Approach to Determine Crop Nitrogen Fertilizer Needs

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This document summarizes the approach and calculations used to determine site-specific nitrogen (N) fertilizer requirements for different crops grown in California. These calculations are used by the online crop N calculators, which can be found here: http://geisseler.ucdavis.edu/Crop_N_Calculator.html

The calculator is intended for systems where mineral fertilizer is used exclusively. Nitrogen mineralized from organic materials, e.g. manure, lagoon water or compost, is not calculated.

User input

Table 1 provides an overview of the input required and how these inputs are used by the calculator.

Table 1: Inputs required by the calculator and the purpose of these inputs

Input	Use
Crop	• Create an uptake curve • Determine total N uptake by the crop together with input for expected yield
Region	• Region specific daily soil temperatures are used to determine N mineralization from soil organic matter. Soil temperatures values from CIMIS stations from each region were used. Daily average values from a 10-year period from 2011-2020 were calculated. • Calculate crop evaporation
Planting date; expected harvest date	• Planting date and harvest date are used to determine length of growing season and for the determination of N mineralization from soil organic matter and crop evaporation
Expected yield	• Used to determine total N uptake by the crop together with input for crop type
Previous crop	• When users select “alfalfa”, a comment box is displayed in the output providing information on N availability after alfalfa. • Selecting “alfalfa” does not affect calculations because the contribution of alfalfa has been found to be highly variable.
Residual soil nitrate	• Used to calculate residual soil nitrate in spring
Nitrate irrigation water	• Used to determine N applied with irrigation water
Irrigation system	• Used to determine N use efficiency
Liquid starter fertilizer	• Used to determine amount of N added with starter
Soil organic matter	• Used to determine bulk density and net N mineralization during season
Soil type	• Used to determine bulk density and net N mineralization during season. Users often do not know the exact texture of their soil. For this reason, users can select from a short list of soil types. Clay content is assumed to be 10, 30 and 50% of sandy, loamy and clayey soils, respectively. Organic soils are assumed to have a clay content of 30% (Table 2).

Table 2: Options for soil type and associated clay content used for calculations. The exact texture of a field is often not known. For this reason, the input is simplified, giving users three options for soil texture, plus an option for high organic matter soils.

Soil type	Clay content (%)
Sandy (gritty)	10
Loamy (neither sticky nor gritty)	30
Clayey (sticky when wet)	50
Organic (e.g. Delta or Tulelake)	30

Crop nitrogen uptake curve

The N uptake curves were determined in commercial fields by collecting plant samples multiple times during the growing season. Most commonly, samples were collected every three weeks. Each time, the total aboveground biomass from a certain number of plants or a certain area was removed and dried in an oven at 60 °C. Once the samples had reached a constant weight, they were weighed to determine the dry matter.

The samples were then ground to a fine powder in several steps using a garden shredder, a Wiley mill and a paint shaker. The finely ground material was analyzed for total N by dry combustion. In fields where a certain number of plants were removed, the biomass and N in the biomass were converted to a per area basis using the plant density, which was determined by counting the plants from areas of known size in the field. All plant samples were collected from 3-4 replicated spots in each field. For crops with a small number of field sites, the data was supplemented with results from other studies conducted in California (Figure 1).

A curve (Eq. 1) was fit to the biomass N data from all sampling times across all field sites of the same crop.

$$biomass\ N = N_{max} \times (1 - e^{-a \times t^{b}}) \qquad \text{Eq. 1}$$

where *biomass N* is the N in the aboveground biomass (in lb/ac), *t* is the fraction of the time between transplanting and harvest, N_{max} is the biomass N at harvest (in lb/ac) and *a* and *b* are constants that determine the shape of the curve.

