Project Title

Cost effective spatial data visualization and decision support for small and medium-sized vineyards.

Project Type

Standard Research and Extension

Focus Area Being Addressed

Agricultural Economics and Rural Communities

Small and Medium-sized Farms program area priority

Program Staff

Name	Title	Affiliation	Address	Email
Terence Bates (PD)	Senior Research Associate	Cornell University	6592 W Main Rd, Portland, NY 14769	trb7@cornell.edu
Katie Gold	Assistant Professor of Grape Pathology	Cornell University	Barton Laboratory, 15 Castle Creek Drive Geneva, NY 14456	kg557@cornell.edu
Yu Jiang	Assistant Research Professor	Cornell University	301 Hedrick Hall, 635 W North St Geneva, NY 14456	yj522@cornell.edu
Hans Walter-Peterson	Extension Specialist	Cornell Cooperative Extension – Finger Lakes Grape Program	417 Liberty St., Penn Yan NY 14527	hcw5@cornell.edu
Jennifer Russo	Extension Specialist	Cornell Cooperative Extension – Lake Erie Grape Program	6592 W Main Rd, Portland, NY 14769	jjr268@cornell.edu
Nick Gunner	Full-stack software developer	Orbitist LLC.	2159 Bedell Rd, APT B., Grand Island, NY 17072	ngunner@orbitist.com

Introduction

Project Goals: Using small/medium sized vineyard operations in the northeast US as a target audience, the goal of this project is to increase the adoption of precision viticulture by (A) completing the development of a web-based spatial data platform for growers, (B) demonstrating the value of precision viticulture through research field trials, and (C) providing experiential learning activities for producers to implement in their own operations. Our model for this project is to provide the process (software tools), content (research-based information), and experience (hands-on learning activities) for transformational education (Blewett et al. 2008) and improved adoption of spatial-data-driven vineyard management. Although we will use New York vineyards as our model system, collecting and using spatial data for variable-rate management decisions is not unique to vineyards. Our expectation is that the tools and information developed in this project would be applicable to all small farm operations in the U.S.

Theme 1: Developing an accessible, intuitive, and affordable spatial data management software platform for small and medium-sized farms. This new project proposal stems from the completion of the USDA-NIFA-SCRI project, "Precision Vineyard Management: Collecting and Interpreting Spatial Data for Variable Vineyard Management" (Award Number 2015-51181-24393). It is also known as the "Efficient Vineyard" project to industry stakeholder groups (https://www.efficientvineyard.com/overview). The main goal of the Efficient Vineyard project was to investigate the use of precision agriculture tools to (A) measure vineyard soil, canopy, and crop characteristics with proximal sensors (B) model spatial information to inform spatial management decisions, and (C) manage vineyard blocks with variable-rate applications. Successful activities included:

- Development and/or evaluation of proximal sensors to measure soil, canopy, and crop vineyard characteristics (Taylor et al. 2013, 2016, Nuske et al. 2014, Mirbod et al. 2016, Pothen and Nuske 2016).
- Translation of sensor data into viticulture information through in-field validation protocols (Taylor and Bates 2012, Brillante et al. 2017, Taylor et al. 2017).
- Integration of multi-layer vineyard information through data fusion (Taylor et al. 2019).
- Generation of vineyard prescription maps through spatial decision support (Guillaume et al. 2020).
- Application of variable-rate management through semi-automated mechanized implements (Bates et al. 2020).
- Evaluation of spatial-data-driven variable-rate management on vineyard production efficiency (Bates et al. 2018).

The technological components of digital agriculture, from new sensing mechanisms to spatial data analytics to variable-rate mechanized management, are developing quickly (Tisseyre et al. 2007, Matese and Di Gennaro 2015). Furthermore, there is growing evidence that the application of digital agriculture solutions is having positive impacts on farming and the environment and will only continue to grow (Bramley 2010, Whelan and Taylor 2013). The goal of this new project proposal is not to repeat the Efficient Vineyard project, but to make precision viticulture accessible and affordable for the small producer.

In the Efficient Vineyard project, we observed that early adopters of digital agriculture technologies tended to be large farm corporations who had the resources to invest in precision agriculture teams, training, and equipment. Small vineyard operations, however, lacked the tools, knowledge, and experience to get started with spatial-data-driven farm management. A common small vineyard stakeholder response was, “I see the potential value in the Efficient Vineyard technology, but my business operation does not justify investing $20,000 in field computers and software to collect and process data.” The barrier to adoption also appeared to be weighted toward spatial data processing and use. Growers are becoming more familiar with proximal and remote sensing, whether they own an inexpensive canopy sensor or pay for imagery. Similarly, producers are familiar with farm implements and potential variable-rate applications. The main barrier was in translating sensor spatial data into useable management maps without having to hire a GIS specialist to process the data.

Using this producer feedback, we identified the need to develop and deliver a cost-effective and approachable digital agriculture tool to small and medium-sized producers so they may experience the benefits of spatial-data-driven farming. Toward the end of the Efficient Vineyard project, Terry Bates (Cornell) and Nick Gunner (Orbitist) began developing a free web-based spatial data processing platform for grape growers called MyEfficientVineyard or MyEV (https://my.efficientvineyard.com/login). Our goal was to develop the software to upload, process, visualize, and download spatial vineyard data.

