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Estimating Nitrogen Availability in Organic Annual Production: For Nitrogen Budgeting and Other Purposes

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This document is not WCAG 2.0 PDF–compliant for people with disabilities. A compliant version of this publication is scheduled to be released in the first quarter of 2023. For assistance, please contact Margaret Lloyd at mglloyd@ucanr.edu.

This organic nitrogen estimation document is intended to serve as an interactive guide to help users understand and estimate a seasonal crop-specific organic nitrogen budget. It includes a Worksheet (section 3 of the document), which can be used to estimate a budget for organic production. Because users will have to make many decisions to complete the Worksheet, we have developed an Overview (section 1), which outlines the factors affecting nitrogen release and discusses key considerations for making the necessary decisions. The Overview can be read as a stand-alone document to explain nitrogen release in organic production, but it is organized to match the Worksheet. Likewise, the Worksheet refers to many of the tables and figures that appear in the Overview. While completing the Worksheet, users will often find that they have to do side calculations so that the units they use at home will match the units used in the Worksheet. Examples of common conversions are linear bed feet to acreage, yards to tons, and gallons to acre-inches. The Conversion Tool that accompanies this publication allows quick access to these conversions.

The Worksheet is best completed using detailed information specific to the individual farm operation. As such, we have developed a Preparation Guide (section 2) to lay out the information that users will need to complete the Worksheet. Users can work through the Preparation Guide before sitting down to complete the Worksheet. If workshops or one-on-one sessions are scheduled, the Preparation Guide can also be given to users in advance so they will be prepared with the information they need. Brief descriptions of the sections appear below.

Section 1. Overview of "Estimating nitrogen availability in organic vegetable production: For nitrogen budgeting and other purposes"

This descriptive document (the Overview) explains all categories in the Worksheet and explains how organic nitrogen budgeting works. The Overview can also be used as a stand-alone document by those who want to understand organic nitrogen budgeting.

Section 2. Preparation Guide: Gathering information for the nitrogen Worksheet

This document (the Preparation Guide) is intended to serve as a cheat sheet that helps users collect information before preparing a nitrogen budget, thus making it faster and easier to complete the Worksheet. Section 2 contains numbering that corresponds with the locations in the Worksheet where information will be used.

Section 3. The Worksheet: Estimating nitrogen availability

This Worksheet serves as a guide for calculations undertaken in a nitrogen budget. All tables and figures mentioned in the Worksheet refer to the tables and figures in section 1.

Section 4. The Demonstration Worksheet: A completed worksheet for illustrative purposes

This completed Demonstration Worksheet serves as an example for users. It includes notes about decisions that one grower made during the process of completing the Worksheet.

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Glossary

Ammonium (NH_4^+): A mineral form of nitrogen that is readily plant-available.

Crop residue: Plant material remaining after harvesting, including leaves, stalks, and roots (OECD 2001).

Culling: Sorting of produce, usually to eliminate injured, decayed, or otherwise defective items (culls) before cooling or additional handling (Kitinoja and Kader 2015). Cull fruit is the fruit removed by this process.

Denitrification: Denitrification occurs when nitrogen is lost through the conversion of nitrate to gaseous forms of nitrogen, such as nitric oxide, nitrous oxide, and dinitrogen gas. This occurs when the soil is saturated and the bacteria use nitrate as an oxygen source (Johnson et al. 2005).

Immobilization: The reverse of mineralization. All living things require nitrogen; therefore, microorganisms in the soil compete with crops for nitrogen. Immobilization refers to the process in which nitrate and ammonium are taken up by soil organisms and therefore become unavailable to crops. Incorporation of materials with a high carbon-to-nitrogen ratio (for example, sawdust, straw, and so on), will increase biological activity and cause a greater demand for nitrogen, and thus result in nitrogen immobilization. Immobilization only temporarily locks up nitrogen. When the microorganisms die, the organic nitrogen contained in their cells is converted by mineralization and nitrification to plant-available nitrate (Johnson et al. 2005).

Leaching: A pathway of nitrogen loss that is a matter of high concern where water quality is concerned. Soil particles do not retain nitrate very well because both are negatively charged. As a result, nitrate easily moves with water in the soil. The rate of leaching depends on soil drainage, rainfall, amount of nitrate present in the soil, and crop uptake. The U.S. Environmental Protection Agency has set the maximum contaminant level for drinking water at 10 parts per million of nitrogen as nitrate. Well-drained soils, unexpectedly low crop yields, high nitrogen inputs (especially outside the growing season), and high rainfall are all conditions that increase the potential for nitrate leaching (Johnson et al. 2005).

Mineralization: The process by which microbes decompose organic nitrogen from manure, organic matter, and crop residues to ammonium (Johnson et al. 2005). Because mineralization is a biological process, rates of mineralization vary with soil temperature, moisture, and the amount of oxygen in the soil (aeration).

Mineral forms of nitrogen: Forms of nitrogen including ammonium and nitrate.

Nitrate (NO_3^-): A mineral form of nitrogen and the most plant-available form of nitrogen. Mineral forms of nitrogen include ammonium and nitrate.

Nitrification: The process by which microorganisms convert ammonium to nitrate to obtain energy. Nitrate is the most plant-available form of nitrogen, but is also highly susceptible to leaching losses. Nitrification is most rapid when soil is warm (67–86°F), moist, and well-aerated, but is virtually halted below 41°F and above 122°F (Johnson et al. 2005).

Nitrogen fixation: The conversion of atmospheric nitrogen to a plant-available form. This occurs either through an industrial process, as in the production of commercial fertilizers, or a biological process, as with legumes such as alfalfa and clover. Nitrogen fixation requires energy, enzymes, and minerals, so if a plant-available form of nitrogen is present, the crop will use it instead of fixing it from the air (Johnson et al. 2005).

Plant-available: The forms of nitrogen—nitrate and ammonium—that are readily available for use by most plants.

Soil organic matter (SOM): The organic fraction of the soil, exclusive of undecayed plant and animal residues (SSSA 2020).

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Section 1
Overview of "Estimating nitrogen availability in organic vegetable production: For nitrogen budgeting and other purposes"

A crop-based nitrogen (N) budget can help estimate whether a crop's nitrogen supply is appropriate for both optimal crop production and water-quality protection.

This document covers the typical sources of nitrogen in organic, annual cropping systems, which include:

- soil organic matter
- granular fertilizers
- liquid fertilizers
- crop residue, including cover crops
- irrigation water
- compost
- residual soil nitrate

While each of these materials can be a source of nitrogen, the total nitrogen in a material often differs from the amount available to plants. This fact is especially relevant in organic systems due to their reliance on soil microorganisms to mineralize complex organic forms of nitrogen into plant-available nitrogen. This document will help organic vegetable growers estimate the amount of plant-available nitrogen in soil based on a variety of nitrogen sources.

Soil tests are an important component of a nitrogen plan because they provide a snapshot of nitrogen status at the time of testing. This snapshot can be used to determine whether a sidedress application is needed; to cross-check expected nitrogen availability from a nitrogen application against actual nitrogen availability; to gain insight into the contributions of nitrogen from soil organic matter; to check for residual nitrogen after a growing season; and for other purposes. This document includes a discussion of utilizing soil test results for nitrogen management.

When growers more accurately predict how much nitrogen will be available to plants, they increase their ability to synchronize nitrogen supply with plant nitrogen demand and to minimize nitrogen loss to the environment.

The goal of this Worksheet is to help producers of organic vegetables understand how to estimate plant-available nitrogen to ensure crop demand is met and loss of nitrogen to the environment is minimized.

Importance of nitrogen management

Nitrogen management in organic systems is challenging because complex organic forms of nitrogen originating from compost, manures, crop residue, and other organic materials must be converted by microbes into mineral forms of nitrogen to become plant-available. Because nitrogen is an essential plant nutrient and building block for plant growth and development, it is important to maintain enough available nitrogen in the soil to meet a crop's nitrogen needs during periods of rapid growth (fig. 1).

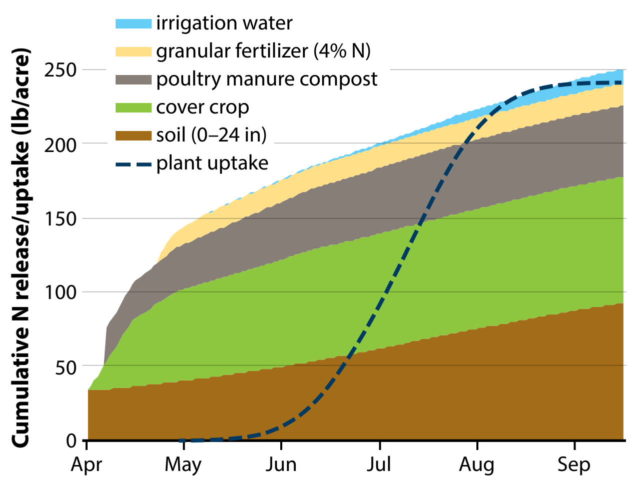

Figure 1. An example of nitrogen uptake and nitrogen supply in an organic tomato field (fresh-market tomato cv 'Brandywine'). Data are based on a field trial in Davis, California.

Note: Field trial occurred in a silt loam soil with average organic matter. Cover crop was an oat-legume mix with 3% nitrogen that averaged approximately 3 tons per acre of biomass, incorporated 1 month before planting. Granular fertilizer was applied at 700 pounds per acre. Irrigation water total is estimated at 3.6 acre-feet, with a concentration of 1 part per million of nitrate nitrogen (Geisseler, Lloyd, and Lazicki, unpublished).

The role of microbes in nitrogen availability and immobilization

Amending the soil with organic forms of nitrogen stimulates microbial activity by providing carbon (C) and nitrogen, both essential for microbial metabolism. Carbon is the primary energy source for microbial metabolic processes. To use carbon, microbes require nitrogen. "Feeding the soil" with organic forms of nitrogen stimulates microbial activity; population booms because the microbes can now break down the carbon and nitrogen sources in both the added organic material and the soil. With this activity, there is also rapid turnover of microbes as well as decomposition of soil organic matter, which become the two main ways in which ammonium (NH_4^+) and nitrate nitrogen (NO_3-N) are released and become available for plant use. As such, from each application of organic forms of nitrogen, only a portion becomes available to plants in the short term. Materials with a higher C:N ratio (for example, greater than 24:1) require additional nitrogen to facilitate microbial breakdown; this additional nitrogen is taken from the pool of plant-available forms of nitrogen in the soil. When materials with a higher C:N ratio take up more nitrogen than is produced by mineralization, the result is net nitrogen immobilization and a reduction in the amount of nitrogen available to plants. This process is sometimes referred to as "tying up nitrogen," or favoring nitrogen immobilization. As microbial populations grow and become more active, they can cycle both carbon and nitrogen in the soil matrix, releasing nitrogen from previously bound organic forms into forms readily taken up by plants. **Unmineralized organic nitrogen becomes part of the pool of nitrogen in soil organic matter, available in the future because most material eventually is subject to mineralization processes** (fig. 2)**.**

Soil-dwelling organisms—bacteria, fungi, nematodes, and microarthropods, along with plant roots—live in the environment of soil aggregates, which are aerobic except when very wet. Here, these organisms form a soil food web in which soil microbes are consumed by predators like amoeba, nematodes, and ciliates, which in turn are consumed by organisms higher in the trophic level. In this way, carbon and nitrogen move from soil organic matter to life forms up the soil food web, while the waste materials from those organisms contribute back to the soil organic matter. Consequently, the soil organic matter is in continuous flux, in both the amount and type of nitrogen and carbon. To facilitate microbially-driven plant-available nitrogen is to have active soil organic matter pools and a dynamic soil food web, rich with predators, that keeps the system moving through these phases. It takes time to establish such an environment in an organic system, especially more complex food webs that include predators. In addition to the soil food web, we can also increase plant-available nitrogen through microbial symbioses, like legume-rhizobial symbiosis. This issue is more fully discussed in "Crop residue: Available nitrogen from cover crops and postharvest residues."

