University of California
Agriculture and Natural Resources

Companion to the Worksheet:

ESTIMATING NITROGEN AVAILABILITY IN ORGANIC CROP PRODUCTION:

For N budgeting and other purposes

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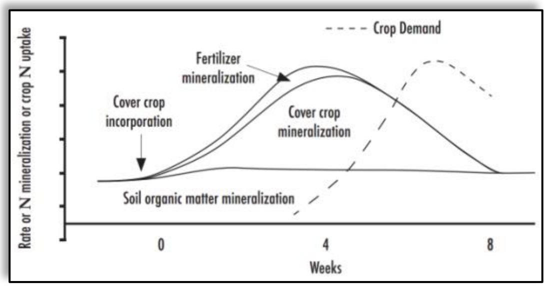
Overview

A crop-based nitrogen (N) budget can help estimate whether a crop's N supply is appropriate for its needs, and over the long term, show whether N supply is in excess or deficit of what is needed for optimal crop production.

Figure 1: Timing of N mineralization and uptake.



It's important to build up enough available N in the soil to meet the crop's N needs during periods of rapid growth. When N is maintained in its organic form as compost, crop residue or soil organic matter, it is bound to material. However, once mineralized, it becomes plant-available mineral forms of N: nitrate (NO_3) and ammonium (NH_4). Ammonium has a positive charge and is attracted to the negative charges on clay particles and soil organic matter. Nitrate has a negative charge and is repelled by the soil and is at risk for being leached below the root zone by excess rainwater or irrigation. To avoid loss, irrigation needs to be carefully managed, especially with young plants with shallow roots.

N management in organic systems is challenging because complex organic forms of N originating from compost, manures, crop residue and other organic materials need to be mineralized by microbes to mineral forms of N before they are plant-available. Ammonium is typically short-lived in the soil as microbes convert it to NO_3. The microbial metabolic process requires N in order to breakdown carbon, the primary energy source for microbes. As such, higher carbon inputs require more N to break down the material in order for the microbes to access the sugars. "Feeding the soil" organic forms of N stimulates microbial activity and population booms because the microbes can now breakdown carbon sources in the soil. With this activity, there is also rapid turnover of microbes as well as organic matter decomposition, which become the two main sources of nitrate N release, available for plant use. As such, with each application of organic forms of N, only a portion of it becomes available to plants in the short term. The unmineralized organic N becomes part of the soil organic matter pool of N, available in the future. Soil testing can provide useful information on current plant-available N, relevant for monitoring and adjusting fertilization, but will not describe future plant-available N. Further, N mineralization in the soil, a biological process, and plant N uptake are affected by environmental factors such as soil temperature and moisture making both predicting and synchronizing plant-available N with crop demand challenging. This worksheet intends to serve as a guide to improve prediction and synchronization of plant available N.

PART 1. CROP N DEMAND

A. Crop N Uptake

The amount of N taken up by the crop is a good starting point for estimating how much fertilizer N to apply to the crop. Both the N removed with harvested fruit and the total crop N uptake to support the plant can be roughly estimated based on the predicted yield (Table 1). Crops that grow either in winter or summer usually take up less N in winter. In Table 1, where crop N uptake ranges are given, the lower end of the range is appropriate for a winter production season for non-coastal climates.

Depending on the levels of residual soil nitrate in the soil, the quantity of N needed to be added by the grower can be adjusted. For instance, on a sandy soil following a wet winter in which residual soil nitrate from prior crops has been leached, it is often necessary to apply more fertilizer N to make up for the lack of residual soil N than after a dry winter. The amount of fertilizer N needed for optimal crop growth can exceed crop uptake due to inefficiencies in irrigation management and variability in the field. However, following a crop that leaves lots of residual soil N in the soil (e.g. from crop residue, such as broccoli or alfalfa), the amount of fertilizer N needed for optimal growth may be less than the total crop uptake because the mineralization of N from crop residues can supply a significant portion of crop needs. The best way to determine how much N to add, is to take a soil nitrate test prior to planting or prior to a fertilizer event. This will give an indication of the amount of residual soil N in the soil and fertilizer applications rates can be adjusted accordingly. Another source of N that needs to be taken into account is nitrate in the irrigation water.

Guidelines for crop N demand for a number of vegetable crops are available, but be attentive to the source and type of guideline. A reliable source would include those from a university, extension publication, commodity group or other reputable source. When reviewing an N demand estimate, consider how the location, production method (organic, conventional), yield and other factors associated with the information may affect that yield relative to your expected yield, and adjust accordingly. Most data will be based on yields achieved when grown on commercial-scale, conventional production under optimal conditions. As the amount of fertilizer N needed for optimal crop growth often exceeds crop uptake due to inefficiencies in irrigation management and variability in the field, uptake numbers are best used as a starting point.

