dry matter. In contrast, Ru140 induced the lowest yields (462g), and was able to continue the accumulation of root dry matter under both irrigation regimes. The findings suggest that maturing fruit has a high priority for assimilated carbon, followed by the shoot and root system. However, when grown in a vegetative state, root and shoot growth appeared to have equal priority. The apparently lower priority of root growth for assimilated carbon in fruiting vines than shoot growth may be therefore be related to differences in active growth periods, with shoot biomass largely established before the start of fruit maturation.

Root-temperature effects on vine development, reserve utilization and cytokinin production.

Shiraz vines were exposed to two different root-zone temperatures (13 and 23^{o}C) to evaluate the effects of soil temperature on vegetative growth and reproductive development in the period between bud-break and veraison. In two additional treatments, root-zone temperatures were changed from cool to warm or warm to cool at flowering. Soil temperature did not have a significant effect of the time of bud-break, or the number of flowers per inflorescence. There was also no significant effect on fruit-set for vines maintained at constant warm or cool soil temperatures since bud-break, or for those with the soil temperatures changed at flowering. Shoot and trunk dry weights (DW) of vines grown at a warm root temperature were significantly higher at flowering compared to vines at a cooler root temperature. However, total biomass gain to flowering was similar for both treatments, with the higher shoot weights of the warm temperature treatment offset by a greater reduction in root dry matter than for the cool treatment. In bleeding sap collected at bud-break, the cytokinins *trans*-zeatin riboside (t-ZR), isopentenyl adenosine (iPA) and isopentenyl adenine (iP) were present in approximately equal concentrations. Lower concentrations of dihydrozeatin (DZ), *trans*-zeatin (*t*-Z) and the nucleotides of DZ, iP and *t*-Z were also present. In xylem sap collected at flowering, fruit-set and veraison *t*-ZR was the predominant cytokinin. With the exception of the nucleotide forms, which were not detected at flowering, all other cytokinins identified in bleeding sap at bud-break were present but at reduced concentrations. The effect of soil temperature on both qualitative and quantitative differences in cytokinin production by the roots will be discussed in the presentation.

Water stress and carbohydrate partitioning

Nicola Cooley[1,2,3], Peter Clingeleffer[2,3] and Rob Walker[2,3]

[1]Land & Food Resources, Univesity of Melbourne, Vic. [2]Cooperative Research Centre for Viticulture, SA. [3]CSIRO (Plant Industry), Merbein, Vic.

The effects of deficit irrigation treatments on Cabernet Sauvignon grapevines were investigated in a warm climate region. A standard irrigation practice (STD) was compared to a regulated deficit irrigation (RDI) and a prolonged deficit irrigation treatment (PD). The first stage of the PD treatment water stress was identical to the RDI stress period. The second stage was a period of extreme deficit (no water) after the RDI stress period until veraison.

During the extreme deficit period on a warm day, water potential measurements were taken throughout the day and leaves were collected for starch concentration. Leaf water potential becomes more negative throughout the day. Water potential for the PD treatment by 11:00 am was below -1.0 MPa and remained at this level until 5:00 pm. Water potential for the PD treatment was significantly more negative than the STD treatment. Significant reductions in assimilation rate, stomatal conductance and transpiration rate were found with the PD treatment compared to the STD treatment throughout the day. Leaf starch concentration doubled from pre-dawn measurements to early evening. The PD treatment vines had significantly lower leaf starch concentration at most time points throughout the day.

Trunk carbohydrates were measured at significant phenological periods over three seasons. Significant seasonal variation was found with all carbohydrates measured (starch, sucrose, glucose and fructose). Starch concentrations found in the PD treatment were significantly lower than starch concentrations in the STD treatment in season 2003 and 2004 during the PD stress period, whereas there were no significant differences during season 2005. Sucrose was significantly lower in the PD treatment during the water stress (season 2003) period compared to the control. The opposite response occurred during season 2005. No differences were found during season 2004. Variation in total soluble solids (TSS) was found with each season. Deficit irrigation can result in increases to TSS but not in all seasons. A serve deficit can reduce TSS accumulation (not in all seasons). Seasonal impacts are greater than water stress on berry sugar reserves.

Pruning, rootstock and seasonal impacts on vine carbohydrate status

Peter Clingeleffer and Anne Pellegrino

Cooperative Research Centre for Viticulture, PO Box 154, Glen Osmond, South Australia, 5064; CSIRO Plant Industry, PO Box 350, Glen Osmond, South Australia, 5064.