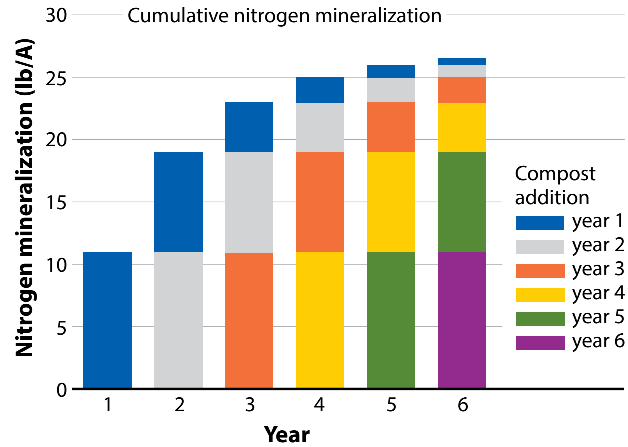

Figure 2. A model of available mineral nitrogen increasing and approaching a steady state after about 4 years, when receiving continual application of the same amount of organic nitrogen (43 lb N/acre) from a cover crop (Crohn 2004).

Nitrogen leaching

Once mineralized, organic forms of nitrogen are converted into plant-available mineral forms of nitrogen: ammonium and nitrate (NO_3^-). Ammonium has a positive charge and is attracted to the negative charges on clay particles and soil organic matter. Ammonium is typically short-lived in warm soils because microbes convert it to nitrate. Nitrate has a negative charge and is repelled by these negative charges (fig. 3). Nitrate is used by plants, used by microbes, or leached with water. To minimize nitrate leaching, irrigation needs to be carefully managed, especially with young or shallow-rooted plants.

Conclusion

The available nitrogen pools in a soil can be estimated by considering the plant uptake curve, inputs like compost and fertilizers, crop residue, soil type, and

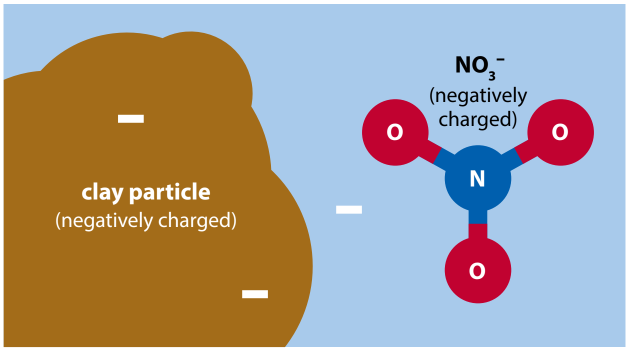

Figure 3. Sketch of a negatively charged nitrate molecule and a negatively charged clay particle.

irrigation management. Therefore, understanding and calculating the influence they each have are central to nitrogen management. This article provides estimates of nitrogen availability and timing around these components as a tool to guide nitrogen management decisions.

Part 1. Crop nitrogen demand

The key ideas in establishing crop nitrogen demand are the following:

- Target nitrogen need is established based on crop uptake demand.
- Winter-grown crops generally use less nitrogen than summer-grown crops.
- Uptake numbers are best used as a starting point, not as an absolute.

A. Crop nitrogen uptake: Establishing your target need

Crop nitrogen demand and yield are very closely linked. Crop nitrogen demand includes nitrogen requirements to produce the plant material, harvested crop, and cull produce, so yield is a good starting point for estimating how much nitrogen the crop needs. Predicted yield is useful for tailoring the total crop nitrogen demand to your operation and calculating nitrogen removed from the field with harvested fruit (table 1). When reviewing crop nitrogen demand estimates, consider how the location, production method (organic or conventional), yield, and other factors associated with this information may differ from your conditions and expected yield—and adjust accordingly. Most data will be based on yields achieved when crops are grown on commercial-scale, conventional production operations under optimal conditions. A few reputable sources that publish this type of information are land-grant universities, UC Cooperative Extension, and commodity groups.

Time of year and soil properties must be considered. Crops that can be grown in both winter and summer usually take up less nitrogen in a winter planting. Soil texture influences water movement, which influences nitrate movement. In contrast to clay soils, which hold water more tightly, sandy soils allow more pronounced leaching of residual nitrate. On a sandy soil after a wet winter,

Table 1. Estimates of nitrogen uptake by major California crops

Crop	Example yield (tons/acre)	Total crop N uptake		N in harvest (lb N/ton yield)
		(lb N/ton yield)	(lb N/acre)	
Lettuce*	20	8	160	3
Tomato (fresh-market)[†]	30	8	240	4
Tomato (processing)[‡]	50	5	250	3
Sweet potato[§]	20	5	100	5
Broccoli[#]	10	35	350	11
Carrot[a]	20	10	200	3
Melon[b]	20	7	140	4
Potato[c]	25	11	275	6
Strawberry[d]	40	5	200	3
Spinach[e]	15	8	120	5

Note: For additional crops, see the "Resources" section.
*Bottoms et al. 2012; Hartz et al. 2017.
[†]Lazicki et al. 2019.
[‡]Hartz and Bottoms 2009.
[§]Weir and Stoddard 2001.
[#]Hartz et al. 2017.
[a]Lazicki and Geisseler 2016.
[b]Contreras et al. 2012; Soto-Ortiz 2008.
[c]Wilson et al. 2012.
[d]Bottoms et al. 2013.
[e]Heinrich et al. 2013.

it is often necessary to apply more fertilizer nitrogen to make up for the loss of residual soil nitrogen than after a dry winter.

Despite one's best efforts, the amount of nitrogen applied may not match the amount of nitrogen taken up by plants. One scenario in which more nitrogen is applied than taken up occurs when mineral nitrogen is leached below the root zone via rain or irrigation water. In this case, a crop may show nitrogen deficiency despite carefully calculated additions. On the other hand, when crops are planted in fields where crops such as broccoli and alfalfa have left large amounts of nitrogen-rich residues in the soil, the amount of fertilizer nitrogen needed for the new crop's optimal growth may be lower than the crop's total uptake. Mineralization of nitrogen from crop residues can supply a significant portion of crop needs, meaning that less additional nitrogen is required. Lastly, field variability can lead to differences between nitrogen additions and nitrogen uptake. To address these scenarios, soil testing provides guidance on the current status of available soil nitrogen. Depending on the levels of residual nitrate in the soil, the quantity of nitrogen that the grower needs to add can be adjusted up or down. While these inefficiencies can be minimized with good management, they cannot be eliminated. This also means that uptake numbers are best used as a starting point, not a prescription.

Part 2. Nitrogen supply: Baseline

B. Available nitrogen from soil organic matter

The amount of nitrogen released from the soil organic matter depends on

- the amount of soil organic matter
- soil temperature
- soil moisture
- soil texture

A common rule of thumb is that about 1 to 3 percent of the total nitrogen in soil organic matter becomes available annually (roughly 50–120 pounds of nitrogen per acre per year in the top 12 inches) (table 2).

Long-term additions of cover crops, manures, and compost all increase soil organic matter, thereby increasing the amount of nitrogen that will become available from the soil.

Under warm, moist conditions, more available nitrogen is released from the soil (and amendments) than when the weather is cool or dry (see table 2). For irrigated California crops, more nitrogen will be available in summer than winter (fig. 4). This means that a crop planted in warm weather will be able to meet more of its nitrogen needs from nitrogen

Table 2. Estimates of nitrogen mineralization (lb N/acre/month) from soils with low and high soil organic matter (SOM) in three climate regions of California, assuming 2 percent of soil nitrogen is mineralized annually in the top 12 inches

	Central Coast*		Sacramento Valley†		Imperial Valley‡	
	1.5% SOM	3.0% SOM	1.5% SOM	3.0% SOM	0.75% SOM	1.5% SOM
January	3	6	2	5	2	3
February	3	6	2	5	2	3
March	4	7	3	6	2	5
April	5	9	4	8	3	6
May	6	11	6	11	4	8
June	6	12	7	14	5	10
July	7	14	9	17	6	12
August	7	15	8	17	6	13
September	7	13	7	14	5	10
October	6	11	5	11	4	8
November	4	8	3	7	3	5
December	3	6	2	5	2	4

Note: Data were modeled using 5-year average soil temperatures for each region.

*The Central Coast extends from Ventura to Santa Cruz counties and is known for a mild coastal climate. It receives about 10 inches of annual precipitation.

†The Sacramento Valley is the northern end of the Central Valley. It receives about 20 inches of annual precipitation.

‡The Imperial Valley extends from the Salton Sea to Mexico. Part of a hot desert climate, it receives less than 3 inches of annual precipitation.

released from soil organic matter than will a crop planted in cooler weather.

Soil texture also influences nitrogen mineralization from soil organic matter because soils with higher clay typically have higher soil organic matter and higher nitrogen mineralization rates than those with lower clay content, such as sandy and loamy soils (Colman 2013).

Example calculation

How much nitrogen may become available in a year from mineralization of soil organic matter in the top 7 inches of an acre if

- the soil is a Yolo silt loam
- the mineralization rate of soil organic matter is 2 percent
- organic nitrogen constitutes about 5–7 percent of soil organic matter
- the soil is 2 percent organic matter
- the bulk density is 1.45 grams per cubic centimeter

Perform the following operations:

2.3×10^6 lb soil/acre (estimated weight of 1 acre of topsoil from 0 to 7 inches in depth) × 0.02 (% organic matter) x 0.07 (% N) × 0.02 (% mineralized) = 64.4 lb N/acre.

Additional nitrogen is likely available from pools of soil organic matter down to 7 inches in depth. See the Worksheet for further guidance when using your own information.

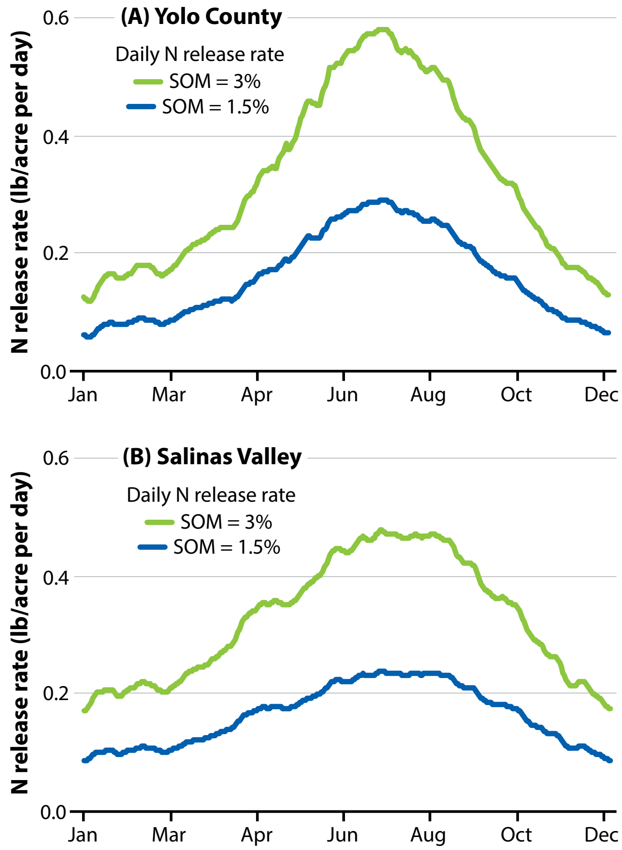

Figure 4. Modeled daily nitrogen release from soil organic matter in the top 1 foot of soils from Yolo County (A) and the Salinas Valley (B), with high and low soil organic matter content, assuming that 2% of the soil nitrogen is mineralized annually. In this example, 60 and 120 lb N/acre were mineralized from the soil with 1.5% and 3% soil organic matter, respectively.

Note: These values are modeled based on daily average soil temperature data for each region from 2014 to 2019, using parameters derived by Miller and Geisseler (2018) and an assumed nitrogen release of 2% of the soil's total organic nitrogen annually (Meisinger et al. 2008). The best way to determine the soil's actual available mineral nitrogen at a given time is through a soil test.

C. Crop residue: Available nitrogen from cover crops and postharvest residues

C1. Available nitrogen from crop residues

The amount of nitrogen made available from crop residues depends on

- biomass of the residues
- nitrogen content of the residues
- carbon-to-nitrogen (C:N) ratio
- soil moisture
- whether residues are left on the surface or incorporated

Vegetable residues can provide a significant amount of biomass nitrogen. For some crops, such as broccoli, only a small part of the nitrogen taken up is removed in the harvested, marketable part of the crop, while the rest is incorporated into the soil. Nitrogen contributions from residue can result in a return of 178 to 255 pounds of nitrogen per acre. Review table 3 for additional estimates of nitrogen contributions from crop residue.

Typically, nitrogen concentration in vegetable residues varies from 2.5 to 5.0 percent, which is similar to a leguminous cover crop. Cereal cover crops can have more than 2.5 percent nitrogen prior to the boot stage, but they decline to below 2.0 percent upon entering the flowering stage.

