

THE EFFECT OF WATER STRESS ON VINEYARDS AND WINE QUALITY

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Basics Of Water Balance In Eastern Vineyards

In the humid climates of the Eastern US, rainfall is erratic. The occurrence, duration and severity of drought stresses are not easy to predict. Do we have significant problems due to drought (significant enough to change cultural practices or invest in irrigation)? We know the answer depends on factors such as how dry the seasons are, how much water our vineyard soil holds, how much the vines need, and loss to competing plants. Since we cannot predict the weather, we must take a risk assessment approach, and then evaluate methods to reduce risks we find. To do that we need to understand the factors that either increase or decrease our risks of significant loss from drought stress.

Similar to our personal economics, risk of water stress is related to the balance of supply to demand, not either alone. The lowest risk of loss due to drought occurs when the water supply is high and the demand is low. Conversely, when the supply is low and the demand is high, the risk is high and the potential benefits of irrigation are greatest. Besides seasonal rainfall several factors are involved in the total risk, and they should be evaluated separately since some cannot be easily changed while others can.

Water Supply

Heavier soils like silts and clays hold more water per cubic foot than light sands or gravels. Compared to a clay soil, the same volume of sandy loam will hold only 50% as much water. This difference can be overcome, however, if the lighter soil allows a greater depth of rooting, such as the deep gravels of the Chatauqua grape belt along Lake Erie where significant rooting to 6 feet or more has been shown. Many heavier soils hold more water per inch, but may have restrictive layers that may reduce the total rooting volume.

Regardless of the soil depth, "available" water is that in the rooting zone of the grapes. Mature grapevines typically can root quite deeply in unrestricted soil, but rooting depth is often limited by restrictive impermeable layers of compacted or stony soil. However, very young vines have restricted root systems in both extent and density for several years, so the rooting volume is limited even if the soil would allow potentially deep rooting. Both rooting depth and water holding capacity are important to the final reservoir of soil water available. Thus, the potential available water equals the rooting volume x soil water holding capacity.

Grapevines are not the only plants in a vineyard using water. Weeds and cultivated cover crops also compete for water, and are an important part of vineyard water balance. We do not think that grapes compete very well with weeds and cover crops since grapevine root systems have very low density (i.e. not very many roots per cubic foot of soil) compared to the other plants. Recent studies with Rick Dunst at our Fredonia station on row middle cover crop effects on mature Concord in Western NY have concluded that:

- 1) Competitive effects of row-middle covers on vines is primarily for water.
- 2) When actively growing and green, all cover crop species were about equally competitive.
- 3) Mowing of green covers, in general, has a relatively small and temporary effect on water use by covers; mowing should not be depended on to save much water.

- 4) Competition drops off markedly if and when the cover crop goes dormant and turns yellow or brown; herbicide treatment gives the strongest effect.
- 5) The period around bloom and the following 4-6 weeks is the critical time when competition for water reduces vine growth; this is why no-till herbicide treatment at bloom is effective.

Our best estimates of mid-summer water use by row-middle green covers suggest that they may use about 2 to 2 1/2 acre-inches per month in a typical vineyard in NY. In cases where other factors lead to a moderate risk of water stress, changes in row-middle management, such as switching between bloom herbicide and permanent grass sod, can significantly affect risk of water stress. Moving to a water-conserving row-middle management system may eliminate the need for irrigation in some cases.

These results do not, however, extend to weed or cover competition under the vines. In further studies, we have found that full cover with no bare strip under the vines was very detrimental to vine growth and productivity of Concord vines. This could not be reversed by irrigation. It appears that vines need at least some bare soil with no competition.

