Final Report

A. Project Information

Development of site-specific nitrogen fertilization recommendations for annual crops

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B. Abstract

Growers need reliable tools to determine optimal rates and times of nitrogen (N) applications. The objective of the project was to develop robust site-specific estimates of the contribution of N mineralization from soil organic matter (SOM) to the plant-available N pool for different regions in California and incorporate them into user-friendly online N fertilization calculators. 36 field trials were set up over three growing seasons from 2021 to 2023. Each trial consisted of two treatments, namely: (i) no N fertilizer applications in plots within the field and (ii) grower's N management. Soil samples were collected from the top 120 cm of the profile pre-plant and post-harvest and analyzed for residual mineral N content (ammonium-N and nitrate-N). The aboveground biomass of fertilized crops (corn, cotton, sunflower and spring wheat) was harvested in 3-week intervals to determine biomass dry matter accumulation and N concentration. Prior to harvest, the aboveground biomass if the unfertilized and fertilized plots were also collected. Nitrogen accumulation in the aboveground biomass followed an S-shaped curve. Generally, less than 45 kg N ha^{-1} (40 lb N/ac) accumulated in the aboveground biomass during the first four weeks after seeding. After the initial four weeks, rapid N uptake occurred during vegetative growth, before slowing down during generative growth stages. Across all sites, the average amount of N in the aboveground biomass at harvest was 185 kg ha^{-1} (165 lb/ac) for sunflower, 265 kg ha^{-1} (237 lb/ac) for corn, 203 kg ha^{-1} (181 lb/ac) for cotton, and 223 kg ha^{-1} (199 lb/ac) for spring wheat grown in the Tulelake basin. Apparent daily net N mineralization in the top 120 cm (4ft) of the soil profile averaged 0.94 kg N ha^{-1} d^{-1} (0.84 lb N/ac/d) over the growing season in soils with a low SOM content and 2.41 kg N ha^{-1} d^{-1} (2.15 lb N/ac/d) in soils with a high SOM

content. Samples from more than 80 sites from previous projects were analyzed using Fourier transform infrared spectroscopy (FTIR). Analysis of the data revealed that FTIR did not sufficiently improve estimates of site-specific net N mineralization rates to recommend its use as an alternative for soil chemical and physical lab analyses. The results of this project were presented at numerous meetings and are being incorporated into an online calculator that allows users to determine site-specific N fertilizer needs.

C. Introduction

To minimize nitrate leaching to groundwater while maintaining high yields, growers need reliable tools to determine optimal rates and times of N applications. These tools should be based on field-specific information, including availability of N from non-fertilizer sources, such as residual soil nitrate, nitrate in the irrigation water and N mineralization from SOM. With funding from FREP, we recently developed such a tool for processing tomatoes. This online calculator estimates the N fertilizer requirements based on expected yield, residual soil nitrate, nitrate in the irrigation water and in-season N mineralization from SOM. However, the calculator currently estimates in-season N mineralization based on an N budget for Central Valley cropping systems and does not consider site-specific soil properties and cropping history.

In a recent project, we found that combining measures of soil texture as well as SOM content and quality can provide accurate site-specific N mineralization estimates. In soils with a high SOM content from the Delta and the Tulelake basin, particulate organic matter was a good measure for SOM quality, while in soils from the Central Valley with a low SOM content, fluorescein diacetate (FDA) hydrolysis, a measure for microbial activity, was a better predictor. However, these estimates have not yet been validated in field trials. Furthermore, while both SOM quality methods are relatively simple to use, they may not be attractive to commercial soil test labs, where growers and consultants routinely send their samples. The particulate organic matter analysis requires several steps, which are carried out over a period of three days, while for FDA analysis a strict protocol needs to be followed to reduce user-variability. Fourier transform infrared spectroscopy (FTIR) has been shown to be useful to identify labile SOM fractions that are related to N mineralization. We hypothesize that FTIR can be used to assess soil quality measures such as particulate organic matter and FDA hydrolysis. Infrared spectroscopy is a rapid and cost-effective method and is already commonly used to characterize feed and forage samples. Therefore, the personnel of many analytical labs are already familiar with the principals of infrared spectroscopy, which will greatly facilitate adoption by commercial labs.