The lower the C:N ratio, the faster mineralization becomes and the more nitrogen is available for plant uptake. Vegetable crop residues typically have a C:N ratio below 15:1, which allows for rapid nitrogen mineralization to begin immediately following incorporation into moist soil. In residues with a C:N ratio between 15:1 and 20:1, as is common in cover crops, nitrogen mineralization will proceed more slowly. Residues with C:N ratios greater than 20:1 may temporarily immobilize, "tying up" nitrogen. Figure 5 shows the results of an incubation with incorporated high-nitrogen, medium-nitrogen, and low-nitrogen residues at optimum moisture. The reduction of nitrogen contributions from material with a lower nitrogen percentage is twofold. For example, comparing a material that contains 5 percent nitrogen to one with 3 percent nitrogen, the total amount of nitrogen in material of the same weight will be lower in the latter because 3 percent of the total is less than 5 percent of the total. But in the material with 3 percent nitrogen, *a lower proportion of nitrogen in the material will be mineralized* than in the material with 5 percent nitrogen. That is, close to 60 percent of the nitrogen in the material with 5 percent nitrogen may be mineralized—whereas closer to 30 percent will become available in the material with 3 percent nitrogen.

The lower the percentage of nitrogen in the material, the lower the mineralization rate (see fig. 5).

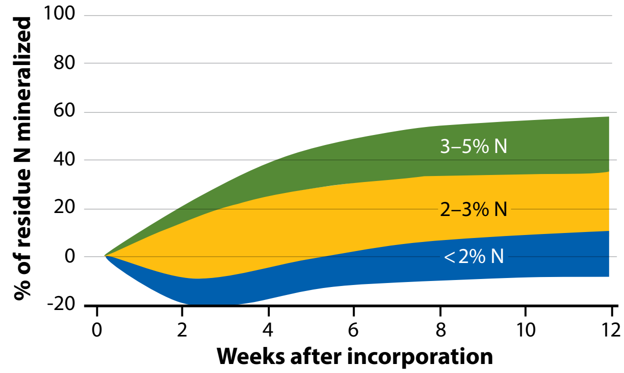

Figure 5. Examples of nitrogen release timing from high, medium, and low-N residues (Hartz 2016). The C:N ratios average about 10:1, 20:1, and >20:1, respectively. Examples of residue with nitrogen in the range of 3–5% are broccoli, lettuce, and celery; an example of residue with nitrogen in the range of 2–3% is tomatoes.

The majority of crop residue is mineralized in the first 2 to 4 weeks after incorporation into moist soil. Because of this timing, nitrate made available from the mineralization processes is susceptible to loss via rain, irrigation, volatilization, or denitrification during establishment of the subsequent crop. Leaching of residual soil nitrate that a crop does not yet need is one reason that it is best to make nitrogen budgets for first spring crops on the basis of soil testing that determines how much nitrogen remains at planting, before a rapid growth phase, or both (fig. 6).

Table 3. Estimated nitrogen amount and availability of residues from common California crops (Central Coast of California)

	Example yield (tons/acre)	N in residues (% of total)	Expected residue N	
			(lb N/ton yield)	(lb N/acre)
Lettuce*	20	68	5	100
Tomato (fresh-market)[†]	30	56	4	120
Tomato (processing)[‡]	50	46	2	100
Broccoli[§]	10	68	24	240
Carrot[#]	20	67	7	140
Melon[a]	20	40	3	60
Potato[b]	25	44	5	125
Strawberry[c]	40	46	2	80
Spinach[d]	15	38	3	45

Note: "N in residues" refers to the percentage of the total nitrogen taken up by a plant that remains in the postharvest residue. For example, after marketable lettuce is removed from the field, 68 percent of the total nitrogen taken up by the lettuce remains in the field as residue. The values in this table are mostly based on studies with commercial, conventionally managed vegetables in high-production areas, so the yield values may be high compared to comparable organic production. The amount of nitrogen expected to be in the residues can be adjusted for the actual expected yield by multiplying the actual yield by the value shown for "lb N/ton yield."

*Bottoms et al. 2012; Hartz et al. 2017.

[†]Lazicki et al. 2019.

[‡]Hartz and Bottoms 2009.

[§]Hartz et al. 2017.

[#]Lazicki and Geisseler 2016.

[a]Contreras et al. 2012; Soto-Ortiz 2008.

[b]Wilson et al. 2012.

[c]Bottoms et al. 2013.

[d]Heinrich et al. 2013.

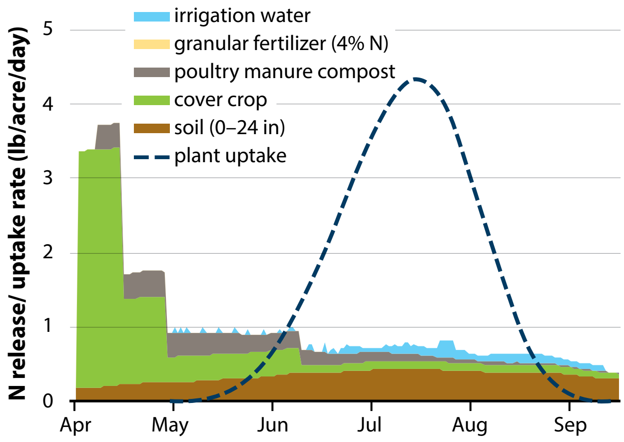

Figure 6. Example of how an early season soil nitrate test can be used to assess the available nitrogen for rapid growth.

The more mature a crop is (for example, a crop is more mature when it is producing fruit or grain), the lower the nitrogen in the residue and the higher the C:N ratio.

Surface-applied residues decay more slowly than incorporated residues because residue decomposition is a microbial process that requires contact with microbes and moisture. In addition, surface-applied residues are more vulnerable to nitrogen loss via volatilization to the atmosphere.

C2. Available nitrogen from cover crops

The following issues influence the amount of nitrogen provided by cover crops for subsequent vegetable crop growth:

- biomass of cover crop
- nitrogen content of cover crop, which is higher in legumes and in younger material
- C:N ratio, which increases as material ages, lowering plant-available nitrogen
- cover crop incorporation, with crops left on the surface mineralizing less nitrogen than those incorporated

The vast majority of nitrogen in cover crop biomass is found in the aboveground plant biomass, regardless of whether the nitrogen came from residual nitrate in the soil or atmospheric nitrogen fixed by bacteria in legume roots. Often cover crop mixes include both grasses and legumes. Grasses have deep, efficient root systems and scavenge residual nitrogen from throughout the soil profile. Legumes form a symbiotic relationship with bacteria in the soil and fix atmospheric nitrogen for their own metabolic use. This ability to extract atmospheric nitrogen means that legumes provide a net input of nitrogen to the soil when incorporated, and also typically have higher nitrogen content in their tissues. Biomass production and nitrogen content of cover crop species commonly used in vegetable production are shown in table 4.

Generally, cover crop age and nitrogen content drive nitrogen availability: The younger the crop and the higher the nitrogen content of that species, the higher the nitrogen availability following incorporation. Legumes and mustards have higher nitrogen content in their tissue (for example, greater than 2%), which results in more rapid nitrogen

Table 4. Measurements of cover crop biomass production and nitrogen content in aboveground biomass (Central Coast of California)

Cover crop	Crop biomass, dry (T/A)	Tissue N content (%)	Total N in crop biomass (lb/A)
'Cayuse' oat	4	1.7	136
'Merced' rye	3.6	1.9	137
Mustard*	3	2.6	156
Bell bean	3	2.7	162
Cereal/legume mix†	3	2.9	174
'Magnus' pea	2	3.6	144
Purple vetch	2	3.7	148
'Lana' woollypod vetch	2	4.7	188

Note: Measurements were taken "at maturity," typically in March. Data represent a summary of more than 5 years of cover crop field evaluations. The amount of cover crop nitrogen that is made available for vegetable-crop growth varies widely, and estimates range from nitrogen immobilization to 50 percent mineralization. Compare the "Tissue N content" column to the "Percent of N residue mineralized" in figure 5 to calculate available N from the cover crops in this table.

*50:50 mix of *Sinapis alba* and *Brassica juncea*.

†Oats, bell beans, peas, and vetch.

mineralization and at a higher percentage. The nitrogen content of cereals can be higher than 2 percent when they are juvenile (for example, prior to flowering), but it significantly declines as cereals mature. As a result, the amount of nitrogen that is mineralized from cereal cover crop biomass can be less than from legumes planted in the same mix. For most crops, peak total nitrogen content occurs at peak flower, when the biomass is high and nitrogen remains in the tissue prior to being used for seed production.

> Cover crop mixes with a higher proportion of legumes will release more of their nitrogen than grass-heavy mixes, particularly when terminated before flowering.

Oregon State University has developed a calculator for estimating cover crop nitrogen contributions, extension.oregonstate.edu/organic-fertilizer-cover-crop-calculators. The calculator requires sampling small representative areas, recording the total fresh weight, and sending in a subsample to a lab for analysis. Since the calculator uses location-specific climate and moisture conditions, values should only be taken as broad estimates.

The amount of cover crop nitrogen that is made available for subsequent crop growth varies widely, and estimates range from tying up nitrogen to 50 percent mineralization. The majority of nitrogen mineralization from a cover crop typically happens within the first 6 weeks. Therefore, crops grown from transplants can initially use the available nitrogen better than crops grown from seeds following a legume cover crop because their root systems are more developed and can explore the soil to take up that nitrogen. Unmineralized nitrogen from cover crops contributes to the total nitrogen in the soil organic matter and long-term soil fertility.

Soil testing for residual nitrate will measure nitrogen from cover crop mineralization and might be a useful tool for understanding the contribution of nitrogen from cover crops. Refer to part 4 of this section for more guidance on soil testing.

D. Irrigation water

D1. Sampling water for testing

Where nitrate leaching has led to elevated nitrogen in well water or groundwater, a considerable amount of nitrate may be applied to the crop in irrigation water. This can be seen in figure 7, derived from field trials with drip-irrigated lettuce in Salinas. It shows the relationship between nitrogen concentration in the irrigation water and plant-available nitrogen, at irrigation rates ranging from 4 to 10 acre-inches (R.F. Smith et al., unpublished data). Data points represent different fields. Be sure to include the nitrate from irrigation water in your budget. Also, keep in mind that nitrogen from irrigation water will be immediately plant-available upon irrigating (see figs. 1 and 7).

For more information on the fertilizer value of irrigation water nitrate, see calag.ucanr.edu/archive/?type=pdf&article=ca.2017a0010.

Part 3. Nitrogen supply: Seasonal inputs

E. Available nitrogen from organic amendments

Composts, manures, and organic fertilizers are all applied to supplement soil nitrogen. Nitrogen availability from these materials varies widely (table 5). Figure 8 shows how quickly nitrogen became available from different amendment types when mixed with organically managed field soil and incubated for 84 days in warm and moist soil (73°F and 60% water-holding capacity). A negative value indicates nitrogen immobilization. In other words, nitrogen is "tied up," so it is plant-unavailable. Actual nitrogen release rates in the field will depend on soil moisture and temperature but will follow a similar pattern.

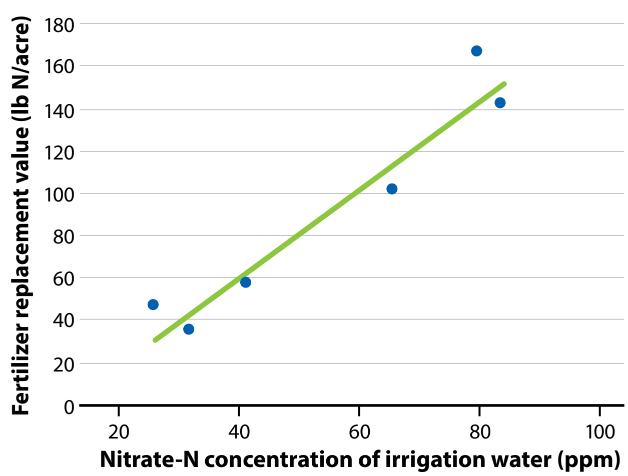

Figure 7. The relationship between nitrate-N concentration in irrigation water and its contribution to nitrogen fertilizer savings. Each dot represents a farm sampled.