Water Demand

The greatest controller of demand is obviously the weather. Hot, dry weather can evaporate 8-10 inches of water per month from an open pan while cool summer months as we have in New York may evaporate less than 5 inches. This means that in some years no vineyard will need irrigation, but in some years many may benefit. Some of the greatest benefits of irrigation are that a guaranteed water supply will maintain continued productivity from year-to-year, helping to avoid the ups and downs of production following variable years. Also drought just means lack of rainfall; this does not always mean vines will be stressed. A cool drought may not have much effect due to low demand for water. Similarly, hot, dry periods in-between rains may cause stress due to exceptionally high demand even with normal rainfall. Again it's the balance of supply and demand.

Water use by vines is driven by the drying capacity of the air (temperature and humidity) and by the amount of sunlight energy absorbed by the vines. Sunlight capture by different training systems is the basis of improved productivity by systems like Geneva Double Curtain (GDC) since the sunlight capture also drives photosynthesis. But, when the pores in the leaves open up to allow the carbon dioxide in, water vapor escapes from the leaves at the same time. So, productive systems generally use more water than less productive systems. Divided canopies like GDC and Open Lyre that capture more sunlight (60-70% of available sunlight at full canopy) than single curtains (40-50%) will use and need more water. In a 12-year-long study Bob Cline and colleagues in Ontario found that GDC vines clearly benefited from supplemental irrigation while conventional single curtains did not. Similarly, we have shown that the effects of drought (or benefits of irrigation) are greater on minimally pruned vines compared to conventional single curtains.

How much water do vines use in the East? Our recent studies indicate that at full canopy in average Julys and Augusts single curtain Concord grapevines in Western NY use about 30-40 gallons of water per vine per week (Table 1). That works out to about 3 1/2 inches of water per month for an acre of vineyard. Interestingly, that is very near the 50-year monthly average rainfall for the season for Fredonia. Vinifera vines that typically are more heavily pruned and are grown for relatively open canopies will capture less sunlight and use less water. We do not yet have good direct measurements of water use for vinifera in our climate, but vine performance in current irrigation trials suggest that vinifera vines use about 75% as much water as Concord vines. Of course, for optimum wine quality, it seems best to give vinifera vines less water than their demand (see later section on wine quality). Young vines with less leaf area and sunlight capture will use proportionately less.

It should be noted that these are needs of just the vines not the whole vineyard. With natural rainfall not all the water gets to the root zones of the grapes as there are losses from soil and canopy evaporation and runoff, and usage by competing weeds or cover crops. In general in NY the natural rainfall is probably not adequate alone, but the soil water reservoir fills in the difference. On average it appears that the needs of the traditional single curtains with conventional pruning and crop levels are fairly well balanced to the total available water supply in Western NY vineyards.

In the warmer climates of the East and Midwest the water use rates should be somewhat higher. In the Central Valley of California vines use about twice the water per month in July (about 7 inches/month) as in NY. Based on climate comparisons to NY, we would expect mid-summer water use rates to be to be similar in Michigan, about 4 to 4 1/2 acre-inches per month in Southern Pennsylvania/Virginia, and perhaps 5 acre-inches per month in Missouri and Arkansas. This compares to about 7 acre-inches per month in Fresno, California.

Vine Responses To Water Stress

Besides the actual stress levels that may develop, it is important to understand how and when the vines respond to those stresses. The most obvious example is that we may have very long periods with low precipitation, but if it occurs in the winter when the vine is dormant, there is no problem.

One of the most sensitive processes in the vine to water stress is shoot growth. It reduces almost directly with any level of stress. This may be bad for vines needing growth, such as young vines or juice grapes that need to maintain vines size. But it may be beneficial for wine grapes that have excessively dense canopies. In arid climates, withholding irrigation in mid-season to regulate shoot growth is a useful practice.

Early growth of the berries in the first 3-4 weeks after bloom is due to cell division to produce new cells and is quite sensitive to water stress. The effects of stress at this time can persist for the rest for the season (Fig. 1). Again, for juice grapes this will reduce yields, but this may be beneficial for wine grapes that produce greater extract with more intense flavors with smaller berries (more skin/volume).