The results of this project shall be used to generate site-specific estimates of N mineralization from SOM and yield-based estimates of crop N uptake, improving the precision of N fertilizer budgets for annual crops.

D. Objectives

The objective of the project is to develop robust site-specific estimates of the contribution of N mineralization to the plant-available N pool for different regions in California and incorporate these estimates into user-friendly online N fertilization calculators. Specific objectives are (i) to validate N mineralization estimates in field trials in the Central Valley, including the Delta, and Tulelake basin, (ii) to characterize the chemical composition of SOM using FTIR and correlate it to soil quality, and (iii) to develop user-friendly and site-specific online N fertilization calculators for different crops.

E. Methods

Field trials were set up in spring of 2021, 2022 and 2023 in 36 fields (Table 1). Each trial consisted of two treatments, namely: (i) no N fertilizer applications in plots within the field and (ii) grower's N management. The goal of the field trial was discussed with the collaborating growers. Zero N plots were identified and marked.

Soil samples, including undisturbed soil cores, were collected pre-plant from the top 15 cm of the profile and analyzed for soil properties and N mineralization potential. Pre-plant soil samples were also collected from the top 120 cm (4 feet) of the profile in 30-cm increments and analyzed for residual mineral N content (ammonium-N and nitrate-N). The aboveground biomass of fertilized crops was harvested in 3-week intervals. The plant samples were dried and weighed, and subsamples were analyzed for total N by dry combustion.

Prior to harvest, soil samples were again collected from the top 120 cm of the profile in 30-cm increments and analyzed for residual mineral N content (ammonium-N and nitrate-N). The aboveground biomass of fertilized and unfertilized plants was also determined and analyzed for total N.

Apparent net N mineralization in the unfertilized plots was calculated as

$$Net\ N\ mineralization = N\ outputs - N\ inputs \qquad \text{Eq. 1}$$

with

$$N\ inputs = Mineral\ N_{initial} + N\ fertilzer + Water\ N + N\ Deposition \qquad \text{Eq. 2}$$

and

$$N\ outputs = Crop\ N + Mineral\ soil\ N_{final} + N\ losses \qquad \text{Eq. 3}$$

Nitrogen inputs consisted of mineral soil N (nitrate-N and ammonium-N) in the top 120 cm of the soil profile before planting, N in irrigation water, and atmospheric N deposition. Dry atmospheric deposition was estimated for each site based on average regional values (Fenn et al., 2010; Weiss, 2006). The values were corrected for each site for the duration of the growing season. Fertilizer N applications were zero in the experimental plots, except in three fields where N fertilizer was applied accidentally. In these fields, fertilizer N was included as an input (Eq. 2).

Among the outputs, crop N consisted of N measured in the aboveground biomass at harvest and an estimate of root N. Root N was estimated for the top 30 cm of the profile using crop-specific data from the literature for harvest index, shoot:root ratio, and N concentrations in harvested plant parts, residues and roots as described by Geisseler et al. (2019). Root biomass N below 30 cm was estimated based on the root distribution with depth (Fan et al., 2016). Mineral soil N was measured as nitrate-N and ammonium-N in the top 120 cm of the soil profile at harvest. Nitrogen losses may include nitrate leaching below 120 cm, and gaseous losses from ammonia volatilization, denitrification and nitrification. For this study, which was done in unfertilized plots, these losses were assumed to be insignificant. While this may result in an underestimation of the actual net N mineralization, the calculated N mineralization is more likely to be representative of what the crop will have available for plant growth and development.

For the determination of the N mineralization rate, field sites were divided into two groups based on their SOM content, which ranged from 1.2 to 2.9% in the group with low SOM contents and from 5.7 to 44% in the high-SOM soils. A previous study with undisturbed soil cores from the same region indicated that net N mineralization was better correlated with soil properties when the dataset was divided into high and low-SOM soils (Miller et al., 2018). These two groups also differed in their geographic location and dominant soil forming factor. The low-SOM soils were located in the Central Valley and formed on alluvium deposited by the Sacramento and San Joaquin rivers and their tributaries. The high-SOM soils were located in the Sacramento-San Joaquin River Delta on the western border of the Central Valley, and in the Tulelake basin. Before being drained for crop production in the early 20th century, these soils were submerged for at least part of the year, and SOM accumulated under anaerobic conditions.

