Grapevine Physiology – a primer for serious wine growers

Dr. K. Helen Fisher
University of Guelph
Department of Plant Agriculture/Vineland

Carbohydrate partitioning

The carbon fixed during photosynthesis is allocated to expanding the leaf and some temporary storage (Figure 1). Very little is exported when the leaves are young. At maturity when the leaves are no longer expanding, the carbon is then exported and partitioned to expanded growth, fruit development, new roots or storage within the large permanent roots and trunk. The "sink" strength determines the direction of partitioning. The direction of partitioning is governed by the **relative strength of the sink or destination tissues**. If the vine is growing extremely rapidly, because light, water and nitrogen are plentiful, then the leaf and shoot development get priority. As the photoperiod of the season changes and the days get shorter, the vine goes into storage mode, the leaves and shoots stop growing and starch is deposited in the heavy permanent roots and the trunk. In between these two major developments, the young roots have priority, usually in late spring or the fruit development has priority, usually in late summer.

All parts of the plant have their turn, and as a manager of a vineyard, the **vigneron can manipulate this partitioning** to their advantage. By restricting growth, **more energy can be diverted** into fruit development. If this is too much for the capacity of the vine, it will stop growing. If fruit is removed from the vine in spring, root development will be encouraged. If too much fruit is left on a vine, root development will be restricted, making the vine prone to drought or mineral deficiency. If too much fruit is left on the vine to ripen in the fall, not enough starch will be stored for respiration over winter and the winter hardiness of the vine may be compromised. Everything is interconnected and it is the knowledge of the vine manager to make all things work to advantage for vine survival, fruit quality and profitability

Phenology

In the grapevine, the description of these stages is called **phenology**. Many of these stages are numerically designated because they are important stages of growth at which many field operations are implemented. In Figure 2, stylized grapevine growth cycle are presented with the **Eichorn-Lorenz notation (E-L), a universal description of a specific stage of growth**. Using a notation like this means that growers and/or researchers in Australia or South Africa in the southern hemisphere can communicate with growers and/or researchers in Germany or Canada and not get confused with the day of the year. It also means that a specific physiological stage of growth can be documented regardless of the lateness or earliness of a season. This is important when timing fertilization, specific sprays, specific crop control systems, etc.

In Figure 3, the important stages and their corresponding numbers are illustrated. The grapevine grows very rapidly in the spring, between early May and late June and then flowers during late June and early July. After this, the flowers set and the berries begin to grow. First the berries increase in size due to cell division (stage I). Then there is a rest period when the seeds mature (stage II). Then there is the final increase in size due to cell expansion (stage III) when berries enlarge, colour, soften and begin to accumulate sugar.

The beginning of this ripening stage is called **véraison**, a French term that really has no literal English translation, but roughly means "towards ripening". This beginning of colouration and softening is a key marker during the growing season. The date of this occurrence is often referred to in describing the advance of a season or a particular variety. Shoot growth usually decreases or stops about this time. **<u>Fruit maturity itself is a not a fixed point but depends on the end use of the fruit – juice, wine, table or raisins</u>**. After fruit maturity, the vine prepares for dormancy, stores carbohydrates in the trunk and roots, drops its leaves and goes into dormancy.

One of the things that distinguishes temperate zone perennials from evergreen tropical and subtropical species is that there is a period of dormancy when there is no active photosynthesis. This requires a defence mechanism which is the accumulation of starches in various perennial organs. This acts as a food supply for low levels of respiration which keep the plant alive during this period of apparent inactivity, be it induced by cold or drought. This starch supply is directed to storage and dormancy survival. Many tropicals are evergreen and do not shed their leaves at one time during the growing season. They are shed asynchronously, as they age, and floral development is similar, asynchronous and therefore occurring sporadically throughout the year, since there is hardly any variability in the growing season.

As can be in Figure 3, the temperate zone grapevine is extremely busy during the period from early May to about mid August. This is the period during which the vine must be in its healthiest condition. Particularly as the vineyard location reaches the northern, or very southern, limit of its capability of ripening fruit, all activities during this period must be maximized and timed within the available growing season to ensure ripe fruit and ripe grapevines at the end of the active season. If this condition is not met, ripe fruit for profitability and ripe vines for sustainability are not possible.

What controls flowering?

Flowering in most seed plants is triggered by **day length and light intensity**. How does a Christmas cactus know it's Christmas?? The winter solstice is near Christmas and this is the period when the nights are the longest and the days are the shortest. However, the flowers take a few months to develop, and the trigger is the September equinox, when the days are equal but then begin to get shorter. This change triggers the development of flower buds that eventually flower around mid December. Like most house plants, if they don't go dormant, they will have a similar bloom, perhaps not as numerous, in the spring as it passes through a similar period of day length change, but in the reverse. Some plants, particularly tropicals, are sensitive to very subtle changes in day length, perhaps a matter of only minutes. Others, like temperature zone plants, require greater changes in day length and some are coupled with temperature changes as well. Both of these features are evolutionary success stories of plants that have adapted their flowering strategies to take advantage of a rainy season that is connected with a specific time of year, or a spring period following a winter dormancy period, so that the seeds develop in a period when water (desert plants) or heat (temperate plants) is plentiful.

Flower cluster development

Grapevines, being perennials, have a period of flower development that stretches over one year. **Flower cluster initiation** actually begins during bloom of the previous year's flowers (Figure 4). This period of mid to late June (in North America) is an extremely active period of the grapevine. Shoots are growing rapidly. The vascular connections of the new shoots with the main structural arms of the vine are just being completed. The roots are starting to grow now that the soil is warm. **Flowers clusters** are emerging on the active shoots and new **flower cluster primordia** are being developed in the buds axillary to the active leaves on these active shoots. In other words, flowering and the next season's flower development are going on at the same time. After fruit set and the beginning of berry development, these primordial flowers clusters also continue developing but the detail of the cluster will not be completed until just before flowering the following year. These clusters are the ones seen in the dormant winter bud.

Light intensity and light quality are also critical to the development of these axillary buds. The **exposure of the leaf** in which axil this bud is developing has a profound effect on the fertility of this bud. If these leaves are developing in the shade, that axillary bud will be much less fruitful. Remember the wild grapevines, always scrambling to get back into the light and climb higher on the tree. These leaves must be well illuminated to guarantee fruitfulness of the next season's buds. This is where the commercial grape grower can influence the fruitfulness of next season's crop. By training vines so that the maximum number of leaves is well exposed and in full sunlight, the fertility of the following season is assured.