Mid- and later-season drought stress has different effects in that once grape berries are near or after veraison, they are strikingly resistant to water stress. In the first few weeks after veraison, the berry growth and sugar accumulation are hardly affected by drought, even quite severe drought. Final sizing and sugar accumulation will be inhibited by continued drought however in the last few weeks before harvest.

Supporting a crop is a stress on a vine, so heavily-cropping vines tend to react more sensitively to added stresses like water stress. We have found that a drought-induced reduction in Brix in Concord vines cropped at 8 tons/acre was about twice that of vines cropped at 4 tons/acre. So, drought in a heavy crop year can have a double whammy. So, irrigation will probably have greater and greater benefits as we push yields upward. This may not be as important in wine grapes where yields are kept at lower levels.

We think that as yields or wine quality goals are pushed higher and the production needs to be a stable as possible in erratic climates, then water management will be a critical component. This may be in the form of just good evaluation of your site, changes in floor management, or perhaps drip irrigation. How these factors all add up may be totally different for low-value juice grapes and for high-value vinifera vineyards. The principles still apply, but the final actions may be very different in different sites and for different markets.

Summary Of Factors Affecting Vineyard Water Balance

Weather conditions - Hot sunny dry conditions cause maximum water use

Canopy Fill - Early season or young vines with < full canopies use less

Seasonal Sunlight Interception - GDC or Minimal Pruning capture more sunlight so need more water

Type of Vine and Use

Native American juice grapes usually produce best with minimum water stress

Vinifera wine grapes use somewhat less than juice grapes and also perform best with some stress, especially after canopy fill.

Weeds and Cover Crops - they may use one-third to one-half of the water used in the vineyard, so their management is very important to vineyard water balance.

Drought Risk Assessment - any practice that is based on weather-controlled resources like water is complex and variable with the weather. A risk assessment should be done for each vineyard as each vineyard is a unique combination of the risk factors.

Implications of Water Balance To Wine Quality

In wine production the role of water stress has been debated for many years. It has become clear that neither end of the spectrum of water stress is optimal for desired balances of yields and wine quality (Seguin, 1983).

Excessive Water.

The "wet" end of the water balance spectrum tends to induce excessive vegetative growth that often leads to dense canopies, large dilute berries and compact clusters, poor fruit exposure and related disease problems. All of these lead to poor fruit and wine quality. Since in erratic climates like ours we may have years of very low stress due to rain and cool temperatures, approaches have been developed to try to overcome these limitations. Canopy management to control the canopy form and to keep the canopy open via limiting shoot numbers, shoot positioning, topping, and leaf pulling has been very effective in many cases. Also, canopy division was first proposed for dense canopies in juice grapes by Nelson Shaulis in the Geneva Double Curtain. The concept was later adapted to viniferas with the Open Lyre by Alain Carbonneau or vertically-divided systems such as the Scott Henry. Canopy division spreads the canopy out to reduce canopy density and improve fruit exposure and utilize vigor rather than fight it. But many times it also increases light interception by the vine, causing more water use and therefore potentially more water stress. Additional approaches of encouraging competitive cover crops to use up the excess water have been successful in some cases, but the success depends on how wet it is and how deep the soil is. If the soil is deep, the grape roots simply grow deep and not compete with the cover crops. Excessively vigorous vines in wet sites also may grow too late into the fall and not ripen the canes adequately. This can lead to significant losses to winter cold.

Experience in many wine-growing regions suggests that vineyards on well-drained soils will have fewer problems in wetter years although canopy management is especially critical for avoiding the problems of cool wet seasons.

Excessive Drought Stress.