These values are mostly derived from experiments with crops managed conventionally. Uptake estimates should be adjusted for actual yield expectation. A rough estimate can be made by multiplying the total N uptake per ton yield (Column 3) by your expected yield.

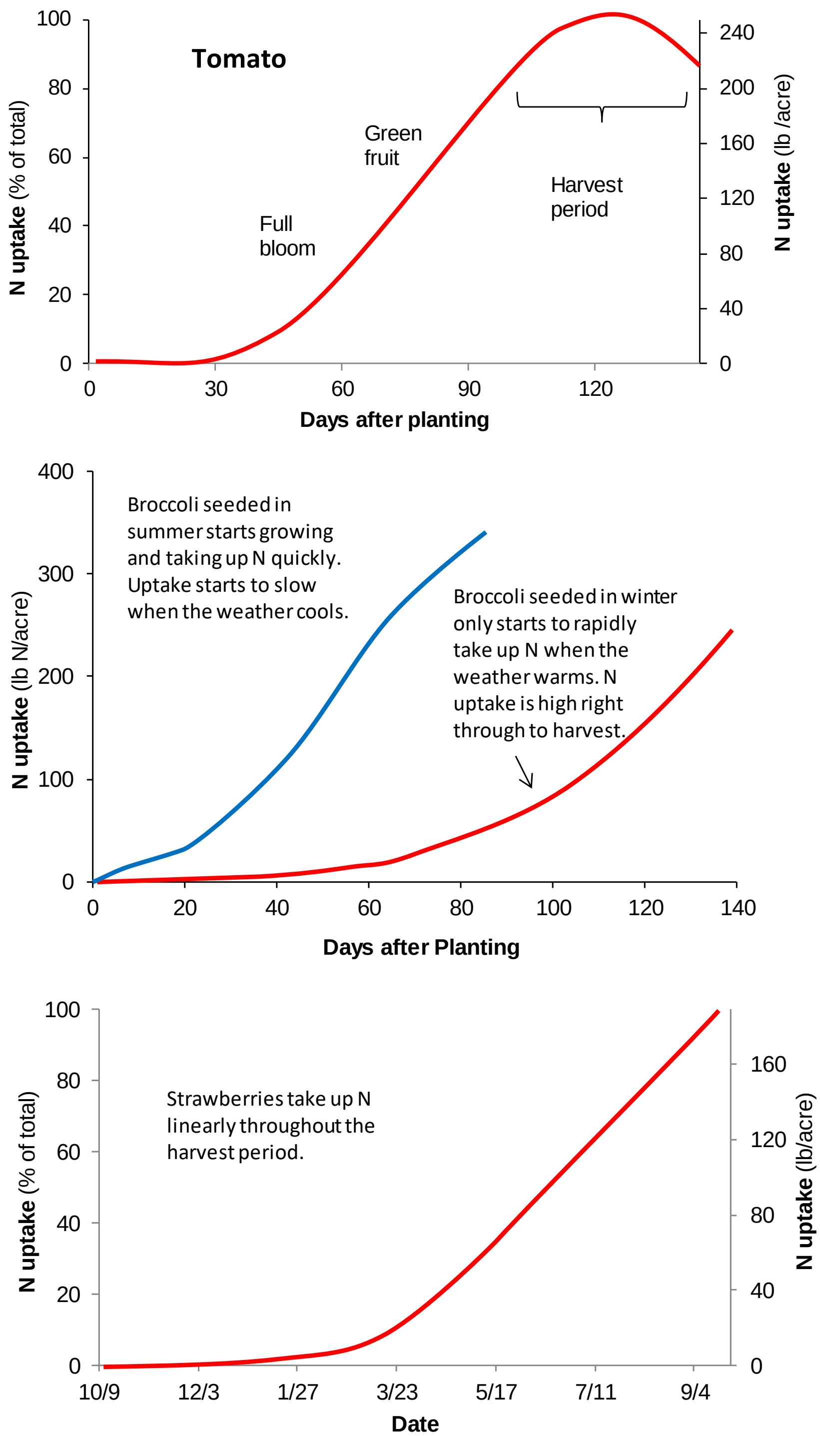
Table 1: Estimates of N uptake by major California crops

Crop	Example yield (tons/acre)	Total crop N uptake (lbs N/ton yield)	Total crop N uptake (lbs N/acre)	N removal (lbs N/ton yield)	Source
Lettuce	16-21	7.5	120 - 160	2.6	[1,12]
Tomato (fresh-market)	32	7.1	228	2.6	[17, w/ supplemental data]
Tomato (processing)	54	5.0	265	2.7	[9]
Sweet potato	17	5.0	82.7	4.7	[20]
Broccoli	7 -10	36.6	250 - 350	11.2	[12]
Carrot	20	10.4	208	3.3	[15]
Melon	17	7.2	122	4.2	[6,19]
Potato	24	11.0	265	6.2	[21]
Strawberry	36	5.3	190	2.7	[2]
Spinach	9-16	7.7	83-135	4.5	[13]