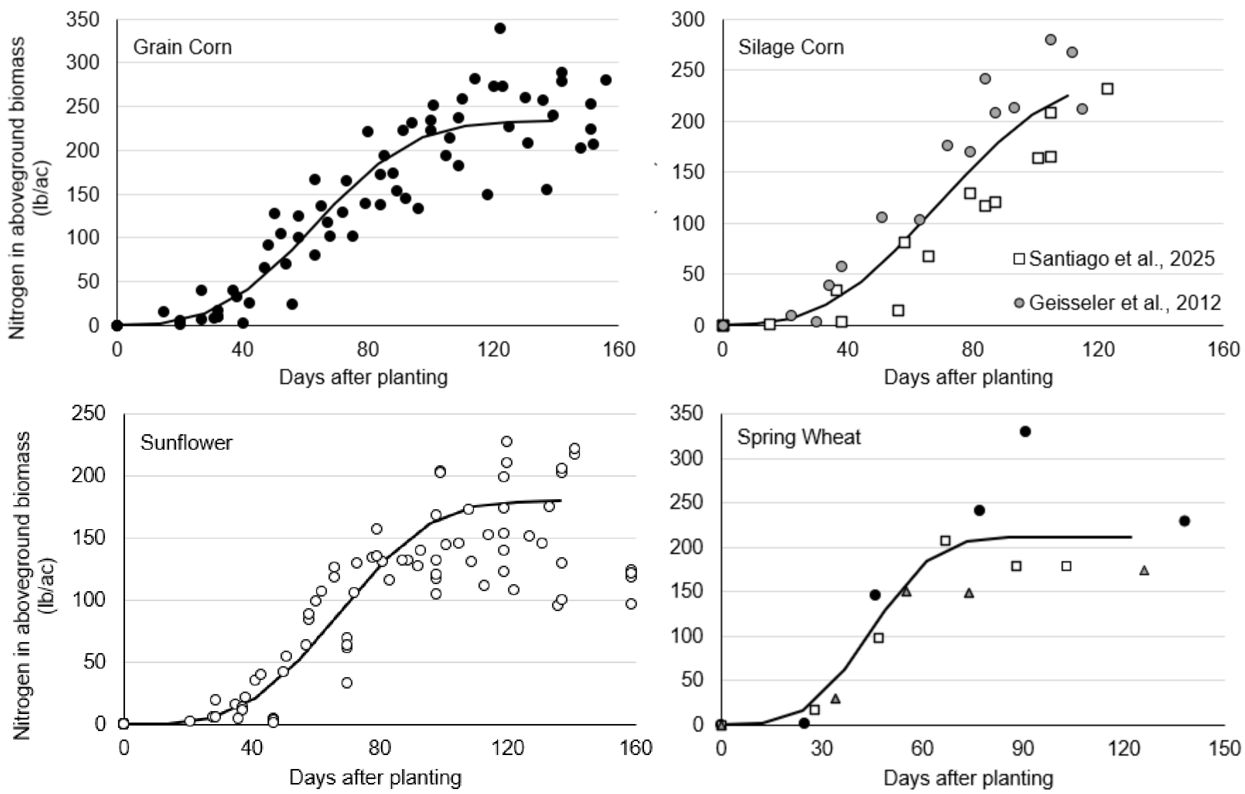

Figure 1: Nitrogen uptake curve of selected crops grown in California. Unless otherwise indicated, data is from Santiago et al. (2025b).

Estimated N uptake

Prior to harvest, the biomass collected in the field was divided into the harvested portion (e.g. grains) and the non-harvested portion (e.g. stover). The two parts were processed separately and the correlation between yield and N uptake was determined. This correlation is used to calculate the estimated N uptake based on the users' input for yield. As was the case for the N uptake curve, small datasets were complemented with results from other California studies (Figure 2).

