Fertilizer Research and Education Program

Final Report

A. Project Information

Project Title: Assessment of Harvested and Sequestered Nitrogen Content to Improve Nitrogen Management in Crops, Phase 2
Project leaders: Ms. Charlotte Gallock, P.E., Mr. Ken Miller, Dr. Ken Cassman, Dr. Daniel Geisseler
Grant Number: 20-0879
Project Duration: Start Date: January 1, 2021, End Date: December 31, 2025
Email and Phone (Lead PI): kmiller@formationenv.com, 631-745-4488
Final Report
Reporting Period: Start Date: January 1, 2021, End Date: December 31, 2025

B. Abstract

Through the Irrigated Lands Regulatory Program (ILRP), the Central Valley Regional Water Quality Control Board (CV Water Board) requires producers to implement management practices that are protective of groundwater quality and to document the effectiveness of those practices by providing, among other things, information on field nitrogen (N) balances. In addition, the Agricultural Expert Panel convened by the State Water Resources Control Board recommended metrics composed of N applied (A) and N removed (R) to gauge program progress in reducing the mass of leachable N (Agricultural Expert Panel, 2014). To comply with this new reporting requirement, growers and their water quality coalitions need reliable data about N removed from fields in harvested crop materials. Also, growers can use rates of N removal in crops to plan nutrient management programs that reasonably minimize N at risk of leaching below the root zone.

The objective of this project is to assess harvested and sequestered N content for priority crops. By partnering with commodity organizations, growers, processors, and packers, it is possible to procure hundreds of samples that represent a range of varieties and growing environments for each crop. In most cases, substantial information about source fields, such as age of perennial crops, crop management, variety, yield, quality, and dates of bloom or planting, are also acquired. In this way, some of the factors that affect N content of the harvest can be investigated and explained. In Phase 1 of this project, updated conversion factors for 11 crops were incorporated into a 2021 N-Concentrations Report and the Yield to N-Removed Calculator (http://agmpep.com/calc-y2r/). As a part of Phase 2 (this project), updated conversion factors will be developed for approximately 34 additional crops.

C. Introduction

The ILRP has issued waste discharge requirements (WDRs) that affect agricultural irrigators throughout California. The WDRs are intended to improve water quality by affecting implementation of more effective N-management practices, where necessary. One metric of ILRP success is the ratio of applied N (A) to N removed (R) from the field in crop biomass, and/or sequestered in perennial tissues (A/R). A similar metric, the surplus N (A minus R, units in pounds of N per acre-year) is often formulated from the same raw data. To provide these data, the ILRP coalitions have developed an approach that involves growers reporting A and crop yield to the coalitions. The coalitions transform these data into populations of A and A/R (by crop for each township) that are analyzed and reported to the CV Water Board.

As part of N-management planning, producers need to estimate N removed from fields in harvested biomass. In addition, perennial crop growers need to know the amount of N sequestered in perennial tissues (e.g., wood retained in the tree or vine after pruning). These quantities are part of the crop N demand, and thus inform calculation of N application rates aimed to reasonably minimize surplus N and N lost to leaching below the root zone, while maintaining crop yields.

Thus, growers need reliable coefficients to convert measured crop yields to R, and perennial tissues' biomass into N sequestration rates. The need for these coefficients was brought to light in Geisseler (2016). In 2015, the CV ILRP coalitions contracted with Dr. Geisseler to develop factors to convert the yields of 72 major crops of the region into N removed from the field. The resulting coefficients were based on the best available information in scientific literature, with the understanding that further refinement would occur later. Due to the age and location of some of the studies referenced, the report showed that about 8 crops, accounting for approximately 19% of irrigated lands in the CV had a solid underpinning for N concentration in removed material. The goal of Phase 1 of this study was to combine new sampling with data from separately funded studies to boost this to about 68%, and to develop N sequestration for several perennial crops. It now appears that Phase 1 will cover more acreage, with the total reaching about 74% by mid-2021. The status of coefficient updates resulting from the Phase 1 project are shown in Table 1. Average and variability of N concentration for samples of crops analyzed so far are compared to concentrations in Geisseler (2016). The goal of Phase 2 (this project) is to reach about 98%, mainly by collecting and analyzing samples of many, smaller-acreage crops.

D. Objectives

The following are the objectives of the Project:

1. Assess N concentration of harvested material removed from fields (N removed [R]) for approximately 33 crops over several growing seasons, and N sequestration rates for 8 perennial crops, by working with grower/packer/shipper partners to

obtain samples, and UC Davis to analyze samples and interpret results. One additional crop was sampled, for a total of 34 crops.

2. Refine crop yield (Y)-to-R conversion factors, and add N-sequestration rate estimates, for use by growers and grower advisors during nutrient management planning and by coalitions for large-scale performance assessment.

3. Promote and enable expanded knowledge and appropriate use of N-removal coefficients and N-sequestration rates (as part of routine N-management planning and evaluation) by growers, grower advisors, and coalitions. This includes the following:

    a. Incorporate results in an update of Geisseler (2016).
    b. Update existing online and off-line tools for estimating N removed in crops and incorporate into regional assessments of N balance in irrigated crop lands. Update N accumulation rates in crop models used in the ILRP.

E. Methods

This project developed updated conversion factors for priority crops. Sampling spanned several seasons to account for variation due to differences in weather conditions that affect yields and N use efficiency. Sampling protocols and analysis methods were developed to account for variability among cultivars, harvest dates, individual fields, and years of harvest. Methods included the following:

- **Task 1. Establish sampling protocols and analysis methods for each crop.**
    - **Sample protocol**. Sampling protocols focused on 1) obtaining sufficiently representative samples (i.e., representative of environmental, cultural, and varietal variation among harvested blocks, weighting differing conditions in proportion to their predominance, and selection of the stage of processing [e.g., directly from field bins or at a later processing stage), 2) including directions for sampling points and timing, sample number and volume or weight, 3) compositing of samples, 4) gathering relevant cultural data about the context (location and conditions) in which the sample was produced, and 5) sample packaging and shipping. Sample protocols are described in Geisseler (2026).
    - **Sample analysis**. Samples were processed in the nutrient management lab at UC Davis. All samples were analyzed for total N by dry combustion in the nutrient management lab. A standard curve using acetanilide was prepared for each batch of samples. After every 11 samples, an acetanilide sample was analyzed for quality control. Only finely ground samples can be analyzed on the elemental analyzer. Sample preparation depended on the commodity. Samples were always dried first and then ground to a fine powder. Every time samples were dried, the initial and final weights were

recorded to determine the dry matter content. This allowed calculating the N concentration in the fresh weight of the crops. Samples were always mixed thoroughly before taking subsamples to ensure that subsamples were representative of the larger sample (Geisseler, 2025). Additional detail on sample analysis for different commodities is available in Geisseler (2026).

- **Task 2. Sample and assess harvested and sequestered N concentration.** Sampling and analysis occurred during the 2021 through 2025 harvest seasons. Sampling was coordinated with project partners, including scientists and grower/packer/shippers. When no packing facility could be found to supply samples, samples were sourced from collaborating growers or fresh produce markets when the crop origin could be verified as the Central Valley.
- **Task 3. Interpret results and develop and publish Geisseler (2016) update**. In 2024, 2025, and again in 2026, Dr. Geisseler updated the N removed/sequestered database and develop an update of the N-concentrations Report. The updated crops and their respective N removal coefficients are presented in Table 1.
- **Task 4. Develop and publish calculator update**. This task included revision and refinement of the SSJV MPEP online Y-to-R calculator for use by anyone, but especially by coalitions, growers, and grower advisors. The calculator estimates N removed (R) and the ratio of N applied (A) to N removed (A/R), based on inputs for a single crop or for multiple crops. Growers may also download a workbook version that can be operated locally, which may increase usership by facilitating work with batches of fields at once, and by eliminating concerns about online data privacy.
- **Task 5. Outreach to growers and advisors**. Results were shared through outreach activities to growers, grower advisors, and FREP through grower meetings, events, conference presentations, and online and print media. Outreach activities are described in Section J.