Crop N Uptake Timing

N uptake by crops producing fruits or seeds often follows an “S” shape. Uptake is slow during crop establishment, followed by rapid uptake as the crop starts to quickly grow, and then slows or stops late in the season when seed or fruits ripen. An example for a crop with an "S" shaped N uptake curve is shown for tomatoes in Figure 2. For crops where the leaves, stems or flowers are harvested during vegetative growth (broccoli, lettuce, celery), N uptake is normally rapid until harvest.

Figure 2: Example N uptake curves of different crop growth patterns



For most crops where a mature fruit or grain is harvested, such as tomato, N uptake slows during the harvest period.

Temperature matters: Crops planted in warm weather and from transplants start the rapid N uptake stage earlier than crops planted in cool weather or from seeds.

Strawberries steadily take up N during harvest, unlike most crops where a mature fruit or grain is harvested.

Broccoli data from a conventional field in the Salinas Valley. Yields were 28,000 and 22,000 lb/acre for summer and winter-seeded broccoli, respectively[18]. Tomato data from a fresh-market organic heirloom trial in Yolo County. Total yield was 62,000 lb/acre[17], with unpublished data. Strawberry from conventional fields in the Salinas and Pajaro valleys Yield was 72,000 lb/acre[2].

Nitrogen uptake curves for additional crops can be found here: https://apps1.cdfa.ca.gov/FertilizerResearch/docs/N_Uptake.html

PART 2. N SUPPLY: BASELINE

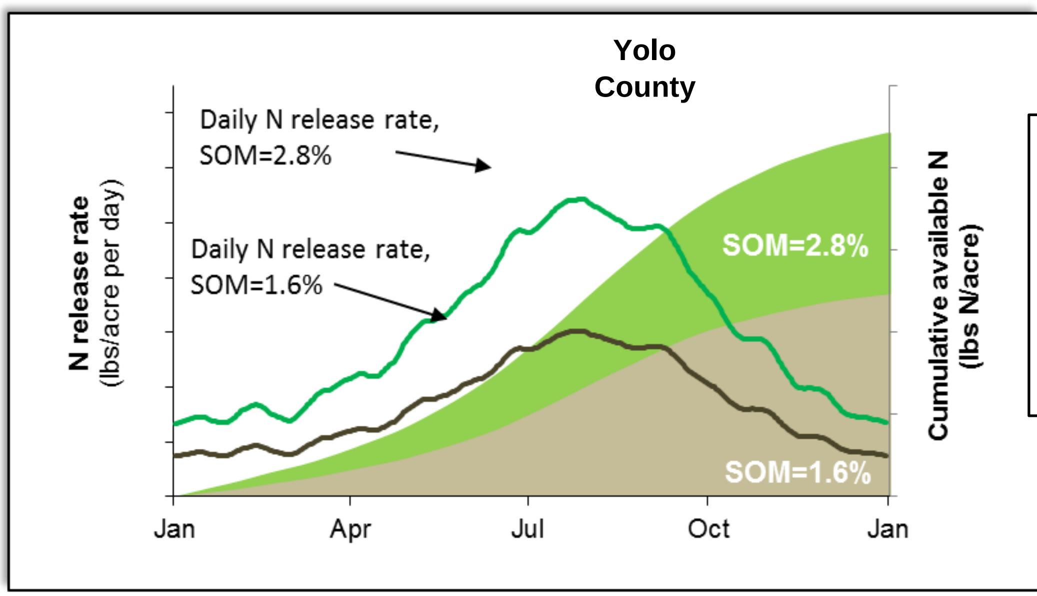
B. Available N from Soil Organic Matter

The amount of N released from the soil organic matter (SOM) depends on the amount of SOM, soil temperature, soil moisture and soil texture. Long-term additions of cover crops, manures and compost all increase SOM, increasing the amount of N which will become available from the soil. Under warm, moist conditions, more available N is released from the soil and amendments than when it is cool or dry. For irrigated California crops, more N will be available in summer than winter. This means a crop planted in warm weather will be able to meet more of its N needs from N released from SOM than a crop planted in cooler weather. Soil texture also influences N mineralization from SOM because higher clay content soils typically have higher SOM and higher N mineralization rates as compared with those with lower clay content, such as sandy and loam soils[5]. A common rule of thumb is that during a summer growing season, about 1-3% of the total soil N becomes available (often ~50-120 lb N/acre).