In 2020, we completed this goal and the MyEV software was made live for growers to use. As of June 2021, 196 free user accounts were established, both in the U.S. and internationally (Figure 1). The users are predominantly small vineyard operations or small farm-wineries. MyEV is also being used by viticulture researchers in the new USDA-NIFA-SCRI project, High-Resolution Vineyard Nutrient Management (Award Number: 2020-51181-32159), led by Markus Keller at Washington State University. We have received substantial feedback from grower and research stakeholders on improving MyEV by adding functions to the platform to make it a more complete spatial data processing resource.

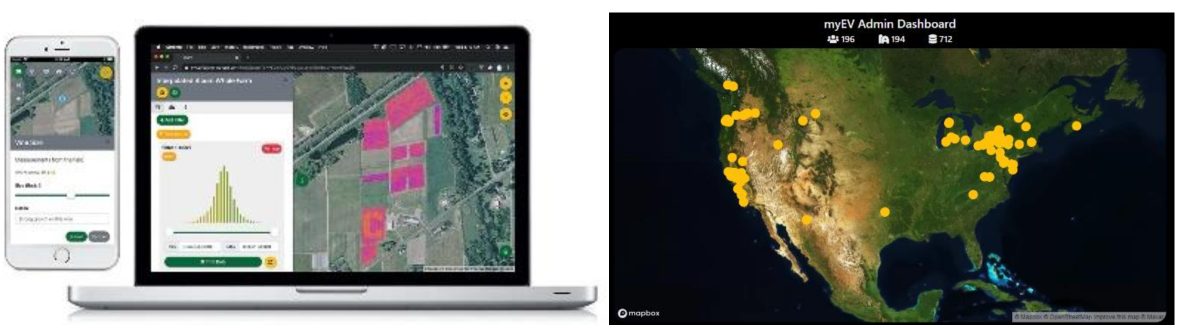

Figure 1. The MyEfficientVineyard (MyEV) is a free web-based software platform for farmers to collect, upload, process, and visualize spatial data in their own operations (left). Currently there are 196 vineyard users in the US and internationally (right). We propose to complete the development of the MyEV tool as a spatial data resource for small vineyards and farms.

MyEV already exists with functions related to uploading, visualizing, and interpolating spatial point data from proximal sensors and human observations through a smart phone application. We propose to complete MyEV as an easy-to-use spatial data processing platform by developing additional functions to import common raster data, assist with data validation and translation, and generate spatial prescription maps for variable-rate management applications (Figure 2).

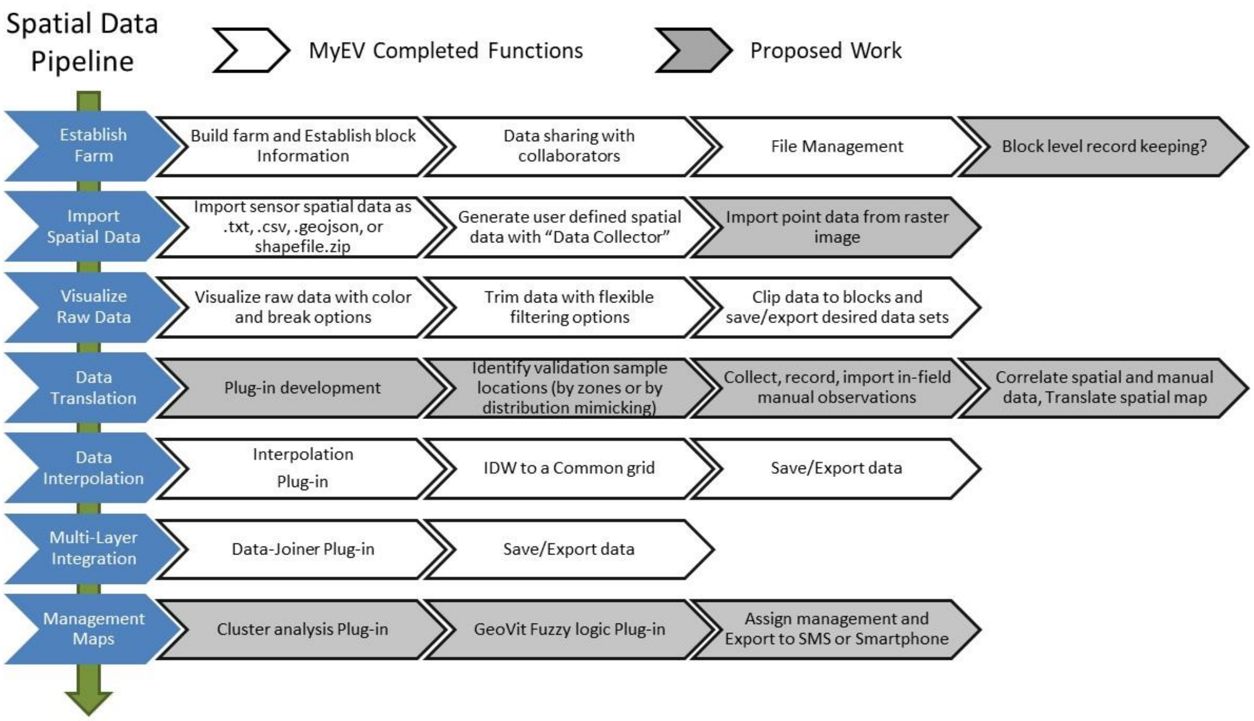

Figure 2. The spatial data pipeline needed to convert collected spatial data into variable-rate management maps. MyEV already has many functions completed for importing, visualizing, and processing sensor or human-collected spatial data. The gray shaded areas indicate the proposed software development to complete the MyEV platform.

