Baseline Soil Nitrogen Mineralization: Measurement and Interpretation

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Highlights

Baseline soil nitrogen (N) mineralization refers to the plant-available nitrogen (PAN) release that accompanies the biologically mediated decomposition of soil organic matter (SOM).

Baseline soil N mineralization usually supplies about half of crop N uptake (pages 3–4). Although this N is not mentioned explicitly in Pacific Northwest (PNW) nutrient and fertilizer guides, N fertilizer rate recommendations do account for typical baseline N mineralization amounts. Soils that have been heavily manured for many years or are naturally very high in SOM can supply most of the N required for crop production via mineralization.

The rate of baseline soil N mineralization is governed by the quantity and quality of SOM, as modified by soil moisture and temperature (pages 4–5). Annually, about 1% to 3% of the N present in SOM is mineralized to nitrate (NO_3).

Laboratory tests to measure baseline soil N mineralization rate (Nmin tests) are often included in soil health assessment packages because they reflect the digestibility of SOM and the capacity of the microbial community to convert organic N to plant-available forms. Many laboratory Nmin test methods have been proposed, and a variety of test methods are offered by commercial laboratories. Most laboratory tests for N mineralization are useful only as measures of relative changes in soil health. We review four general categories of laboratory tests (pages 6–9):

- Aerobic and anaerobic lab incubations to directly measure mineralized N.
- Soil total N, organic C or SOM by routine commercial methods.
- Active N fraction of SOM (hot water, amino sugar and ACE protein methods).
- Active carbon (C) fraction of SOM (carbon dioxide (CO_2) "burst" and permanganate C methods).

To be useful in managing site-specific N inputs, these laboratory tests must be calibrated to accurately predict actual field N mineralization rates. We describe two methods used in calibration studies to measure N mineralized in the field: the buried bag and the zero N plot methods (pages 10–11).

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Contents

Supplemental resources

Oregon State University and Pacific Northwest Extension publications address related aspects of N and soil health management, including:

- *Nitrogen Uptake and Utilization by Pacific Northwest Crops* (PNW 513).
- *Soil Organic Matter As A Soil Health Indicator* (EM 9251).
- *Understanding And Measuring Organic Matter In Soil* (Washington State University Extension, EM118E).
- *Soil Nitrate Testing for Willamette Valley Vegetable Production* (EM 9221).
- Management of N supplied by organic sources, including manure (PNW 533 and EM 8954), compost (EM 9217), cover crops (PNW 636) and municipal biosolids (PNW 508 and 511).
- *OSU Organic Fertilizer & Cover Crop Calculator: Predicting Plant-available Nitrogen* (EM 9235). Includes cost comparison, based on PAN.

Additional N management guidance is provided in crop-specific nutrient management guides (catalog.extension.oregonstate.edu).

Process: baseline N mineralization of soil organic matter

We consider organic materials (for example, manure, compost and crop residues) part of baseline soil organic matter (SOM) after they have been in the soil for at least three months in spring or summer, or for at least six months after a fall application (Figure 1). Nonbaseline nitrogen (N) mineralization occurs in the first three to six months following application of organic material (Table 1, page 3). Crop residues that remain on the soil surface in no-till cropping systems are not considered part of baseline SOM.

Mineralization is the biologically mediated process whereby organic matter is decomposed and inorganic, plant-available nutrients such as N, phosphorus (P) and sulfur (S) are released. Nitrogen in SOM is decomposed by soil biota in two steps, yielding nitrate as an end product (Figure 1). In this publication, we refer to the nitrate accumulated in soil from the decomposition of SOM as “mineralized N” and the overall biological process that converts organic N to nitrate as “mineralization.” Ammonium is a short-lived intermediate in the conversion of organic N to nitrate.

Decomposition of SOM and the accompanying baseline N mineralization rate are slow compared to decomposition of other OM inputs (Table 1, page 3). Despite its low carbon-to-nitrogen ratio (typically 10–15), SOM decomposes very slowly.

Because SOM contains a large amount of total N, considerable plant-available N (PAN) is released by mineralization each year. For example, an acre-foot of a soil with 3 percent SOM contains about 5,000 lb total N. Thus, when baseline soil N mineralization is 2 percent per year, 100 lb N/acre of PAN (5,000 lb total N/acre × 0.02) is released via mineralization per year.

