Progress Report and Continuation Proposal

NIFA Award Number: 2020-51181-32159

Project Title: High-Resolution Vineyard Nutrient Management

Project Type: SCRI CAP

Reporting Period: 9/30/2020 – 6/30/2021

Objectives and Activities

Vineyard nutrient management is critical to sustainably reach production-specific quality standards. However, growers cannot quickly assess grapevine nutrient status. The current standard practice is to manually collect tissue samples (leaves and/or petioles) once or twice during the growing season, combine them into a single sample for vineyard blocks of up to 50 acres, and send them to a lab for analysis. Test results are often unclear due to a lack of well-defined nutrient recommendations. This sampling approach fails to provide any spatial resolution for large vineyards, and fertilizers are often applied based on historical tissue nutrient status data of a vineyard. This project seeks to enable grape growers to make data-driven nutrient-management decisions for spatially heterogeneous vineyards and diverse production markets. Because effective nutrient management is multi-faceted and requires effective long-term solutions, our approach integrates collaborative research and extension by investigators from multiple disciplines and institutions. We will accomplish our long-term goal by pursuing four integrated objectives, each of which will be completed by an intersecting set of key personnel that comprise a Focus Group as described below. Moreover, since travel and other restrictions related to the COVID-19 pandemic prevented us from having an in-person project kickoff meeting, two Zoom meetings were held on December 17, 2020, and June 7, 2021, to solicit feedback from our Project Advisory Panel.

1) Sensors/Engineering: Develop non-destructive, near-real-time tools to measure grapevine nutrient status

Aerial platforms: In California and New York, five unmanned aerial system (UAS) platforms (three at UCD and two at RIT) were used to collect spectral imagery using 5-band multispectral sensors and 170-band short-wave-infrared hyperspectral sensors. Imagery data from 250 vines in commercial vineyards that had induced nutrient deficiencies were collected during 2020 and 2021. Images were taken at times coinciding with tissue sample collection (Objective 3). Processing procedures were developed to radiometrically correct the VNIR and SWIR hyperspectral imagery (HSI), extract individual vine spectra from canopy classified pixels, build 13 different nutrient models using subsets of optimized wavelengths, and finally to create maps of the resulting nutrient predictions. Similarly, data processing procedures were developed to evaluate vine nutrient status based on vegetation indices such as NDRE, NDVI, EGI, and MCARI2. Trials were also initiated with potted vines where a field spectrometer is being used to measure leaf spectral signatures of vines varying in nitrogen (N) or magnesium (Mg) status in parallel with leaf tissue samples that will be analyzed for nutrient content (Objective 3). The potted vine experiments will determine the N and Mg variability within a vine; a leaf's spectral characteristics of N and Mg status; and the relationship between leaf position, nutrient level, and spectral reflectance.

Ground-based platform: In Washington, a ground-based sensing platform was developed at WSU for use with a utility vehicle to estimate and map grapevine nutrient status over 3D canopy surfaces. This mobile platform comprises a hyperspectral camera, a multispectral camera, and an RGB-D (color and depth) camera, all of which are mounted at the same height and face the center of the canopy. Canopy images of 30 vines in each of three commercial vineyard blocks in WA with varying N or potassium (K) treatments were acquired in 2021 at times coinciding with tissue sample collection (Objective 3).

2) Precision Management: Assess efficiency and suitability of precision vineyard nutrient management

Sampling protocols: Multiple in-field tissue sampling strategies are being tested in NY (cool/humid) and WA (warm/dry) to validate and translate sensor data. In random-stratified sampling, select data layers are subject to k-means cluster analysis, and samples are then randomized within each of the identified clusters. In an alternative sampling protocol, SAR imagery from Sentinel-1 and NDVI imagery from Sentinel-2 are used to compare the accuracy and efficiency of random and spatially directed manual sampling.