Theme 2: Evaluating strategic and efficient deployment of spatial data validation protocols and spatial decision support for efficient variable-rate management. The two main areas we propose for MyEV software development are in "Data Translation" and "Management Mapping." Both areas require in-field research support to determine the most cost-effective approach for growers.

Data Translation: Agricultural sensors and satellite imagery produce relative maps which must be validated with in-field measurements for translation into useful information. Many growers miss the importance of the validation step or do not have an in-field validation plan. Manual sampling can be expensive in time and labor, so producers want methods that are both accurate and cost effective. Research is needed to determine when random, stratified-random, or fully directed sampling is best in production situations.

Management Mapping: Once spatial data is collected, validated, translated, and integrated using MyEV or other software, the goal for the producer is to generate a sensible spatial prescription map for variable-rate management. One spatial-statistics method uses k-means cluster analysis on multiple user-defined layers to generate a spatial vineyard map with distinct management classifications. These management classifications or “zones” are used in the application of variable-rate management. An alternate method is to use fuzzy-logic inference models where the end user defines management rules on multiple input data-layers. Once rules are established, the fuzzy-logic model translates the input data layers into a single variable-rate prescription map. In-field research is needed to test these two methods and inform the direction for MyEV software development.

Evaluation (We can do it…but is it worth it?): The Efficient Vineyard project demonstrated the benefits of precision viticulture technology in crop estimation, berry counting, and vineyard crop load mapping. It also investigated the effect of variable-rate management, such as mechanical shoot and fruit thinning, on vineyard yield and fruit quality. MyEV grower-users have also commented on the potential benefits of simple spatial scouting for disease or nutrient deficiencies. Furthermore, the results of spatial management can be evaluated using yield and fruit quality monitors, also developed in the Efficient Vineyard project. To show the economic potential of these technologies, vineyard research is needed which integrates and evaluates precision viticulture at different levels of complexity.

Using Cornell research vineyards, we propose to use multi-layer prescription mapping to study the impact of spatial-data-driven decision support at three levels of complexity. The research trials will target real production/business management issues, such as variable-rate pesticide applications to reduce production costs or differential crop load management to improve yield and fruit quality (Figure 3). The field research plots will be used to test data translation sampling protocols, generate different prescription maps, and evaluate the economic impact of variable-rate management. Success in this theme would provide producers with research-based information on how to efficiently conduct in-field sampling for spatial data translation and then generate variable-rate prescription maps which positively impact their management practices.

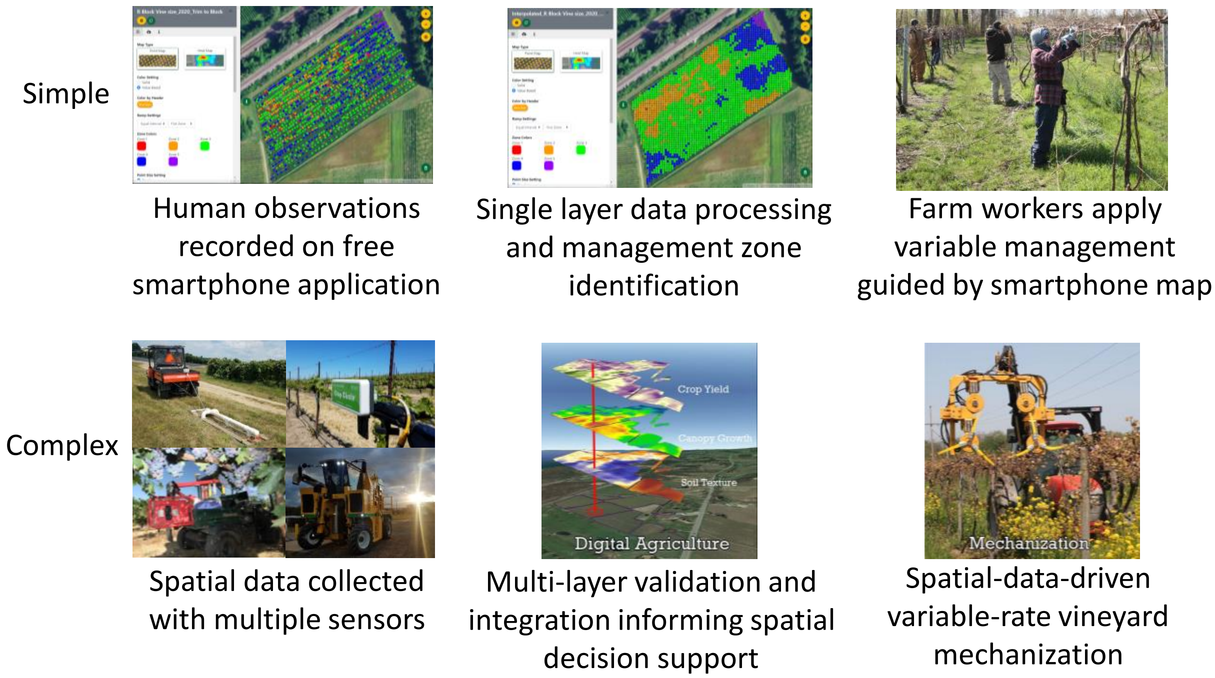

Figure 3. We propose to conduct precision viticulture field research at three levels of complexity and grower investment and document a cost/benefit analysis for each case. The research trials will also support the development of spatial data validation and generating management maps in the MyEV software platform.

