Introduction

Grapevines are dependent on soil mineral nutrient uptake and assimilation to support optimal growth, physiological function, and crop production. Mineral nutrient deficiencies limit plant growth and metabolism, while excessive amounts of some nutrients can result in toxicity. Therefore, it is important to quantify vine nutrient status to evaluate and correct vine nutrient levels so optimal vine growth is maintained. While soil tests are indicative of nutrient availability at the time of sampling, they often do not reflect the nutrient status of grapevines (Schreiner and Linderman 2005). However, it may be prudent to take soil samples in tandem with tissue samples so one can understand what may be causing a vine tissue nutrient imbalance—is the issue with soil nutrient imbalance or soil nutrient uptake? Measuring tissue nutrient concentrations can give an indication of the current nutritional status of vines. In grapevines, tissue tests are typically conducted using petioles (the “stems” connecting the leaf blade to the shoot; Figure 1) or leaf blades. A brief history of tissue testing in vineyards can be found in Schreiner and Scagel (2017). The intent of this fact sheet is to answer when, how, and why growers should sample grapevine tissues for nutrient analyses.

When to Collect Grapevine Tissues

Within the Season

Grapevine nutrient guidelines have mostly been developed for two phenological (growth) stages: bloom and veraison. Bloom, also called “flowering,” is the stage at which flower caps fall from the flowers and fertilization occurs; veraison is the stage when berries soften (red and white cultivars) or become colored (red cultivars) and transition to ripening (Figure 2). Since mineral nutrient concentrations fluctuate in vine tissues over the growing season (Schreiner et al. 2006, Benito et al. 2013, Romero et al. 2013), leaf blades or petioles should be sampled at bloom or veraison to routinely monitor vine nutrient status. Sampling at bloom may allow time for nutrient adjustments to be made within the current growing season, although the success of postbloom fertilization depends on many factors, including method of application, properties of material used, and weather conditions. Sampling at veraison may provide a better indication of grapevine macronutrient levels such as nitrogen (N), phosphorus (P), and potassium (K) due to greater fluctuations of these nutrients that often occur at bloom and their relative mobility within the plant (Schreiner et al. 2006).
### Over Seasons

Tissue nutrient sampling should be conducted on a routine basis to monitor nutritional health before a given nutrient limits crop yield or substantially reduces vine growth. It is unnecessary to sample soils every year. However, conducting tissue tests every second or third year ensures that fertilizer inputs are catered to optimize vine nutrition and meet production goals for each vineyard block. Therefore, routine tissue sampling is recommended for vineyards. It is important to collect samples at the same growth stage each year to avoid errors that result from seasonal fluctuations in nutrients. Nutrient concentrations in plant tissues can be diluted by rapid growth; therefore, it is helpful to monitor vine growth at the time of sampling. It is also wise to keep records of yield and pruning weights for each block to aid in the interpretation of tissue test results. Tissue tests are also used to diagnose suspected nutrient deficiencies or toxicities encountered in the vineyard. We recommend collecting separate tissue samples from both symptomatic vines and healthy vines nearby when trying to diagnose potential nutrition problems. Samples from the healthy vines should be collected from tissues of the same age as those displaying symptoms. More frequent (annual) tissue nutrient testing may be necessary to follow up on a diagnosed nutrient imbalance in which corrective action has been taken (e.g., fertilization, liming, or cover crop incorporation); annual sampling may only be necessary over a few growing seasons or until vine nutrient balance has been achieved.

### Time of Day (Theory and Preliminary Testing)

There has been concern about how, or if, time of day affects nutrient concentrations in tissues. Past results indicate that petiole nitrate concentrations could be transient in samples collected from the same vines at different times of day. Petioles are transportation tissues—their nutrient concentrations may fluctuate with changing water flow through the vines as impacted by changing meteorological conditions. As leaf blades are the “physiological powerhouse” of the canopy and not transportation tissues, their nutrient concentrations would be expected to be less affected by transient changes in weather conditions. We tested this theory by collecting petioles and leaves at predawn and solar noon on two sunny, clear days (at bloom and veraison). Results from these preliminary tests in the southeastern United States did not show considerable variation in tissue N, P, and K concentrations between predawn and solar noon, regardless of the tissue sampled (Table 1). Thus, at least under the humid, subtropical growing conditions where this data was collected, it may not be important to collect grapevine tissues at the same time of day for reliable nutrient tissue concentration comparison across repeated samplings over time. Note that only total N, P, and K concentrations were measured in the tissues; nutrient forms (e.g., nitrate, phosphate) may show different patterns. Similar work should be conducted in drier climates and with detailed data on meteorology and the hydrological, chemical, and physical properties of the soils at the vineyard site. A fundamental take-home from Table 1 is that petioles and leaves contain different concentrations of nutrients. Therefore, it is important to reference the recommended sufficiency ranges that correspond to the grapevine tissue that was sampled (more on this below).