F. Data/Results

Table 1 provides updated N removal coefficients for crops studied under this project. Additional information regarding these estimates, including the origin and number of samples, a measure and description of data variability, and discussion of the resulting N removal coefficients is available in Geisseler (2026) (Appendix A) or online.[1]

[1] http://geisseler.ucdavis.edu/Geisseler_Report_U4_2026_04_03.pdf

Table 1. Updated N Removal Coefficients

Commodity Group	Commodity	N in Harvested Plant Parts	
Field Crops	Barley - Feed Grain	31.3	lbs N/ton @ 12% moisture
	Barley - Malt Grain	28.3	lbs N/ton @ 12% moisture
	Corn - Grain for humans	22.4	lbs N/ton @ 15.5% moisture
	Cotton - Acala	49.9	lbs N/ton lint, seed & trash
	Cotton - Pima	51.7	lbs N/ton lint, seed & trash
		33.7	lbs N/bale of lint (500 lb)
	Sorghum - Grain	35.2	lbs N/ton @ 13.5% moisture
Vegetables	Corn, sweet	7.43	lbs/ton of fresh ears
	Garlic - dehydrator	22.1	lbs/ton of fresh weight
	Garlic - fresh market	16.42	lbs/ton of fresh weight
	Melons, Cantaloupe	4.07	lbs/ton of melons
	Melons, Honeydew	2.72	lbs/ton of melons
	Melons, Watermelons	2.25	lbs/ton of melons
	Onions - dehydrator	8.53	lbs/ton of fresh weight
	Onions - fresh market	2.43	lbs/ton of fresh weight
	Pepper, Bell	3.32	lbs/ton of fresh weight
	Potatoes	6.48	lbs/ton of fresh weight
	Pumpkins	4.84	lbs/ton of fresh weight
	Squashes	4.17	lbs/ton of fresh weight
	Sweetpotatoes	5.21	lbs/ton of fresh weight
	Tomatoes, fresh market	2.77	lbs/ton of fresh weight
Trees and vine crops	Apricots	4.25	lbs/ton of fruits
	Cherries	5.97	lbs/ton of fruits
	Grapes - Raisin	11.24	lbs/ton @ 15% moisture
	Grapes - Table	2.28	lbs/ton of grapes
	Grapes - Wine	3.43	lbs/ton of grapes
	Kiwis	3.57	lbs/ton of fruits
	Lemons	3.49	lbs/ton of fruits
	Mandarins	4.31	lbs/ton of fruits
	Nectarines	3.83	lbs/ton of fruits
	Olives - Processing	6.63	lbs/ton of olives
	Olives - Table	7.12	lbs/ton of olives
	Oranges - Navel	3.61	lbs/ton of fruits
	Oranges - Valencia	4.66	lbs/ton of fruits
	Pears	1.26	lbs/ton of fruits

G. Discussion and Conclusions

A total of 34 crops were sampled over the course of five years based upon their irrigated acreage and the existence/quality of literature-based N removal coefficients compiled in Geisseler 2016. These new data will supplement existing datasets with results for additional recent, local, samples from fields across the Central Valley. With these results, growers now have more reliable information with respect to crop N requirements that can help refine N-management planning. Furthermore, growers, coalitions, and the Water Board may more accurately assess progress in the reduction of leachable N in agricultural systems across the Central Valley and achievement of key performance metrics including Groundwater Protection Targets and A/R Acceptable Ranges.

Values for the annual amount of N sequestered in standing biomass were compiled for citrus and cherries based upon available information published in Geisseler (2024). Beyond these crops, the best estimates available at this time for N sequestration are presented in Geisseler (2016) for pistachio, walnut, and peaches and in Geisseler (2021) for almonds.

Two main objectives related to this project include the refinement of Y-to-R conversion factors and the promotion and enablement of expanded knowledge and appropriate use of N-removal coefficients and N-sequestration rates (as part of routine N-management planning and evaluation) by growers, grower advisors, and coalitions. These goals were achieved under Tasks 3, 4, and 5. Specifically, Dr. Geisseler updated the N removed/sequestered database and developed an update of the N-concentrations Report (Geisseler, 2024, Geisseler, 2025, Geisseler, 2026). Furthermore, the updated N removal coefficients were integrated into the N removal calculator (https://agmpep.com/tools/calc-y2r/) for public use. Outreach activities outlined in Section J. also support the objectives of this project.

The removal/sequestration rates were also used to refine the N-removal rates embedded in crop growth models in the Central Valley Soil and Water Assessment Tool (CV-SWAT), which is being used to assess N fate in irrigated agriculture throughout the CV. CV-SWAT refinement was funded and completed outside the scope of this Project.[2]

H. Challenges

Difficulties obtaining additional existing data on N sequestration rates for select perennials.

[2] The proposal for this project originally identified preparation of a technical memorandum comparing results from this project to the N content in crop and perennial biomass that are implicit in SWAT. The intent was to inform potential refinement of CV-SWAT (outside the scope of this project). However, the CV-SWAT refinement is already complete for many crops assessed in this project and the remainder are currently being updated accordingly. Thus, no memorandum was necessary.

I. Project Impacts

The N-removal coefficients developed as a part of this Project are usable by growers, grower advisors, scientists, coalitions, and regulators. The information will directly and indirectly contribute to better N-management decisions and more accurate evaluations of environmental performance of agricultural fields. Known limitations of the coefficients such as variation induced by cultivars, the environment, crop moisture content, and management, as well as unavoidable inefficiencies of translating applied N into plant biomass, are described to inform appropriate use. The coefficients have been incorporated into N-management calculators available on the SSJV MPEP website (https://agmpep.com/tools/calc-y2r/) to enable users to plan N management, and to facilitate evaluating environmental performance of agricultural regions. In addition to environmental benefits of reducing the mass of leachable N, improved N management should benefit growers' returns by helping stabilize yields in the high range, improving fertilizer efficiency, and managing regulatory obligations through documentable, improved performance.

With the results from this Project, growers may more readily plan field-specific N programs, and coalitions and the Water Boards may more accurately assess regional progress in the reduction of leachable N in agricultural systems across the CV. This will help protect groundwater quality by attenuating agricultural nitrate leaching where needed, and ultimately slowing, halting, or reversing degradation of groundwater quality. Within the SSJV and the adjacent Salinas Valley, over 250,000 people currently depend on groundwater for their drinking water supply, and that number is anticipated to grow along with the regions' populations. In addition, because the knowledge and tools developed as a part of this Project are transferable to other regions and states with similar environmental quality concerns and cropping systems, groundwater quality could become better protected in those locations as well.

J. Outreach Activities Summary

The N removed coefficients refined by the Project feed into several outreach processes and tools. Outreach processes into which the N removed coefficients are directly incorporated include the following:

- The peer-reviewed Crop Yield to Nitrogen Removed Calculator (also known as the Y-to-R Calculator) is published at https://agmpep.com/tools/calc-y2r/ and available for download in an excel workbook. It was developed based on conversion factors developed by Geisseler (2016, 2021, 2026). The calculator can be used by growers and advisers with anticipated or actual yield information to estimate N removed (R) and the ratio of N applied (A) to N removed (A/R). Results can be calculated on inputs for a single crop or for multiple crops. Recent updates include clarification on reporting units and plant parts, as well as plant parts in which N removal is considered.
- Irrigation and Nitrogen Management Plan (INMP) Summary Report yield data are processed by coalitions with N removed coefficients and then reported back to growers so that they can check to make sure that they are properly accounting for N

removal as they plan N applications. Coefficients used by coalitions reflect updates from this Project.

- Coalitions conduct annual outreach meetings to their grower members and routinely discuss documentation and reporting requirements, including INMP Worksheets and Summary Reports. The concept and calculation of R is fundamental to these reports and is reviewed with grower members.
- INMP Summary Reports are integral to multiple assessments and performance metrics under the ILRP, including the Groundwater Protection Provisions and A/R Acceptable Ranges. As such, discussions of these metrics and their achievement with growers and their advisors intrinsically includes R, which is now more accurately calculated for crops considered in this Project.
- INMP Summary Report data from throughout the Central Valley are analyzed from an agronomic perspective. The results are then shared with commodity groups and grower/grower advisor communities, so that they can evaluate the meaning of what growers have reported, relative to future nutrient management study and outreach. The N removal coefficients are employed directly in calculation of the N balance in this analysis. This is a key parameter that reflects the maximum mass of leachable N.

Additional outreach activities include:

- A project summary is posted here on the SSJV MPEP website (http://agmpep.com). The website is shared by the SSJV MPEP Committee with the over 9,000 growers in the member coalitions.
- A presentation, *Crop Nitrogen Removal Coefficients,* was presented at the Annual Conference of the Fertilizer Research and Education Program / Western Plant Health Association, October 25 and 26, 2022.
- A presentation, *Groundwater Protection Targets,* was presented at the Annual Conference of the Fertilizer Research and Education Program / Western Plant Health Association, October 25 and 26, 2022.
- A panel discussion titled "*Panel: Nitrogen Removal Coefficients for Planning and Reporting: Where We Are and Where We Are Going*" was held at the Annual Conference of the Fertilizer Research and Education Program / Western Plant Health Association, October 30, 2024.
- A presentation, "Joint-Coalition Submittal: Workplan Addressing Uncertainty and Validating the Groundwater Protection Formula, Values, and Targets" was presented at an ILRP Stakeholder Meeting, June 26, 2024.
- A presentation, "SSJV MPEP Overview", was presented to the Fresno State Graduate Level Class EES 226.
- A presentation provided as a part of the SSJV MPEP's WETA Program: *Integrated Water & Nitrogen Management Trainings*, presented January 27, 2025, in Bakersfield, CA.
- A presentation provided as a part of the SSJV MPEP's WETA Program: *Integrated Water & Nitrogen Management Trainings*, presented January 28, 2025, in Parlier, CA.