The green and black lines of Figure 3 represent estimates of daily N release from the top foot of soils from Yolo County and the Salinas valley, with high and low SOM contents. The shaded regions represent the cumulative annual N released. These values are modeled based on average soil temperature data for 2017 and 2018, and an assumed N release of 2% of the soil's total N during the growing season (~May-September).

Figure 3: Modeled annual N mineralization from soil organic matter (SOM) in the top foot of soil

NOTE: These values represent modeled potential N availability, based on several assumptions. Actual available N will be affected by soil moisture, leaching, the quality of the organic matter, and other factors. At this point, these numbers are not yet backed by University of California research. The best way to determine the actual soil mineral N available at a given time is with a soil test.

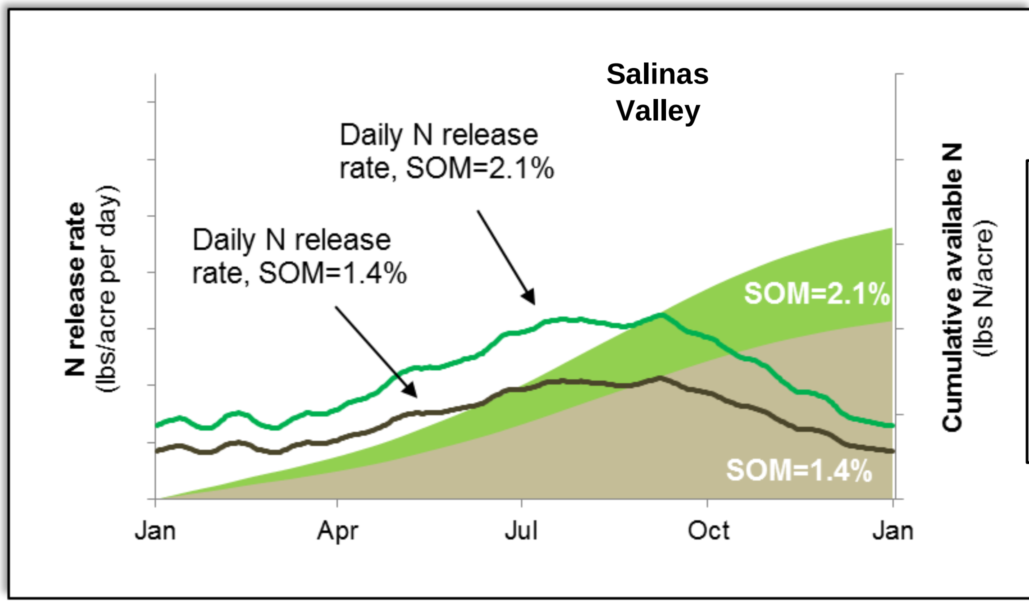


Modeled Yolo County summer N mineralized from the top foot of soil: (~May 1 – Sept 30th)

SOM 1.6%= 80 lb N/acre

SOM 2.8%=140 lb N/acre

Average soil temp, May-Sept: 72 °F



Modeled Salinas summer N mineralized from the top foot of soil: (~May 1 – Sept 30th)

SOM 1.4%= 60 lb N/acre

SOM 2.1%= 90 lb N/acre

Average soil temp, May-Sept: 68 °F

Estimating your SOM release is based on the history of cover cropping, compost amendments and N management. For soils with a long history of building soil organic matter through activities such as composting and cover cropping, estimate a higher N release and for those with a shorter history of soil building, estimate N release on the lower end. In addition, warm season production should have higher numbers than cool season production. For more guidance, read Part 2 Section B in the companion.

C. Crop Residue: Available N from Cover Crops and Post-Harvest Residue

The amount of N made available from crop residues can be considerable depending on N content of the tissue, the C:N ratio, soil moisture and whether residues are left on the surface or incorporated. N content of the tissue will determine the amount of N that is mineralized from crop residue. Typically, N concentration in vegetable residues vary from 2.5 to 5.0% which is similar to a leguminous cover crop. Cereal cover crops can have >2.5% N prior to the boot stage, but decline to below 2.0% upon entering the flowering stage. Crop residues typically contain 40% carbon and vegetable crop residues will have a C:N ratio below 15:1 which allows for N mineralization to begin immediately following incorporation into moist soil. The lower the C:N ratio, the faster mineralization and the more N available for plant uptake. For crop residues with a C:N ratio from 15 to 20, as is common in cover crops, N mineralization will proceed more slowly. Residue with C:N ratios >20 may temporarily immobilize N (Figure 4).

The majority of crop residue is mineralized in the first 2-4 weeks following incorporation into moist soil. During establishment of the subsequent crop this nitrate is susceptible to loss via rain or irrigation. This is why, N mineralized the previous fall may be leached by winter rains and not be available to a spring crop. A soil nitrate test immediately prior to a crop planting will show the total available N (see section D1) at that time. Because residue decomposition is a microbial process, surface-applied residues decay more slowly than incorporated residues. In addition, surface-applied residues are more vulnerable to N loss via volatilization to the atmosphere.