Theme 3: Engaging producers to use personalized digital agriculture solutions in their own operations. The Efficient Vineyard project was strongly supported by the U.S. grape industries through the National Grape Research Alliance, in both financial contributions and project participation (https://graperesearch.org/research/current-research/). The MyEV software platform was initiated by a need identified by stakeholders and continues to improve based on user feedback. The goal of this theme is to develop the best digital agriculture tool possible by working with and receiving feedback from growers on the implementation of precision viticulture in their own operations.

In our past research, sensor development, validation, and variable-rate applications were conducted with cooperating growers. For the most part, these activities and project needs were driven by the research team and not the stakeholder. Activities were based on discovery and the development of new tools, and not necessarily on how the producer would use the tools. With the advancement in technology, there is a need to engage stakeholders on the use of the technology in their own operations for "creative implementation of a purpose" (Mezirow 1991).

We propose to follow a transformational education model to engage growers and drive the way precision viticulture is used in the industry. The transformational education model in extension addresses issues in process, content, and high impact activities to drive a change of behavior in a community of interest (Blewett et al. 2008). Theme one of this proposal addresses the process of precision viticulture with the development of the MyEV software tool. Theme two addresses content by providing research-based information on the use of spatial data in vineyard management. Theme three will focus on high impact activities by supporting immersive grower experiences with precision viticulture (Figure 4).

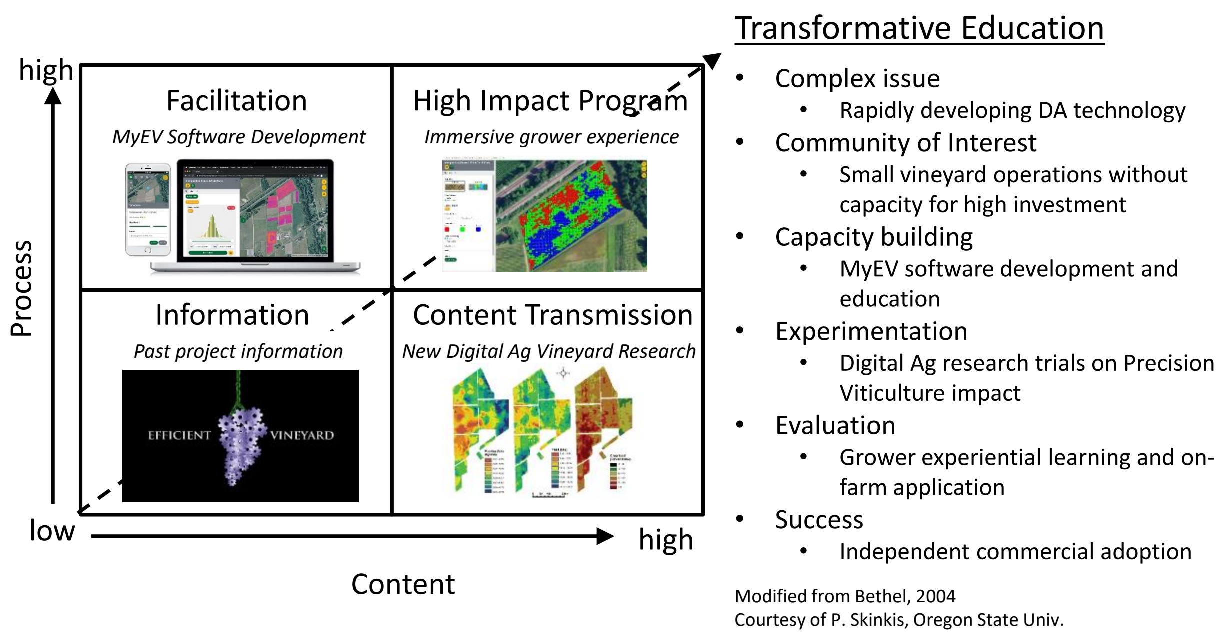

Figure 4. Using the transformational education model for precision viticulture with small vineyard operations. Building on the information and deliverables from the previous Efficient Vineyard project, we propose to improve the process (MyEV software, Theme1) and the content (research-based information, Theme 2) and integrate them through on-farm applications with cooperating growers.

We will leverage industry early adopters already using the MyEV tool to identify their business need for spatial data management, establish on-farm precision viticulture trials, and measure the change in their operations. Unlike the Efficient Vineyard project, the intent is that the activities and needs be driven by growers and not the research team. The growers will provide feedback to the software and viticulture teams to improve the MyEV functions, and we will measure the change in grower operations.