- A presentation provided as a part of the SSJV MPEP's WETA Program: *Integrated Water & Nitrogen Management Trainings*, presented January 29, 2025, in Tulare, CA.
- A presentation, *Groundwater Protection Values Update*" was presented at the ILRP Stakeholder Meeting, March 26, 2024.
- A presentation provided as a part of the SSJV MPEP's WETA Program: *Integrated Water & Nitrogen Management Trainings*, presented January 20, 2026, in Bakersfield, CA.
- A presentation provided as a part of the SSJV MPEP's WETA Program: *Integrated Water & Nitrogen Management Trainings*, presented January 21, 2026, in Tulare, CA.
- A presentation provided as a part of the SSJV MPEP's WETA Program: *Integrated Water & Nitrogen Management Trainings*, presented January 22, 2026, in Parlier, CA.

K. References

Agricultural Expert Panel. 2014. Recommendations to the State Water Resources Control Board pertaining to the Irrigated Lands Regulatory Program. In fulfillment of SBX2 1 of the California Legislature. September 9.

Geisseler, Daniel. 2016. Nitrogen Concentrations in Harvested Plant Parts – A Literature Overview. UC Davis. Available online: http://geisseler.ucdavis.edu/Geisseler_Report_2016_12_02.pdf.

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L. Appendix

One appendix is provided: Appendix A: Nitrogen Concentrations in Harvested Plant Parts (update 04/2026) (Geisseler 2026)

M. Factsheet/Database Template

1. **Project Title:** Assessment of Harvested and Sequestered Nitrogen Content to Improve Nitrogen Management in Crops, Phase 2
2. **Grant Agreement Number (Assigned by CDFA):** 20-0879
3. **Project Leaders:** Ms. Charlotte Gallock, P.E., Mr. Ken Miller, Dr. Ken Cassman, Dr. Daniel Geisseler
4. **Start Year/End Year:** 2021/2025
5. **Location:** Various locations in the Central Valley
6. **County:** Samples were collected from multiple counties across the Central Valley including Sutter, Glenn, Solano, Sacramento, Yolo, San Joaquin, Stanislaus, Merced, Madera, Fresno, Tulare, and Kern counties.
7. **Highlights**
    - To comply with ILRP requirements, growers need reliable data about N removed from fields in harvested crop materials.
    - Samples for 34 crops were collected from Central Valley locations between 2021 and 2025 and analyzed for total N.
    - Building on previous work, updated conversion factors for are now available for about 98% of Central Valley irrigated acreage.
    - These data will contribute to better N-management decisions and more accurate evaluations of environmental performance of agricultural fields.
8. **Introduction:** The Central Valley Water Board requires growers to document the effectiveness of management practices to minimize nitrate leaching. To comply with this requirement, growers need reliable information about the N content of crop portions removed from the field, so that reported yields can be accurately converted into N removal rates. To provide this information, sampling and analysis was necessary to develop N removed conversion factors reflective of contemporary Central Valley conditions.
9. **Methods/Management:** Sampling under this Project spanned several seasons to account for variation due to differences in weather conditions that affect yields and N use efficiency. Sampling was coordinated with project partners, including scientists and grower/packer/shippers. When no packing facility could be found to supply samples, samples were sourced from collaborating growers or fresh produce markets when the crop origin could be verified as the Central Valley. All samples were analyzed for total N by dry combustion in the nutrient management lab at UC Davis.
10. **Findings.** The N-removal coefficients developed as a part of this Project are usable by growers, grower advisors, scientists, and regulators, contributing to better N-management decisions and more accurate evaluations of environmental performance of agricultural fields. Findings are displayed in Table 1. All of the latest N-removal coefficients can be found at http://geisseler.ucdavis.edu/Project_N_Removal.html.

Table 1. Updated N Removal Coefficients

Commodity Group	Commodity	N in Harvested Plant Parts	
Field Crops	Barley - Feed Grain	31.3	lbs N/ton @ 12% moisture
	Barley - Malt Grain	28.3	lbs N/ton @ 12% moisture
	Corn - Grain for humans	22.4	lbs N/ton @ 15.5% moisture
	Cotton - Acala	49.9	lbs N/ton lint, seed & trash
	Cotton - Pima	51.7	lbs N/ton lint, seed & trash
		33.7	lbs N/bale of lint (500 lb)
	Sorghum - Grain	35.2	lbs N/ton @ 13.5% moisture
Vegetables	Corn, sweet	7.43	lbs/ton of fresh ears
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	Grapes - Table	2.28	lbs/ton of grapes
	Grapes - Wine	3.43	lbs/ton of grapes
	Kiwis	3.57	lbs/ton of fruits
	Lemons	3.49	lbs/ton of fruits
	Mandarins	4.31	lbs/ton of fruits
	Nectarines	3.83	lbs/ton of fruits
	Olives - Processing	6.63	lbs/ton of olives
	Olives - Table	7.12	lbs/ton of olives
	Oranges - Navel	3.61	lbs/ton of fruits
	Oranges - Valencia	4.66	lbs/ton of fruits
	Pears	1.26	lbs/ton of fruits

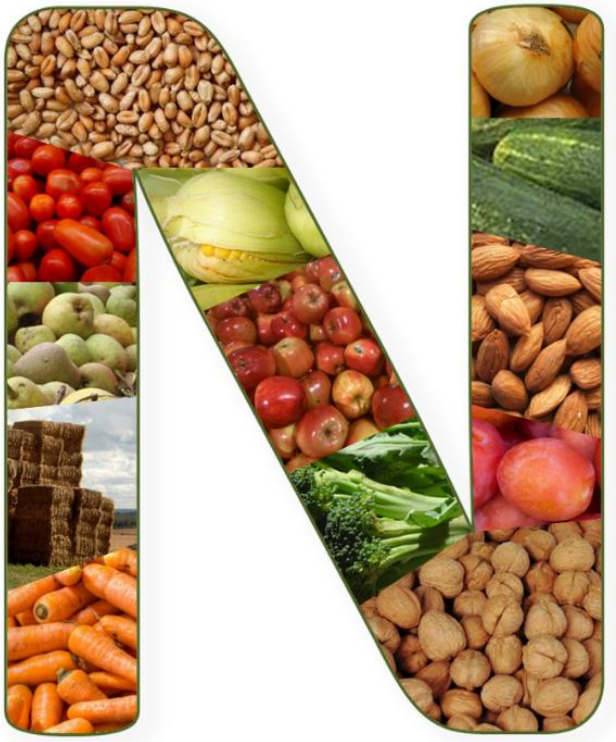
N. Copy of the Product/Result

Not applicable.

Appendix A.

Nitrogen Concentrations in Harvested Plant Parts (update 4/2026) (Geisseler 2026)

Nitrogen concentrations in harvested plant parts – Update 04/2026



Includes updated values for

- **Apricot**
- **Barley, feed grain**
- **Barley, malt grain**
- **Corn, grain for humans**
- **Garlic, dehydrator**
- **Grapes, raisin**
- **Olives, processing**
- **Onion, dehydrator**
- **Pear**
- **Pumpkin**
- **Sweetpotato**

Daniel Geisseler

April 3, 2026

Content

About the Author:

Daniel Geisseler is a University of California Cooperative Extension Specialist in the Department of Land, Air and Water Resources at the University of California, Davis. The focus of his research and outreach is nutrient management in cropping systems. An overview of his team's projects can be found at http://geisseler.ucdavis.edu/

Acknowledgments

The research was supported by a grant from the California Department of Food and Agriculture – Fertilizer Research and Education Program (CDFA- FREP) awarded to the Kings River Watershed Coalition (acting as fiscal entity for the Southern San Joaquin Valley Management Practices Evaluation Program Committee). A big thanks to Megan Harmon from the Department of Land Air and Water Resources at UC Davis for processing and analyzing the samples in the laboratory. Thanks to John Dickey, Ken Miller and their team at the Southern San Joaquin Valley Management Practices Evaluation Program for acquiring the samples and delivering them to Davis, and to the many growers and packers who provided those samples. Ken also provided important comments on drafts of the report. I also wish to thank scientists who shared N content data from other studies for use in this update.

Summary

Nitrogen (N) balances in agricultural fields are important components of the Central Valley Irrigated Lands Regulatory Program. The ratio and difference of N applied to N removed are key metrics for the Central Valley Regional Water Quality Control Board. The approach involves growers reporting applied N and yield to the water quality coalitions. The coalitions in turn convert yield to N removed and report various statistics to the Water Quality Control Board. Nitrogen accumulated into perennial plant tissues may also be counted as “removed”. For these calculations, reliable values of N concentrations in the harvested parts and perennial tissues of crops are needed.

The present report is the fourth update of a 2016 report, which was a review of available data. Samples for apricots, barley (for malt and feed), grain corn for human consumption, dehydrator garlic, raisin grapes, processing olives, dehydrator onions, pears, pumpkins, and sweetpotatoes were collected from Central Valley locations between 2021 and 2025. All samples were analyzed for total N by dry combustion at UC Davis.

The updated values are highlighted in Tables 1-3. The results of the analyses are presented and discussed in more detail starting on page 9. This report, as well as the previous reports, can be accessed at http://geisseler.ucdavis.edu/Project_N_Removal.html.

Table 1: Overview of N concentrations in harvested plant parts of field crops. The highlighted commodities are those updated in this report.