Data analytics: Our main goal is to translate spatial nutrient sensor data into actionable variable-rate vineyard nutrient management for commercial producers. Several processing steps are required to convert raw sensor data into usable viticulture information for more informed management decisions, and growers need research-based knowledge and access to affordable spatial-data processing tools for successful precision viticulture implementation. This project theme is dependent on and closely integrated with the sensors/engineering (Objective 1) and plant nutrition (Objective 3) themes. Leveraging outputs from the Efficient Vineyard project, MyEfficientVineyard (MyEV), a free web-based spatial-data analytics software platform was developed at Cornell to upload, process, visualize, and download sensor data and vineyard maps (https://my.efficientvineyard.com). MyEV works with point data and interpolates data to a common fishnet grid for comparison. Because satellite and drone imagery is raster data, these data are imported into MyEV and converted into point data for comparison with other vineyard information. For variable-rate nutrient applications, spatial prescription maps are being integrated with precision agriculture hardware/software for variable-rate application of dry or liquid fertilizers. This work will expand project findings to larger scale vineyard applications.

3) Plant Nutrition/Product Quality: Define grapevine nutrient thresholds based on environment and production market

Field trials: Seventeen trials were established in California, Washington, Oregon, New York, and Virginia, mostly in commercial vineyards. These trials will serve as test beds for sensor development, ground-truthing, and validation (Objective 1); to test precision vineyard nutrient management approaches (Objective 2); to modernize tissue sampling for more accurate and timely nutrient assessment in vineyards (Objectives 2 and 3); and to provide data for socioeconomic analysis (Objective 4). Directed soil amendments and supplemental fertilizers were applied to generate nutrient imbalances, using completely random designs, randomized block designs, or split-plot designs were used depending on site characteristics and type of treatments applied. In some cases we took advantage of existing variation in vineyards to sense and map vine nutrient status. In CA, work is ongoing with table grapes (Allison, Valley Pearl, Solbrio), raisin grapes (Sunpreme), and wine grapes (Riesling); in WA, field trials were established with wine grapes (Syrah, Chardonnay, Sauvignon blanc) and juice grapes (Concord); in OR, trials focus on wine grapes (Pinot noir, Chardonnay); in NY, trials were established with juice grapes (Concord) and wine grapes (Riesling); and in VA, field trials include European and hybrid wine grapes (Chardonnay, Chardonel). The use of common varieties (Chardonnay, Riesling, Concord) in both cool/humid and warm/dry regions will ensure that sensor data can be analyzed with respect to interactions between spectral signatures arising from differences in nutrient status versus those arising from other sources of variation (e.g. water stress, high or low temperature). Nitrogen supply is being manipulated in ten of the grower-cooperator trials given the key role that N plays in grape production regardless of market, while K is being manipulated at two sites, and Mg at a single vineyard.

Potted vine experiments: Five experiments are being conducted in CA and WA to explore sensor responses to a wider range of nutrient supply than is possible in field trials (focusing on N, K, and Mg) for wine and table grapes (Merlot, Cabernet Sauvignon, Flame Seedless). Potting substrates range from native soil to perlite depending on the specific focus of each experiment. Sensor data will be collected in conjunction with tissue samples to test differences due to leaf age and position. Plant responses to nutrient application rate and timing, and interactive effects on leaf spectral signatures of nutrient supply and soil moisture will also be tested.

Treatments: All on-farm nutrient trials were established in spring of 2021, and the application of different rates and times for specific fertilizers has begun at all sites. Some additions (split applications for some soil-applied fertilizers, foliar applications) will continue into the growing season. Application methods vary among the trials in accordance with regional practices and infrastructure available at each site. For example, in WA all fertilizers were applied by fertigation (N as UAN32 in three split applications between the 6-leaf stage and fruit set, K as soluble potash at bloom), in OR, N was also applied as UAN32 via fertigation, K was applied to the soil or to the foliage, and Mg is being applied to the foliage, while in VA, N was applied to the soil as $CaNO_3$, and urea will be applied to the foliage in half of the plots within each of three varying soil N rates.