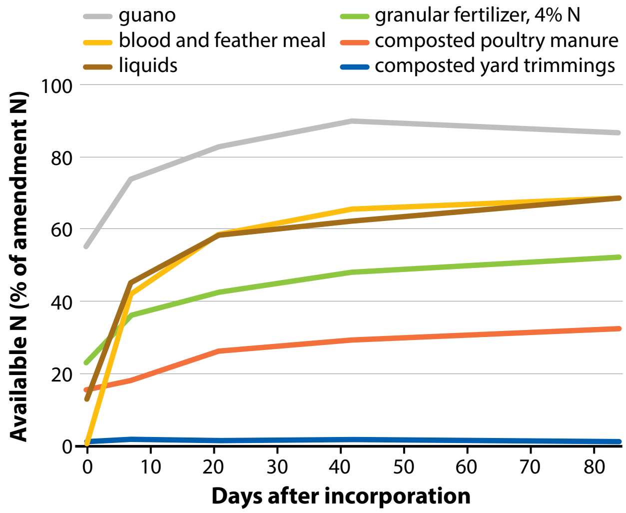

Figure 8. Predicted nitrogen release curves from different amendment types under warm, moist conditions (Lazicki et al. 2020).

The C:N ratio of an amendment is a good predictor of how quickly nitrogen will be released (fig. 9A; see table 5). The lower the C:N ratio in the material, the more quickly nitrogen will be released. As the C:N ratio exceeds 15:1, available soil nitrogen moves closer to zero due to the temporary "tying up" of nitrogen. In that case, the amendment should not be applied too close to planting.

- Materials with low C:N ratios, like guano, feather meal, and fish emulsion release much of their nitrogen in the first week, and almost all their nitrogen within 3 weeks. This quality makes them good sidedress materials, or materials to quickly remediate known nitrogen deficiency.
- Poultry manure composts and granular fertilizers contribute some available nitrogen as soon as they are applied, but release their nitrogen more slowly. When applied in or near moisture under warm conditions, they will release more quickly, though still over weeks, not days.
- Materials with high C:N ratios, like plant-based yard-trimming composts, release almost no nitrogen. They provide carbon, which supports microbial communities and over time improves soil physical structure, but provide little nitrogen for the current crop. Long-term soil fertility may be improved.
- When C:N ratio is unavailable, the total nitrogen concentration is closely related to availability. Generally, as total nitrogen increases, availability of nitrogen increases, forming a curve similar to that seen in figure 9B.

The C:N ratio of an amendment is a good predictor of how quickly its nitrogen is released (see fig. 9A). The lower the ratio, the more quickly nitrogen will be released.

Plant-based liquid fertilizers ranged from 48 percent to 92 percent nitrogen availability, whereas manure-based liquid fertilizers (typically fish) ranged from 83 percent to 99 percent nitrogen availability, after 4 weeks (Hartz et al. 2010; Lazicki et al. 2020). Organic liquid fertilizers are suspensions and often include particulate matter with which 8 to 21 percent of total nitrogen content is associated. Without proper filtration, these materials increase the risk of clogging drip emitters. If they are injected before the filter, a significant amount of the nitrogen

Table 5. Potential nitrogen availability from several types of organic amendments under warm, moist conditions

Material	Typical % N	Typical C:N ratio	N available after 12 weeks	Releases in
Municipal yard-trimming composts	0.5–2	13–20:1	−3% to +4%*	years
Poultry manure composts	2–5	6–8:1	30–35%	weeks to months
Granular fertilizers (except guano)	2–7	5–7:1	38–60%	days to weeks
Blood and feather meal	13–15	3–4:1	65–70%	days
Liquid fertilizers	2–4†	4–6:1	65–70%	days
Guano	12–13	3–4:1	80–90%	days

Note: All % N numbers for solid amendments are on a dry-weight basis.

*Negative numbers mean the compost addition resulted in net nitrogen immobilization (Lazicki et al. 2020).

†Because liquid % N is reported on a fresh-weight basis, it isn't a good indicator of the release rate (see fig. 9B).

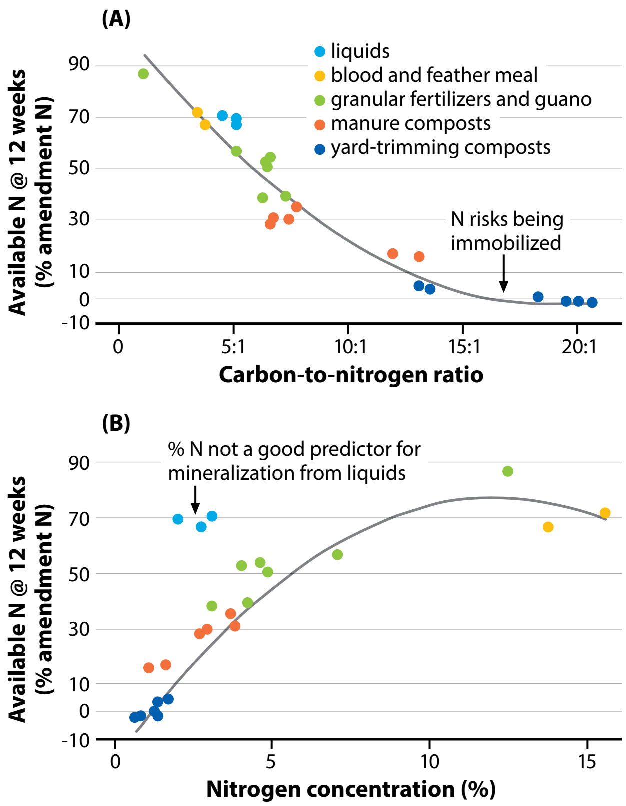

Figure 9. Relationship between potentially available nitrogen and ratio of amendment carbon to nitrogen (Lazicki et al. 2020).

can be removed from the suspension (Hartz et al. 2010). Regular backflushing may be required to maintain system flow. New technology in liquid organic fertilizers is now providing materials in which nitrogen is thoroughly dissolved and which do not present the issues just discussed. Taking into account the high per-unit cost of nitrogen in a liquid product, liquid fertilizers can be an easy way to supplement in-season fertility but are often viewed as too expensive to provide the bulk of a crop's nitrogen demand.

In all cases, amendment nitrogen release is slower in cool weather or dry conditions because microbial activity is decreased. Crops planted in cold temperatures may benefit from starter fertilizers that contain some available nitrogen initially—those with a higher amount at day 0 and a steep initial curve (see fig. 8). For example, roughly 15 percent of total nitrogen in the poultry manure–based composts tested was available at initial application, while granular fertilizers started with an average of about 22 percent (see fig. 8).

Part 4. Soil and tissue testing for verification and monitoring

The objective of soil–nitrate nitrogen sampling is to capture the amount of soil nitrogen that will be available for crop uptake in the current season. Nitrogen is a very dynamic nutrient. It's constantly being released from organic forms, taken up by plants and soil organisms, leached downward in water, or volatilized into the atmosphere. Therefore, the results of a soil nitrate test are only relevant for that moment in time. A soil nitrate test in fall will *not* show how much nitrogen will be available for plant uptake the following spring. Soil tests can be sent to a lab for analyses for $25 to $50 per sample, or conducted in the field using nitrate test strips, which provide an estimate for roughly $1 per sample.

> Nitrogen is a very dynamic nutrient. It's constantly being released from organic forms, taken up by plants and soil organisms, leached downward in water, or volatilized into the atmosphere. Using an appropriate soil sampling method and doing so at the right time are critical for nitrogen budgeting.

F. Reasons to conduct a soil test

1. **Testing can verify that applied amendments are releasing nitrogen at the anticipated rate.** Because many organic fertilizers require microbial activity to mineralize and release nitrogen in plant-available forms, there is a time lag between application and availability. As discussed above, we can make rough estimates of the amount of nitrogen that will become available from mineralization of soil organic matter, crop residue, compost, and soil amendments. And we can consider the factors that influence the rate of mineralization—namely, soil moisture, soil temperature, C:N ratio, and total nitrogen percentage. However, for more refined management objectives, soil nitrate tests that measure plant-available nitrogen in the root zone offer a snapshot of what is currently available to support plant growth. For example, if a soil test conducted in mid-June measured 20 parts per million of nitrate nitrogen, this equates to approximately 75 pounds per acre of currently-available nitrogen in the top 12 inches of soil. Figure 8 can help you predict nitrogen

availability from those amendments during the subsequent growth period of the crop.

2. **Testing can provide a guide to how much fertilizer supplementation is needed for a crop, assuming irrigation does not leach it before crop uptake occurs.** When taken prior to a fertilization event, results will indicate if there is sufficient residual soil nitrate to provide for the crop or if additional fertilizer is needed to achieve desired crop yield (see fig. 6). Soil amendments and soil organic matter continue to release nitrogen over the season and can contribute toward the nitrogen needs of the crop. Residual soil nitrates can satisfy the needs of the crop during the rapid uptake phase of the crop cycle.

Following are example scenarios of the use of preplant and presidedress soil tests that can help growers make decisions about whether additional fertilizer is needed.

For processing tomatoes, a soil nitrate test early in the crop cycle can indicate whether an in-season sidedress as late as 5 to 6 weeks after transplanting may increase fruit yield (Bottoms et al. 2012). A yield response of furrow-irrigated tomatoes was unlikely when the presidedress nitrate-nitrogen concentration in the top 2 feet of the profile was higher than 16 parts per million (Bustamante and Hartz 2015; Krusekopf et al. 2002).

For a 50- to 65-day lettuce crop, a soil sample can be taken following establishment of the crop. A test value of 20 to 25 parts per million nitrate nitrogen, or higher, indicates that there is adequate residual soil nitrate to provide for the crop's needs for a period of 10 to 14 days (Breschini and Hartz 2002).

Fast-growing 30-day crops such as spinach require that soil tests be taken prior to planting. There is not sufficient time in the crop cycle to test later, given the time required for the release of nitrogen from organic fertilizer and the crop's rapid growth rate. Testing soil nitrogen immediately prior to planting ensures that residual nitrogen is credited in the nitrogen application budget and that the crop is optimally fertilized.

3. **Postseason soil tests can also be taken just after harvest to measure how much nitrogen is left over from the crop.** High postharvest nitrate in the top foot of soil may indicate that too much fertilizer was applied or that poorly timed application of organic sources has led to nitrogen release too late in the crop production cycle.

   High postharvest nitrate content below the top 1 or 2 feet of soil may indicate excess irrigation, which can move nitrate below the root zone.

4. Soil tests can be useful for comparing or tracking performance of fields, fertilizers, and practices. They also serve as a general feedback tool for farming decisions and for farm-history purposes. Keeping records supports this monitoring ability over time and can be used to fine-tune nitrogen management.

Proper soil sampling

Proper soil sampling procedure and handling are very important for capturing the desired information. For most vegetable crops, the majority of the root system is in the top 1 foot of soil, which is also where cover crop residues are incorporated and amendments are generally placed. Therefore, soil samples are normally taken from the top foot. However, some deep-rooted crops, such as broccoli and tomato, can obtain a significant proportion of nitrogen from deeper depths. For these crops, deeper sampling improves accuracy. Each foot should be sampled separately. When nitrogen is sampled at multiple depths, results should be added together to present a single total amount of available nitrogen.

For postharvest tests, sampling as deep as 3 feet (if possible) is informative because low available nitrogen in the top foot may be the result of efficient nitrogen management or of excess irrigation, which causes nitrogen to leach below the crop rooting zone.

If sampling in beds where amendments have been banded, the bands should be avoided and more samples should be taken to allow for the possibility of hitting a band.

Please refer to the following resources for detailed descriptions of how to collect a high-quality soil sample.

- Taking and interpreting soil tests, calag.ucanr.edu/Archive/?article=ca.2016a0027
- Guidelines on soil sampling, geisseler.ucdavis.edu/Guidelines/Soil_Sampling_Nitrate.pdf
- How to use and interpret the nitrate quick test, ucanr.edu/blogs/blogcore/postdetail.cfm?postnum=4406 and smallgrains.ucanr.edu/Nutrient_Management/snqt/

Interpreting the soil test report

Nitrate nitrogen is the nitrogen form used for nitrogen budgeting. The two major forms of nitrogen which are available for plant uptake are ammonium and nitrate. Under normal growing conditions, ammonium is quickly converted to nitrate, so almost all the plant-available nitrogen will be in the form of nitrate nitrogen.

Labs normally report values as a concentration, given in parts per million, which is the same value as milligrams per kilogram. Because crop nitrogen demand is generally provided in pounds per acre, it can be difficult to relate the parts-per-million value provided by a lab report. To convert parts per million to pounds per acre, multiply this number by a factor of 3 to 4 for every foot of soil—depending on the soil bulk density, with low values for soil with very high organic matter or very heavy clay soils, and higher values for more compacted or very sandy soils. A commonly used factor for the top 12 inches of agricultural soils is 3.6, assuming a soil bulk density of 1.35 milligrams per cubic meter. See the Worksheet for more guidance on this calculation.