Commodity	Last update	N in harvested plant parts		CV (%)	Page
Alfalfa - Hay		**62.3**	lbs N/ton @ 12% moisture	12.5	
Alfalfa - Silage		**24.0**	lbs N/ton @ 65% moisture	17.5	
Barley - Feed Grain	03/2026	**31.3**	lbs N/ton @ 12% moisture	12.4	10
Barley - Malt Grain	03/2026	**28.3**	lbs N/ton @ 12% moisture	10.1	11
Barley - Straw		**15.4**	lbs N/ton @ 12% moisture	31.3	
Beans, dry - Blackeye		**73.0**	lbs N/ton @ 12% moisture	10.4	
Beans, dry - Garbanzo		**67.2**	lbs N/ton @ 12% moisture	11.3	
Beans, dry - Lima		**72.3**	lbs N/ton @ 12% moisture	5.4	
Corn - Grain for humans	03/2026	**22.4**	lbs N/ton @ 15.5% moisture	13.0	12
Corn - Grain for feed		**24.0**	lbs N/ton @ 15.5% moisture	20.8	
Corn - Silage	03/2021	**7.53**	lbs N/ton @ 70% moisture	10.9	
Cotton - Acala	02/2024	**49.9**	lbs N/ton lint, seed & trash	18.1	
		34.6	lbs N/bale of lint (500 lb)		
Cotton - Pima	02/2024	**51.7**	lbs N/ton lint, seed & trash	8.0	
		33.7	lbs N/bale of lint (500 lb)		
Fescue, Tall - Hay		**50.8**	lbs N/ton @ 12% moisture	16.2	
Oat - Grain		**37.7**	lbs N/ton @ 12% moisture	9.6	
Oat - Straw		**14.8**	lbs N/ton @ 12% moisture	34.7	
Oat - Hay		**21.7**	lbs N/ton @ 12% moisture	18.2	
Orchard Grass - Hay		**54.5**	lbs N/ton @ 12% moisture	20.0	
Ryegrass, Perennial - Hay		**54.9**	lbs N/ton @ 12% moisture	16.8	
Safflower	03/2021	**51.7**	lbs N/ton @ 8% moisture	10.2	
Sorghum - Grain	02/2024	**35.2**	lbs N/ton @ 13.5% moisture	14.2	
Sorghum - Silage		**7.34**	lbs N/ton @ 65% moisture	21.0	
Sunflower	03/2021	**63.2**	lbs N/ton @ 8% moisture	11.1	
Triticale - Grain		**40.4**	lbs N/ton @ 12% moisture	13.0	
Triticale - Straw		**11.5**	lbs N/ton @ 12% moisture	38.3	
Triticale - Silage		**9.03**	lbs N/ton @ 70% moisture	13.7	
Wheat, common - Grain		**43.0**	lbs N/ton @ 12% moisture	10.3	
Wheat - Straw		**13.8**	lbs N/ton @ 12% moisture	33.0	
Wheat - Silage		**10.5**	lbs N/ton @ 70% moisture	18.6	
Wheat, durum - Grain		**42.1**	lbs N/ton @ 12% moisture	3.7	

Table 2: Overview of N concentrations in harvested plant parts of vegetables. No updated values for vegetables are included in this report.

Commodity	Last update	N in harvested plant parts		CV (%)	Page
Asparagus		**5.85**	lbs N/ton of fresh spears	14.0	
Beans, green (snap beans)		**5.78**	lbs/ton of fresh weight	25.7	
Broccoli		**11.2**	lbs N/ton of fresh weight	20.4	
Carrots	03/2021	**2.80**	lbs/ton of fresh weight	22.7	
Corn, sweet	03/2025	**7.43**	lbs/ton of fresh ears	15.8	
Cucumbers		**2.16**	lbs/ton of fresh weight	17.4	
Garlic - dehydrator	03/2026	**22.1**	lbs/ton of fresh weight	19.2	13
Garlic - fresh market	03/2025	**16.42**	lbs/ton of fresh weight	20.4	
Lettuce, Iceberg		**2.63**	lbs/ton of fresh weight	16.7	
Lettuce, Romaine		**3.62**	lbs/ton of fresh weight	13.7	
Melons, Cantaloupe	03/2025	**4.07**	lbs/ton of melons	28.1	
Melons, Honeydew	03/2025	**2.72**	lbs/ton of melons	21.6	
Melons, Watermelons	03/2025	**2.25**	lbs/ton of melons	24.1	
Onions - dehydrator	03/2026	**8.53**	lbs/ton of fresh weight	19.3	16
Onions - fresh market	03/2025	**2.43**	lbs/ton of fresh weight	23.0	
Pepper, Bell	03/2025	**3.32**	lbs/ton of fresh weight	23.0	
Potatoes	03/2025	**6.48**	lbs/ton of fresh weight	27.4	
Pumpkins	03/2026	**4.84**	lbs/ton of fresh weight	28.9	18
Squashes	03/2025	**4.17**	lbs/ton of fresh weight	30.2	
Sweetpotatoes	03/2026	**5.21**	lbs/ton of fresh weight	27.9	19
Tomatoes, fresh market	03/2025	**2.77**	lbs/ton of fresh weight	18.8	
Tomatoes, processing	03/2021	**2.92**	lbs/ton of fresh weight	15.0	

Table 3: Overview of N concentrations in harvested plant parts of tree and vine crops. The highlighted commodities are those updated in this report.

Commodity	Last update	N in harvested plant parts		CV (%)	Page
Almonds		**136**	lbs/ton of kernels	4.1	
Apples		**1.08**	lbs/ton of fruits	35.1	
Apricots	03/2026	**4.25**	lbs/ton of fruits	22.3	9
Cherries	03/2025	**5.97**	lbs/ton of fruits	37.7	
Figs		**2.54**	lbs/ton of fruits	18.1	
Grapefruits		**2.96**	lbs/ton of fruits	7.8	
Grapes - Raisin	03/2026	**11.24**	lbs/ton @ 15% moisture	19.0	14
Grapes - Table	03/2025	**2.28**	lbs/ton of grapes	25.0	
Grapes - Wine	03/2025	**3.43**	lbs/ton of grapes	30.8	
Kiwis	02/2024	**3.57**	lbs/ton of fruits	15.0	
Lemons	02/2024	**3.49**	lbs/ton of fruits	10.4	
Mandarins	02/2024	**4.31**	lbs/ton of fruits	10.9	
Nectarines	02/2024	**3.83**	lbs/ton of fruits	24.2	
Olives - Processing	03/2026	**6.63**	lbs/ton of olives	21.5	15
Olives - Table	03/2025	**7.12**	lbs/ton of olives	12.2	
Oranges - Navel	02/2024	**3.61**	lbs/ton of fruits	15.1	
Oranges - Valencia	02/2024	**4.66**	lbs/ton of fruits	20.1	
Peaches	03/2021	**3.04**	lbs/ton of fruits	19.0	
Pears	03/2026	**1.26**	lbs/ton of fruits	31.7	17
Pistachios	03/2021	**20.4**	lbs N/ton net green weight	21.6	
Plums	03/2021	**2.27**	lbs/ton of fruits	14.5	
Pomegranates	03/2021	**3.96**	lbs/ton of fruits	15.4	
Prunes		**11.2**	lbs/ton of dried fruits	16.3	
Tangerines		Replaced by a value for mandarins			
Walnuts	03/2021	**31.8**	lbs N/ton of nuts @ 8% moist.	10.9	

Introduction

The ratio and difference of N applied (A) to N removed (R) are key metrics in the Central Valley Irrigated Lands Regulatory Program (CVILRP). Growers report applied N and yield to agricultural water quality coalitions. The coalitions in turn convert yield to N removed from fields and report various statistics to the Central Valley Regional Water Quality Control Board. Nitrogen accumulated into perennial plant tissues may also be counted as "removed". For these calculations, reliable values of N concentrations in the harvested parts and perennial tissues of crops are needed.

For a report released in 2016, we mined the scientific literature for data on N concentrations in harvested crop parts with an emphasis on California data (Geisseler, 2016). For many commodities, a robust dataset of recent samples from California was not available. With financial support from the California Department of Food and Agriculture – Fertilizer Research and Education Program (CDFA-FREP) and the help of the Kings River Watershed Coalition, John Dickey, Ken Miller, and their team at the Southern San Joaquin Valley Management Practices Evaluation Program, a large number of samples were collected and then processed in the author's nutrient management lab at UC Davis. The present report is the fourth update of the 2016 report and includes results for apricots, barley (for malt and feed), grain corn for human consumption, dehydrator garlic, raisin grapes, processing olives, dehydrator onions, pears, pumpkins, and sweetpotatoes.

Procedures

Sample acquisition

Sampling protocols containing methods and logistical information were developed and shared with industry partners. Methods generally took advantage of existing steps in production or processing where/when samples are routinely collected, often to assess the quality of the material harvested from a field to help establish equitable pricing and/or to guide subsequent processing, packing, and marketing. Obtaining samples at these steps in production and processing avoided interruption of normal operations at cooperating facilities. Furthermore, since decisions based on these samples are consequential, the industry has designed approaches to produce samples that represent harvested lots or whole fields. Samples were generally refrigerated to stabilize them until processing commenced.