Figure 4 shows the results of an incubation with incorporated high-N, medium-N and low-N residues at optimum moisture. In general the more mature a crop is (ex. producing fruit or grain), the lower the N in the residue and the higher the C:N ratio.

C1. Available N from Cover Crops

Cover crops can be a source of N in the soil. In addition to what is mentioned above, the amount of N they contribute depends on several factors including the species, how dense the stand is, and at what stage it is terminated.

Often cover crop mixes include both grasses and legumes. Grasses have deep, efficient root systems and "mop up" excess N from deeper in the soil. Legumes fix N from the atmosphere into an available form for itself to use. Some examples of N fixation rates are given in Table 2.

It's estimated that about 4-30% of cover crop N is directly used by the next crop[14].Cover crop mixes that are terminated younger, before flowering and with a high proportion of legumes, will release more of their N than older crops and grass-heavy mixes.

Oregon State University has developed a calculator for estimating cover crop N contributions, available online at: https://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, value should only be taken as broad estimates.

Table 2: N fixation estimates for common California leguminous cover crops. Adapted from data provided by the UC SAREP Cover Crop Database.

Common name	Estimated N fixed lbs N/acre/year
Berseem clover	240 - 360
Purple vetch	130 - 300
Field pea	210 - 300
Lana woolypod vetch	230
Subterranean clover	140 - 180
Austrian winter pea	150
Bell bean	80 - 150
Medic	80 - 130
Cowpea	50 - 70

C2. Available N from Crop Residue

For some crops, such as broccoli, only a small part of the N they take up is harvested as the marketable crop, while the rest is incorporated into the soil from residue resulting in 178-255 lb-N/ Ac. Review Table 3 for more additional crop residue N contributions.

Table 3: Estimated N amount and availability of residues from common California crops

Crop	Example yield (tons/acre)	Expected crop residues (lb N/ton yield)	Expected crop residues (lb N/acre)	Source
Lettuce	16-21	4.9	78-102	[1,12]
Tomato (fresh-market)	20	4.5	88	[17, w/ supplemental data]
Tomato (processing)	54	2.2	119	[9]
Sweet potato	17	0.2	4	[20]
Broccoli	7 - 10	25.4	178 - 255	[12]
Carrot	20	7.1	142	[15]
Melon	23	3.0	69	[6,19]
Potato	24	4.7	114	[21]
Strawberry	36	2.7	95	[2]
Spinach	9-16	3.2	29-51	[13]

The values in Table 3 are mostly based on studies with commercial, conventionally managed vegetables in high production areas, and so the yield values may be high. The amount of N 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 in column 3. .