Some labs report the concentration of nitrate rather than nitrate nitrogen. Reports given in nitrate include the weight of the oxygen as well as the nitrogen. Use the Worksheet to convert nitrate to nitrate nitrogen.

Ways to use a tissue test

Tissue testing provides information about the current nitrogen status of a plant but does not indicate future availability of the nutrient, as is provided by a soil test. Typically, tissue tests are used to monitor nitrogen levels in a crop to check for sufficiency prior to or during rapid growth, or to determine deficiency based on symptoms. Tissue type used for sampling varies by crop, as do nitrogen percentage levels and timing. Refer to table 6 for crop-specific guidance.

Table 6. Plant tissue sampling guidance for sampling method and result interpretation

Crop	Growth stage	Plant part to sample	Number of plants to sample	Sufficient leaf N (%)
		Vegetables		
Broccoli*	first buds to heading	recently matured leaf, typically 3 to 4 nodes down from the growing point	20–60	3.0–5.0
Carrot†	midgrowth (>4 inches high)	most recently matured leaf or petiole	20–30	2.1–3.5
Cauliflower*	head initiation	recently matured leaf, typically 3 to 4 nodes down from the growing point	20	3.0
	preharvest	recently matured leaf, typically 3 to 4 nodes down from the growing point	20	3.0
Celery*	midgrowth	most recently matured leaf or petiole	20	2.5
	preharvest	most recently matured leaf or petiole	20	2.0
Lettuce‡	early heading to preharvest	youngest wrapper leaf	20–60	4.3–5.6
Melon§	early flower	most recently matured leaf or petiole, typically sixth from the growing tip	20–30	2.7–4
	early fruit set/bulking	most recently matured leaf or petiole, typically sixth from the growing tip	20–30	2.3–3.5
	first harvest	most recently matured leaf or petiole, typically sixth from the growing tip	20–30	2.0–3.0
Onion#	early season	tallest leaf	20–30	3.0
	midseason	tallest leaf	20–30	2.5
	late season	tallest leaf	20–30	2.0
		Berries		
Strawberry[a]	preharvest	young mature leaves	30–40	3.1–3.8
	main harvest	young mature leaves	30–40	2.4–3.0

**Source*: Hartz 2007; Jones 1998.
†*Source*: CPHA 2002; Jones 1998.
‡*Source*: Hartz et al. 2007; Jones 1998.
§*Source*: CPHA 2002; Lorenz and Tyler 1976.
#*Source*: Maynard and Hochmuth 2007.
[a]*Source*: Hartz 2012; Ulrich et al. 1992.

Part 5. Timing nitrogen with crop demand

To optimize nitrogen-use efficiency it is essential to synchronize nitrogen application with periods of plant nitrogen demand (fig. 10).

- Nitrogen uptake by crops producing fruit or seeds often follows an “S” shape, as shown for tomato (fig. 10B). Uptake is slow during crop establishment. Uptake is rapid as crop growth accelerates, but slows or stops late in the season when seed or fruit ripen. One exception is strawberry, which maintains nitrogen demand through harvest (fig. 10C).
- For crops whose leaves, stems, or flowers are harvested during vegetative growth (broccoli, lettuce, celery), nitrogen uptake is normally rapid until harvest (fig. 10A). This has implications for management of residual nitrogen, as crops that require high levels of nitrogen in the soil right up to harvest may be more challenging to manage in a way that minimizes residual nitrogen vulnerable to postseason leaching. Postharvest soil testing can be an important check for residual nitrogen levels to determine whether postharvest nitrogen management steps are needed to minimize nitrogen leaching to the environment.

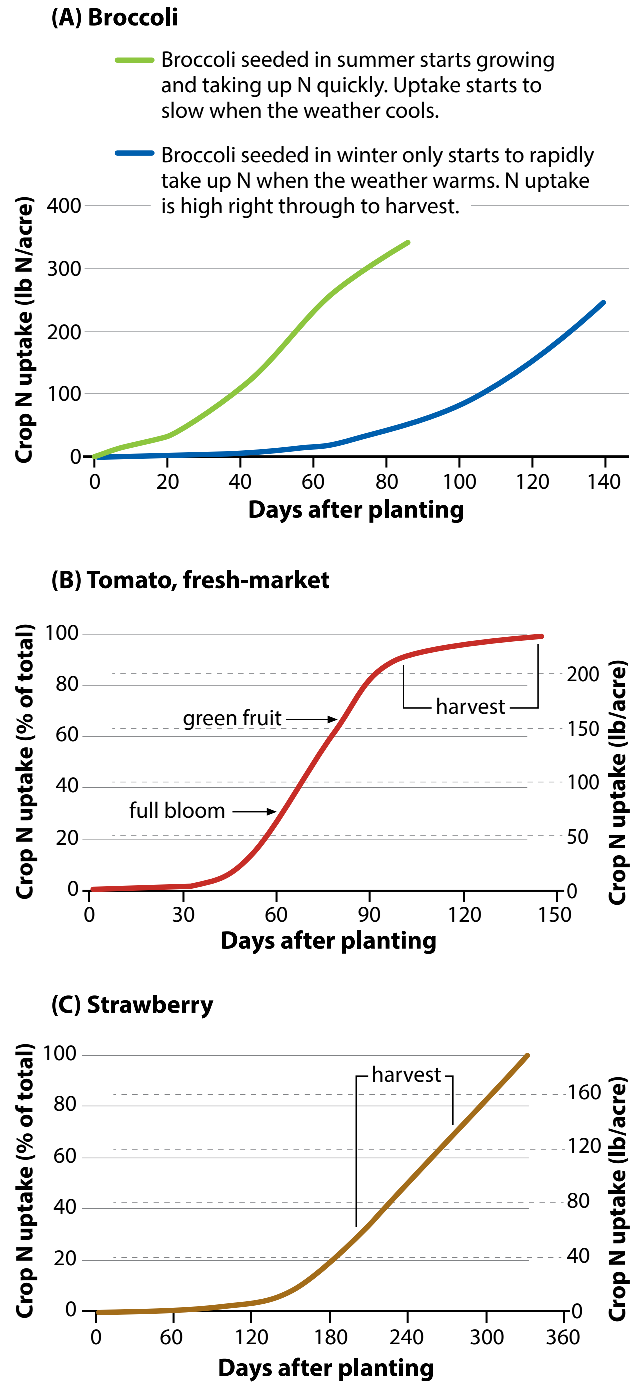

Figure 10. Example nitrogen uptake curves of different crop growth patterns (Smith et al. 2015, in Monterey, California; Bottoms et al. 2013, in the Salinas and Pajaro Valleys). *Note:* Broccoli data are based on a conventional field in the Salinas Valley. Yields were 28,000 and 22,000 lb/acre for summer- and winter-seeded broccoli, respectively. Tomato data are derived from a fresh-market organic heirloom trial in Yolo County. Total yield was 62,000 lb/acre, with unpublished data. For strawberry from conventional fields in the Salinas and Pajaro valleys, yield was 72,000 lb/acre. Nitrogen uptake curves for additional crops can be found at geisseler.ucdavis.edu/Guidelines/N_Uptake.html.

Conclusion

Nitrogen availability on an organic farm is influenced by many factors—including cropping choices, amendment applications, and tillage—and aspects of the land and climate such as soil type, water quality, rainfall, and temperature. Consequently, it can be very challenging, if solely relying on the worksheet approach, to achieve a real balance between nitrogen inputs and nitrogen outputs. This is largely because the amount of nitrogen mineralized from soil organic matter is likely to be highly variable among fields and cropping histories, which can contribute a very wide range of available nitrogen. For this reason, it is essential to combine the worksheet approach with soil sampling during the growing season to determine whether nitrate in the root zone is deficient, adequate, or excessive.

Successfully predicting nitrogen availability from multiple, diverse sources on an organic farm is a learning process. Your ability to synthesize and refine your understanding of nitrogen mineralization on your farm will come from using data like those presented in this article—in combination with taking regular soil and tissue tests, crunching numbers in your nitrogen budget, recordkeeping, and making field observations. With dedication and time, you will hone your ability to understand and predict nitrogen release on your farm to optimize crop productivity and minimize environmental pollution.

Resources

Resource: Soil fertility management for organic crops (UC ANR publication 7249)

Description: UC Cooperative Extension guide to using organic soil fertility sources

Location: https://anrcatalog.ucanr.edu/pdf/7249.pdf

Resource: California fertilization guidelines: Crop nitrogen uptake and partitioning

Description: Estimates total nitrogen uptake amount and timing for major California Crops (annual and perennial)

Location: http://geisseler.ucdavis.edu/Guidelines/N_Uptake.html

Resource: Nitrogen calculator for Central Valley Crops

Description: Estimates total nitrogen uptake amount and timing for minor Central Valley crops (annual only)

Location: http://geisseler.ucdavis.edu/Guidelines/N_Calculator.html

Resource: California fertilization guidelines

Description: Estimates of nitrogen, phosphorus, and potassium requirements for major California crops (annual and perennial)

Location: http://geisseler.ucdavis.edu/Guidelines/Home.html

Resource: Nutrient management resource links

Description: Collection of links to a variety of tools and informational resources related to nutrient management

Location: http://geisseler.ucdavis.edu/Guidelines/Resources_Topic.html

Resource: Nitrogen concentrations in harvested plant parts—a literature overview

Description: Estimates of nitrogen removal for major California crops; gives expected ranges

Location: http://geisseler.ucdavis.edu/Project_N_Removal.html

Resource: Natural Resources Conservation Service nutrient removal calculator

Description: Estimates N, P, and K removal for a wide variety of temperate and tropical crops

Location: https://plantsorig.sc.egov.usda.gov/npk/AboutNutrient

Resource: UC Sustainable Agriculture Research and Education Program cover crop database

Description: Contains extensive information on more than 40 cover crop species

Location: https://asi.ucdavis.edu/programs/ucsarep/research-initiatives/are/nutrient-mgmt/cover-crops

Resource: Online calculator for nitrogen mineralized from organic amendments

Description: Estimates nitrogen mineralization for several common organic amendments based on information provided by the user

Location: http://geisseler.ucdavis.edu/Amendment_Calculator.html

Resource: Oregon State University—organic fertilizer and cover crop calculators

Description: Provides information about cover crops and organic fertilizers, including a free calculator to compare nutrient values and costs

Location: https://extension.oregonstate.edu/organic-fertilizer-cover-crop-calculators

Resource: Sustainable Agriculture Research and Education cover crop topic room

Description: Organized collection of educational materials developed from decades of cover crop research

Location: https://www.sare.org/Learning-Center/Topic-Rooms/Cover-Crops

Resource: Managing Cover Crops Profitably (free e-book)

Description: Explores how and why cover crops work and provides all the information needed to build cover crops into any farming operation

Location: https://www.sare.org/Learning-Center/Books/Managing-Cover-Crops-Profitably-3rd-Edition

Resource: Estimating plant-available nitrogen release from cover crops

Description: Explores how and why cover crops work, and provides calculations for estimating nitrogen release and availability from different cover crops

Location: https://catalog.extension.oregonstate.edu/sites/catalog/files/project/pdf/pnw636.pdf

Resource: How much nitrogen is in your cover crop?

Description: UC Cooperative Extension short report on cover crop analysis in Yolo County.

Location: https://ucanr.edu/sites/soils/files/310425.pdf

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Section 2

The Preparation Guide: Gathering information for the nitrogen Worksheet

Some information needed to complete a nitrogen budget can be collected in advance. If you have this information handy, you will be able to move much more quickly through the Worksheet.

Supporting documents

- Nutrient analysis from the compost supplier
- Fertilizer label(s)
- Most recent or relevant soil, water, and tissue test results

Background information

- Field size or area for which the budget is being developed
- Bed length and width
- Volume of application tools—for example, wheel-barrows, compost spreaders, buckets, and so on
- Yield data

PART 1. CROP N DEMAND

A. About the crop for which you're making this budget

1. ___________ lb N/acre — 1. Total crop N uptake (average value or range) provided by a reliable source (e.g., table 1). Visit section 1's "Resources" section to find guidance on N uptake levels for various crops.

