The performance of the grapevine in a regime of changing seasons

By Erland Happ

Erl Happ has 28 years of experience as owner of the brands 'Happs' and 'Three Hills' operating vineyards located in Dunsborough and Karridale in the South West of Western Australia.

This article presents the author's observations based on a study of vine behaviour in relation to seasonal temperature at his own vineyards and in other different situations, both cool and warm. The figures presented are original to the author. Hourly temperature data for this study was sourced from the Australian Bureau of Meteorology.

The article:

- describes a methodology for precise analysis of site thermal relations from hourly temperature data.
- relates site thermal relations to plant productivity and ripening date.
- presents new concepts relating to the interaction between site, vine and cultural circumstances that are useful in the quest to secure fruit with superior flavour for wine making purposes.

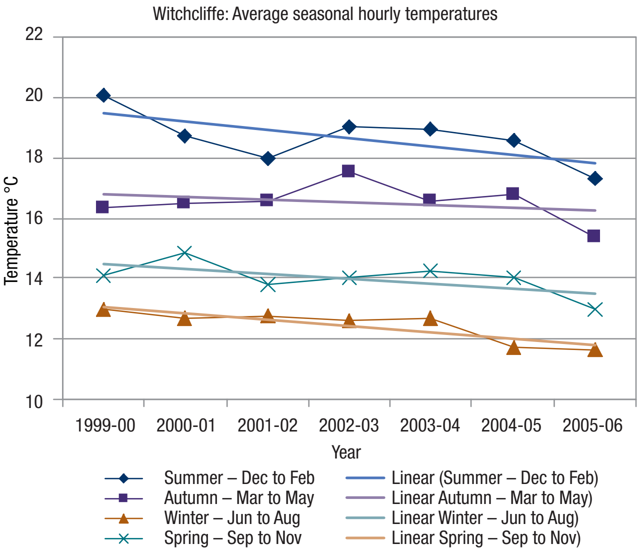

Figure 1. Raw data source: Australian Bureau of Meteorology.

DETERIORATING THERMAL CIRCUMSTANCES IN MARGARET RIVER

Margaret River lies on a peninsula in the south-west of Australia. A Bureau of Meteorology weather station is located 10km south of Margaret River town and the same distance from the sea at Witchcliffe (34.03°South Latitude). Margaret River town is centrally located with about 50km of land to the north and to the south. Most of the vineyards are to the north of Witchcliffe and experience more summer warmth. In recent years vines have also been planted to the south of Witchcliffe in the area called Karridale. The difference in ripening date from north to south can be three weeks.

Figure 1 reveals a fall in the average hourly temperature in each season of the year over the period 1999 to 2006 but a relatively greater fall in summer.

This has important consequences for vine growth and crop maturation.

PLANT RESPONSE

Chemical reactions in plants depend upon a time-temperature relationship that is more adequately represented by a degree hour statistic than the average (of 24 hourly) or mean (of daily maximum and minimum) temperatures. Figure 2 presents the statistic 'Degree Hours >10°C. This is conceptually similar to an index of degree days but more accurate. Although average summer temperatures have fallen by only 1.75°C, the degree hour index for September to March has fallen by almost 20%. There has also been a small rise in the incidence of temperatures below 10°C.

With plant function depending upon temperatures remaining above 10°C can growers expect a reduction in plant capacity? Will reduced plant capacity manifest as less sugar in the grapes or an increase in the time taken for fruit to reach maturity or a failure to ripen?

TEMPERATURE AND PLANT PRODUCTION

Where winter temperatures fall below 9°C, vines leaf out as air temperatures rise through 9°C to 12°C in Spring, depending upon variety. Carbon production then increases with temperature to about 28°C and declines thereafter. The optimum temperature for growth is 25°C. This reflects accelerating respiration of

