IMPROVED SMALL GRAIN NITROGEN USE EFFICIENCY WITH CALIFORNIA SITE-SPECIFIC DECISION SUPPORT

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ABSTRACT

California (CA) small grains cover approximately 500,000 acres annually and are generally fall-sown and grown during the winter months when most precipitation occurs. Highly variable precipitation and irrigation patterns across CA plus more recent fertilizer nitrogen (N) price volatility makes determining fertilizer N application recommendations particularly challenging. With a goal to improve N use efficiency (NUE) in CA small grains, our objectives were to 1) establish field-scale improved NUE demonstration sites, 2) host field days to view and discuss results of new decision support tools, 3) measure learning outcomes among participants, 4) and measure crop productivity as a result of improved NUE methods. We established 16 field-scale demonstration sites over three growing seasons starting in 2019. We hosted six field day events, four being held virtually due to COVID-19 restrictions. Participants at these education events (n = 42) indicated they had increased knowledge about using improved NUE practices and were likely to use these methods. Crop outcomes were measured, and when in-season N fertilizer applications were recommended, there was an average yield increase of 28% (~1500 lb/ac) (p = 0.01, n = 6). Yield increase at these sites ranged from 14%, or 1,088 lb grain/ac, to 75%, or 3,672 lb grain/ac. When no fertilizer application was recommended, yields in the grower field were equal to the control (p = 0.80, n = 4).

INTRODUCTION

Small grains are grown throughout the state of California (CA) on approximately 500,000 acres annually. They are generally fall-sown and grown during the winter months when most precipitation occurs. However, because precipitation and irrigation patterns and timing vary across the geography of CA, there is a strong interaction between total water and plant available nitrogen (N). Determining fertilizer N application recommendations is particularly challenging in this cropping system.

Recently, fertilizer price volatility, irregular access to water for irrigation, and increasingly strict regulatory orders for protecting groundwater from leached nitrate have all made N use efficiency (NUE) improvement in CA small grains an increasingly urgent matter. One of the biggest improvements growers can make is to shift the majority of their N fertilizer application budget to an in-season application as opposed to applying all of it pre-plant. To do this, growers and crop consultants engaged in N fertilizer management applications must be able to navigate and evaluate several variables strongly influencing NUE in small grains. Considering all the variables involved, this must be done on a field-by-field and year-by-year basis. To address the need to improve NUE in CA small grain production, a multifaceted method for determining site-specific fertilizer N application is needed. This method and an associated decision support tool were utilized at 16 commercial farm demonstration sites over the course of three growing seasons between 2019 and 2022, in cooperation with farmers and crop consultants.

METHODS

Our objectives in this demonstration project were to 1) establish field-scale improved NUE demonstration sites, 2) host field days to view and discuss the results of using new decision support tools, 3) measure learning outcomes among participants, and 4) measure crop productivity as a result of using improved NUE methods.

Establishing sites

Between 2019 and 2022, we implemented a total of 16 demonstrations of improved small grain NUE practices on commercial farms spanning the northern CA intermountain region (3 sites), the Sacramento Valley (8 sites), the Delta region (2 sites), and the San Joaquin Valley (3 sites). At each of these sites, one to four replications of N-rich reference zones (NRZ) were established to serve as *in situ* positive controls for plant nitrogen status within the growing season. These NRZs were created by applying a known quantity of N fertilizer near planting time in multiple plots chosen to represent the variability of the given demonstration field (https://tinyurl.com/NRZdemos). Collaborating growers were asked to commit to adjusting their N fertilizer plans to accommodate shifting at least 50% of their planned seasonal N fertilizer budget to one or more in-season applications. Growers were then asked to maintain all other typical farming practices for the given fields.