### How to Collect Grapevine Tissues

#### Sampling Within the Vineyard

Tissue samples should be taken from the same rows within a block that are revisited and resampled annually. Samples should be collected from interior rows within uniform blocks, or uniform areas within a block, that represent from 0.5 to 5 acres. Note that scale of sampling will vary greatly with scale of production—some commercial vineyards have one-acre blocks of each cultivar, while other vineyards may have the same cultivar planted over several contiguous acres. Locations with known problems should be sampled separately from healthy (or typical) areas within a block to avoid misdiagnosis of nutrient imbalances in nutrient-sufficient blocks due to contamination with nutrient-deficient blocks. Samples should represent a single area with the same cultivar and rootstock, vine age, soil type, topography, and suspected vine health. Sample using a consistent pattern that reflects the two-dimensional area of interest every year. For example, collect a single leaf from every 20 vines in every 2 or 3 rows (make it fit your particular circumstance). Avoid collecting samples immediately following pesticide applications and from vines located at the vineyard periphery or near wooded areas.

#### Sampling Based on Grapevine Anatomy and Health

Grapevine tissues collected at bloom should be taken from the leaf directly opposite the flower cluster that is closest to the cordon or cane (basal cluster) on a primary shoot (Figure 3, left). Do not sample from a lateral shoot, which grows horizontally from the nodes of the same vines at different times of day. Petoioles are transportation tissues—their nutrient concentrations may fluctuate with changing water flow through the vines as impacted by changing meteorological conditions. As leaf blades are the “physiological powerhouse” of the canopy and not transportation tissues, their nutrient concentrations would be expected to be less affected by transient changes in weather conditions. We tested this theory by collecting petioles and leaves at predawn and solar noon on two sunny, clear days (at bloom and veraison). Results from these preliminary tests in the southeastern United States did not show considerable variation in tissue N, P, and K concentrations between predawn and solar noon, regardless of the tissue sampled (Table 1). Thus, at least under the humid, subtropical growing conditions where this data was collected, it may not be important to collect grapevine tissues at the same time of day for reliable nutrient tissue concentration comparison across repeated samplings over time. Note that only total N, P, and K concentrations were measured in the tissues; nutrient forms (e.g., nitrate, phosphate) may show different patterns. Similar work should be conducted in drier climates and with detailed data on meteorology and the hydrological, chemical, and physical properties of the soils at the vineyard site. A fundamental take-home from Table 1 is that petioles and leaves contain different concentrations of nutrients. Therefore, it is important to reference the recommended sufficiency ranges that correspond to the grapevine tissue that was sampled (more on this below).

#### Table 1

<table>
<thead>
<tr>
<th>Nutrient</th>
<th>Source</th>
<th>Sample Timing</th>
<th>Petiole</th>
<th>Leaf Blade</th>
</tr>
</thead>
<tbody>
<tr>
<td>N (total)</td>
<td>Bloom</td>
<td>Predawn</td>
<td>1.46%</td>
<td>3.04%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Solar noon</td>
<td>1.45%</td>
<td>2.92%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Predawn</td>
<td>1.20%</td>
<td>2.95%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Solar noon</td>
<td>1.21%</td>
<td>2.85%</td>
</tr>
<tr>
<td>P</td>
<td>Bloom</td>
<td>Predawn</td>
<td>0.52%</td>
<td>0.29%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Solar noon</td>
<td>0.53%</td>
<td>0.28%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Predawn</td>
<td>0.33%</td>
<td>0.19%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Solar noon</td>
<td>0.35%</td>
<td>0.21%</td>
</tr>
<tr>
<td>K</td>
<td>Bloom</td>
<td>Predawn</td>
<td>2.08%</td>
<td>1.02%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Solar noon</td>
<td>2.04%</td>
<td>1.02%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Predawn</td>
<td>3.10%</td>
<td>0.98%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Solar noon</td>
<td>2.80%</td>
<td>1.03%</td>
</tr>
</tbody>
</table>

