A. Project Information

Report type: Final Report

FREP grant number: #19-0953

Time covered by the grant period: 1/1/2020 - 12/31/2022

Project title: Achieving Efficient Nitrogen Fertilizer Management in California Wheat

Project leaders:
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B. Abstract

Wheat and other small grains are grown in diverse and highly variable agricultural environments throughout California. Efficient nitrogen (N) fertilizer management is difficult to achieve because the right rate varies from field-to-field and year-to-year. The goal of this project was to demonstrate and enable new ways of achieving best N management practices in California wheat and related winter cereals. Between the 2019-20 and 2021-22 cropping seasons, UC agronomists demonstrated the use of tools to optimize N management in wheat and other small grains on diverse commercial farms throughout California. The tools included an interactive website that provides customized, site-specific N fertilizer recommendations based on monitoring of crop health and soil N using handheld, drone, or satellite-based sensors and an in-field soil nitrate quick test. The tools and methods demonstrated increased crop productivity and farmer net income by optimizing N fertilizer applications. Recommendations resulted in an average yield increase of 28% when N deficiency was detected. In addition, when monitoring confirmed that crops were sufficient in N supply, growers saved an average of 50 lb/ac N compared to their typical N fertilizer rates. Overall, crops in the demonstration activities removed more N from the soil than was applied as fertilizer, indicating efficient N fertilizer management. The N fertilizer management practices demonstrated over the course of this project can help California farmers manage their N fertilizer more efficiently. Further adoption will improve economic outcomes and reduce N pollution in the state. Case studies detailing site specific management practices and outcomes by region can be found on the project website along with links to other project resources.

C. Introduction

Wheat and other small grains are grown in highly diverse agricultural environments throughout California. A large majority (more than 90%) of small grains are fall-sown and grown in interaction with Mediterranean precipitation patterns that vary dramatically across the state. Average rainfall totals less than 2 inches per year in the Imperial Valley and more than 23 inches per year in portions of the Sacramento Valley (PRISM, 2019). In addition to this geographic variability, California precipitation totals are uniquely variable between years, with recent historical examples of statewide precipitation varying from as little as 50% of average to over 200% of average within a few seasons (Dettinger and Cayan, 2014). Furthermore, increasing inter-annual precipitation extremes are expected as a result of climate change (Berg and Hall, 2015; Swain et al., 2018).

The interaction between precipitation variability and the diverse cropping systems that characterize California agriculture results in a wide range of productivity potential among farms and across years for wheat and other small grains (George and Lundy, 2019). As a result, nutrient and water management approaches for wheat vary dramatically both across the state and from grower to grower. Some systems are entirely rainfed, while others are supplementally irrigated and/or irrigated if necessary to avoid crop failure, and still others are fully irrigated with respect to estimated crop demand. Likewise, rates of N fertilizer applications vary from as little as 0 lb ac^{-1} yr^{-1} to over 300 lb ac^{-1} yr^{-1} (George & Lundy, 2019). Similarly, the temporal distribution of fertilizer application (i.e. pre-plant vs in-season) also varies widely from grower to grower and across regions. These conditions result in a wide range of fertilizer use efficiency, which makes it difficult to produce N fertilizer rate recommendations that are robust across seasons and among farms.

With increasing regulatory attention related to N management in the state of California, there is a need for improved N fertilizer management strategies and innovative tools that enable adaptive management and responsive farming. The broad geographic distribution of wheat, its integration as a rotation crop within a majority of cropping systems in the state, and the relatively inefficient use of N fertilizer in this crop argue for prioritization of related extension efforts.

This project sought to address this need by demonstrating measurement-based, site-specific N fertilizer management strategies across a wide range of small grain cropping systems in the state of California. To enable the communication and extension of this information, web-based decision support tools were developed to provide customized, site-specific N fertilizer recommendations based on real-time measurements of the crop and soil N status. In addition, the N management principles and related tools were communicated through a series of outreach events carried out over the course of the project, and outcomes of the demonstration efforts were documented via a series of case studies.

D. Objectives

1) Establish 14-16 field-scale demonstrations of the use of N reference zones in combination with site-specific measurements of the soil, plant and canopy environments to guide real-time N management decisions. Demonstration sites will be located in the Intermountain Region, Sacramento Valley, Delta Region, and the San Joaquin Valley.

2) Measure crop productivity and quality outcomes of management actions taken/not taken in response to real-time information. Compare agronomic efficiency, apparent fertilizer recovery efficiency, and economic performance in the alternative scenarios both within and across demonstration sites.

3) Host 9 field days at demonstration sites during the growing season to discuss the decision support framework in real-time, as it is being enacted.

4) Measure learning outcomes resulting from extension efforts via surveys conducted at live extension events and in follow-up emails.

5) Each demonstration site will produce a case-study documenting agronomic conditions, specific measurements, interpretations of measurements in the decision support framework, management responses, and the associated crop productivity/profitability outcomes. Case-studies will be compiled and made available on a UC website.

6) Develop generalized summaries and guidelines for implementing N rich reference strips, taking site-specific measurements, interpreting results, and making responsive farming decisions. Provide these summaries in both printed and web-based formats.

7) Beta-test, improve, and extend a dynamic, web-based decision support tool that provides customized information based on site- and time-specific environmental conditions and California-specific models of wheat growth and development.

8) Report analytics of California-specific web traffic related to new content, including changes in web traffic and geographic distribution over the course of the project.