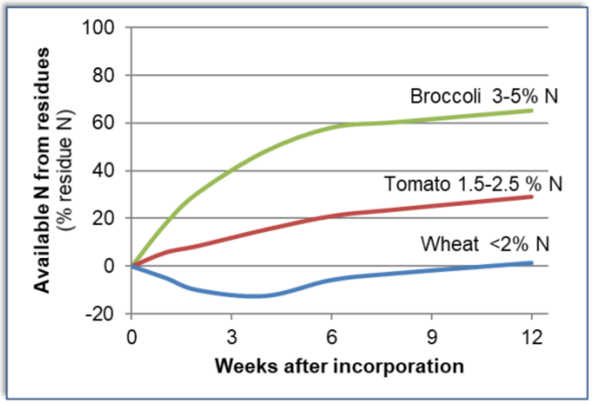


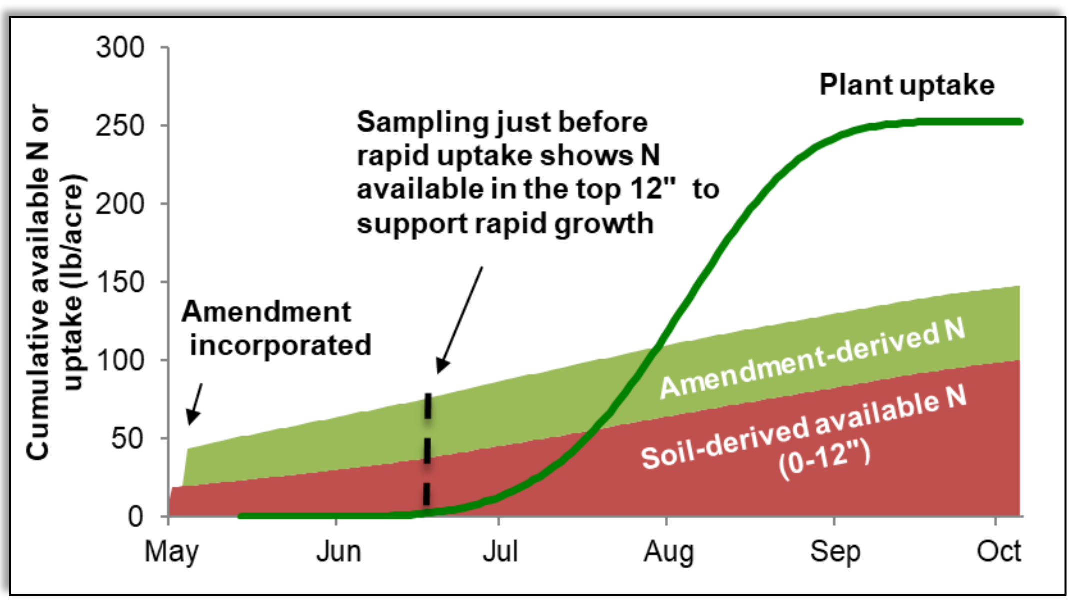
Figure 4: Examples of N release timing from high, medium, and low-N residues[11].

D. Taking and Interpreting Soil and Water tests

D1. Soil nitrate tests

As discussed above, we can make rough estimates of the amount of N that will become available from mineralization of SOM. However, soil nitrate tests assess how much is currently available. This quantity of nitrate represents the amount that has not been lost to leaching from winter rains and is immediately available for plant growth. For example, Figure 5 shows modeled N available from the top foot of soil and 2 tons/acre of poultry manure compost for a tomato crop in Yolo County. The soil test in mid-June measured 20 ppm NO_3-N which is equivalent to 75 lb/acre of available N in the top 12" of soil. This worksheet can help you estimate what to expect over the season.

Figure 5: Example of how an early season soil nitrate test can be used to assess the N available for rapid growth



When to sample: In-season

Because N is a very dynamic nutrient, it's constantly being released from organic forms, taken up by plants and soil organisms, leached downwards in water or volatilized into the atmosphere. Therefore, a fall soil nitrate test will not show how much N will be available for plant uptake the following spring. If the soil test is taken prior to fertilization, it can provide a guide to how much fertilizer is needed for the crop. For a 30 day cool season vegetable such as spinach, this is the only practical time to make adjustments the fertilizer program. This is due to the lag in the time that it takes for organic fertilizers to release N. While soil amendments and soil organic matter will continue to release N over the season, a soil test will only tell us about the current availability.

For processing tomatoes, soil nitrate tests a few weeks after planting can predict whether an in-season sidedress as late as 5-6 weeks after transplanting may increase fruit yield[Error! Reference source not found.]. For a 50-65 day lettuce crop, a sample can be taken following establishing the crop. A test value of 20-25 ppm NO_3-N or above indicates that the crop may not respond to a side-dress application. Given the N uptake characteristics of lettuce a test value of 20-25 ppm NO_3-N indicates that there is adequate residual soil nitrate to provide the crop needs for a period of 10-14 days[3].

When to sample: Post-season

Soil tests can also be taken just after harvest to measure how much N was left over from the crop. High postharvest NO_3 below the top foot of soil, may be an indicator of overfertilization. High postharvest NO_3 contents below the top foot or two may also indicate excess irrigation.

Records of soil samples taken over time can be used to fine-tune N management.

Where to sample

Vegetable crops have the majority of their root systems in the top foot (12") of soil, which is also where cover crop residues and amendments are 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 N from deeper depths. For these crops, the accuracy is improved by deeper sampling. Each foot should be sampled separately.

For postharvest tests, sampling as deeply as three feet (if possible) is informative, as a low available N in the top foot may be a result of efficient N management or of excess irrigation causing N 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 account for the added variability.

Interpreting the report

The two major forms of N which are available for plant uptake are ammonium (NH_4) and nitrate (NO_3) so labs may report either/both forms. Under normal growing conditions, NH_4 is quickly converted to NO_3, so that almost all the plant available N will be in the form of NO_3 and should be used for N budgeting.

Labs normally report values as concentration, or "ppm". The amount in lb/acre can be calculated by multiplying this number by a factor of 3-4 for every foot of soil, depending on the soil bulk density, with low values for 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" of agricultural soils is 3.6 assuming a soil bulk density of 1.2 Mg/m_3.

Some labs report the concentration of NO_3 rather than NO_3-N. When reporting in NO_3, this includes the weight of the oxygens as well as the N. To convert NO_3 to NO_3-N, see the worksheet.