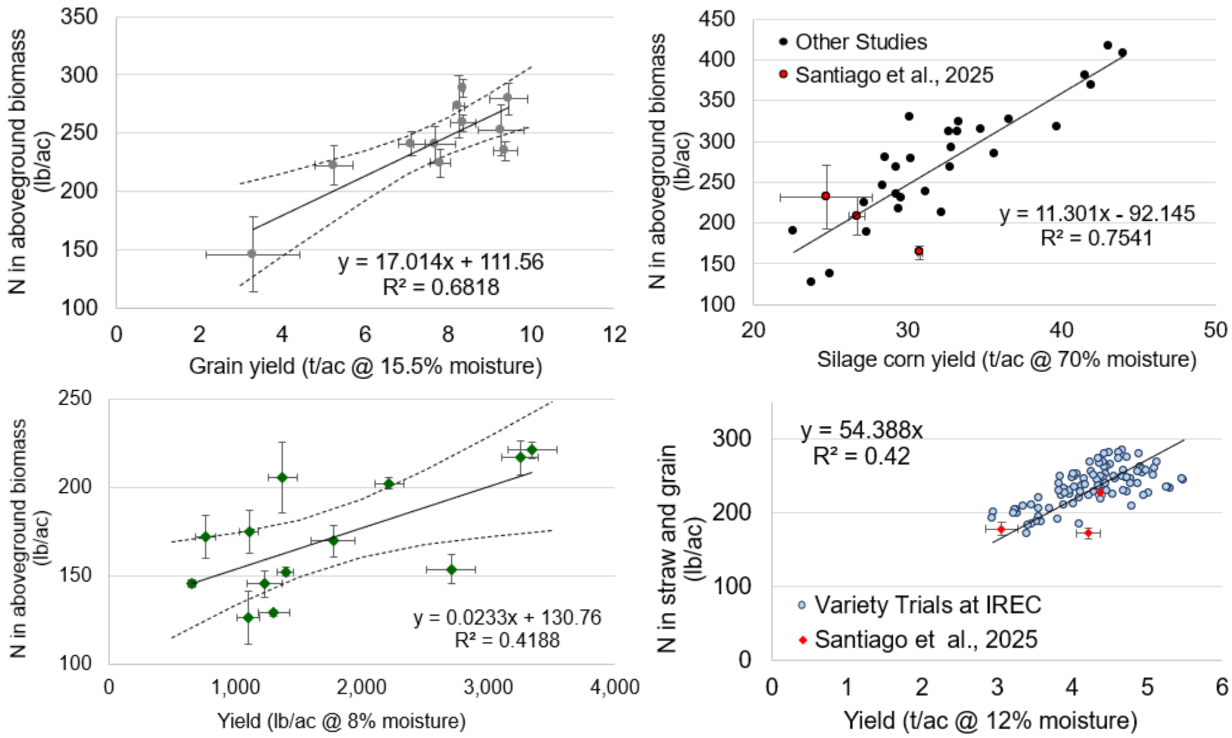

Figure 2: Relationship between yield and N in the aboveground biomass (Santiago et al., 2005b). Other studies for silage corn include Campbell Mathews et al., 2001; Meyer et al., 2001; Heinrich, 2009; Geisseler et al., 2012; and Lazcano et al., 2016. Data from wheat variety trials can be accessed at https://smallgrainselection.plantsciences.ucdavis.edu/explore/

Estimated bulk density

Bulk density is used to calculate the amount of total N in the soil profile.

Bulk density strongly depends on total N and clay contents of the soil (Figure 3). Nitrogen content in the top ft. of the profile is calculated based on user input for SOM content and soil type. It is assumed that 50% of SOM is carbon (C) and the C:N ratio of SOM is 9.33 in low-SOM soils and 13.08 in high-SOM soils (Santiago et al., 2005b). High-SOM soils include soils in the Delta and Tulelake basin. Low-SOM soils are soils in the Central Valley, excluding the Delta.

Combining total N and clay content to predict bulk density results in this best-fit model:

$$Bulk\ density = -0.34 + 1.66 \times\ total\ N^{-0.22} - 0.0009 \times clay \qquad \text{Eq. 2}$$

Where bulk density is in g cm^{-3}, total N in g kg^{-1} and clay in %. Clay content is based on the soil type selected by users (Table 2).

Upper and lower boundaries for bulk density were set to 1,5 and 0.5 g cm^{-3}, respectively. For the 2nd ft. of the profile, bulk density is assumed to be 0.08 g cm^{-3} higher than in the top ft. (Rawls, 1983).

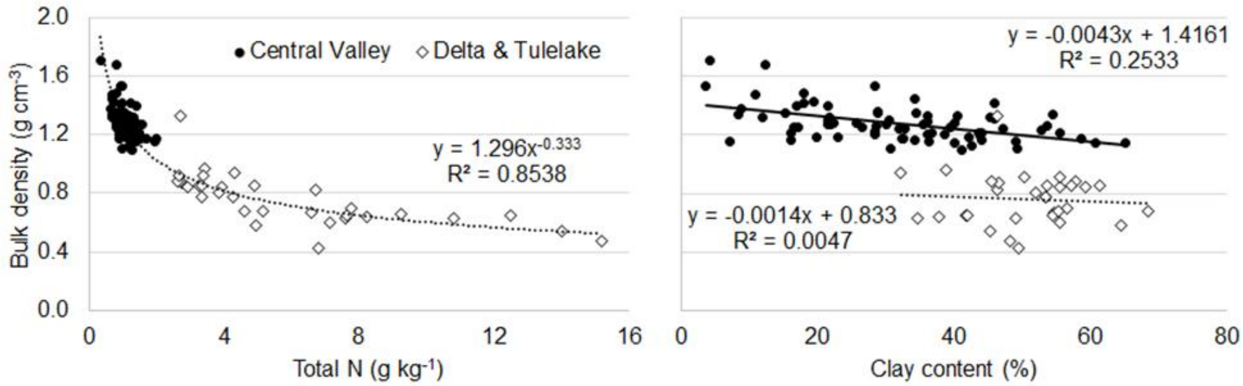

Figure 3: Relationship between total soil C and bulk density (left panel) and between clay content and bulk density (right panel). Correlations are based on undisturbed core analyses from 106 California sites.