On the dry end of the spectrum, vine growth is inhibited and fruit ripening may be delayed or suppressed. Optimum wine quality requires some stress but does not appear to come from stunted

vines with non-functional leaves. Too much early stress will not allow the development of the desired leaf-to-fruit ratio of roughly 12-15 exposed leaves per cluster (this will vary with cultivars, but is a reasonable average). This means the vine will not have the capacity to properly ripen the fruit. Mid- to late-season stress, however, will shut down the leaf photosynthetic function and suppress ripening also (why produce a canopy if it can't function?). It may appear that the crop is ripening due to increases in Brix, but that is often a result of stealing carbohydrate reserves from the vine or simple dehydration, not actual import of sugar. Many flavors in the fruit tend to develop in the last few weeks, so late stress may also limit flavor development.

Although difficult to control stress and quantify all the effects of excessive stress, our observations have been that although small berries might suggest good extract and concentration, excessively stressed vines tend to produce wines of dull or little fruit, less complexity, relatively short life. The "untypical or atypical" aging (UTA or ATA) that has been a problem in Germany and New York appears to be due to a stress syndrome, of which water stress is a key factor (also low nitrogen stress seems to be important too). We have seen more of the UTA symptoms in the Finger Lakes following dry years.

Optimal Stress for Wine Quality

Different processes in the vine respond differently to water stress. Growth processes like shoot growth and early berry growth are very sensitive to water stress, leaf photosynthetic function is less sensitive, and post veraison berry growth is quite resistant to water stress. So there is a level of water stress that allows good leaf function but reduces shoot growth. It appears that in general optimal fruit ripening for good flavor and complexity development requires an intermediate level of water stress that leads to a full, but open, canopy with good fruit exposure, but healthy, functional leaves. Experience and visits to top wine producers in many areas suggest that the optimal stress scenario during the course of a season.

- Adequate water early in the season to have good, but not overly-vigorous, canopy and cluster development through bloom. In the East this typically occurs as soils are moist, the early growth period is normally cool, and there is limited leaf area and water demand.
- Mild stress should gradually develop after bloom so that good fruit set can occur, but the growth of the berries and shoots are slowed.
- After fruit set, and initial berry growth, the canopy should fill the trellis. At this time, the stress should increase so that the shoots slow growth markedly, the berries stop their first phase of growth at a somewhat reduced size with the leaves remaining fully functional.
- From mid-season to harvest the vines should be maintained with enough stress to reduce vegetative growth, but keep the leaves healthy until harvest. There should be some, but not a lot of basal leaf yellowing before harvest if the canopy is kept open. Observations suggest that red wine grapes seem to do best with somewhat more stress than is optimal for white wine grapes although this has not been confirmed.

In New York this period is most commonly the time that water stress develops to be too severe. Maintaining vines in a healthy state at this stage in drought years is the most greatest value of irrigation in New York.

This general scenario was seen in practice at Chateau Cheval Blanc in Bordeaux where the vineyard manager explained that they have very gravelly, stony soil that is extremely well drained. However, water is available deep under the gravel. A few of the roots probably always tap into the water supply, but not enough to overstimulate the vines. In the wet years the gravel does not hold excessive water. In the dry years the vines are stressed moderately, but develop an adequate canopy, and have

enough water to maintain healthy leaves. At the time of the visit near harvest, the topsoil was extremely dry, yet the leaves were not overly stressed. Combined with meticulous canopy management and careful thinning to balance the crop, some of the greatest wines in the world are made.

Another example with more controlled conditions is from a research trial in Washington State at Columbia Crest with Sauvignon Blanc (Wample, 1996) in which they used either a high irrigation or a low irrigation regime all season (HH, LL) or alternated during the period either before or after canopy fill (HL, LH). The full irrigation all season, HH, or full only in the first half, HL, gave somewhat higher yields and similar brix, but the wines were "leafier and more austere, higher acidity and more tart" (Irvin and Clore, 1999). The wines from the L irrigation regime early or full season were both fruitier, but "It (LH wine) was fruitier in the aroma, highlighting melon-like fruit aromas with just a bit of the grassy character of this grape. On the palate the wine was rounder and fruitier..... The LL wine had a tarter, more austere finish." (Irvin and Clore, 1999). These results support the need to have some stress-induced slowing of early growth and to maintain canopy health in the last half of the season. It also suggests that if the stress level is correct early in the season, the amount of water received or applied later is less critical.

