

BUILDING A NITROGEN BUDGET FOR ORGANIC CROP PRODUCTION

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Overview

An 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 removed with the harvest.

It's important to build up enough available N in the soil to meet the crop's N needs during periods of rapid growth. However, soil nitrate (NO₃) can easily be leached below a shallow root zone by rainwater or excess irrigation. To avoid loss, irrigation needs to be carefully managed, especially with young plants.

Soil testing can be a useful tool for monitoring and adjusting soil available N.

1.1 Crop N Uptake

Over the long term, external N additions should approximately match the N removed with the harvest. However, the available N must also be sufficient to supply the crop's needs. Both the N removed and the total crop N uptake can be roughly estimated based on the predicted yield (Figure 2).

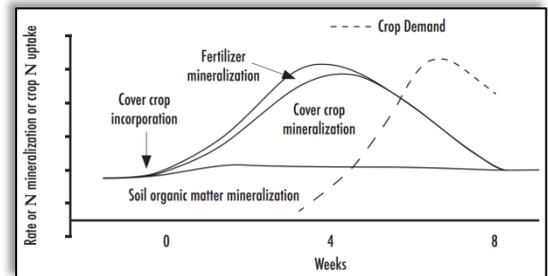
Crops that grow either in winter or summer usually take up less N in winter. Where crop N uptake ranges are given in this chart, the lower end of the range is appropriate for winter crops.

Figure 2: Estimates of N uptake by major California crops

Crop	Example yield (tons/acre)	Total crop N uptake		N removal lbs N/ton yield
		(lbs N/ton yield)	(lbs N/acre)	
Lettuce	18	7.5	120 - 160	2.6
Tomato (fresh-market)	20	11.6	228	2.6
Tomato (processing)	54	5.0	265	2.7
Sweet potato	17	5.0	82.7	4.7
Broccoli	8	36.6	250 - 350	11.2
Carrot	20	10.4	208	3.3
Melon	23	5.4	125	4.9
Potato	24	11.0	265	6.2
Strawberry	36	5.3	190	2.7
Garlic	7	19.3	135	15.1

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 by the expected yield.