Flowering and fruit set

The detailed development of the **florets** with their individual organs occurs in the late spring, although the axis on which this is all attached is developed the previous summer (**floral primordium**). If there is failure or partial failure in the fertilization of the berries at bloom, then berries of uneven size develop. The **fertilization** of the ovary and the development of the seed **stimulate** the expansion of the berry. If this fertilization is incomplete, the berries do not fail completely but they do not size, a condition called **millerandage**. This gives the appearance of "**hens and chicks**", the hens being the completely sized berries and the chicks the smaller ones. Occasionally berries will grow slightly with no seed at all, but do not fall. These are very small and are called **shot berries**. If the fertilization is very poor, the infertile ovaries **shatter** and fall, leaving only a few berries set on the whole cluster. This is called **coulure.**

Many conditions affect the success or failure of flowering:

1. **Nutritional** status of the vine – boron deficiency or nitrogen toxicity can cause set or rachis failure
2. **Soil water** availability – drought conditions over winter will affect bud break and flower cluster development; waterlogged soils in spring will cause impaired growth and delayed flower cluster development
3. Previous **winter cold** temperatures – in general, temperatures below -10° to -15° C in November, -15° to -20° C in December, -20° to -25° C in January, -15° to -20° C in February, -10° to -15° C in March and – 5° C in April can potentially kill all flower buds.
4. **Weather during bloom** - rain during bloom will prevent or delay pollination, cold (< 15° C) or very hot (>30° C) weather will prevent pollen tube growth or dry out the stigma prematurely.

In the commercial management of vineyards, obviously guaranteeing the success of flowering is key to the production of fruit, wine, juice or raisins and ultimately profit. The vineyard manager has options to intervene in the growth cycle and either increase or decrease the amount of fruit produced. The period of extreme activity during May through July (in north eastern North America) is the time at which the vine must be properly fed, properly watered, properly managed for pests and properly managed for crop level.

Principles affecting pruning, cropping and vine capacity

Fruiting is the obvious continuation of flowering. The vineyard manager can control both fruiting and flowering by managing the amount of wood on the grapevine, but there are several physiological principles of pruning woody perennial plants that must be understood.

1. **Pruning has a stunting effect on the vine**. Even though the appearance is that of invigorated growth after pruning, this really translates into more growth from fewer growing points. You have removed substantial carbohydrate reserve by removing plant parts, and the overall effect is that of a smaller plant. Pruning is reducing the ability to store carbohydrate and increase "**capacity**".

2. **The production of crop in one season will affect the capacity of the vine for cropping the following year**. If you have a large crop on a vine in season one, the amount of shoot growth that season will be depressed and subsequently the vine's capacity to bear fruit the following season. If only a small crop is carried by a vine in season one, shoot growth is promoted and therefore the capacity of the vine to carry crop the following season is increased. This is governed by carbohydrate distribution/partitioning. This large crop demands the carbohydrate reserves to ripen, forfeiting the ability to use those carbohydrates for storage to promote the following season's growth.

3. **The capacity of vine varies <u>directly</u> with the number of shoots that develop**. Again, we are talking about carbon partitioning. If you don't prune a vine and all the potential buds develop, you have a great number of shoots. You can develop more carbohydrate for partitioning, and therefore have increased the capacity of the vine.

4. **The vigour or rate of growth of a shoot varies inversely with the number of shoots and the amount of crop on the vine**. Again, carbon partitioning and sink competition!! More shoots, less carbohydrate to go around, therefore short shoots. Also, more crop (fruit clusters) on the vine, less carbohydrate to go around and, again, short shoots.

5. **A given vine in a given season can only properly ripen a specific amount of crop**, dependent upon its history and its environment. In any one season, a vine has a **fixed capacity** determined by the leaf area, the carbohydrate balance of the previous season, and the environment of the present season.

Crop control

Pruning to manage **fruiting capacity** is a common practice in the management of woody, perennial crops. The manager makes a conscious decision to have many small fruits or a few large fruits. This decision is determined by the profitability of a large amount of small fruit or a small number of much larger fruit. Growing apples for juice, which is a lower price market, would necessitate very low cost inputs (i.e. little if any pruning and mechanical harvesting) and a market that does not demand a very specific quality. Growing apples for the fresh market, on the other hand, is a much more lucrative market but demands much higher inputs (lots of pruning to guarantee large fruit size, better field management inputs) because the market requires a very specific quality of fruit to be competitive. Grapevines operate in a similar set of parameters, but quality is not so easily defined or controlled.

Growers, large or small, must decide the **amount of fruit their vineyard can properly ripen** within their normal environment, and prune the vine to that level. A grapevine, depending on variety and species, will produce a **relatively predictable amount of fruit per bud/node retained on a dormant cane.** During the winter, almost 90% of the growth of the previous season is removed, and only a few canes (dormant shoots) of a specific length are retained. From the total number of buds/nodes retained on these canes, the approximate final harvest can be predicted, because, come spring, each bud on each cane will produce a shoot containing floral primordia and produce 2-3 clusters of fruit. Knowing the final weight of these clusters at harvest, **one can predict the total yield**, within limits.

If the growing season is not favourable (i.e. cold, wet, cloudy), the manager has the option of **removing more shoots or more fruit during the growing season**, at various times when it can affect the development of the final fruit quality. If the vine is carrying too much fruit, there will not be enough shoot growth to sustain healthy development. Not only with this have a detrimental effect on the fruit quality (delayed harvest, low sugars), but as seen above**, it will affect the capacity to bear fruit** the following season, and in locations with cold winters, **increase the risk of winter injury**. In some seasons, the spring weather is favourable, but the summer cool and rainy. In these conditions, extra fruit is removed at cluster closure or véraison **to improve both colour and sugar accumulation**. Water withdrawal (deficit irrigation) can also be used to control crop quantity and quality. Although during the bloom and post bloom period, vines should be well hydrated, withdrawal during stage II and III can help to restrict berry size, a quality improvement in grapes for wine, unlike apples!

Harvesting ripe fruit

The most difficult decision the vine grower has to make is precisely **when harvest should occur** because grape quality is measured by many different parameters, including the risk of disease and spoilage. The decision to pick table grapes is determined by the drop in acidity and accumulation of sugar to the point where the grapes are "pleasant" to taste. Uniform colour is also an issue with table grapes. In wine grapes, sugar and acid are critical, but so is the "ripeness" of the flavours, the tannins in the seeds, the bitterness or lack thereof in the skins, the specific flavours of the flesh, the presence of a fungus contamination that increases sugars and develops unique flavours for sweeter wines - all of these coupled with the calculated risk of more disease infection, spoilage, rain and/or frost. It is **a delicate balance** between the grower wishing to maximize returns and the winemaker wishing to make the perfect wine.

What is ripe fruit?

One of the keys to successful vineyard site selection is the ability to **ripen fruit to the end users' specification** in a regular and sustainable manner – i.e. **ripe fruit every year**!! But what is it that constitutes ripe fruit??

Each variety has its own taste and aroma characteristics, based on the wine history of the variety. These flavour components are part of the berry development. Different parts of the flavour and aroma are developed at different parts of the season (Figure 5).

Once berries have set, they go through a period of very **rapid cell division**. Once this period is complete, there is "**lag phase**" when seed growth is completed, after which berries grow again, this time through **cell expansion**. At this point, berry colour and texture also changes dramatically. This beginning of rapid change is called **véraison** and is a common marker for the beginning of the ripening period. At various times during these growth stages, certain compounds are synthesised that may be directly involved in or precursors to important **flavour and aroma compounds**. It is important that the relative timing of these developmental periods is known so that conditions in the field may be optimized to encourage the appropriate development of typical flavour and aroma compounds for the variety in question.