Sampling and analysis: Baseline tissue and/or soil samples were collected from the various field sites during the 2020 growing season, in anticipation of receiving project funding. Bloom-time leaf and petiole samples were collected at all sites in 2021 and are being prepared for nutrient analysis. Additional tissue samples have been, or will be, collected at different times in various trials, including dormant season canes, whole shoots at 6-leaf stage, berries or whole clusters at lag-phase and harvest, leaves and petioles at veraison, and whole leaves at leaf-fall. Macro- and micronutrients were analyzed in tissue samples from most of the field trials. The remaining samples were dried and archived so that they can be analyzed in bulk to reduce costs. Total N and C are analyzed by dry combustion (Dumas method); nitrate and ammonium following KCl extraction; P, K, S, Ca, Mg, Na, Zn, Mn, Cu, Fe by ICP-OES following nitric/perchloric digestion. Matching the timing of tissue sampling, the Sensors/Engineering team has been collecting spectral signature data from the wine and juice grape field trials in WA and NY, and from the table and wine grape field trials in CA (Objective 1). Spectral signatures will be correlated with tissue macroand micronutrient status. Plant growth, yield, and fruit composition data will be collected from all field trials, and effects on wine quality will be evaluated in WA, OR, and VA.

4) Social Science/Extension: Estimate economic impact and feasibility of vineyard nutrient management, extend knowledge to stakeholders, and advance understanding of grower decision making

Survey: An industry survey was developed and vetted with the Project Advisory Panel during fall-winter 2020/21, and administered online from March 16 to May 25, 2021. Extension viticulturists and grower associations nationwide invited industry members in their states/regions to participate. The survey was analyzed by the OSU Survey Research Center during June 2021.
Economic analysis: For an initial economic meta-analysis, historical vineyard data were obtained that include mineral nutrients, yield, and fruit composition for farms in OR and NY. The first dataset includes OR vineyard data from 2012-2018 for 22 farms and comprises nutrient and fruit composition data along with farm-level characteristics. The other sources of data include nutrient status, vegetative growth, yield, skin and pulp metabolites, and wine metabolites from 2012-2015 for farms in OR and spatial grids with nutrient data for a vineyard in NY. Weather data were obtained from OSU's PRISM group in a 2.5-km grid across the US and were used to calculate nonlinear weather responses using degree days binned across various thresholds to establish more realistic impacts than simple average temperature mid-points. Our initial exploratory analysis used these data to produce correlation and scatter plots, and a principal component analysis (PCA) for yield and fruit composition. We are soliciting more data from the project team and are contacting growers who are willing to share datasets as indicated in the industry survey.
Outreach: A logo and branded project name (HiRes Vineyard Nutrition) were developed at OSU for project recognition and use in outreach activities. A project website (highresvineyardnutrition.com) was developed and includes information on the project team, news, events, and grower resources. Reports will be added to "Research Findings" as they are developed by the project. Three social media networks are being used, including Twitter, Instagram, and LinkedIn. We recognize that social media is an important information exchange venue for industry, and it is critical for projects to be sharing information here during the research process.

Accomplishments

1) Sensors/Engineering

The UAS-based data collected in CA and NY were radiometrically calibrated and georectified to Google satellite images. Remotely sensed datasets were created for the early 2021 growing season and also for some data from 2020. So far, models developed using UAS-based images for each nutrient with ≤10 optimized HSI bands perform slightly better than nutrient models produced with the benchmark 5-band multispectral imagery. Per-vine grid layers have been created and georeferenced for the three field trials in CA and another commercial vineyard for which processed data (e.g. vine N status maps) were shared with the vineyard management team as a preliminary decision support tool for testing in a real-world scenario. Processing of color, depth, HSI and multispectral images collected using the ground-based platform in WA is ongoing to develop spectral indices of vine canopies that correlate best with tissue nutrient status.

2) Precision Management

Validation sampling protocols were established in five grower cooperator vineyards in NY and three in WA. Additional commercial test vineyards and nutrient management activities have been identified in NY and VA. Prototype configuration was developed to convert vineyard spray equipment for use with variable-rate liquid urea applications. Moreover, raster plug-in software was developed and added to the MyEV platform.