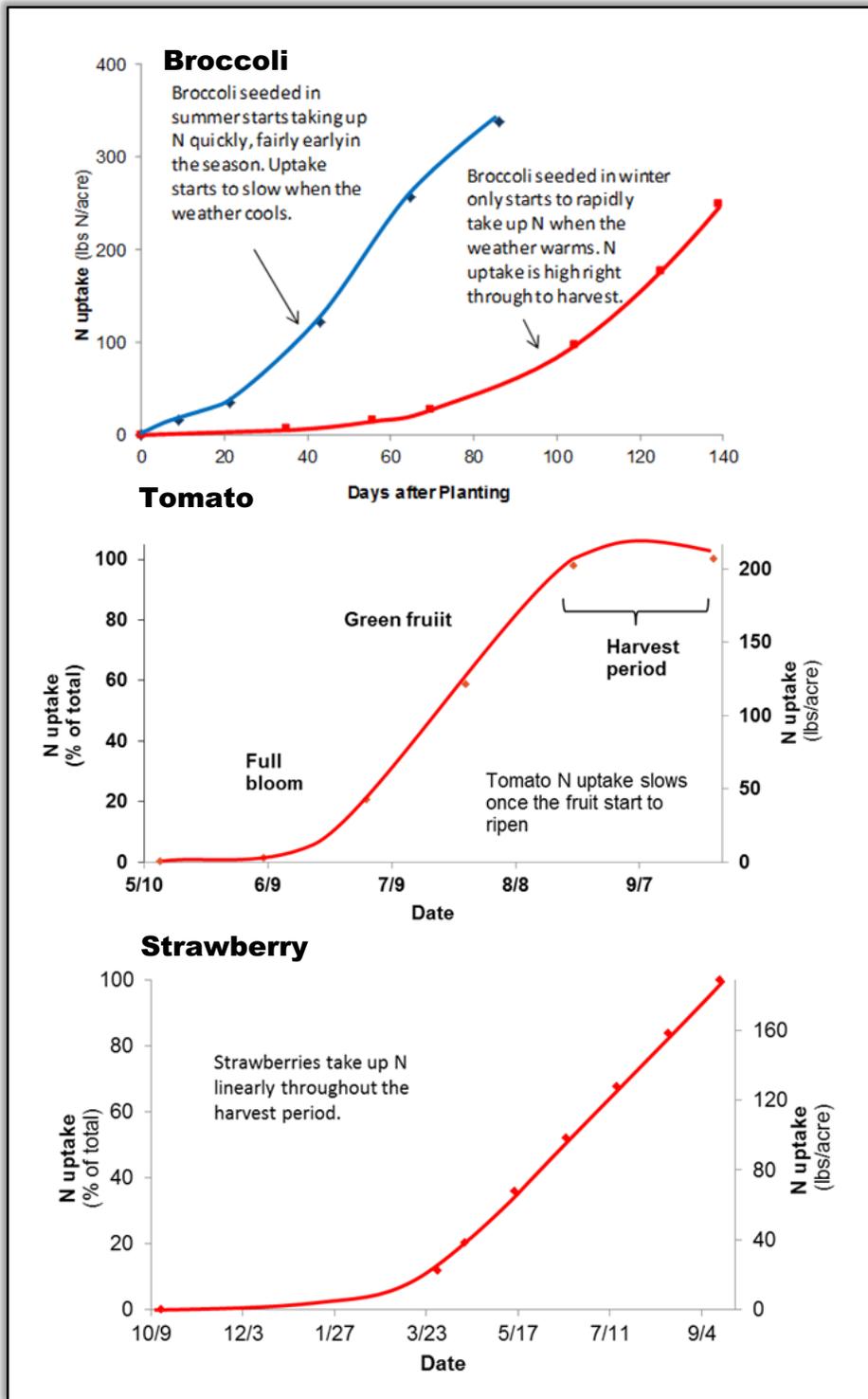
Figure 1: Timing of N mineralization and uptake. From Gaskell et al., 2006 "Soil Fertility Management for Organic Crops" (ANR Pub 7249)



1.2 Crop N Uptake Timing

Crop N uptake follows an “S” shape. Uptake is slow during crop establishment, and then becomes rapid as the crop starts to quickly grow (Figure 3).

Figure 3: Example N uptake curves of different crop growth patterns



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

For some crops, especially where the product harvested is a mature fruit, N uptake may slow or stop during fruit ripening. For crops where the leaves, stems or flowers are harvested, N uptake is normally rapid until harvest.

Broccoli data from a conventional field in the Salinas Valley (Smith et al., 2016). Tomato data from a fresh-market organic heirloom trial in Yolo County (Lloyd et al., unpublished data). Strawberry from conventional fields in the Salinas and Pajaro valleys (Bottoms et al., 2013). References available on request.

