**CALIFORNIA DEPARTMENT OF FOOD AND AGRICULTURE (CDFA)**
**Agreement 15-0360-SA**
**FINAL REPORT**

## A. Project Information

| **Project Title:** Evaluation of the Multiple Benefits of Nitrogen Management Practices in Walnuts. | | | |
|---|---|---|---|
| **Grant Recipient:** Coalition for Urban Rural Environmental Stewardship | **Grant Agreement No.:** 15-0360-SA | **Date Submitted:** July 30, 2020 | **Period Covered:** July 1, 2015 – June 30, 2020 |
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| Grant Award Amount (A) | Amount Invoiced to Date (B) | Remaining Grant Balance (A-B) | Program Income | Committed Match/In-Kind Funds | Match/In-Kind Funds Utilized to Date |
|---|---|---|---|---|---|
| $224,993.92 | $224,993.86 | $0.06 | $0.00 | $64,000.00 | $63,993.92 |

## B. Abstract

Nitrate is a major contaminant in groundwater in the Central Valley region. Elevated concentrations are primarily attributed to applied nitrogen fertilizers leaching past the root zone. Growers in the Central Valley are required through the Irrigated Lands Regulatory Program (ILRP) to keep an “on farm” Nitrogen Management Plan (NMP) to track nitrogen fertilizer applications. Coupled with information on yield, ILRP Coalitions are required to calculate the ratio of Nitrogen Applied to Nitrogen Removed. Implementation of management practices are focused on improving this ratio. However, there are knowledge gaps in understanding the effectiveness of various management practices in reducing the amount of nitrogen moving past the root zone in walnut orchards. This project documented the amount of nitrogen applied and measured the amount of nitrogen moving past the root zone using a combination of soil cores, soil water content, and soil pore water sampling. By capturing the movement of nitrate during both irrigation events and periods of winter rain, it is possible to assess the effectiveness of management practices on nitrate leaching from two walnut orchards. Results indicate that microsprinkler irrigation, as opposed to flooding, reduces the amount of nitrogen moving past the root zone. Additionally, more frequent, and smaller applications of nitrogen fertilizer appear to reduce nitrate leaching when compared to less frequent, larger applications. However, soil conditions play a major role in leaching and it appears that preferential flow paths may be responsible for increased leaching

regardless of the frequency of application. Modeling physical processes in the vadose zone with the 1-dimensional Hydrus model supports the results of the field work.

## C. Introduction

Elevated levels of nitrate present in groundwater in Central Valley locations are being attributed, in part, to inputs from farming. The Central Valley Regional Water Board estimates that approximately three million acres of irrigated lands overlay groundwater aquifers that have elevated concentration of nitrate or are vulnerable to nitrate contamination. As a result, the Water Board has adopted regulations to reduce nitrate leaching. In the Central Valley, approximately 33,000 landowners/operators are regulated by the Irrigated Lands Regulatory Program (ILRP) requirements and must implement practices to protect groundwater from further contamination by nitrate. Similar groundwater issues and regulations are found in other regions of California.

ILRP agricultural coalitions are working to assist their members to understand and better manage nitrate fertilizer applications. The effective management of fertilizer applications can be done by utilizing the four R's (right time, right place, right source, and right rate) for each crop. Very little is known about the four R's for most of the crops grown in the Central Valley. Although there has been some research on nutrient management, this research often has been focused on optimizing yields that can lead to an over-application of nitrogen fertilizer. Heightened concern about groundwater quality has prompted new research into the management of nitrogen fertilizer with the dual goals of minimizing leaching while maintaining crop health and yield.

One study conducted by DeJong et al. (2014) determined that depending on variety and location, approximately 25 – 30 pounds N/ton is removed in harvested biomass (nuts and hulls) in walnut orchards. DeJong et al. (2014) also found that there was more variability between sites than between cultivars. Preliminary results indicated that soil variability was high even within a small portion of the orchard. Analysis of leaching showed leaching of nitrate as early as late July, increasing towards the end of the season in association with heavy precipitation events. Leaching did not appear to occur during the growing season due to the limited movement of water below the root zone.

The objective of the current study is to improve our understanding of how split applications affect leaching of N to groundwater. A combination of pore water collected by lysimeters, soil samples, collection of irrigation water, and crop tissue analyses allow us to estimate the nitrate present in the system. The main goal for this project is to identify the benefits of the different nitrogen management systems implemented in the two orchards, and to determine potential cost savings and groundwater protection benefits provided by each of these two management systems. By using a vadose ground fate and transport model, HYDRUS (developed using the grantee funds), additional management practices can be evaluated through computer modeling. Finally, these results are being disseminated to walnut growers at outreach events, such as Field Days.

## D. Objectives

**Objective 1)** Identify the management practices being implemented to reduce the amount of nitrogen moving through the root zone for Orchard 1 and Orchard 2.

**Objective 2)** Determine the amount and timing of nitrogen moving through the root zone.

**Objective 3)** Identify the multiple benefits of nitrogen management practices implemented in Orchard 1 and Orchard 2 including potential cost savings (reduce water costs, reduce amount of money spent on fertilizer) and groundwater protection (reductions in the amount of nitrogen that is moving through the root zone).

**Objective 4)** Determine if additional practices that could be implemented in order to further reduce the amount of nitrogen moving through the root zone.

**Objective 5)** Disseminate results to growers of walnuts.

## E. Methods

**Task 1 – Project Management:** *Project management will occur throughout the duration of the project to ensure that Tasks 2 – 6 are being completed on time and on budget. This task ensures that **Objectives 1-5** are met. Project Management includes coordination of the study team personnel including the Co-PI, Project Advisor, Project Cooperators, Project Supporters and personnel from the Subcontractor MLJ-LLC.*

**Task Activities:** The first interim report was compiled and submitted on January 29, 2016 describing the activities to that date. A kickoff meeting was coordinated between the Co-PI, Project Advisor, Project Cooperators, Project Supporters and Subcontractor MLJ-LLC and CDFA staff to discuss the study design, timing and management practices to be studied. The second interim report was compiled and submitted on July 11, 2016. During this time multiple meetings were scheduled with the cooperator grower. The third interim report was compiled and submitted on January 31, 2017 describing the activities from July 1, 2016 through December 31, 2016. From January through April 2017, the project team held several meetings with the cooperator grower to discuss results from 2016 sampling, get approval to install a second set of deeper suction lysimeters, and adjust the amount and timing of fertilizer applications in 2017 on one of the study blocks. In May 2017, a meeting was held with project staff, UC Cooperative Extension, and CDFA staff to discuss study results and plans for 2017.