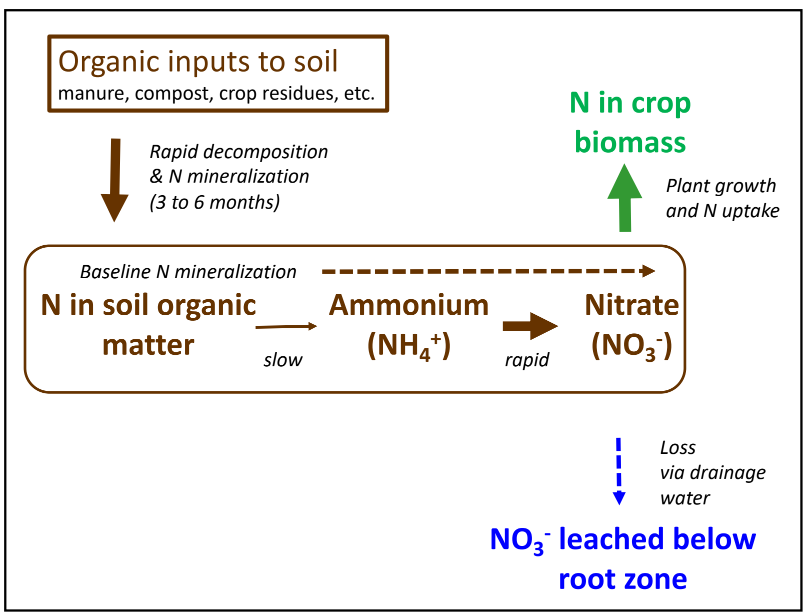

Figure 1. Baseline N mineralization within the nitrogen cycle. **New organic inputs** are included in soil organic matter after approximately three to six months residence time in soil. **Nitrogen mineralization** is the conversion of N from an organic form to an inorganic form as a result of microbial activity. **Baseline N mineralization** describes the conversion of N in soil organic matter to nitrate. Ammonium-N is typically a short-lived intermediate in conversion of organic N to nitrate-N.

The amount of PAN released via baseline mineralization depends on many factors, including SOM quality and quantity, soil temperature, soil moisture and tillage.

In addition to being a source of PAN for crop production, the nitrate generated by mineralization can also be an environmental concern. Ideally, crops would take up all of the nitrate produced by mineralization, but this is seldom the case. Synchronization between crop N need and mineralization is difficult to achieve. Crop N uptake rate is rapid during midseason vegetative growth. Later in the season (after flowering), crop N uptake slows to near zero, but soil continues to produce nitrate via mineralization. Nitrate that is mineralized from SOM and is not taken up by crops can be leached below the crop root zone during the fall and winter in western Oregon. Much of the N that is leached below the root zone is eventually transported to groundwater.

How baseline N mineralization affects crop yield response to N fertilizer

Although baseline N mineralization is not mentioned explicitly in PNW nutrient and fertilizer guides, N fertilizer rate recommendations do account for typical baseline N mineralization amounts. This is true because the guides are based on N fertilizer rate response trials (crop yield versus N fertilizer rate applied) conducted on the soils that are used to grow specific crops.

Crop and soil management history, particularly the history of organic inputs, affect baseline N mineralization amounts and the amount of N fertilizer input required to meet crop yield goals. This relationship is reflected in two ways in the crop yield response curves (Figure 2):

- Crop yield with no fertilizer N applied is greater when baseline N mineralization increases from "typical" to "high."
- The amount of fertilizer N required to reach maximum yield is reduced (by 50 lb N/acre in this example) when baseline N mineralization increases from "typical" to "high."

Baseline soil N mineralization typically supplies about half of crop N uptake (Figure 3). Soils low in SOM that have received minimal N inputs may supply less than a quarter of crop N uptake via mineralization. Soils that

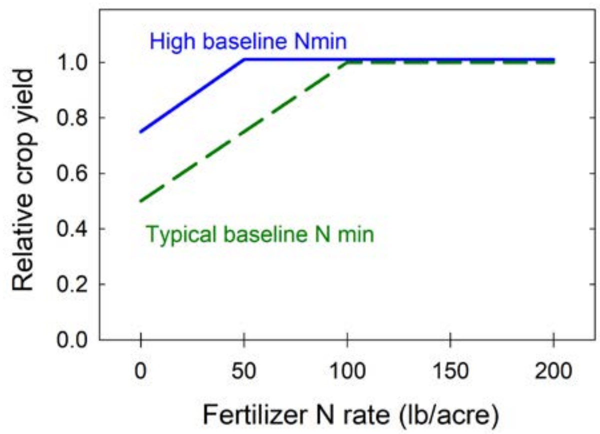

Figure 2. Recommendations given in OSU and PNW nutrient management guides assume typical background soil N mineralization amounts. As the amount of baseline soil N mineralization increases, the amount of N fertilizer required to maximize crop yield decreases.