F. Data/Results

Nitrogen accumulation in the aboveground biomass followed an S-shaped curve (Figure 1). Generally, less than 40 kg N ha^{-1} accumulated in the biomass during the first four weeks after seeding. The following weeks were characterized by rapid N uptake, before slowing down during generative growth stages. Across all sites monitored from 2021 through 2023, the average amount of N in the aboveground biomass at harvest was 185 kg ha^{-1} (165 lb/ac) for sunflower, 265 kg ha^{-1} (237 lb/ac) for corn, 203 kg ha^{-1} (181 lb/ac) for cotton, and 223 kg ha^{-1} (199 lb/ac) for spring wheat grown in the Tulelake basin. As spring wheat was grown on soils with high SOM contents in the Tulelake basin, the plants may have accumulated more N than plants grown on soils with a low SOM content.

By considering all sources and sinks of N over the growing season, apparent net N mineralization was calculated for the top 4 ft of the soil profile. Apparent daily net N mineralization over the growing season averaged 0.94 kg N ha^{-1} d^{-1} (0.84 lb N/ac/d) in soils with a low SOM content and 2.41 kg N ha^{-1} d^{-1} (2.15 lb N/ac/d) in soils with a high SOM content.

Samples from each 30-cm layer were incubated to determine the distribution of N mineralization in the soil profile. Net N mineralization decreased with depth, closely following total soil N content. The results from the incubation were used to determine the fraction of the total that was mineralized in the top 60 cm of the profile, which represents the main root zone of the crops included in this study. The correlations between net N mineralization in the top 60 cm of the profile and soil properties measured in the top 30 cm, which is the depth most often collected for soil fertility analyses in the region, were then determined (Figure 2). The proportion of total soil N mineralized decreased with increasing clay content in soils with a low SOM content and decreased with increasing total soil N in soils with a high SOM content.

The variability in the dataset underscores the importance of combining N budgets with N monitoring tools, such as soil or plant tissue sampling prior to in-season N applications. These practices allow for making corrections to the N fertilizer program when needed, optimizing yield while minimizing N losses.

FTIR spectroscopy in conjunction with partial least-squares regression (PLSR) was used to determine whether this approach could be used to accurately predict site specific N mineralization rates from 86 sites across California. FTIR predicted net N mineralization with an R^2 of 30.9% across all sites included in this study. The prediction of net N mineralization was not enough of an improvement over current estimates to warrant recommendation of FTIR as a tool for site-specific N mineralization estimates at this moment.

Results of this project were included in 20 presentations during the project period. In addition, the results are being incorporated into an online calculator that allows for site-specific estimates of crop N demand, N mineralization from SOM and other non-fertilizer sources to determine N fertilizer needs (Figure 3). A test version of the online calculator is currently evaluated for accuracy and user friendliness. Its release on the nutrient management lab group’s website (http://geisseler.ucdavis.edu/) is planned for summer 2025. In addition, a manuscript of a scientific paper is currently under review. A second article is in preparation.

Table 1: Characterization of the field sites. Soil properties were measured in the top 30 cm of the profile.