Studies reported demonstrate that the status of carbohydrate reserves (ie. Reducing sugars, sucrose and starch) of grapevines grown under warm irrigated conditions is largely a function of vine size. While large fluxes in carbohydrate concentration occurred over the season in the various plant parts (ie. roots, trunk, cordons, old wood and canes) they were largely unaffected by Ramsey rootstock compared to own roots, adoption of various pruning systems (ie. spur, hedging or minimal pruning) or water stress during the flowering to veraison period. Carbohydrate concentrations were highest during dormancy, when measured prior to budburst and lowest in the flowering to veraison period. For example in Cabernet Sauvignon the total concentration of carbohydrate in new shoots was about 4 % in late spring and 8% soon after harvest in autumn. The respective concentrations in winter, late spring and after harvest were 10%, 5% and 8% in old wood, 9%, 5% and 6% in trunks and 10%, 8%, 7%. The proportion of reducing sugars, sucrose and starch varied between the various organs and over the season. Large differences in carbohydrate concentration over the season determined across different varieties may be linked to crop load and management. Total carbohydrate removed in berries at harvest was 2-3 times that stored as reserves during dormancy. About 10% of the vines carbohydrate reserves were removed by spur pruning. It is postulated that the development of smaller vines with cane pruning compared to spur pruning is due to the reduction in total carbohydrate reserves due to the removal of one and two-year wood.

Some effects of crop load and canopy management on bud fertility, inflorescence size and carbohydrate storage

Andrea Watt[1] and **Greg Dunn[2]**

[1]Faculty of Land and Food Resources, The University of Melbourne, Parkville VIC 3010; [2]Faculty of Land and Food Resources, The University of Melbourne, Dookie College VIC 3647

Reducing yield from 13.1 t/Ha to 5.8 and 5.6 t/Ha by severe shoot thinning prior to flowering or severe bunch thinning at veraison of 14 year-old Chardonnay vines did improve bud fertility, assessed microscopically during dormancy. Neither did bunch thinning have a positive effect on starch content of trunks or shoots. Severe shoot thinning caused a significant 15% decline in the starch content of cordons but not vine trunks. Despite this reduction in starch content, bud fertility was unaffected. Increased severity of pruning in Cabernet Sauvignon vines stimulated branching of inflorescences during budburst leading to higher flower numbers per inflorescence.

Grapevine root dynamics

David Eissenstat[1], Alan Lakso[2], David Smart[3], Taryn Bauerle[1], and Louise Comas[1].

[1]Department of Horticulture, The Pennsylvania State University, University Park, PA, USA; [2]Department of Horticultural Sciences, New York State Agricultural Experiment Station, Cornell University, Geneva, NY, USA; [3]Department of Viticulture and Enology, University of California-Davis, Davis, CA, USA

Grapevine roots have rarely been studied in detail. Results of early studies that have become widely accepted often were without replication and for short periods of time. Our root work with Concord in Fredonia, NY spans six years and was well replicated through the use of minirhizotrons. Seasonal patterns of root production can vary widely from year to year, but most production occurs between bloom and veraison. Low root production was typically observed after veraison or before bloom. Similar results were found in our first year of observations in a Merlot block in the Napa Valley of California (Oakville). Pruning regime also affected root production, with minimally pruned vines producing more roots and roots earlier in the season than balanced prune (44 buds/kg pruned canes). During dry years, irrigated vines produced many more roots than unirrigated vines, especially in soils depths less than 60 cm. Crop load has mixed effects on root production. Mass of previous year's crop was positively correlated with early season root production (before bloom). Crop load studies are now underway to better understand the relationship of root production to crop load. Median root lifespans ranged from 60 to 140 days while roots remain white typically for 20 to 60 days. Soil depth, root diameter and time of birth consistently influenced root lifespan in all years ($P<0.05$). Deeper and coarser roots had longer lifespans. Roots born near bloom were shorter-lived than roots born later in the season. Pruning and irrigation influenced root lifespan in some years but their effects seemed to vary with growing season environmental conditions. We found little evidence that root lifespan was reduced for roots in dry soil. Linking root lifespan to root physiology can be accomplished by estimating how root physiology changes with root age. Grape roots have very high nitrate uptake capacity when only 1 day old but then it diminishes very rapidly. Respiration rates also are initially very high but decline. We estimate that it takes about 12 days for the carbon costs associated with root respiration to match that of root construction. If roots maintained very high N concentrations and N uptake capacity it would only take about four days.

From sprinklers to drippers – impacts on grapevine root architecture

Chris Soar[1,2] and Brian Loveys[1,2]

Cooperative Research Centre for Viticulture, PO Box 154, Glen Osmond, South Australia, 5064; CSIRO Plant Industry, PO Box 350, Glen Osmond, South Australia, 5064.