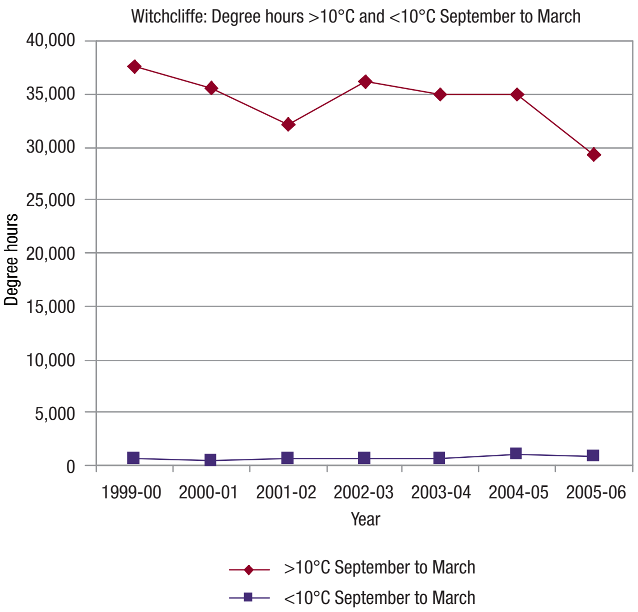

Figure 2. Raw data source: Australian Bureau of Meteorology.

carbohydrate as temperature increases and a diminishing carbon acquisition due to lower photosynthetic output at temperatures above 28°C. At 38°C growth ceases reflecting carbon acquisition in balance with respiration. Above that temperature tissue damage may be expected.

In the past many efforts have been made to relate plant performance and ripening date to indices reflecting time and temperature. The critical weakness of a simple linear index is its failure to reflect reduced plant efficiency at temperatures above 25°C. In midsummer temperatures in excess of 25°C are experienced in all areas where vines are grown including Geisenheim in Germany. The linear index comes closest to predicting maturity date only where the incidence of temperatures above 25°C is least. In the case of crops that mature prior to the heat of midsummer the linear index is predictive of maturity date but for crops maturing in summer and autumn, not so.

THE CONCEPT OF CARBON GAIN

Plant growth depends upon the balance between production and consumption of carbohydrate. Carbohydrate is produced by photosynthesis. It is consumed by respiration. Respiration drives transport, storage and tissue creation. The amount of carbohydrate that a plant can devote to these purposes per unit time depends upon the balance between photosynthesis and respiration during that time and is represented by additional starch and sugar present in leaves, wood and roots. About 50% of the dry weight of roots can be carbohydrate in one form or another and perhaps 15% of the dry weight of the trunk (Smith *et al.* 1993). Substrate is also stored in shoots and leaves. At the end of a day carbon must be gained if the plant is to grow overnight or partition carbohydrate to fruit development. Shoot extension ceases in mid season in dry summer Mediterranean climates, well short of verasion, and unless carbohydrate is then devoted to root extension the vine stores carbon. Where photosynthesis is impaired after veraison due to late season moisture deficit, leaf loss or temperature decline, carbon production falls away and the crop is consequently starved of carbohydrate unless withdrawals are possible from reserves. Carbohydrate storage is therefore a vital part of grapevine function.

CARBON GAIN IS DRIVEN BY TEMPERATURE ALONE

Carbon gain is rarely limited by inadequate sunshine because vines can accumulate carbon at a maximum rate at about one-third of full sunlight intensity. The period of activity on a daily basis seems to be limited by stomatal closure associated with adverse environmental circumstances and the inability of the local storage facilities and product transport mechanisms to cater for the amount of carbohydrate that can be generated by leaves in more than a few hours. If light is limiting it is probable that leaves work a little longer each day before they encounter these restraints. Similarly, low rainfall may not be a major barrier to a plant that has the ability to recover leaf water potential overnight from a root system capable of exploring the soil to great depth. Great wines are produced without irrigation under dry-land culture in the desert of Central Otago where the soil is deep glacial moraine. Fine trees also grow without assistance. The plant accommodates such restraints if it is given a few years to develop an appropriate structure to suit the local circumstances and appropriate cultural arrangements are pursued to conserve the soil moisture that is available. In the absence of a water deficit, temperature is the driver of carbon gain and, at the cool margin of viticulture, the limiting factor.