E. Methods

Demonstration sites were established by project leaders on commercial farming operations during each of the three seasons of the project. Cooperating growers used relatively low pre-plant rates of N fertilizer and expressed interest in acquiring plant and soil monitoring information to support their in-season N fertilizer application decisions. N-rich reference zones were implemented by hand and/or in coordination with cooperating producers. The goal of the N-rich reference zone was to provide a point of comparison for the broader field, where N availability was high enough to ensure that crop growth was not N-limited in the reference zone (Raun et al, 2005). In general, N-

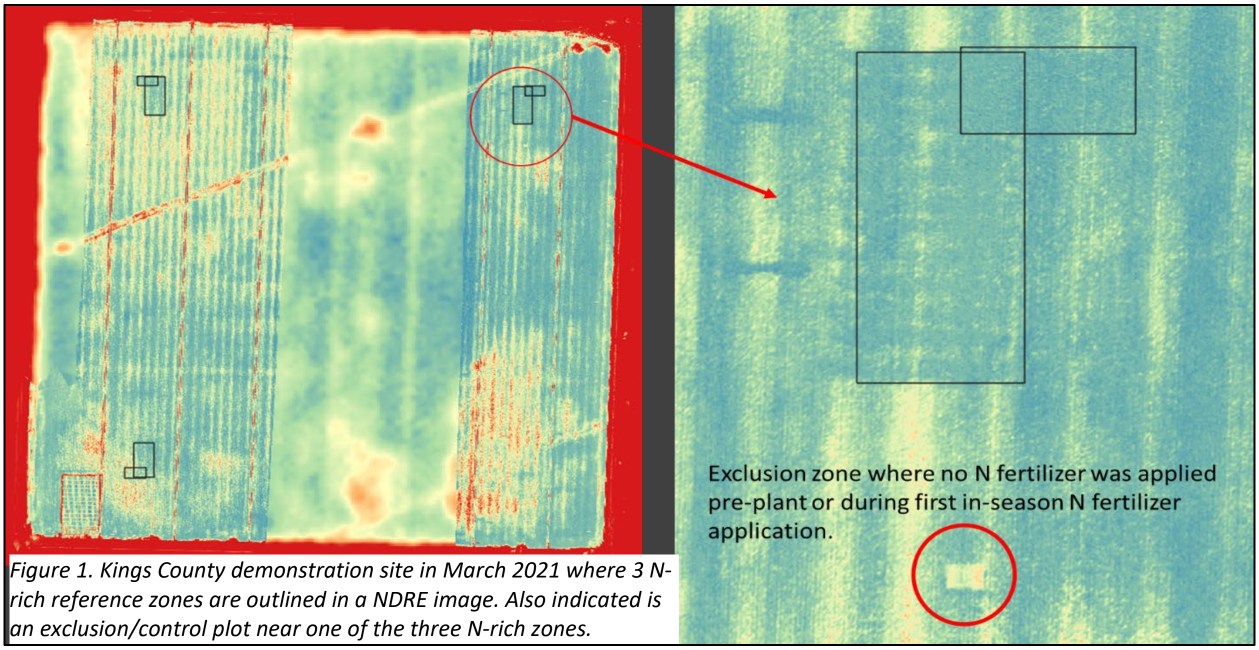

Figure 1. Kings County demonstration site in March 2021 where 3 N-rich reference zones are outlined in a NDRE image. Also indicated is an exclusion/control plot near one of the three N-rich zones.

rich zones were created using broadcast applications of urea at/near sowing and immediately prior to a significant rainfall (> 0.5”) or irrigation event.

At critical periods of decision making, project leaders recorded canopy reflectance measurements (using a combination of handheld devices and remote sensing platforms), soil nitrate-N in the top foot of the soil, and other agronomic observations of relevance. Measured values were applied to a decision support framework that indicated the likelihood and degree of plant response to subsequent fertilizer applications based on the in-field measurements and the related agronomic context. Project leaders communicated fertilizer recommendations to participating growers. When possible, the alternative to the cooperating grower’s management action (either applying N fertilizer when the grower applied none or excluding fertilizer when the grower decided to apply) was enacted to measure the effect of the management decision and the accuracy of the in-season fertilizer recommendation (see Figure 1). At the end of the season, representative grain samples were harvested from subplots in each of the management scenarios enacted at the demonstration sites.

Extension events were conducted during the project and learning outcomes were assesses after outreach activities for a subset of events. Participants were asked to rate their knowledge and behavior related to project concepts and tools prior to and as a result of the program. In addition to measurement of learning outcomes, utilization of decision support web-tools was also measured across the project period via web-analytic software.