3) Plant Nutrition/Product Quality

Field plots were successfully established with vine nutrient deficiencies. Baseline data were generated from pruning weights and nutrient analysis of plant tissue and soil samples collected from vineyard blocks in 2020 and/or 2021. Preliminary data from 2020 show that leaf blade nutrient levels are not well correlated with petiole nutrient levels. In berries, N concentrations declined 2.5-fold from preveraison through harvest, P concentrations decreased 1.7-fold, while K concentrations decreased only 26%. Depending on the variety, nutrient removal with harvested fruit amounted to 2-3 lbs N, 0.6-0.7 lbs P, 5-7 lbs K, and 0.4-0.5 lbs Mg per ton of grapes. Nutrients contained in abscised leaves at the end of the 2020 growing season amounted to 35-50 lbs N, 3-9 lbs P, 15-30 lbs K, and 15-20 lbs Mg per acre. A preliminary conclusion is that plant nutrient status, crop yield, and leaf loss (e.g. due to wind) vary among vineyards and varieties, and thus all three factors are important to estimate replacement fertilizer rates. This information is critical to define new nutrient guidelines based on productivity and quality for producers in different growing regions and markets, and to develop new tissue sampling protocols that better reflect in situ vine nutrient status and vine responses to nutrient manipulation. Initial data from the field trials initiated in 2021 show that early season leaf chlorophyll and shoot growth remained unaltered by varying N, K or Mg supply treatments. Harvest has already begun for some table grape trials in CA, and the ensuing workload has not afforded time to analyze data already collected from these trials.

4) Social Science/Extension

The industry survey was completed by 322 individuals, primarily grape growers (remainder were consultants and management companies), representing 176,000 acres, which is approximately 10% of the US vineyard acreage. The survey provided key information on how growers are sampling their vineyards and making nutrient management decisions, mostly from vine tissue sampling at bloom or veraison using petioles combined with periodic soil analyses. We gained useful information about how growers are sampling (1 sample per 1-5 acres), and how frequently (annual or less frequently). The top five most important nutrients they manage are N, K, B, Mg, and phosphorus (P), respectively. Many growers are working with crop consultants to devise nutrient management plans, and many are not currently using technology for nutrient management. While respondents indicated that vineyard nutrient management accounts for only ~10% of their annual production budget, they view proper nutrient management as critical to production goals, as 65% rated nutrient management as being very important to extremely important to quantity or quality of grapes produced.

An initial exploratory metadata analysis of the OR vineyard data to examine relationships between yield and berry composition found the top three positive correlations were for berry K, titratable acidity (TA), and total phenolics, while the bottom negative correlations were catechin and anthocyanins. With correlations and marginal impacts, we can begin to untangle the economic relationships between berry composition and yield. The PCA indicated that berry N (yeast-assimilable N, amino acids, ammonia) and anthocyanins were the most influential variables. These results provide a basis for the economic modeling strategy going forward and will be helpful in assessing nutrient impacts on quality and economics within multi-year, multi-vineyard datasets.

Information about the project and team has been created through the website and social media venues as noted previously. Given the early nature of this work, relatively few presentations and no publications have occurred to date. Presentations include:

Bates T. Vineyard nutrition update and variable-rate management. Lake Erie Grape Program Grower Meeting. June 23, 2021.

Bates T. and Walter-Peterson H. MyEfficientVineyard software for precision viticulture. Finger Lakes Grape Program Grower Meeting. June 22, 2021.

Bates T. Leveraging sensor information for variable rate vineyard management. ASEV-NGRA Precision Viticulture Symposium. June 21, 2021.

Pourreza A. Monitoring grapevine nitrogen status by aerial and ground spectral sensing. ASEV-NGRA Precision Viticulture Symposium. June 21, 2021.

Pourreza A. Identification of nitrogen deficiency in table grape by spectral sensing. CalPoly College of Agriculture Seminar. February 26, 2021.

Pourreza A. High resolution nitrogen monitoring in vineyards. California Plant and Soil Conference. February 1, 2021.

Pourreza A. Remote sensing to monitor grapevine nutrient status. San Joaquin Valley Virtual Grape Symposium. December 16, 2020.

Schreiner R.P. Grapevine nutrition: requirements, tissue tests and mycorrhizas. Penn State and Cornell Universities - Vineyard Outreach Webinar Series. January 20, 2021.

