Project Information

Project Title: Development of Nutrient Budget and Nutrient Demand Model for Nitrogen Management in Cherry

Project's duration: 3 years (2020/2023)

Grant number: 19-0954

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Objectives

Develop nutrient demand curves to guide the quantity and time of fertilizer application in cherry. Repeat for most representative cultivars and production systems.

Develop and extend nutrient Best Management Practices (BMP) for cherry cultivars.

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. Currently, nutrient management decisions in cherries are based on leaf analysis and critical value interpretation which only indicates a deficiency or sufficiency and is performed too late to respond to deficiencies or plan N applications. In other high value crops such as Almond, Pistachio and Walnut, nutrient management is increasingly based on yield and vegetative growth estimated crop demand coupled with an understanding of seasonal nutrient demand dynamics. This approach has not been developed for cherry cultivars in California and hence cherry growers do not have improved fertilizer management decision tools to apply the right rate of fertilizer at right time, to optimize productivity and avoid environmental losses. Current approaches to nutrient management in cherries rely heavily on leaf sampling collected during late summer which is too late to respond to deficiencies or adjust fertilizer regimes. The concept of demand driven nitrogen management is not widely practiced but is essential to meet ILRP guidelines and achieve a high efficiency of N use. Critical data on N export rates, seasonality of N demand and differences between cultivars and practices in N dynamics, is not currently available from California cherry production. A holistic nutrient management protocol was developed to guide the fertilization rate and time of fertilizer application as well as in season monitoring to adjust fertilizer rate to optimize yield and reduce leaching of nitrate to ground waters.

Introduction

Matching fertilizer application with plant demand is important to maximize production as well as to minimize losses to the environment. Application of nitrogenous fertilizers to tree crops when not needed or in excess of crop demand, has resulted in leaching of N to ground water (Weinbaum et al., 1992) with nitrate levels in ground water now exceeding the maximum contamination level of 45 ppm in many parts of the world (Burow et al., 2008; Viers et al., 2012). In response to evidence of widespread nitrate pollution of groundwater, the Central Valley Region Water Quality Control Board has adopted a regulatory widespread nitrate pollution of groundwater, the program to protect groundwater resources that requires growers to use best nitrogen (N) management practices to reduce nitrate leaching.

In annual crops, knowledge of crop nutrient demand and the application of fertilizers at rates and times consistent with crop demand has been central to the improvement of N use efficiency and the reduction in leaching potential (Fessehazion et al., 2011). Our knowledge of crop demand and patterns of nutrient uptake in deciduous perennial tree species is currently very poor and hence our ability to optimize fertilization strategies is limited. The large size and perennial nature of deciduous tree crops complicates the derivation of nutrient uptake patterns. The ability of perennials to store nutrients to meet a substantial proportion of the early demands of growing leaves and flowers/fruits further complicates the determination of seasonal uptake patterns (Millard and Grelet, 2010). The amount of stored nutrients also varies depending on environment, tree age and species (Weinbaum and Van Kessel,1998).

Understanding of the pattern of nutrient acquisition and demand in trees is relevant in an agricultural context when nutrients must be applied to maximize productivity and minimize wastage. Climate change is predicted to change the quantity and distribution of precipitation, while changing temperatures will alter the rate of soil microbial processes that in turn determine soil nutrient availability. Knowledge of the patterns of nutrient acquisition by tree species will enhance our ability to predict the impact of changes in climate on tree growth and productivity.

Efficient management of nutrients in agricultural production is essential for both economic sustainability and to minimize the movement of nutrients from the field where they may result in environmental degradation. According to the most recent California Agricultural Statistics Review publication, California sweet cherry production grossed $330,773,000 in revenues during the 2017 growing season. Albeit a relatively high-value crop, to date, no research has been conducted in California to evaluate either the seasonal demands or indicators of sufficiency of nutrients in sweet cherry cultivars.