2. ___________ tons/acre — 2. Yield associated with the above N value (table 1)

3. ___________ tons/acre — 3. Your predicted yield (2000 lb = 1 ton)

C. Cover crops and crop residues (tables 3 and 4)

C1. Crop residue

7. ___________ tons/acre — 7. Previous crop yield

or

C2. Cover crops

11. ___________ lb/acre — 11. Estimated legume biomass dry weight

12. ___________ % — 12. Percent N in cover crop

D. Irrigation water

D1. Interpreting water tests

13. _____________ _____________ Water test result [Test date: ______________]

Result — Unit (ppm or mg/L, other)

PART 3. N SUPPLY: SEASONAL INPUTS

E. Available N from organic amendments

E1. Compost

_______________**Product name**

16. __________ C:N ratio 16. Identify the C:N ratio of the compost (ask compost supplier)

17. __________ % water 17. Identify the amount of water in the compost (ask compost supplier)

18. __________ % N 18. Total N in compost (inquire with compost supplier)

E2. Granular fertilizer

______________ **Product name**

23. __________ % N 23. Total N in product (for example, 5-8-0 is 5% N)

25. __________ lb/acre 25. Application rate

E3. Liquid fertilizer

______________ **Product name**

28. __________ lb/gal 28. Fertilizer weight (water is 8 lb/gal; many liquid fertilizers are slightly more)

29. __________ % N 29. Percentage of N in product (3-2-2 = 3% N)

30. __________ gal/acre 30. Application rate

PART 4. SOIL AND TISSUE TESTING FOR VERIFICATION AND MONITORING

F1. INTERPRETING SOIL TESTS

_____________________ _________________ Soil test result [Test date: ______________]

Result Unit (ppm or mg/L, other)

Section 3
The Worksheet for "Estimating nitrogen availability in organic vegetable production: For N budgeting and other purposes"

This Worksheet is intended to be used with section 1, an Overview of "Estimating nitrogen for organic vegetable production: For nitrogen budgeting and other purposes." The figures and tables mentioned in this section can be found in that document. This Worksheet can be useful for developing a complete nitrogen budget—or for estimating and understanding plant-available nitrogen from individual sources, such as compost, cover crops, and fertilizers.

Completing each section of this Worksheet offers detailed insight into nitrogen management, offering the opportunity to maximize the value of added nitrogen and minimize the risk of over-or underapplication. Some of the information calculated can inform other crop budgets or cropping seasons in which similar practices are followed, or that involve use of the same products. The intent is to allow users to best understand how applied nitrogen, in the form of amendments, irrigation water, crop residues, or cover crop residue, will be available to optimize crop production. As discussed in the Overview that accompanies this Worksheet (section 1), nitrogen in soil may change rapidly as a result of rainfall or irrigation, and predicted nitrogen release from organic materials is highly dependent on microbial processes, which are in turn dependent upon weather, contact with soil, and other factors. Verification of predicted available nitrogen is highly recommended—through use of soil nitrate test strips, soil lab analyses, or tissue analyses.

This Worksheet focuses on plant-available nitrogen from organic sources but does not discuss the timing of crop nitrogen demand in great detail. Understanding when crops demand nitrogen and when nitrogen is available to plants is important when making fertilization decisions. Figure 10 provides a few examples of nitrogen uptake curves over time. More examples can be found at geisseler.ucdavis.edu/Guidelines/Home.html.

This crop-based budget Worksheet is for ____________________ .
crop

PART 1. CROP N DEMAND

A. Crop N Uptake: How much N does your crop need?
Select one method below to identify the N uptake demand.

Method 1. Use N uptake suggested by a reliable source.

1. [ ] lb N/acre (5.) — 1. Total crop N uptake (average value or range) provided by a reliable source (e.g., table 1)

Method 2. Use N uptake suggested by a reliable source and adjust based on your yield goal.

1. __________ lb N/acre — 1. Total crop N uptake (average value or range) provided by a reliable source (e.g., table 1)
2. __________ ton/acre — 2. Yield associated with the above N value (table 1)
3. __________ ton/acre — 3. Your predicted yield (ton/acre; 1 ton = 2,000 lb)

Then, (_____ ton/acre/_____ ton/acre) × _____ lb N/acre = [ ] lb N/acre
(3.) (2.) (1.) (5.)

Method 3. Use your predicted yield and estimated lb N needed per ton of yield

3. __________ tons/acre — 3. Your predicted yield (ton/acre; 1 ton = 2,000 lb)

4. ________ lb N/ton yield — 4. Crop N uptake per ton of yield (table 1)

Then, ________ (3.) ton/acre × ________ (4.) lb N/ton = [ ] (5.) lb N/acre

5. [ ] lb N/acre — 5. Total crop N uptake. Insert result from box 5, based on method used above.

PART 2. N SUPPLY: BASELINE

B. Available N from soil organic matter (SOM)

Estimates of release of soil organic matter are based on both the percent soil organic matter and the history of cover cropping, compost amendments, and nitrogen management. For soils with a long history of building soil organic matter through activities such as applying compost and cover cropping, estimate a higher nitrogen release. For those with a shorter history of soil building, estimate nitrogen release on the lower end. Similarly, higher rates of compost application and crop residue will increase soil organic matter accumulation, whereas tillage reduces soil organic matter. In addition, warm-season production should have higher numbers than cool-season production.

6. [ ] lb N/acre — 6. Estimated N from SOM. Refer to figure 4 and table 2. A typical release rate will likely be from 50 to 120 pounds of nitrogen per acre per year in the top 12 inches of soil, based on roughly 2 percent of the total soil nitrogen becoming available.

C. Available N from crop residue: Cover crops and postharvest residue

If a cover crop or commercial crop is incorporated no more than 6 weeks prior to planting the crop intended for this budget, the nitrogen from these residues should be accounted for. Choose from either the cover crop or crop residue option.

________ C:N ratio of previous crop residue at time of incorporation

C1. Available N from previous crop

This section uses crop yield to estimate nitrogen values. If your crop does not appear in table 3, or if you prefer to use residue and percent nitrogen calculations, use the method in section C2 to estimate "available nitrogen from previous crop."

________________________ **Specify previous crop**

7. __________ ton/acre — 7. Previous crop yield

8. __________ lb N/ton — 8. N in crop residue (table 3)

9. __________ lb N/acre — 9. Estimated N in crop residue

The amount of nitrogen expected to be in the residues can be adjusted for the actual expected yield by multiplying the actual yield by the value for lb N/ton yield.

__________ (7.) ton/acre × __________ (8.) lb N/ton = __________ (9.) lb N/acre

10. [ ] lb N/acre — 10. Total N from previous crop available this season

Refer to figure 5 to estimate percentage of residue nitrogen mineralized using tissue nitrogen content. Use a lower percentage of nitrogen available when material is left on the surface and not incorporated, or when the soil is drier. C:N ratio is an excellent predictor of nitrogen availability. A C:N ratio greater than 20:1 will generally not release nitrogen, whereas 10:1 will provide intermediate rates of release.

__________ lb N/acre × __________ %/100 = __________ lb N/acre
9. −10 to 50% 10.

C2. Available N from cover crops

The amount of nitrogen a cover crop contributes depends on several factors including species, how thick the stand is, and at what stage it is terminated. The C:N ratio is the best predictor of nitrate release rates.

________ C:N ratio of cover crop residue

____________________ **Specify cover crop type**

11. __________ lb/acre

11. Estimate legume biomass dry weight

Use your own information on biomass dry weight, refer to table 4, or refer to the “Resources” section (UC SAREP cover crop database and Oregon State calculator). When referring to another source that provides a range, consider your own scenario regarding crop density and crop height/maturity to select a number in the range. For example, if a crop is terminated earlier, at 50 percent of maturity, select a biomass weight on the lower end of the range. Denser production and longer production times will likely correspond to numbers at the higher end of the range.

12. __________ %

12. Percent N in cover crop

Use your own information from a sample sent to a lab, utilize table 4, or refer to the “Resources” section.

13. __________ lb N/acre

13. Total N from cover crop (refer to table 4)

__________ lb/acre × __________ %/100 = __________ lb N/acre
11. 12. 13.

14. __________ lb N/acre

14. Total N from cover crop available this season

Refer to figure 5 to estimate percentage of residue nitrogen mineralized using tissue nitrogen content. It’s estimated that −10 to 50 percent of cover crop nitrogen is directly available for the next crop. Expect lower availability when material is left on the surface or not incorporated, or when the soil is drier. Use an intermediate availability for legume-cereal mixes. Estimate higher availability when the cover crop is terminated at optimum growth (early flower) and a lower availability for more mature crops. C:N ratio is an excellent predictor of nitrogen availability. A C:N ratio greater than 20:1 will generally not lead to releases of nitrogen. Rather, nitrogen will be used to break down carbon. A ratio of 10:1 will provide intermediate rates of release.

__________ lb N/acre × __________ %/100 = __________ lb N/acre
13. −10 to 50% 14.

D. Irrigation water

D1. Sampling water for testing

To convert NO_3-N concentration in the water to lb N/acre-inch, NO_3-N concentration reported in ppm is multiplied by 0.227 and by the number of acre-inches of water applied. For example, for 1 acre-inch of water containing 10 ppm nitrate nitrogen: (10 ppm) × (1 acre-inch) × (0.227) = 2.27 lb N are applied per acre.

15. ____________ lb N/acre — 15. N contribution from irrigation water based on water test result
[Test, result: ____________ date: ______________]

Estimate total water use ___________ acre-inches × ___________ lb N/acre inch = ___________ lb N
(water use) (NO_3-N in water) (15.)

Conversion Tool

Convert ppm to lb N/acre-inch ____________ ppm × 0.227 = ____________ lb N/acre-inch
(NO_3-N) (NO_3-N)

PART 3. N SUPPLY: SEASONAL INPUTS

E. Available N from organic amendments

E1. Compost

Most compost companies will provide an analysis of the compost material, which will include the total percent nitrogen and C:N ratio.

___________________________ **Product name**

16. ___________ C:N ratio — 16. Identify the C:N ratio of the compost

17. ___________ % water — 17. Identify the amount of water in the compost

18. ___________ % N — 18. Total N in compost (dry weight) (Check the report to see if the total N is given on a wet- or dry-weight basis. "As is" or "fresh weight" is typically equivalent to "wet weight.")

If your compost nitrogen is given in dry weight, adjust the amount of compost you applied "as is" to dry weight:

19. ___________ lb/acre — 19. Application rate in lb, wet weight "as is" or "fresh weight")
(1 ton = 2000 lb; 1 ton = 2–2.5 cubic yards)

20. ___________ lb/acre — 20. Application rate in lb, adjusted to dry weight
___________ lb/acre × (100– ___________ %)/100 = ___________ lb/acre
(19.) (17.) (20.)

21. ___________ lb N/acre — 21. Estimated total N from compost added to field
___________%/100 × ___________ lb/acre = ___________ lb N/acre
(18.) (20.) (21.)

22. ___________ lb N/acre — 22. Estimated available N from compost

Composts are estimated to release −3 to 35% of total nitrogen in the first year (see fig. 8 and table 5). Yard-trimming composts can initially tie up nitrogen, whereas manure-based composts have more available nitrogen. Take a look at table 5 to see estimates of percent nitrogen release from composts, and figure 9 to see the correlation between C:N ratio and available N. Place the C:N ratio of the compost used on the curve to estimate the nitrogen release percentage.

__________ lb N/acre × __________ %/100 = __________ lb N/acre
21. −3 to +35% 22.

E2. Granular fertilizers

____________________ **Product name**

23. __________ % N — 23. Total N in product (e.g., 5-8-0 is 5% N)

24. __________ lb N/lb — 24. Pounds of N per pound of product

__________ %/100 = __________ lb N/lb
23. 24.

25. __________ lb/acre — 25. Application rate (1 ton = 2000 lb; 1 ton = 2–2.5 cubic yards)

26. __________ lb N/acre — 26. Total N applied

__________ lb N/lb × __________ lb/acre = __________ lb N/acre
24. 25. 26.

27. __________ lb N/acre — 27. Total available N

For irrigated crops grown in warm weather, granular fertilizers with a low C:N (ex. 6:1 or lower) are estimated to release 40–90% of total nitrogen in a season (see fig. 9 and table 5). Colder or drier conditions will reduce the nitrogen release rate. Surface-applied granular fertilizer releases a lower percentage of the total it contains. Granular fertilizer shanked into the soil releases a higher percentage of the nitrogen it contains. Higher-analysis fertilizers release a greater percentage of nitrogen than lower nitrogen (Hartz and Johnstone 2006).