As the berries grow after set, the first compounds to be set down are some of the organic acids, particularly **tartaric acid**. Grape berries accumulate several organic acids in quantity, particularly tartaric and **malic acid**. These make up about 90% of the titratable acidity in a mature fruit. Tartaric acid is accumulated early in the berry development and malic acid later, during late stage I through lag phase. At this point the berry is still small, hard and green and photosynthetically active.

As berry cell division becomes very active, the **tannins and other complex phenols** are beginning to accumulate. These compounds are the basis for berry flavour, colour, juice/wine "texture" or mouth feel, and the stability of wines and their colour over time. They also play a role in subtle flavours, particularly of red wines. The complex flavones and **pyrazines** (green, herbaceous, vegetative flavours) are synthesized before véraison and the **anthocyanins and other colour components**, many of which have sugar side chains are developed after véraison. In particular, the **terpenes**, a family of very aromatic compounds common in Riesling, Gewürztraminer and many muscat varieties, begin to accumulate after véraison as both free and bound (non-volatile) compounds. These tend to rise until maturity after which they decline. The proportion of free terpenes decreases versus bound terpenes after maturity, meaning the fruit become less aromatic, but the bound forms release some of their aromatics over time with bottle age.

At véraison, once the berry begins to **lose chlorophyll** and become translucent (green berries) or **develop colour** (red berries), it begins to soften and accumulate large volumes of sugar. These sugars are primarily single sugars, **frustose and glucose**, but some species, *V. rotundifolia*, will accumulate up to 20% of the total sugar content as the double sugar **sucrose**. At this point, berry metabolism changes, moving towards malic acid-based respiration rather than glucose-based respiration. As a result, malic acid begins to **decrease** and sugars begin to **increase**.

In addition to sugar accumulation after véraison, berries also show an increased **potassium content**. This is thought to be related to osmotic balance, since sugar is being accumulated against a concentration gradient in the berry flesh. The accumulation of K^+ necessitates an exchange of H^+ to maintain electrical neutrality, resulting in a **decrease in acidity** and an **increase in pH** of the berry solutions.

Figure 5 illustrates the timing of these particular developments. Poor canopy architecture and inappropriate viticulture will seriously affect the development of these compounds and the subsequent juice/wine quality from this vineyard.

When is a shoot importing and when is it exporting photoassimilates?

In order for us to maximize the development of the flavour compounds, we need to know at what time a developing shoot can feed a developing berry and at what time it cannot (Figure 6). This has implications on vineyard management. How do we encourage growth and healthy foliage? We need to benefit and not detract from optimal berry growth and typical flavour maturity.

During floret development in the early stages of spring shoot growth, the bulk of the photoassimilate created by the quickly maturing leaves must be re-directed to the **high demand** area (sink) of the **new shoot growth**. The shoot at this point, and the early part of floret development depends on **stored material** housed in the mature wood and the overwintering buds. Once the pre-bloom stage is reached, some photoassimilates can be **redirected to the developing cluster** which continues throughout the growing season. Once véraison is reached and shoot growth slows or stops, then the bulk of the photoassimilates can be **directed to the cluster** and the balance to the **overwintering structures** of the vine.

If the vine is struggling and there are **insufficient leaves** (through excess leafing, excess crop or diseased, non-functional leaves) to provide for the ripening fruit, material from the old wood is again **re-directed to the cluster**, at the **expense** of starch buildup for the coming dormant season. On the other hand, if shoot growth is still very active at the véraison period, photoassimilates will not be directed preferentially to the cluster because the **shoot tip remains a strong sink**, **delaying** the ripening of the fruit and the acclimation of the canes and wood, compromising overwintering.

Managing vineyards to maximize quality

The world is never perfect and Mother Nature will prevail. A number of vineyard conditions have consequences for both juice and wine quality. It is only in the past 15-20 years that vineyard trials have been complimented with replicated wine trials. In addition, the important **aroma and flavour compounds that are organoleptically important** but very difficult to quantify with traditional detection equipment **can now be measured using modern gas/liquid chromatography**. Now we can link, definitively, vineyard management techniques to flavour and aroma compounds in the mature fruit and the finished wines.

Yield versus quality

There is standard myth suggesting that large yields constitute poor quality wine and that small yields result in good quality wine. It is extremely difficult to actually measure the absolute effect of yield of a vine and fruit quality because larger yield infers a larger vines and more growth and hence more potential shading. However, where **yields have been increased** with the use of an appropriate training system that can make good use of the extra leaves and structure, **fruit and wine quality have not been adversely affected.** However, yield control can be accomplished by the following strategies:

1. **Balanced pruning** - leaving a specific number of buds during the winter on a dormant cane for this year's crop, the number based on the amount the vine grew the previous season – i.e. you make a judgment of vine capacity, based on buds/m of row or buds/kg of winter prunings.
2. **Cluster thinning** – leaving a specific number of buds on a dormant cane for the coming season, letting all shoots and clusters grow and then thinning a specific number of clusters off, the number removed based on your estimate of the whole vine capacity.

3. **Balanced thinning** – same as above but adjusting the number thinned off by the relative vigour (capacity) of each shoot.
4. **Remedial thinning** – when none of the above are successful and a poor or late season indicates that fruit will not ripen at the present cropping level, clusters are removed near véraison to boost the leaf/fruit ratio and hopefully accelerate ripening

The yield/quality relationship has more to do with vine balance and recognizing the capacity of a vineyard. Remember the source-sink relationship with photoassimilates. If we have a vine with a **large capacity** and we prune it very hard, we will have very **few growing points** but **an increased vigour** of the individual shoots. Within that vine, the very active shoot tip will be a commanding sink and **the fruit cluster will not receive the allotted assimilates** for its prime development – i.e. this vine has **too little crop**. In this case, reducing yield has not been a good strategy. Most of the yield relationships have to do with **carbohydrate (or photoassimilate) distribution** or the lack of same.

Sunlight

The **biggest** factor in the internal competition in a grapevine is sunlight. Put a big vine in a small space and you have **shading**. Prune a vine to too few growing points and you have excess vigour per shoot and therefore **shade**. Put a vine in very good soil but in a narrow row and vine spacing, and you have **shade**. Put a vine on a vigorous rootstock on good soil but in a narrow row and vine spacing, and you have **shade**. Reduce the crop level excessively through thinning clusters or shoots and you have **shade**. Anything that promotes vigour, either through pruning or crop reduction, will **increase the probability of internal shade** of either leaves or clusters or both.

The biggest challenge of the vineyard manage is **to manage shade**. You want your vine to grow quickly in the early summer as these are the days with **the longest photoperiod**. You want the maximum amount of photoassimates produced in that frenetic period between flowering and seed set (stage II) to produce a **full canopy capable of supporting your crop**. You want the right amount of carbohydrate diverted to the fruit to produce all those flavour and aroma compounds at the right time during the summer growth period. All these metabolic reactions **require leaves for photosynthesis, but leaves create shade.**

Here are some of the vine consequences of excess shade:

1. The **bud in the axil of the leaf** needs to be well exposed to guarantee fertility the next season.
2. Only **10% of the ambient light is transmitted** through a leaf.
3. Leaves that function in the shade for extended periods of time **will not recover** to full photosynthetic efficiency if returned to full sunlight.
4. Shaded leaves reach the compensation point where the light level is too low for photosynthesis reactions to fully function. As a result, **shaded leaves become parasitic** over time.