LEAF TEMPERATURE VERSUS AIR TEMPERATURE

Carbon gain depends upon leaf temperature rather than air temperature. Leaf temperature can be greater than air temperature when the leaf is in bright sunlight and especially if stomata close down. Shaded leaves are commonly at lower than air temperature due to the evaporative cooling effect of moisture escaping from open stomata. However, air temperature is the major influence on leaf temperature during the day and night, taken as a whole. Plant process demands respiration and that, with growth, continues during the hours of darkness. A conclusion that might be drawn from the correlation between carbon gain, as computed here, and sugar maturity at harvest, regardless of environment, is that night temperature is just as influential as day temperature.

CONSTRUCTION OF THE CARBON GAIN INDEX

It is difficult to derive the index from empirical data. The experimentally-derived data on the relationship between respiration, photosynthesis and temperature is often skewed by factors other than temperature, and in the case of respiration poorly documented. It is sufficient to know that growth, as the product of these processes, begins at about 12°C, is maximal at 25°C and ceases at 38°C. This tells us what the index has to look like at these points. The intermediate points can be derived by interpolation. The outcome is that the relationship between air temperature and carbon gain for grapevines is likely to be very similar to that depicted in Figure 3.

For ease of calculation this relationship can be expressed as a spreadsheet formula. Using the formula each hourly temperature is weighted according to its contribution to plant process. The result is units of 'carbon gain'. This is

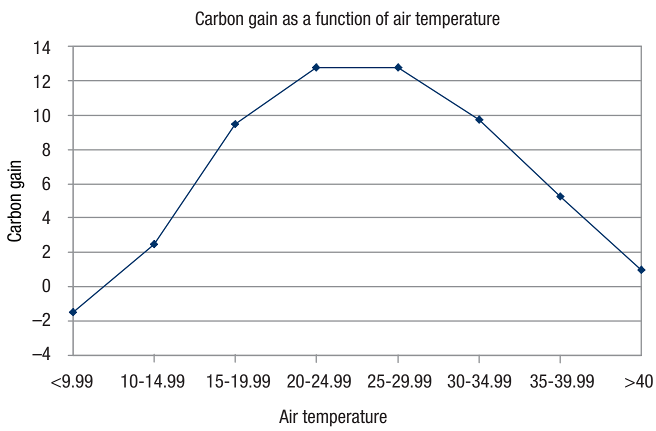

Figure 3. Conceptual relationship between temperature and carbon gain.

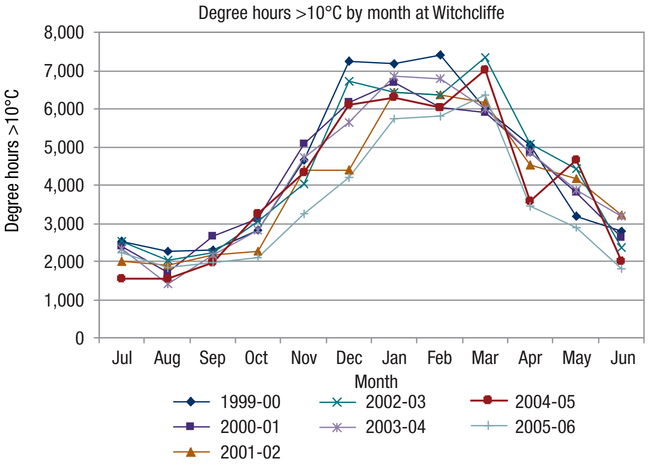

Figure 4. Raw data source: Australian Bureau of Meteorology.

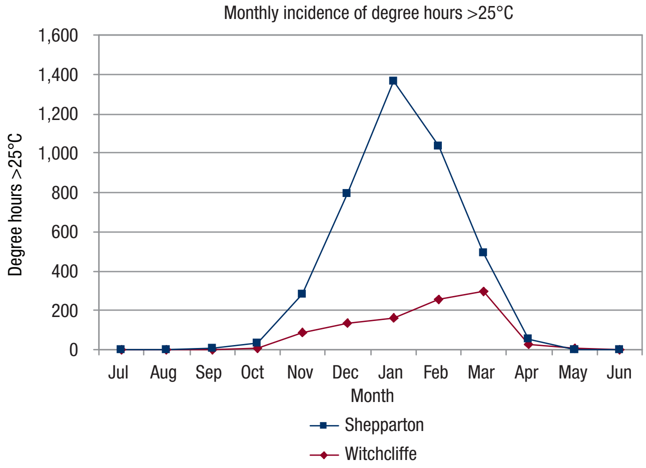

Figure 5. Raw data source: Australian Bureau of Meteorology.

aggregated for the month and the season that varies in length from place to place.

