Potassium fertilization revisions
- Tony Wolf

Nutrient maintenance is one of the many practices required to ensure productivity, plant health, and ds to the subject in the Wine Grape Production Guide (Wolf, 2008). And while many aspects of vine nutrition are more or less "standardized", some aspects are being tweaked and even rewritten. We have, in our own work for example (e.g. D'Attilio, 2014; Moss et al. 2016), been exploring how best to manage vine nitrogen fertilization in situations where the extensive use of vineyard floor cover crops to reduce soil erosion potential and/or to devigorate vines puts vines – and musts (juice) -- at risk of nitrogen (N) deficiency. We've seen under those situations that foliar-applied urea (46% N) can be used quite effectively to increase juice N, but that additional, soil-applied N might be needed to maintain or increase vine capacity where cover crops are used competitively in vineyard floor management ("capacity" is a measure of the vine's potential to produce both vegetation and crop). Although fairly small amounts of nitrogen fertilizer are used in mid-Atlantic vineyards, it is a primary component of Total Maximum Daily Loads (TMDLs) targeted by EPA towards improving water quality in the Chesapeake Bay watershed, and elsewhere.

Potassium (K) is another essential plant nutrient that has come under increased scrutiny in our grape production; not as a contributor to TMDLs, but as a potential contributor to elevated juice and wine pH values. The issues, including relationship of K to juice and wine pH, assessment of K, and potential remedies, were discussed at the Virginia Vineyards Association's winter (2016) technical meeting by myself, Lucie Morton, and Bubba Beasley. In sum, the soil test recommendations for potassium in Virginia often overstate the need for potassium fertilizer. At minimum, this will cost the grower who follows such recommendations added fertilizer and application labor costs, and at worst, it can lead to undesirably altered fruit chemistry under some circumstances. In fact, the soil test basis for potassium determination is of questionable value for vineyards in most of the soils found in Virginia. Accordingly, the low end of the acceptable range of soil K for Virginia vineyards has been revised down from 150 lbs/ac (75 ppm) to 80 lbs/acre (40 ppm). This will affect the rate determination used in the footnote of the potassium table recommendations on page 298 of the Wine Grape Production Guide (Wolf et al., 2008). Instead of 100 ppm, the example should now start with "40 ppm K desired". Potassium fertilizer is not commonly recommended in established Virginia vineyards (see details below), so the revised recommendations are not going to have major impacts on vineyard nutrition, but adherence to the revised fertilizer recommendations should help avoid unnecessary and potentially adverse effects of surplus K, particularly in the pre-plant phase. Starting with a description of the issues, the following provides background details and rationale for the revised K fertilizer recommendations.

Issue: Potassium (K) is unquestionably an essential nutrient for grapevine growth and development. Unlike calcium or magnesium, K is not a structural component of plant tissue; however, it performs a number of critical functions in plant physiology and biochemistry such as:

- A co-transport cation in phloem loading and translocation of assimilates (i.e., sucrose)
- Maintenance of water status in its role as an osmotically active material
- Enzyme activation (> 60 separate enzymes)
- Photosynthetic processes including maintenance of cell membrane potential and the generation of ATP, an energy currency used in cellular processes.

For the purposes of this newsletter article, there's no point in going into details on the metabolic function of K. The practical aspects of recognizing and avoiding potassium deficiency are covered in some detail in the Wine Grape Production Guide. It is important to point out here that K *deficiencies* do occasionally occur in Virginia. Symptoms are usually manifest over an area of the vineyard (such as the thinner soil at the top of a hill), not just on individual vines, and the affected leaves acquire a scorched appearance, with leaf necrosis and reddening (on red varieties) developing centripetally – which means advancing towards the center of the leaf from the leaf margins. Potassium is critical to proper functioning of the guard cells that control the aperture of stomates, the pores that allow gas exchange of leaves to and from the surrounding atmosphere. Inadequate K+ supply affects stomatal regulation of water loss from leaves, but it also affects the performance of roots to absorb water. Both conditions lead to a severe desiccation of the leaves, which is visually apparent as a "scorch" of the tissue. Potassium deficiency in Virginia is most apt to occur with young vines and under drought conditions; potassium deficiencies with older vines on most Virginia soils are rare. Irrigating young vines during droughts can alleviate K deficiency by increasing the availability of K in the soil solution and uptake of K by the relatively small root system of the young vines.