An abstract was developed for the FREP conference in Modesto which was included in the conference program materials. Several meetings were held at the field site between project personnel and the cooperator, and the cooperator's PCA was contacted numerous times to obtain information about the management of the two blocks.

All required activities associated with the study have been completed but outreach continues. Successful project coordination between Project Cooperators, the cooperator grower, and the Subcontractor occurred to stage two workshops for walnut growers. Project personnel continued to work with the cooperator and CDFA staff to

complete the study.
**Completion Date: June 2019**

**<u>Task 2 – Grower Identification:</u>** *The cooperator grower will be identified based on availability and willingness to participate with the assistance of the Project Team in order to meet **Objective 1**. **Task Products** include the recording of management practices implemented to increase the efficiency of nitrogen use including application timing and irrigations. This task will occur prior to the implementation of sampling and during both years of the study. Grower identification will be completed 3 months after project initiation (October 2015).*
**Task Activities:** The cooperator grower was identified, and the project team met with him and/or his PCA numerous times. The project team documented the practices used by the cooperator including nitrogen applications and irrigation timing and method. Year one (2016) fertilizer applications involved a combination of broadcast and fertigation, and irrigation following fertilizer applications involved a combination of flood and microsprinklers. The project team met with the cooperator prior to the second year (2017) and he agreed to use split applications on one of the orchard blocks with all applications by fertigation.
**Completion Date: April 2017**

**<u>Task 3 – Study Design</u>:** *The cooperator grower will be identified based on availability and willingness to participate with the assistance of the Project Team in order to meet **Objective 1**. **Task Products** include the recording of management practices implemented to increase the efficiency of nitrogen use including application timing and irrigations. This task will occur prior to the implementation of sampling and during both years of the study. Grower identification will be completed 3 months after project initiation (October 2015).*
**Task Activities:**

Two blocks of Chandler variety walnuts between 10 and 15 years old were selected for instrumentation. The “East Block” (Orchard 1) is slightly over 4 acres in size and the “West Block” (Orchard 2) is just under 6 acres. The Coalition for Urban/Rural Environmental Stewardship and the project team mapped the fields and used the SSURGO soil survey data to identify relevant soils within the two blocks. The team established 15 equal area grid cells on each block for the sampling, installed the equipment in the grid cells, and collected samples for analysis. In addition, a database to house all data collected during the study was developed. At the time of harvest, harvested material on both blocks was weighed and samples were collected for analysis of N content.

The Project Team refined the study design and made changes after the first year to better reflect the goals of the project. On the recommendation of experts from CDFA and University of California Cooperative Extension, soil permeability measurements were removed from the study in year two. These were replaced with soil volumetric water content (VWC) sensors that provided continuous measurement of soil water content. Water content allows a determination of the total flux of nitrogen leaching past the root zone.  The VWC sensors were placed at depths of two feet and four feet in five locations in each block. Soil sampling was modified in year two from three sets of 15 samples per year at five locations to two sets of 40 samples per year at 8 locations.

Based on laboratory results from the first set of soil core data, changes were made for the second set collected in 2016. The results of the first year's Soil Labile Amino-N (SLAN) test on soils collected between 2 and 4 feet in the soil profile indicated that the mineralization potential within the root zone is negligible. Soil cores were also analyzed for Total Organic Carbon (TOC) in 2 foot intervals down to 10 feet to calculate C:N. The results indicated that there is little organic material down to 10 ft.  No SLAN tests or TOC analyses were conducted in 2017.  However, in an effort to better characterize the soils, in 2017 a one-time analysis of soil texture was conducted for the 2-ft to 4-ft interval.

During 2017, the cooperator made changes to amount and timing of N applications and lysimeters were installed at a depth of 10-ft.  The project team received additional funding from several ILRP Coalitions to cover the majority of the cost of purchasing and installing the 10-ft suction lysimeters, and laboratory analyses.  Soil cores were collected and analyzed as described above. During the 2017 irrigation season, the cooperator agreed to apply 150 units of N via microsprinkler fertigation over 3 applications on the West Block and 6 applications on the East Block. The cooperator performed petiole analysis in early July and determined that no further applications of fertilizer were necessary. After fertilization was complete in 2017, all remaining irrigation events were done by flood.  See Table 1 for parameters, analyses and measurements collected during the second year of the project.

Based on information gathered during meetings with the cooperator grower in spring 2017, and a better understanding of the irrigation system, it was determined that three fertilization regimes were applied across the two blocks (see Table 3).  The West Block was sub-divided, with grid columns 4 and 5 grouped as a separate block and grid columns 1, 2, and 3 grouped as an additional block, hereafter referred to as West Block and Center Block, respectively (Figure 1).

**Completion Date: December 2017**

**Table 1. Study parameters, analyses, and measurements collected during the second year of the project.**

| Parameter | Analyses | Distribution | Collection depth | Frequency |
|---|---|---|---|---|
| Pore water | Nitrate as N | 15 locations per block | 4 feet, 10 feet | 6 irrigation events, or more as needed |
| Irrigation water | Nitrate as N | Groundwater and surface water | NA | As needed to characterize nitrate applied. |
| Soil cores | Nitrate as | 8 random | 2 foot intervals to | early season only |

| | | | | |
|---|---|---|---|---|
| | N, % moisture, wet weight, dry weight | locations per block | 10 feet (5 samples per 10-foot core) | |
| Tissue (nut and hull only) | Total nitrogen, % moisture, wet weight, dry weight | 10 random locations per block | NA; samples collected from multiple trees within the grid square | Annually, just prior to harvest. |
| Soil volumetric water content | % VWC | 5 random locations per block | 2 feet, 4 feet | Continuous logging; 15-minute interval |

**Figure 1.** Map of the original walnut blocks (West and East) with grid system and sampling locations. The blue outline represents the Center block, within the West block, that is considered a different treatment due to differences in applied N.