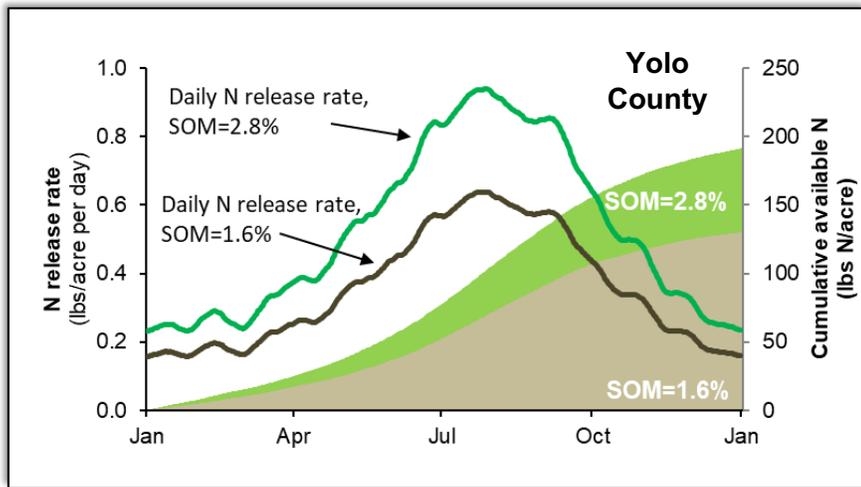
2. Available N from Soil Organic Matter

The amount of N available in the soil depends on the amount of soil organic matter (SOM), soil temperature and soil moisture. A common rule of thumb is that during a summer growing season, about 1-3% of the total soil N becomes available (often ~50-100 lbs N/acre). 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 the SOM than a crop planted in cooler weather.

The green and black lines of Figure 4 represent 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 4: Modeled annual N mineralization from soil organic matter (SOM) in the top foot of soil

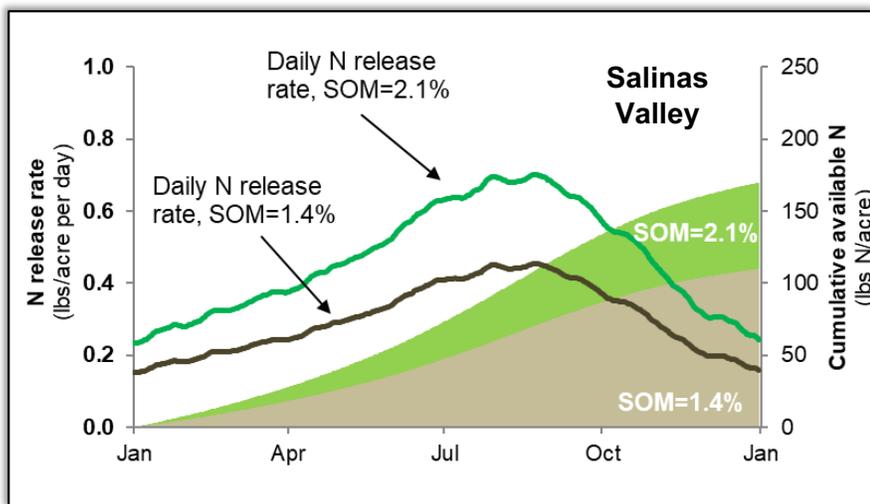


Modeled Yolo County summer N mineralized from the top foot of soil: (~May 1 – Sept 30th)

SOM1.6%= 85 lbs N/acre

SOM2.8%=120 lbs N/acre

Average soil temp, May-Sept: 72 °F



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

SOM1.4%= 60 lbs N/acre

SOM2.1%= 90 lbs N/acre

Average soil temp, May-Sept: 68 °F

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

3. Available N from Cover Crops and Crop Residues

Cover crops can be a significant source of N in the soil. The amount of N they contribute depends on several factors including the species, how thick 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 plants to take up.

It's estimated that about 4-30% of cover crop N is directly used by the next crop (Jackson, 2000). Cover crops that are terminated before flowering and have 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>. This 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.

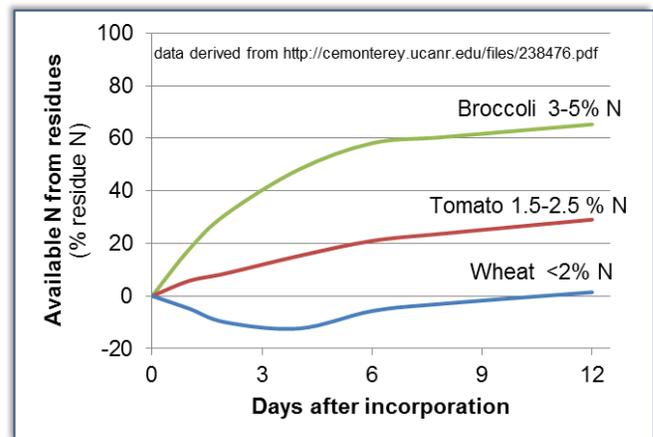
Available N from the Previous Crop

For some crops, only a small part of the N they take up is harvested, while the rest is incorporated into the soil. A considerable amount of N may be added in this way (Figure 6).