Potassium is absorbed by grapevine roots along with soil moisture. It exists in four principal forms in the soil: (1) mineral structures such as mica and feldspar; (2) as components of secondary minerals such as vermiculite; (3) exchangeable K on cation exchange sites; and (4) in soil solution. The latter 2 forms are readily available to the plant whereas the former two are less readily available but nevertheless do supply K when considered over longer periods of time.

Attendees of the VVA's 2016 winter technical meeting in January and the Eastern Winery Exposition in March heard Ernest (Bubba) Beasley, a geologist with HydroGeo Environmental, provide detail on how clay mineralogy affects the availability of K in the soil solution and, ultimately, availability to the plant. Not all clays are created equal; some, such as vermiculite and smectite have the capacity to bind considerable amounts of K between the crystalline layers of the clay, and that K can be released slowly over time (where "time" is measured in years, not minutes). Clay, along with sand and silt, determine the texture of soil, and many Virginia (vineyard) soils comprise a large component of clay in this textural classification (e.g., clay loam). But even the younger, sandy soils of the eastern coastal plain may contain potassium-bearing minerals that can supply adequate K to the plant.

Adding K fertilizer when it is not needed incurs a financial cost at minimum and may, under some conditions, lead to elevated K levels in grape berries. Elevated berry potassium is a contributing factor to elevated juice and wine pH (Fig. 1).

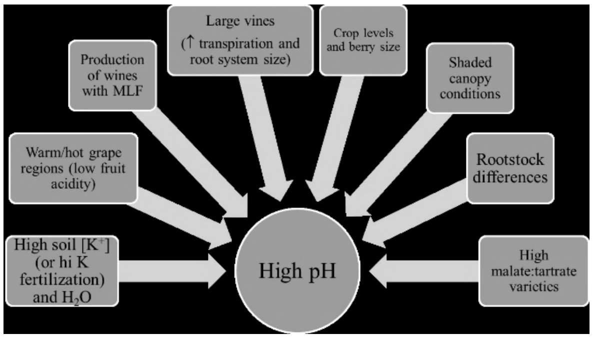

Figure 1. A number of factors, including high potassium concentration, can contribute to elevated juice and wine pH.

The role of juice K and juice (and ultimately wine) pH is complex and while there is a (positive) correlation between juice K and juice pH, potassium is not the only factor that affects pH, as illustrated by Figure 1. Aside from soil K levels, factors that increase the size of the root system (increased K absorption) and canopy (increased transpirational pull), or the evaporative potential of the atmosphere (e.g., high temperatures) will increase K uptake by the plant. Potassium is highly mobile within the plant and berries are a strong sink for K, especially post-véraison. We also know that shading, and consequent premature senescence of leaves, results in a mobilization of K out of these tissues. Between véraison and harvest, the berries are a very strong sink for this K.

The relationship between wine K concentration and wine pH is illustrated by the data collected in the 1980s by Dr. Bruce Zoecklein (Fig. 2). The data loosely show the positive trend or correlation between measured wine pH and wine K concentration for commercial, bottled, Virginia Cabernet Sauvignons. While juice (and less optimally, wine) pH can be adjusted somewhat, most winemakers would prefer to harvest fruit before the pH exceeds about 3.7 to 3.8. Although the correlation between juice K and juice pH is far from perfect, there is some interest and applied effort to limit the uptake of K with the belief that this will concomitantly limit the rise in juice (and ultimately wine) pH. We'll explore those efforts shortly. Just a bit more on K concentration and juice pH. The often positive correlation between juice (and wine) pH and potassium concentration has been reported by a number of researchers (Boulton, 1980; Schmidt et al. 2011; Walker and Blackmore, 2012, to cite just 3).