**Task 4 – Sampling:** *Sampling included soil, pore water, irrigation water and plant tissue N. The study also included the measurement of volumetric water content at 2 depths in order to meet* ***Objective 2.*** *Sampling occurred after a rain event each year (November – March) and approximately 4 irrigation events (this may include a pre-irrigation event).* ***Task Products*** *included sample collection and receipt of results from the laboratory/field sampling.*

**Task Activities:**

Between July 2015 and December 2016, all necessary sampling equipment and supplies were purchased and suction lysimeters (4 ft), moisture sensors and data loggers were installed in orchard blocks. In February 2016 and 2017, soil cores were collected in the East and West blocks. Irrigation water was collected from microsprinklers in July 2016. Tissue collection occurred prior to harvest, and harvest weights were recorded at the time of harvest.

Volumetric water content (VWC) data was downloaded from in-field data loggers from April 29$^{th}$, 2016 through June 29$^{th}$. Sensor failures occurred in both the West and East Blocks. In July 2016 both the 2-ft and 4-ft sensors failed at one grid cell location in the West Block. The logger and shallow sensor were repaired in October 2016. In May 2017, there was a failure of both sensors at one location in the East Block. Due to budget constraints, the three failed sensors were not repaired or replaced.

In 2017, 10 ft. suction lysimeters were purchased and installed in all orchard blocks. Pore water samples were collected at two depths (4-ft and 10-ft) in both the East and West Blocks for the first six irrigation events of 2017 (Table 2). Irrigation water was sampled once in June 2017. During these irrigation events, the West Block received 150 units of N via three split applications of UAN32 and the East Block received 15 units of N via six split applications of UAN32. Tissue samples of harvestable material were collected at the end of the growing season. All laboratory results are stored in the database developed for this project

**Completion Date: January 2018**

**Table 2. S**ample events and parameters measured.

| Parameters | Location | Collection Date | Collection Depth | Samples collected | Results received | Loaded to Database |
|---|---|---|---|---|---|---|
| **Pore water** | East Block, West Block | 4/28/2016 | 4-ft. | 24 | Yes | Yes |
| **Soil cores** | East Block | 5/5/2016 | 0-10 ft. | 50 | Yes | Yes |
| **Soil cores** | West Block | 5/6/2019 | 0-10 ft. | 50 | Yes | Yes |
| **Irrigation water** | East Block, West Block | 5/18/2016 | 4-ft. | 2 | Yes | Yes |
| **Pore water** | East Block, West Block | 5/19/2016 | 4-ft. | 29 | Yes | Yes |
| **Pore water** | East Block, West Block | 6/3/2016 | 4-ft. | 10 | Yes | Yes |
| **Pore water** | East Block, West Block | 6/6/2016 | 4-ft. | 30 | Yes | Yes |
| **Pore water** | East Block, West Block | 6/17/2016 | 4-ft. | 30 | Yes | Yes |
| **Pore water** | East Block, West Block | 6/20/2016 | 4-ft. | 10 | Yes | Yes |
| **Irrigation water** | East Block, West Block | 7/14/2016 | N/A | 2 | Yes | Yes |
| **Pore water** | East Block, West Block | 7/15/2016 | 4-ft. | 30 | Yes | Yes |
| **Irrigation water** | East Block, West Block | 7/18/2016 | N/A | 4 | Yes | Yes |
| **Tissue** | East Block, West Block | 10/5/2016 | N/A | 20 | Yes | Yes |
| **Pore water** | East Block, West Block | 10/31/2016 | 4-ft. | 19 | Yes | Yes |
| **Soil cores** | East Block | 11/15/2016 | 0-10-ft. | 40 | Yes | Yes |
| **Soil cores** | West Block | 11/16/2016 | 0-10-ft. | 40 | Yes | Yes |
| **Soil cores** | East Block | 2/22/2017 | 0-10-ft. | 8 | Yes | Yes |
| **Soil cores** | West Block | 2/23/2017 | 0-10-ft. | 8 | Yes | Yes |
| **Pore water** | East Block, West Block | 5/8/2017 | 4-ft.,10-ft. | 60 | Yes | Yes |
| **Pore water** | East Block, West Block | 5/9/2017 | 4-ft.,10-ft. | 20 | Yes | Yes |
| **Pore water** | East Block, West Block | 5/10/2017 | 4-ft.,10-ft. | 20 | Yes | Yes |
| **Pore water** | East Block, West Block | 5/12/2017 | 10-ft. | 10 | Yes | Yes |
| **Pore water** | East Block, West Block | 5/17/2017 | 10-ft. | 10 | Yes | Yes |
| **Pore water** | East Block, West Block | 5/18/2017 | 4-ft. | 30 | Yes | Yes |
| **Pore water** | East Block, West Block | 5/19/2017 | 10-ft. | 30 | Yes | Yes |
| **Pore water** | East Block, West Block | 5/26/2017 | 4-ft.,10-ft. | 60 | Yes | Yes |
| **Pore water** | East Block, West Block | 5/30/2017 | 4-ft.,10-ft. | 60 | Yes | Yes |