More information about taking and interpreting soil tests can be found here:
https://apps1.cdfa.ca.gov/fertilizerresearch/docs/Soil_Sampling_Nitrate.pdf and here:
http://calag.ucanr.edu/Archive/?article=ca.2016a0027

D2. Sampling water for testing

When well water is used for irrigation, a considerable amount of NO_3 may be applied to the crop in irrigation water.

Figure 6 derived from field trials with drip-irrigated lettuce in Salinas, shows the relationship between N concentration in the irrigation water and available N, at irrigation rates ranging from 4-10 inches/acre (Smith et al., data from 2016). Data points S1 through S6 represent different fields.

More information on the fertilizer value of irrigation water NO_3 can be found here:
http://calag.ucanr.edu/archive/?type=pdf&article=ca.2017a0010

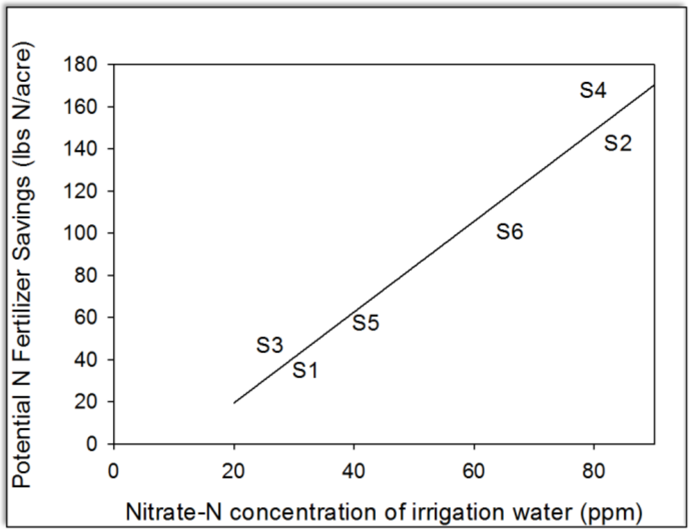


Figure 6. The relationship between nitrate-N concentration in irrigation water and its contribution to N fertilizer savings.

PART 3. N SUPPLY: SEASONAL INPUTS

E. Available N from Organic Amendments

Composts, manures, and granular and liquid organic fertilizers are all applied to supplement soil N. The N availability from these materials differs widely. Figure 7 shows how quickly N became available from different amendment types when they were mixed with soil and incubated for 84 days in warm and moist soil (73°C and 60% water holding capacity). Actual N release rates in the field will depend on soil moisture and temperature but will follow a similar pattern.

Table 4: Potential N availability from different types of organic amendments under warm, moist conditions[16]

Material	Typical C:N ratio	N available after 12 weeks	Releases in
Municipal yard trimmings composts	13 - 20	-3% - 4%	Years
Poultry manure composts	6 - 8	30 - 35%	Weeks-months
Granular fertilizers	5 - 7	38 - 86%	Days-weeks
Blood & feather meal	3 - 4	65 - 70%	Days
Liquid fertilizers	4 - 6	65 - 70%	Days

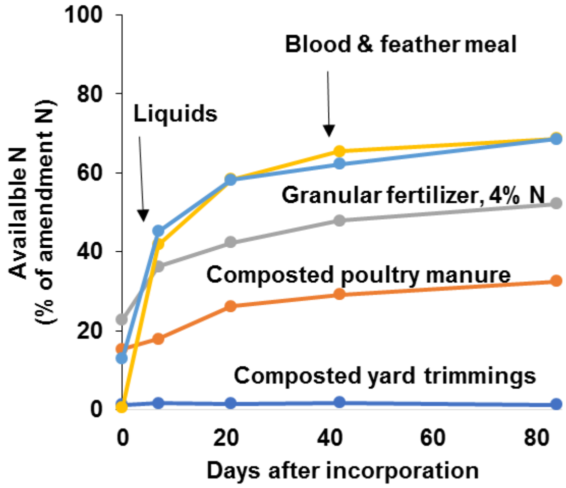


Figure 7: Predicted N release curves from different amendment types under warm, moist conditions[16]

The C:N ratio in an amendment is a good predictor of how quickly its N is released (Figure 8). As a general rule, materials with a C:N ratio above 15 may temporarily make soil N less available for plant use and should not be applied too close to planting.

- Low C:N ratio materials like guano, feather meal and fish emulsion released much of their N in the first week, and almost all their N within three weeks. This quality makes them good sidedress materials.
- Poultry manure composts and granular fertilizers contributed some available N as soon as they are applied, but released their N more slowly. In general, the lower the C:N ratio in the material, the more quickly N will be released.
- High C:N materials like plant-based composts released almost no N. They are good for building long-term soil fertility and soil physical structure, but provide little N for the current crop.

For dry amendments the total N concentration also was closely related to availability.