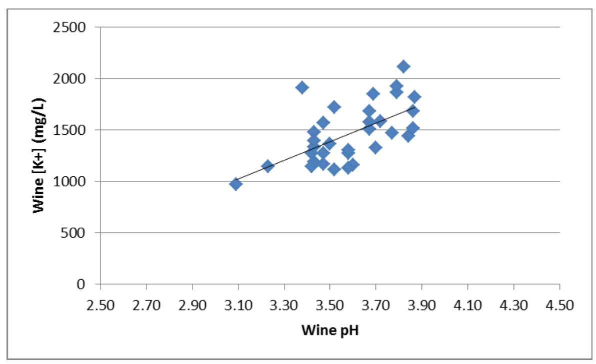

Figure 2. Data from Zoecklein "pH imbalance in Cabernet Sauvignon"; ASEV/ES meeting held in Virginia, March 1987; Data are from 33 Cab Sauvignon wines from Virginia.

Again, it's important to emphasize that this relationship is not perfect; Boulton (1980) for example found examples of wines with low (<3.25) pH yet which had high K concentration. Potassium can exchange for protons (H^+) of tartaric acid in the vacuoles of berry mesocarp cells resulting in formation of potassium bitartrate. Although the liberated protons would be expected to reduce the pH of the vacuole, they are pumped out of the vacuole in exchange for additional K^+. Thus, while K does not have a direct bearing on the measurement of pH, its role in the formation of potassium bitartrate from tartaric acid can raise juice and wine pH. Adding additional tartaric acid to juice to reduce the pH can help in some situations, but it can also lead to a greater malic: tartaric acid ratio, and can result in perceptible tartness in the finished wine.

Determining the need for potassium fertilizer (the "potassium paradox"):

As with most other essential nutrients, we practice and recommend a tripartite approach to assessing potassium status in the established vineyard: soil analysis, plant tissue analysis, and visual assessment of foliage for symptoms of deficiency. Soil analysis is done pre-plant, and then every 2 to 3 years thereafter. Plant tissue analysis should be done at least every other year to monitor vine nutrition, or as needed to diagnose potential nutrient deficiency symptoms. Visual assessment is ongoing. All three tests/observations are based on benchmarks. Soil testing, however, has limitations in accurately predicting the need for additional potassium fertilizer, and current recommendations for K fertilizer are likely excessive in most cases, particularly with established vineyards. This is worth explaining in a bit more detail. Once submitted to diagnostic labs, soil samples are subjected to extraction procedures that have been developed and standardized to release essential elements into a liquid testing solution. Two commonly used extraction protocols are Mehlich 1 and Mehlich 3. Results differ between the two extraction methods, but one can convert results from one to the other with conversion formulae (see below). Following extraction, the solution is then analyzed on equipment that can accurately determine the concentration of phosphorus, potassium, magnesium and other essential elements. There are certain limitations with any soil testing protocol and one fundamental limitation rests with soil sampling. Grape roots are incredibly "patchy" or disperse in their exploitation of soil. If we couple that fact with the inherent variability that we often find in vineyard soils, particularly those of the piedmont and mountain regions, it's not surprising that soil testing provides, at best, a rough estimate of the vineyard availability of potassium and other nutrients that individual vines might have access to. But it gets worse. Soil extraction methods are generally done over minutes (e.g., 5 minutes), whereas grapevines and other plants have days, months and years to perform their own extraction. While "years" might seem excessive, think of the growth and expansion/penetration of a grapevine root system over the course of its life in the vineyard. It is not surprising, therefore, that soil test K results often correlate poorly, or not at all, with corresponding plant tissue (leaf petioles) results. We've seen this poor correlation over the years with comparative soil and plant tissue (petiole) analyses coming from the same vineyard blocks, and it was also observed in the work of Beasley et al. (2015).

The discrepancy is particularly exacerbated when the soil sampling is limited to the top 12 inches of soil and compared to tissue samples from vines that have been grown for 10 or more years (deeply rooted) on the site.