5. Shaded leaves **do not** remain photosynthetically **active as long** as a well exposed leaves.

Here are some of the fruit/wine consequences of excess shade:

1. decreased **sugar** levels
2. decreased **anthocyanins** and **phenols** in red wines
3. decreased **tartaric** acid
4. decreased **terpenes** in aromatic varieties
5. decreased **varietal character** in the wine
6. increased juice and wine **K+** and **pH**
7. increased **malic** acid
8. increased **herbaceousness** and grassy flavours

And how do we manage shade? The literature is full of work describing **improved yield and/or flavour/aroma compounds in the fruit/wine by managing shade** through:

1. better **trellising** systems
2. better **shoot distribution** within the vine (thinning)
3. better shoot distribution within the row (better pruning)
4. better **leaf management** around the clusters (leaf removal, especially in cooler climates)
5. better **nitrogen management** (better timing of the right quantities)
6. better **organic matter management** (timing and composition of materials)
8. better **water management**

In other words – **better vigour management**. Look at the diagram above. Shading effects manifest themselves very rapidly (Figure 7). Once you have more that two leaf layers in a grapevine canopy, you have **created interior leaves**. The light wavelengths particular to photosynthesis are transmitted at **only 10% through each leaf** layer. This means the first interior leaf receives only 10% of the ambient light and the second interior leaf receives only 10% of the original 10%, i.e. **1% of the ambient light**. Only under very high light levels does this third leaf photosynthesise at all efficiently. It soon reaches the compensation point when there is no net gain through photosynthesis. The leaf becomes "**revenue neutral**" – not adding carbohydrates to the pool, but just "treading water". After a period of time, it becomes "**parasitic**" and is gradually re-assimilated, the mineral components that can be re-mobilized are used elsewhere and **the leaf yellows and falls**. If this leaf is re-exposed some time later in the growing season, it will not likely regain full photosynthetic powers after a prolonged period in the shade.

Temperature

One of the main effects of shade, besides the reduction of light, is the reduction in temperature. A shaded leaf is under the canopy where it is **cooler,** particularly in the morning. It is also much less windy under the canopy, meaning that humidity and CO_2 levels may be higher and therefore the **stomates may not open as readily**, translating into poorer photosynthesis rates. Warm, exposed leaves, on the other hand, will be

more metabolically active and sugar production, destined for berry accumulation, will accelerate.

However, under very hot conditions, shade may be an advantage, as photosynthesis **peaks at about 30-32 °C.** If the stomates close at this point, due to heat stress, transpiration decreases, evaporative cooling ceases and the leaves gain heat up to and exceeding ambient air temperatures. Temperature responses in berries are a little different, as they have few functional stomata by the time they pass véraison, When berries are fully exposed, not only do they have few stomata to contribute to evaporative cooling, red varieties are also dark and absorb heat readily. Many of the flavour and aroma compounds spoken of above accumulate through enzyme mediated reactions which are **very temperature sensitive**. As a result, well exposed berries/clusters have a much better chance of developing the appropriate chemicals to result in a typical ripe fruit flavour and colour of that particular variety. **Terpenes tend to increase** (the aromatic compounds present in Gewürztraminer, Riesling and many muscats) and the methoxypyrazines **(vegetal, "green" flavours in unripe Cabernet sauvignon) tend to decrease**. **Anthocyanin production generally responds positively** to increased heat, but many northern varieties have decreased colour development under very long, ripening periods, where the night temperatures remain high. **Malic acid degradation progresses rapidly with warm temperatures**, potentially dropping too low for good balanced wine when both days and nights remain warm.

Water

Water management is not only an environmental responsibility, it is an extremely useful tool in **managing vigorous vineyards** and **maximizing flavour development** while controlling vine vigour. Areas that use irrigation as a standard practice have developed very specific watering guidelines that allow the vineyard manager to keep a vine under a highly controlled water regime. Plant water use **is replaced by irrigation at a level that is less than what is actually being consumed** and/or lost by the vine (transpiration) and what is lost through evaporation at the soil surface. These water budgets are calculated weekly (daily in some areas) and the amount of water replaced depends on the point in the growing season.

Flavour developmental stages and whole vine growth events all have different sensitivities to water stress. The vines should have no water stress during flowering and fruit set. After this period **deficit irrigation (replacing less than has been consumed)** can be used to **reduce shoot growth, reduce berry size, advance maturity and increase anthocyanins and phenolics**. Deficit irrigation is often used in the period from véraison to harvest to reduce growth. However, berry size and final yield can be affected, sugar accumulation can be delayed, and if severe, interior leaves may be lost through premature senescence.

Water management, if possible, is a very powerful tool in vineyard management if used properly, but severe stress at inappropriate times of the season can not only seriously affect the present crop, but most definitely **affect the development of the following season's crop**. In humid climates, such as Niagara, deficit irrigation is still a possibility as we do experience periods of delayed rainfall during the summer season, and a little judicious watering can improve general vine health without promoting excessive growth and berry swell.

Finally, vine balance

Problem vineyards can be repaired through many management systems, but they first have to be recognized as being problematical. In nearly every case, a problem canopy is characterized by **excess vigour and shade**. We have discussed above the impacts of shade, temperature and water on the vine performance. If excess vigour is a problem, it can be corrected by several methods, some that will last the life of the vineyard (**enlightened**) and some which need to be repeated and/or modified every season ("**band-aid**").

Good planning and good site assessment will give you the appropriate parameters to **estimate vine vigour potential** before you start. At the planning stage, soil type, soil fertility, heat unit accumulation, rainfall and potential for cold injury or drought stress will give you a good estimate of potential vine vigour of the site. After that, an appropriate choice of **rootstock, row spacing, vine spacing, and trellis system** will give the right combinations to achieve balance within the vineyard without a lot of extra help. If vigour is still in excess**, reduced fertilization, the judicious use of cover crops as competition and properly timed deficits irrigation** should help. However, if the decisions at the planning stage were incorrect and vigour is very difficult to control, "**band-aid" solutions will have to be employed – beating down the vegetation every season using hedging, leaf removal and reducing the pruning level.** These remedial methods will **never cure the problem,** just mitigate it for the time being.

An ideal canopy may have some of the following features:

1. 15 shoots/m of canopy
2. 10-15 nodes shoots
3. 1.5 – 2.0 leaf layers (few interior leaves)
4. >50% exterior clusters
5. >80% exterior leaves
6. <5% active shoot tips at véraison
7. medium sized, dull green leaves

NOTHING IN A VINEYARD CAN BE DONE IN ISOLATION. Everything eventually leads back to more or less vigour, more or less fruitfulness, more or less fruit maturity (Figure 7, 8). The manager has all these tools, with which he/she can deliver the best quality fruit to the winemaker.