Site	Year	Soil series	Crop	pH	EC dS m^{-1}	Total C g kg^{-1}
1	2021	Yolo loam	Sunflower	7.9	0.44	7.9
2	2021	Reiff fine sandy loam	Sunflower	6.8	0.13	7.0
3	2021	Sacramento clay	Sunflower	7.4	0.28	12.5
4	2021	Sycamore silty clay loam	Sunflower	7.3	0.20	9.0
5	2021	Sycamore silty clay loam	Sunflower	7.1	0.22	13.7
6	2022	Sycamore complex	Sunflower	6.8	0.17	13.9
7	2022	Sacramento Clay	Sunflower	6.4	0.19	12.9
8	2022	Sacramento Clay	Sunflower	5.8	0.20	10.2
9	2022	Yolo loam	Sunflower	6.3	0.33	5.8
10	2023	Brentwood silty clay loam	Sunflower	6.8	0.07	7.3
11	2023	Tehama loam	Sunflower	0.0	0.00	7.3
12	2023	Grandbend loam	Sunflower	6.9	0.12	13.6
13	2023	Sycamore silty clay loam	Sunflower	7.2	0.17	12.0
14	2021	Wheelridge gravelly loamy sand	Cotton	7.3	0.15	7.3
15	2021	Panoche loam	Cotton	8.3	0.37	7.4
16	2021	Biggriz loam	Cotton	8.1	0.43	19.0
17	2022	Colpien loam	Cotton	7.5	0.44	17.5
18	2022	Colpien loam	Cotton	8.1	0.44	8.1
19	2022	Panoche clay loam	Cotton	7.6	0.24	14.7
21	2021	Gazwell mucky clay	Grain corn	6.9	0.33	49.9
22	2021	Rindge mucky silt loam	Grain corn	7.3	0.15	121.7
23	2021	Rindge muck	Grain corn	8.3	0.37	128.4
24	2022	Rindge Muck	Grain corn	5.4	0.32	212.7
25	2023	Rindge Muck	Grain corn	6.2	0.23	220.3
20	2023	Sacramento clay	Grain corn	7.0	0.10	10.0
26	2023	Valdez silt loam	Grain corn	6.1	0.44	12.0
27	2023	Oswald clay	Grain corn	7.2	0.17	12.0
28	2023	Colpien loam	Grain corn	7.5	0.16	14.7
29	2023	Akers fine sandy loam	Grain corn	7.0	0.20	9.1
30	2023	Panoche loam	Grain corn	8.4	0.45	8.5
31	2022	Rindge Mucky Silt Loam	Silage corn	6.4	1.64	108.2
32	2022	Gazwell mucky clay	Silage corn	7.5	0.52	56.6
33	2023	Rindge Muck	Silage corn	7.5	0.16	124.3
34	2021	Tulebasin mucky silty clay loam	Wheat	7.2	0.27	28.6
35	2022	Tulebasin mucky silty clay loam	Wheat	7.3	0.30	32.9
36	2023	Tulebasin mucky silty clay loam	Wheat	6.9	0.07	36.3

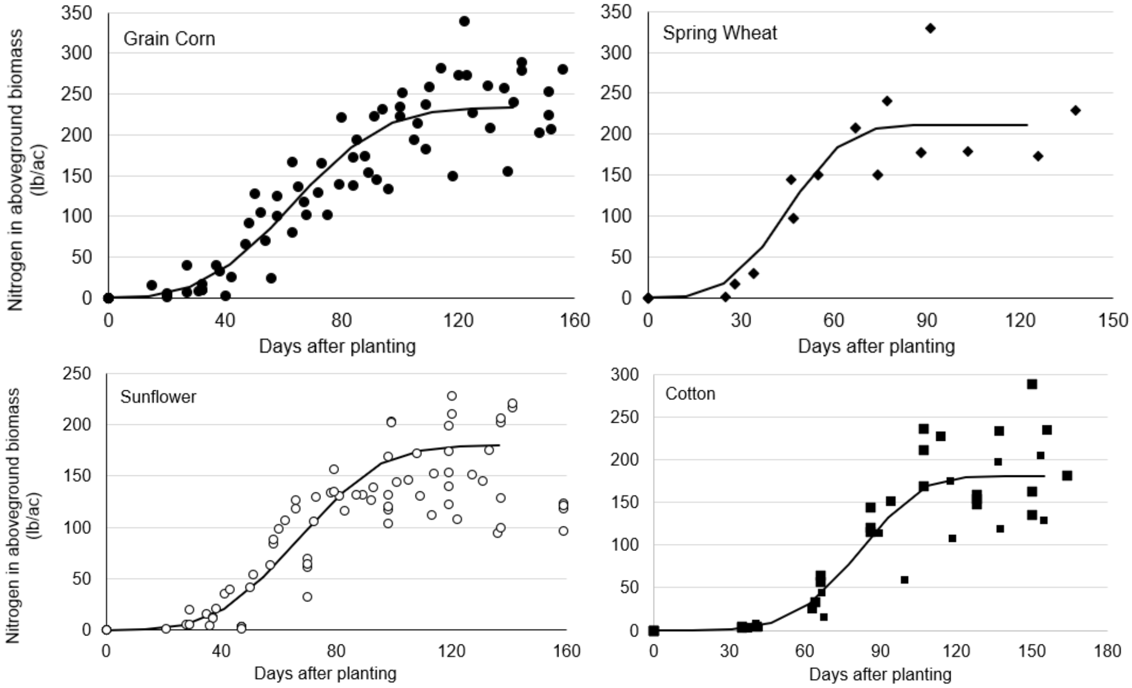

Figure 1: Seasonal nitrogen accumulation of field crops grown in California.