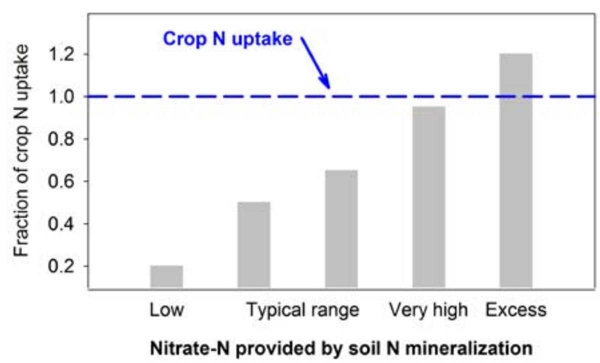

Figure 3. The amount of nitrate-N released by baseline N mineralization varies widely among soils and N input histories. Conceptual N mineralization categories (low to excess) represent scenarios observed in field research trials. Source: D. Sullivan.

Table 1. Relative rates of decomposition and cumulative plant-available N (PAN) release for a range of organic matter types.

Organic matter example	Rate of decomposition	Cumulative PAN released by mineralization (% of total N)		
		4 weeks[a]	10 weeks[a]	One year
Baseline soil organic matter	Very slow. Years to centuries.	—	—	1 to 3
Well-cured, stable compost[b]	Slow	0–5	5–10	5–10
Legume cover crop	Rapid	20–40	40–60	50+
Chicken manure	Rapid	20–40	40–60	50+
Feather or fish meal	Very rapid	60+	75+	near 100

[a]See *OSU Organic Fertilizer and Cover Crop Calculator: Predicting Plant-available Nitrogen* (EM 9235) for more precise PAN estimates for cover crops, manures and specialty organic fertilizer inputs.
[b]Compost stability testing is used to define how "finished" a compost is. See *Interpreting Compost Analyses* (EM 9217) for compost stability criteria. When the compost C-to-N ratio is greater than 15, PAN release is near zero during the first year following application.

have been heavily manured for many years or that are naturally very high in SOM may supply most of the N required for crop production.

Soils that supply a small amount of N for crop production via N mineralization require greater and more frequent N inputs to supply crop N need. Soils that supply most or all of the crop N requirement via baseline N mineralization are more susceptible to nitrate loss, because the timing of baseline N mineralization is controlled by soil temperature and moisture rather than by crop need.

Most soils and cropping histories do not have excess N mineralization capacity. However, when organic inputs have been applied to a field for many years, soil N mineralization capacity can build so that mineralization alone supplies more nitrate-N than crops can use (Figure 3).

Effects of soil moisture and temperature on mineralization

The rate of baseline soil N mineralization is governed by the quantity and quality of SOM, as modified by soil temperature and moisture (Figures 4 and 5; Cassman and Munns, 1980; Paul, et al., 2003; Curtin, et al., 2012). Computer simulation models can integrate these variables and make predictions for N mineralization rate. Modeled soil N mineralization rate is typically estimated as:

soil N mineralization rate = default soil N mineralization rate × TF × MF

where:

Default soil N mineralization rate = typical N mineralization rate (ppm N per unit time) at specified temperature and moisture

TF = relative rate of N mineralization based on temperature (Figure 4)

MF = relative rate of N mineralization based on soil moisture (Figure 5)

The default N mineralization rate is based on laboratory test data for soil total N, organic carbon (C) or SOM by routine commercial methods.

The rate of baseline N mineralization increases exponentially with temperature. For example, the rate of N mineralization increases about fivefold as soil temperature increases from 40 to 80°F (Figure 4).