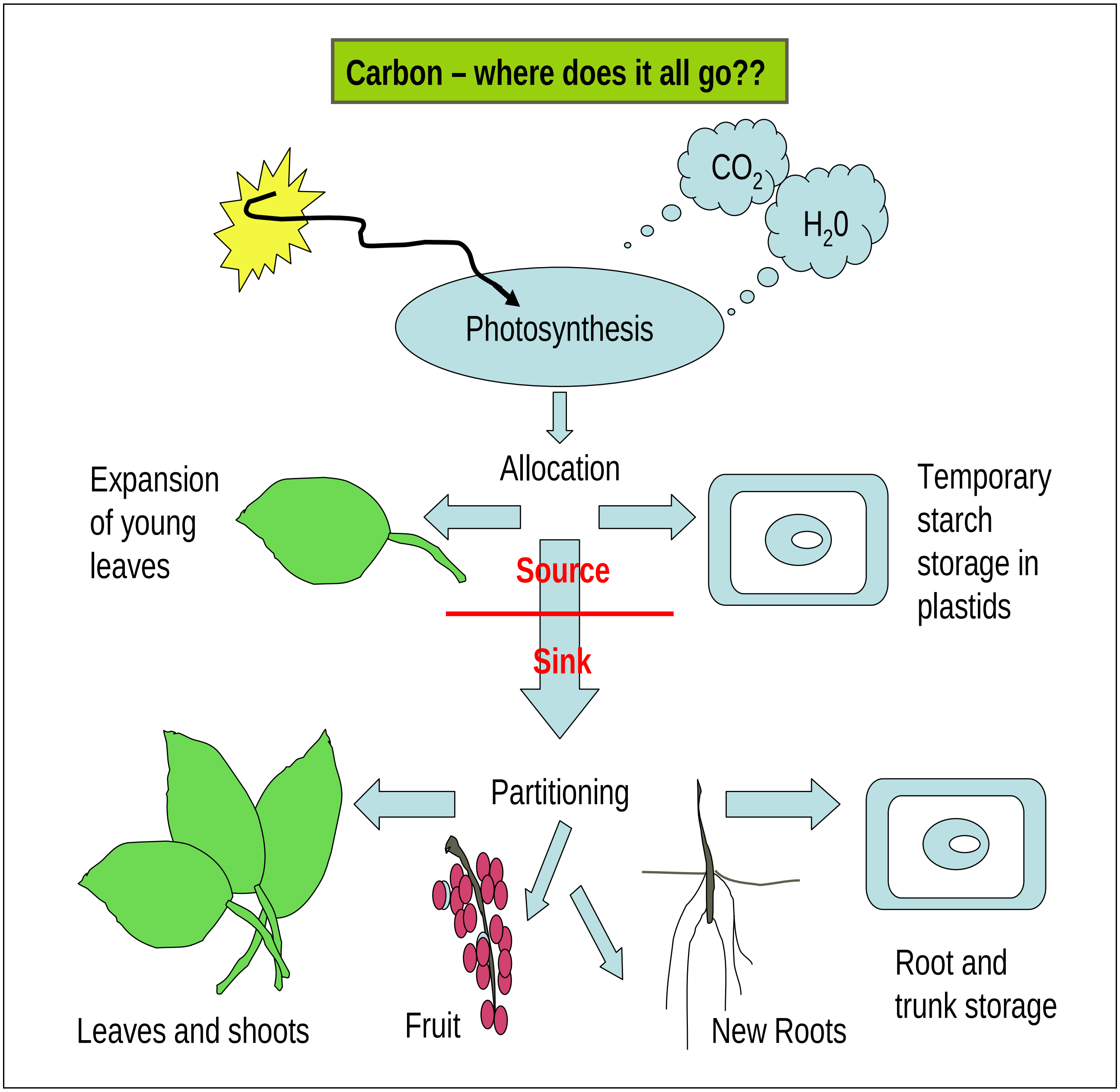

Figure1: The destination of manufactured carbohydrates as a result of photosynthesis.

