A. Project Information

2019 Final Report CDFA Fertilizer Research and Education Program 150492SA

Prediction of summer leaf nitrogen concentration from early season samples to better manage nitrogen inputs at the right time in walnuts, prunes, and pears

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B. Objectives:

This project is designed to achieve the following three objectives:

Objective 1: To develop a leaf nitrogen prediction model using spring collected samples to predict late summer tissue values. This will allow growers to better manage nitrogen in nut (walnuts) and fruit (prunes, pears) orchards in California by sampling 30 representative orchards for each of three species during 2016 and 2017.

Objective 2: To create a user-friendly online interface to help growers, extension specialists and consultants design nutrient plans based on early season leaf samples for walnuts, prunes and pears as well as pistachios and almonds (for which models have already been developed).

Objective 3: To promote the use of this tool, and an understanding of these models, to better manage nitrogen inputs at the right time in these nut and fruit trees.

The achievement of these objectives will allow for early season monitoring of N application that will help achieve the “right rate and “right time” of N application.

C. Abstract

Increasing awareness of the environmental impact of excess nitrogen (N) and new N management regulations demand user-friendly tools to help growers make fertilization decisions. Walnuts (227,000 acres), prunes (58,000 acres), and pears (14,000 acres) are important crops in California, with approximately 300,000 acres combined. Each of these crops uses significant amounts of nitrogen to maintain high yields in fully mature orchards. While these crops have high N demands, application of N in excess of need can occur. This is, in part due to a lack of tools to correctly monitor tree nitrogen status early in the season which limits the ability of growers to make fully informed fertilizer decisions.

Summer leaf nutrient analysis has historically been the most widely used monitoring tool to track tree nitrogen status, this involves collection of leaf samples in summer, submission of samples to an analytical laboratory for analysis and comparison against established standard critical values for summer. Sampling in summer, however, is too late in the season to adjust current season nitrogen management if needed. An industry-wide grower survey conducted in 2007 suggested that while leaf nutrient sampling is useful to guide fertilization management it would be achieve greatly enhanced utility if ways to collect and interpret leaf analysis results in the spring rather than the late summer were developed.

This current project builds upon results of the CDFA-FREP project ("Development of leaf sampling and interpretation methods for Almond and Pistachio") conducted between 2009 to 2012 where we developed a robust early season sampling protocol for almonds and pistachios. The results of this project were implemented by the almond and pistachio industries in 2013 and so far, have contributed significantly to the improvement of nitrogen management in these crops. The tools developed subsequently been adopted by commercial labs in California (i.e. Fruit Growers Laboratory, Inc.) and incorporated into the Almond Board of California's CASP online toolkit and have been made available for all private and commercial users free of charge at: http://fruitsandnuts.ucdavis.edu/Weather_Services/Nitrogen_Prediction_Models_for_Almond_and_Pistachio/.

We have achieved the following objectives: 1) development of a leaf nitrogen prediction model for walnut, prune, and pear, and 2) integration of the resultant models and tools into a user friendly online interface for growers, extension specialists and crop consultants and, 3) the results of this project have been widely extended through farmer field days and publications.

California growers of walnuts, prunes and pears will benefit from this research as it will aid in N management decisions. Commercial analytical labs will also benefit by offering an improved product to their customers allowing them to sample and interpret leaf samples collected in Spring. Consumers and the general public will also benefit from an improved supply of healthy fruits and nuts with decreased environmental impacts.

D. Introduction

Problem: In tree crop production in California, leaf sampling and critical value analysis represents the primary tool for fertilizer decision making (Brown and Uriu, 1996). Leaf nutrient analysis, is the most widely used monitoring tool to track tree nitrogen status. To use this methodology, growers must collect leaf samples in summer and then send leaves for lab analysis to compare their values against established standard critical values for summer. However, a major perceived constraint with current protocols for leaf sampling in fruit trees is that samples are collected too late in the growing season to be of use for current season nutrient management decisions (Abadia et al., 2004; Abadia et al., 2000; El-Jendoubi et al., 2011; El-Jendoubi et al., 2012; Saa et al., 2014). This problem is particularly evident since more of the 80% of N uptake is complete by the time results of a late summer tissue sampling are available to the grower in August (Muhammad et al., 2015; Saa et al., 2014). Late sampling limits the grower's ability to make in-season fertilizer adjustments and may encourage late-season fertilizer application that is inefficient and can result in groundwater contamination (Neilsen and Neilsen, 2002; Viers et al., 2012).

Summer sampling (July-August in California) has historically been recommended because leaf nutrient concentration has been shown to be more stable at this time than earlier in the season (Al-Khayat, 2004; Cresswell, 1989; Lilleland and Brown, 1941; Robinson, 1993). The rationale for collecting leaf samples in mid-summer is based on the observation that leaf nutrient concentrations change with leaf development and that the daily change in leaf nutrient concentrations is smallest once leaves have reached their full size and weight, which occurs in most deciduous species in mid-summer. Leaf critical values were therefore developed for this timing.

To forecast leaf nitrogen concentration from spring to summer, would require addressing the issue of changing leaf nutrient requirements with leaf development (Lewis et al., 1993). Lau and Wong (1993), and Radrizzani et al. (2011) have proposed that leaf Ca concentration can be used to predict leaf age and to improve interpretation of leaf nutrient concentration in *Hevea* and *Lecaena leucophala*. This approach is however compromised by luxury uptake of Ca when there is abundant Ca in the soil or by low uptake of Ca when K and Mg in the soil compete with its uptake. The potentially confounding effects of these minerals was solved by Saa et al. (2014) who observed that the inclusion of Ca, K, and Mg as a marker of leaf age resulted in an ability to predict leaf nitrogen concentration in almonds. Specifically, Saa et al. (2014) detected in almonds that leaf nitrogen concentration in summer can be predicted (r^2 = 0.9) from the leaf N and B concentration in spring with the sum of positive charge from K, Ca, and Mg.

This proposal seeks to develop nitrogen prediction models for early season sampling of walnuts, prunes, and pears so that tree nitrogen status can be measured early enough in the season to guide current season fertilization strategies. The first 18 months of this project were used to develop the leaf sampling protocols and models, subsequently results were integrated into an easy-to-use online interface, and results were shared in a systematic way with the agricultural community to promote adoption. The understanding of how farmers adopt new agricultural technologies is highly complex and depends upon a range of social, cultural, personal, and economic factors as well as the nature of the innovation itself (Pannell et al., 2006). The adoption of novel technologies and practices is often slower than predicted and is often adopted by less of the target population than desired (McRoberts and Franke, 2008). However when technologies are perceived to be simple, low-risk and low investment, their adoption and diffusion are significantly increased (Batz et al., 1999) and can be enhanced by a thoughtful and systematic plan of information diffusion (Vanclay, 2004).