Currently, cherry growers know little about efficiently supplying demand-driven nutrients. Historically, the management of nutrition of cherries has mostly been based on leaf sampling and subsequent contrast with established critical values (CVs). CVs are the nutrient concentration in a standard leaf sample at which growth is 90% of the maximum growth (Ulrich and Hills, 1967, 1990). While this has been a useful tool for diagnosis of nutrient deficiency or excess (Ulrich and Hills, 1967), it is now recognized that this approach does not provide sufficient information to define the rate and timing of fertilizer applications. Thus, knowledge of tree internal N dynamics is important to determine the timing and amount of N supply in spring and summer.

Recognizing the limitations of traditional leaf sampling as a mean of managing fertilization in high value crops such as cherries, several alternate approaches have been developed. Most promising among these is the use of seasonal nutrient uptake dynamics and demand estimations to construct a 'budget' approach to fertilizer management. For a wide range of annual and perennial field crop species, nutrient budgets have been developed to determine time and rate of fertilizer applications (Geraldson and Tyler, 1990; Ulrich and Hills, 1990; Benbi and Biswas,1999).

The development of nutrient budgets for mature trees is complex and costly requiring whole plant excavation and determination of the nutrient concentration and biomass of the individual plant organs to calculate the nutrient accumulation rate over the season and hence has rarely been performed (Weinbaum et al., 2001; Muhammad et al, 2015). Nutrient demand curves have not been developed for cherry and those available for other deciduous tree species were generally limited in scale. The objective of this project was to develop and extend nutrient Best Management Practices (BMP) to optimize N use efficiency in cherry cultivars with the outcome of reducing N leaching.

Work description

Our goal was to develop knowledge of the pattern of nutrient uptake and allocation of nitrogen in cherry and to provide insight into nitrogen allocation patterns, the storage of nitrogen in perennial tissue and the role of nitrogen remobilization in supplying early season nutrient demand and direct application for the management of nitrogen in commercial orchards.

Activity 1. Develop nutrient demand curves to guide the quantity and time of fertilizer application in cherry. Repeat for most representative cultivars and production systems. (*Years 1 and 2*).

The study was conducted in three mature (15-year-old) high yielding commercial cherry cultivars "Bing", "Coral", and "Rainier" orchards in the California Central Valley. All varieties were grafted on Mazzard rootstock with an approximate planting density of 120 trees per acre.

Figure 1. Highly productive groves of cherry cultivars (Bing, Coral, and Rainier) were selected in the California Central Valley.

Three replicated blocks of trees (4 trees per block, totaling 12 trees per orchard) for each cherry cultivar (“Bing”, “Coral”, and “Rainier”) were monitored for changes in nutrient concentrations in annual (leaves and fruits) and perennial organs (roots, trunk, scaffold, canopy branches and small branches) six times during the season at different phenological stages. Samples were collected from different tree organs as follow:

Roots: several root sections were dug randomly from around the trunk from roots <1cm and >1cm diameter.

Trunk: two 5.0 cm-deep holes were drilled.

Scaffold: three 2.5 cm-deep holes were drilled.

Canopy branches: five 1.0 cm-deep holes were drilled.

Small branches: one- and 2-years old branches were sampled randomly from each tree canopy.

Leaf and Fruit samples: Leaves of different age from the same tree were collected. Fruit samples were also collected at the same time. Individual yield of the trees was determined at harvest.

Figure 2. Three trees of each cultivar were sampled six times during the growing season at different phenological stages and processed for nutrient analyses.

Three trees of each species were excavated in March of 2020 2021, and 2022 before flowering and were separated into small and large roots, trunk, scaffold, canopy branches, small branches, and leaves to determine total biomass accumulation during the growing season (Figure 3).

Figure 3. Three trees of each cultivar were excavated at the beginning of each growing season and separated into small and large roots, trunk, scaffold, canopy branches, small branches, and leaves.

Activity 2. Develop and extend nutrient Best Management Practices (BMP) for cherry cultivars (*Year 3*).