Table 1. Chambourcin N, P, and K concentrations in petioles and leaf blades collected at predawn and solar noon at two phenological stages (bloom, veraison) in 2019.
Detach leaves from the vine and separate the petiole from the leaf blade; either the petiole or blade, but not both, should be submitted for analysis (see below). Analyzing both leaf blades and petioles separately from the same vineyard sample provides the most accurate information of nutrient status, but this doubles the cost of analysis. Collect between 80 to 100 petioles or 30 to 50 leaf blades per vineyard block. Avoid collecting samples from leaves that have been damaged by insects or diseases or from abnormally growing vines or shoots. Place each sample in a clean paper bag labeled with vineyard location, block, cultivar, growth stage, and date. Make a key or draw a map to ensure you correctly log which vineyard blocks and cultivars were sampled so that results can be correlated to the correct blocks. Results will help guide appropriate fertilizer application (if needed) or other corrective actions based on the unique nutritional requirements of individual blocks.

## Why to Sample Grapevine Tissues for Nutrient Analyses

All plant macronutrients and micronutrients are critical for plant metabolism—this is the fundamental reason for quantifying vine nutrient status with tissue analyses. The goals of this publication did not include an in-depth discussion of how individual nutrients impact plant physiological and metabolic function. However, from a commercial and applied perspective, two nutrients, N and K, are particularly important to understand and manage because of their impact on wine quality. Nitrogen is often the key driver of vine growth and productivity, influencing the size of the canopy and the size of the crop and having both direct and indirect effects on fruit composition (Schreiner et al. 2018). Nitrogen status also impacts levels of yeast assimilable nitrogen (“YAN”), a yeast nutrient resource, during wine fermentation. Under-trellis cover crops have been shown to depress vine growth, and this has been linked with lower vine N status in some cases (Hatch et al. 2011, Giese et al. 2015, Hickey et al. 2016). Substantial reduced vine N levels can limit photosynthesis and fruit set. Thus, understanding vine N status may be particularly important when under-trellis cover crops are used and soil organic matter is low. A review of vineyard floor management practices, including vine nutrient management considerations, was recently published (Wolf and Giese 2020). Potassium is important due to its impact on must and wine pH (Schreiner and Osborne 2020). Potassium levels are often sufficient to excessive in eastern U.S. vineyards and grapevine tissues. Potassium is generally positively related to juice and wine pH (Boulton 1980), and excessive K can cause undesirable increases in wine pH (Schmidt et al. 2011, Gardner 2016). Thus, avoiding excessive K levels may mitigate high wine pH and avoid related issues with wine microbial and color instability. Using *V. berlandieri*-based rootstocks (e.g., 420-A) (Wolpert et al. 2005, Hatch et al. 2011, Hickey et al. 2016), avoiding K-based fertilizers, and managing canopy vigor may help moderate grapevine K uptake. See Moss (2016) and Centinari (2018) for a review of the importance of K in viticulture and enology.

## Petioles or Blades?

Which tissue is better to sample for grapevine nutrient analysis: leaf blades or petioles? There are pros and cons for each tissue (Table 2). Petioles are generally advantageous due to their smaller size (compared to blades) and their longer history of use in the United States (Europe has used, and currently uses, blades for grapevine nutrient analysis). Leaf blades are the “workhorse” of the canopy, and nutrient levels within the blade have been better correlated to vine performance as compared to petioles (Schreiner and Scagel 2017). However, leaf blades have been used less extensively in the United States (and therefore may have less robustness in comparison to sufficiency ranges) and require careful washing prior to analysis. Further, because of their relatively larger size, fewer numbers of leaves may need to be sampled per block, which could introduce bias in sampling. Field research that evaluated the correlation of leaf and petiole nutrient levels with vine health and performance