Figure 3 indicates carbon gain at temperatures in excess of 38°C. Consider this an allowance for possible plant adaptation to high temperatures, when long sustained, and for the influence of berry dehydration due to heat and aridity that will accelerate sugar maturity. If there is an error due to this factor it will be small because the exposure to temperatures above 38°C is mercifully brief, even in the warmest climates.

ESTABLISHING TIME OF BUDBURST AND RATE OF GROWTH IN SPRING

It is vital to know when leaves appear because the presence of leaves enables carbon gain. Budburst, in environments where winter temperatures do not fall below 10°C, responds to temperature increase rather than any particular temperature threshold. Between 1999 and 2004, Witchcliffe experienced an average hourly temperature of 11.9°C in August, the coolest month (Source: Australian Bureau of Meteorology). Figure 4 shows the pattern of increase of the index 'degree hours greater than 10°C'. Typically, the index begins to rise in September and the earliest grape varieties begin to burst.

THE RELATIONSHIP BETWEEN CARBON GAIN AND DEGREE HOURS GREATER THAN 10°C

Although Shepparton in Victoria is a full two degrees of latitude further south than Witchcliffe it experiences warmer days in the summer growth period. The comparison with Witchcliffe appears in Figure 5. The average incidence of degree hours greater than 25°C is shown for both locations. Between November and March temperatures swing into the less favourable zone to a smaller extent at Witchcliffe with the difference greatest in January. By April the difference is insignificant. Shepparton has a greater exposure to temperatures greater than 25°C in March but there is little difference between the two in April. Temperatures above 25°C are not only unfavourable to carbon gain but also to the retention of flavour in ripening fruit.

Figure 6 compares a simple linear index with carbon gain. In mid season, carbon gain is numerically superior to 'degree hours greater than 10°C' in Witchcliffe while the reverse applies in Shepparton. However, carbon gain is still slightly faster in Shepparton indicating that a given grape variety will ripen earlier in Shepparton than in Witchcliffe provided that it ripens prior to April.

THE RELATIONSHIP BETWEEN LEAF APPEARANCE AND FRUIT FLAVOUR MATURITY

Early and late season carbon gain is superior in the maritime climate of Witchcliffe. The potential for carbon gain in late season is important not for the crop for it is already picked, but for reserve replenishment, presuming that functioning leaves remain on the vines. This will enhance shoot growth, leaf area, inflorescence nutrition and fruit set in the following season.

There is a downside to this potential for carbon gain in late season. Carbon gain in late season can only be secured at the price of immature flavours in the fruit. In cool climates green canopies during ripening are associated with 'green flavours' that carry into the wine. This is associated with the presence of chlorophyll and green seeds in the fruit. More fruit represents a larger sink and that in turn keeps the leaves functioning. The trade-off of flavour maturity for extra crop is not so apparent in warmer climates where subtle flavours, even the methoxypyrazines, are fugitive and the flavour of raisins can be dominant.