The combination of nutrient budget, seasonal changes in tree N content and in-season prediction of tissue nutrient status will help in developing a robust new fertilizer management tool for cherry growers of California. The findings from the research helped in the development of the 'Right Rate' and 'Right Time' to guide N applications.

Results:

Tree biomass and nutrient content

Total nutrient amounts per tree was obtained by summing the nutrient content of tree organs calculated by multiplying the dry weight of each tree organ by its nutrient concentration. Data refer to the average of three trees excavated in 2020, 2021, and 2022 for each "Bing", "Coral", and "Rainier" blocks. Overall canopy branches and roots accounted for the majority of the biomass in all orchards and also included a notable fraction of nutrients present in tissues as shown in Figure 4.

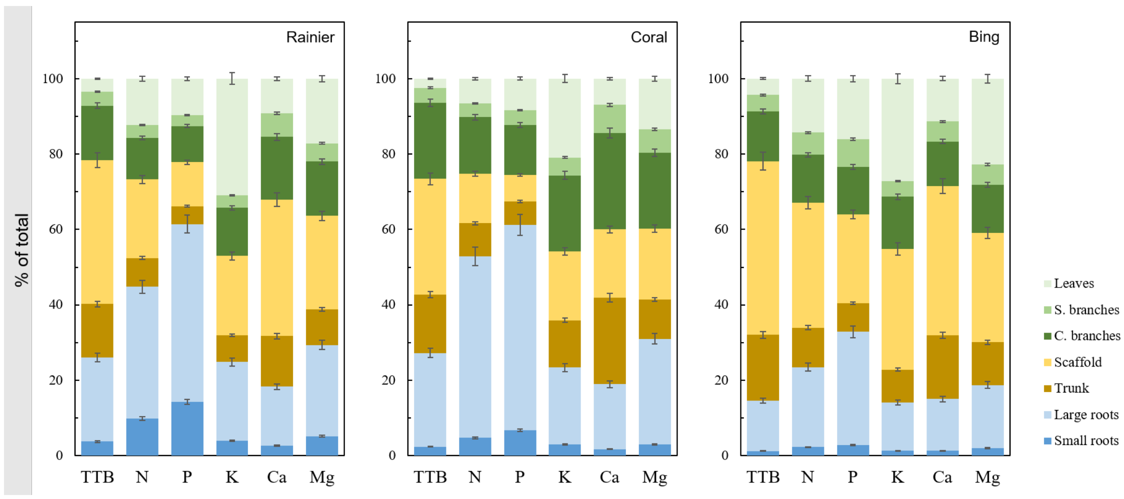


Figure 4. Tree partitioning (% of total) of total tree biomass (TTB) and macronutrients (N, P, K, Ca, and Mg) content. Data refer to cherry cultivars "Rainier", "Coral", and "Bing". Bars represent standard errors.

Dynamics of Nitrogen uptake during the season

Seasonal N content in perennial organs (trunk, scaffold, canopy branches and roots), leaves and fruits of cherry trees is shown in Figure 5. Data refer to the average of 27 trees. Overall, commencement of uptake coincides with 50% leaf out and completion coincides with early leaf senescence. The production of flowers is totally dependent on the remobilization of stored N. In general, the accumulation of N was rapid from April until the end of August, while continued later with a lower rate. Low net accumulation of N after October was observed. From December to February the amounts of N present in the tree canopy remained stable or decreased.