Figure 6: Estimated N amount and availability of residues from common California crop

Crop	Example yield (tons/acre)	Expected crop residues	
		(lbs N/ton yield)	(lbs N/acre)
Lettuce	16 - 21	0.5	78 - 104
Tomato (fresh-market)	20	4.5	88
Tomato (processing)	54	2.2	119
Sweet potato	17	0.2	4
Broccoli	7 - 10	25.4	178 - 255
Carrot	20	7.1	142
Melon	23	3.0	69
Potato	24	4.7	114
Strawberry	36	2.7	95
Garlic	7	4.2	29

(Adapted from many studies from around the world; references available on request.)



The table values 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 in column 2, lbs N/ton yield.

How much of this is available to the next crop depends on the N concentration and carbon to nitrogen (C:N) ratio, soil moisture, and whether residues are left on the surface or incorporated. The graph on the right shows the results of an incubation with incorporated high-N, medium-N and low-N residues at optimum moisture. In general, if a mature fruit or grain is harvested, less N will be available from the residues. Residues with a C:N ratio of over 30:1 usually tie up N temporarily, as seen with wheat. Surface-applied residues decay more slowly than incorporated residues.

N mineralized the previous fall may be leached out by winter rains and not be available to a spring crop. A soil nitrate test will show the total available N (see section 5).

Figure 5: N fixation estimates for common California leguminous cover crops

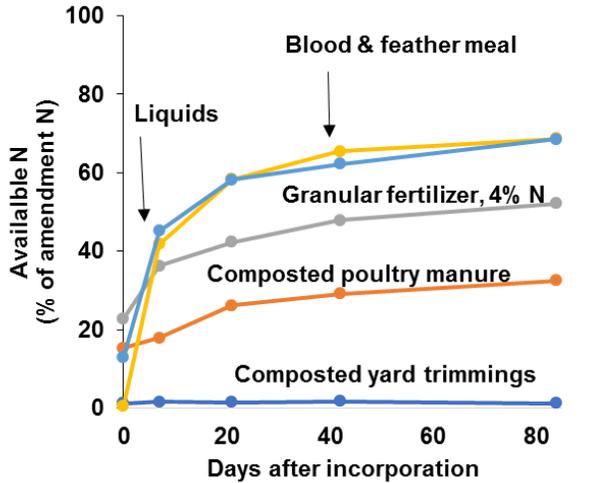
Common name	Estimated N fixed
	lbs N/acre/year
Berseem clover	243 - 357
Purple vetch	129 - 301
Field pea	210 - 297
Lana woolypod vetch	230
Subterranean clover	143 - 175
Austrian winter pea	150
Bell bean	80 - 150
Medic	85 - 131
Cowpea	55 - 70

(Adapted from data provided by the UC SAREP Cover Crop Database.)

4. 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 under ideal conditions for N release. Actual N release rates in the field will depend on soil moisture and temperature.