F. Results

Agronomic Outcomes

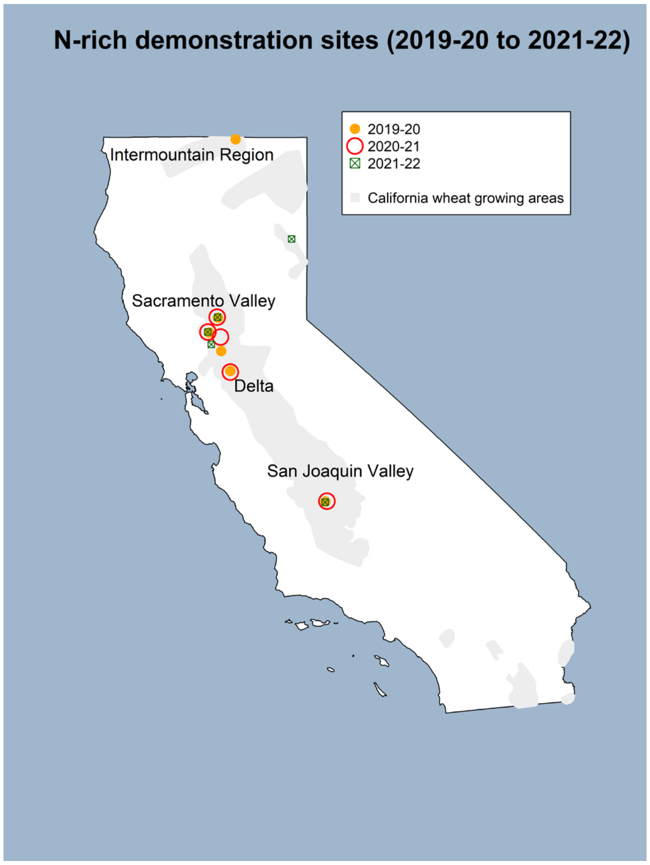

Figure 2. Illustrates locations of demonstration sites established over the course of the project in various California regions.

Sixteen field-scale demonstrations were completed between the 2019-21 and 2021-22 seasons. Demonstration sites included 8 fields in the Sacramento Valley, 3 fields in the San Joaquin Valley, 3 fields in the Intermountain region of Northern California, and 2 in the Delta region (Figure 2). Fields included highly productive, irrigated locations with grain yields as high as 9000 lb/ac. They also included low productivity, rainfed locations with yields as low as 1500 lb/ac. Each site had between one and four 90-ft by 180-ft N-rich reference zones that were established in representative areas of the field at or near the time of planting. N fertilizer rates in these zones were 2-3 times the amount of expected crop N uptake from planting until the start of in-season plant and soil monitoring.

From the tillering stage of growth to the heading stage of growth, project leaders measured canopy reflectance (i.e. NDVI/NDRE) both within N-rich reference zone(s) and in the broader field and also measured soil nitrate-N in the top foot of soil using quick tests. Measurements were made prior to participating growers' fertilizer management decisions. N fertilizer recommendations were produced using a combination of the site-specific measurements and the expected crop N demand remaining for the field via a customized decision support tool. When no deficiency was detected, monitoring continued until either deficiency was detected or the grower decided to apply N fertilizer in-season. When possible, the alternative to the cooperating grower's management action (either applying N fertilizer when the grower applied none or excluding fertilizer when the grower decided to apply) was enacted to measure the effect of the management decision and the accuracy of the in-season fertilizer recommendation. Alternative N management scenarios were implemented at 10 of the 16 locations. When the crops reached maturity, yields and crop N uptake were measured within the main field, the N-rich reference zones, and the alternative management zones (when applicable).

Table 1. Indicates whether in-season N fertilizer was recommended, the rate of N fertilizer applied, and the resulting changes in yield at sites where alternative management plots permitted comparison ("-" indicates that the effect was not measured).

Location	In-season N recommended	In-season N applied (lb/ac)	Yield change (compared to control, lb/ac)	Total N Applied (lb/ac)	Total N Uptake (lb/ac)
Solano 2019-20	N	0	no change	0	97
Yolo 2019-20	Y	50	-	76	30
Siskiyou 2019-20	Y	200	+ 3672 (75%)	200	181
Colusa 2019-20	Y	46	+844 (15%)	106	156
Kings 2019-20	Y	61	-	209	161
Sacramento 2019-20	N	0	-	60	148
Yolo 2020-21 (irrigated)	Y	50	+1119 (26%)	50	115
Yolo 2020-21 (rainfed)	N	0	no change	74	58
Colusa 2020-21	N	0	-	60	146
Kings 2020-21	Y	140	+ 1088 (14%)	140	177
Sacramento 2020-21	N	0	no change	60	163
Yolo 2021-22 (rainfed)	N	60	no change	110	41
Yolo 2021-22 (irrigated)	Y	30	-	139	130
Kings 2021-22	Y	80	-	210	164
Lassen 2021-22 (forage)	Y	92	+ 3548 (29%)	98	129
Lassen 2022 (barley)	Y	40	+ 604 (15%)	46	127