The soil and plant N status was repeatedly measured to inform a decision support model using a web-based user interface with the purpose of generating site-specific N fertilizer recommendations which we call the "Nitrogen Fertilizer Management Tool for California Wheat" or Nitrogen Fertilizer Web Tool for short (https://tinyurl.com/WebTooldemo). Additional common crop management and environmental variable information were also collected to inform this model. Measurements of pre-plant soil nitrate were conducted using a unique quick test method with water quality testing strips (https://tinyurl.com/SNQTdemo). When site teams observed opportunities for in-season N fertilizer application approaching, plant N status was measured using canopy reflectance. Measurements were made using various hand-held (https://tinyurl.com/Devicesdemo) and aerial devices to determine common indices such as normalized difference vegetation index (NDVI) and normalized difference red edge (NDRE). These measurements were made in the NRZs as well as in the adjacent parts of the field area, and the quotient of the reflectance in the normal grower practice area divided by the NRZ area was used to generate a plant N sufficiency index. Previous empirical research (Lundy, et al. 2017) determined plant and soil sufficiency thresholds indicating the degree of crop N deficiency and likelihood of response to applied N fertilizer.

Methods described above for soil and plant N status measurement were repeated throughout the growing season at the demonstration sites at each opportunity to apply N fertilizer. When soil and plant N status were determined, this information along with management and environment information including planting date, crop variety, site location, crop growth stage, N fertilizer management, irrigation management, and yield and protein estimates were entered into the Nitrogen Fertilizer Web Tool to help generate a site-specific N fertilizer recommendation. These recommendations were vetted with the site teams then shared with the grower with the goal of informing their N fertilizer application decisions.

Field days and educational events

Due to in-person meetings and travel restrictions imposed during peaks in the COVID-19 pandemic, no field days were held in the first year. In the second and third years, we held small in-person gatherings as well as hosted webinars to disseminate the outcomes of the demonstrations. At these events, we presented current results from the ongoing demonstration sites. These results focused on soil and plant status measurements, fertilizer N management decision-making, and crop productivity outcomes. We also took time to refine teaching on the methods critical to this improved NUE decision support system through hands-on demonstrations, lecture presentations, and provisioning web-based resources for further information. Finally, we facilitated discussion among farmers and crop consultants to elicit feedback about what worked, what failed, and what would be pertinent to explore further or try differently.

Measuring learning outcomes

At five of the live events we hosted, we disseminated surveys to participants asking about what they had learned and which practices they intended to use in the future. We asked participants to rate their level of knowledge prior to and after the event about soil N testing, plant N status measuring, how to use the Nitrogen Fertilizer Web Tool, and how to deploy N-rich reference zones. We also asked about their likelihood to use the above practices in their small grain N management decisions after participating in our events. Finally, we asked about their need for further training in any of the above practices. Surveys were provided either on-paper or electronically depending on the nature of the event. In all, 45 participants answered questions pertaining to NRZs and associated methods and 41 participants answered questions about the Nitrogen Fertilizer Web Tool.

Measuring crop outcomes

At 10 of the 16 demonstration sites, site teams implemented alternative management zones to demonstrate the effect of the grower's fertilizer N decision. That is, if a grower decided not to fertilize with N, we added a small plot of N fertilizer and vice versa. At the end of each crop season, we hand-harvested representative sub-plots within the NRZs, the broader grower-managed fields, and any alternative management zones implemented within the season. Yield and N content were measured to estimate grain protein and total N uptake by the crop. Grower-reported yields for the whole field were then used to normalize and calibrate the hand-harvested yield estimates.

RESULTS AND DISCUSSION

Learning and behavior outcomes

Participants in the education events we hosted indicated an average increase in knowledge about NRZs and associated methods (n = 45) as well as about the Nitrogen Fertilizer Web Tool (n = 41). After the events, participants stated their knowledge level about NRZs and associated methods increased from 2.4 ± 1.3 to 3.9 ± 0.8 (mean ± standard deviation) on a scale of 1-5 where 1 = "none" and 5 = "high." At the same time, participants stated their knowledge level about the Nitrogen Fertilizer Web Tool increased from 2.8 ± 1.3 to 4.2 ± 0.7 on the same scale. When asked about how likely participants were to use the NRZs and associated methods and the Nitrogen Fertilizer Web Tool, they responded 4.0 ± 1.1 and 4.0 ± 1.0, respectively, on a scale of 1-5 where 1 = "not likely" and 5 = "very likely" (Figure 1)