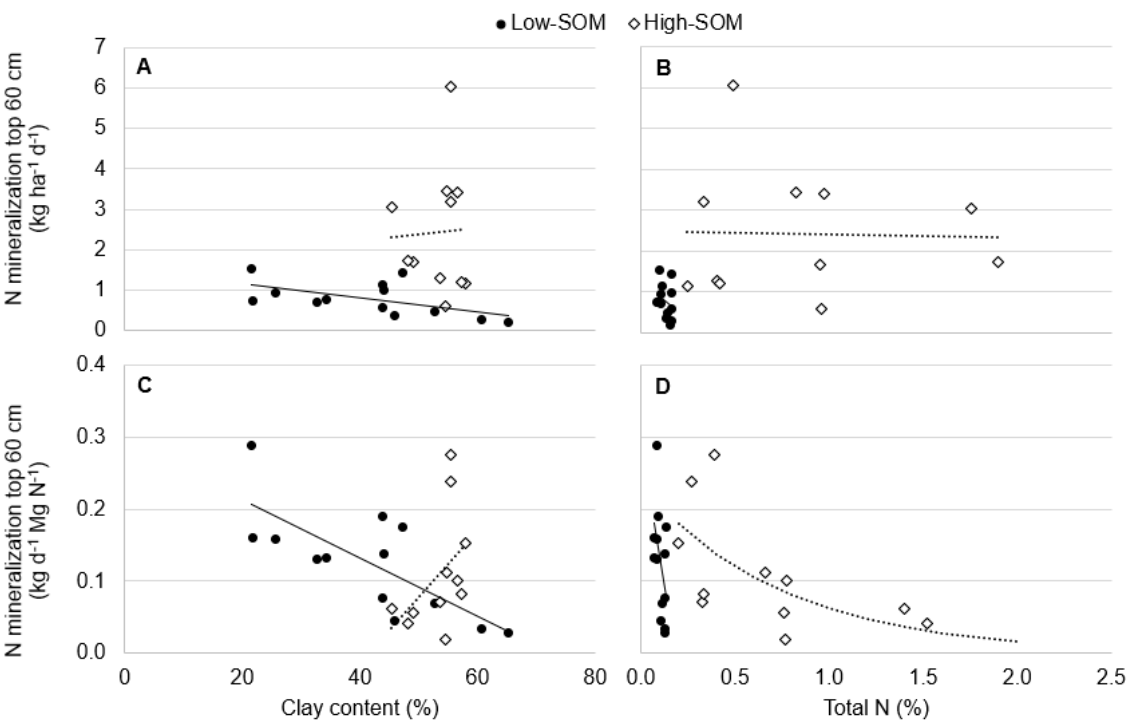

Figure 2: Correlation between daily N mineralization at 25 °C in the top 60 cm of the profile and soil clay content (left, panels A and C), as well as total soil N (right, panels B and D) measured in the top 30 cm. Daily N mineralization is expressed in kg ha^{-1} d^{-1} (top, panels A and B) and kg Mg N^{-1} d^{-1} (bottom, panels C and D).