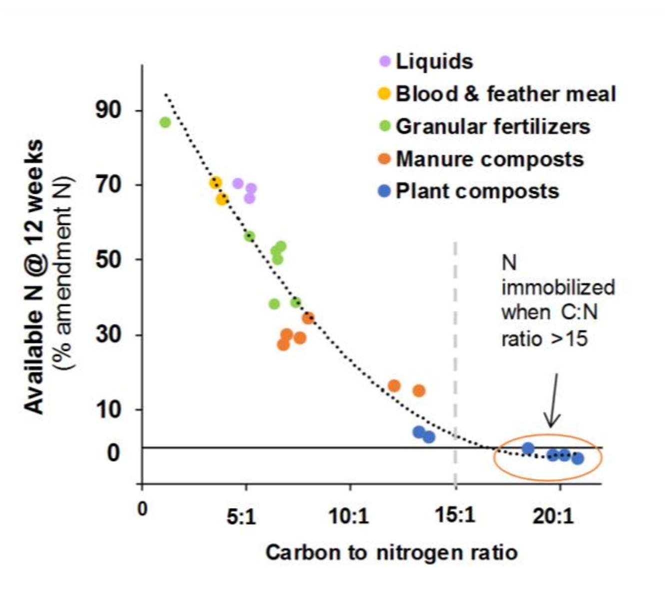


Figure 8: Relationship between potentially available N and amendment C to N ratio[16]

Plant-based liquid fertilizers ranged from 48% to 92% availability whereas manure-based liquid fertilizers (typically fish) ranged from 83% to 99% availability after 4 weeks[10,16]. Organic liquid fertilizers often include particulate matter and are suspensions. Without proper filtration these materials increase the risk of clogging drip emitters. If they are injected before the filter, a significant amount of the N can be removed from the suspension[10]. Regular backflushing may be required to maintain system flow. New technology in liquid organic fertilizer is now providing materials in which N is thoroughly dissolved and does not have the issues just discussed. Coupled with the high cost of N in a liquid product, liquid fertilizers are often viewed as an easy way to supplement in-season fertility, but not provide the bulk of the crops N demand.

In all cases, amendment N release is slower in cool weather. Crops planted in cold temperatures may benefit from starter fertilizers that contain some available N initially. For example, manure-based composts 15% of their total N available at initial application, whereas granular fertilizers started with an average of about 20% (Figure 7).

RESOURCES

Soil Fertility Management for Organic Crops. UCANR Publication 7249.

Resource	Description	Location
Soil fertility management for organic crops (UCANR publication 7249)	University of California extension guide to using organic soil fertility sources.	https://anrcatalog.ucanr.edu/pdf/7249.pdf
CDFA/ FREP California Fertilization Guidelines: N uptake and partitioning	Estimates total N uptake amount and timing for major California Crops (annual and perennial)	https://apps1.cdfa.ca.gov/FertilizerResearch/docs/N_Uptake.html
CFDA/ FREP Nitrogen calculator for Central Valley Crops	Estimates total N uptake amount and timing for minor Central Valley crops (annual only)	https://apps1.cdfa.ca.gov/FertilizerResearch/docs/N_Calculator.html
CDFA/ FREP California Fertilization Guidelines	Estimates of N, P, and K requirements for major California crops (annual and perennial)	https://apps1.cdfa.ca.gov/FertilizerResearch/docs/Guidelines.html
CDFA/ FREP Nutrient management resource links	Collection of links to a variety of tools and informational resources related to nutrient management	https://apps1.cdfa.ca.gov/FertilizerResearch/docs/resources_Topic.html
Nitrogen concentrations in harvested plant parts - A literature overview	Estimates of N removal for major California crops, gives expected ranges	http://kingsriverwqc.org/wp-content/uploads/2017/01/geisseler_report_2016_12_02.pdf
NRCS nutrient removal calculator	Estimates N,P and K removal for a wide variety of temperate and tropical crops	https://plants.usda.gov/npk/main
UC SAREP Cover Crop Database	Contains extensive info on more than 40 different cover crop species	https://asi.ucdavis.edu/programs/ucsarep/research-initiatives/are/nutrient-mgmt/cover-crops
Oregon State University—organic fertilizer and cover crop calculator	Provides info about cover crops and organic fertilizers, including a free calculator to compare nutrient values and costs.	https://extension.oregonstate.edu/organic-fertilizer-cover-crop-calculators
SARE Cover Crop Topic Room	Organized collection of educational materials developed out of decades of cover crop research	https://www.sare.org/Learning-Center/Topic-Rooms/Cover-Crops
"Managing Cover Crops Profitably" (Free ebook)	Explores how and why cover crops work and provides all the information needed to build cover crops into any farming operation.	https://www.sare.org/Learning-Center/Books/Managing-Cover-Crops-Profitably-3rd-Edition

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