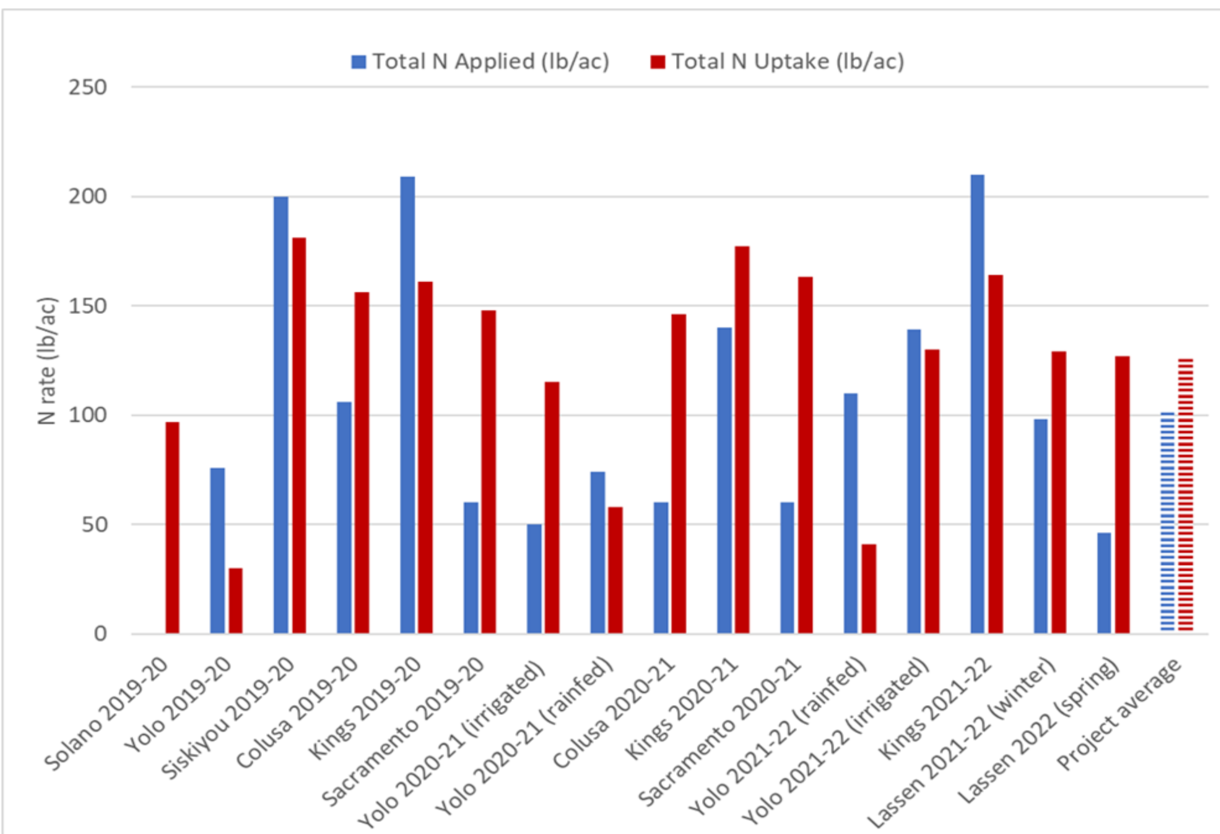

Figure 3. Crops at the demonstration sites removed 24 lb/ac more N than was applied as fertilizer for an average applied/removed ratio ≈ 0.80 (N fertilizer applied ≈ 80% of N fertilizer removed).

In-season monitoring of the plant and soil resulted in a wide range of measurements, N fertilizer recommendations, and outcomes (Table 1). Based on site-specific, real-time measurements, [The Nitrogen Management Tool for California Wheat] produced a targeted recommendation. Overall, in-season N fertilizer applications were recommended at 10 of the 16 sites and were not recommended at 6 of the sites. When in-season N fertilizer applications were recommended, they resulted in an average yield increase of 28% (~1500 lb/ac) compared to an in-field control ($p = 0.01$, $n = 6$). When monitoring indicated that crop response to N fertilization was unlikely and no fertilizer application was recommended, yields were equal to the control ($p = 0.80$, $n = 4$). In addition, these growers saved an average of 50 lb/ac N compared to their typical N fertilizer rates, which translated to savings of ~$40/ac in fertilizer costs. Overall, crops at the demonstration sites removed 24 lb/ac more N than was applied as fertilizer for an average applied/removed ratio of 81% (Figure 3). These outcomes, measured over three seasons and across a wide range of California small grain agroecosystems, illustrate that efficient N fertilizer management can be achieved by combining plant and soil monitoring with site- and time-specific decision support information.

Figure 4. Screen shot of project website on the UC Small Grains Research and Information Center, where case studies, how-to articles, videos and links to web-tools related to the use of N-rich reference zones for N fertilizer management can be found.

Outreach products and learning outcomes

In addition to the agronomic outcomes recorded at the demonstration sites, a diverse set of outreach materials and educational outcomes were produced throughout the course of the project. These include a devoted University of California webpage containing information about the project and links to related resources (Figure 4). Among these resources are case studies that provide a full-season agronomic overview for the demonstration sites, blog posts and articles that describe important considerations for implementing and measuring N-rich reference zones, and videos illustrating and discussing demonstration outcomes. In addition, interactive decision support web-tools were developed during the course of this project along with videos describing how to use these web-tools. The tools provide customized, site-specific fertilizer recommendations and help to convert measurements from an in-field soil nitrate quick test to a N fertilizer equivalent based on site-specific soil parameters.