Figure 7: Potential N availability from different types of organic amendments

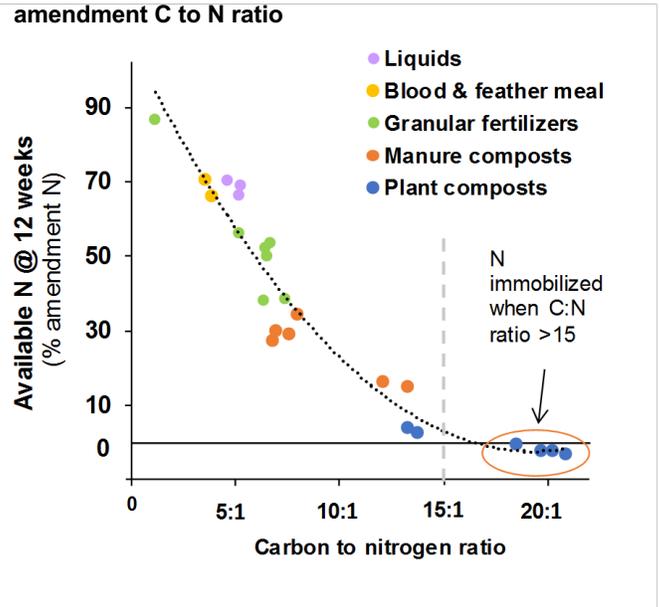


Material	Typical C:N ratio	N available after 12 weeks	Releases in
Municipal yard trimmings composts	13 - 20	-3% - 4%	Years
Poultry manure composts	6 - 8	30 - 35%	Weeks-months
Granular fertilizers	5 - 7	38 - 86%	Days-weeks
Blood & feather meal	3 - 4	65 - 70%	Days
Liquid fertilizers	4 - 6	65 - 70%	Days

The ratio of C to N in an amendment was a good predictor of how quickly its N was released (Figure 8). As a general rule, materials with a C:N ratio above 15 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 property 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 higher the amount of N in the material (%N), 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.

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



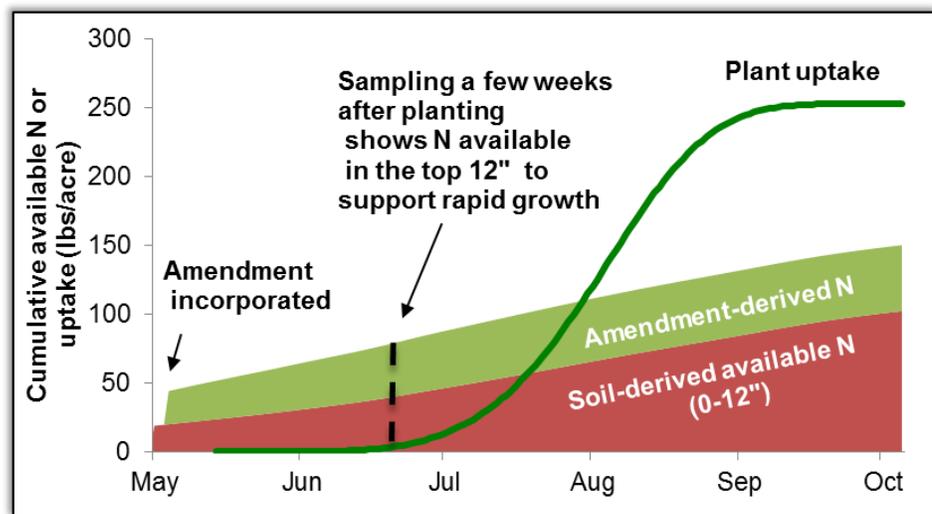
For dry amendments the %N also was closely related to availability. For liquid amendments %N was not a good indicator, since the % N depends on how dilute the liquid is.

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 the materials we tested, manure-based composts and fertilizers usually had about 10-30% of their total N available at initial application.

5. Taking and Interpreting Soil and Water tests

It's difficult to accurately predict the amount of N which will be available to crops using multiple organic N sources. Soil testing provides a direct way of assessing how much is currently available in the soil. For example, Figure 9 shows modeled N available from the top foot of soil and 2 tons/acre of poultry manure compost in for a tomato crop in Yolo County. The soil test value shows about 75 lbs/acre of available N in the top 12" of soil in mid-June (corresponding to a concentration of about 20 ppm $\text{NO}_3\text{-N}$).