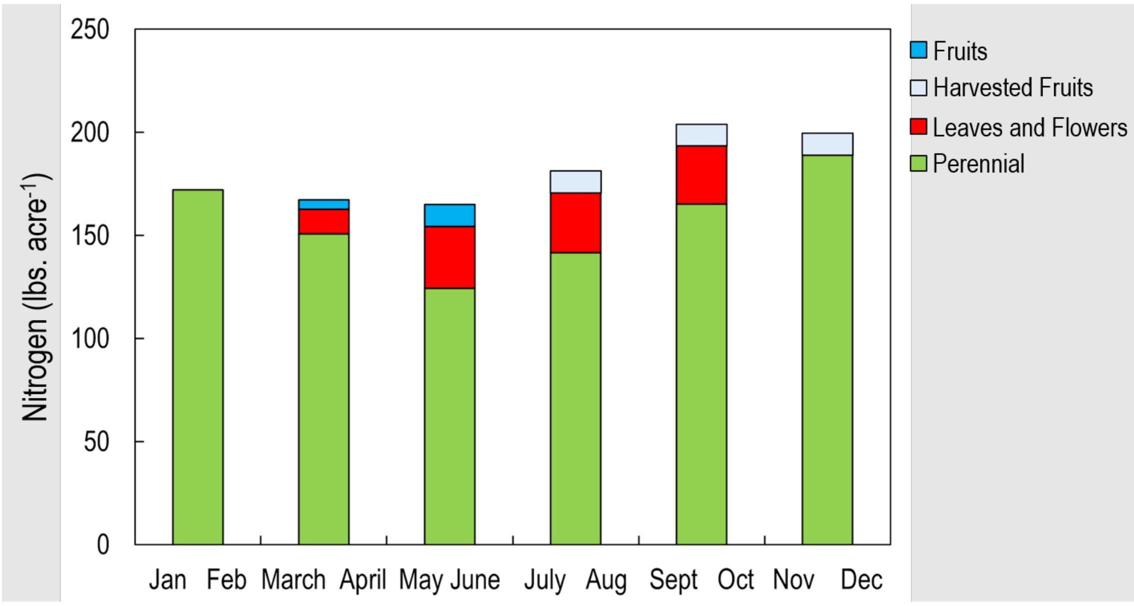


Figure 5. Total initial N and seasonal trends in Nitrogen partitioning in fruits, leaves, and perennial organs (trunk, scaffold, canopy branches and roots) of mature cherry trees. The overall average is weighted for the number of observations in all trials (n = 27). ****Note that the nitrogen (N) amount shown on Y axis is for entire orchard N content, not N recommended rate per acre**.

Seasonal nutrient content in aboveground organs and in roots is shown in Figure 6. Data refer to the weighted average of 27 trees. In general, trees directed more pre-harvest N to fruit and more post-harvest N to vegetative growth. Growth of leaves, stems and fine roots were dependent on stored N, with root uptake beginning about 20-30 days after full bloom. No significant net accumulation of N in shoots after late October was observed. From November to February the amount of nutrients presents in the tree canopy remained stable or decreased, likely suggesting nutrient translocation to perennial organs.