Soil moisture is the other major environmental variable that governs baseline N mineralization rate (Figure 5). Soil moisture is in the optimum range for mineralization during most of the summer for irrigated crops and during the fall and winter throughout western Oregon. Excess soil moisture reduces the rate of N

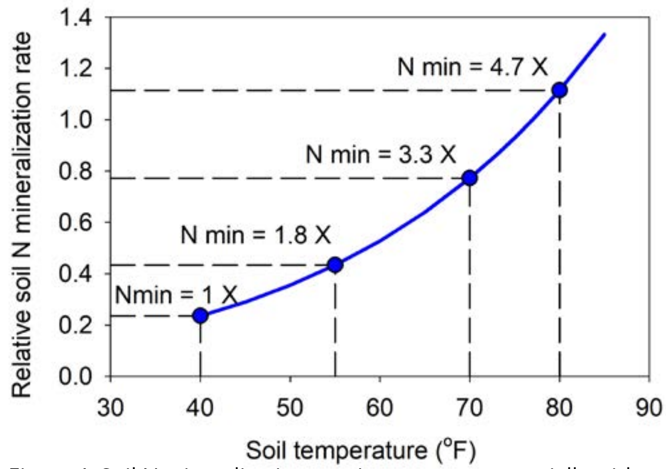

Figure 4. Soil N mineralization rate increases exponentially with soil temperature. The rate of mineralization is near zero when soil temperature is less than 40°F. Adapted from Gilmour, 1998.

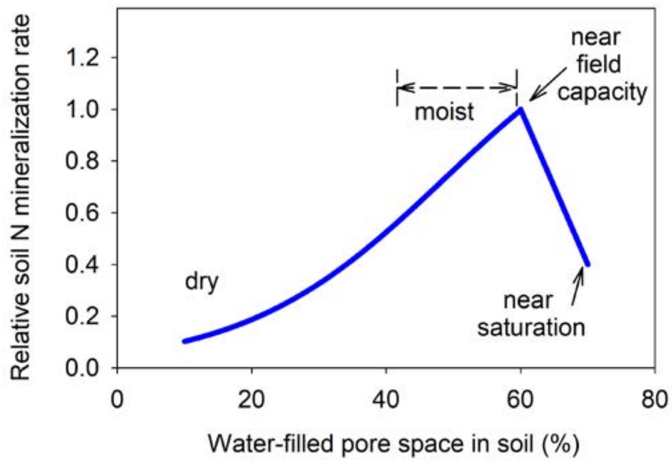

Figure 5. Effect of soil moisture on the relative rate of N mineralization from SOM. Adapted from Linn and Doran, 1984; Shaffer, et al., 2009.

mineralization. As soil nears saturation, net nitrate production is reduced, because some of the mineralized N is lost to the atmosphere via denitrification (Figure 5).

Computer simulation models incorporate a variety of measurements to characterize soil moisture. The most common parameter is percent water-filled pore space (WFPS). Water-filled pore space describes the percentage of soil pores that are filled with water. WFPS is calculated as:

water-filled pore space (%) = (soil water volume/total porosity of soil) × 100

Optimum N mineralization occurs at or near 60 percent WFPS (Figure 5; Linn and Doran, 1984; Shaffer, et al., 2009). In irrigated crop production, soil moisture typically is maintained above 40 percent WFPS.

Example: baseline soil N mineralization rate in the field

The rate of baseline soil mineralization for irrigated crops depends primarily on soil temperature and organic input history. Figure 6 shows an example of the timing of baseline N mineralization in soils (0- to 8-inch depth) that differ in manure application history. No N fertilizer or manure was applied to either treatment in the spring of the year represented in Figure 6. Soils were maintained with consistent moisture, so moisture did not limit the N mineralization rate. Both “manure” and “no manure” soils contained approximately 5 percent SOM. Soil N mineralization was determined in the field using a buried bag method (see the open cylinder method in “Field measurements of N mineralized,” pages 10–11).

Baseline N mineralization rate was slow in spring (Figure 6a) until soil temperatures exceeded 60°F. In summer, baseline N mineralization rate increased with soil temperature, peaking in July. In fall, when soil temperatures were below 60°F, baseline N mineralization rate slowed again.

Cumulative soil N mineralized was approximately two times greater in the soil with a history of manure application compared to the soil with a no-manure history (Figure 6b). The peak rate of baseline N mineralization observed in July increased from 0.4 ppm/day with no manure to 1 ppm per day with a manure application history (Figure 6c).

Because both of the soils in this example (“manure” and “no manure”) had similar amounts of SOM (5 percent), the quantity of SOM did not explain the difference in observed N mineralization rates. Apparently, manure application increased the “active” fraction of SOM, although the increase in total SOM was not measurable.