Growers have historically applied nitrogen to their orchards without the availability of a timely monitoring tool to orientate their fertilization plans. The uncertainty that occurs in the absence of a on-time nutrient monitoring strategy may have resulted in applications of more nitrogen than is truly needed (Viers et al., 2012). The development of the ability to predict tree nitrogen early in the season will therefore reduce nitrogen contamination and save fertilizer costs, while maintaining potential yields.

E. Work Description

Objective 1/Task 1: To develop a leaf nitrogen prediction model to better manage nut (walnuts) and fruit (prunes, pears) orchards in California by sampling 30 representative orchards per cultivar during 2016.

Task 1.1 Collection of orchard management data (grower's survey)
Historical yield, current nutrient management, tree age, tree space and expected yield will be noted for each site. This information will be provided by Farm Advisers or property managers at the time of data collection.
Initiate January 2016: Complete March 2016

Task 1.2 Soil, leaf sample collection and tissue analysis
Ninety orchards will be sampled in 2016 and 30 orchards will be sampled in 2017. Leaves from each orchard will be collected in spring and summer of both years to develop the prediction models. The sampling protocol proposed by Saa et al. (2014) will be used to collect one representative sample per orchard. One soil sample per orchard will also be collected. Soil and tissue determination for the major elements (N, P, K, S, Ca, Mg, B, Zn, Fe, Mn, Cu) in all leaf samples will be processed by the Fruit Growers Laboratory, Inc. Spring leaf samples will be collected April-May, soil samples May-June, summer leaf samples July-August. Database construction, data organization and preliminary statistics will commence May and run through November 2016.
Initiate March 2016: Complete November 2016

Task 1.3 Compilation of weather data
Growing degree from leaf-out to the sampling date in spring for each site by using the integrated model provided in UC Davis Fruit & Nut Research Information website (http://fruitsandnuts.ucdavis.edu/). Detailed weather data will be collected from each location using the California Irrigation Management system (CIMIS website). Since not all locations have nearby CIMIS stations we will also utilize data interpolation routines as needed.

Initiate January 2016: Complete November 2016

Task 1.4 Data Management and Statistical Modeling
Data management and Statistical Modeling will be performed on spring and summer tissue samples, soil data, and weather data using three analytical software programs. JMP program version 11 (SAS Institute Inc., Cary, NC, 1989-2010) will be used for data management. R core program will be used to program the statistical models. Model development will commence once summer samples have been received in September. Sigma Plot program version 12.5, Systat Software, Inc., San Jose California 95110, USA will be used to plot selected outputs.

Initiate May 2016: Complete March 2018

Task 1.5 Model validation and Cross Validation.
Eighty-one of the 90 orchards sampled in 2016 will be used to develop the statistical models. The remaining 9 orchards will be used to validate the resulting models. In addition, 30 orchards will be sampled in 2017. Orchards sampled in 2017 will serve to perform a cross validation of the selected models. Please see 'Methods' section for further details about this task.

Initiate March 2017: Complete November 2017

Objective 2/Task 2: To create a user friendly online interface to help growers, extension specialists and consultants design nutrient plans based on early season leaf samples for walnuts, prunes and pears as well as pistachios and almonds (for which models have already been developed).

Task 2.1 Create an online user-friendly N prediction tool
Create an online user-friendly interface that allows growers, extension specialists and consultants to easily interact with, understand and use the new leaf N models for walnut, prune, pear, as well the previously developed models for almond and pistachio. This tool will allow users to input their spring leaf N values and see as an output their expected summer leaf N values and how those compare to critical values. Work on this task will commence in 2016 using previous almond and pistachio data as a template.
Initiate May 2016: Complete June 2018

Task 2.2 Integrate N prediction tool with other nutrient management tools and current information
In 2013, Dr. Brown's lab partnered with SureHarvest to create a full interactive nutrient budget that allowed users to input particular field level data as well as their leaf N values to create comprehensive N plans for their almond orchards

(https://www.sustainablealmondgrowing.org.. We will replicate this approach in pear, prune and walnut utilizing results from the current study. These tools as well as other current research on N management for important California fruit and nut crops will be incorporated into the CropManage platform in an engaging, interactive and simple way so that this website may eventually become a "one-stop-shop" for nutrient planning for fruit and nut orchards. The website is optimized for smart device use and the package will include extensive written instructions as well as an instructional video.
Initiate Jan 2017: Complete December 2018

Task 2.3 Plan for website sustainability and upkeep
Upon completion of the first edition of the website that will include both new and already established leaf N models, as well as additional information and tools (such as the almond N budget tool), Drs. Brown and Saa will continue to stay up to date on current research with field applicable orchard nutrient research to include within the online platform. Costs of upkeep of the website, which will be housed within UC Davis servers, are included in the requested funds and upkeep is guaranteed for a total of 5 years with the intention that ongoing upkeep beyond that period will be included in future research proposals if needed. In addition, we will make the underlying models available free for public, governmental and commercial adoption with the requirement that any commercial user sign a licensing agreement specifying that the contributions of UC and CDFA will be recognized and that models updates developed by UC will be implemented immediately upon their release.
Initiate July 2018: Complete December 2018

Objective 3/Task 3: To promote the use of this tool, and an understanding of these models, to better manage nitrogen inputs at the right time in these nut and fruit trees.

Task 3.1 Informational Material Creation
Several extension articles will be written for distribution to farm advisors, industry groups and agricultural press such as 'Western Farm Press'. These articles will summarize the technical work and results for farmers, PCAs/CCAs, consultants and others that are interested in directly applying the results of this work in the field.
A peer review scientific manuscript will be a contribution to knowledge base in the scientific field. This manuscript will summarize the findings of this project and will serve to develop further research in this area. The target audience of this manuscript will be researchers working in the area of fruit tree production and plant nutrition.