Rationale and Significance

A 2020 study reported that >60% of ag businesses that invested in digital ag technologies did not see a positive return on investment (Bryan et al. 2020). Three identified key components for digital ag success were *at-scale investment*, a clear *business use strategy*, and *education* of decision makers. While several large wine companies have successfully made the high precision viticulture investment in people, training, and technology, there is a need to develop and deliver cost-effective and approachable digital agriculture tools to small and medium-sized producers so they may also experience the benefits of spatial-data-driven farming. We believe our approach to this project addresses at-scale investment for smaller operations through the MyEV tool, identifies vineyard management business needs for the technology, and educates vineyard managers and owners on the use and benefit of precision viticulture.

At-scale Investment: Many producers do not consider digital agriculture solutions because they do not have the tools to collect, process, validate, and interact with spatial data. Specialized software, such as ArcGIS and QGiS, are not geared for agriculture and require training. Proprietary software, such as AgLeader SMS, require an investment that small and medium farms are not yet prepared to make. Our intent with the MyEV software platform is not to replace these commercial products but to give small farms an affordable option to get started with spatial data and precision viticulture technology. We have already developed the base MyEV platform to upload and work with spatial data from commercial sensors, and we have developed a free smartphone application for growers to collect user-defined spatial vineyard observations without a sensor. The MyEV platform is currently active and free for growers to use.

Business-use strategy: The goal of this project is to increase the adoption of spatial-data-driven farm management for small growers by giving them a mechanism to manage variation within a block. While many large farm operations use spatial data to manage variation between blocks and farms, small farms are more interested in improving production efficiency within a block. We propose to work with cooperating growers in this project to identify the business needs in their own operations which can be addressed through spatial data management.

Education of Decision Makers: We propose to conduct precision viticulture field research that addresses the use of the technology at three levels of complexity, representing real-world business use. For example, simple spatial scouting for disease and insects with the MyEV data collector tool may inform variable and more efficient spray applications. More complex spatial data integration with canopy sensors and yield monitors may inform variable-rate crop load management for higher fruit quality and payment. The Efficient Vineyard web site already has a webinar series on the development of precision viticulture and tutorials on how to use the MyEV software. In addition to the immersive on-farm experience for growers, we will continue to develop and post these education materials to the web site.

Program Area Priorities Addressed

This project proposal addresses the following Program Area priorities for Agricultural Economics and Rural Communities, Small and Medium Sized Farms Program:

- Identify and develop affordable small farm appropriate digital agriculture tools that improve production, labor management and farm profitability.
    - The main goal of the Efficient Vineyard project theme was to use spatial data and precision agriculture technology to measure, model, and manage sub-block vineyard variability to improve the efficiency of land, labor, and materials and increase profitability. The major barrier to adoption of the deliverables of the Efficient Vineyard project for small farms was the lack of access to affordable and approachable spatial data processing. The main goal of this new project proposal is to improve the accessibility of spatial data processing and precision viticulture by developing a free digital agriculture software tool for small farms to collect, process, validate, integrate, and manage spatial data.

- Research and outreach efforts that develop new tools to ensure that the next generation of small and medium-sized farmers have access to the information and resources they need to operate their farms on a sustainable and profitable basis.
    - The MyEV tool allows small farm producers to build their farm block maps and then add information and spatial data layers to those farm blocks. Farm and block information is stored in the user's MyEV account in the cloud. Farm and data information can also be individually downloaded for storage on a local computer. One function we propose to add to MyEV is a one-button action to download all farm data to a local computer at one time as a secure data backup. This historical data can be passed on to the next generation of farm owners.

- Examine the challenges of small and medium-sized farms to increase profitability, sustain farming as a livelihood, and transition to the next generation.
    - Our target audience for this project are the small sized grape producers in the northeast, U.S., specifically the grape producers of the Lake Erie and Finger Lakes grape regions. Over 80% of the grapes in those regions are for the juice grape market with very low profit margins. Precision viticulture, with a focus on production efficiency and farm profitability, is a solution to sustain this industry to the next generation.

Approach

Theme 1: Developing an accessible, intuitive, and affordable spatial data management software platform for small and medium-sized farms.

In the recent USDA-SCRI Efficient Vineyard project (https://www.efficientvineyard.com/), we identified a stakeholder need to easily work with spatial data and the project team responded by initiating development of a free web-based platform for uploading and visualizing high-density sensor data. We propose to complete the "MyEV" software tool by addressing seven logical data stream steps, from uploading raw spatial data to generating prescription management maps (Figure 2).

Theme 1 Objectives:

1. Add data import functions to the existing MyEV platform to record block data and capture raster imagery. MyEV already has functions to import spatial data from commercially available field sensors and databases. The platform accepts point data as .txt, .csv, .geojson, shapefile.zip. In addition, users can generate their own spatial data layers using the built-in data collector function and smartphone application. In this objective, we propose to improve the recording and storage of block level information for farm management. In addition, other sensing platforms, such as drone and satellite imagery are collected as raster images. We propose to develop MyEV to import raster imagery and convert it to point data for integration with any other data layer.