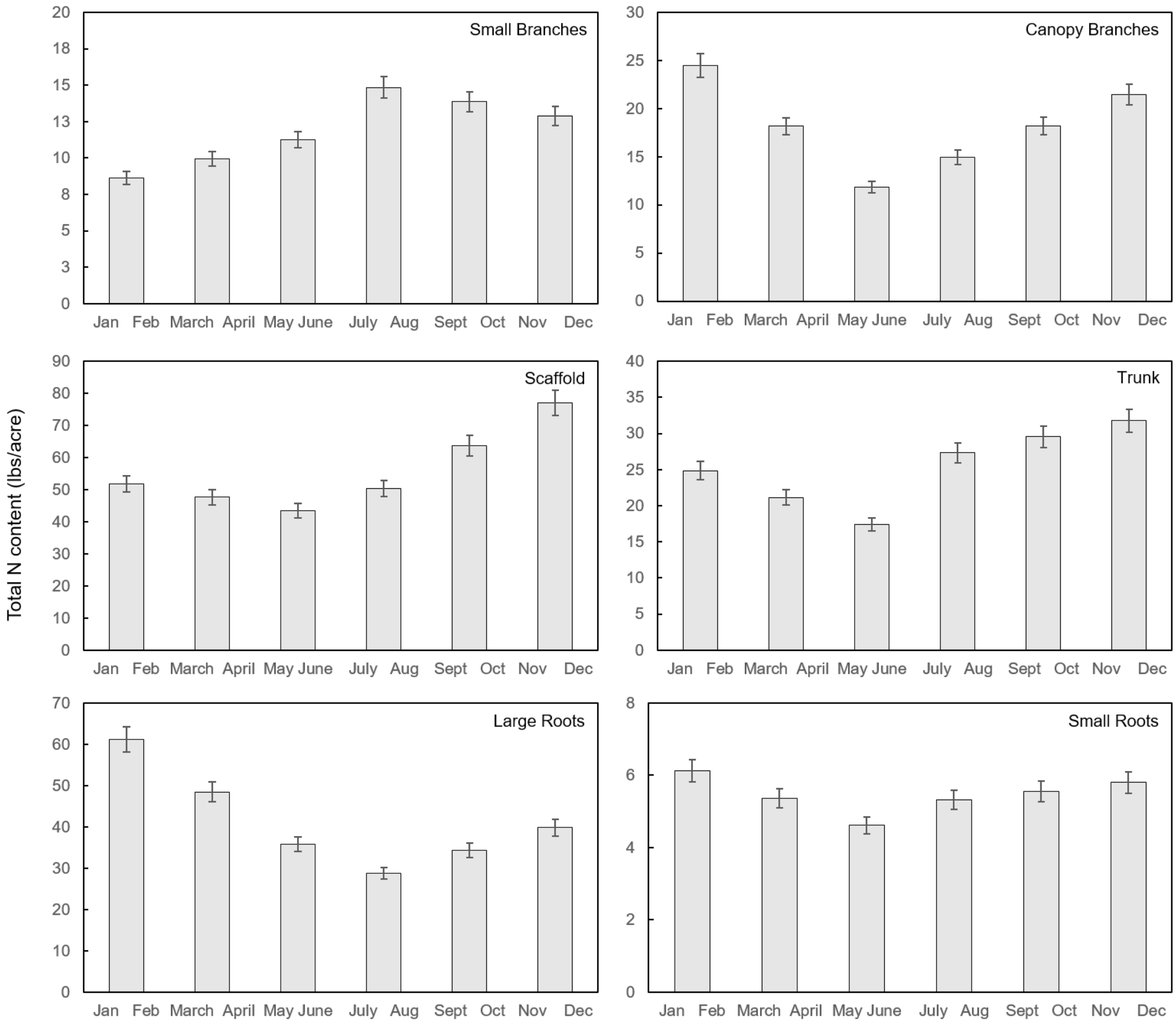
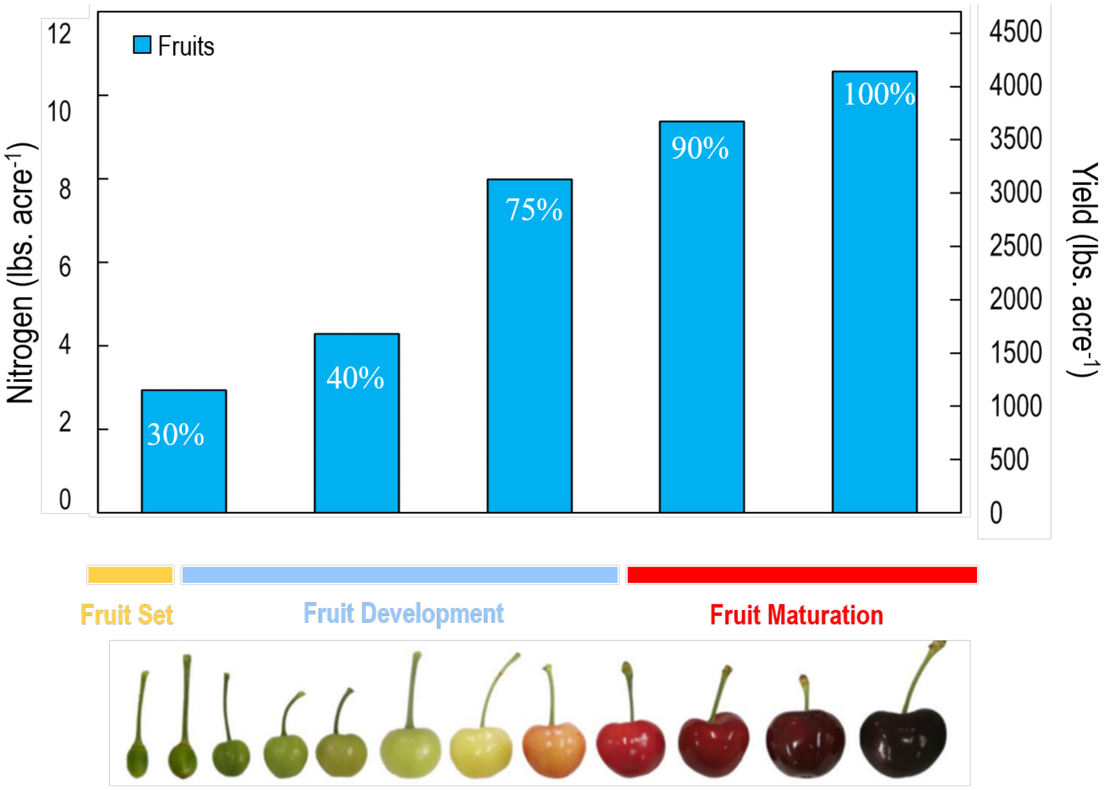