| | | | | | | |
|---|---|---|---|---|---|---|
| **Pore water** | East Block, West Block | 5/31/2017 | 10-ft. | 30 | Yes | Yes |
| **Irrigation water** | East Block, West Block | 6/6/2017 | N/A | 9 | Yes | Yes |
| **Pore water** | East Block, West Block | 6/7/2017 | 4-ft. | 30 | Yes | Yes |
| **Pore water** | East Block, West Block | 6/8/2017 | 10-ft. | 30 | Yes | Yes |
| **Irrigation water** | West Block | 6/16/2017 | N/A | 1 | Yes | Yes |
| **Pore water** | East Block, West Block | 6/17/2017 | 4-ft. | 30 | Yes | Yes |
| **Pore water** | East Block, West Block | 6/19/2017 | 10-ft. | 30 | Yes | Yes |
| **Pore water** | East Block, West Block | 6/28/2017 | 4-ft. | 30 | Yes | Yes |
| **Pore water** | East Block, West Block | 6/29/2017 | 10-ft. | 30 | Yes | Yes |
| **Pore water** | East Block, West Block | 8/31/2017 | 4-ft., 10-ft. | 60 | Yes | Yes |
| **Tissue** | East Block, West Block | 10/11/2017 | N/A | 20 | Yes | Yes |
| **Soil VWC** | East Block, West Block | 4/29/2016 – 6/29/2017 | 2-ft.,4-ft. | Continuous (15-minute interval) | Yes | Yes |

<u>**Task 5 – Data Management**</u>: *Results obtained from sampling (both laboratory and field results) as well as management practice information (details regarding timing and rates of applications) will be recorded in an electronic database. Data will be analyzed to evaluate differences in nitrate leaching between orchards **(Objective 2)** and estimate costs for implementing practices **(Objective 3). Task Products** include an electronic database of results to be used for data analysis in the Summary Report. Data Management will begin with the first sample collection (2015/2016) and end with the draft Summary Report (2018).*

**Task Activities:**

Contractors to the Coalition for Urban/Rural Environmental Stewardship (CURES) developed a database that includes field, irrigation, and management practice information, as well as measurements taken in the field and laboratory analyses. All data are in the database and available upon request.

**Completion Date: March 2018**

<u>**Task 6 – Summary Report**</u>: *The Summary Report will include the identification of management practices, sample design, analysis of results, evaluation of nitrate leaching*

*between fields, a cost analysis of BMP implementation, identification of additional practices that could be implemented, and documentation of outreach efforts* ***(Objectives 1-5). Task Products*** *include a draft Summary Report that will be disseminated to the Project Team for comments/edits. A final Summary Report will incorporate comments from the Project Team and submitted to CDFA. Information from the Summary Report will be utilized in outreach materials.*
**Task Activities:**

The project team analyzed data from 2016 and 2017 and estimated the amount of nitrate leaching past the root zone during each irrigation event and during the entire year. Estimates of nitrogen leaching were made using three methods modified from Baram et al. (2016). The one-dimensional version of HYDRUS is parameterized for the three blocks (West, Center and East). Hydrus was used to estimate the amount of N leaching, and these estimates are compared with simple mass-balance estimates, and flow calculation-estimates for data collected in 2016 and 2017.

Additional analyses to examine the differences in leaching rates between the nitrogen application methods are complete. Project staff utilized the information to create outreach materials describing the relative efficacy of the management practices in reducing leaching of nitrate.

**Completion Date: June 2018**

**Task 7 –Outreach:** *Outreach will include Field Day demonstrations and dissemination of results to growers and CV Coalitions. Field Days will be conducted to demonstrate the management practices being implemented and the results from the Summary Report will be distributed to the MPEP GCC and CV Coalitions to meet* ***Objective 5. Task Products*** *include outreach materials summarizing the conclusions of the study.*
**Task Activities:** The CURES project manager has given presentations about the project in several meetings held with growers in the East San Joaquin Water Quality Coalition and San Joaquin County and Delta Coalition regions. Two Walnut Field Days were held near Ceres at the project cooperators farming operation. Approximately 100 growers, Pest Control Advisors and other ag interests attended the two field days and feedback was very positive. The ESJWQC conducted a series of meetings with growers in areas known to be highly vulnerable to groundwater contamination, as well as annual meetings for all members. Lessons learned from this study along with the results obtained from other CDFA-funded studies were provided to ESJWQC members. In addition, the CURES project manager discussed the results with other ILRP agricultural coalition leads during meetings.

In 2020, a publication and educational video series were developed for Central Valley walnut growers. The publication, titled 4Rs and Walnut Nitrogen Management, explains how to optimize walnut crop applications of nitrogen while minimizing leaching of excess nitrates. The approach is called the 4Rs: Right Rate, Right Time, Right Place and Right Source. This publication will be distributed by Water Quality Coalitions, UC, CDFA and the Walnut Board of California. An order form was also added to the CURES website at www.curesworks.org/walnuts/, for those that would like to order directly.

The educational video series, also titled 4Rs and Walnut Nitrogen Management, was developed in collaboration with the UC and Walnut Board of California and is composed of a 30-minute continuing education video and a 5-minute “snapshot” that a grower can quickly watch on-the-go. CURES staff and UC Walnut Farm Advisor, Katherine Jarvis-Shean, explains the science behind leaching of excess nitrates and gives tips and techniques that growers can use in the field. Both videos are posted on the CURES website at www.curesworks.org/best-management-practices/#agPubs. The 30-minute video will also be posted on the Continuing Education website at www.curesworks.org/cecourses/, upon approval for Continuing Education Units.

**Completion Date: June 2020**

## F. Data/Results

**Objective 1: Identify the management practices being implemented to reduce the amount of nitrogen moving through the root zone for Orchard 1 and 2.**

In 2016, a combination of microsprinkler irrigation, and flood irrigation was used to deploy fertilizer on all blocks (Table 3). In 2017, only microsprinkler irrigation was used to deliver fertilizer although flood irrigation (without fertilizer) was used after applications were complete. In both years, leaf tissue analysis was used by the cooperator to guide the amount of nitrogen applied.