2. Create semi-automated data validation software for growers. Currently, MyEV will import, interpolate, and visualize spatial data. A key component in informing sensible management is the conversion of raw spatial data into useable viticulture information. For example, early season canopy NDVI can be translated to vineyard shoot density through in-field validation sampling to then inform variable-rate shoot thinning management. We propose to develop a software plug-in which processes high-density spatial data into management classifications and then automatically stratifies low-density validation sample locations for in-field vine measurements. The relationship between sensor signal and in-field validation will then be used to translate the sensor map into a high-density viticulture map.

3. Develop spatial decision support software to generate spatial prescription management maps. Raw spatial data from various sources are difficult to compare and use for management decisions because the data are rarely co-located. MyEV uses data interpolation to a common fishnet grid to co-locate data from various data layer sources (data fusion). Currently, our process is to export the fused data files to outside software (JMP, Excel, GeoVit, or AgLeader SMS) to generate prescription maps through k-means cluster analysis or fuzzy logic models. We propose to keep prescription mapping within the MyEV platform by allowing growers to select spatial data layers of interest for multi-layer cluster analysis.

Theme 1 Activities, Deliverables, and Success Criteria

Year	Activities	Deliverables	Success Criteria
1	• MyEV core accessibility and security audit/refinement. • Mobile data collector functionality expanded. • Refine data interpolation, data joining, raster management/analysis, and grid/validation-point. generation features. • User support and bug mitigation.	• Stable, secure, and accessible version of MyEV Core • MyEV mobile data collection features for form creation, in-field data collection, photo capture, form templates for easy form replication, and ongoing data logger fields. • Stable MyEV plugins for data interpolation, data joining, raster management/analysis, and grid/validation-point generation. • Respond to grower support and bug inquiries within 5 business days.	• Error free use of the base platform by MyEV account users. (Establishing farm, importing data, interpolation, visualization, and data export) • 90% success rate in importing raster imagery and converting to point data. • Document all trial growers utilizing data interpolation, data joining, raster management/analysis, and grid/validation-point generation to glean meaningful insights from their farm data.
2	• Data redundancy, user exports and backups. • K-means analysis functionality • Prescription map generation • User support and bug mitigation	• Automated MyEV backup infrastructure and processes established. Ability for users to easily export their data localy. • Stable MyEV multilayered data analysis plugin utilizing k-means clustering as a primary means of identifying underlying trends. • Stable MyEV prescription map plugin that modulates and exports datasets into a variety of prescription mapping formats that can be directly used in variable-rate farming equipment. • Respond to grower support and bug inquiries within 5 business days.	• Complete redundancy of MyEV database and file storage environments with a minimum of monthly platform snapshots. • 80% success rate with MyEV users and the in-field validation protocol. • Six trial growers using our multilayer analysis plugin to generate a k-means cluster dataset with multiple interpolated datasets from soil, canopy, and/or cropload. • Platform metrics: growers reached, % usage growth in datasets, farms, users etc.
3	• Automated, real-time, proximal sensor data ingestion. • Autonomous hardware integration. • 2nd specialty crop trial. • User support and bug mitigation.	• A plugin that connects to and consumes data in real-time from a moving, in-field proximal sensor remotely. • A plugin that generates autonomous data collection mission commands and monitors autonomous hardware status. • Work with a trial grower of a non-grape specialty crop in NY to implement MyEV functionality into their operation. • Respond to grower support and bug inquiries within 5 business days.	• Fully functional platform for complete spatial data pipeline for growers. • Six successful grower-defined precision agriculture trials using MyEV platform. • 80% success rate with MyEV users generating spatial prescription maps. • Document viability of MyEV in non-grape, NY specialty crops. • Resolve 90% of bug fixes within five days of being reported.

Theme 2: Evaluating strategic and efficient deployment of spatial data validation protocols and spatial decision support for efficient variable-rate management.

In the past Efficient Vineyard project, we identified a usable spatial data pipeline (Figure 2) for importing, translating, integrating, and using spatial data to generate prescription management maps. Within that pipeline, however, there remains questions on the most useful and cost-effective methods for growers to use with respect to data validation and spatial decision support processing. We propose to use research vineyards at Cornell University to address questions concerning sampling protocols and prescription mapping techniques.

Theme 2 Objectives:

1. Test various low-density sampling protocols against high-density sensor and manual measurements. In a six-acre Concord vineyard at the Cornell Lake Erie Research and extension laboratory, we have collected four years of repeated soil (DualEM), canopy (CropCircle NDVI), yield (OXBO Yield Tracker), and juice quality spatial data layers. Spatial data have been validated with both low-density and high-density manual sampling. We propose to leverage the past information in this block and continue to build the sensor dataset to test random, stratified-random, and fully directed validation sampling. Results will be used to inform validation software protocols in Theme 1.

2. Compare spatial prescription maps generated by two data processing techniques. Our default process for generating prescription maps is to select data layers of interest and perform a k-means cluster analysis on the selected layers. This method generates user-defined "k" number of clusters and attempts to maximize the mean separation between cluster and minimize the variance within a cluster. The appropriate number of clusters can be determined by looking at the total variance in the data set as the clusters increase, but commercial vineyards typically separate into 3-4 meaningful management classifications. An alternate method is to use fuzzy logic models based on rules generated by the grower to create prescription maps. Available GeoFiz/GeoVit software will be used to generate spatial prescription maps for comparison with our default process. Map comparison, ease of use, and accessibility will be evaluated and used to inform software development in Theme 1.