Literature Cited

- Cline, R.A., K.H. Fisher , and O.A. Bradt. 1985. The effects of trickle irrigation and training systems on the performance of Concord grapes. p. 220-230. In: Drip/Trickle irrigation in action. Proc. 3rd Intl. Drip/Trickle Irrig. Cong. I, ASAE Publ. 10-85. Amer. Soc. Agric. Engin., St. Joseph, MI.
- Irvine, R. And W.J. Clore. 1999. The irrigation experiment proof is in the wineglass. Wash. Wine Monthly, December.
- Poni, S., A.N. Lakso, J.R. Turner , and R.E. Melious. 1993. The effects of pre- and post-veraison water stress on growth and physiology of potted Pinot Noir grapevines at varying crop levels. *Vitis* 32:207-214.
- Seguin, G. 1983. The influence of vineyard soils on the composition and quality of harvested grapes. *Bulletin de l'OIV*. 56:3-18.
- Wample, R.L. 1996. Issues in vineyard irrigation. *Wine East* 24:8-21, 44.

**Estimates of *Maximum* Mid-summer Water Use per Vine in New York
(Acre-inch = about 27,000 gallons)**

Note that minimally-pruned vines will tend to have similar mid-summer water use rates to normally-pruned vines, but have higher early-season water use, giving perhaps 10% higher total seasonal water use. Values for Missouri and Arkansas are likely to be about 20-25% higher.

Vineyard	Water Use in Gal. per Vine per:		Water Use per Acre in:		
	Day	Week	Gal/Day	Gal/Week	Inch/Week
Single Curtains					
Vinifera	4-5	30	2,500	18,000	(0.7")
Concord/Niagara	5-6	40	3,500	24,000	(0.9")
Minimal Pruned Concord/Niagara	5-6	40	3,500	24,000	(0.9")
Double Curtains					
Concord GDC	7-8	50	4,300	30,000	(1.1")

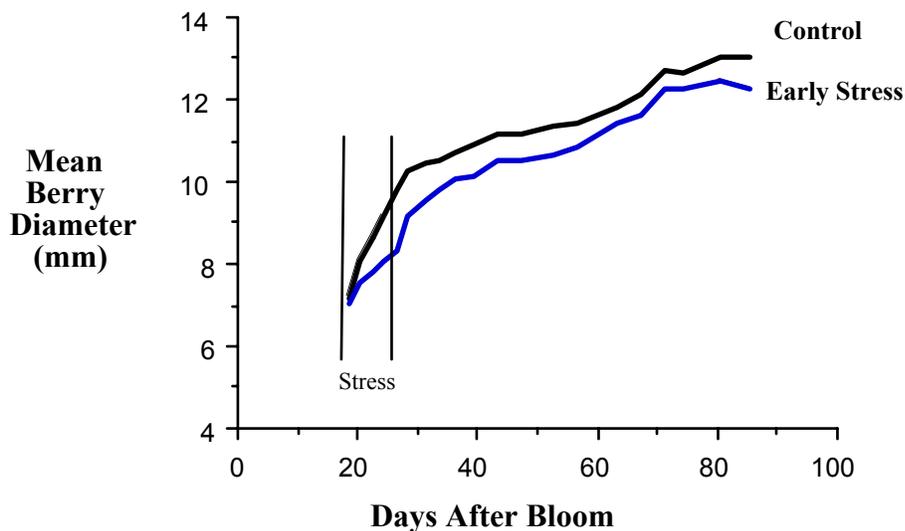


Fig. 1. Growth curves of Pinot Noir grape berries that were well-watered (Control) or were water stressed for only a 10 day period in the cell division growth period after bloom. Modified from Poni et al. 1993.