__________ lb N/acre × __________ %/100 = __________ lb N/acre
26. 40–90% 27.

E3. Liquid fertilizers

Liquid fertilizers are estimated to release 45 to 85% of total N in the season (see fig. 9 and table 5).

____________________ **Product name**

28. __________ lb/gal — 28. Fertilizer density. Read product label to determine (water is 8 lb/gal; many products range from 9 to 10.5 lb/gal)

29. __________ % N — 29. Percent of N in product (ex. 3-2-2 = 3% N)

30. __________ gal/acre — 30. Application rate

31. __________ lb N/acre — 31. Total N applied

________ lb/gal × ________ % N × ________ gal/acre/100 = ________ lb N/acre
28. 29. 30. 31.

32. __________ lb N/acre — 32. Total available N

________ lb N/acre × ________ %/100 = ________ lb N/acre
31. 45–85% 32.

PART 4. SOIL AND TISSUE TESTING FOR VERIFICATION AND MONITORING

F. Interpreting soil tests

When using results from a soil test, consider the timing of the soil test. The results from a soil test can be used for a budget when the test is taken before amendments are added and before crop residue (or cover crop) incorporation. However, if a soil test is taken after cover crop, crop residue, or amendment applications are added, the soil test results will include some of the nitrogen made available from the recent activity. As such, the soil test should be fully counted toward the budget, but the crop residue and organic amendments can be reduced. Adjust accordingly. Similarly, if soil samples are more than several months old, consider what activities have since occurred that could influence nitrogen levels (crop production, rain, amendment application, and so on). To use a soil test to adjust the quantity of fertilizer applied to meet the crop needs, test for residual soil nitrate prior to fertilization.

33. [ ] lb N/acre   33. Available N at time of soil test [Test, result: ________ date: ________]

Conversion tool

1 mg/kg = 1ppm

If soil test is in NO_3^-, convert to NO_3-N: ____________ ppm/4.42 = ____________ ppm
(Result NO_3^-) (Result NO_3-N)

If soil test is in ppm, convert: _______ ppm × ___3.6___ = _______ lb N/acre
(NO_3-N) (conversion factor for soil bulk density*) (14.)

Labs typically report values as concentration, or parts per million (ppm). The amount in lb/acre can be calculated by multiplying this number by a factor of 3 to 4 for every 12 inches of soil depth, depending on the soil bulk density. Soils with very high organic matter, as well as very heavy clay soils, will be lower, while more compacted or very sandy soils will have higher values. A commonly used factor for the top 12 inches of agricultural soils is 3.6, assuming a soil bulk density of 1.35 g/cm^3. If a soil sample was taken to a depth of 12 inches, use 3.6 as a conversion factor for soil bulk density. If a soil sample was taken to a depth of 6 inches, use 1.8. For vegetables, a 12-inch soil sampling depth is recommended for most crops in order to capture the soil where the majority of roots will grow.

*** To determine the conversion factor using your soil bulk density information:**

43,560 ft^2 × 1 ft depth × 62.4 lb/ft^3 × __________ g/cm^3 = __________ /6 = __________________
(your soil bulk density) (conversion factor for your soil bulk density)

THE BUDGET

Part 1. Crop N demand	lb N/acre
5. Crop demand	

Part 2. N supply: Baseline	lb N/acre
6. SOM contributions	
10. Previous crop or 14. Cover crop	
15. Irrigation water	
TOTAL (6 + 10 or 14 + 15)	
Part 3. N supply: Seasonal inputs	lb N/acre
22. Compost	
27. Granular fertilizer	
32. Liquid fertilizer	
TOTAL (22 + 27 + 32)	

Part 4. Soil test	
33. Residual soil N (from a soil test) Compare the estimates from Parts 2 and 3 with the soil test results. Use this to check what is actually available at the time of the soil test with what you predicted would be available. Feel free to make adjustments to the N balance using information from the soil test.	

Available N grand total Part 2 + Part 3	

N balance ________________ – ________________ = ________________ **lb N/acre**

Available N grand total	Crop demand lb N/acre	N balance

How to interpret the budget result

If the nitrogen balance is positive, the crop is likely to have enough nitrogen supply, assuming zero loss of nitrogen during the growing season. However, the larger the positive number, the greater the chance that nitrogen will be lost to the environment. This is because crops have a limit on daily nitrogen demand and, with irrigation or rainfall, unused nitrate can be leached below the root zone. Taking a soil sample after harvest to a depth of 2 to 3 feet and analyzing it for residual nitrate will allow you to determine how much nitrate is left over. Leftover nitrate may be at risk of being leached with winter rains, unless a winter crop or cover crop can utilize this nitrogen.

A negative nitrogen balance suggests that nitrogen supply is not adequate to meet the crop demand. Consider increasing the nitrogen supply by adding more fertilizers. Recalculate the nitrogen balance until a positive number is reached.

That said, it can be very challenging to achieve a real balance between nitrogen inputs and nitrogen outputs solely relying on the worksheet approach. This is largely because the amount of nitrogen mineralized from soil organic matter is likely to be highly variable among fields and cropping histories, which can contribute a very wide range of available nitrogen. For this reason, it is essential to couple a worksheet approach with soil or leaf-tissue sampling during the growing season to determine whether nitrogen availability is deficient, adequate, or excessive.

After a rough nitrogen budget is made, and a crop is grown with the budget in mind for a year or two, revisit the nitrogen budget Worksheet to adjust numbers based on in-season soil-nitrate and leaf-tissue monitoring data.

Section 4
The Demonstration Worksheet: A completed worksheet for illustrative purposes

Below, we have provided an example of a completed nitrogen budget worksheet (the Demonstration Worksheet) for the following scenario:

I have been an organic farmer for 12 years in Yolo County. I'm a year-round, diversified vegetable farmer, but fresh-market tomatoes are an important crop for me. My midseason tomatoes follow a cover crop and I typically add compost just prior to planting. Also at that time, I amend with a granular fertilizer. Then, during the growing season, I run a liquid fertilizer 3 to 5 times during rapid growth. My tomatoes are drip-irrigated. I test the soil 1 time per year. The tomatoes are transplanted in early May and harvest is completed by mid-September. The SOM content is 3%.

This crop-based budget Worksheet is for *fresh-market tomato* **.**
crop

PART 1. CROP N DEMAND

A. Crop N uptake: How much N does your crop need?

Select one method below to identify the N uptake demand.

Method 1. Use N uptake suggested by a reliable source.

1. [240] lb N/acre — 1. Total crop N uptake (average value or range) provided by a reliable source (e.g., table 1)
5.

I chose this based on table 1. The table says this is based on 30 tons/acre. I average about 29 tons, so I'll stick with this number.

Method 2. Use N uptake suggested by a reliable source and adjust based on your yield goal.

1. ________ lb N/acre — 1. Total crop N uptake (average value or range) provided by a reliable source (e.g., table 1)
2. ________ ton/acre — 2. Yield associated with the above N value (table 1)
3. ________ ton/acre — 3. Your predicted yield (ton/acre; 1 ton = 2,000 lb)

Then, (_____ ton/acre/_____ ton/acre) × _____ lb N/acre = [ ] lb N/acre
(3.) (2.) (1.) (5.)

Method 3. Use your predicted yield and estimated lb N needed per ton of yield

3. ________ tons/acre — 3. Your predicted yield (ton/acre; 1 ton = 2,000 lb)
4. ________ lb N/ton yield — 4. Crop N uptake per ton of yield (table 1)

Then, ________ ton/acre × ________ lb N/ton = [ ] lb N/acre
(3.) (4.) (5.)

5. [240] lb N/acre — 5. Total crop N uptake. Insert result from box 5, based on method used above.

PART 2. N SUPPLY: BASELINE

B. Available N from soil organic matter (SOM)

Estimates of release of soil organic matter are based on both the percent soil organic matter and the history of cover cropping, compost amendments, and nitrogen management. For soils with a long history of building soil organic matter through activities such as applying compost and cover cropping, estimate a higher nitrogen release. For those with a shorter history of soil building, estimate nitrogen release on the lower end. Similarly, higher rates of compost application and crop residue will increase soil organic matter accumulation, whereas tillage reduces soil organic matter. In addition, warm-season production should have higher numbers than cool-season production.

55 lb N/acre

6. Estimated N from SOM. Refer to figure 4 and table 2. A typical release rate will likely be from 50 to 120 pounds of nitrogen per acre per year in the top 12 inches of soil, based on roughly 2 percent of the total soil nitrogen becoming available.

I have been farming organically for 12 years, with annual cover cropping and compost application, so the SOM and the nitrogen bank have been building on my soil for many years. Therefore, nitrogen mineralization may be higher than in a conventional soil with the same SOM content.

On the other hand, I use drip irrigation, which keeps a smaller soil volume moist than sprinkler or furrow irrigation. Nitrogen mineralization in the dry soil will likely be lower.

I reviewed table 2 from early May through mid-September in the Sacramento Valley, which estimated 66 pounds of nitrogen per acre.

C. Available N from crop residue: Cover crops and postharvest residue

If a cover crop or commercial crop is incorporated no more than 6 weeks prior to planting the crop intended for this budget, the nitrogen from these residues should be accounted for. Choose from either the cover crop or crop residue option.

________ C:N ratio of previous crop residue at time of incorporation

C1. Available N from previous crop

This section uses crop yield to estimate nitrogen values. If your crop does not appear in table 3, or if you prefer to use residue and percent nitrogen calculations, use the method in section C2 to estimate "available nitrogen from previous crop."

The residues of the previous cash crop were incorporated in fall **Specify previous crop**

7. __________ ton/acre — 7. Previous crop yield

8. __________ lb N/ton — 8. N in crop residue (table 3)

9. __________ lb N/acre — 9. Estimated N in crop residue

The amount of nitrogen expected to be in the residues can be adjusted for the actual expected yield by multiplying the actual yield by the value for lb N/ton yield.

__________ ton/acre × __________ lb N/ton = __________ lb N/acre
7. 8. 9.

10. 0 lb N/acre — 10. Total N from previous crop available this season

Refer to figure 5 to estimate percentage of residue nitrogen mineralized using tissue nitrogen content. Use a lower percentage of nitrogen available when material is left on the surface and not incorporated, or when the soil is drier. C:N ratio is an excellent predictor of nitrogen availability. A C:N ratio greater than 20:1 will generally not release nitrogen, whereas 10:1 will provide intermediate rates of release.

__________ lb N/acre × __________ %/100 = __________ lb N/acre
9. −10 to 50% 10.

C2. Available N from cover crops

The amount of nitrogen a cover crop contributes depends on several factors including species, how thick the stand is, and at what stage it is terminated. The C:N ratio is the best predictor of nitrate release rates.

__12:1__ C:N ratio of cover crop residue

I use a cover crop mix of the following:
__Bell beans (30%), peas (30%), vetch (20%), oats (20%)__ **Specify cover crop type**

11. __4,600__ lb/acre

11. Estimate legume biomass dry weight

Use your own information on biomass dry weight, refer to table 4, or refer to the "Resources" section (UC SAREP cover crop database and Oregon State calculator). When referring to another source that provides a range, consider your own scenario regarding crop density and crop height/maturity to select a number in the range. For example, if a crop is terminated earlier, at 50 percent of maturity, select a biomass weight on the lower end of the range. Denser production and longer production times will likely correspond to numbers at the higher end of the range.

I referred to an article called "How much nitrogen is in your cover crop?" by Margaret Lloyd. I used the mix described there and planted it at 100 lb/acre and waited for the first rain to germinate the seed. I terminated the cover crop in March, about a month before the sampling took place in that document, so I discounted my biomass by 1,000 lb. Also, looking at the picture, my crop was not as tall as it is in the photo for field 5. Because I terminated it in March and not April, I also lowered the C:N ratio, since it was not as mature as an April cover crop.

12. __3.5__ %

12. Percent N in cover crop

Use your own information from a sample sent to a lab, utilize table 4, or refer to the "Resources" section.

Again, referring to the same article, it shows that this cover crop was 2.9 percent N. Because I terminated it a month earlier than the sample here, I would expect a higher nitrogen content, so I increased it to 3.5 percent.