A series of short instructional videos (i.e. 2 minutes long) will be made to explain how to conduct early season tissue sampling (Prune video link , Walnut video link , Pear video link)

In addition, this video will be promoted in Dr. Brown's presentations widely during and after grant completion.
Initiate November 2017: Complete March 2018

Task 3.2 Stakeholder involvement
Involving stakeholders early in the scientific process enhances buy-in in all projects, when stakeholders know what we are planning they tend to be more receptive to the results. This project has been discussed intensively with the Walnut Board Committee, the prune industry and the pear industry who have pledged a significant commitment to this and associated N management projects. We have also worked closely with analytical labs to ensure the developed models have been available for their use. The involvement of these commercial entities will encourage grower recognition and fertilizer industry attention. Moreover, we will continue to work with farm advisors in each sampling region and will keep them informed of our results to share with their grower networks.
Initiate January 2016: Complete December 2018

Task 3.3 Lab workshops
Field workshops will be performed from January 2018 to April 2019. These workshops will focus on teaching commercial labs how to implement the models into their spring sampling results. This will help adoption of the developed models by the Ag. industry. Ideally, the majority of the leaf lab analysis will become familiar with the leaf sampling models by spring 2018 and several of them have already adopted these models for use in Almond and Pistachio.
Initiate January 2018: Complete December 2019

Task 3.4 Scientific seminars and conferences
Annually, Dr Brown and Farm Advisors will present this ongoing research and ultimately the outcomes of this project at numerous events. Dr. Brown for example, typically presents 13-15 large audience presentations annually to meetings of the Almond Research Conference, Western Plant Heath Association, Cal-ASA Plant and Soil conferences, Pistachio Conferences, almond industry events, FREP events, regional Almond Meetings (eg SJV Almond Day, Nickels Field Day), Chemical Industry Grower Days (Actagro, Tesenderlo Kerley, Yara), PCA/CCA events.
The participation of Almond, Pistachio, Walnut, Dried Plum and Pear boards in supporting this research ensures that the research results will reach growers through industry meetings and websites.
Initiate August 2017: Complete December 2018

F. Data/Results

The initial stages of this experiment involved the identification and characterization of a large number of diverse orchards of each crop from across their predominant growing regions. Samples were collected from these orchards over the 18-month data collection period, in addition intensive grower interviews were conducted to identify management practices and yield, and data on local environmental and climatic variable were collected and analyzed according to the work plan. Following this intensive period of data-collection we developed a series of mathematical and statistical models that were used to predict the late season N status of the orchards as a predictive analytic. The iterative model development strategy identified a wide range of viable models which were subsequently validated against a sub-set of previously collected data as well as new data collected in year 2 and 3 of the project. In the final model selection process weather variables were dropped out automatically during the model selection process and therefore were no longer considered. This does not suggest that weather is not an important variable but rather that other measured variables adequately captured the influence of weather on the final model accuracy.

Three final candidate models were developed and cross validated in this experiment. The first model was the most accurate of all models proposed but suffered from the requirement for a large amount of site-specific information, "Highly Intensive". The second model relied upon fewer input variables but would still be too complex for the majority of growers to implement and was named "Moderately Intensive". Either of these first two models offer improved accuracy and are valuable for growers who routinely collect in depth orchard information. The third model was the most grower approachable "Grower Friendly". Results show that the three models can each accurately predict leaf nitrogen concentration in summer for each cultivar, but the level of precision and inputs needed to make the predictions differ. The most precise model ("Highly Intensive") requires a combination of leaf nutrient, soil nutrient, and orchard management input (i.e. yield, and in season nitrogen applications) to estimate summer leaf values. While this model is very precise, the amount of data needed to produce an output makes it impractical and not user-friendly for the majority of growers. The second model "Moderately Intensive" requires spring leaf nutrient values, excludes soil variables, but also asks for in season nitrogen management inputs. Model adoption of the "Moderately Intensive" model is predicted to be low as not only nutrients in spring, but also in season nitrogen management need to be provided by the user. The third model ("Grower Friendly") only requires spring leaf nutrient data to make accurate predictions of leaf nitrogen values in summer. This model has a bigger variance than the other two models, but is easier to use. Table 1 below summarizes the statistical characteristics of each of the models, as well as, the inputs needed to perform summer leaf nitrogen predictions.

Table 1. Summary of the statistical characteristics for each of the selected and statistically validated models, as well as, the equations and inputs needed to perform summer leaf nitrogen predictions.

<table>
<tr><td colspan="8">Model Dummy Name: "Highly Intensive"</td></tr>
<tr><td>Model Inputs*</td><td colspan="7">crop + NMayJul + spSoilNO3 + spSoilExK + ilr1 + ilr2 + ilr4 + ilr5 + ilr6 + crop:ilr1 + crop:ilr4. Model coefficients are provided in a separated excel file (see appendix 1 at the end of this document).</td></tr>
<tr><td>Model performance**</td><td>R^2
0.93</td><td>sigma.hat
1.689</td><td>cv.rsq
0.87</td><td>cv.sigma.hat
2.068</td><td>n
61</td><td>MOEconf
0.4</td><td>MOEpred
3.8</td></tr>
<tr><td colspan="8">Model Dummy Name: "Moderately Intensive"</td></tr>
<tr><td>Model Inputs*</td><td colspan="7">crop + spLeafN + NMayJul + ilr4 + ilr7 + ilr4:spLeafN + ilr7:ilr4 + crop:spLeafN. Model coefficients are provided in a separated excel file (see appendix 1 at the end of this document).</td></tr>
<tr><td>Model performance**</td><td>R^2
0.91</td><td>sigma.hat
1.815</td><td>cv.rsq
0.89</td><td>cv.sigma.hat
1.983</td><td>n
61</td><td>MOEconf
0.5</td><td>MOEpred
4.1</td></tr>
<tr><td colspan="8">Model Dummy Name: "Grower Friendly"</td></tr>
<tr><td>Model Inputs*</td><td colspan="7">crop + spLeafN + ilr4 + ilr8 + ilr8:ilr4 + crop:spLeafN
Model coefficients are provided in a separated excel file (see appendix 1 at the end of this document).</td></tr>
<tr><td>Model performance**</td><td>R^2
0.73</td><td>sigma.hat
2.851</td><td>cv.rsq
0.71</td><td>cv.sigma.hat
2.967</td><td>n
120</td><td>MOEconf
0.5</td><td>MOEpred
6.2</td></tr>
</table>

*NMayJul is the in season nitrogen applied between spring and summer.
"ilr" are inverse log ratios of measured nutrients as described by Modesto et al. (2014).
spLeafN is Spring leaf N analysis
Crop = crop of interest (i.e. almond, walnut, prune, apple or pear)

**"MOE" is margin of error or Confident Interval radius. "conf" refers to making a prediction for the population parameter. "pred" refers to making a prediction for an orchard. "cv" means cross-validation. Units are parts per thousand.

