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Leveraging the grapevine drought response to increase vineyard sustainability

>>> Climate change will likely increase the risk of drought because of increased temperatures and changing rainfall patterns, and growers are already struggling to adapt. This is apparent in the increased use of irrigation in traditionally rain-fed regions, which threatens environmental sustainability[1]. In a water scarce future where irrigation cannot be universally implemented, the use of more drought tolerant varieties and vineyard designs can provide a more cost effective and sustainable solution[2]. <<<

■ The resilient grapevine

Growers have long observed that some varieties are more drought tolerant than others, and in the past may have selected for such varieties. Today, there is a large and under-utilized diversity of varieties available, and science is revealing the complex mechanisms underlying the vine's response to drought[3]. What traits make one variety more drought tolerant than another and which winegrape varieties are the most tolerant? In order to answer these questions we need to understand how a grapevine responds to drought and which traits differ among varieties.

The level of water deficit in plants is measurable as the water potential (Ψ), which reflects the tension in the xylem sap. Ψ is measured directly using a pressure chamber and the measurement of Ψ across different studies, soils, climates, and varieties has allowed the definition of specific thresholds for the intensity of water stress[4]. As drought intensifies, Ψ decreases, and the grapevine responds. Slowed growth is the earliest response, but shortly thereafter the stomata, tiny pores on the underside of the leaf begin to close. Stomata close due to a loss of cell turgor, decreasing the size of their opening that controls the flow of water and CO_2 into and out of the leaf. The speed at which stomata close is specific for each variety (Figure 1) and is related to their maximum water use, or transpiration (E_{max}; under well-watered conditions). Over the short term stomatal closure leads to a reduction in photosynthesis (i.e. CO_2 assimilation) and a decrease in the evaporative cooling of the canopy. Over the longer term it can impair berry ripening and cause depletion of the vine's carbohydrate reserves which can decrease yield in the current season and in some cases in the following season as well.

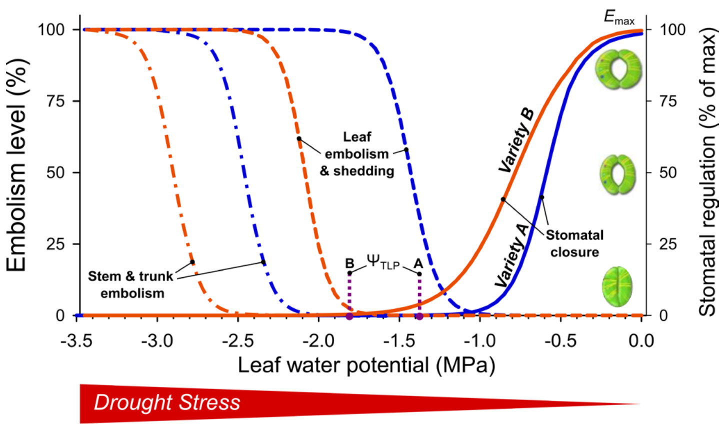

Figure 1. The sequence of vine responses to drought in two generic varieties "A" and "B". Numerous traits such as maximum transpiration (E_{max}), the speed of stomatal closure, the turgor loss point (Ψ_{TLP}), and the thresholds of embolism formation in leaves and stems can differ between varieties and together constitute its drought tolerance.

Throughout the initial phase of the drought response the vine resists reductions in growth and performance through a process called "osmotic adjustment". This is the process by which the vine increases the concentration of ions and small molecules in cells to maintain turgor. But eventually if the drought continues stomata close completely and the vine reaches levels of Ψ where cells lose their turgor and become flaccid causing the leaves to wilt. This point is referred to as the turgor loss point (Ψ_{TLP}), a trait that is also variety dependent (Figure 1). Differences in Ψ_{TLP} between varieties represent, in part, differences in those varieties' ability to osmotically adjust during drought.