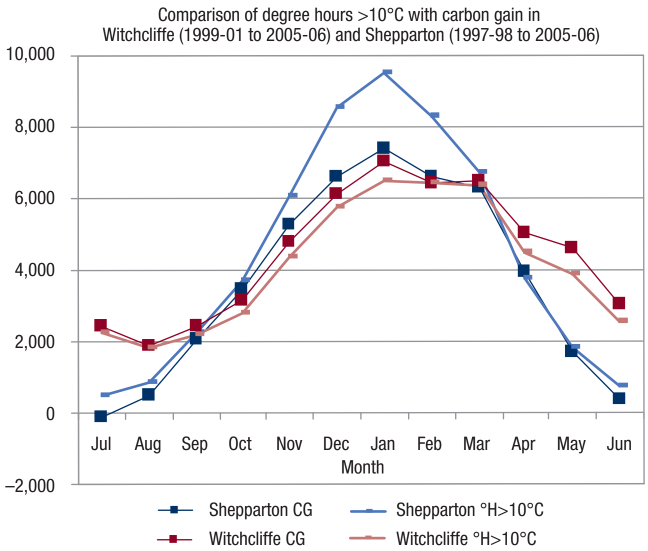

Figure 6. Raw data source: Australian Bureau of Meteorology..

These observations that link leaf colour and fruit flavour maturity are therefore tied to growing conditions. The point is confirmed by experienced Margaret River practitioners (Brocksopp, J. and Pearse, B). In addition the published work of Van Leeuwen *et al.* (2004) confirms the link between plant water potential and vintage success in Bordeaux. Plant water potential is linked to the extent of shoot growth after mid season, the consequent need for foliage trimming and the persistence of shoot growth to verasion and beyond. This in turn is related to lower than expected sugar concentration at maturity and the extent of green flavour in the fruit. It is the driest terroirs and the dry years that deliver the highest sugar levels and the most mature flavours. From personal observation Chateau Petrus is a study in gold and orange hues at vintage time. Full green canopies at harvest date are associated with low sugar content and immature flavours.

CARBON GAIN, SUGAR AND FLAVOUR MATURITY

Grape varieties are variously efficient in acquiring carbon. The date of veraison responds to carbon availability in relation to fruit demand (Petrie 2000) and also perhaps day length and certainly water supply. The result is a date where the vine has the capacity to mature fruit to a level of sugar suitable for a stated purpose so long as the season has been warm enough for long enough to provide sufficient carbon gain.

With insufficient carbon gain flavour maturity is still possible at a lower sugar level depending upon the physiological maturity of the rest of the plant. Flavour maturity is visually indicated by the state of seed and pulp and is tied to the seasonal progress of the plant itself. Sugar maturity is different and rarely coincides. Sugar maturity depends upon carbon gain. Sugar maturity can be secured with an adequate working leaf to fruit ratio and the availability of reserves to compensate for cool years when carbon gain is deficient.

The carbon gain figures in Table 1 relate to grapes with sugar content between 12.5 and 14 Baume for the making of table wines. Riesling may demand 12.5 Baume and Shiraz 14 Baume. Riesling can be flavour-mature at 10 Baume in Geisenheim in the middle of October. It can also be flavour-immature at 13 Baume at the end of September in a very warm season like that experienced in 2003, (H. Schultz, personal communication).

CARBON GAIN TO BRING DIFFERENT GRAPE VARIETIES TO A CUSTOMARY SUGAR MATURITY

The carbon gain required for sugar maturity has been established by experience at the author's vineyard in Karridale and validated against vine performance in other environments, both warm and cool. The requirement is set out in Table 1. The stated figure is dependent on the maintenance of an adequate working leaf area to fruit ratio for a sufficient period. Reduced seasonal length, diminished leaf area or insufficient leaf exposure trades against crop volume and sugar content. Alternatively, the plants will produce less in the following year via a reduction in standing carbohydrate reserves.

Carbon gain is computed from one month after budburst to avoid the following sources of error.

1. In early season vine dry weight falls until the 6-8 leaf stage as revealed in potted plant studies (Miller, 1996). After this point dry weight gain is observed. Dry weight gain signals carbon gain.
2. Development is related to air temperature change and reserve mobilisation rather than temperature per se. Places with very cool springs can therefore see as good an early season development of foliage as is experienced in places where spring temperatures are considerably warmer.

PREDICTING RIPENING DATES

Figure 7 sets out the ripening windows for early and very late varieties at Witchcliffe. Pinot Noir is sugar-ripe as early as 19 February in a warm year such as 2000 and as late as 20 March in a cool year like 2006. The very latest varieties ripen as early as 25 March and as late as 20 May. However, early harvest is often forced due to rainfall and fruit rot. In seasons such as 2006 where early picking is forced it is vital that sugar and flavour maturity is not further handicapped by overcropping or excess soil moisture. In late season leaf senescence will interrupt carbon gain and is itself a programmable event.