The isometric log ratio approach (Modesto et al. 2014). Isometric log ratios are used to organize information about all nutrients into synthetic variates that represent biologically meaningful nutrient ratios, such as cation:anion and (Ca + Mg):K.

The calculation of the isometric log ratios involves the following steps and is integrated into the model calculators in CropManage.

1. Calculate the proportion of mass represented by each leaf nutrient. This is done by the function compositions::acomp. Include one component that represent everything else but nutrients identified separately (called Fv).

2. Calculate the clr value for each nutrient in each sample. This value is the natural log of the nutrient proportion minus the average of the logs of all nutrients in the sample. Although this is done implicitly by the ilr() function, there is a clr() function that explains the calculation.

3. Multiply (vector multiplication) the vector of clr values by each column of the V matrix that define the nutrient contrasts. This multiplication yields one ilr for each sample and for each column of the V matrix.

Specifically, model development for each of the three models was done as follow:
Specifically, model development for each of the three models was done as follow:

*Model 1. "*Highly Intensive*"*

We started with a full model that included all variables and the interaction between inverse log ratios and crop, to account for the possibility that the different crops have different nutrient balances. Interactions between crop and spring N concentration, N fertilization and soil available N were also included. The full model was subjected to variable selection using all possible subsets with a maximum of 11 predictors to preserve a minimum of 6 observations per predictor.

The resulting best model with 11 predictors was completed by adding all variables involved in each predictor. For example, a predictor is a one-df interaction, so both variables involved in the interaction were added into the model. After all variables were included, the model was further simplified by removing the least significant terms. Several candidate models were produced at this stage and subjected to k-fold cross-validation. The final model selected was the one whose cross-validation performance was closest to the performance when all data were included (Figure 1).

Figure 1. Verification and validation of the "Highly Intensive" model performance. Black line is the 1:1 concurrence between predicted and observed values. Circles represents average N (parts per thousand) observed in July (y axis) and predicted by the model (x axis) with a sample of 30 pooled trees per site.

*Model 2. "*Moderately Intensive*"*

A new set of models was developed under the assumption that soil analyses are expensive and that few growers routinely do them. In addition to this assumption, the inverse log ratios considered were only those related to the balance of cations, ilr4, ilr7 and ilr8, to reflect the fact that leaf age is mostly reflected in cation ratios.

A full model was constructed with the restricted set of variables and the best 20 models were identified using the AIC. The best of the 20 candidate models was identified by 5-fold cross-validation with 10 replications as described above (Figure 2).

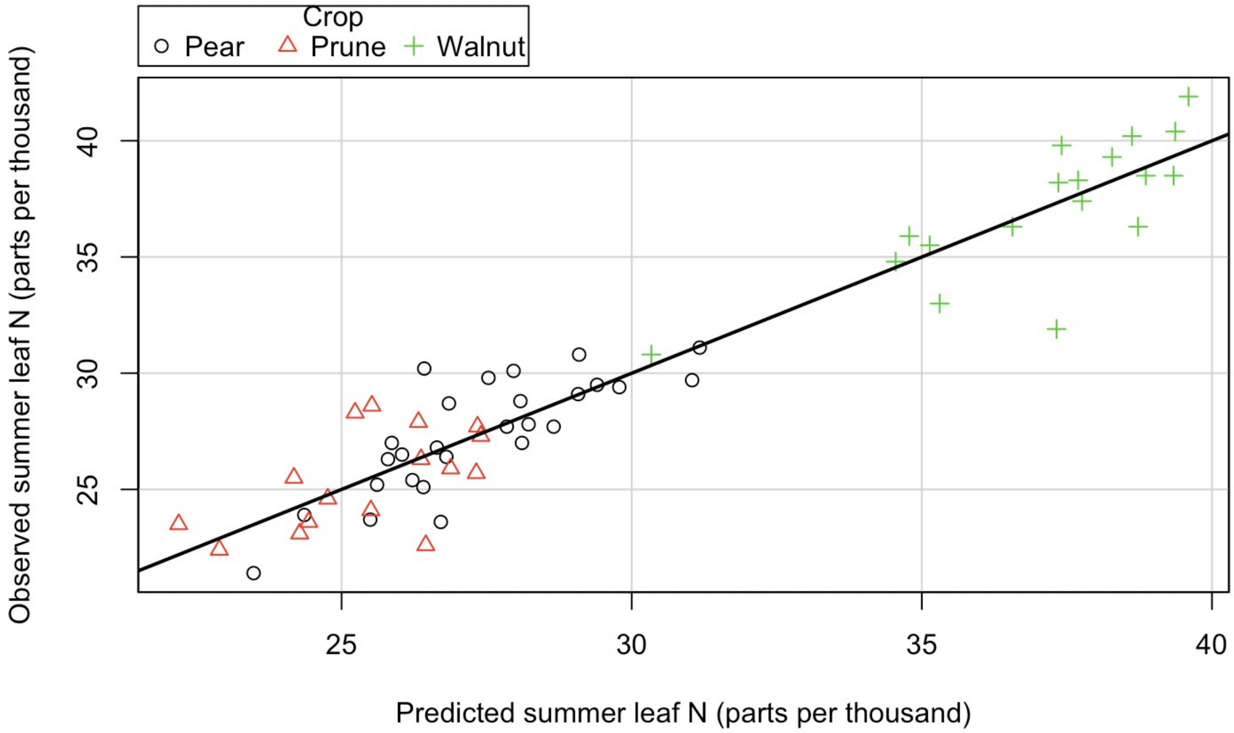

Figure 2. Verification and validation of the “Moderately Intensive” model performance. Black line is the 1:1 concurrence between predicted and observed values. Circles represents average N (parts per thousand) observed in July (y axis) and predicted by the model (x axis) with a sample of 30 pooled trees per site.

*Model 3. “*Grower Friendly*”*

Recognizing that grower entry of nitrogen management rates between sampling dates (NMayJul variable) may not be possible, a third set of candidate models was selected following the method described for model 2. The best model was once again identified by cross-validation.

In the final iteration of this model in CropManage, all data remains locally with the grower and this may encourage inclusion of NMayJul which will automatically engage Model 1.