**Table 3.** Date of fertilization, fertilization type and amount of nitrate applied for the three treatment blocks. In 2017, the East block switched fertilization regimes to more frequent, but smaller applications of nitrate.

| Date | Fertilization Type | West Block (lbs/acre $NO_3N$) | Center Block (lbs/acre $NO_3N$) | East Block (lbs/acre $NO_3N$) |
|---|---|---|---|---|
| **3/11/2016** | Banded before rain | 50 | 50 | 50 |
| **5/17/2016** | Fertigation | 43 | 50 | 50 |
| **6/16/2016** | Banded before flood | 50 | 50 | 50 |
| **5/4/2017** | Fertigation | 43 | 50 | 25 |
| **5/15/2017** | Fertigation | 0 | 0 | 25 |
| **5/25/2017** | Fertigation | 43 | 50 | 25 |
| **6/5/2017** | Fertigation | 0 | 0 | 25 |
| **6/15/2017** | Fertigation | 43 | 50 | 25 |
| **6/26/2017** | Fertigation | 0 | 0 | 25 |

Although the nominal concentration of nitrate in the fertigation treatment on the west block is 50 lbs/acre, analysis of the water used for fertigation indicated that only 43 lbs/acre were applied on the West Block. The amount of nitrate applied by the cooperator is based solely on the nitrate in the fertilizer and does not include the amount of N in the irrigation supply water. Irrigation water (groundwater) contained 13 mg NO3-N/L in both 2016 and 2017. Water received from the Turlock Irrigation District (TID) contained 0.08 mg NO3-N/L.

**<u>Objective 2:</u> Determine the amount and timing of nitrogen moving through the root zone.**

Using funds from outside sources to perform the analyses, three methods were used to estimate water leaching and N load for each treatment; weekly mass balance, Darcy flux, and a direct modeling approach using HYDRUS 1D. The weekly mass balance was conducted as outlined by Baram et al. (2016). The weekly mass balance calculation somewhat overestimated nitrate load because of low resolution of measured concentrations over time (generally single weekly samples during fertigation and less frequent monitoring after applications were completed), particularly in 2016, but gives a reasonable estimate of leaching. The Darcy flux method also overestimated leaching because volumetric water content sensors, when calibrated against laboratory soil moisture using a one-point calibration, were 10% high on average. HYDRUS models were constructed for each of the three grid squares, and leaching and nitrate loads for both years at all three sites were modeled.

We calculated mean nitrate (mg/L) and standard deviation for each block, year and lysimeter depth (Table 4, Figure 2). To examine whether the mean nitrate concentration differed across the three blocks for the 10 foot lysimeters (Figure 3), a Welch's t-test was performed. Mean nitrate concentrations between the blocks were significantly different ($p < 0.05$). A second Welch's t-test was used to test for differences in mean nitrate concentration in the 4 foot lysimeters in the east block between 2016 and 2017. Mean nitrate concentration did not differ between the two years ($p = 0.1547$). A third Welch's t-test tested for differences in nitrate concentration between the three blocks in the 4 foot lysimeters between 2016 and 2017. The concentration of nitrate in the blocks were significantly different ($p < 0.05$).

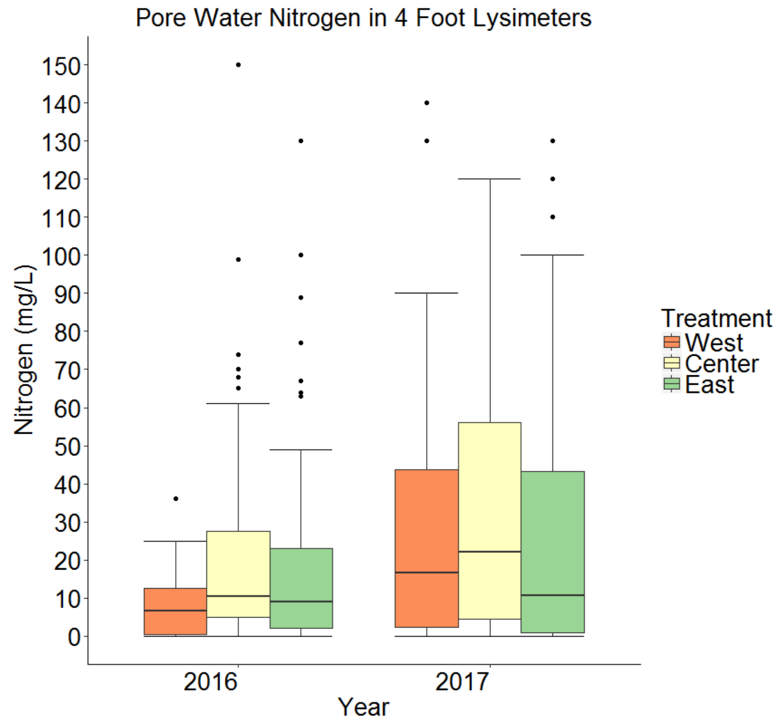


**Figure 2.** Nitrogen present in pore water samples collected from 4-foot lysimeters in the West, Center, and East blocks of the walnut orchard in 2016 and 2017. Outliers greater than 150 mg/L N are excluded from this graph, but are included in boxplot calculations.