TABLE 1. CARBON GAIN REQUIRED FOR SUGAR MATURITY OF SOME COMMON GRAPE VARIETIES.

Carbon gain	Grape variety
25,000	Mueller Thurgau
26,000	Pinot Noir
27,500	Chardonnay, Muscat a Petit Grains, Verdelho, Muscadelle, Gewürztraminer
28,000	Sauvignon Blanc, Gamay, Riesling.
28,500	Semillon
29,000	Chenin Blanc, Marsanne
30,500	Malbec, Cabernet Franc, Viognier
33,500	Merlot Tempranillo, Tinta Cao
34,250	Cabernet Sauvignon, Shiraz, Grenache
34,500	Graciano, Mataro, Nebbiolo, Petit Verdot, Souzao, Touriga

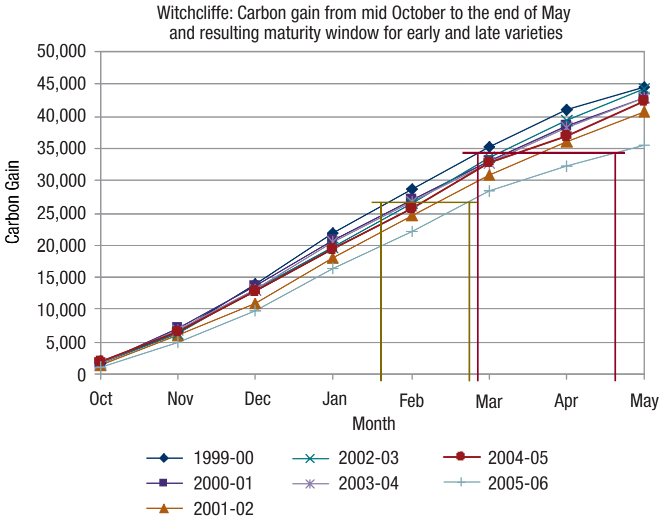

Figure 7. Raw data source: Australian Bureau of Meteorology.

CONCLUDING REMARKS

The utility of temperature indices

The most important aspect of site and seasonal variability is air temperature. The relationship between plant performance and air temperature is complex and non linear. Hitherto site characteristics have been inferred from 'biologically effective degree days with a 19°C cut-off' (Gladstones 1992), 'growing degree days on a 10°C base' (Winkler) the mean temperature of the warmest month, mean temperature of the hottest month, the average of growing season monthly mean temperatures and even annual average temperature.

The degree day index and the Hughlin index used in Europe are based upon the invalid assumption that plant work increases linearly with temperature. This gives rise to the apparent anomaly that the hotter the location, the more heat appears necessary to bring the fruit to maturity. Gladstone's index of 'biologically effective degree days' relates broadly to maturity phenomena. It does so because it allows for a non-linear relationship between temperature and plant performance. A cut off at a mean of 19°C implies a daily range between 13°C and 25°C or thereabouts. The Gladstone index therefore completely discounts temperatures above 25°C. A difficulty with any index calculated from daily mean temperatures is that it must be adjusted for day length and diurnal temperature range. It is an intellectual feat to have devised an index that can predict ripening date from mean temperatures but the process is not simple. In addition one notes that the mean often poorly reflects the average and is therefore a source of error. By contrast the carbon gain index relates to hourly temperatures in a precise, direct and simple fashion.

The carbon gain index meets two critical requirements that must be met by any index purporting to mimic plant response. The first is the requirement for accurate measurement of the thermal environment. That requires close-spaced observations across the diurnal period. The second is the requirement that the index correlates well with plant response at the range of temperatures experienced.

Using the index of carbon gain it is possible to document the influence of temperature on vine growth and performance. This enables reliable prediction of vine performance prior to planting. It therefore provides a reliable tool to match variety to site to secure favourably cool ripening circumstances and anticipate quality outcomes. Further, and this is very important, it is possible to estimate the impact of temperature variations between seasons and gauge the likely economic impact of temperature change over time.