A graphical display of the “Grower Friendly” model performance is also presented in Figure 3. Even though the model does a good job at predicting summer nitrogen concentration for each crop, there are six observations in pears with low values of N in the summer that were not well predicted by the model. While there is no clear explanation to this issue in pears, the underline cause could be related to the management between measurements, which this model ignores.

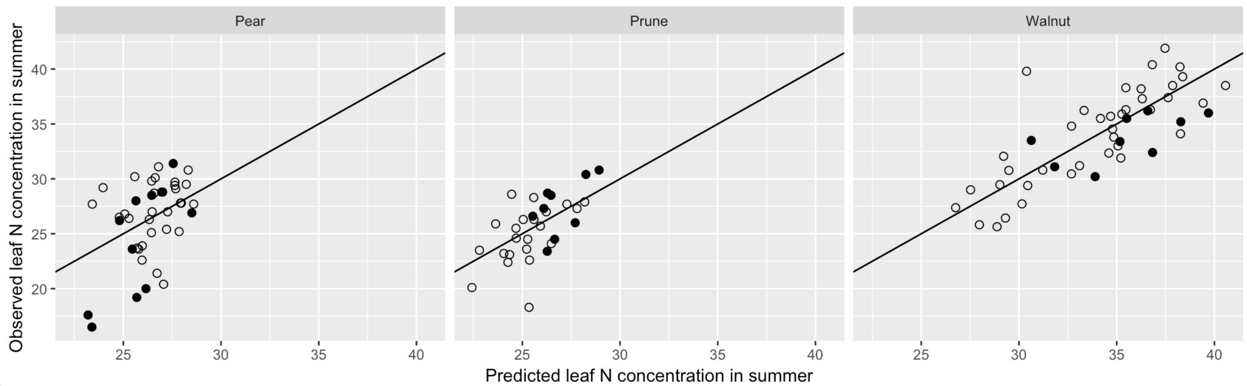

Figure 3. Verification (open circles) and validation (filled circles) of the "Grower Friendly" model performance. Black line is the 1:1 concurrence between predicted and observed values. Circles represents average N (parts per thousand) observed in July (y axis) and predicted by the model (x axis) with a sample of 30 pooled trees for the 29 validation sites sampled in the study during 2017.

Leaf sampling videos for each crop were recorded and are available for pears, walnut, and prune.

Addition of tree nitrogen recommendation module to CropManage irrigation and nutrient management decision support software

1. Finalized spreadsheet nitrogen management model for trees. In collaboration with current and past graduate students in the Patrick Brown Lab, we evaluated and modified the spreadsheet program for estimating N needs of almonds, pears, pistachio, prunes, and walnuts. We added an equation to estimate the cumulative uptake of the crop from days from after spring leaf out. We reformatted the spreadsheet program for transferring the code to CropManage and for providing method for the Breyta software development staff to test their code (Fig. 1).
2. Transference of spreadsheet model to CropManage. Breyta software developers modified the user interface for crop settings in CropManage to accommodate the tree N model (Fig. 2). These modifications included allowing the user to enter the expected yield, age, and vigor of the orchard (Fig. 3), and spring tissue nutrient values (Fig. 4). The algorithms for estimating seasonal N requirement of trees from these and other user inputs were also added to CropManage.
3. Addition of manure N, compost N, and cover crop N credit calculators. Breyta developers added calculators for crediting nitrogen from manure (Fig. 5), compost (Fig. 6), and winter legume cover crops (Fig. 7) to the *crop settings* section of the tree plantings. The calculators are based on the spreadsheet calculations provided by the Brown group.
4. Adaptation of fertilizer event for trees. Breyta software developers modified the fertilizer events for tree crops. The fertilizer event interface allows the user to input the fertilization interval (days to the next fertilization event), display the fertilizer N recommendation for the interval, display a summary of how the

recommendation was calculated, and provides an option for the user to credit nitrate added from the irrigation water. The farm manager can also add his/her recommendation to the fertilizer event, and farming staff can add the final amount of fertilizer applied to the event.

5. Add tissue test event to CropManage. Currently, users can only add one leaf tissue analysis per year in the crop settings that corresponds to the spring leaf tissue analysis. Breyta software developers are creating a leaf tissue event in CropManage so that users can enter tissue samples for several dates during the season.
6. **Create commodities and crop types for almonds, pears, pistachio, prunes, and walnuts.** Breyta developers have added almonds as a first tree commodity to CropManage and within almonds a preliminary crop type was created for testing purposes. A *crop type* presets the model parameters for a variation of the production practices within a commodity group. For example "Almonds without cover crop" would be crop type within the almond commodity group that reflects that the orchard does not have a cover crop. After confirming that the tree modifications in CropManage are operating and calculating recommendations correctly, we will begin adding other commodities and crop types.

Almond N recommendation model		Comments	12/31/2017
Yield (lbs/ac)	3000	Include in Seasonal N uptake calculator	
Age	2 - 4 years	Include in Seasonal N uptake calculator	
Vigor	high vigor	Include in Seasonal N uptake calculator	
Leaf out date	2/15/2018		
End of season	11/15/2018		
Yield N Demand	204	Include in Seasonal N uptake calculator	
Vegetative N Demand	25	Include in Seasonal N uptake calculator	
Spring Leaf Nutrient Values:		User inputs as plant tissue test event	
N (%)	3.433		
P (%)		not required for model	
K (%)	2.2251955		
Ca (%)	1.74888827		
Mg (%)	0.36		
S (%)		not required for model	
B (ppm)	44.390782		
Predicted Summer Leaf N (%)	2.48	Include in Seasonal N uptake calculator	
Total Crop N demand (lbs N/acre)	229	Include in Seasonal N uptake calculator	
N from cover crop	15	soil amendment calculator included in Seasonal N uptake calculator	
N from soil amendments	4	cover crop calculator included in Seasonal N uptake calculator	
Total Fertilizer N (lbs N/acre)	300	Include in Seasonal N uptake calculator	
fertilizer event date	4/14/2018	enter date	
days to next fertilization	15	enter days to next fert	
N fert to apply (lbs N/acre)	32.63978346		

Figure 1. Reformatted fertilizer N calculator used for transferring the tree N model to CropManage.