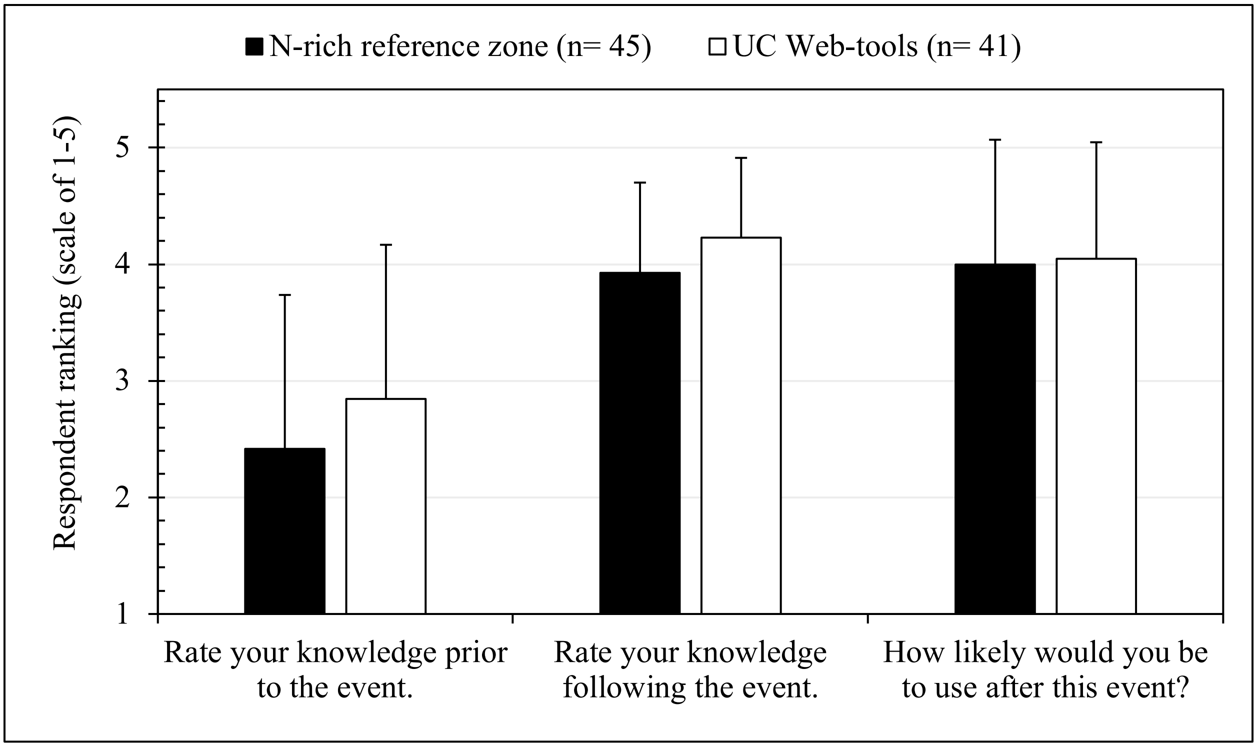

Figure 1. Change in knowledge and likelihood of adoption recorded after outreach events explaining N-rich methods and tools (1 = none/not likely; 5 = high/very likely). Bars represent 1 standard deviation.

Crop outcomes

When in-season N fertilizer applications were recommended, there was an average yield increase of 28% (~1500 lb/ac) compared to an in-field control ($p = 0.01$, $n = 6$). The range of yield increase at these sites was from 14%, or 1,088 lb grain/ac, to 75%, or 3,672 lb grain/ac. When monitoring indicated crop response to N fertilization was unlikely and no fertilizer application was recommended, yields in the grower field were equal to the control ($p = 0.80$, $n = 4$) (Table 1). We estimated an average savings of $40/ac in fertilizer costs for these sites. Furthermore, across all sites, crop N removal was greater than fertilizer N application where total fertilizer N applied only accounted for 80% of the N removed in the harvested crop (Figure 2).