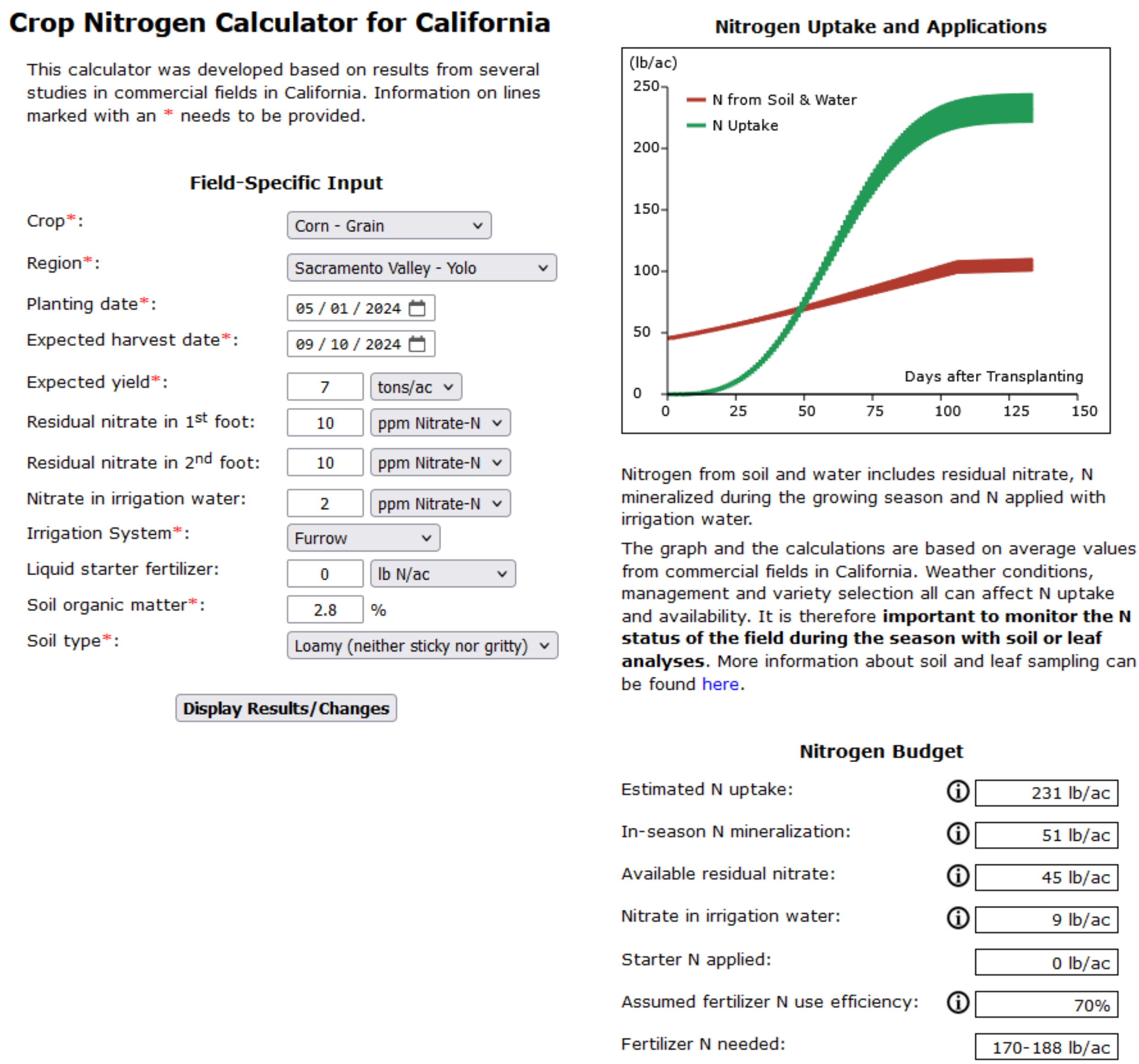

Figure 3: Screenshot of the test version of the online calculator. Inputs are shown on the left, outputs on the right.

G. Discussion and Conclusions

The measured N accumulation in the aboveground biomass allows determining crop N requirements and the periods of high and low N uptake. Furthermore, the site-specific N mineralization estimates close an important gap in our knowledge of the amount of N available from the decomposition of SOM. Measured residual mineral N in the soil profile in spring differed widely, highlighting the need for site-specific N fertilization practices.

The data generated in this project, combined with results from previous studies, allow calculating site-specific N budgets and N fertilizer application rates to meet crop demands. Nitrogen budgets that take all major inputs and outputs into account are challenging and time-consuming to calculate. The online N calculator which was developed in this project performs these calculations based on readily available information entered by the user.

H. Challenges

Due to water shortage in the Tulelake area, wheat acreage has been reduced. We could only include one field each year in the area.

In three fields, the zero N plots were accidentally fertilized. These fields were used to measure N accumulation in the aboveground biomass during the growing season but were not included in the budget calculations.

I. Project Impacts

The results of this project will support growers making site-specific N fertilization decisions based on expected yield, residual soil nitrate, soil texture, soil organic matter content and irrigation system. The online calculator was designed so that it can be easily expanded with N uptake data from additional crops. The data generated can be used to support site-specific N fertilizer decisions that ensure high yields while minimizing the risk of N losses to the environment.