When no packing facility could be found to supply samples, samples were sourced from collaborating growers or fresh produce markets when the crop origin could be verified as the Central Valley. The present report includes updated N removal coefficients for apricots, barley (for malt and feed), grain corn for human consumption, dehydrator garlic, raisin grapes, processing olives, dehydrator onions, pears, pumpkins, and sweetpotatoes. Samples were collected from Central Valley locations between 2021 and 2025. All samples were analyzed for total N by dry combustion at UC Davis.

Sample processing and analysis

Samples were processed in the nutrient management lab at UC Davis. All samples were analyzed for total N by dry combustion (Nelson and Sommers, 1996) in the nutrient management lab. A standard

curve using acetanilide was prepared for each batch of samples. After every 11 samples, an acetanilide sample was analyzed for quality control.

Only finely ground samples can be analyzed on the elemental analyzer. Sample preparation depended on the commodity. Samples were always dried first and then ground to a fine powder. Every time samples were dried, the initial and final weights were recorded to determine the dry matter content. This allowed calculating the N concentration in the fresh weight of the crops. Samples were always mixed thoroughly before taking subsamples to ensure that subsamples were representative of the larger sample. The following procedures were used for the different commodities:

Apples, pears, and figs: Samples were first cut in half lengthwise. One half was cut into thin slices to be dried in an oven at 80 °C until reaching a constant weight and samples were no longer sticky. This process took several months. The dried samples were first ground using a coffee grinder and then ball-milled on a paint shaker. Ground samples were held in a desiccator until weighed due to their hygroscopic nature.

Apricots: The flesh and pits were first separated. The pits were dried in an oven at 80 °C, crushed with a heavy weight, and then dried again in an oven at 80 °C, before being ground with a disc mill. The flesh (including the skin) was cut into pieces and dried in an oven at 80 °C until the samples reached a constant weight. The dried samples were ground in a coffee grinder then ball-milled on a paint shaker. The dry flesh and pits were analyzed separately for total N.

Barley and Grain Corn: A subsample of grain was first dried in an oven at 60 °C. The dried samples were ground with a Wiley mill to pass a 1 mm screen and ground grain was dried again at 60 °C until a constant weight was reached. Dried samples were then ground into a finer powder using a disc mill.

Cucumber, dehydrator garlic, green onions, dehydrator onions, pumpkins, and sweetpotatoes: Samples were cut in half lengthwise and one half was cut into thin slices to be dried in an oven at 60 °C until a constant weight was reached. Seeds and stems were not separated from pumpkins during this process. Dried samples were ground on a Wiley mill to pass a 1 mm screen, then ball-milled on a paint shaker.

Raisin Grapes: A representative subsample including any leaves or stems was dried in an oven at 80 °C until reaching a constant weight and samples were no longer sticky. This process took several months. The dried samples were first ground using a coffee grinder and then ball-milled on a paint shaker. Ground samples were held in a desiccator until weighed due to their hygroscopic nature.

Processing Olives: A representative subsample including any leaves or stems was processed by crushing the whole fruit (flesh and pit) with a heavy weight. Samples were dried at 60 °C until a constant weight was reached, before being ground using a disc mill. As samples were in the form of an oily paste, a known quantity of cellulose powder was combined using a Micro-Mill II Grinder (Bel-Art Products, Wayne, NJ) for easier handling when weighing.

Data analysis

Nitrogen concentrations are expressed in lbs/ton at a moisture content common for the commodities at harvest or after drying. For each commodity, we calculated the **mean** of each dataset and the weighted mean among datasets. The weight of a dataset was determined by the number of observations. Recent data from California that were included in the 2016 report were combined with the new results for these crops, while data based on samples from other regions were excluded.

The reported measures of variability are **standard deviation (SD)** and **range** (smallest and largest value in the dataset). The overall SD in this report represents the pooled SD across the different datasets with more than one observation. If the distribution of the data is approximately normal, then about 68% of the data values are within one SD of the mean, and about 95% are within two SD. To facilitate comparison of different commodities, we calculated the **coefficient of variation (CV)**, which is expressed as the SD in percent of the mean. The CV was also used to determine the contribution of dry matter content and N concentration in the dry matter to the overall variability. Data presentation followed the outline from the 2016 report.

Results and discussion

Detailed analyses for specific commodities can be found in the second part of this report.

Limitations

Nitrogen concentrations in harvested crop parts can vary considerably from field to field and from one year to the next. For the commodities included in this report, it was not uncommon for the highest value being twice as large as the lowest value measured. The variability statistics provided for each coefficient indicates the expected magnitude of variation. For a single year, the calculated amount of N removed from a specific field, and thus the N balance (A-R) or ratio (A/R), may differ considerably from their actual values. However, these computed statistics become more reliable when considered in an aggregate fashion across over time and across space,

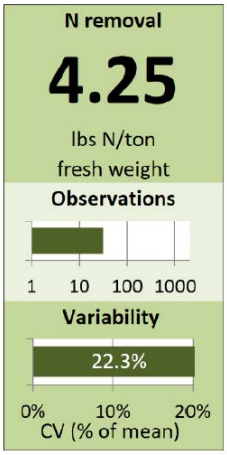
Calculating the amount of N removed based on yield and N concentration will underestimate the amount of N removed for crops where cull or trash is removed from the field but not included in the reported yield. For a more accurate estimate of the total amount of N removed from the field, N in cull or trash needs to be included (for example as a percent of the N in the marketable portion of the yield). For the commodities included in this report, cull and trash is minimal.

Furthermore, reported yields need to be converted to the units and moisture content associated with the crop's N concentration if different from Tables 1 through 3.

References

Geisseler, D., 2016. Nitrogen concentrations in harvested plant parts - A literature overview. Available online at: http://geisseler.ucdavis.edu/Geisseler_Report_2016_12_02.pdf

Apricot



Data sources

Apricot samples were purchased multiple times during the season from produce markets across the Central Valley. A total of 32 samples consisting of many varieties were collected and analyzed over five seasons from 2021 to 2025. Varieties included: Blenheim, Dreamcot, Flaming Gold, Gold Bar, Patterson, Red Sunset, and Royal Derby.

Data sources and number of observations.

Source	Sites		Years sampled		Observations
	Location	n	Years	n	
Own analyses	Central Valley	3	2021	1	3
Own analyses	Central Valley	7	2022	1	7
Own analyses	Central Valley	3	2023	1	3
Own analyses	Central Valley	2	2024	1	2
Own analyses	Central Valley	17	2025	1	17
Overall					**32**

Summary statistics of apricot N removal data.

Source	Summary (lbs/ton of fresh weight)			
	mean	SD	Range	CV (%)
Own analyses 2021	4.80	0.67	4.13 – 5.46	13.9
Own analyses 2022	4.26	1.00	2.88 – 5.87	23.5
Own analyses 2023	2.68	0.65	1.96 – 3.22	24.2
Own analyses 2024	3.62	0.46	3.30 – 3.95	12.6
Own analyses 2025	4.50	0.78	3.18 – 6.19	17.4
Overall	**4.25**	**0.95**	**1.96 – 6.19**	**22.3**

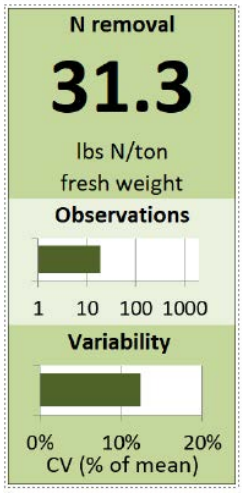
Variability

Nitrogen contents ranged from 1.96 – 6.19 lbs/ton of fresh weight. Across all samples, the variability in N removal was high, with the CV reaching 22.3%. Differences in total N in the dry matter contributed more to the observed variability than the dry matter content. The Royal Derby variety was the only variety with significantly higher N removal than the other varieties (5.58 lbs/ton of fresh weight).

Discussion

On average, N removed by apricots is 4.25 lbs/ton of fresh weight. The average N removal is based on 32 samples collected during five growing seasons from Central Valley growers and can be considered a good estimate.

Barley – Grain for Feed



Data sources

Barley grain samples for feed were sourced from a processor in the Central Valley and consisted of samples from northern Central Valley counties in the Sacramento Valley. 19 samples were collected and analyzed from the 2023 season.

Data sources and number of observations.

Source	Sites		Years sampled		Observations
	Location	n	Years	n	
Own analyses	Central Valley	19	2023	1	19
Overall					**19**

Summary statistics of feed barley N removal data.

Source	Summary (lbs/ton @ 12% moisture)			
	mean	SD	Range	CV (%)
Own analyses 2023	31.3	3.87	25.1 – 38.7	12.4
Overall	**31.3**	**3.87**	**25.1 – 38.7**	**12.4**

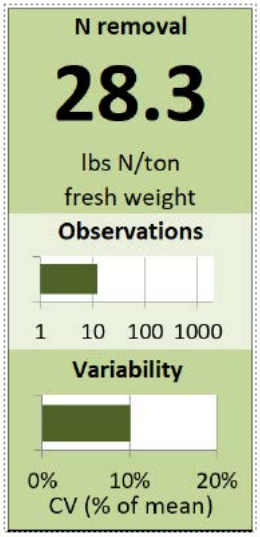
Variability

Nitrogen contents ranged from 25.1 – 38.7 lbs/ton at 12% moisture. Across all samples, the variability in N removal was moderate, with the CV reaching 12.4%.