3. Apply precision viticulture at three levels of complexity to demonstrate versatility in commercial production. Many small vineyard (farm) operations in New York do not adopt precision viticulture technology because they perceive it to have high investment costs and complex multi-layer data processing. Using research vineyards at the Cornell Lake Erie Research and Extension Laboratory, we will establish three precision viticulture trials:

- <u>Simple Univariate Method:</u> The MyEV data collector and manual observations will be used to spatially map a vineyard characteristic and then used for a business purpose. Examples of this include:
    - Vine leaf nutrient deficiency scouting for fertilizer management.
    - Insect scouting to inform spatial pesticide application.
    - Crop estimation sampling for yield forecasting.

- Moderate Multi-variate Method: Use spatial sensor data and/or MyEV data collector observations together for multi-layer management mapping. Examples include:
  - Satellite imagery for disease detection and NDVI for canopy size to inform VR fungicide spray applications.
  - Soil, canopy, and yield mapping to inform vineyard nutrient supply and demand for VR fertilizer applications.
  - Yield and Juice soluble solids mapping to calculate farm revenue.
- Complex multi-year, multi-variate Method: Use all available data to generate new indexes, perform multi-variate modeling, and generate prescription maps evaluated with additional spatial data.
  - The gold standard for vineyard efficiency is in achieving vine crop load balance, which is the optimal relationship between vine yield (demand) and vine size (supply). Spatially, a crop load layer is calculated from validated yield and NDVI maps in year 1. The crop load index is then compared to a yield prediction layer from bloom NDVI in year 2. Together, the spatial data is used to inform variable-rate mechanical fruit thinning to improve vine balance and fruit quality, which is evaluated with harvest yield and juice soluble solids monitoring.

Theme 2 Activities, Deliverables, and Success Criteria

Year	Activities	Deliverables	Success Criteria
1	• Evaluate potential research vineyard plots for three levels (univariate, bivariate, and multivariate) of VR management. • Collect spatial data on potential vineyards using proximal and remote sensing technologies. • Measure the degree of spatial structure in each vineyard and select 3 research vineyards based on VR management suitability. • Test validation sampling protocols.	• An approach to evaluate vineyard VR management at three levels of complexity. • Integrated and comparative vineyard sensing from proximal and remote sensors. • A commercially useful evaluation of vineyard spatial data to recommend (or not recommend) VR management. • A comparison of in-field validation sampling protocols • Identification of 3 research vineyards of VR evaluation.	• 10 research vineyards scanned and evaluated for spatial structure. • 3 research vineyards selected for further VR management and evaluation. • 3 sampling protocols tested for in-field spatial data validation. • Full baseline spatial data collected in year 1 on three research vineyards and VR management plan established for years 2 and 3.
2	• Use year 1 spatial vineyard information and spatial decision support (SDS) to determine uni- bi- and multi-variate VR management plans. • Compare VR treatment	• Evaluation of spatial-data-driven variable-rate vineyard management at three levels of complexity using the MyEV platform. • Repeated testing of three spatial data validation protocols	• Needed spatial data collected and validated in 3 research vineyards with successful application of VR management. • Complete analysis of validation protocols with feedback to MyEV software development

	applications against uniform management control plots and evaluate the viticultural and economic impact of VR management.	● Comparison of k-means clustering and fuzzy logic modeling in generating prescription maps.	and recommendations to grower community. ● 50% complete statistical comparison between prescription mapping methods.
3	● Multi-sensor data collection ● Validation of spatial data with in-field sampling ● Data interpolation and multi-layer integration in MyEV ● Spatial decision support and prescription map generation ● Evaluation of VR and uniform treatments with yield and juice quality monitoring ● Economic evaluation of VR including production inputs and farm gate outputs.	● Demonstration of the MyEV spatial data pipeline used in three precision viticulture trials at three levels of complexity. ● Three cost-benefit evaluations of precision viticulture. ● Researched-based information to assist with software development (theme 1) and inform grower management (theme 3)	● One successful example of low cost (free) spatial data collection and processing leading to a high benefit in precision viticulture, such as more accurate crop estimation. ● One successful example of multi-layer spatial data collection and processing to inform a common management practice, such as VR fertilizer applications. ● One successful example of high cost and integrated spatial data collection and processing for higher-level vineyard management, such as improved vine balance through VR fruit thinning.

Theme 3: Engaging producers to use personalized digital agriculture solutions in their own operations.

Most small producers do not have the tools (process) or information (content) or experience (high impact activities) to achieve transformational education in digital agriculture. Integrating research-based digital agriculture education, new spatial processing tools, and producer-led on-farm activities will lead to transformational education in spatial-data-driven variable-rate farm management. Our goal is to increase precision viticulture adoption by focusing on activities which promote at-scale investment, identify a business purpose, and educate vineyard managers and owners.

Theme 3 Objectives:

1. Coordinate on-farm and user-defined precision viticulture management trials in cooperating commercial vineyards (key early adopters). Currently, there are more than 45 MyEV user accounts in the Lake Erie grape production region and 20 in the Finger Lakes grape production region. We will identify three key grower-cooperators in each region to establish commercial precision viticulture demonstration trials. Our intent is for these trials to be grower led where they identify the business need for variable-rate management and choose the treatment applications. The project team will assist the cooperating grower with needed data collection, guide them in field validation, and evaluate the change in the operation. These on-farm experiments will be the site of grower education meetings.