After the stomata close, water continues to be lost (but at a much slower rate). So Ψ continues to become more negative and ultimately reaches a critical threshold at which embolisms, air bubbles in the plant xylem that block water transport, begin to form. Extensive embolism in stems can lead to vine death, but the vine has developed a mechanism to protect against this. Vines exhibit a quality referred to as "vulnerability segmentation", where leaves are more vulnerable to embolism than stems (Figure 1). This means that during extreme drought vines shed their leaves to protect their stems and trunks from embolism. Recent work suggests that this mechanism is extremely effective in protecting vines[5]. Nevertheless, extreme drought can result in the loss of the canopy and crop in the current season. As a perennial plant, vines that survive an extreme drought may recover over winter and regrow

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the following season, but may also suffer carryover effects through the depletion of carbohydrate reserves causing lower bud fertility and yield reductions.

During the phases of the drought described above, a number of different traits participate to determine a vine's response to water stress. It is impossible to measure every trait, so we need to identify and integrate those traits that best describe a variety's drought tolerance so they can be measured and compared.

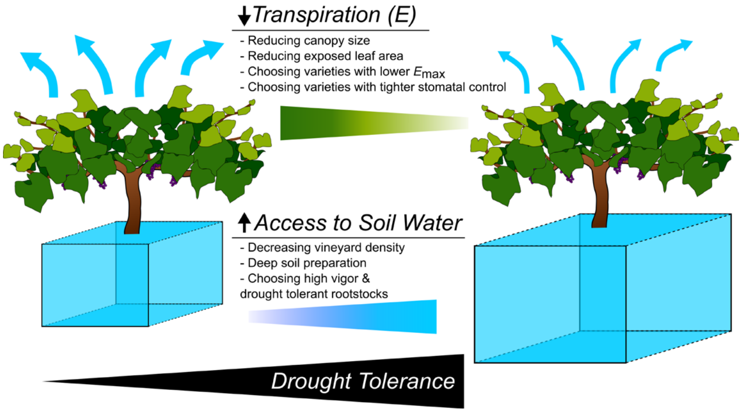

Figure 2. There are a variety of management strategies that can help create a more drought adapted vineyard by decreasing the ratio of transpiration demand relative to the available soil water supply.

■ The drought adapted vineyard

Growers can take advantage of the responses by which vines tolerate drought to increase vineyard sustainability. Some striking examples can be found in the Mediterranean basin, where farmers have grown vines in dry environments for thousands of years, in many cases without irrigation. The ideal drought adapted vineyard can be designed following their experience and many of their observations are consistent with what scientists are discovering about the mechanisms of drought tolerance. Fundamentally, drought adapted vineyards maximize the ratio of water supply to transpiration demand using approaches that decrease transpiration and increase the available soil water (Figure 2). Growers observe that some varieties perform better in dry conditions (e.g. Grenache and Carignan are known to be tolerant) and scientists have found that some of these varieties like Grenache have lower maximum water use (E_{max}) and tighter stomatal control. In some Mediterranean islands (Baleares, Cyprus) highly tolerant varieties exist, and these valuable resources should be further explored[6]. Increasing available soil water can be accomplished by using high-vigor, drought tolerant rootstocks like 110R, 140Ru, and Ramsey[7], but effects on yield and canopy size should also be considered. Choosing soils with higher soil water holding capacity (SWHC), or promoting deeper rooting through deep ripping prior to plantation, can also contribute to increased soil water availability. Reduced planting density increases drought tolerance for two reasons: transpiration is reduced by reducing the canopy size and exposed leaf area at the parcel scale, and available soil water is increased through an increased rooting volume for each vine[8]. A particularly drought tolerant training system is goblet, also known as head-trained or bushvine. Unfortunately, the science is scarce regarding the mechanisms underlying its high tolerance, but it may partly result from reduced transpiration due to a smaller canopy that intercepts less light. When vineyards are designed to be drought adapted, the use of irrigation water can be minimized, or maybe even eliminated, decreasing demand on increasingly scarce freshwater resources and contributing to sustainable winegrape production.

■ Conclusion

The changing climate will likely increase the risk of drought. Through increasing knowledge of the vine's drought response scientists hope to aid growers in choosing the best management strategies to create drought adapted vineyards and increase sustainability in the face of climate change. ■

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