13. __161__ lb N/acre

13. Total N from cover crop (refer to table 4)

__4,600__ lb/acre × __3.5__ %/100 = __161__ lb N/acre
(11.) (12.) (13.)

14. __48__ lb N/acre

14. Total N from cover crop available this season

Refer to figure 5 to estimate percentage of residue nitrogen mineralized using tissue nitrogen content. It's estimated that –10 to 50 percent of cover crop nitrogen is directly available for the next crop. Expect lower availability when material is left on the surface or not incorporated, or when the soil is drier. Use an intermediate availability for legume-cereal mixes. Estimate higher availability when the cover crop is terminated at optimum growth (early flower) and a lower availability for more mature crops. C:N ratio is an excellent predictor of nitrogen availability. A C:N ratio greater than 20:1 will generally not lead to releases of nitrogen. Rather, nitrogen will be used to break down carbon. A ratio of 10:1 will provide intermediate rates of release.

I'm incorporating my cover crop into soil with some moisture to encourage degradation so that I can plant my tomatoes into it in early May.

I estimated my C:N ratio at 12:1, so it's on the low-to-intermediate side of release.

I'm using a legume-cereal mix which releases at an intermediate rate, due to the higher carbon from cereal crops.

Below is an example of how to use figure 5 to estimate nitrogen availability from crop residue using % nitrogen of tissue.

Residue	Total dry biomass (lb/acre)	Total N (lb/acre)	Estimated N mineralization	Available N from residue (lb/acre)
5% N	6,000	300	58%	174
3% N	6,000	180	30%	54

161 lb N/acre × 30 %/100 = 48 lb N/acre
13. −10 to 50% 14.

D. Irrigation water

D1. Sampling water for testing

To convert NO_3-N concentration in the water to lb N/acre-inch, NO_3-N concentration reported in ppm is multiplied by 0.227 and by the number of acre-inches of water applied. For example, for 1 acre-inch of water containing 10 ppm nitrate nitrogen: (10 ppm) × (1 acre-inch) × (0.227) = 2.27 lb N are applied per acre.

15. 55 lb N/acre — 15. N contribution from irrigation water based on water test result [Test, result: 8 ppm date: 5/7/2018]

Estimate total water use 30 acre-inches × 1.816 lb N/acre inch = 54.5 lb N
water use — NO_3-N in water — 15.

Conversion Tool

Convert ppm to lb N/acre-inch 8 ppm × 0.227 = 1.816 lb N/acre-inch
NO_3-N — NO_3-N

PART 3. N SUPPLY: SEASONAL INPUTS

E. Available N from organic amendments

E1. Compost

Most compost companies will provide an analysis of the compost material, which will include the total percent nitrogen and C:N ratio.

ABC Compost, yard-trimming compost **Product name**

16. 15:1 C:N ratio — 16. Identify the C:N ratio of the compost

I requested a compost analysis from the company and got the C:N ratio, percent N, percent moisture.

17. ___35___ % water — 17. Identify the amount of water in the compost

18. ___1___ % N — 18. Total N in compost (dry weight) (Check the report to see if the total N is given on a wet- or dry-weight basis. "As is" or "fresh weight" is typically equivalent to "wet weight.")

It was given in dry weight (1%).

If your compost nitrogen is given in dry weight, adjust the amount of compost you applied "as is" to dry weight:

19. ___20,000___ lb/acre — 19. Application rate in lb, wet weight "as is" or "fresh weight") (1 ton = 2000 lb; 1 ton = 2–2.5 cubic yards)

I apply 10 tons/acre, wet weight = "as is" when it arrives at my farm. Compost leaves the supplier at the rate you ordered (e.g., 10 tons) and at the "as is" weight. Even if it sits on your farm for a long time and gets very dry or very wet (from winter rain), it is still 10 tons of "as is" or wet-weight compost). Confirm with your supplier how they determine the weight of your compost and adjust accordingly.

20. ___13,000___ lb/acre — 20. Application rate in lb, adjusted to dry weight

___20,000___ lb/acre × (100– ___35___ %)/100 = ___13,000___ lb/acre
(19.) (17.) (20.)

21. ___130___ lb N/acre — 21. Estimated total N from compost added to field

___1___ %/100 × ___13,000___ lb/acre = ___130___ lb N/acre
(18.) (20.) (21.)

22. [3] lb N/acre — 22. Estimated available N from compost

Composts are estimated to release –3 to 35% of total nitrogen in the first year (table 5). Yard-trimming composts can initially tie up nitrogen, whereas manure-based composts have more available nitrogen. Take a look at table 5 and figure 8 to see estimates of percent nitrogen release from composts, and figure 9 to see the correlation between C:N ratio and available N. Place the C:N ratio of the compost used on the curve to estimate the nitrogen release percentage.

___130___ lb N/acre × ___2___ %/100 = ___2.6___ lb N/acre
(21.) (–3 to +35%) (22.)

Looking at figure 7 and 9A, I can see that my yard-trimming compost at 15:1 C:N ratio does not release much if any nitrogen, and may actually tie it up. I'm going to say that it has a 2% release rate.

E2. Granular fertilizers

___Pelleted chicken manure___ **Product name**

23. ___4___ % N — 23. Total N in product (e.g., 5-8-0 is 5% N)

Bag says: 4-2-2

24. ___0.04___ lb N/lb — 24. Pounds of N per pound of product

___4___ %/100 = ___0.04___ lb N/lb
(23.) (24.)

25. ___500___ lb/acre — 25. Application rate (1 ton = 2000 lb; 1 ton = 2–2.5 cubic yards)

26. ___20___ lb N/acre

26. Total N applied

___0.04___ lb N/lb × ___500___ lb/acre = ___20___ lb N/acre
24. 25. 26.

27. **10** lb N/acre

27. Total available N

For irrigated crops grown in warm weather, granular fertilizers with a low C:N (ex. 6:1 or lower) are estimated to release 40–90% of total nitrogen in a season (see fig. 9 and table 5). Colder or drier conditions will reduce the nitrogen release rate. Surface-applied granular fertilizer releases a lower percentage of the total it contains. Granular fertilizer shanked into the soil releases a higher percentage of the nitrogen it contains. Higher-analysis fertilizers release a greater percentage of nitrogen than lower nitrogen (Hartz and Johnstone 2006).

___20___ lb N/acre × ___50___ %/100 = ___10___ lb N/acre
26. 40–90% 27.

These fresh-market tomatoes are being grown in the summer, under irrigation, so the release rate will not be limited by cool or dry soil.

I apply this fertilizer in a band above my drip tape so the moist soil will encourage release.

When I look at figure 9, I can see that a 4 percent granular fertilizer will release about 50 percent over 12 weeks, so I chose 50%.

E3. Liquid fertilizers

Liquid fertilizers are estimated to release 45 to 85% of total N in the season (fig. 9 and table 5).

___Liquid fish emulsion___ **Product name**

28. ___9.15___ lb/gal

28. Fertilizer density. Read product label to determine (water is 8 lb/gal; many products range from 9 to 10.5 lb/gal)

The label that I found online said it weighed 9.15 lb/gal.

29. ___5___ % N

29. Percent of N in product (ex. 3-2-2 = 3% N)

Label: 5-2-1

30. ___50___ gal/acre

30. Application rate

Over the season, I apply 50 gallons.

31. ___23___ lb N/acre

31. Total N applied

___9.15___ lb/gal × ___5___ % N × ___50___ gal/acre/100 = ___22.875___ lb N/acre
28. 29. 30. 31.

32. **20** lb N/acre

32. Total available N

___23___ lb N/acre × ___85___ %/100 = ___19.5___ lb N/acre
31. 45–85% 32.

Animal-based liquids tend to release at higher rates, so I chose a higher rate.

PART 4. SOIL AND TISSUE TESTING FOR VERIFICATION AND MONITORING

F. Interpreting soil tests

When using results from a soil test, consider the timing of the soil test. The results from a soil test can be used for a budget when the test is taken before amendments are added and before crop residue (or cover crop) incorporation. However, if a soil test is taken after cover crop, crop residue, or amendment applications are added, the soil test results will include some of the nitrogen made available from the recent activity. As such, the soil test should be fully counted toward the budget, but the crop residue and organic amendments can be reduced. Adjust accordingly. Similarly, if soil samples are more than several months old, consider what activities have since occurred that could influence nitrogen levels (crop production, rain, amendment application, and so on). To use a soil test to adjust the quantity of fertilizer applied to meet the crop needs, test for residual soil nitrate prior to fertilization.

33. ______ lb N/acre   33. Available N at time of soil test [Test, result: 55 ppm of NO_3^- date: 2/15/19]

Conversion tool

1 mg/kg = 1ppm

If soil test is in NO_3^-, convert to NO_3-N: 55 (Result NO_3^-) ppm/4.42 = 12.4 (Result NO_3-N) ppm

If soil test is in ppm, convert: 12.4 (NO_3-N) ppm × 3.6 (conversion factor for soil bulk density*) = 44.6 (14.) lb N/acre

*Because I took the soil sample in February and we had several rain events after that, and I had the cover crop growing, which was likely using some of the soil nitrate, I reduced my soil nitrate.

Labs normally report values as concentration, or parts per million (ppm). The amount in lb/acre can be calculated by multiplying this number by a factor of 3 to 4 for every 12 inches of soil depth, depending on the soil bulk density. Soils with very high organic matter, as well as very heavy clay soils, will be lower, while more compacted or very sandy soils will have higher values. A commonly used factor for the top 12 inches of agricultural soils is 3.6, assuming a soil bulk density of 1.35 g/cm³. If a soil sample was taken to a depth of 12 inches, use 3.6 as a conversion factor for soil bulk density. If a soil sample was taken to a depth of 6 inches, use 1.8. For vegetables, a 12-inch soil sampling depth is recommended for most crops in order to capture the soil where the majority of roots will grow.

*** To determine the conversion factor using your soil bulk density information:**

$43,560 \text{ ft}^2 \times 1 \text{ ft depth} \times 62.4 \text{ lb/ft}^3 \times$ ______ g/cm³ = ______ (your soil bulk density) /6 = ______ (conversion factor for your soil bulk density)

THE BUDGET

Part 1. Crop N demand	lb N/acre
5. Crop demand	240

Part 2. N supply: Baseline	lb N/acre
6. SOM contributions	55
10. Previous crop or 14. Cover crop	48
15. Irrigation water	55
TOTAL (6 + 10 or 14 + 15)	158
Part 3. N supply: Seasonal inputs	lb N/acre
22. Compost	3
27. Granular fertilizer	10
32. Liquid fertilizer	20
TOTAL (22 + 27 + 32)	33

Part 4. Soil test	
33. Residual soil N (from a soil test) Compare the estimates from Parts 2 and 3 with the soil test results. Use this to check what is actually available at the time of the soil test with what you predicted would be available. Feel free to make adjustments to the N balance using information from the soil test. *The soil test was taken before inputs and before the cover crop was mowed and incorporated, so I'm going to include all of it and all of the other inputs.*	35

Available N grand total Part 2 + Part 3	226

N balance 226 (Available N grand total) – 240 (Crop demand lb N/acre) = -14 (N balance) **lb N/acre**

Now that I have completed this, my current regime is close to supplying sufficient nitrogen to my fresh-market tomatoes and the high yield that I expect. However, it is quite close and could fall short. To monitor sufficient nitrogen during the season, I will consider taking a soil sample right before planting and/or right before rapid growth to inform a side-dress or liquid application. In addition, I will take leaf samples.

How to interpret the budget result

If the nitrogen balance is positive, the crop is likely to have enough nitrogen supply, assuming zero loss of nitrogen during the growing season. However, the larger the positive number, the greater the chance that nitrogen will be lost to the environment. This is because crops have a limit on daily nitrogen demand and, with irrigation or rainfall, unused nitrate can be leached below the root zone. Taking a soil sample after harvest to a depth of 2 to 3 feet and analyzing it for residual nitrate will allow you to determine how much nitrate is left over. Leftover nitrate may be at risk of being leached with winter rains, unless a winter crop or cover crop can utilize this nitrogen.

A negative nitrogen balance suggests that nitrogen supply is not adequate to meet the crop demand. Consider increasing the nitrogen supply by adding more fertilizers. Recalculate the nitrogen balance until a positive number is reached.

That said, it can be very challenging to achieve a real balance between nitrogen inputs and nitrogen outputs solely relying on the worksheet approach. This is largely because the amount of nitrogen mineralized from soil organic matter is likely to be highly variable among fields and cropping histories, which can contribute a very wide range of available nitrogen. For this reason, it is essential to couple a worksheet approach with soil or leaf-tissue sampling during the growing season to determine whether nitrogen availability is deficient, adequate, or excessive.

After a rough nitrogen budget is made, and a crop is grown with the budget in mind for a year or two, revisit the nitrogen budget Worksheet to adjust numbers based on in-season soil-nitrate and leaf-tissue monitoring data.

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