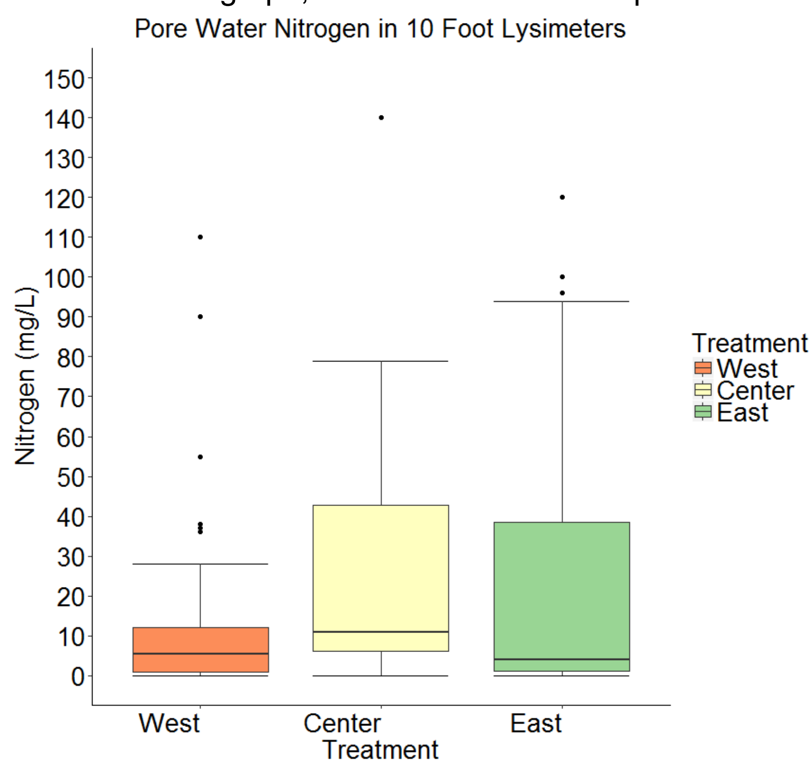


**Figure 3.** Nitrogen present in pore water samples collected from 10-foot lysimeters in

the West, Center and East blocks of the walnut orchard in 2017. Outliers greater than 150 mg/L N are excluded from this graph, but are included in boxplot calculations.

**Table 4.** Number of samples collected by year, block and lysimeter depth, as well as mean and standard deviation for nitrate in collected pore water samples. In all cases, the standard deviation is greater than the mean indicating substantial variation within each block.

| Block | Year | Lysimeter Depth (feet) | Count | Mean (nitrate mg/L) | Standard Deviation (nitrate mg/L) |
|---|---|---|---|---|---|
| East | 2016 | 4 | 80 | 21.3 | 35.9 |
| East | 2017 | 4 | 128 | 29.4 | 45 |
| East | 2017 | 10 | 154 | 47.9 | 102 |
| Center | 2016 | 4 | 51 | 26.7 | 41.5 |
| Center | 2017 | 4 | 74 | 33.5 | 37.1 |
| Center | 2017 | 10 | 93 | 39.3 | 54.3 |
| West | 2016 | 4 | 34 | 8.09 | 8.39 |
| West | 2017 | 4 | 50 | 30.0 | 43.6 |
| West | 2017 | 10 | 60 | 12.5 | 20.7 |

**Objective 3: Identify the multiple benefits of nitrogen management practices implemented in Orchard 1 and Orchard 2 including potential cost savings (reduce water costs, reduce amount of money spent on fertilizer) and groundwater protection (reductions in the amount of nitrogen that is moving through the root zone).**

Management practices that implemented by the grower include tissue sampling to determine whether late-season N applications are needed, and split applications of fertilizer. Tissue sampling resulted in a decrease in the application of 50 lbs/ac of fertilizer in both 2016 and 2017, which translates to a reduction in the cost of fertilization and a reduction in the amount of N leached to groundwater.

**Objective 4: Determine if additional practices could be implemented in order to further reduce the amount of nitrogen moving through the root zone.**

Additional practices that could be implemented to further reduce the amount of nitrogen moving though the root zone include adjusting the timing of the fertilizer injection during each irrigation set to occur toward the end of the irrigation set. This should reduce the opportunity for water to push nitrate past the root zone.

**Objective 5: Disseminate results to growers of walnuts.**

Data developed in this project were shared with Katherine Pope and Patrick Brown, UC Davis faculty who work on walnuts. Joe Grant, Research Director for the California Walnut Commission, participated in the Walnut Field Day and received results of the project. Two Walnut Field Days were held near Ceres in June 2018 and April 2019. Approximately 100 growers, Pest Control Advisors and other ag interests attended the two field days and feedback was very positive. The San Joaquin County and Delta Coalition also held a Continuing Education workshop that focused on walnut production including irrigation and nutrient management. A 45-minute presentation was given on this project study design, results and an overview of nitrogen management practices. Approximately 70 growers and crop advisors attended. The ESJWQC is also conducting a series of meetings with growers in areas known to be highly vulnerable to groundwater contamination, as well as annual meetings for all members. Lessons learned from the current study along with the results obtained from other CDFA-funded studies will be provided to ESJWQC members. In addition, the CURES project manager discusses the results with other ILRP agricultural coalition leads during meetings.

## G. Discussion and Conclusions

In general, the median concentration of nitrate in lysimeters at 4-ft is lower than the concentration found at 10-ft although there is greater variability in concentration at 10-ft compared to 4-ft (Figures 2 and 3, respectively).

Nitrate leaching depends upon the amount and timing of N and water inputs, the storage capacity of the soil, and the amount and timing of N uptake by plants. Both the weekly mass balance and the Darcy flux indicate that nitrate leached past the root zone during the 2016 and 2017 growing seasons. Changes in application timing and fertilizer amount may minimize leaching losses. Losses are also a function of the irrigation practices. During 2016, the cooperator used a combination of sprinklers and flood irrigation during the period of fertilizer applications. In 2017, the cooperator used sprinklers exclusively for fertigation and rotated to flood irrigation after applications were completed. Despite the change in irrigation practices, nitrate was detected in the lysimeters at 4-ft in both 2016 and 2017, and in the 10-ft lysimeters in 2017. Although the 4-ft lysimeters could be within the root zone, 10-ft lysimeters are almost certainly below the root zone where active uptake of N by the tree occurs. It is likely that leaching to groundwater is occurring although it is difficult to determine the relative contribution of nitrate in the irrigation water and the nitrate applied as synthetic fertilizer. A relatively elevated concentration of nitrate in groundwater used for irrigation would result in nitrate being found in any irrigation water moving past the root zone, even if no residual nitrate from fertilizer was present.

The in-season leaching indicated by lysimeter data is reflected in the HYDRUS modeling results. The timing of leaching losses in model output during 2016 is informative, suggesting that management practices during the irrigation season (banding and flooding) become more likely to leach N in-season on coarser textured soils such as WB4. Winter leaching at this site is also apparent, though it is a smaller portion of the total leaching losses at this site than at the finer textured sites. Outputs from HYDRUS uniformly give low estimates as compared with the other three estimation methods, likely due to the assumption of no preferential flow paths through the root zone. HYDRUS model results indicate that splitting applications may be effective in preventing leaching as deep percolation losses are higher for the site receiving three applications of 43lb/ac compared to 6 applications of 25 lbs/ac.

