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Title: "Mycorrhizas and mineral acquisition in grapevines"

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This is a comprehensive review of the role of mycorrhizas in vineyards. The author reviews over one hundred studies and distills the beneficial effects of these organisms on grapevine growth and mineral uptake. With the current trend of vineyards receiving less water and being planted in less fertile soils, the author stresses how mycorrhizas are expected to play an increasingly important role in vineyard production.

- Mycorrhizal fungi, also called mycorrhizae or mycorrhizas (literally, "root-fungi"), are fungi that live in association with plant roots and are present in nearly all soils. They are a heterogeneous group comprising at least 37 different species, having a wide range of affinities for different hosts, and varying responses to farming practices. When mycorrhizas associate with a grapevine, the fungi help the vine increase its nutrient uptake by increasing the volume of soil explored and accessing nutrients the vine cannot. In exchange, the vine provides photosynthates to the mycorrhizas. This type of association is called a symbiosis, and both vine and mycorrhizas become *symbionts*). The nutrient exchange takes place through branched tree-like structures inside the vine root cells (arbuscules) whose role is to increase the surface between host and fungus. This is how *arbuscular mycorrhizal fungi*, or AMF, got their name. To put things in perspective, the finest vine root is 500-1000 times larger in diameter than a mycorrhizal filament (or hyphae).

- 1) Besides improving **nutrient uptake**, there are other ways in which mycorrhizas benefit plants and soil ecosystems. 2) They play a role in **protecting plants from soil-borne pathogens**, probably through competition or by modifying the rhizosphere microbial community. 3) They also improve the **stability of soil aggregates** through the physical entanglement of soil particles by their external hyphae. This aggregation has important consequences on infiltration, gas exchange, and erosion control. Finally, 4) mycorrhizal fungi can confer more **drought-resistance** to their hosts .

Grapevines have low root densities compared to other crops and, according to some studies, they actually depend on mycorrhizal fungi to meet their nutrient and water needs for normal growth. This was illustrated in a study on a newly established vineyard in California, in which survival of young plants was linked to the establishment of mycorrhizas in the roots. Even after three years, vines that were stunted were not colonized by mycorrhizas, whereas those vines with normal growth were completely colonized.

- **Soil fertility** seems to be an important factor in mycorrhizal colonization, and high nutrient status has been linked with reduced colonization. In a study in Oregon, the growth of potted Pinot noir cuttings stopped early in a low fertility soil, whereas the same cuttings that had been inoculated with mycorrhizas grew to be 4 times larger in the same period of time. However, cuttings on a rich soil grew equally well with or without mycorrhizal associations. Another factor affecting root colonization is **soil pH**. Two studies found a positive correlation between the amount of mycorrhizas and pH for ranges somewhere between 5 and 7.5. In general, studies suggest that low pH (5 to 5.5) will reduce mycorrhizal colonization of grapevines. Colonization and nutrient uptake do not seem to be influenced by soil texture, since increased nutrient uptake with mycorrhizas was detected in all sandy loam, clay loam, and silty clay loam soils.

- **Nutrient uptake.** Growth increase due to the presence of soil mycorrhizas has been found in all grapevine varieties and rootstocks examined. Authors agree that phosphorus (P), a mineral of limited mobility, is the nutrient primarily enhanced by the presence of mycorrhizas. But others have found increased uptake additionally of zinc (Zn), copper (Cu), nitrogen (N), potassium (K), calcium (Ca), magnesium (Mg), sulfur (S), and iron (Fe), depending on conditions. Still, some authors have reported reduced, rather than increased levels, in shoots and leaves of vines colonized by mycorrhizas as compared to non-mycorrhizal vines. As some authors noted, since mycorrhizal plants have enhanced growth when compared to non-mycorrhizal plants, it is not uncommon for the concentrations of some nutrients in the mycorrhizal plants to appear reduced or diluted. This is why, it is important to measure uptake at the whole vine level, or total content, in contrast with concentration.

- **Whole-vine nutrient uptake.** Concentration of minerals within leaves or petioles does not provide accurate information of nutrient uptake, or gives only a partial picture. Due to the extensive re-allocation of nutrients in vines, changes in *whole-vine nutrient content* (concentration x biomass) need to be considered. A Japanese author was the first to look at whole-vine mineral uptake, in 1961. He found the bulk of macronutrient uptake (N, P, K, Ca, Mg) to be between bloom and veraison. Subsequent studies confirmed that, for both N and K, peak uptake takes place between bloom and veraison. A couple of studies found N losses between harvest and leaf-fall. This suggests that post-harvest application of N fertilizer should be avoided in cooler regions, since uptake does not occur after harvest. Even though one South African study showed similar peak uptake periods for P, N and K (bloom to veraison), a second study in Oregon showed that most P uptake occurs before bloom. The current author believes that vines in the first study were not representative and were probably accumulating luxury amounts of nutrients, since the researchers used potted vines with a continuous nutrient supply.

- **Nutrients in the clusters**. As the author notes, understanding when specific nutrients accumulate in the fruit is critical to be able to manipulate juice quality. Most studies found that the bulk of N movement to developing clusters had occurred by veraison. Attempts to boost cluster N concentration (for instance to avoid a sluggish fermentation) by increasing soil N through fertilization will be inefficient, since most N movement to the cluster has already happened. The excess N will instead encourage excessive canopy growth. In contrast to N, movement of K to the clusters increases linearly from bloom to harvest. Clusters are strong sinks for K throughout their development, and in fact, K seems to be the only nutrient that accumulates at a significant rate in the clusters after veraison. The author notes that a low K concentration is preferable and easier to fix than a high concentration. The former will be seen in foliar symptoms and in petiole analyses, while the latter will manifest itself only after harvest, in the form of a high-pH juice. P, as well as Ca and Mg, are similar to N in that they primarily move to the fruit early in the season.

- **Drought tolerance.** Even though it was once debatable whether mycorrhizas enhanced drought resistance, it is now believed that grapevines avoid drought through the following mechanisms: 1) development of a deep root system, 2) leaf movements to avoid direct sun, 3) sensitive stomatal regulation, and 4) relying on mycorrhizas to obtain more soil water. Some authors showed that mycorrhizal vines that were drought-stressed had significantly less negative water potential, higher rates of stomatal conductance, higher rates of photosynthesis, and improved P uptake and growth, than non-mycorrhizal vines. Additionally, drought stress seems to stimulate mycorrhizal colonization. In a study in Oregon, the author found significantly more arbuscules per length of vine fine root when vines had reduced irrigation (30% ET) as compared to the standard deficit treatment (60% ET).

So how can we manage vineyards for mycorrhyzas?

Things to avoid include:

- *fumigation of soil*, or long fallow periods, so mycorrhizal inocula are not reduced,
- *stock propagated in soil-less media*, which unlike field-grown stock, lacks native populations,
- *high rates of fertilizer*, which hurt mycorrhizal colonization,
- tillage may reduce mycorrhizal colonization indirectly, by renewing the relatively-immobile soil P closer to the vine. In contrast, shallow cultivation does not affect mycorrhizal adversely.
- a *soil pH lower than 5.5* will likely depress mycorrhizal colonization and should be corrected.

Things to favor include:

- *cover crops*, which boost mycorrhizal inocula. (However, some species of cover crop, such as those in the mustard family and lupines, are not hosts for mycorrhizal fungi.)
- *reduced water inputs* will likely increase mycorrhizal colonization. (This, however, does not apply to young vines, as the author found higher colonization in nursery stock after the irrigation rate had been increased.)

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