The disconnect between soil K test values and plant response – in fact, the *lack* of response – to added K fertilizer contributed to what Khan et al. (2014) termed the "potassium paradox". Briefly, Khan and colleagues evaluated the response of agronomic crops (such as field corn) to added K in situations where soil testing had led to K fertilizer recommendations. In all but a few cases, there was no response to the added K, and yet recommendations continued to be made for K fertilizer. Moreover, when they evaluated the long-term availability of potassium from corn plots that had not received K fertilizer in 50 years, the amount of soil exchangeable potassium had actually increased by as much as 165 kg/ha K, despite the loss of 900 – 1700 kg/ha K in harvested crop. The underlying soils in that case were principally montmorillonite and illite clays, which are known to release K over time. The contribution of "non-exchangeable" and mineral K for plant uptake is not unique to clays. Sand- and silt-size particles of muscovite and biotite can also be a major source of K. Those primary minerals, as well as K feldspars, are thought to account for the K-supplying power of sandy soils of the Atlantic Coastal Plain.

Virginia Tech's AREC research vineyard serves as an interesting case study of soil K dynamics over time. The vineyard was established in 2006 on a Poplimento-Hagerstown "sandy loam". Soil test results for K are shown in Table 1. The pre-plant soil tests were taken at two separate depths, 0-8 inches, and 9-16 inches. Both sample sets showed adequate K, and no K fertilizer was applied then, or since. Based on our cropping history, the crop removal of K between 2008-2015 has totaled an estimated 214 lbs K per acre or about 20-30 lbs K/acre/year (we crop the vines at about 1.5 – 1.7 pounds of crop per foot of row). Despite the K export from the vineyard via crop, the soil tests have revealed a steady availability of K from the soil.

Table 1. Soil potassium (K) levels over a 10-year period from the AREC research vineyard. See text for details.

	Soil sampling depth (in.)	K soil test results (lbs/acre)
2006	0 – 8	234
2006	9 – 16	159
2011	0 – 12	158
2012	0 – 12	172
2015	0 - 12	246

In sum, there is compelling evidence to suggest that soil testing based on exchangeable K has very limited utility for determining the K availability to grapevines under most soil conditions found in Virginia. Does this mean that soil testing should be abandoned all together? Absolutely not. Soil testing, if done with appropriate sampling procedures, still gives important and useful information on soil pH, organic matter (with some labs), cation exchange capacity, as well as quantitative data on most of the plant-essential nutrients. Even with its limitations, soil testing can signal a *potential* problem with K availability in the pre-plant phase of the vineyard. Obviously, we don't have the benefit of tissue sampling or visual observations at this point in the vineyard's life, and soil testing is the only source of data we have.

Let's look at the current recommendations: The Wine Grape Production Guide (WGPG) (Wolf et al., 2008) currently recommends 75 ppm (150 lbs/ac) as the lower limit of optimal soil K. In other words, K fertilizer would be recommended, proportionally, at soil test levels of 75 ppm or below. The current Virginia Tech soil testing lab recommendations for K associates a soil test range of 51 to 75 ppm (101 - 150 lbs/ac) as a "medium" exchangeable K test result. Soil test values < 28 ppm (56 lbs/ac) would be considered "critically" low. But even so, the Virginia Tech soil testing lab provides the following footnote for K: In loamy sands and deep sandy loams, K tends to move downward and accumulate in the subsoil. For these soils, an L or L- test of the plow layer does not necessarily indicate a problem since plant roots can reach the subsoil K.

A potentially confusing point here is that the WGPG appendices are based on a Mehlich-3 extraction process, similar to that used by Penn State and by Waypoint Analytical (formerly A&L Eastern Labs, http://waypointanalytical.com/Contact). The Virginia Tech soil testing lab uses the Mehlich-1 extraction process. Results of the 2 extractions can be compared if the Mehlich-1 (VT) results are divided by 0.71 to approximate Mehlich-3 (e.g., Waypoint Analytical) results. Thus, 28 ppm (Mehlich-1) becomes 39 ppm – round to 40 ppm (Mehlich-3), which is substantially lower than the 75 ppm fertilizer application threshold currently used in the WGPG. Confused? The following sentence encapsulates my proposed change to the soil test recommendations for K:

> Potassium fertilizer is not recommended pre-plant or to existing Virginia vineyards if the soil test results are at or above 40 ppm (80 lbs/acre) actual K as determined by Mehlich-3 test procedures, or 28 ppm (56 lbs/acre) actual K as determined by Mehlich-1 test procedures. However, young vines should be visually monitored and irrigated under drought conditions to avoid potential K deficiency on soils that are inherently low in exchangeable K.