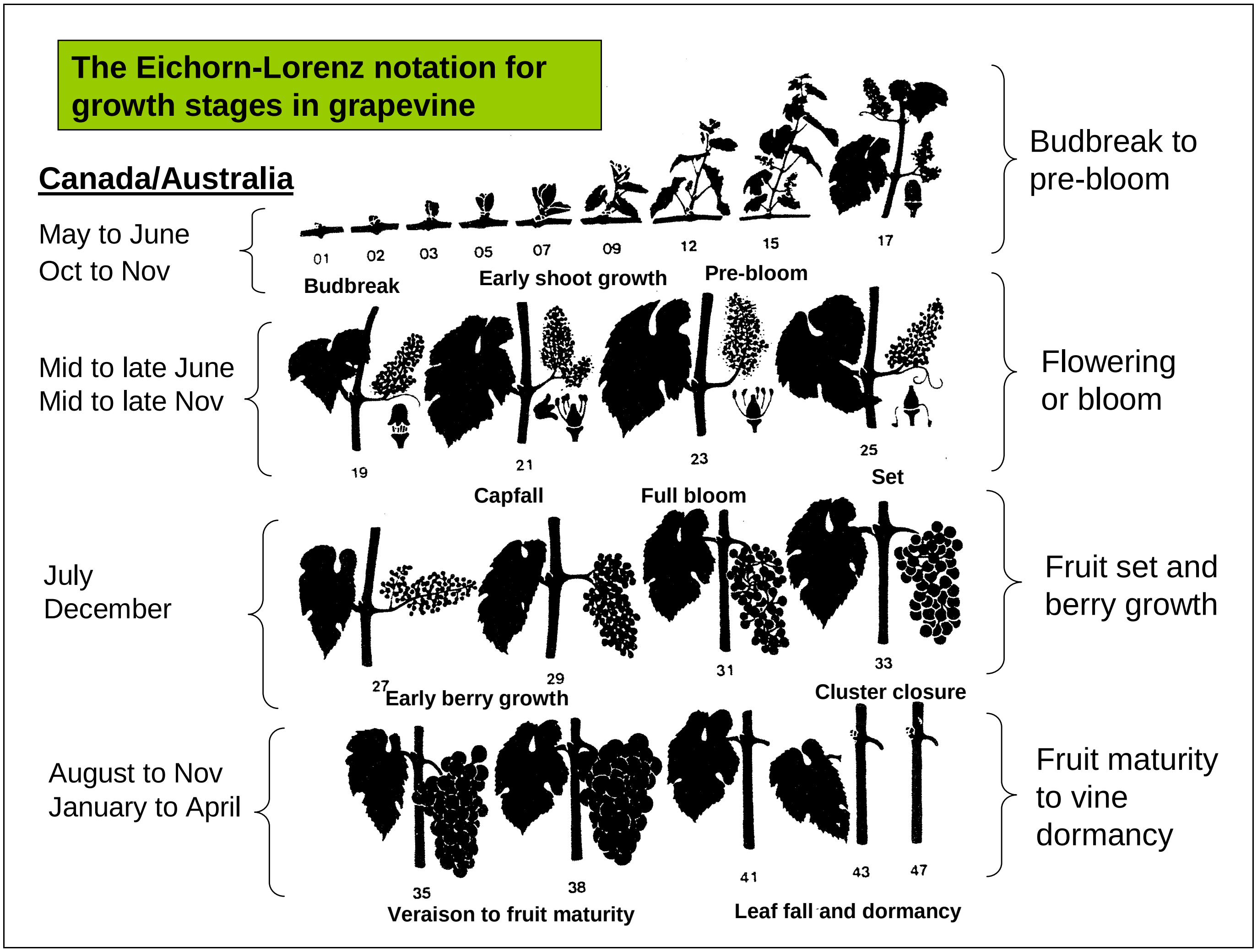

Figure 2: The Eichorn-Lorenz notation scheme for grape vine growth stages

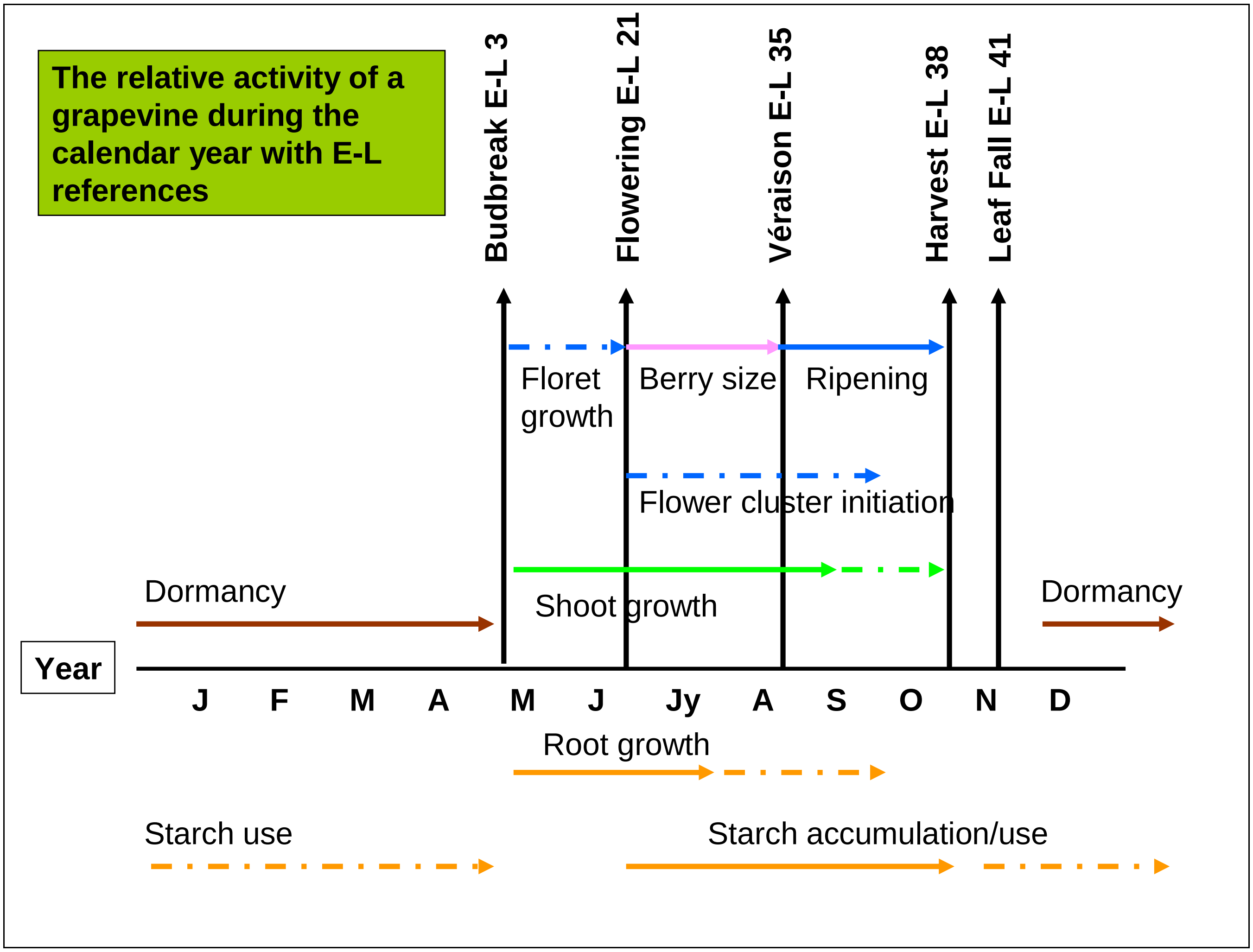

Figure 3: Periods of relative activity during the growing season of a grape vine

Flower Development and Fruitset

Season 1

Late spring through summer

- Floral initiation in axillary bud
  - Inflorescence primordium
  - Peduncle primordium
  - Rachis and branch primordia

Dormancy

Season 2

Early spring (May)

- Inflorescence branching
  - Branches on rachis
- Floret formation
  - Florets on pedicels
  - Calyx (sepals)
  - Calyptra (Petals)
  - Stamens (anther, filament, pollen)
  - Pistil (stigma, style, ovary)

Late spring (June)

- Flowering
  - Fruitset (pollination, fertilization)
  - Millerandage (pollination, partial set)
    - Hens (berries with seed)
    - Chicks (berries with seed remnant)
    - Shot (berries with no seed)
  - Coulure (set failure, no berry)