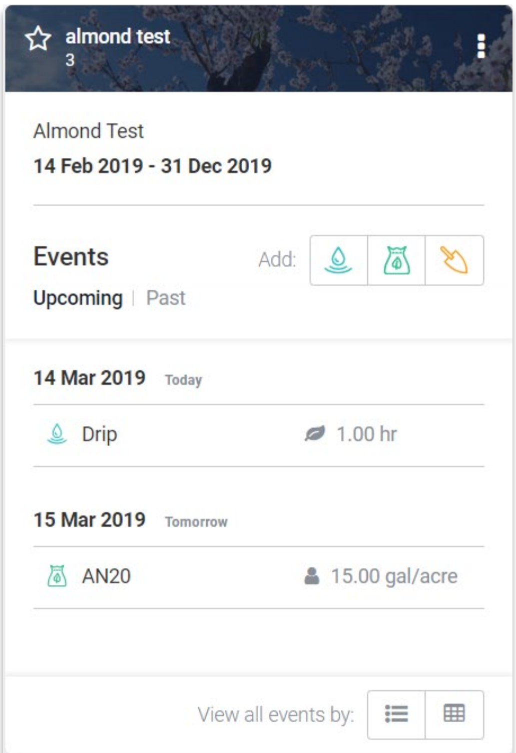

Figure 2. User interface for tree crops in CropManage

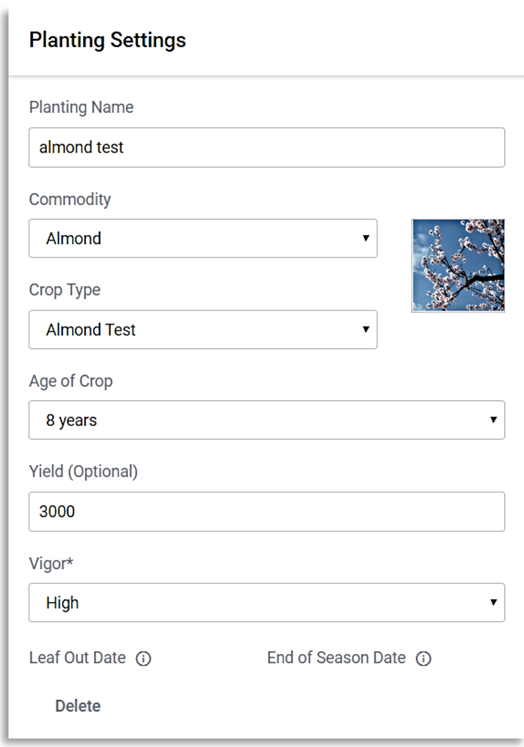

Figure 3. Crop settings user interface for almonds.

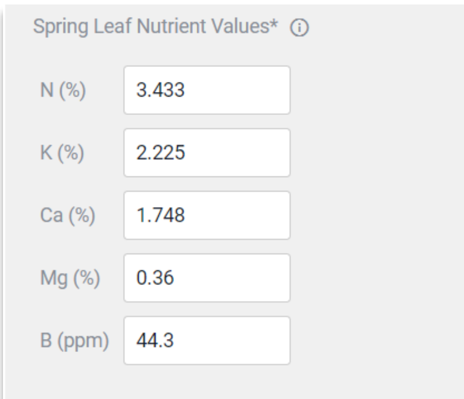

Figure 4. Crop settings user interface showing leaf tissue entry.

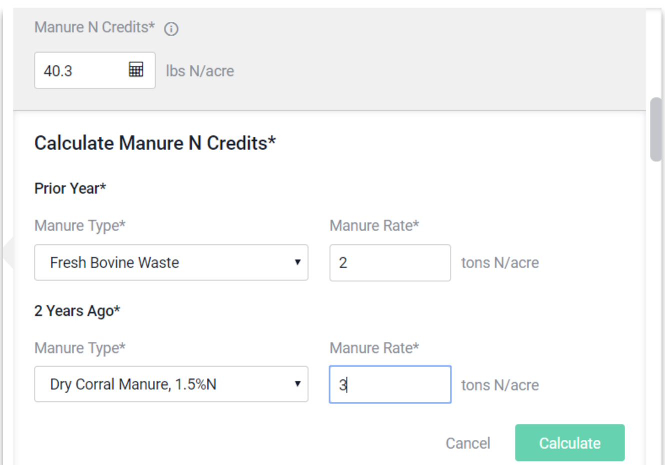

Figure 5. Manure N credit calculator within the crop settings interface.

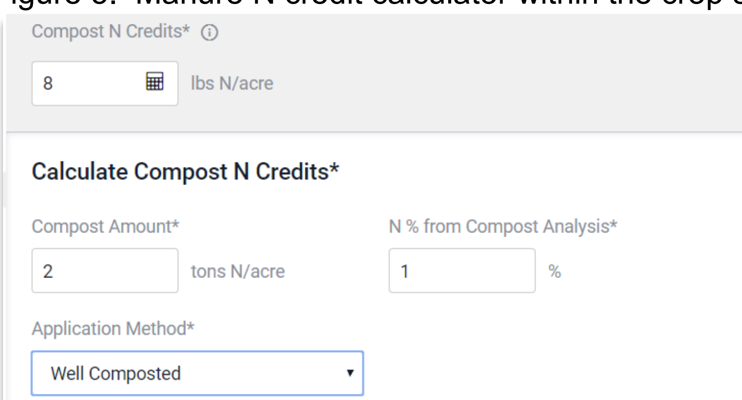

Figure 6. Compost N credit calculator within the crop settings interface.

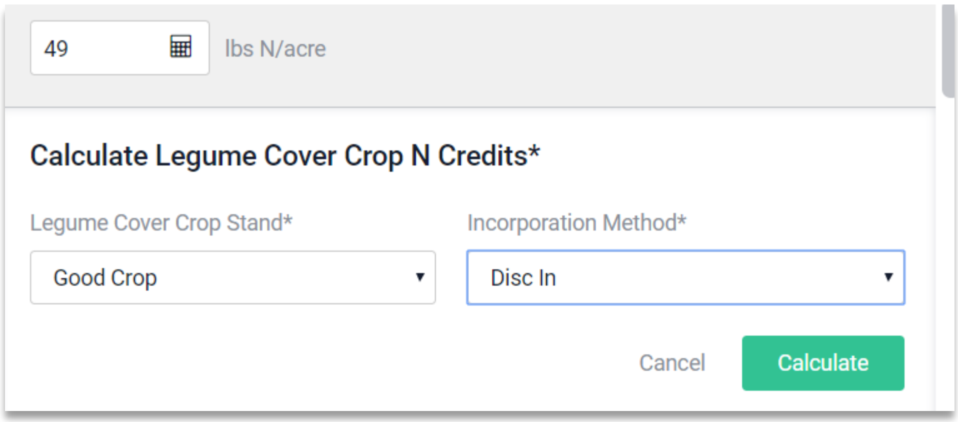

Figure 7. Legume cover crop N credit calculator within the crop settings interface.