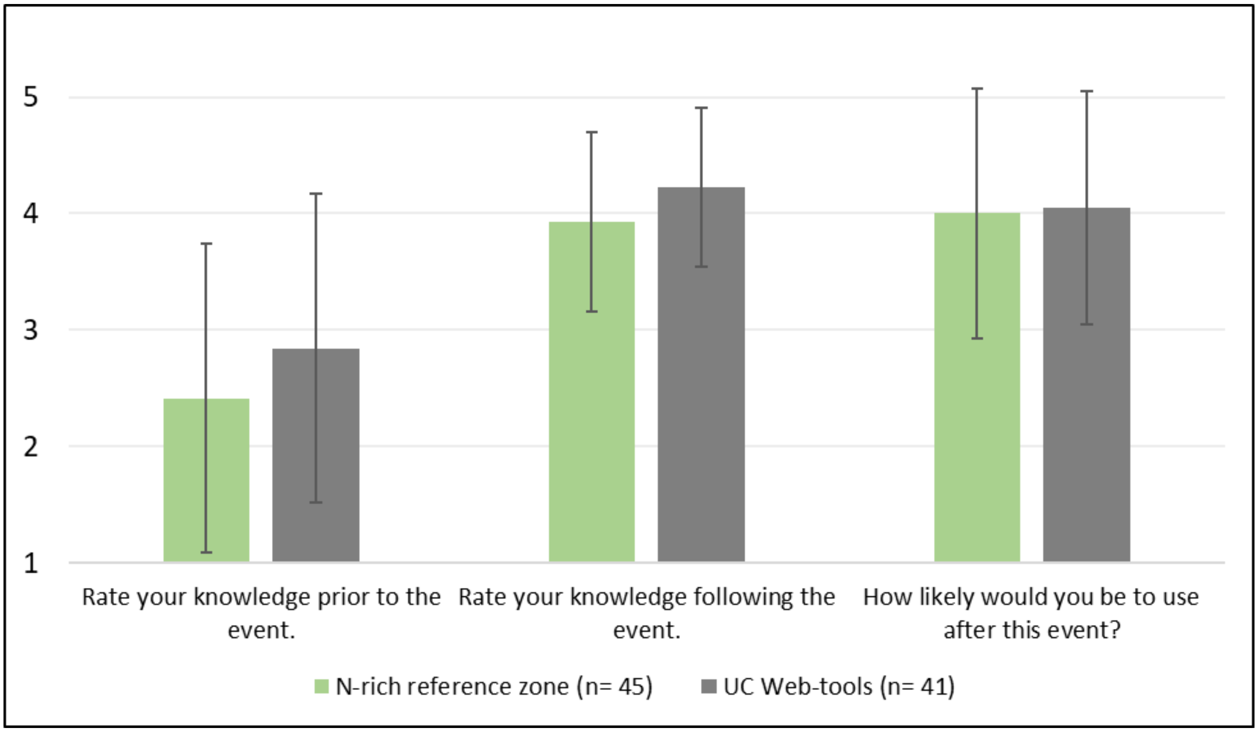

Figure 2. Change in knowledge and likelihood of adoption recorded after outreach events explaining N-rich methods and tools (1 = none/not likely; 5 = high/very likely). Error bars represent the standard deviation for the sample.

Overall, information about the N-rich demonstration activities was presented in a range of extension settings, including six events hosted by project leaders. At five of these events, surveys were used to evaluate efficacy of the educational content. Based on ratings from a subset of attendees at these events (n=45), knowledge of the project concepts and associated tools increased, and attendees were more likely to use N-rich reference zones and associated UC tools as a result of the information presented at these events (Figure 5). In addition, case studies were identified as an effective method for learning about the tools and methods demonstrated by this project.

Web tool development

Two web-tools were released during the course of the project related to the demonstration of measurement-based, site-specific N fertilizer management strategies. The Soil Nitrate Quick Test Web-Tool and The Nitrogen Fertilizer Management Tool for California Wheat were made available on the web on 5/13/20 and 1/28/21, respectively. The tools were incrementally improved for usability and interpretability throughout the period of the grant. Comments and suggestions for revisions by project leaders and cooperators were solicited and implemented throughout the project. These efforts included multiple group meetings with the project team as well as individual meetings with collaborating growers and crop consultants. In addition to the web-tools themselves, a series of how to-videos were created that were specific to the use of the decision support web-tools. These were in addition to how-to videos created for conducting in-field soil nitrate quick tests (both in English and Spanish).

Project-related webpages and web-tools were viewed more than 14,200 times, resulting in over 880 hours of engagement with project content during the project period. Approximately 516 unique California-based users accounted for 74% of the total views of the web-tools and these interactive sites accounted for 42% of the overall content engagement. Project resources available on the project webpage and related portions of the UC Small Grains Research & Information Center websites (e.g. blog posts and case studies) accounted for 48% of the overall content engagement, while project videos accounted for 10% of user engagement.

G. Discussion and Conclusions

Overall, this project successfully met both its agronomic and outreach objectives. The project team carried out the targeted number of demonstration sites in diverse California agroecosystems (Objective 1, Figure 2). Cropping systems outcomes were measured at these locations, and sufficient controls were enacted to determine the efficacy of the decision support systems being demonstrated (Objective 2, Table 1). As is the case in this cropping system more broadly, the fields in this demonstration had highly variable demands for N. Crop and soil monitoring indicated that 62% of fields were likely to respond to in-season applications of N fertilizer, while 38% were unlikely to respond. Growers behavior was typically in-line with the recommendations provided by the decision support systems being demonstrated, and, while there was variability from field-to-field and year-to-year, overall more N was removed from the demonstration fields than applied as N fertilizer (Figure 3). Therefore, the primary agronomic objective of achieving efficient N fertilizer management was accomplished at the demonstration sites.

In addition to the agronomic objectives, the outreach objectives were largely achieved during the course of the project. The COVID-19 pandemic reduced the number of in-person field days held at the demonstration sites (Objective 3). In the end, the project team conducted a combination of virtual and in-person events as social distancing requirements permitted. Across the project period project leaders hosted six events and presented project details in a number of other forums during the project period (see section J, below). Learning outcomes were measured at a subset of these events (Objective 4), and reflected positively on the value of the educational content (Figure 5). Furthermore, the demonstration activities resulted in the production of fifteen 2-page case studies (Objective 5) documented site-specific conditions, practices and outcomes. This format was also used to illustrate the decision support system at outreach events and in a "field day video" produced during the time when social distancing restrictions prevented in-person, public meetings. Feedback received from clientele in a post-event survey indicated that the case study format was an effective method for teaching/learning about the demonstrated practices. The wide array of written and video content produced and made available during the project (Objective 6) as well as the innovative, interactive web-tools released and refined during the project (Objective 7), resulted in broad engagement from a widespread audience comprised primarily of California-based users (Objective 8). In all, the outreach efforts conducted during the project built momentum for further outreach and extension activities that are continuing beyond the project period.