This study illustrated a challenge in timing for effective use of nitrate provided by baseline N mineralization. Many summer row crops (for example, corn) take up N during vegetative growth in June and July, but do not take up N during reproductive growth in August. Yet, as shown in the example, soil often continues to mineralize N during August. Nitrate present in soil in early September is subject to loss via overwinter leaching. Nitrate leaching loss can be reduced, but not eliminated, by planting a fall cover crop.

The timing of N mineralization illustrated here also is important when choosing an N fertilizer rate. Crops planted in June or later in the summer can often be grown with less N fertilization than crops planted in March or April.

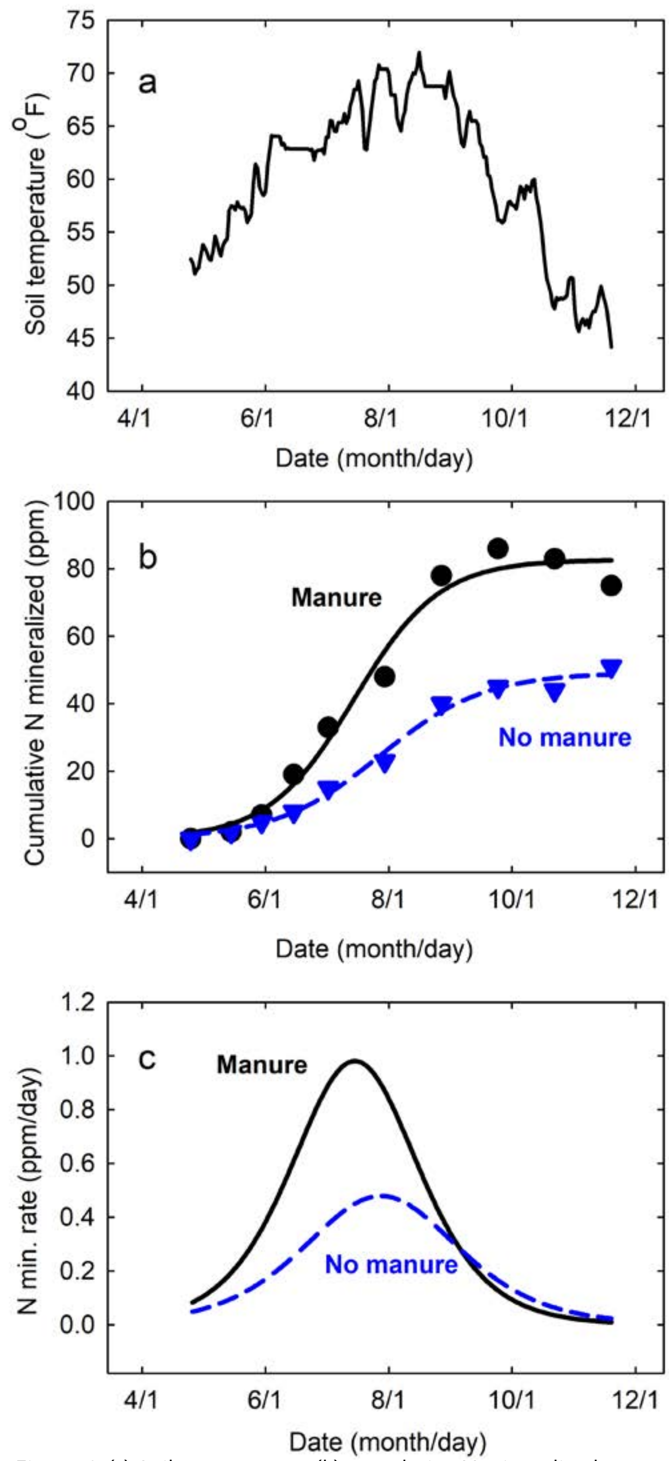

Figure 6. (a) Soil temperature; (b) cumulative N mineralized; (c) daily N mineralization rate. Kickerville silt loam soils (5 percent SOM, 0- to 8-inch depth) incubated in the field using a buried bag method. Soils differed in manure application history (“manure” versus “no manure”) but were not fertilized in the year shown. Adapted from Sullivan, et al., 1999.