Discussion

On average, N removed by barley grain for feed is 31.3 lbs/ton at a moisture content of 12%. The average N removal is based on 19 samples collected from one growing season and sourced exclusively from northern Central Valley counties in the Sacramento Valley. While the results provide a good estimate, the dataset is not expansive enough for robust conclusions for all barley production in California.

Barley – Grain for Malting



Data sources

Malt barley grain samples were sourced from a processor in the Central Valley and consisted of samples from northern Central Valley counties in the Sacramento Valley. 12 samples from the 2023 season were collected and analyzed.

Data sources and number of observations.

Source	Sites		Years sampled		Observations
	Location	n	Years	n	
Own analyses	Central Valley	12	2023	1	12
Overall					**12**

Summary statistics of malt barley N removal data.

Source	Summary (lbs/ton @ 12% moisture)			
	mean	SD	Range	CV (%)
Own analyses 2023	28.3	2.86	24.9 – 35.4	10.1
Overall	**28.3**	**2.86**	**24.9 – 35.4**	**10.1**

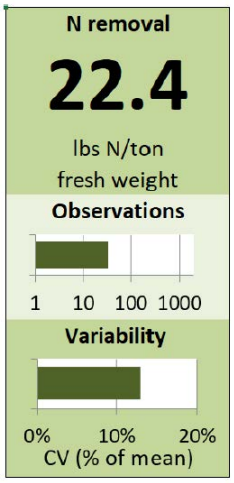
Variability

Nitrogen contents ranged from 24.9 to 35.4 lbs/ton at 12% moisture. Across all samples, the variability in N removal was relatively low, with the CV reaching 10.1%.

Discussion

On average, N removed by malt barley is 28.3 lbs/ton at a moisture content of 12%. This N content is significantly lower than that of feed barley grain, which is expected as malting barley has a lower protein content. The average N removal is based on 12 samples collected from one growing season and sourced exclusively from northern Central Valley counties in the Sacramento Valley. While the results provide a good estimate, the dataset is not expansive enough for robust conclusions for all barley production in California.

Corn - Grain for Human Consumption



Data sources

Samples of corn grain for human consumption were sourced from a processor in the Central Valley and consisted of samples from northern Central Valley counties predominantly in the Sacramento Valley. A total of 33 samples were collected and analyzed from the 2023 and 2025 growing seasons.

Data sources and number of observations.

Source	Sites		Years sampled		Observations
	Location	n	Years	n	
Own analyses	Central Valley	18	2023	1	18
Own analyses	Central Valley	15	2025	1	15
Overall					**33**

Summary statistics of human consumption grain corn N removal data.

Source	Summary (lbs/ton @ 15.5% moisture)			
	mean	SD	Range	CV (%)
Own analyses 2023	23.9	2.23	20.1 – 27.2	8.7
Own analyses 2025	20.6	2.71	14.6 – 23.7	13.1
Overall	**22.4**	**2.91**	**14.6 – 27.2**	**13.0**

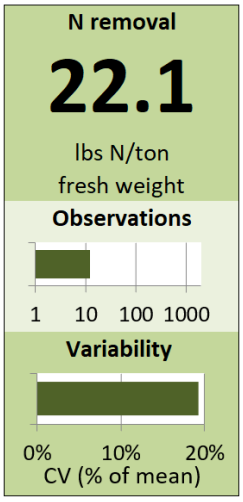
Variability

Nitrogen contents ranged from 14.6 to 27.2 lbs/ton at 15.5% moisture. Across all samples, the variability in N removal was relatively moderate, with the CV reaching 13.0%. Variability across the two years sampled was quite marked, with N content being significantly greater in the 2023 samples than the 2025 samples.

Discussion

On average, N removed by corn grain for human consumption is 22.4 lbs/ton at a moisture content of 15.5%. The average N removal is based on 33 samples collected from two growing seasons and sourced exclusively from northern Central Valley counties predominantly in the Sacramento Valley. Despite variability between seasons, the results provide a good estimate, as samples were sourced from diverse leading grain corn producing counties in California.

Garlic - Dehydrator



Data sources

Samples of dehydrator garlic were sourced from different fields in the Central Valley. A total of 12 samples were collected and analyzed from the 2024 and 2025 growing seasons.

Data sources and number of observations.

Source	Sites		Years sampled		Observations
	Location	n	Years	n	
Own analyses	Central Valley	3	2024	1	3
Own analyses	Central Valley	9	2025	1	9
Overall					**12**

Summary statistics of dehydrator garlic N removal data.

Source	Summary (lbs/ton of fresh weight)			
	mean	SD	Range	CV (%)
Own analyses 2024	26.9	5.38	23.1 – 33.0	20.0
Own analyses 2025	20.5	2.42	16.7 – 24.1	11.8
Overall	**22.1**	**4.24**	16.7 – 33.0	**19.2**

Variability

Nitrogen contents ranged from 16.7 – 33.0 lbs/ton of fresh weight. Across all samples, the variability in N removal was relatively high, with the CV reaching 19.2%. Variability was much greater in the 2024 season analyses and could be attributed to an outlier value in total N in the dry matter. Overall, both N content in the dry matter and the dry matter content had lower variability than N removed, with CVs of 14.5% and 10.1%, respectively.

Discussion

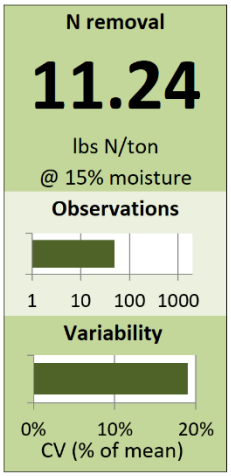
Nitrogen removal with dehydrator garlic bulbs was 34% higher than with fresh market garlic bulbs (Geisseler, 2025). Both dry matter content (40% vs. 35%) and N concentration in dry matter (2.79% vs. 2.38%) were higher in dehydrator garlic.

The average N removal is based on 12 samples collected from two growing seasons and sourced from Central Valley growers. While more samples could better explain observed variability, the average value for N removed was based on samples collected from different locations over two growing seasons and thus may be considered a fair estimate.

References

Geisseler, D., 2025. Nitrogen concentrations in harvested plant parts – Update 03/2025. Available online at: http://geisseler.ucdavis.edu/Geisseler_Report_U3_2025_03_19.pdf

Grapes - Raisin



Data sources

Raisin grape samples were sourced from different growers in Fresno and Kern County. A total of 49 samples were collected and analyzed during five seasons from 2020 to 2025. The samples harvested in 2020 and 2024 were kept in storage and delivered to the lab for analysis the following fall. Most of the analyzed samples were of the “Thompson Seedless” variety (n=30).

Data sources and number of observations.

Source	Sites		Years sampled		Observations
	Location	n	Years	n	
Own analyses	Central Valley	12	2020	1	12
Own analyses	Central Valley	12	2021	1	12
Own analyses	Central Valley	1	2023	1	1
Own analyses	Central Valley	7	2024	1	7
Own analyses	Central Valley	17	2025	1	17
Overall					**49**

Summary statistics of raisin grape N removal data.

Source	Summary (lbs/ton @ 15% moisture)			
	mean	SD	Range	CV (%)
Own analyses 2020	12.99	1.13	11.13 – 15.13	8.7
Own analyses 2021	12.55	1.52	11.10 – 17.06	12.1
Own analyses 2023	11.05			
Own analyses 2024	9.54	1.18	8.26 – 11.18	12.3
Own analyses 2025	9.78	1.90	6.13 – 14.49	19.5
Overall	**11.24**	**1.69**	6.13 – 17.06	**19.0**

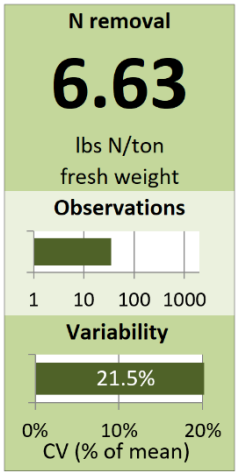
Variability

Nitrogen contents ranged from 6.13 – 17.06 lbs/ton at 15% moisture. Across all samples, the variability in N removal was relatively high, with the CV reaching 19.0%. Nitrogen removed was calculated for a moisture content of 15%. The measured moisture content in the samples was very similar, averaging 13%. There was no significant difference in dry matter content between the samples that were stored for one year and those that were analyzed the same year they were harvested.

Discussion

On average, N removed by raisin grape is 11.24 lbs/ton at 15% moisture. At the average measured moisture content, N removed was slightly lower at 11.08 lbs/ton. The average N removal is based on 49 samples representing five growing seasons from Central Valley vineyards and can be considered a good estimate.

Olives - Processing



Data sources

Processing olives were obtained from a processor and sourced from different orchards across the Central Valley. A total of 35 samples were collected and analyzed over three seasons from 2023 through 2025. Three known varieties were sampled: Arbequina (n=21), Arbosana (n=7), Koroneiki (n=3), Frantoio (n = 1), or a mixture (n = 3).

Data sources and number of observations.