Figure 6. Seasonal trends in nitrogen (N) accumulation in aboveground tissue and roots during the season in cherry trees. Bars represent standard errors. The overall average is weighted for the number of observations in all trials (n = 27).

Seasonal pattern of nitrogen accumulation in fruits

The patterns of N accumulation in fruits during the season is presented in Figure 7. Nitrogen accumulation occurred rapidly in the early season with 90% of the total N accumulated by completion of fruit development. In general, the concentration of N was high at the beginning of the season and stabilized during fruit maturation until fruit harvest.



Growth and development stages of cherry (Chen et al. 2022)

Figure 7. Seasonal trends in nitrogen accumulation in fruits of cherry trees. The overall average is weighted for the number of observations in all trials (n = 27).

Discussion and Conclusions

To improve our understanding of whole orchard nutrient balance, we collected nutrient concentrations and biomass of all major organs of mature field grown cherry trees by whole tree excavation, sequential tissue sampling and nutrient analysis in trees grown under "ideal" nitrogen rate treatments. The amount of nutrient accumulated in perennial organs over two years (2020-2022) was determined as the difference between the total tree nutrient at the completion of each season.

The methodology used in this research allowed to estimate the annual amounts of nitrogen that field grown cherry trees absorbed and allocated to above ground organs. Knowing the dynamics of nutrient uptake during the season is a requirement to allow the management of the timing of nutrient supply with nutrient needs and to avoid nutrient losses, especially N-Nitrate (NO^{-3}).

The seasonal demand of N in cherry is high early in the season from April through September with 80-90% of the total N accumulated by September in all cultivars. Nitrogen uptake rapidly occurs approximately 30 days after bloom and during fruit development, which also coincides with vegetative growth, and continues after harvest. Trees directed more pre-harvest N to fruit and more post -harvest N to vegetative growth stopping uptake during leaf senescence.