Due to the difficulty in sampling and analysis of root tissue in vineyard environments, detailed studies of grapevine root architecture are few in number. This is particularly unfortunate since the size and structure of a grapevine's root system is likely to have profound influence on the performance of the above-ground parts of the vine including impact on growth, vigour and yield (all functions of carbohydrate partitioning); nutrition; drought tolerance, water use efficiency and response to stress. As part of a CRC for viticulture project aimed at optimising deficit irrigation methodologies (CRCV 2.1.8), we decided it was important to assess the effects of within-vineyard soil variability and irrigation history on the root architecture of grapevines. The reasons for this decision were based on the assumption that effectiveness of deficit irrigation techniques would be influenced by the soil volume available to the roots and the distribution of roots relative to drip irrigation emitters.

In this paper we report on differences in root architecture as influenced by current and past irrigation methods and also as a result of within-vineyard variability in topography and soil type. Conversion of vines from sprinkler irrigation to drippers resulted in a marked increase in total root volume under the drip line, particularly 25-50 cm below the surface. The impact of irrigation history on root density varied for different root diameter classes. Variable soil characteristics within a vineyard was found to influence total root density with increasing depth, whereas irrigation history had more influence on horizontal variations in root density within a depth range.

Grapevine root hydraulics: links between root and canopy function

Rebecca Vandeleur, Brent Kaiser and **Steve Tyerman**

School of Agriculture, Food and Wine, Faculty of Sciences, The University of Adelaide, Waite Campus, PMB #1, Glen Osmond SA 5064, Australia.

The hydraulic conductance of roots can have important impacts on the shoot water relations and the efficiency of soil water extraction. Aquaporins (proteinaceous water pores) can account for large proportions of total water flows in roots, the significance of which is that there is the potential for rapid and fine control of water flow (Vandeleur *et al*. 2005). We have found that the hydraulic conductance of *Vitis vinifera* roots is very variable, and changes diurnally with maxima occurring in the middle of the day. It also varies with water stress and shoot treatments (dark and pruning). A portion of these changes can be attributed to altered expression and activity of root aquaporins in addition to anatomical changes, though the rapid changes (within a day) are more likely due to aquaporins. In Chardonnay, but not Grenache, the diurnal variation in hydraulic conductance was greater when the vines were water stressed, suggesting that aquaporins accounted for a larger proportion of water flow. This correlated with increased expression of one sub-type of aquaporin in Chardonnay (from the PIP1 class). PIP1 was shown to up-regulate the water permeability associated with PIP2 when co-expressed in *Xenopus* oocyte cells. A 50% reduction in root hydraulic conductance was observed for *Vitis vinifera* in response to shoot topping. This was also observed in a monocot and another dicot indicating that this is a more general phenomenon. The response occurred within 24 hours, and correlated with decreased expression of PIP1 aquaporin in roots of *Vitis vinifera*. This response, and that also observed from dark treatment of the shoot, indicates a shoot to root signaling process. We are investigating whether this may be in response to hormonal signals or hydraulic signals from the shoot. Preliminary girdling experiments suggest that the signal is a negative one that travels in the phloem to down-regulate aquaporin expression/activity in the roots. The work indicates that shoot-to-root signaling may be as important as root-to-shoot signaling in coordinating water flows in plants.

Appendix II

WORKSHOP PROGRAM

08.45: Introduction, Dr. Rob Walker (CSIRO)
08.50: Welcome, Dr. Jim Fortune (GWRDC)

Morning Session Chairman: Professor John Considine

09.00: "VitiSim" – a simplified carbon balance model of a grapevine, Prof. Alan Lakso, Cornell University, USA.

09.35: Carbohydrate reserves and vine productivity, Dr. Jason Smith, Stewart Field and Dr. Bruno Holzapfel. National Wine and Grape Industry Centre, Wagga Wagga

10.25: Coffee/Tea

10.45: Water stress and carbohydrate partitioning, Dr. Nicola Cooley, The University of Melbourne (formerly CSIRO Plant Industry, Merbein).

11.15: Pruning, rootstock and seasonal impacts on vine carbohydrate status, Mr. Peter Clingeleffer and Dr. Anne Pellegrino, CSIRO Plant Industry, Merbein.

11.45: Some effects of crop load and canopy management on bud fertility, inflorescence size and carbohydrate storage. Ms. Andrea Watt and Dr. Greg Dunn, University of Melbourne.

12.00 Discussion and Integration Session I
(Prof. John Considine, Prof. Alan Lakso and Dr. Doug Godwin).

12.45: Lunch

Afternoon Session Chairman: A/Professor Peter Dry

13.10: Grapevine root dynamics, Prof. David Eissenstat, Pennsylvania State University, USA

13.45: From sprinklers to drippers – Impacts on grapevine root architecture, Dr. Chris Soar and Dr. Brian Loveys, CSIRO Plant Industry.