Plant tissue analysis: So we've considered soil testing, and its shortcomings. What about plant tissue analysis? This has always been the gold standard in the sense that it reveals what the concentration of nutrient element is in the tissue. Generally, grape leaf petioles have shown a greater correspondence to applied potassium than have leaf blades. This, coupled with the logistical (less total tissue collected) ease of petiole testing has led to the adoption of petioles as the tissue of choice. Either bloom-collected or veraison-collected samples will work, although work done by Shaulis and his colleagues in New York State nearly 60 years ago illustrated that samples collected late-summer (70 to 100 days after bloom) were somewhat superior to those collected at bloom. But this is a minor point when the preponderance of our tissue sampling experience for K is considered here in Virginia. Remember: there are places in the midwest and eastern US where K deficiency routinely occurs due to high Mg (dolomitic limestone-derived soils) and/or high (> 6.9) soil pH and associated high Ca base saturation. Neither of these are common occurrences in Virginia. In fact, the vast majority of tissue analysis results that I've seen over the years for VA-grown grapes tend to reflect luxury uptake of K. This is illustrated by the data of Figure 3 which are

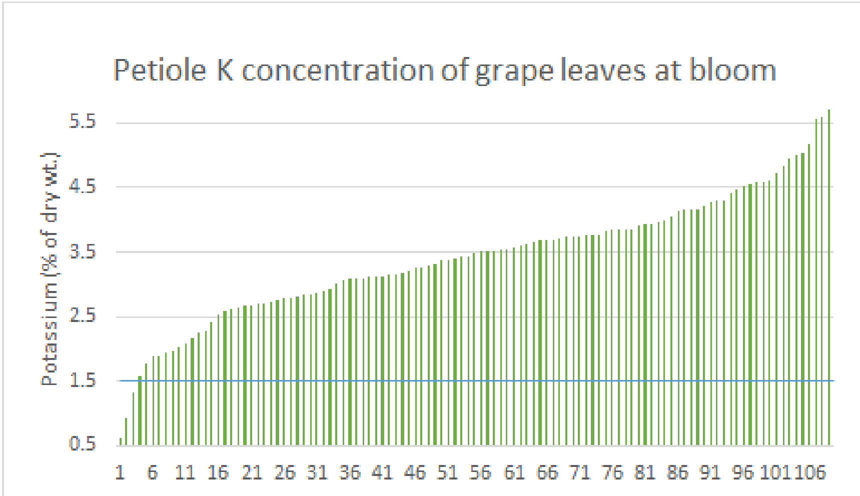

Figure 3. Leaf petiole K concentration of 110 random, commercial samples collected at bloom between 2003 and 2015. The line at 1.5% is the lower limit of tissue K concentration associated with acceptable K concentration in Virginia.

bloom-time petiole K levels for 110 plant tissue tests which I randomly pulled from files of 2003 – 2015. The samples are ranked from lowest to highest K concentration. The horizontal line at 1.5% would be a provisional action threshold for possible K fertilizer application on the basis of bloom-sample leaf petioles. These are "representative" samples, and the vast majority exceed 1.5% K. The 3 samples that fall below 1.5% were young (2-year-old vines) vines. The situation with véraison-sampled vines is no different, most are well above the 1.2% threshold used for K at véraison.

Table 2 provides a comparison of plant tissue analysis standards for K as used by three references: the WGPG, California, and Australia. The tissue standards are comparable, with "adequacy" of K as measured at bloom, starting at 1.50% of petiole dry weight. Late-summer (véraison) samples are a little lower. "Excessive" K values are subject to interpretation, but values above 2.50% would be decidedly surplus at bloom. Again, the vast majority of the samples that we see come through our office are in this "excessive" range (Figure 3).