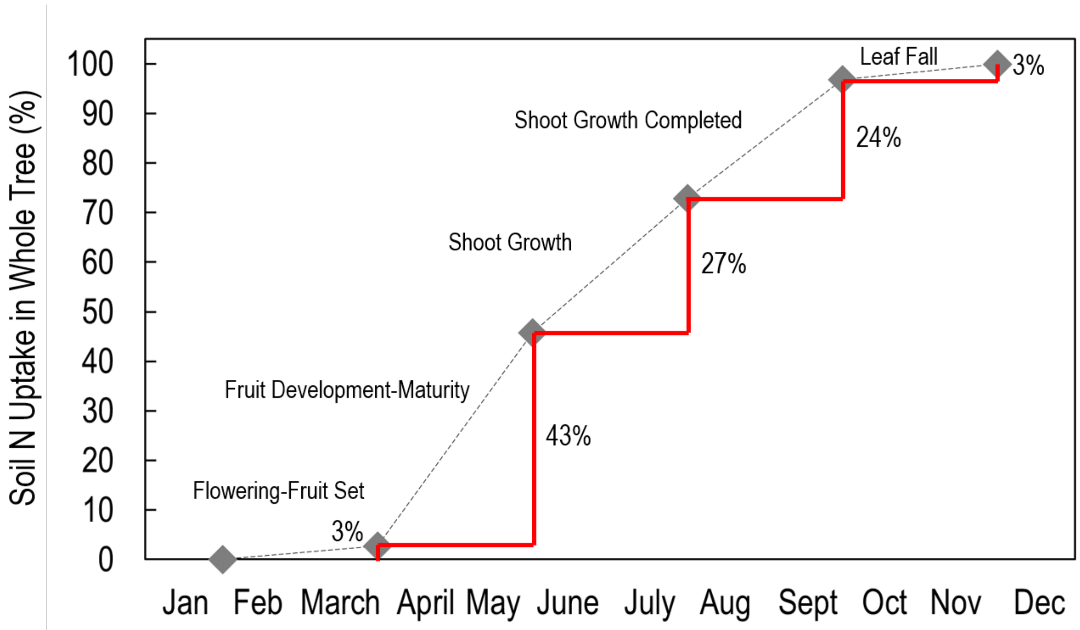


Figure 8. Seasonal trends in nitrogen accumulation in whole cherry trees. The overall average is weighted for the number of observations in all trials (n = 27).

Fruits are an important sink for nutrients and the pattern of nutrient accumulation through the season is largely driven by the pattern of fruit growth with most nutrients accumulated from cell division to cell enlargement. Nitrogen accumulation occurred rapidly in the early season with up to 90% of the total N accumulated by September. In general, cherry fruit development starts with an initial increase in fruit size and once fruit reaches full size, fruit maturation starts. By the end of fruit development stage, fruits had gained 70-80% of their total weight. The majority of nitrogen accumulation in cherry trees coincided with fruit set and development and the rate of fruit N accumulation decreased markedly during fruit maturation. As shown in Table 1, the export of Nitrogen in cherries was estimated to be on average 2.59 lbs. per 1000 lbs. of fruits and biomass N accumulation was estimated to be 28.3 lb. of N per acre.

Table 1. Nitrogen removal in cherry cultivars. The overall average is weighted for the number of observations in each trial ($n = 9$).

Variety	*Removal at harvest (lbs N/1000 lbs of fresh fruits)*
Rainier	2.74
Coral	2.73
Bing	2.32
Weighted Average	**2.59**

	Tree development (lbs N/acre)*
Rainier	28.99
Coral	28.41
Bing	27.51
Weighted Average	**28.30**

*Planting density of 120 trees per acre.

To guide the fertilizer application in orchards, data about total amounts of absorbed nutrient should be integrated with information of their fate in the ecosystem. While we can assume that nutrients contained in fruits and those stored in the tree framework directly or indirectly leave the system – and therefore their reintegration to the soils should be considered, – part of the absorbed nutrients returns to the soil through leaf abscission, pruning wood or root death, where they are potentially available to be re-absorbed by tree roots, after their decomposition and mineralization. For example, N derived from leaf litter residue can provide 3-5% of tree N requirements within 12 months.

In conclusion, our data suggest that N should be available in the soil for root to uptake by cherry trees from 50% leaf out to beginning of leaf senescence but should not be applied in the soil later than 8 weeks after harvest to decrease N leaching potential. The N accumulation in a mature cherry tree is a combination of N derived from the previous season (stored N) and current season uptake from both soil and applied fertilizer.