J. Outreach Activities Summary

September 30, 2021. Turner, S., Geisseler, D. Development of site-specific nitrogen fertilization recommendations for annual crops. Delta Grains Field Meeting, Tyler Island, CA. 15 Participants. CEUs were offered.

October 27-28, 2021. Geisseler, D., Parikh, S., Clark, N., Leinfelder-Miles, M., Light, S., Mathesius, K., Wilson, R. Development of site-specific nitrogen fertilization recommendations for annual crops. Proceedings of the 29th Annual Fertilizer Research and Education Program Conference, 29: 90-93.

March 16, 2022. Geisseler, D. Research and outreach activities in nutrient management. Rothamsted Research Group visiting UC Davis, Davis, CA. 12 Attendees. No CEUs offered.

May 13, 2022. Geisseler, D. Nitrogen mineralization from soil organic matter and organic amendments. UC ANR Agronomic Crops Program Team Meeting. Virtual via Zoom. 30 Attendees. No CEUs offered.

June 2, 2022. Geisseler, D. Nutrient management. California Farm Academy Training. Woodland, CA. 12 Attendees. No CEUs offered.

July 6, 2022. Geisseler, D., Santiago, S. Nitrogen uptake of sunflowers grown in the Sacramento Valley. Colusa County UCCE Agronomy Newsletter.

September 30, 2022. Geisseler, D. Nitrogen availability from organic sources. Students enrolled in course PSSC 453 - Soil Fertility & Plant Nutrition at Chico State University, Chico, CA (via Zoom). 15 Attendees. No CEUs offered.

October 26-27, 2022. Geisseler, D., Parikh, S., Clark, N., Leinfelder-Miles, M., Light, S., Mathesius, K., Wilson, R. Development of site-specific nitrogen fertilization recommendations for annual crops. Proceedings of the 30th Annual Fertilizer Research and Education Program Conference, 30: 51-54.

January 17, 2023. Geisseler, D. Current trends and knowledge gaps in California fertilizer recommendations. Participants of the course in advanced soil fertility at California Polytechnic State University, San Luis Obispo, CA (via Zoom). 15 Attendees. No CEUs offered.

February 8, 2023. Geisseler, D. Nitrogen mineralization in fields under annual crops. California Plant and Soil Conference, Fresno, CA, 150 Attendees. CEUs were offered.

May 26, 2023. Geisseler, D. Tools for efficient nutrient management. SSC109, UC Davis, UC Davis, 15 Attendees. No CEUs offered.

November 9-10, 2023. Parikh, S., Clark, N., Leinfelder-Miles, M., Light, S., Mathesius, K., Wilson, R. Development of site-specific nitrogen fertilization recommendations for annual crops. Proceedings of the 31st Annual Fertilizer Research and Education Program Conference, 31: 34-38.

November 9, 2023. Geisseler, D. Development of site-specific nitrogen fertilization recommendations for annual crops. California Department of Food and Agriculture - Fertilizer Research & Education Program Conference, Modesto, CA, 110 Attendees. CEUs were offered.

November 27, 2023. Geisseler, D. Nitrogen mineralization from soil organic matter. Nitrogen Planning and Management in Organic Production of Annual Crops Workshop, via Zoom, 50 Attendees. CEUs were offered.

January 12, 2024. Geisseler D. Soil organic matter and its contribution to plant available nitrogen. SJC and Delta Field Crops Meeting, Stockton, CA, 35 Attendees. CEUs were offered.

June 20, 2024. Geisseler, D. Soil N mineralization and nitrate testing. Participants of field day Obtaining nutrients from organic sources, Dixon, CA, 15 Attendees. CEUs were offered.

October 4, 2024. Geisseler D. Nitrogen availability from organic sources. Students enrolled in course PSSC 453 - Soil Fertility & Plant Nutrition at Chico State University, Chico, CA, 22 Attendees. No CEUs offered.

October 11, 2024. Geisseler D. Residual nitrate and nitrogen mineralization in corn fields in the Delta. Delta Corn Field Meeting, Tyler Island, CA, 15 Attendees. CEUs were offered.