So, what do we do? Aside from avoiding added K when K is not needed, there is interest in exploring measures that might be used to suppress K uptake. In our own research at Winchester, we have seen two inputs that have had measurable impacts on juice pH at harvest with Cabernet Sauvignon: use of 420-A rootstock and the use of root restriction by planting into root bags (Fig. 4).

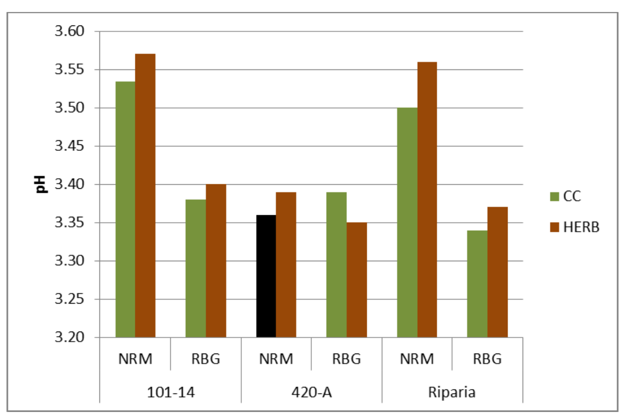

Figure 4. Average juice pH at harvest, 2012-2014, Cabernet Sauvignon, AHS AREC.

Table 2. Standards for Potassium concentration in grape leaf petioles collected at bloom and at véraison and used in the Wine Grape Production Guide, California and Australia.

	Deficient	Marginal	Adequate	Excessive
Wine Grape Production Guide				
Petioles/bloom	< 1.00	1.00 - 1.50	1.50 – 2.50	> 2.50
Petioles/véraison	< 0.80	< 1.20	1.20 – 2.00	> 2.00
SJV, California				
Petioles/bloom	< 1.00	1.00 - 1.50	≥ 1.50	
Petioles/véraison	< 0.50		≥ 0.80	
Australia				
Petioles/bloom	< 1.00	1.00 - 1.50	≥ 1.50	1.80 – 3.00
Petioles/véraison	< 0.60	1.00	≥ 1.20	

Rootstock 420-A is a *V. berlandieri x. V. riparia* stock and our results with Cabernet Sauvignon on this rootstock are consistent with other reports (e.g., Wolpert et al., 2005) showing a reduced uptake of K with rootstocks with *berlandieri* parentage (Figure 5); however, rootstock 420-A has some limitations, one of which has been its virus status, but it (or other *V. berlandieri* hybrids) might be more attractive as they achieve Protocol 2010 standards of the Foundation Plant Services. The reduced uptake of K with use of root bags is consistent with the concept that a smaller root system and a smaller canopy of leaf area would reduce the uptake of potassium. This is illustrated by our data of Table 1 which was collected from Cabernet Sauvignon grapevines at the Winchester Agricultural Research and Extension Center in 2015. Vines had been planted in rootbags (RBG) or not (NRM, not root manipulated) and on three different rootstocks. Note the reduced uptake of K with 420-A rootstock. Although root restriction has produced some very positive results (Hill et al., 2016), I'm only mentioning it here to reinforce the point made earlier with young vines – small root systems often have reduced K uptake; older, larger, more extensively rooted grapevines are typically going to have greater K uptake.

The track record of changing K uptake and thereby effecting changes in berry and wine pH through a direct, soil chemistry approach has had mixed results. Heavy, soil applications of gypsum (calcium sulfate), dolomitic lime (contains a variable, but greater level of Mg than that found in calcitic limestone), or magnesium sulfate (Epsom salt) can under some conditions, reduce K uptake, and the effects are increased when the applied materials are incorporated into the soil. But changing K uptake patterns do not necessarily translate into reduced berry K or reduced berry pH. Small scale trials may be warranted for those wishing to try this approach.