G. Discussion and Conclusions:

This project has successfully developed and implemented an early leaf sampling strategy for Walnut, Pear and Prune and integrated the data into the online CropManage system which simultaneously integrates nitrogen budgeting and irrigation strategies. The development and implementation of this online tool fulfils all project objectives. While the models developed for the implementation of early season leaf sampling in these crops are robust the quality of the resultant prediction will be determined by the management actions taken by the grower subsequent to the early season sampling. The provided models are greatly improved with the inclusion of grower derived data including soil sampling and management practices. Data for pear is less robust than data for walnut and prune due to a lower diversity in tissue sample concentrations in the pear samples and the presence of 3 outlier values. The methodology used here and data developed is complimented by data previously developed for almond further indicating that early season tissue sampling is a valuable tool for grower decision making.

H. Project Impacts: Summer leaf nutrient analysis has historically been the most widely used monitoring tool to track tree nitrogen status, this involves collection of leaf samples in summer, submission of samples to an analytical laboratory for analysis and comparison against established standard critical values for summer. Sampling in summer, however, is too late in the season to adjust current season nitrogen management if needed. An industry-wide grower survey conducted in 2007 suggested that while leaf nutrient sampling is useful to guide fertilization management it would be achieve greatly enhanced utility if ways to collect and interpret leaf analysis results in the spring rather than the late summer were developed. The results produced in this project provide growers with easy to use methods to predict tree N status in the spring giving growers the time to react appropriately to achieve a rational, plant based fertilization regime. The leaf sampling methodology developed is not, however, sufficient in of itself but must be combined with a yield based N management strategy based upon current tree productivity estimates. The integration of these early sampling strategies into the CropManage software that includes an N budgeting strategy along with irrigation management guidelines provides the grower with an integrated approach to N management. By reducing grower uncertainty of tree N status and demand this project has the potential to improve the efficiency of N use and thus advance the environmentally safe and agronomically sound use of fertilizing materials.

I. Outreach Activities Summary

This project is part of a larger integrated outreach effort focused on nitrogen management in Californian agriculture. The following represents the talks and outreach events at which the practice of early season sampling and associated management websites (CropManage and ABC-CASP program) were highlighted.

A series of short instructional videos (i.e. 2 minutes long) will be made to explain how to conduct early season tissue sampling (Prune video link , Walnut video link , Pear video link)

Outreach Events:

Prediction of Summer Leaf Nitrogen Concentration from Early Season Samples to Better Manage Nitrogen Inputs at the Right Time in Walnuts, Prunes, and Pears. XVIII International Plant Nutrition Colloquium, 21-24 August 2017 in Copenhagen.

Prediction of Summer Leaf Nitrogen Concentration from Early Season Samples to Better Manage Nitrogen Inputs at the Right Time in Walnuts, Prunes, and Pears. Sebastian Saa, Patrick Brown, Emilio Laca. 2018 FREP/WPHA Annual Conference October 22-24, 2018.

1. Field Day: Colusa (2018)

- Location: Nickels Soil Lab, Greenbay Rd., Arbuckle, CA
- Date: March 13 (8:30-1pm)
- Title: Spring Almond and Walnut Nutrient and Water Management Field Day
- Session Presentation Titles:
  1. ABC Overview and Almond Sustainability Program (large group talk) - Spencer Cooper, Jenny Nicolau, Rebecca Bailey

2. Water and N management for integrated hull rot management (large group talk) - Franz Niederholzer
3. Barriers to Adoption of Nitrogen Management Practices - Jessica Rudnick, Sat Darshan S. Khalsa, Stephanie Tatge
4. Nitrogen management BMP's in walnut - Katherine Jarvis-Shean
5. Managing boron in irrigation water – Patrick Brown
6. Forward tissue sampling and overview of BMP trials to manage N and water - Miguel Guillen, Sebastian Saa
7. Tools: Irrigation efficiency and timing - Allan Fulton
8. CASP Module- Spencer Cooper/ABC

- Number of participants: 120
- Type of audience: growers, crop advisors
- Supporting documentation (e.g. flyers, program, etc.) – program flyers, grower press coverage, ABC coverage.
- CCA CEUs/Grower CEUs offered: Nitrogen Management = 2, Irrigation and Nitrogen Management = 1, other = 0.5

2. Field Day: Merced (2018)

- Location: Ash Slough Farms, Ave 21, Chowchilla, CA
- Date: Tuesday, March 20th (8:30-1pm)
- Title: Spring Almond Nutrient and Water Management Field Day
- Session Presentation Titles:
  1. Welcome! Grower/management conversation about goals and practices – Chris Morgner
  2. ABC Overview and Almond Sustainability Program (large group talk) - Spencer Cooper/ABC
  3. Nutrient Management Plans-Phoebe
  4. Soil and water testing for planning and feedback- Mae Culumber
  5. Forward tissue sampling and overview of BMP trials to manage N and water –Patrick Brown and Miguel Guillen
  6. Tools: Irrigation efficiency and timing –David
  7. CASP Module- ABC
- Number of participants: 100
- Type of audience: growers, crop advisors
- Supporting documentation (e.g. flyers, program, etc.) – program flyers, grower press coverage, ABC coverage.
- CCA CEUs/Grower CEUs offered: Nitrogen Management = 2, Irrigation and Nitrogen Management = 1, other = 0.5

3. Field Day: Kern (2018)

- Location: UCANR County Office, Bakersfield, CA
- Date: March 21 (8:30-3pm)
- Title: Spring Almond Nutrient and Water Management Field Day
- Session Presentation Titles:
  1. Forward tissue sampling and overview of BMP trials to manage N and water –Patrick Brown and Miguel Guillen