H. Challenges

One of the objectives for the project was to host field days each year at a subset of the demonstration sites. These were proposed as a way to facilitate farmer-to-farmer learning and measure learning outcomes resulting from outreach efforts. Social distancing requirements during the COVID-19 pandemic required adjustments to the outreach plan. No events were held during the first year of the demonstration activities. In subsequent years, broader public events were replaced with small group meetings with growers and cooperators as social distancing allowed. The project team also conducted virtual events via webinar where continuing education credits were offered. By the third season, live events were possible, and two field days took place at demonstration sites. Aside from these live events, during 2021 the project team also produced a "field day video" at the Kings county site as a replacement for an in-person field day. The video discusses the principals and methods for using N rich reference zones as well as the outcomes at the site and was published on the project website ahead of the 2021-22 season.

Even though the project was largely successful in meeting its objectives, there were several obstacles and limitations encountered that provide lessons about how to focus future efforts. One of these was related to the methods for establishing the N-rich reference zones. Some cooperators felt that creating the N-rich reference zone by hand was not practical/desirable for the scale of their operations. As a result, cooperators experimented with establishing reference zones using tractors or airplanes. Some of these methods were effective, but not all of them. In addition, the size of the zone necessary depended on the tool being used to measure crop canopy reflectance. Satellite imagery was used most frequently to monitor canopy reflectance in the project, but this method required larger N-rich reference zones than those required for handheld devices or drones. As a result, further innovation and extension around methods and principles for establishing N-rich zones could improve adoption.

In addition, several collaborators reported that they valued access to recent, ad-hoc satellite imagery as well as the N-rich specific information derived from the imagery. However, collaborator access to pinpointed satellite imagery and their ability to derive necessary values from it was somewhat limited. Therefore, innovation and extension around this need is warranted and could help to make the tools demonstrated in this project useful to a larger group of growers and crop consultants. On a related note, one of the handheld devices used to measure crop canopy reflectance (Greenseeker handheld NDVI meter) was out of stock during a portion of the project. This was partly related to supply-chain issues associated with the global pandemic (the devices are available once again). But, as with the satellite imagery, this occurrence highlighted that access to the measurement technology underpinning the decision support tools demonstrated is critical for the usefulness of the methods demonstrated by this project. As such, streamlined access to customized, site- and time-specific canopy reflectance measurements may still be a barrier for the adoption and expansion of these methods.

Aside from these needs, a subset of collaborating growers expressed interest in using the decision support tools in ways for which they were not specifically developed. These included for forage-related outcomes (rather than grain), in interaction with organic amendments like compost and manure, and for use with multiple in-season fertilizer events (instead of a single in-season event). In addition, there was interest in utilizing measurements of plant tissue N concentrations in concert with the web-based decision support framework, which is currently structured around crop canopy reflectance measures. As a result, all of the aforementioned are potential directions for further research and development of the methods and approaches demonstrated by this project.

I. Project Impacts

This project successfully demonstrated how to implement N-rich reference zones in production fields throughout California while simultaneously developing new tools to interpret real-time plant and soil measurements and determine whether and how much N fertilizer to apply in-season. These activities resulted in fertilizer savings in some instances, increased crop productivity in others, and efficient aggregate N fertilizer use across the demonstration sites. In addition, the project team developed a wide range of outreach products that will continue to improve N fertilizer management in the state. These include interactive web-tools, case studies detailing site specific management practices and outcomes by region, and other information resources, which can all be found on the project website.

Whether from gains in crop productivity or savings in fertilizer use, both the farmer and the environment benefit from the demonstrated practices. One of the most important decisions farmers make is how much fertilizer to apply and when to apply it. Particularly for N fertilizers, matching fertilizer supply to crop demand can optimize both economic and environmental outcomes. However, because there is so much variability in environmental conditions among farm fields and across seasons, this can be very difficult to achieve. The N fertilizer management practices demonstrated over the course of this project are helping California farmers manage their N fertilizer more efficiently. Further adoption will improve economic outcomes and reduce N pollution in the state.

In addition to these broader impacts, the following products and outcomes resulted from the project:

Acres and growers impacted:
- 8 California small grain producers directly engaged
- 1800 acres directly impacted

UC Websites:
- N-rich reference zones for in-season N fertilizer management, UC Small Grains RIC
- Soil nitrate quick test, UC Small Grains RIC

UC Web-tools:
- Nitrogen Fertilizer Management Tool for California Wheat, UC Small Grains RIC
- Soil Nitrate Quick Test Web-Tool, UC Small Grains RIC

Web usage:
- More than 14,200 views of project-related webpages and web-tools and 880 hours of engagement with project content during the project period. Approximately 516 unique California-based users accounted for 74% of the total views of the web-tools.