Figure 4: Chronology of flower development and fruit set

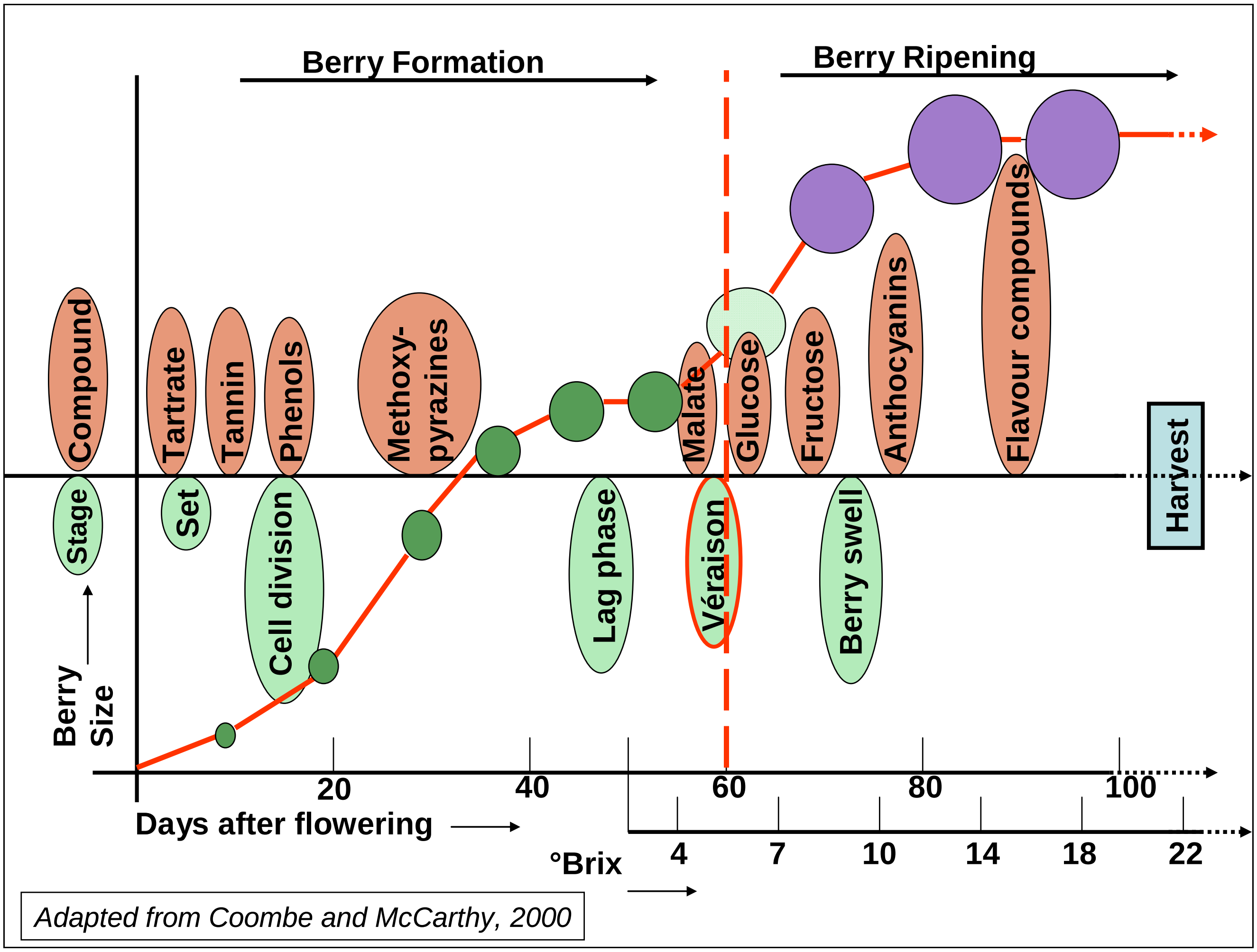

Figure 5: The chronology of flavour components and berry development

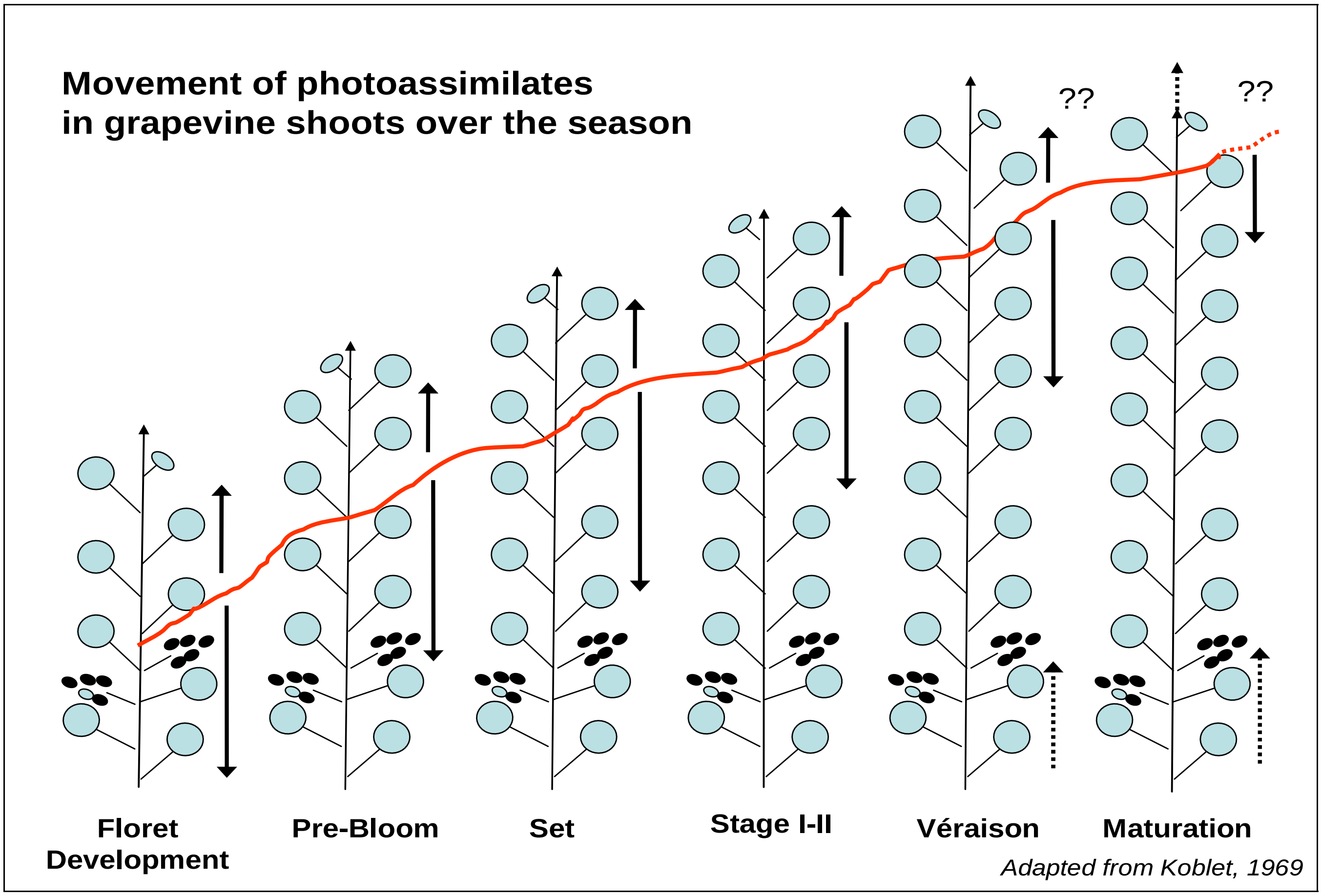

Figure 6: The direction of movement of photosynthates in active shoots throughout the growing season