Timing of soil sample collection for Nmin tests

The best time to collect soil samples for measuring baseline soil N mineralization is usually in early spring, before the application of N fertilizer or organic inputs. Fall sampling may be useful in no-till cropping systems. Avoid sampling within a few months following fertilizer, manure or compost application or incorporation of crop residues. When the purpose is to track changes in baseline N mineralization over time, sampling at the same time every year is recommended.

A specific sampling protocol for Willamette Valley-grown winter wheat is described in *Using the Nitrogen Mineralization Soil Test to Predict Spring Fertilizer N Rate for Soft White Winter Wheat Grown in Western Oregon* (EM 9020).

Laboratory Nmin tests

Many test methods have been proposed and evaluated for assessment of baseline soil N mineralization rate (Griffin, 2008; Ros, et al., 2011). Table 2 provides an overview of four categories of soil test methods:

- Incubation tests to directly measure N mineralized from SOM.
- Soil total N, organic C or SOM by routine commercial methods.
- Active N fraction of SOM.
- Active C fraction of SOM.

Table 2. Overview of baseline N mineralization tests: accuracy, utility, commercial availability and time required for measurement.

	Test rating (5 = best)[a]			
Test	Accuracy of soil N mineralization estimates in the field	Useful for making field-based N input rate decisions	Useful as a soil health index component	Test available from commercial soil testing labs
Incubation tests to directly measure N mineralized from SOM				
Buried bag (in-field)	5	No[b]	No	No
Aerobic, 90+ days	4	No[b]	No	No
Potentially mineralizable N (PMN), aerobic, 28 days[c]	3	2	Yes	Some labs
Potentially mineralizable N (PMN), anaerobic, 7 days[c]	3	2, 3[d]	Yes	Some labs
Soil total N, organic C or SOM by routine commercial methods (<1 day)				
Total N	2	1	Yes	Yes
Organic C	2	1	Yes	Yes
SOM by loss-on-ignition (LOI)	2	1	Yes	Yes
Active N fraction of SOM (<1 day)				
Hot water or hot salt water method	1	1	Yes	Some labs
Amino sugar method	1	1	Yes	Some labs
ACE protein	1	1	Yes	Some labs
Active C fraction of SOM (<3 days)				
CO_2 "burst" (1–3 days)	1	1	Yes	Some labs
Permanganate oxidizable C (POXC, 1 day)	1	1	Yes	Some labs

[a]The buried bag test is performed in the field. All other tests are performed in the laboratory. Relative rankings are based on the best professional judgment of the authors:
5 = Strong relationship between test value and baseline soil N mineralization in the field.
3 = Some field calibration of N mineralization prediction, but test calibration is limited to specified soils and cropping systems.
1 = Few or no field calibration studies in the PNW.
[b]Incubation tests conducted during the growing season do not predict N mineralization. They are useful only for looking backward in time.
[c]Potentially mineralizable N (PMN) is another name for an aerobic or anaerobic soil incubation. "Potentially" recognizes that laboratory incubations are only rough indicators of N mineralization rates and amount under field conditions.
[d]The seven-day anaerobic test is useful for N fertilizer rate adjustment for winter wheat in western Oregon (EM 9020).

Although many tests may be useful for soil health assessment, we do not recommend widespread adoption of any of the current tests as a way to modify N fertilizer recommendations. In general, the necessary field research to calibrate the laboratory test methods with fertilizer recommendations has not been conducted. Converting laboratory tests into site-specific N mineralization forecasts and N fertilizer recommendations requires a calibration equation or computer simulation model. Such equations and models must be validated locally before reliable recommendations can be based on them.

Details about test methodology and the conceptual relationship between test values and baseline N mineralization rates are discussed below (Tables 3–6).

Inorganic N mineralized from aerobic or anaerobic soil incubation (Table 3)

These tests directly measure mineralized inorganic N. Both aerobic and anaerobic tests require two inorganic N analyses (before and after incubation) to determine net N mineralized.

Aerobic. The aerobic test employs temperature and moisture likely to be present in the field (Figure 7). To be a reproducible laboratory test, soil moisture must be adjusted prior to aerobic incubation, based on the moisture-holding capacity of the specific soil. Mineralization proceeds most rapidly when moisture fills 60 percent of soil pore space and air fills the remaining 40 percent (Figure 5, page 4). Optimum soil moisture content for an aerobic N mineralization test is based on soil texture and bulk density, ranging from approximately 12 percent (12 g water/100 g dry soil) for loamy sands to 25 percent or more for silty clay loam soils. Adjusting soil moisture to the ideal range for N mineralization is usually not feasible in commercial laboratories. Aerobic N mineralization is primarily a research method.