Figure 9: Demonstration of how an early season soil nitrate test can be used to assess the N available for rapid growth



When to sample: In-season

Nitrogen 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 test will not show how much N will be available for plant uptake the following spring.

Testing the soil a few weeks after planting can predict whether an in-season sidedress may be beneficial (Heckman et al., 2009). While this tool is more commonly used in conventional agriculture, some work with tomatoes and broccoli suggests it also has value in organic systems. A test value of 20-25 ppm $\text{NO}_3\text{-N}$ or below indicates that the crop may respond to a side-dress application.

When to sample: Post-season

Soil tests can also be taken just after harvest to measure how much N was leftover from the crop. High postharvest NO_3 , especially below the top foot of soil, may be an indicator of inefficient N management.

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 of soil, which is also where cover crops and amendments are placed. Therefore, soil samples are normally taken from the top foot. However, some deep-rooted crops like 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 taken 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). Under normal growing conditions, NH_4 is quickly converted to NO_3 , so almost all the plant available N will be in the form of NO_3 . When soils are cold, waterlogged, or very dry, or had an amendment added in the past couple weeks, NH_4 may be present as well.

Labs normally report values as concentration, or "ppm". The amount in lbs/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 heavy clay soils and higher values for more compacted or very sandy soils. A commonly used factor for agricultural soils is 3.6. For example, a soil test value of 10 ppm $\text{NO}_3\text{-N}$ in the top foot would mean that $10 \text{ ppm} \times 3.6 = 36$ lbs N/acre were available at the time of sampling. If the top two feet were sampled, it means $10 \times 3.6 \times 2 = 72$ lbs N/acre are in the top two feet.

Some labs report the concentration of NO_3 rather than $\text{NO}_3\text{-N}$. This includes the weight of the oxygens as well as the N. To convert NO_3 to $\text{NO}_3\text{-N}$, divide by the given value by 4.42. For example, a soil test value of 44.2 ppm NO_3 in the top foot would mean that $(44.2 \text{ ppm} / 4.42) \times 3.6 = 36$ lbs N/acre were available at the time of sampling.

More information about taking and interpreting soil tests can be found here:

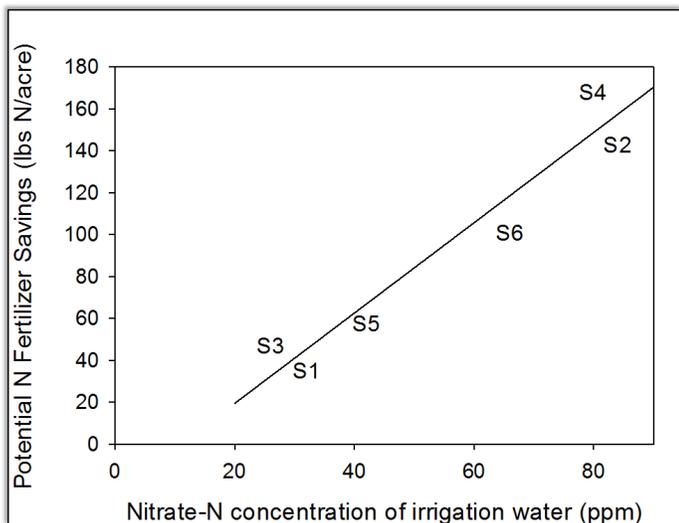
https://apps1.cdfa.ca.gov/fertilizerresearch/docs/Soil_Sampling_Nitrate.pdf and here:

<http://calag.ucanr.edu/Archive/?article=ca.2016a0027>

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.

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



To convert $\text{NO}_3\text{-N}$ concentration in the water to lbs N/acre, $\text{NO}_3\text{-N}$ 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-N, $10 \text{ ppm} \times 0.227 \times 1 = 2.27$ lbs N are applied per acre.

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>