Source	Sites		Years sampled		Observations
	Location	n	Years	n	
Own analyses	Central Valley	18	2023	1	18
Own analyses	Central Valley	1	2024	1	1
Own analyses	Central Valley	16	2025	1	16
Overall					**35**

Summary statistics of processing olive N removal data.

Source	Summary (lbs/ton of fresh weight)			
	mean	SD	Range	CV (%)
Own analyses 2023	7.14	1.06	5.32 – 8.51	14.8
Own analyses 2024	10.82			
Own analyses 2025	5.81	1.07	4.33 – 7.83	18.4
Overall	**6.63**	**1.43**	**4.33 – 10.82**	**21.5**

Variability

Nitrogen contents ranged from 4.33 – 10.82 lbs/ton of fresh weight. Across all samples, the variability in N removal was moderately high, with the CV reaching 21.5%. Differences in total N in the dry matter contributed significantly more to the observed variability than did the dry matter content. There were no significant differences in N removed between the three varieties sampled.

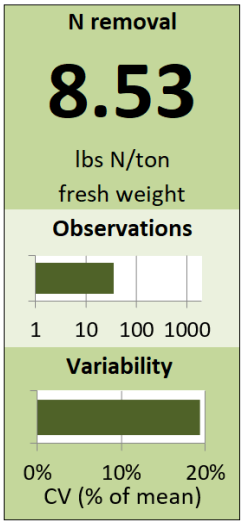
Discussion

With 6.63 lbs/ton of fresh weight, the quantity of N removed with processing olives was slightly, but not significantly, lower than that with table olives (7.12 lbs/ton; Geisseler, 2025). Compared to table olives, the processing olives in our dataset had a significantly higher dry matter, but significantly lower N concentration in the dry matter. The average N removal is based on 35 samples collected during three growing seasons from orchards across the Central Valley and can be considered a good estimate.

References

Geisseler, D., 2025. Nitrogen concentrations in harvested plant parts – Update 03/2025. Available online at: http://geisseler.ucdavis.edu/Geisseler_Report_U3_2025_03_19.pdf

Onion - Dehydrator



Data sources

Samples of dehydrator onion were sourced from different fields in the Central Valley. A total of 36 samples were collected and analyzed over three seasons from 2023 to 2025.

Data sources and number of observations.

Source	Sites		Years sampled		Observations
	Location	n	Years	n	
Own analyses	Central Valley	1	2023	1	1
Own analyses	Central Valley	29	2024	1	29
Own analyses	Central Valley	6	2025	1	6
Overall					**36**

Summary statistics of dehydrator onion N removal data.

Source	Summary (lbs/ton of fresh weight)			
	mean	SD	Range	CV (%)
Own analyses 2023	7.85			
Own analyses 2024	8.60	1.77	5.35 – 15.15	20.5
Own analyses 2025	8.32	1.19	6.78 – 9.82	14.3
Overall	**8.53**	**1.65**	5.35 – 15.15	**19.3**

Variability

Nitrogen contents ranged from 5.35 – 15.15 lbs/ton of fresh weight. Across all samples, the variability in N removal was relatively high, with the CV reaching 19.3%. Overall, the variability in both dry matter content and N concentration was higher than the variability in the N removal value. This was because samples with a higher dry matter content tended to have a lower N concentration in the dry matter and vice versa.

Discussion

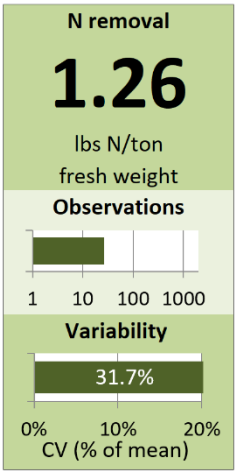
Nitrogen removal with dehydrator onion bulbs was 3.5 times higher than with fresh market onion bulbs (Geisseler, 2025). This is due to a much higher dry matter content (22.8% vs. 5.4%). In contrast, dehydrator onions have a slightly lower N concentration in dry matter (1.91% vs. 2.37%). The large difference in N removal per ton of bulbs justifies using different removal coefficient for fresh market and dehydrator onions.

The average N removal is based on 36 samples collected from three growing seasons and sourced from Central Valley growers and can be considered a good estimate.

References

Geisseler, D., 2025. Nitrogen concentrations in harvested plant parts – Update 03/2025. Available online at: http://geisseler.ucdavis.edu/Geisseler_Report_U3_2025_03_19.pdf

Pear



Data sources

Pear samples were purchased multiple times during the season from produce markets across the Central Valley. A total of 27 samples were collected and analyzed over three seasons from 2023 through 2025. Two types were sampled: Asian pears (n=14) and European pears (n=12). The European pears were all Bartlett. One sample was of an unknown variety.

Data sources and number of observations.

Source	Sites		Years sampled		Observations
	Location	n	Years	n	
Own analyses	Central Valley	2	2023	1	2
Own analyses	Central Valley	6	2024	1	6
Own analyses	Central Valley	19	2025	1	19
Overall					27

Summary statistics of pear N removal data.

Source	Summary (lbs/ton of fresh weight)			
	mean	SD	Range	CV (%)
Own analyses 2023	1.14	0.21	0.99 – 1.29	18.6
Own analyses 2024	1.40	0.26	1.07 – 1.77	18.2
Own analyses 2025	1.22	0.45	0.68 – 2.43	36.4
Overall	**1.26**	**0.40**	0.68 – 2.43	**31.7**

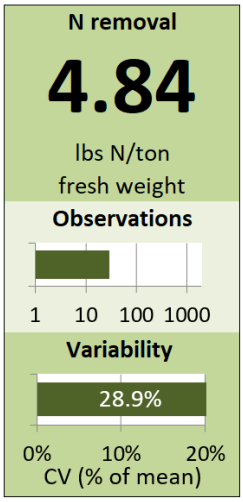
Variability

Nitrogen contents ranged from 0.68 – 2.43 lbs/ton of fresh weight. Across all samples, the variability in N removal was very high, with the CV reaching 31.7%. Differences in total N in the dry matter contributed more to the observed variability than did the dry matter content. Nitrogen removal with Bartlett pears tended to be slightly higher than N removed with Asian pears (1.39 vs. 1.14 lbs/ton), however the difference was not significant.

Discussion

On average, N removed by pears is 1.26 lbs/ton of fresh weight. The average N removal is based on 27 samples collected during three growing seasons from across the Central Valley and can be considered a good estimate.

Pumpkin



Data sources

Pumpkin samples were purchased multiple times during the season from produce markets across the Central Valley. A total of 29 samples consisting of many varieties were collected and analyzed over three seasons from 2023 to 2025. Most samples were “Jack-O-Lantern” pumpkins (n=20).

Data sources and number of observations.

Source	Sites		Years sampled		Observations
	Location	n	Years	n	
Own analyses	Central Valley	10	2023	1	10
Own analyses	Central Valley	4	2024	1	4
Own analyses	Central Valley	15	2025	1	15
Overall					**29**

Summary statistics of pumpkin N removal data.

Source	Summary (lbs/ton of fresh weight)			
	mean	SD	Range	CV (%)
Own analyses 2023	5.16	1.34	3.99 – 8.15	26.0
Own analyses 2024	3.53	1.05	2.19 – 4.52	29.8
Own analyses 2025	4.98	1.40	3.17 – 7.65	28.1
Overall	**4.84**	**1.40**	2.19 – 8.15	**28.9**

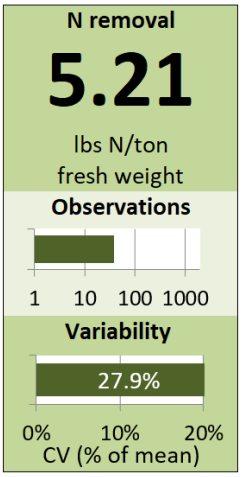
Variability

Nitrogen contents ranged from 2.19 – 8.15 lbs/ton of fresh weight. Across all samples, the variability in N removal was very high, with the CV reaching 28.9%. Differences in dry matter content contributed more to observed variability than the total N in the dry matter. Additionally, this observed variability was not influenced by varietal differences in N content or dry matter content, as individual variety datasets saw high variability as well.

Discussion

On average, N removed by pumpkins is 4.84 lbs/ton of fresh weight. The average N removal is based on 29 samples collected during three growing seasons from Central Valley growers and can be considered a good estimate.

Sweetpotato



Data sources

Sweetpotato samples were sourced from fields in Merced and Stanislaus County. A total of 38 samples consisting of different varieties were collected and analyzed over four seasons. Varieties sampled include: Bellevue (n=6), Bonita (n=6), Covington (n=8), Diane (n=6), Murasaki (n=5), and Vermillion (n=4). Three samples were of an unknown variety.

Data sources and number of observations.

Source	Sites		Years sampled		Observations
	Location	n	Years	n	
Own analyses	Central Valley	2	2021	1	2
Own analyses	Central Valley	20	2022	1	20
Own analyses	Central Valley	3	2024	1	3
Own analyses	Central Valley	13	2025	1	13
Overall					**38**

Summary statistics of sweetpotato N removal data.