These results differ from those found by DeJong et al. (2014) who found essentially no leaching during the growing season due to the retention of water and nitrate in the root zone. The primary leaching in that study was during the winter when rain events pushed the residual nitrate past the root zone. The soils in the current study are sandier than the soils under the orchard studied by DeJong et al. (2014) which undoubtedly contributed to the growing season leaching in the current study. The comparison of results from DeJong et al. (2014) and the current study indicate that management practices may not be equally effective in preventing leaching under different environmental conditions.

There is a large amount of variation in nitrate leaching in the orchard blocks, even between monitoring locations that are in relatively close proximity. In most cases, the standard deviation of nitrate concentration is larger than the mean concentration suggesting significant heterogeneity in the soils, even though the soils appear to be relatively homogeneous (Table 5) with between 83 and 88% sand across the blocks. The apparent homogeneity of the soils and heterogeneity of the nitrate leaching suggests preferential flow paths are important in determining nitrogen leaching.

**Table 5.** Soil descriptions for three locations with the walnut orchard.

| Location | Depth (ft.) | Percent Sand | Percent Silt | Percent Clay | Textural Class |
|---|---|---|---|---|---|
| **EA1** | 0-2-ft. | 84 | 12 | 4 | Loamy Sand |
| **EA1** | 2-4-ft. | 87 | 8 | 5 | Loamy Sand |
| **WB4** | 0-2-ft. | 88 | 8 | 4 | Sand |
| **WB4** | 2-4-ft. | 88 | 9 | 3 | Sand |
| **WC1** | 0-2-ft. | 83 | 12 | 5 | Sandy Loam |
| **WC1** | 2-4-ft. | 88 | 9 | 3 | Sand |

The goal of the cooperator was to apply 200 pounds of nitrogen to his orchard. The cooperator made applications to about 150 pounds and then collected a tissue sample to determine if the additional 50 pounds was necessary. In both years, the tissue analysis indicated that no additional fertilizer was necessary. However, if the amount of nitrate in irrigation supply water is accounted for, the grower applied approximately 200 pounds of nitrate per acre in both years.

## H. <u>Challenges</u>

A miscommunication regarding the field irrigation set up early in the project (that the west block was subdivided into two) presented challenges in analyzing the results. It especially limited the use of the harvest data, which was not parsed out for the west and center blocks, rather one number was reported instead of two.

In general, while it is likely that leaching to groundwater is occurring, it is difficult to determine the relative contribution of nitrate in the irrigation water and the nitrate applied as synthetic fertilizer. A relatively elevated concentration of nitrate in groundwater used for irrigation would result in nitrate being found in any irrigation water moving past the root zone, even if no residual nitrate from fertilizer was present.

## I. Project Impacts

This research will continue to provide growers and crop advisors with information needed to quantify the loss of nitrate through the root zone for selected management practices. This information can be used by growers to adjust their management practices and reduce the amount of nitrate lost to groundwater. Additionally, the information generated by this project will continue to help growers optimize their nitrate applications and save money in their farming operation. The BMP recommendations are vital to walnut growers in the Central Valley, who are an important part of the approximately 33,000 landowners/operators who farm nearly 7 million acres of land and are impacted by ILRP requirements to improve nitrogen and irrigation practices to minimize nitrate discharges to ground and surface water.

In addition, the research techniques and protocols developed during this study can be a demonstration to the Regional Board that this study design can be replicated in other locations and with other crops to evaluate the efficacy of management practices. The information generated by this project is critical in allowing the CV Coalitions to meet the compliance measures outlined in their Waste Discharge Requirements.

Production of the videos in the project on nitrogen management will also provide valuable information that will be useful in enhancing walnut producers understanding of this important nutrient. This video (see description below) will be available on CURES website on a page that has auto-notification to more than 2700 growers regarding availability of online educational materials. This educational resource can be expected to have a positive impact on the understanding of nitrogen management in both the immediate and long term.

## J. Outreach Activities Summary

Two grower field days titled “Walnut Nitrogen and Irrigation Management Field Day” was held at the project cooperators walnut hulling facility in Ceres on June 7, 2018 and April 2, 2019. Postcards and email blasts were sent to local growers to advertise the events. The field days were also approved to offer 2 Continuing Education Units (CEUs) to NMP self-certified growers that attended. Approximately 100 growers, Pest Control Advisors and other ag interests attended the two-hour events. Four presentations were given at separate locations in the facility so that smaller groups could interact with the speakers (each presentation was repeated four times). In addition to explaining the results of the field work, sessions also covered methods for determining proper amounts of fertilizer injections into irrigation systems; a session on fertigation equipment and maintenance of pumping systems; and information on the 4Rs as it relates to walnut production.

A 60-minute presentation was given on this project study design, results and an overview of nitrogen management practices in walnuts in Stockton on February 6, 2018. The San Joaquin County and Delta Coalition held the Continuing Education workshop that focused on walnut production including irrigation and nutrient management. Approximately 70 growers and crop advisors attended.
A 60-minute presentation was in a West Coast Nut magazine-sponsored webinar on nitrogen management in walnuts; time was devoted to promoting the walnut 4Rs brochure produced in this project. Approximately 100 individuals viewed the presentation. The event sponsor obtained Continuing Education credits for the webinar and more than half the viewers received 1 hour of credit.

In 2020, a publication and educational video series were developed for Central Valley walnut growers. The 4-page publication, titled 4Rs and Walnut Nitrogen Management, explains how to optimize walnut crop applications of nitrogen while minimizing leaching of excess nitrates. The publication explains the 4Rs: Right Rate, Right Time, Right Place and Right Source as it relates to walnut nitrogen management. This publication will be distributed at grower meetings or mailed by Central Valley Water Quality Coalitions. Also promoting it will be UC, CDFA and the Walnut Board of California. An order form was added to the CURES website at www.curesworks.org/walnuts/ to accommodate requests and distribution of the publication.