Skinkis P. Rust mites, vineyard floor management, and nutrition. Nutrien Grape Day, March 24, 2021.

Stories about the project, based on interviews with project team members, appeared in the following outlets:

- Flyby for fertilizer (by K. Prengaman). Good Fruit Grower 71: 60-65 (2020).
- https://digitalag.ucdavis.edu/research/nitrogen-tablegrape-rs
- http://news.cahnrs.wsu.edu/article/major-grant-helps-grape-growers-better-manage-nutrients
- https://news.cornell.edu/stories/2020/10/new-grant-fuels-better-nutrient-management-vineyards
- https://www.rochesterfirst.com/news/digital-exclusives/rit-professor-co-designed-drone-imaging-system-that-can-determine-grape-farm-health
- https://graperesearch.org/newsletter (September issue)

Continuation Plans

We are currently on target to achieve project goals. Baseline soil and tissue sampling was conducted, and field trials were initiated in 17 vineyard blocks of wine, juice, table and raisin grapes. Five potted vine experiments were initiated with four varieties. All proposed experiments are underway and progressing on schedule despite difficulties in appointing graduate students due to hiring and travel issues caused by the COVID-19 pandemic. Development of grower-friendly decision-support tools for vineyard nutrient management has already started; these tools will help optimize inputs and business profitability via improved vineyard productivity and fruit and product quality, while minimizing adverse impacts on the environment that result from overapplication of fertilizers. The tools—remote sensors that determine grapevine macronutrient and micronutrient status coupled with modern plant tissue sampling protocols and precise vineyard mapping—will give growers near real-time in-field access to spatial and temporal metrics for vine nutrition variability. These tools will enable growers to act upon these measures via variable rate synthetic or organic fertilizer application. Impacts on crop yield, quality, and economics of production for all grape sectors—fresh, wine, juice, raisins—are being quantified. Anticipated project deliverables include 1) non-destructive sensing tools to measure vine nutrient status; 2) more precise, region-specific plant tissue sampling procedures and guidelines for more precise nutrient management; 3) decision-support tools for vineyard nutrient status mapping to aid variable-rate nutrient application and evaluate economic performance; and 4) website and durable extension publications outlining best nutrient management practices and economic impact of improved nutrient management and sustainability.

1) Sensors/Engineering

We will continue to collect spectral imagery data of vine canopies using ground-based or aerial sensing systems throughout the 2021 growing season and refine our approach to imaging in 2022 and 2023. Consequently, these imaging campaigns will be repeated several times over the course of each growing season in different states. Imaging will coincide with tissue sample collection as outlined for Objective 3 to correlate sensor-acquired data with tissue nutrient status. We will continually improve the sensing systems (including development of over-the-row sensing platform for 3D canopy reconstruction) as new challenges are identified in the field trials. We will also continue data processing to estimate grapevine nutrient status, focusing mainly on N, K, and Mg while also attempting to determine P and micronutrient status. Using the tissue nutrient results from lab assays (Objective 3), hyperspectral data mining and machine learning models will be developed to predict nutrient-deficient vines based on their leaf spectral characteristics collected from ground and aerial sensing systems. Both spatial and temporal variability will be assessed to provide robust insights into nutrient status of vines and help guide variable-rate nutrient applications (Objective 2). The inclusion of early and mid-growth stage imagery and different varieties will help to refine optimal wavelengths from HSI to model each nutrient, and to develop both universal and production-goal-specific nutrient monitoring.

2) Precision Management

We will continue to support and test the development of potential nutrient sensors (Objective 1) which will be integrated with other spatial viticulture data, such as soil and yield maps. Likewise, new plant nutrition information for varieties, climates, and markets will be used in spatial decision support for variable-rate management. One critical function of the precision management theme is to bridge sensing technology and vine nutrition information (Objective 3) by validating high-density sensor data with low-density in-field tissue nutrient sensing to generate sensible high-density nutrient vineyard maps. Current activities test various sampling methods in data validation that are both accurate and cost-effective for growers. Using cooperating growers as a target audience, validated nutrient maps are being layered with other vineyard information in the MyEV web-based spatial-data software for growers. Finally, spatial nutrient management prescription maps will be integrated with variable-rate fertilizer spreaders/sprayers, and precision nutrient management will be evaluated through vine health, nutrient status, and return on investment (Objective 4).