### Table 2. Pros and cons for sampling grapevine leaf petioles or blades for nutrient analysis.

<table>
<thead>
<tr>
<th>Pros</th>
<th>Cons</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Petioles</strong></td>
<td><strong>Blades</strong></td>
</tr>
<tr>
<td>Small size (easier to sample; more tissues needed and thus better chance of a representative sample; less chance for contamination via dust or chemicals)</td>
<td>Stem tissue (not involved in primary metabolism)</td>
</tr>
<tr>
<td>Primary historical use in United States (and therefore much experience and data available to interpret nutrient results)</td>
<td>Less accurate (as transport tissues, there are large diurnal and yearly fluctuation in nutrient concentrations)</td>
</tr>
<tr>
<td>Accuracy (more diagnostic of nutrient deficiencies; less year-to-year variation; larger dynamic range for N concentrations)</td>
<td>Handling needs (require washing; higher chance of contamination from dust and chemicals; mold can develop if not immediately submitted for analysis)</td>
</tr>
</tbody>
</table>

Source: Based on data from Schreiner and Scagel (2017), Schreiner et al. (2018), and Schreiner and Osborne (2018).
would be valuable in determining if one tissue proved superior in diagnosing nutrient status across a wide range of cultivars and growing conditions.

Sample Processing and Interpretation

Immediately deliver or ship grapevine tissue samples to the testing laboratory to ensure freshness. If samples cannot be delivered within one day of collection, then you can rinse samples using distilled water (or very clean tap water) to remove dust and other contaminants, and oven-dry the samples at 140–150°F (60–65°C) prior to delivery to the lab. However, it is best to contact the analytical laboratory that you plan to use and ask about their recommended sample preparation procedures. Several labs conduct mineral nutrient analysis on plant tissue samples. The Penn State Agricultural Analytical Services Lab (https://agsci.psu.edu/aasl) is a local option for Pennsylvania growers, and the University of Georgia Agricultural and Environmental Services Lab (http://aesl.ces.uga.edu) is a local option for Georgia growers. Growers may wish to contact their local county extension educator for assistance with grapevine tissue collection. Reports from analytical service labs include analysis of N, P, K, calcium (Ca), magnesium (Mg), sulfur (S), manganese (Mn), zinc (Zn), boron (B), and copper (Cu). Nutrient sufficiency ranges have been previously defined in regions of the eastern and western United States (Bates and Wolf 2008, Davenport and Horneck 2011, Schreiner and Skinkis 2019). However, when referencing those resources, it is important to note that (1) these are guidelines and not absolute numbers that are customized for each vineyard site and block and (2) ranges are derived from multiple locations, cultivars, and regions. As such, it is important to sample tissues in your own mature vineyard and submit tissue samples for analysis for several years. Comparing tissue nutrient concentrations to vine health status (canopy vigor and foliar color) and performance (crop yield and fruit maturation) will help you develop a nutrient management plan that is catered to your specific vineyard site and growing conditions. Soil sample results and observations of vineyard topography may help explain tissue nutrient values.

Summary

Sound nutrient management is important to sustain vine health and productivity over the lifespan of the vineyard. Tissue sampling is an important tool to objectively quantify vineyard nutrient status. Use the guidance provided herein as a basis for your own vineyard tissue sampling protocol. It is important to treat tissue nutrient concentration results as guidelines. Soil sample results, visual observations of the vineyard topography and soil types, and records of vine growth and crop yield will aid in the diagnosis of nutrient imbalances. Fertilizers should be applied when a combination of objective and anecdotal data has verified that a nutrient imbalance exists. It is also important to note that soil properties (e.g., compaction, dryness, highly acidic or basic pH) may preclude vine nutrient uptake; therefore, soil amendments other than fertilizer may be necessary to ensure sustained and healthy vine nutrient levels.

References


Prepared by Cain Hickey, Penn State Extension Horticulture: Viticulture and Enology, Shane Breeden, Department of Horticulture, University of Georgia; Clark MacAllister, Dawson/Lumpkin County Cooperative Extension Service; Jay Lessl, Agricultural and Environmental Services Lab, Soil, Plant, and Water Lab, University of Georgia; and R. Paul Schreiner, USDA-ARS, Horticultural Crops Research Lab.

extension.psu.edu
Penn State College of Agricultural Sciences research and extension programs are funded in part by Pennsylvania counties, the Commonwealth of Pennsylvania, and the U.S. Department of Agriculture. Where trade names appear, no discrimination is intended, and no endorsement by Penn State Extension is implied. This publication is available in alternative media on request.

Penn State is an equal opportunity, affirmative action employer, and is committed to providing employment opportunities to all qualified applicants without regard to race, color, religion, age, sex, sexual orientation, gender identity, national origin, disability, or protected veteran status.