Outreach Publications:
- New Tools to Improve N Management in California Small Grain Crops
- New resources available for conducting and interpreting soil nitrate quick tests
- Implementing N-Rich Reference Zones to Inform In-Season N Fertilization Practices
- Hand-held electronic devices help you make better nitrogen fertilizer decisions
- Using N-Rich Reference Zones to Inform In-Season Nitrogen Fertilization Practices in California Small Grains
- N-Rich Reference Zone Case Study: Lassen County (winter) 2021-22
- N-Rich Reference Zone Case Study: Lassen County (spring) 2021-22
- N-Rich Reference Zone Case Study: Kings County 2021-22
- N-Rich Reference Zone Case Study: Yolo County 2021-22
- N-Rich Reference Zone Case Study: Yolo County (irrigated) 2020-21
- N-Rich Reference Zone Case Study: Yolo County (rainfed) 2020-21
- N-Rich Reference Zone Case Study: Sacramento County 2020-21
- N-Rich Reference Zone Case Study: Kings County 2020-21
- N-Rich Reference Zone Case Study: Colusa County 2020-21
- N-Rich Reference Zone Case Study: Solano County 2019-20
- N-Rich Reference Zone Case Study: Yolo County 2019-20
- N-Rich Reference Zone Case Study: Sacramento County 2019-20
- N-Rich Reference Zone Case Study: Kings County 2019-20
- N-Rich Reference Zone Case Study: Colusa County 2019-20
- N-Rich Reference Zone Case Study: Siskiyou County 2020

Videos:

- New Tools to Improve Nitrogen Management in California Small Grain Crops
- N-Rich Reference Zones Virtual Field Day (Kings County, 2021-21)
- In-field Soil Nitrate Quick Test: California Grain Production
- Test rápido de nitratos en suelo (doblaje en español)
- How to use: The Nitrogen Fertilizer Management Tool for California Wheat (Beta), Part 1 of 2
- How to use: The Nitrogen Fertilizer Management Tool for California Wheat (Beta), Part 2 of 2
- How to use: The Soil Nitrate Quick Test Web-Tool

Newsletters:

- *Nitrogen Fertilizer Management in Wheat* in San Joaquin County Field Notes, May 2020 and SJC and Delta Field Crops Blog, 4/30/2020.
- *Using N-Rich Reference Zones in Wheat to Guide Fertilizer Management* in San Joaquin County Field Notes, November 2021 and SJC and Delta Field Crops Blog, 11/8/2021.
- *Achieving Efficient Nitrogen Fertilizer Management in California Wheat* in Sacramento Valley Field Crops Newsletter, Issue 6 July, 2020.

Media Coverage:

- Test zones show farmers grain crops' fertilizer needs. Johnson, B. 7/22/2020.
- Software allows wheat farmers to streamline soil tests. Johnson, B. 2/17/2021.
- UC advisor reviews handheld nutrient meters. Johnson, B. 3/3/2021.
- Triticale, wheat farmers get help with new UC software. Johnson, B. 10/20/2021.
- New UC software helps wheat growers on fertilizing. Johnson, B. 10/27/2021.
- New 'big data' tools help California wheat farmers reduce fertilizer guesswork. Hsu, M. 10/28/2021.

Conference presentations:

- Light, S. et al. Remote Education and Demonstrations of Advanced Nitrogen Management Tools for Small Grains Growers in California. ASA, CSSA, SSSA International Annual Meeting, Salt Lake City, UT: Nov 7 -10, 2021 (oral).
- Lundy, M. et al. Achieving Efficient Nitrogen Fertilizer Management in California Wheat. 2022 FREP/WPH Nutrient Management Conference, Visalia, CA: Oct. 26-27, 2022 (oral).

J. Outreach Activities Summary

Trainings/outreach events:

- Demonstrating Efficient N Fertilizer Management in Practices in California Wheat (on-farm field day); Yolo County, 4/28/22; Agenda; 2 CEUs; 18 participants (farmers, farm managers, crop consultants, researchers); Survey responses (n=13) indicated 54% overall increase in knowledge about presentation topics and 'very likely' to use information/tools in the future.

- Demonstrating Efficient N Fertilizer Management in Practices in California Wheat (on-farm field day); Kings County, 4/20/22; Agenda; 2 CEUs; 11 participants (farmers, farm managers, crop consultants, researchers); Survey responses (n=2) indicated 11% overall increase in knowledge about presentation topics and 'very likely' to use information/tools in the future.
- *Demonstrating Efficient N Fertilizer Management in CA Small Grains* at 2022 UC Davis Small Grains and Alfalfa/Forages Field Day; Yolo County, 5/17/2022; Agenda; 2 CEUs; 92 participants (farmers, farm managers, crop consultants, researchers); No survey conducted; follow up communications indicated that event successfully introduced concepts to new individuals involved in California agricultural management.
- Using N-rich Reference Zones to Guide N Management in California Small Grains (webinar); 11/4/2021; Agenda; 2 CEUs; 24 participants (farmers, farm managers, crop consultants, researchers); Survey responses (n=4) indicated 52% overall increase in knowledge about presentation topics and 'very likely' to use information/tools in the future.
- UC Collaborators Meeting: N-rich Reference Zones in California Small Grains; 7/22/2021 & 8/26/2021; Agenda; 14 participants (farmers, farm managers)'; Survey responses (n=2) indicated 54% overall increase in knowledge about presentation topics and 'likely' to use information/tools in the future.
- *Using N-rich Reference Zones to Guide N Management in California Small Grains* at Nitrogen Management in Annual Cropping Systems, Colusa Glenn Subwatershed Workshop; 12/13/2021.
- *Using N-rich Reference Zones to Guide N Management in California Small Grains* at Delta Grains Field Meeting; 9/30/2021; Agenda; 1 CEU; 15 participants
- *Nitrogen Management Tools and Research Updates*. Webinar UC Cooperative Extension Sacramento, Solano, and Yolo Counties; 9/29/2021; Agenda; 1 CEU
- *Using N-rich Reference Zones to Guide N Fertilizer Management* at 2021 University of California Small Grains - Alfalfa/Forages Virtual Field Day (webinar); 5/12/2021; Agenda; 1 CEU; 112 participants (farmers, farm managers, crop consultants, researchers); Survey responses (n=26) indicated 38% overall increase in knowledge about presentation topics and 'likely' to use information/tools in the future.
- *Nitrogen Management in California Small Grains* at Golden State Grains Seminar Series (webinar); 11/6/2020, Agenda; 58 participants (farmers, farm managers, crop consultants, researchers)

K. References

Dettinger, M., & Cayan, D. R. (2014). Drought and the California delta—A matter of extremes. *San Francisco Estuary and Watershed Science*, 12(2).