Project Impacts

As a best management practice, fertilizer in a cherry orchard should be based on expected yield estimated at flowering and fruit set followed by analysis of leaves to diagnose any deficiency. The combination of nutrient budget determination, nutrient response information, improved sampling and monitoring strategies, and yield determination provide a theoretically sound and flexible approach to ensure high productivity and good environmental stewardship.

Outreach Activities Summary

Publications:

Amaral, DC; Camargo, R; Brown, PH. Assessing nutrient uptake by field-grown cherry trees in California. *Research paper in preparation*.

Amaral, DC; Camargo, R; Brown, PH. Monitoring a cherry orchard: nutrient management for optimal production. *Extension paper in preparation*.

Presentations:

Brown, PH. Nitrogen Management in Cherries. CCB Workshop. 2021. Webinar.

Brown, PH. Nitrogen Management in Cherries. FREP Conference. 2022. Webinar.

Brown, PH. Nitrogen Management in Cherries. SSA Conference. 2022. Webinar.

Websites:

Getting ahead of cherry nutrition. https://www.goodfruit.com/getting-ahead-of-cherry-nutrition/

Factsheet/Database Template

1. Project Title: Development of Nutrient Budget and Nutrient Demand Model for Nitrogen Management in Cherry

2. Grant Agreement Number: 19-0954

3. Project Leaders:

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4. Start Year/End Year: 2020-2023

5. Location: Stockton, Lodi.

6. County: San Joaquin.

7. Highlights:

Results demonstrate that fertilizer use in cherry cultivars can be optimized and considerable nitrogen losses can be reduced if nitrogen applications are synchronized with the actual tree demand and uptake pattern. This project provides the baseline data to achieve this goal.

Nitrogen use efficiency can be optimized by adjusting fertilization rate based on realistic, orchard specific yield, accounting for all N inputs and adjusting fertilization in response to spring nutrient status, uptake pattern, and yield estimates.

Cherry offtake of N was 2.59 lb. per 1000 lbs. fruit

Overall, biomass N accumulation was 28.3 lbs. of N per acre

Nitrogen accumulation occurred rapidly in the early season with up to 90% of the total N accumulated by September.

Applications to match demand in as many split applications as feasible is recommended

8. Introduction:

Environmental legislation is forcing a change in farming practices because of many years of excess N application and loss of N below the root zone and consequent contamination of water resources. One of the main opportunities to optimize nitrogen fertilization is to synchronize applications with plant crop demand and apply N coincident with root uptake. This project has provided the data needed to correctly estimate the right rate and right time of fertilizer application for efficient and environmentally sound practices in cherry.

9. Methods/Management:

In this project we monitored highly productive groves of cherry in San Joaquin County during two growing seasons. A holistic nutrient management protocol has been developed to guide the fertilization rate and time of fertilizer application as well as in season monitoring to adjust fertilizer rate to optimize yield and reduce leaching of nitrate to ground waters.

10. Findings:

This project has allowed the development of improved nitrogen management practices for cherry growers. Nutrient budget curve was developed for N and data on timing and quantity of N uptake and removal from orchards was derived. Budget curves quantify the time course of N uptake and total plant demand as determined by tree yield and N required for growth. Yield potential determines fertilizer strategy and there is a large negative impact on overall efficiency that occurs in years or orchards of poor yield in which standardized fertilization strategies are used. Fertilizing accordingly to predicted yields will dramatically enhance nutrient use efficiency. Findings of this research will be adopted by the Cherry Board of California as the new standards for nutrient management and are being widely publicized and distributed.

Copy of the Product/Result

This research will be adopted by the Cherry Board of California industry as the new standards for N management and will be widely publicized and distributed. This research project has been presented at grower, industry, extension, CDFA, and university venues including keynote presentation during the years of the project in conferences. A webpage summarizing this work will be posted on the Cherry Board's main grower information portal and on the University of California Fruit and Nuts Website.