Source	Summary (lbs/ton of fresh weight)			
	mean	SD	Range	CV (%)
Own analyses 2021	6.44	0.02	6.42 – 6.45	0.3
Own analyses 2022	5.27	1.66	2.08 – 8.08	31.4
Own analyses 2024	3.58	0.63	2.92 – 4.16	17.5
Own analyses 2025	5.30	1.09	3.65 – 7.04	20.6
Overall	**5.21**	**1.45**	2.08 – 8.08	**27.9**

Variability

Nitrogen contents ranged from 2.08 – 8.08 lbs/ton of fresh weight. Across all samples, the variability in N removal was very high, with the CV reaching 27.9%. Differences in total N in the dry matter contributed slightly more to the observed variability than the dry matter content. Compared to other varieties, Murasaki had a higher dry matter content, while Vermillion had a slightly lower dry matter and N contents. However, the sample size is too small to draw conclusions regarding varietal differences and more samples would need to be analyzed to determine whether these differences are consistent.

Discussion

On average, N removed by sweetpotatoes is 5.21 lbs/ton of fresh weight. All the samples were collected from fields in the major sweetpotato growing area in California. The average N removal is based on 38 samples collected during four growing seasons and can be considered a good estimate.

Appendix

Table A1 describes crops where an insufficient number of samples were collected over the 2021 – 2025 growing seasons to confidently estimate N removal. The N content in the dry matter, dry matter content, and N removal for each individual sample are reported below. Sample processing and analysis for these crops are reported on Page 6.

Table A1: N removed from analyzed crops with low total sample number. Each row reflects results for individual samples. All samples were from the Central Valley.

Crop	Type / Variety	Year Sampled	Dry Matter Content (%)	N Content (% DM)	N Removed	
Apple	Pink Lady	2021	16.7	0.42	1.41	lbs N/ton of fresh weight
	Fuji	2022	15.7	0.38	0.59	lbs N/ton of fresh weight
	Pink Lady	2022	18.2	0.40	0.72	lbs N/ton of fresh weight
	Fuji	2023	12.0	0.49	1.18	lbs N/ton of fresh weight
	Pink Lady	2023	12.7	0.36	0.91	lbs N/ton of fresh weight
Cucumber	n/a	2021	2.83	3.29	1.86	lbs N/ton of fresh weight
	n/a	2022	3.74	2.20	1.65	lbs N/ton of fresh weight
Fig	n/a	2021	34.3	1.0	6.9	lbs N/ton of fresh weight
	Kadota	2021	23.6	1.1	5.3	lbs N/ton of fresh weight
	Mission	2021	19.3	1.3	4.9	lbs N/ton of fresh weight
	Black Mission	2023	13.9	0.97	2.69	lbs N/ton of fresh weight
	n/a	2023	16.5	0.74	2.45	lbs N/ton of fresh weight
Green Onion	n/a	2023	4.5	4.07	3.63	lbs N/ton of fresh weight
Corn - Grain for feed	Yellow	2023	91.4	1.36	23.0	lbs N/ton @ 15.5% moisture
	Yellow	2025	86.2	1.31	22.2	lbs N/ton @ 15.5% moisture
	Yellow	2025	88.7	1.15	19.5	lbs N/ton @ 15.5% moisture
	Yellow	2025	89.1	1.20	20.3	lbs N/ton @ 15.5% moisture
	Yellow	2025	89.0	1.41	23.9	lbs N/ton @ 15.5% moisture
	Yellow	2025	91.9	1.24	20.9	lbs N/ton @ 15.5% moisture
	Yellow	2025	92.1	1.18	20.0	lbs N/ton @ 15.5% moisture
	Yellow	2025	90.5	1.14	19.3	lbs N/ton @ 15.5% moisture
	Yellow	2025	90.6	1.36	22.9	lbs N/ton @ 15.5% moisture
	Yellow	2025	90.3	1.33	22.4	lbs N/ton @ 15.5% moisture
	Yellow	2025	91.1	1.38	23.3	lbs N/ton @ 15.5% moisture
	Yellow	2025	90.1	1.23	20.9	lbs N/ton @ 15.5% moisture
	Yellow	2025	90.9	1.41	23.8	lbs N/ton @ 15.5% moisture
	Yellow	2025	91.3	1.10	18.6	lbs N/ton @ 15.5% moisture
	Yellow	2025	92.0	1.38	23.3	lbs N/ton @ 15.5% moisture
	Yellow	2025	91.2	1.23	20.7	lbs N/ton @ 15.5% moisture

Table A2: Acreage of crops grown in the Central Valley (San Joaquin Valley and Sacramento Valley combined). Data is from the USDA Agricultural Census 2022, which is currently the most recent year with a detailed list of crops (available online at: https://quickstats.nass.usda.gov/).
*The percentages of each crop as well as the cumulative % are estimates of the proportion of the total irrigated acreage in the Central Valley. Rice was excluded from the list. The commodities written in **bold red** typeface are those with updated values from California, which are included in this report and previous updates (Tables 1-3). The commodities written in **bold black** typeface are those included in the literature review (Geisseler, 2016).*

#	Commodity	Acreage	% of total	Cumulative %
1	ALMONDS	1622601	30.2	30.2
2	GRAPES	570034	10.6	40.8
3	PISTACHIOS	513511	9.6	50.3
4	CORN, SILAGE, IRRIGATED	417688	7.8	58.1
5	WALNUTS, ENGLISH	363078	6.8	64.9
6	HAY, ALFALFA, IRRIGATED	311621	5.8	70.6
7	TOMATOES, PROCESSING	195392	3.6	74.3
8	HAYLAGE, (EXCL ALFALFA), IRRIGATED	190400	3.5	77.8
9	HAY, (EXCL ALFALFA), IRRIGATED	151756	2.8	80.6
10	ORANGES, MID & NAVEL	138397	2.6	83.2
11	COTTON	131854	2.5	85.7
12	TANGERINES	75642	1.4	87.1
13	PEACHES	42972	0.8	87.9
14	CHERRIES, SWEET	39253	0.7	88.6
15	OLIVES	39015	0.7	89.3
16	PRUNES	38105	0.7	90.0
17	HAYLAGE, ALFALFA, IRRIGATED	37629	0.7	90.7
18	POMEGRANATES	32172	0.6	91.3
19	LEMONS	30587	0.6	91.9
20	ORANGES, VALENCIA	26479	0.5	92.4
21	SWEET POTATOES	24019	0.4	92.9
22	SUNFLOWER, IRRIGATED	22728	0.4	93.3
23	CORN, GRAIN (FEED; HUMAN CONSUMPTION)	21987	0.4	93.7
24	CARROTS	21435	0.4	94.1
25	GARLIC	21230	0.4	94.5
26	WHEAT, WINTER, IRRIGATED	20695	0.4	94.9
27	NECTARINES	19367	0.4	95.2
28	ONIONS, DRY	17700	0.3	95.5
29	MELONS, CANTALOUP	16888	0.3	95.9
30	TRITICALE, IRRIGATED	15479	0.3	96.2
31	SORGHUM, SILAGE, IRRIGATED	14342	0.3	96.4

Continued on next page

Table A2 continued

32	**POTATOES**	**14206**	**0.3**	**96.7**
33	**PLUMS**	**12151**	**0.2**	**96.9**
34	NURSERY TOTALS, IN THE OPEN	11769	0.2	97.1
35	**MELONS, WATERMELON**	**11176**	**0.2**	**97.3**
36	**SAFFLOWER, IRRIGATED**	**9194**	**0.2**	**97.5**
37	**SWEET CORN**	**8739**	**0.2**	**97.7**
38	BLUEBERRIES	7983	0.1	97.8
39	**FIGS**	**7245**	**0.1**	**98.0**
40	**GRAPEFRUIT**	**6450**	**0.1**	**98.1**
41	VEGETABLES, OTHER	6318	0.1	98.2
42	**BROCCOLI**	**6296**	**0.1**	**98.3**
43	**CUCUMBERS**	**5857**	**0.1**	**98.4**
44	**LETTUCE**	**5536**	**0.1**	**98.5**
45	**PEARS**	**5442**	**0.1**	**98.6**
46	**APRICOTS**	**4877**	**0.1**	**98.7**
47	**KIWIFRUIT**	**4614**	**0.1**	**98.8**
48	**MELONS, HONEYDEW**	**4225**	**0.1**	**98.9**
49	**BEANS, DRY EDIBLE, LIMA, IRRIGATED**	**4071**	**0.1**	**99.0**
50	**APPLES**	**3877**	**0.1**	**99.0**
51	**SQUASH**	**3613**	**0.1**	**99.1**
52	**WHEAT, SPRING, DURUM, IRRIGATED**	**3469**	**0.1**	**99.2**
53	TANGELOS	3332	0.1	99.2
54	GRASSES & LEGUMES TOTALS, SEED	3242	0.1	99.3
55	PLUM-APRICOT HYBRIDS	3222	0.1	99.3
56	**PUMPKINS**	**3015**	**0.1**	**99.4**
57	**BARLEY, IRRIGATED**	**2618**	**0.0**	**99.4**
58	**PEPPERS, BELL**	**2543**	**0.0**	**99.5**
	OTHER COMMODITIES	27488	0.5	100