The educational video series, titled 4Rs and Walnut Nitrogen Management, was developed in collaboration with the UC and Walnut Board of California and consists of a 30-minute video for use in continuing education meetings or online courses. A 5-minute condensed version was also produced that highlights the key points of the 30-minute video. The shorter version is targeted to growers and crop advisors so they can watch quickly and see the key points on nitrogen management in walnuts while on-the-go. In the videos, CURES staff and UC Walnut Farm Advisor Katherine Jarvis-Shean, explain the science behind leaching of excess nitrates and gives tips and techniques that growers can use in the field to manage nitrogen. Both videos are posted on the CURES website at www.curesworks.org/best-management-practices/#agPubs. The 30-minute video is also posted on the Continuing Education website where growers who need credits for their Irrigation and Nitrogen Management Plan Self Certification can view online presentations. Online courses for numerous crops are posted at www.curesworks.org/cecourses/.

## K. References

Baram, S., V. Couvreur, T. Harter, M. Read, P.H. Brown, M. Kandelous, D.R. Smart, and J.W. Hopmans. 2016. Estimating Nitrate Leaching to Groundwater from Orchards: Comparing Crop Nitrogen Excess, Deep Vadose Zone Data-Driven Estimates, and HYDRUS Modeling. Vadose Zone Journal. 15. doi:10.2136/vzj2016.07.0061

DeJong, T, K. Pope, P. Brown, B. Lampinen, J. Hopmans, A. Fulton, R. Buchner, and J. Grant. 2014. Development of a nutrient budget approach and optimization of fertilizer management in walnut. Walnut Research Reports, California Walnut Board.

## L. <u>Appendix</u>

Not applicable

## M. Factsheet/Database Template

1. **Project Title:** Evaluation of the Multiple Benefits of Nitrogen Management Practices in Walnuts

2. **Grant Agreement Number:** 15-0360-SA

3. **Project Leaders:** Parry Klassen, Executive Director, CURES

4. **Start Year/End Year:** 2015/2020

5. **Location:** Ceres, California

6. **County:** Stanislaus

7. **Highlights:**

   - The amount of nitrate moving past the root zone was measured in two walnut orchards to evaluate different practices for nitrate management,

   - Results indicate that microsprinkler irrigation, as opposed to flooding, reduces the amount of nitrate moving past the root zone,

   - More frequent, and smaller applications of nitrogen fertilizer appear to reduce nitrate leaching when compared to less frequent, larger applications,

   - Leaching appears to be exacerbated by preferential flow paths that allow surface applications to move past the root zone quickly.

8. **Introduction:**

   Elevated concentrations of nitrate in Central Valley groundwater are attributed, in part, to inputs from farming. As a result, the Regional Water Board developed the Irrigated Lands Regulatory Program (ILRP), which contains requirements to reduce the leaching of nitrate to groundwater. In the Central Valley, approximately 33,000 landowners/operators must meet these requirements by implementing practices to protect groundwater from further contamination by nitrate.

   The effective management of fertilizer applications utilizes the four R's (right time, right place, right source, and right rate) for each crop. Very little is known about the four R's for most of the crops grown in the Central Valley. Although there has been research on nutrient management, this research often focuses on optimizing yields, which can lead to an over-application of nitrogen fertilizer. Heightened concern about groundwater quality has prompted new research into the management of nitrogen fertilizer with the dual goals of minimal leaching while maintaining crop health and yield.

The goal of this project was to identify the benefits of the different nitrogen management systems implemented in the two orchards, and to determine potential cost savings and groundwater protection benefits provided by each of these two management systems. The results are provided to walnut growers at outreach events, such as Field Days.

## 9. Methods/Management:

After locating a cooperator grower and discussing the cooperator's fertilization regime, which consisted of broadcast and fertigation with a combination of flood and microsprinkler irrigation, the cooperator's orchards were instrumented to measure soil volumetric water content and nitrate leaching at 4 feet. In 2017, 10 foot lysimeters were installed to measured nitrate leaching past the root zone. To guide fertilizer applications, tissue samples were collected to determine the amount of N in plant tissue. Harvest weights were recorded and the amount of nitrogen in the harvested material was measured.

After the first year of the project, the project team met with the cooperator prior to the second year of data collection. The cooperator changed fertilizer applications to fertigation and eliminated flood irrigation during the period of applications. The cooperator also changed from three to six applications on one orchard block. Also, the cooperator targeted 200 pounds per acre as sufficient fertilizer and used tissue samples to determine if fertilization was sufficient. After application of 150 pounds of synthetic fertilizer, the grower ceased fertilizing. However, accounting for the nitrate in his irrigation supply water indicates that the grower did apply approximately 200 pounds per acre.

## 10. Findings:

In these orchards there is a large amount of variation in nitrate leaching, even between monitoring locations that are relatively close to each other. It is possible that soil heterogeneity is influencing nitrate leaching in the orchards, and preferential flow paths within the orchards likely play an important role in determining nitrogen leaching. The mean nitrate concentration of water collected from the 10-foot lysimeters were significantly different between blocks (east, west and center). The mean nitrate concentration of water collected from the 4-foot lysimeters were significantly different between blocks (east, west and center) and years (2016 and 2017). When looking only at the 4-foot lysimeters in the east block in 2016 and 2017, we found no significant difference between the mean nitrate concentration.

## N. <u>Copy of the Product/Result</u>

Videos are posted on the CURES Best Management Practices website:
www.curesworks.org/best-management-practices/

Copies of products are included in the attached zipped file.

The zipped file includes:
- 2 field day flyers
- 4Rs and Walnut Nitrogen Management publication
- 4Rs and Walnut Nitrogen Management video script
- West Coast Nut Webinar Presentation Walnut Nitrogen Management (6/24/20)
- Delta Coalition CE Presentation on Walnut Nitrogen Management (2/6/18)
- Project Overview after First Year Results (4/26/17)