In-season N mineralization

Baseline N mineralization rates

In a first step, daily N mineralization at a temperature of 77 °F (25 °C) is calculated.

Based on field trials, N mineralization in soil with a low SOM content and a clay content of 30% averaged 0.17 g kg^{-1} N d^{-1} in the top two ft. at 77 °F (Santiago et al., 2025a). In high-SOM soils from the Delta and Tulelake basin, this value averaged 0.143 g kg^{-1} N d^{-1}. Net N mineralization in low-SOM soils is significantly correlated with clay content, while it is correlated with total N in high-SOM soils.

The proportion of total soil N mineralized in low-SOM soils depends on the clay content. A correction factor based on 47 field sites included in Geisseler et al. (2024) was used. No correction was used for loamy soils (assumed clay content of 30%), N mineralization was decreased by 0.00222 g kg^{-1} N d^{-1} for each percent point increase in clay content and vice versa.

Maximum N mineralization

In a recent paper, Geisseler et al. (2019) determined N mineralization rates for low-SOM soils from the same region. Their approach was based on organic N inputs and outputs with annual crops. For the top 30 cm of the profile, their N mineralization estimate averaged 110 lb N/ac per year. Including estimates for root biomass and exudates based on root distribution proposed by Fan et al. (2016) for the 30-60 cm as well as N mineralization estimates for the same layer based on the distribution with depth found by Santiago et al. (2025a), the organic N approach would result in N mineralization rates of 121 lb N/ac per year. The estimate was used to cap N mineralization rates in low-SOM soils. Therefore, either the clay-corrected N mineralization rate or 121 lb N/ac per year was used, whichever was lower.

Temperature correction

Nitrogen mineralization was temperature corrected based on daily soil temperature data from local CIMIS stations and a relationship developed by Miller and Geisseler (2018). The correlation is shown in Figure 4. The resulting seasonal N mineralization rates are shown in Figure 5.

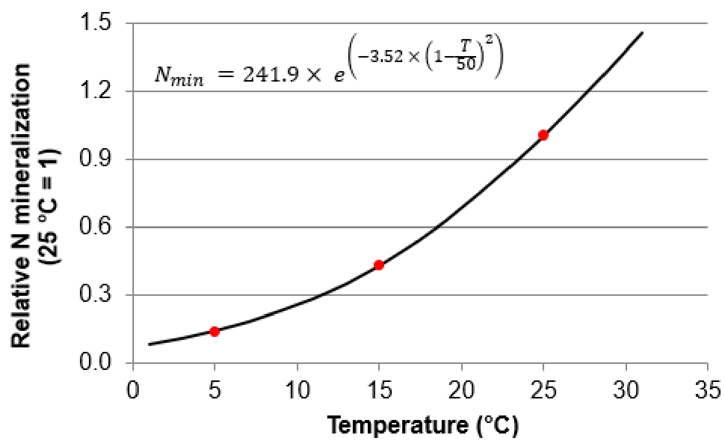

Figure 4: Temperature correction factor used to calculate site-specific N mineralization rates.