3) Plant Nutrition/Product Quality

We will continue to collect tissue samples and physiological data from all field trials and potted vine experiments throughout the 2021 growing season. The field trials will be continued through at least 2023, and the potted vine experiments will be repeated and/or adapted to evolving research needs through 2024. The vineyard blocks in CA and WA will also be used by the Sensors/Engineering focus group to remotely assess vine nutrient status in 2021-2024, and the OR and VA sites starting in 2022 (Objective 1). Our tissue analysis data will serve to ground-truth and validate the non-destructive vineyard nutrient status monitoring tools based on sensor data, in addition to developing improved tissue sampling protocols and enhanced management practices for spatially diverse vineyards (Objective 2). Two of the vineyard blocks in WA (Syrah, Chardonnay), two in VA (Chardonnay, Chardonel), and one in OR (Chardonnay) will be harvested for winemaking each year to assess impacts of vine nutrient status on final product quality. Fermentation kinetics, wine composition, and sensory analysis on finished wines will be conducted. In addition, yield components, soluble solids, pH, and TA will be measured in all wine and juice grape trials, and yeast-assimilable N and amino acid profiles, and/or anthocyanins and tannins will be determined in a subset of the N trials in wine grapes. Quality of table and raisin grapes will be assessed based on berry weights, dimensions, firmness, color, soluble solids, and air-stream grade.

4) Social Science/Extension

Outreach efforts will increase as research results are generated within the project. A podcast series is being planned for production during the second half of 2021 and release in 2022 and beyond. Content will continue to be generated and shared with industry and the public through the social media outlets and the project website. We will develop "train the trainer" programs and products (publications, resources) for extension specialists nationwide in 2023 and carry out through 2024 to help guide standard practices for nutrient assessment across regions and grape markets, and share new sampling methodologies and sensor technologies developed from the project.

We will develop two decision-support tools that may ultimately be merged into a single tool. The mapping tool developed at UCD will include sensor-based plant status maps (e.g. N maps) with per-vine precision (Objective 1) and a method for defining management zones. These zones can be used as a prescription map for both variable rate nutrient application (Objective 2) and directed sampling (Objective 3). We have already developed a prototype mapping tool and shared it with a cooperating grower for practical testing during the 2021 growing season. The economic tool developed at OSU will allow growers, crop consultants, and/or crop advisors to input nutrient readings from the sensors (or automatically) at a given time during the growing season. Using this real-time data along with training data from Objectives 1-3 and results from our economic models (Objective 4), the tool can provide information about a vineyard's current nutrient status. It will then project out yield or nutrient deficiencies for the remaining season and show different scenarios based on different decision points. Ideally, we can offer an optimal strategy given farm-level inputs to optimize yield and/or fruit composition by grape market. Both decision tools can be hosted online, either on regional web servers or on the MyEV platform, with an easy-to-use interface, and generate reports for tracking results.

During early 2024, a second industry survey will be administered to address key goals and outcomes of our research. That survey will be tailored to understand changes in knowledge, practice, or acceptance/adoption of new technologies that are developed, which will also permit us to analyze barriers to technology adoption in the US grape sector.

As we obtain more datasets, both from cooperating growers and from the project field trials (Objective 3), we will compile and analyze them together using econometric models to disentangle marginal effects of nutrients on fruit quantity (yield) and quality (multiple parameters) and to compare outcomes across vineyards and regions. The models will test the impact of different nutrient management decisions on yield and quality, as well as costs and returns, at different vineyard locations. Results will contribute to an economic impact assessment of how decisions influence vineyard costs and farm income. A full meta-analysis report will be developed that includes a literature review, an econometric model that incorporates yield and nutrient data, and a discussion of results and implications going forward. We will also continue to engage with the other members of the project team to provide results for developing experiments related to the economic impact and return on investment of nutrient management on vineyard production.