2. Continue to engage and support current and new MyEV users through the Efficient Vineyard web site (engaged users). The MyEV platform has an active grower support interface built into the software. On the main farm screen, we have created a feedback button where users can leave a message for the project team if they encounter a software bug, have a wish list item, or want to ask a precision viticulture question. This feedback has been very useful for us in the development of the software as a tool built by growers, for growers.

3. Develop technical support and training materials for MyEV (broad grower audience). Like the MyEV feedback mechanism, the Efficient Vineyard website has been a successful resource for educating growers about precision viticulture research and in teaching them how to use the MyEV software. We created a series of article/video tutorials as the software developed and the tutorials follow a "curriculum" reflective of the spatial data pipeline in Figure 2 (https://www.efficientvineyard.com/docs). As new functions are added to MyEV in this proposal, we will continue with the tutorial series.

Theme 3 Activities, Deliverables, and Success Criteria

Year	Activities	Deliverables	Success Criteria
1	● Select cooperating grower vineyards aligned with precision viticulture project objectives and identify farming goals which could be addressed through PV. ● Collect baseline spatial data (NDVI, Soil ECa, etc.) and relevant farm business information into MyEV platform. ● Develop and post technical user articles / tutorials on new MyEV functions (farm data, raster imagery, validation sampling) ● Create sample data sets for interactive hands-on grower training.	● An identified group of key early adopters interested in PV and willing to share their experiences with the larger grower community. ● Multiple commercial blocks with layered spatial data in MyEV and an identified business purpose for PV. ● Timely documentation and tutorial videos on new software development and platform functions. ● Online training course for MyEV, which will include formal instruction modules and informal group discussion.	● Identified and initiated 3 commercial PV trials in the Lake Erie region and 3 in the Finger Lakes region. ● 6 cooperating commercial growers with relevant spatial data collected in MyEV and a business action plan. ● Three education modules for block data recording, importing raster data, and validation sampling posted on the Efficient Vineyard website. ● Two sample data sets (raster import and validation sampling) for hands-on user training.
2	● Assist cooperating growers in the development of PV Action Plans	● Business driven uses for spatial data and variable-rate vineyard	● 6 cooperating growers have completed the full spatial data pipeline in MyEV and using the

	● Allow cooperating growers to collect and process their own relevant spatial data in MyEV, assist where necessary, and receive feedback. ● Develop and post technical user articles / tutorials on new MyEV functions (Generating VR prescription maps) ● Create sample data sets and incorporate grower feedback into technical documentation and training materials for MyEV.	management identified by growers. ● Immersive experiences for growers to provide feedback on success and challenges in the current MyEV platform. ● Timely documentation and tutorial videos on new software development and platform functions. ● Real-time feedback and response to grower educational experience and challenges.	platform for a relevant vineyard purpose. ● 95% of grower feedback addressed with 50% of suggestions incorporated into MyEV software development. ● Two education modules on prescription mapping with two supporting data sets for grower training.
3	● Assist cooperating growers with the third season of data collection, processing, and management. ● Full field-trial evaluation of viticulture, economic, and grower impact of MyEV and precision viticulture techniques. ● Conduct field demonstrations for the grower community at the cooperating vineyard sites. ● Incorporate grower feedback into MyEV training course.	● Real-world precision viticulture trials in commercial NY vineyards with at-scale investment, a grower identified business purpose, and user education. ● Supporting data on the benefits and challenges of PV, including feedback from cooperating growers on how it will/or will not change their management practices. ● Grower education which targets the local NY stakeholder group as well as the broader MyEV user audience.	● 6 commercial examples of PV supported with MyEV software development (theme 1) and research-based information (theme 2). ● A complete set of training/tutorial materials for MyEV functions that can be navigated by any new user. ● A spatial data platform built for growers, by growers. ● 30% of NY grape producers learn about MyEV and establish an account. 70% of growers that establish an account, stick with the platform.

Pitfalls and Limitations

We believe this project has a high degree of potential success. Many of the processes and procedures have already been successfully used in the previous Efficient Vineyard project, the need was generated by the stakeholder group, and the base MyEV platform is live and ready for additional functions. If COVID-19 restrictions continue, it would inhibit our ability to easily conduct field trials with cooperating growers. The strength of this project, however, is that the project team has experience continuing with software development, research trials, and “remote” grower collaborations during the pandemic.

The main goal of this project is to provide an affordable, easy-to-use, entry-level spatial data processing platform for small vineyards, or any small farm, to effectively use spatial data in their business. We have purposely designed the MyEV platform to limit the functions and choices to make complex GIS workflows more pleasant for growers new to precision agriculture. This may be seen as a limitation to more advanced GIS users, but our intent is to provide an experiential tool to small growers who may choose to move on to more advanced software.

At the end of this project, our objective is to have a functional spatial data platform supported by research and built with grower input. We are working with the Cornell Center of Technology and Licensing on available options to support MyEV after the project is over. The project team agrees that we want MyEV to remain an affordable and accessible tool for small producers into the future.