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

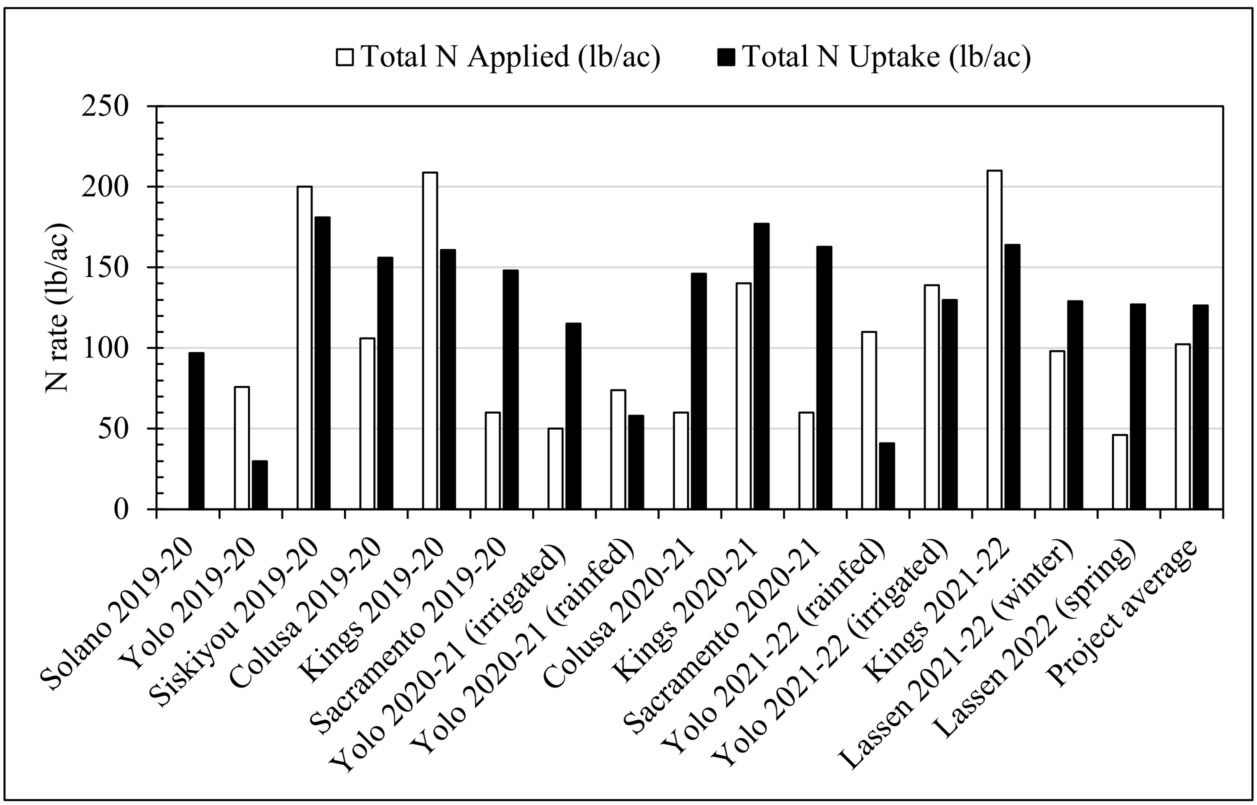

Figure 2. Crops at the demonstration sites removed 24 lb/ac more N than was applied as fertilizer for an average applied/removed ratio ≈ 0.80 (N fertilizer applied ≈ 80% of N fertilizer removed).

In summary, these tools and methods present an opportunity for improved N use efficiency in California small grain crops. Implementation will require more intensive observations and site-by-site adaptability from farmers and crop consultants. We continue to provide support and collaboration with growers and crop consultants to extend these tools to the agricultural community thereby increasing yields, reducing per-unit fertilizer costs, and improving stewardship of natural resources by small grains farmers and crop consultants in CA.

WORKS CITED

Lundy, M.E., Orloff, S., Wright, S., Hutmacher, R., Developing Nitrogen Management Strategies to Optimize Grain Yield and Protein Content while Minimizing Leaching Losses in California Wheat. Final report submitted to CDFA Fertilizer Research and Education Program, 23, May 2017. Available: https://www.cdfa.ca.gov/is/docs/13-0267-SAHutmacher.pdf