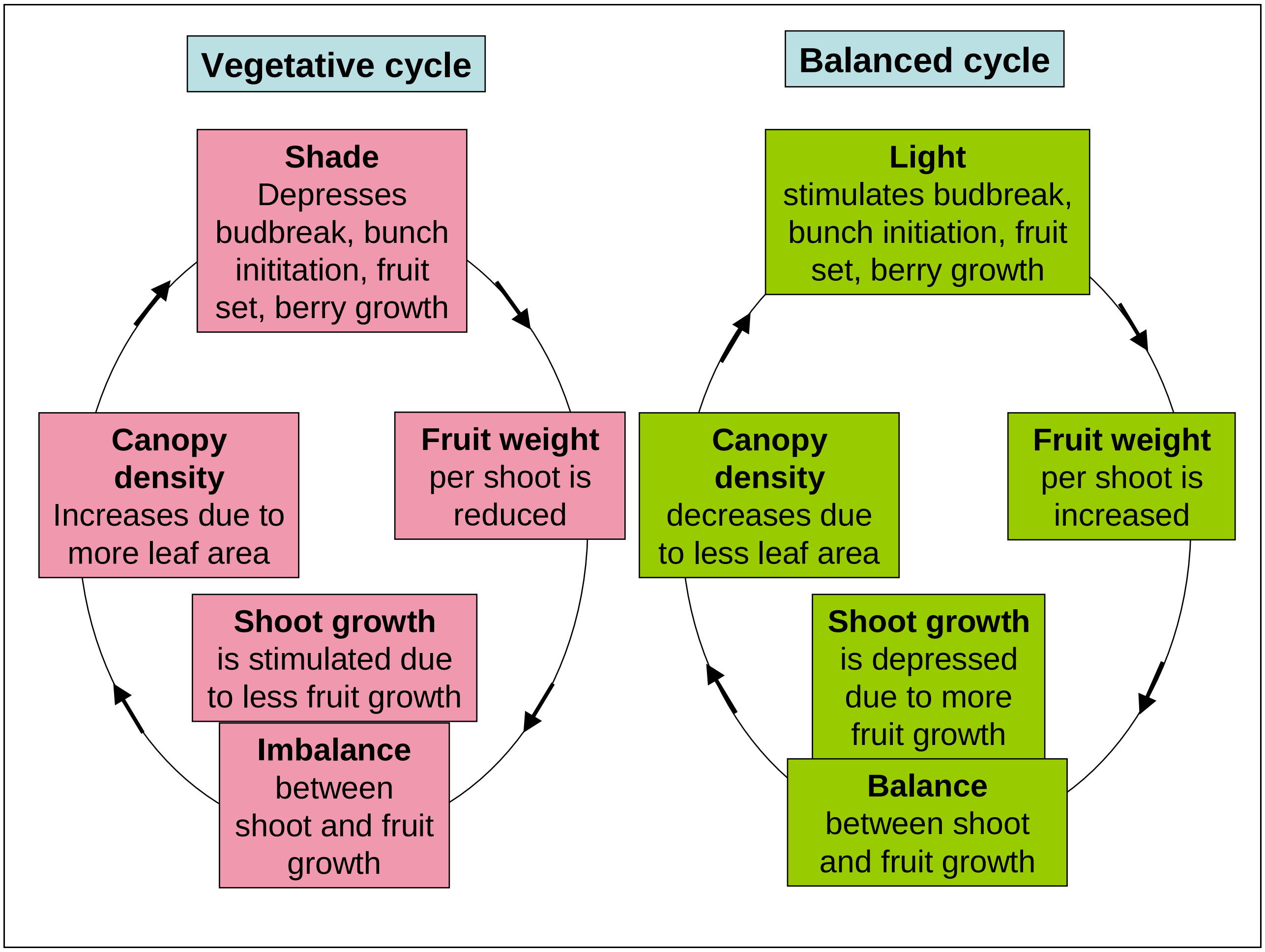

Figure 7: The interaction between the vegetative and fruiting capacity of a grapevine

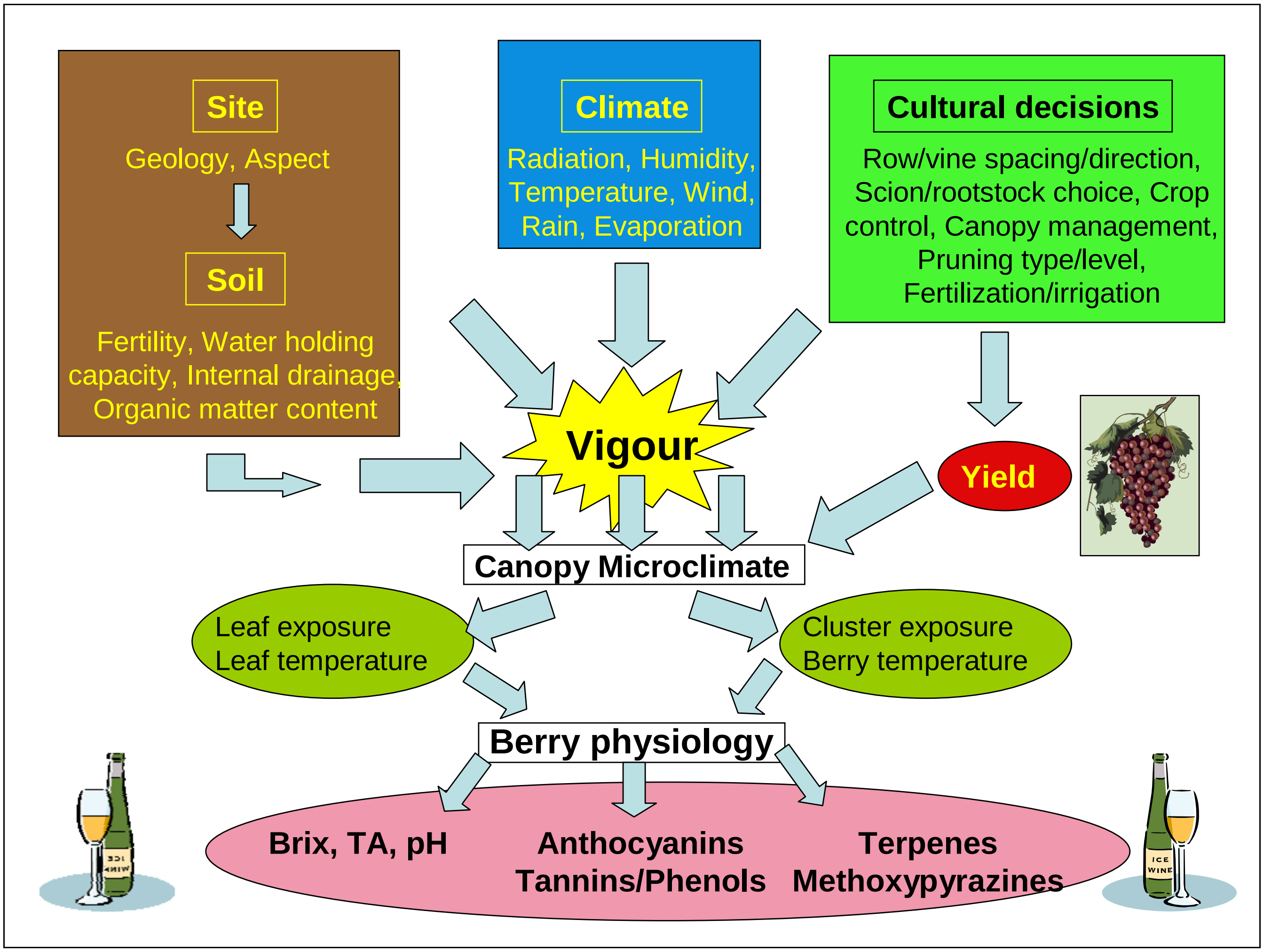

Figure 8: The interaction among all vineyard processes and wine quality