George, N., & Lundy, M. (2019). Quantifying genotype× environment effects in long-term common wheat yield trials from an agroecologically diverse production region. *Crop Science, 59(5)*, 1960-1972.

M. Factsheet/Database Template

Project Title: Achieving Efficient Nitrogen Fertilizer Management in California Wheat

Grant Agreement Number: #19-0953

Start Year/End Year: 1/1/2020 - 12/31/2022

Project Leaders:

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Sarah Light, Agronomy Farm Advisor, UCCE Sutter-Yuba
Konrad Mathesius, Farm Advisor, UCCE Yolo County

Location/Counties: Yolo, Colusa, Solano, Sacramento, Kings, Lassen, and Siskiyou

Highlights:

- Demonstrated the use of N-rich reference zones, plant and soil measurements, and UC web-tools at 16 commercial farms across 3 seasons.
- Growers using the demonstrated practices achieved efficient N fertilizer management, increased crop productivity and saved N fertilizer.
- Multiple outreach events educated about these N management practices, and attendees indicated that the educational content was effective.
- Resources such as articles and videos summarizing aspects of the practices and case studies detailing outcomes from efforts were produced.

Introduction:

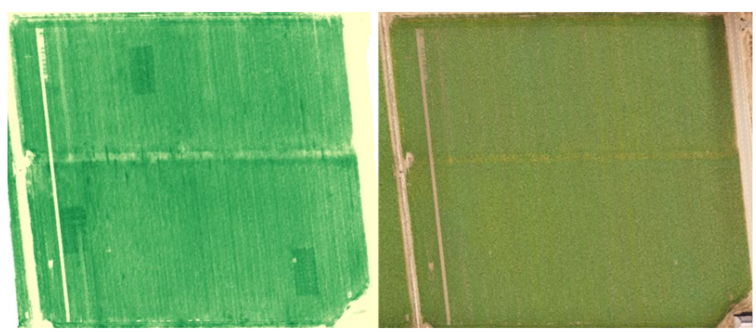

Figure 3. Demonstration site showing crop N deficiency signal. The three N-rich reference zones appear in the NDRE measurement (on the left) but are not visible to the naked eye (RGB image on the right).

Wheat and other small grains are grown in diverse agricultural environments throughout California. Approximately 90% of the wheat, triticale and barley in California is fall-sown and relies to some degree on precipitation that varies dramatically across the state. These conditions make efficient nitrogen (N) fertilizer management difficult because the right rate varies from field-to-field and year-to-year. Therefore, the goal of this project was to demonstrate and enable new ways of achieving best N management practices in California wheat and related winter cereals.

Methods/Management:

Between 2019-20 and 2021-22 UC agronomists demonstrated the use of tools to optimize N management in wheat and other small grains on commercial farms across diverse California environments and management systems. The tools included an interactive website that provides customized, site-specific N fertilizer recommendations. These recommendations are based on monitoring of crop health and soil N using handheld, drone, or satellite-based sensors and an in-field soil nitrate quick test. The tools demonstrated increased crop productivity and farmer net income by optimizing N fertilizer applications.

Findings:

In-season crop and soil monitoring were central to this project. The Nitrogen Fertilizer Management Tool for California Wheat uses crop monitoring information to produce a targeted in-season N fertilizer recommendation. Recommendations resulted in an average yield increase of 28% when N deficiency was detected. In addition, when monitoring confirmed that crops were sufficient in N supply, growers saved an average of 50 lb/ac N compared to their typical N fertilizer rates. Overall, crops in the demonstration activities removed more N from the soil than was applied as fertilizer, indicating efficient N fertilizer management.

In addition to the agronomic outcomes recorded at the demonstration sites, a diverse set of outreach materials and educational outcomes were produced throughout the course of the project. These include a devoted University of California webpage containing information about the project and links to related resources. Among these are case studies that provide a full-season agronomic overview for the demonstration sites, blog posts and articles that describe important considerations for implementing and measuring N-rich reference zones, and videos illustrating and discussing demonstration outcomes. Information about the N-rich demonstration activities was presented at a range of forums, including six events hosted by project leaders. At five of these events, surveys were used to evaluate efficacy of the educational content. Based on ratings from a subset of attendees at these events (n=45), knowledge of the project concepts and associated tools increased, and attendees were more likely to use N-rich reference zones and associated UC tools as a result of the information presented.

Whether from gains in crop productivity or savings in fertilizer use, both the farmer and the environment benefit from the demonstrated practices. One of the most important decisions farmers make is how much fertilizer to apply and when to apply it. Particularly for N fertilizers, matching fertilizer supply to crop demand can optimize both economic and environmental outcomes. However, because there is so much variability in environmental conditions among farm fields and across seasons, this can be very difficult to achieve.

The N fertilizer management practices demonstrated over the course of this project can help California farmers manage their N fertilizer more efficiently. Further adoption will improve economic outcomes and reduce N pollution in the state. Case studies detailing site specific management practices and outcomes by region can be found on the project website along with links to other project resources.