November 17-18, 2024. Parikh, S., Clark, N., Leinfelder-Miles, M., Light, S., Mathesius, K., Wilson, R. Development of site-specific nitrogen fertilization recommendations for annual crops. Proceedings of the 32nd Annual Fertilizer Research and Education Program Conference, 32: 39-43.

November 18, 2024. Geisseler, D. Nitrogen mineralization from soil organic matter. Nitrogen Planning and Management in Organic Production of Annual Crops Workshop, via Zoom, 90 Attendees. CEUs were offered.

K. References

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L. Appendix

n/a

M. Factsheet/Database Template

1. **Project Title**
   Development of site-specific nitrogen fertilization recommendations for annual crops

2. **Grant Agreement Number (Assigned by CDFA)**
   20-0880

3. **Project Leaders**
   Daniel Geisseler, Department of Land, Air and Water Resources, University of California, Davis;
   Sanjai Parikh, Department of Land, Air and Water Resources, University of California, Davis;
   Nick Clark, University of California Cooperative Extension Kings, Tulare, & Fresno Counties;
   Michelle Leinfelder-Miles, University of California Cooperative Extension San Joaquin County;
   Sarah Light, University of California Cooperative Extension Sutter, Yuba, and Colusa Counties;
   Konrad Mathesius, University of California Cooperative Extension Yolo, Solano & Sacramento Counties;
   Rob Wilson, University of California Intermountain Research & Extension Center, Tulelake

4. **Start Year/End Year**
   2021/2024

5. **Location**
   Field trials in commercial fields; laboratory at UC Davis

6. **County**
   Colusa, Fresno, Sacramento, Siskiyou, Solano, Tulare, Yolo

7. **Highlights**
   - Net N mineralization in conventional annual cropping fields was estimated for the growing season using an N balance approach.
   - Nitrogen mineralization averaged 0.84 lb N/ac/d in the top 4 ft of soils with an organic matter content below 3%.
   - In soils with an organic matter content of 5.7-44%, N mineralization averaged 2.15 lb N/ac/d in the top 4 ft.
   - Total soil N, and to a lesser degree clay content, were correlated with N mineralization rates.

8. Introduction

Growers need reliable tools to determine optimal rates and times of nitrogen (N) applications. The objective of the project was to develop robust site-specific estimates of the contribution of N mineralization from soil organic matter to the plant-available N pool for different regions in California and incorporate them into user-friendly online N fertilization calculators.

9. Methods/Management

36 field trials were set up over three growing seasons from 2021 to 2023. Each trial consisted of two treatments, namely: (i) no N fertilizer applications in plots within the field and (ii) grower's N management. Soil samples were collected from the top 120 cm of the profile pre-plant and post-harvest and analyzed for residual mineral N content (ammonium-N and nitrate-N). The aboveground biomass of fertilized crops was harvested in 3-week intervals to determine biomass dry matter accumulation and N concentration. Prior to harvest, the aboveground biomass in the fertilized and unfertilized plots was also collected.

10. Findings

Nitrogen accumulation in the aboveground biomass followed an S-shaped curve. Generally, less than 40 lb N/ac accumulated in the aboveground biomass during the first four weeks after seeding. After the initial four weeks, rapid N uptake occurred during vegetative growth, before slowing down during generative growth stages. Across all sites, the average amount of N in the aboveground biomass at harvest was 185 kg ha^{-1} (165 lb/ac) for sunflower, 265 kg ha^{-1} (237 lb/ac) for corn, 203 kg ha^{-1} (181 lb/ac) for cotton, and 223 kg ha^{-1} (199 lb/ac) for spring wheat grown in the Tulelake basin.

Apparent daily net N mineralization over the growing season averaged 0.94 kg N ha^{-1} d^{-1} (0.84 lb N/ac/d) in the top 120 cm of soils with a low SOM content and 2.41 kg N ha^{-1} d^{-1} (2.15 lb N/ac/d) in soils with a high SOM content.

Samples from more than 80 sites from previous projects were analyzed using Fourier transform infrared spectroscopy (FTIR). Analysis of the data revealed that FTIR did not sufficiently improve estimates of site-specific net N mineralization rates to recommend its use as an alternative for soil chemical and physical lab analyses.

The results of this project were presented at numerous presentations and incorporated into an online tool that will allow users to determine site-specific N fertilizer needs.