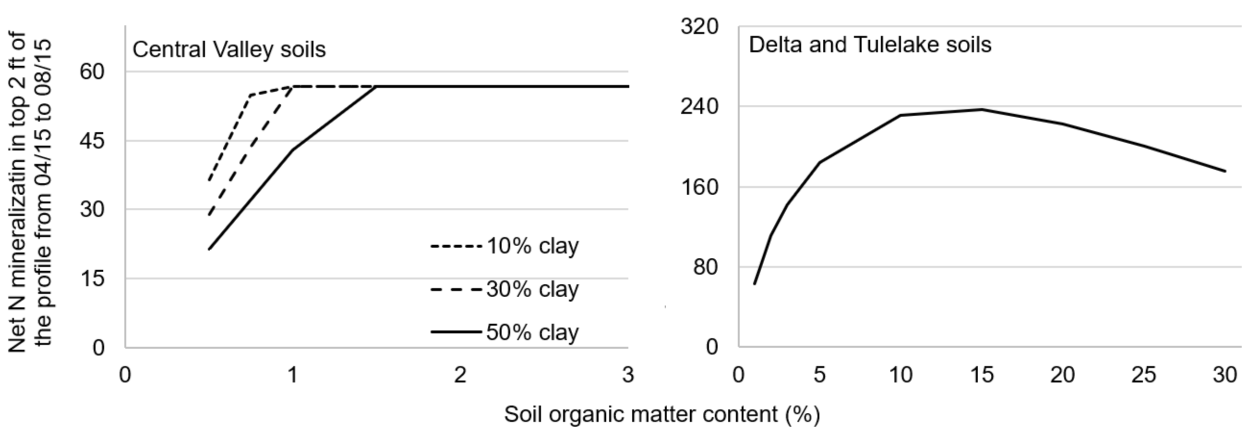

Figure 5: Calculated N mineralization rate (in lb/ac) during the summer growing season (April 15 to August 15) using soil temperature data from the CIMIS Davis weather station for both graphs.

Correction for crop specific N uptake curve

The proportion of the N mineralized that is crop-available also depends on the crops' N uptake curve, more specifically on the N uptake prior to harvest. For crops with low N uptake before harvest, it is assumed that N in irrigation water and N mineralized prior to harvest is no longer taken up by the crops (Table 3).

Table 3: Proportion of season during which N mineralization from soil organic matter and irrigation water N is considered plant available. The value depends on the crop's N uptake curve. A value of 1 is used for crops that take up N until they are harvested.

Crop	Proportion of season
Corn -Grain	0.8
Corn - Silage	1.0
Sunflower	0.8
Tomatoes- processing	0.8
Wheat - Spring	0.7

Available residual nitrate

Users are asked to enter residual nitrate values either in ppm NO_3 or ppm NO_3-N. These values are converted to lb N/ac using the estimated bulk density.

The availability of the residual nitrate-N depends on the irrigation system (Table 4). The nitrate availability in the top ft. and the 2nd ft. is assumed to be equal, except for subsurface drip irritation where the availability of the residual nitrate in the top ft is assumed to be only 50%. This is because the soil near the surface dries out quickly in spring, likely limiting root growth and nutrient uptake.

Table 4: Nitrogen use efficiencies used by the program for different irrigation systems

Irrigation system	Nitrogen use efficiency (%)
Surface Drip	0.6 (1st ft.), 0.8 (2nd ft.)
Subsurface Drip	0.5 (1st ft.), 0.8 (2nd ft.)
Furrow	0.7
Sprinkler	0.7
Flood	0.6
Ditch	0.8

Nitrate in irrigation water

The nitrate concentration in the irrigation water as entered by the user is converted to lb N/ac. Only nitrate in the amount of water needed to cover evapotranspiration (ET) is assumed to be taken up by the crops. Nitrate applied with excess water is assumed to be leached below the root zone.

Crop specific ET values (ETc) are calculated using monthly ET_0 values from CIMIS for different regions in California (https://cimis.water.ca.gov/Content/pdf/CimisRefEvapZones.pdf) and crop coefficients published by UC Davis (https://biomet.ucdavis.edu/basic-irrigation-scheduling-bis/).

The calculations use Region, Planting Date and Expected Harvest Date as entered by users.

As is the case with N mineralized from SOM, it is assumed that irrigation water N applied prior to harvest is no longer taken up by crops with low N uptake before harvest (Table 3).

Starter N applied

Nitrogen applied with starter is converted to a per area basis using the quantity entered by the user. When the input is in gal/ac of material, the amount of N applied per ac is calculated using the products' density. It is assumed that starter N is 100% available.

Fertilizer N needed

The amount of fertilizer N needed is calculated by first subtracting available N in the from of residual nitrate, nitrate in the irrigation water, soil N mineralization and starter N from the estimated N uptake. The resulting value is the amount of N the crop needs to take up from applied fertilizers. This value is divided by the fertilizer use efficiency (Table 4) to determine the amount of fertilizer N needed (Table 5).

Table 5: Nitrogen budget calculations. The values in the table were chosen to illustrate the calculations and do not represent an actual scenario.

N source or sink		**Quantity (lb/ac)**
Expected N uptake		**200**
- Residual soil nitrate		40
- Irrigation water N		10
- Soil N mineralization in top 2 ft		40
- Starter N		10
= Difference (uptake - non-fertilizer N)		**100**
Fertilizer N efficiency (%)	*80*	
Fertilizer N (= Difference / NUE)		**125**

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