2. How does NMP reporting fit into the larger Irrigated Lands Regulatory Program? – Nicole Bell.
3. ABC Sustainability Program: On-line tools for water and fertilizer management – Spencer Cooper/ABC
4. Nutrient Management Plans- Nick Clark
5. Soil/Plant/Water testing for planning and trouble-shooting NMP's – Keith Backman
6. Tools for field assessment: Distribution uniformity, aerial/remote sensing – Blake Sanden
7. ABC Overview and Almond Sustainability Program (large group talk)- ABC
8. Barriers to Adoption of Nitrogen Management Practices – Sat Darshan Khalsa, Stephanie Tatge, Jessica Rudnick
9. Control of navel orange worm via mating disruption / puffers etc. – Dave Haviland
10. Spring diseases in Almonds- Mohammed Yagmour

- Number of participants: 150
- Type of audience: growers, crop advisors
- Supporting documentation (e.g. flyers, program, etc.) – program flyers, grower press coverage, ABC coverage.
- CCA CEUs/Grower CEUs offered: CURES – 3, CCA – 4, PCA – 1

4. Field Day: Tehama (2018)

- Location: California Almond Packers and Exporters (CAPEX), 21275 Simpson Road, Corning, CA.
- Date: Wednesday, March 27 (8:30-12pm)
- Title: Spring Almond and Walnut Nutrient and Water Management Field Day
- Session Presentation Titles:
  1. Grower/Management conversation about goals of practices (large group talk)-Corning Grower Matt Esteve.
  2. ABC Overview and Almond Sustainability Program (large group talk)- Spencer Cooper/ABC 3. Nitrogen management BMP's in walnut - Katherine Jarvis Sheen
  4. Soil and water testing for planning and feedback – Luke Milliron
  5. Forward tissue sampling and overview of BMP trials to manage N and water –Patrick Brown and Miguel Guillen
  6. Tools: Irrigation efficiency and timing-Allan Fulton
  7. CASP Module- Spencer Cooper/ABC
- Number of participants: 129
- Type of audience: growers, crop advisors
- Supporting documentation (e.g. flyers, program, etc.) – program flyers, grower press coverage, ABC coverage.
- CCA CEUs/Grower CEUs offered: Nitrogen Management = 2, Irrigation and Nitrogen Management = 1, other = 0.5

Impact measures

- Evaluation tools (surveys, interviews, etc.) – planned for 2019 in conjunction with field days.

J. Factsheet/Database Template:

1. Project Title: **Prediction of summer leaf nitrogen concentration from early season samples to better manage nitrogen inputs at the right time in walnuts, prunes, and pears**

2. Grant Agreement Number (Assigned by CDFA): 15-0942

3. Project Leaders (Include names and affiliations): Patrick Brown, Professor, Department of Plant Sciences, One Shields Ave., University of California, Davis, CA, 95616; Phone: 530 752-0929; e-mail: phbrown@ucdavis.edu. Emilio Laca, Professor, Department of Plant Sciences, One Shields Ave., University of California, Davis, CA, 95616; Phone: 530 754-4083; e-mail: ealaca@ucdavis.edu. Sebastian Saa, Project Scientist, Department of Plant Sciences, One Shields Ave., University of California, Davis, CA, 95616; Phone: 530 752-0929; e-mail: ssaasilva@ucdavis.edu.

4. Start Year/End Year: 2015-2018

5. Location (Locations where research was performed): Grower orchards in Sacramento and San Joaquin Valleys

6. County (Counties where research was performed): Yolo, Colusa, Glenn, San Joaquin, Fresno, Glann, Butte, Amador, Merced, Madera, Fresno, Kings, Kern, Tulare, Sutter, Colusa, Lake, Yuba, Solana, Stanislaus, Tehama.

7. Highlights

- An early season leaf nutrient prediction model was developed for pear, walnut and prune
- The model was integrated into the CropManage program to provide growers with integrated nitrogen fertilization and irrigation strategies.
- Model use and fertilization strategies were extended to growers and other stakeholders through meetings and publications.
- Leaf sampling videos for each crop were recorded and are available for pears, walnut, and prune.

8. Introduction: Summer leaf nutrient analysis has historically been the most widely used monitoring tool to track tree nitrogen status, this involves collection of leaf samples in summer, submission of samples to an analytical laboratory for analysis and comparison against established standard critical values for summer. Sampling in summer, however, is too late in the season to adjust current season nitrogen management if needed. The ability of growers to predict tree nutrient status early in the season would aid in the development of sound nitrogen management decisions. An industry-wide grower survey conducted in 2007 suggested that while leaf nutrient sampling is useful to guide fertilization management it would be achieve greatly

enhanced utility if ways to collect and interpret leaf analysis results in the spring rather than the late summer were developed.

9. Methods/Management: A detailed leaf sampling campaign was conducted across all major pear, walnut and prune growing regions of California. Leaf analysis data, soil samples and grower management strategies and yields were collected and utilized to develop a statistical model to predict late season leaf tissue concentrations based upon early season sampling. Three models with differing degrees of data intensity were developed and validated. Results were then integrated into the CropManage program to provide and results were extended to growers and stakeholders.

10. Findings: We have successfully developed and implemented an early leaf sampling strategy for Walnut, Pear and Prune and integrated the data into the online CropManage platform to provide integrated nitrogen budgeting and irrigation strategies for almond, prune, pear and walnut. Three discrete models were developed reflecting three different levels of grower available data, growers may choose to utilize whichever model best fits their circumstance. The quality of the resultant prediction will be determined by the management actions taken by the grower subsequent to the early season sampling by the inclusion of grower derived data including soil sampling and management practices. The methodology used here and data developed is complimented by data previously developed for almond and pistachio and the integration into the CropManage platform. A series of videos were prepared to assist growers with leaf sampling protocols.

K. Copy of the Product/Result:

Publications and Web Resources Resulting in part or whole from this research:

Outreach or educational materials published and/or printed in the past year:

- A series of Nitrogen Management Publications (4) were developed in coordination with the Californian Institute for Water Resources
- https://ucanr.edu/sites/scri/Crop_Nutrient_Status_and_Demand__Patrick_Brown/
- http://www.ceresimaging.net/blog/nitrogen-needs-in-almonds-tips-from-ucs-patrick-brown
- http://www.ceresimaging.net/blog/nitrogen-refresher-patrick-brown-offers-tips-to-almond-growers-in-chowchilla
- http://fruitsandnuts.ucdavis.edu/Weather_Services/Nitrogen_Prediction_Models_for_Almond_and_Pistachio/
- Event Flyers Appended to this document
- Leaf sampling videos for each crop were recorded and are available for pears, walnut, and prune.

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