VARIETAL CHOICE: WORKING AT THE MARGIN

The most favourable choice of site from the quality viewpoint may involve the risk of not ripening the crop in a cool season. However, there is much that can be done to ensure that the vine is managed to secure a favourable outcome if we are aware of the importance of the leaf area to fruit weight ratio and the plant's capacity to store carbohydrate.

LIMITS AND CAUTIONS

Despite its utility the index of carbon gain cannot account for the variation in performance that arises due to differences in distribution between vegetative and fruit sinks. There are also differences in the efficiency of various trellising systems. If the vegetative sink is maintained beyond mid-season the fruit sink must suffer either in volume or sugar maturity date. Minimally pruned vines will mature more fruit because they devote less carbon to vegetative sinks. Traditionally pruned vines will suffer in the yield comparison because they must devote more carbon to vegetative sinks and reach full leaf only later in the season. Vines that put more of their foliage in the sun at an earlier date will perform better than vines that have shaded leaves. Vines that have a larger trunk and root system have the carbohydrate storage potential to buffer against seasonal deficiencies.

TRADING QUANTITY FOR QUALITY

When fruit matures later than the norm provided by the carbon gain figure a grower should question if he is carrying too much crop or whether a change in the design will increase the efficiency of the leaves. If the flavours are immature he must ask if his leaves are working too long into the season and it might be better to leave more water in the dam. If the reverse is the situation the grower can be confident that he is operating within plant capacity. The vine is truly 'in balance' it goes into dormancy with adequate carbohydrate reserves and is doing the job easily. This sort of balance cannot be calculated from pruning weights in relation to yield. The balance referred to here secures a stable yield across the years.

The nature of the flavours present in the grape at harvest date has a lot to do with the physiological state of the plant as indicated by the colour of the leaves and the maturity of the canes. The physiological state of the plant is not usually regarded as a matter for conscious manipulation. It is unlikely to be a matter of interest in the hot irrigated areas. However, it is critical to outcomes in cool ripening areas where all grape flavours, including the green ones, are more intense. An understanding of the mathematics of carbon gain will facilitate decisions as to how much crop can be carried without compromising flavour maturity at harvest. Seasonal length must be regarded as a matter for conscious and deliberate manipulation. When we truncate the season by reducing the moisture supply we affect yield and there will be great scope for friction between grower and winemaker. Without appropriate incentives the grower will not produce 'the goods' and understandably so.

CLIMATIC CLASSIFICATIONS IN VITICULTURE

All viticultural climates are necessarily warm in the growing season. Some are desirably cool in the time of ripening. The freedom from damaging heat is readily assessed in terms of 'degree hours greater than 22°C' (Happ, 1999). Varietal choice is part of the process of securing the best potential in a site. This realisation leads one to the conclusion that there are places where good matches of variety to site are possible and others where the season is so warm for so long that even the latest varieties ripen in warm conditions. In that circumstance flavour is traded against volume.

The concepts described in this article are elaborated at length in a publication entitled 'Grapegrowing for Winemakers' available at: http://www.happs.com.au/pages/research_great_wine.html

FORMULAS

The spreadsheet formulas in MS Excel for the statistics described herein are:

°C >10°C:

=IF(E3>10,E3-10,0) where E3 is the hourly temperature in °C.

°C less than 10°C

=IF(E3<10,10-E3,0) where E3 is the hourly temperature in °C.

Carbon gain:

IF(D5>39.9,"1",IF(D5>34.9,"5.25",IF(D5>29.9,"9.75",IF(D5>24.9,"12.75",IF(D5>19.9,"12.75",IF(D5>14.9,"9.5",IF(D5>9.9,"2.5",IF(D5>-10,"-1.5")))))))) Where D5 is the hourly temperature in °C.

Ripening Heat Load > 22°C over the month of ripening:

=IF(E3>22,E3-22,0) where E3 is the temperature in °C.

Raw temperature data sourced from Australian Bureau of Meteorology.

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