14.15: Grapevine root hydraulics: links between root and canopy function, Ms. Rebecca Vandeleur, Mr. Brent Kaiser and Prof. Steve Tyerman, University of Adelaide

14.45: Discussion and Integration Session II (A/Prof. Peter Dry, Prof. Alan Lakso, Dr. Doug Godwin)

15.15: Table Group Session (Facilitated by Dr. Erika Winter)
Recommendations for further research on sustainable vine performance:
(A) What we don't know
(B) Priority rating and feasibility
(C) Where to from here

16.15 Plenary discussion
17.15: Close

Ref: Users on 'Sultana-mb'/WAL350/Forums, seminars, workshops/Vine carbohydrate dynamics & source-sink relationships January 2006.

Appendix III Workshop Participants

NAME. Organisation
Jim Fortune, GWRDC
Alan Lakso, Cornell University
Anne Pellegrino, CSIRO Plant Industry
Brian Loveys, CSIRO Plant Industry
Bruno Holzapfel, National Wine and Grape Industry Centre
Chris Soar, CSIRO Plant Industry
David Eissenstat, Pennsylvania State University
Doug Godwin, Godwin Consulting
Erika Winter, GrapeLinks
Greg Dunn, University of Melbourne
Jason Smith, National Wine and Grape Industry Centre
John Considine, University of Western Australia
Nicky Cooley, University of Melbourne
Peter Clingeleffer, CSIRO Plant Industry
Peter Dry, University of Adelaide
Steve Tyerman, University of Adelaide
Stewart Field, National Wine and Grape Industry Centre
Kerry Degaris, Hardy Wine Company

Ref: Users on 'Sultana-mb'/WAL350/Forums, seminars, workshops/Vine carbohydrate dynamics & source-sink relationships January 2006.

Dejan Tesic, National Wine and Grape Industry Centre

Dennis Greer, National Wine and Grape Industry Centre

Mark Gibberd, Curtin University

Nicole Dimos, DPI Victoria

Mike McCarthy, SARDI

Paul Petrie, Fosters Wine Estates

Russell Johnstone, Orlando Wyndham

Simon Robinson, CSIRO Plant Industry

Ron Hutton, National Wine and Grape Industry Centre

Aude Gourieroux, National Wine and Grape Industry Centre

Ian Goodwin, DPI Victoria

Liz McGuire, Murray Valley Wine Grapes

Rob Walker, CSIRO Plant Industry

Michael Treeby, CSIRO Plant Industry

Steve Swain, CSIRO Plant Industry

Jeremy Giddings, NSW Department of Primary Industries

Karl Sommer, DPI Victoria

Mark Thomas, CSIRO Plant Industry

Deidre Blackmore, CSIRO Plant Industry

Keith Hayes, GWRDC

Appendix IV

VISIT OF ALAN LAKSO AND DAVE EISSENSTAT

Schedule Monday 23 January to Friday 3 February

Monday 23 January

12:30	Alan arrives in Wagga Wagga Meetings with NWGIC staff

Tuesday 24 January

	Wagga Wagga, NWGIC meetings with staff
11:00	Seminar

Wednesday 25 January, 2006

17:10	David arrives in Merbein from Melbourne
	Accommodation in on-site flat.

Thursday 26 January, 2006

09:35	Alan arrives from Melbourne
	Mid-morning departure for Adelaide via Barossa Valley
	Accommodation: Chifley Hotel, South Terrace, Adelaide

Friday 27 January, 2006

Time	Meeting with……
9:00 - 9.40	Peter Dry
9:40 - 10:10	Cassandra Collins
10:10 - 10:40	Matthew Hayes (including coffee)
10:40 - 11:15	Dan Smith
11:15 - 11:55	Mark Thomas
11:55 - 13:00	Seminar
13:00 - 14:00	Lunch
14:00 - 14:35	Dougal Currie
14:35 - 15:15	Cameron Grant
15:45	Arrive GWRDC offers. Meet Jim Fortune, John Harvey, and Keith Hayes.

Ref: Users on 'Sultana-mb'/WAL350/Forums, seminars, workshops/Vine carbohydrate dynamics & source-sink relationships January 2006.

17:00	Depart for Mildura
22:30	Arrive Hotel Mildura Accommodation arranged Friday 27/1 to Thursday 2/2

Saturday/Sunday

Mildura and surrounds/discussions in modeling

Sunday evening – Dinner with Rob and Doug Godwin.

Monday 30 January, 2006

8:00	Car to CSIRO Merbein (Rob)
	Discussions with Doug, Rob, Peter, Anne

Tuesday 31 February, 2006

All Day	Workshop

Wednesday 1 February, 2006

	David departs
	Alan: follow-up discussions to workshop at CSIRO Merbein

Thursday 2 February, 2006

	Discussions with CSIRO and DPI Victoria Staff Mike Treeby and Steve Swain (carbon balance and fruit set) Mark Krstic (DPI Victoria) Visit DPI Irymple laboratories

Friday 3 February, 2006

	Alan departs