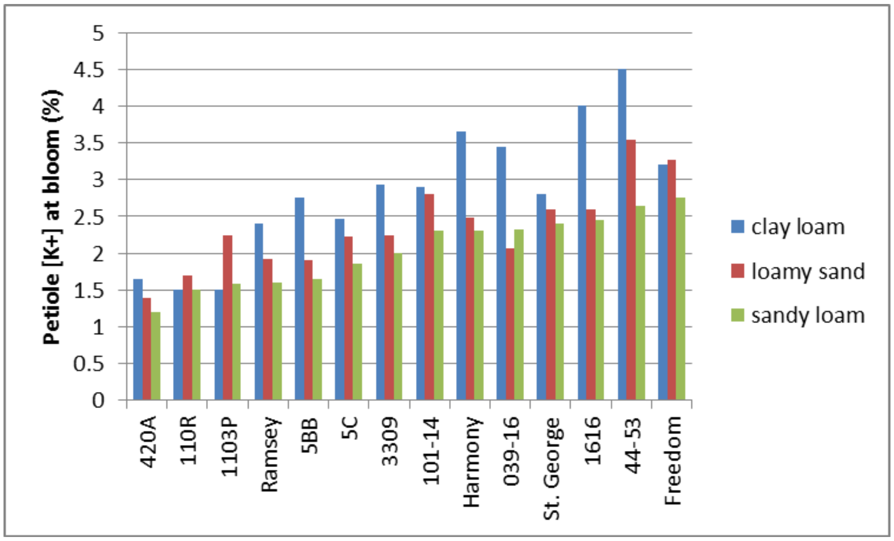

Figure 5. From Wolpert et al. 2005. Lower petiole potassium concentration at bloom in rootstocks with Vitis berlandieri genetic backgrounds. Am. J. Enol. Vitic. 56:163-169. Data are means of 3 sequential years.

Canopy management to effectively limit leaf shading and premature leaf senescence is helpful. This slows the remobilization of K out of leaves and into berries. For example, either lateral shoot removal or partial defoliation of the fruitzone of Tannat vines in Uruguay (similar growing season climate to central Virginia) reduced both must and wine pH (by about 0.14 pH units), reduced must concentration of K, and increased must tartaric acid concentrations (Coniberti et al., 2012). Selecting vineyard sites that promote a relatively small vine/root system would also be expected to help reduce K uptake.

A more in-depth discussion of the relationship between K and berry pH, as well as the role of mineralogy on soil K availability can be found in our web-based resources, here: http://www.arec.vaes.vt.edu/alson-h-smith/grapes/viticulture/extension/index.html

Table 1. 2015 véraison leaf petiole K concentration (% of dry wt.) and juice [K concentration at harvest with Cabernet Sauvignon planted in rootbags (RBG) or not (NRM). Data also include leaf petiole K concentration as affected by three different rootstocks (juice [K] was not measured for all three rootstocks).

Treatment	**Leaf petiole K at véraison (%)**	**Juice [K] at harvest**
NRM	5.71	930
RBG	3.94	701
420-A	3.21	Not measured
101-14	5.10	"
Riparia	4.93	"

Conclusions: Potassium (K) is a soil-derived nutrient essential for healthy growth and development of grapevines. Although K deficiency can occasionally occur in young vines under drought conditions, the far more common situation in Virginia is a luxury consumption of K by the vines. Luxury, or supra-optimal uptake of K does not cause "toxicity" *per se*, but it can be associated with elevated juice and wine pH under some conditions. For this reason, and because all vineyard inputs entail some costs, additions of potassium fertilizer to the vineyard should be carefully considered. For established grapevines, plant tissue analysis (leaf petioles collected either at bloom or at véraison) and visual observations of canopy health provide useful means of assessing vine K status. Soil testing, which is recommended and is very useful for some aspects of soil chemistry, does not predict the mature vine's uptake of K under most conditions found in Virginia; relatively low test levels of exchangeable K in the soil are often associated with luxury uptake of K. Accordingly, our critical values for exchangeable K in soil tests have been revised downward from those currently found in the Wine Grape Production Guide. These changes are expected to have subtle but constructive changes in our vineyard nutritional program and will save money on unnecessary K fertilizer applications in the future.

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