Anaerobic. When conducting an anaerobic test, soil samples are saturated, then incubated in an airtight container for seven days at 104°F (40°C). Because all soils are saturated for this test, regardless of soil texture, it is simpler and faster than the aerobic test. The high temperature doubles or triples the rate of N mineralization versus that observed at 68–86°F (20–30°C).

In Oregon, the anaerobic test is employed to forecast N mineralization and adjust N fertilizer rates for winter wheat in western Oregon (Christensen and Mellbye, 2006; EM 9020). The anaerobic test was evaluated for its ability to predict N mineralization for perennial ryegrass (for seed) in western Oregon. The relationship between test values and crop response in the field was weak (Hart, et al., 2007), and the test is not recommended for ryegrass. A few commercial laboratories offer the anaerobic test.

Photo: Dan Sullivan

Figure 7. Aerobic soil incubation method used in Sullivan laboratory. Method details: A sieved, moist soil sample (approximately 0.8 lb) is put into a zippered freezer bag. Drinking straws are inserted through the zipper to facilitate air flow. Bags are placed into a box with a loose-fitting lid. A foam pad, moistened with water, is placed on the floor of the box to maintain humidity in the box and to reduce moisture loss from soil.

Table 3. Tests to directly measure N mineralized from SOM.

Test[a]	How the test estimates N mineralization[b]
Potentially mineralizable N (PMN), aerobic, 28 days @ 68–86°F (20–30°C)	Direct measurement of mineralized N. When temperature and water-filled pore space in soil are standardized, Nmin is determined by SOM quantity and its decomposition rate. In most aerobic incubations, NH_4-N concentrations are insignificant, and they often are ignored. *Nmin = NO_3-N accumulated during incubation*
Potentially mineralizable N (PMN), anaerobic, 7 days @ 104°F (40°C)	Direct measurement of mineralized N. When soil is anaerobic and warm, microbes mineralize SOM to NH_4, but nitrification (conversion of NH_4 to NO_3) is inhibited by the lack of oxygen. *Nmin = NH_4-N production during incubation*

[a]A general overview of test methods is provided in Griffin, 2008. Potentially mineralizable N (PMN) is another name for an aerobic or anaerobic soil incubation. “Potentially” recognizes that laboratory incubations are only rough indicators of N mineralization rate and amount under field conditions.

[b]To predict N mineralization in the field, lab results are extrapolated to field temperatures based on an assumed time/temperature relationship, such as degree days or an exponential equation similar to that shown in Figure 4 (page 4).

Soil total N, organic C or SOM by routine commercial methods (Table 4)

Total C, total N or total SOM is measured in commercial laboratories using rapid, precise and accurate laboratory methods. However, the relationship between these tests and the actual N mineralization rate in the field is only approximate (Vigil, et al., 2002; Griffin, 2008; Ros, et al., 2011). The failure of total SOM as an accurate predictor of baseline N mineralization rate has stimulated research to develop tests to measure "active" soil N and C.

Extractions to estimate a labile or "active" N fraction in SOM (Table 5)

These tests are based on the idea that an "active" soil N fraction is a relevant indicator of soil N mineralization. The amount of "active" soil N extracted varies among test methods. These test methods can be rapidly performed by commercial testing laboratories in less than a day. Attempts at field calibration have generally shown that the active N tests are highly correlated with SOM or with soil total N concentration (Barker, et al., 2006; Griffin, 2008). Research to date has shown some benefit of using these tests to improve N mineralization estimates in soils from limited geographic areas (see, for example, Curtin, et al., 2017; Rogers, et al., 2018) or to modify default N mineralization estimates based on SOM concentration (Klapwyk and Ketterings, 2006; Klapwyk, et al., 2006).

The active SOM tests (Table 5) are typically more expensive and less reproducible than routine test methods (Table 4). Therefore, active SOM tests are currently recommended only for *qualitative* soil health assessments. The ACE protein test has been evaluated only as a soil health indicator test (Hurisso, et al., 2018; Stott, 2019). Research relating ACE protein to soil N mineralization has been initiated but not reported.

Table 4. Routine commercial laboratory tests that can be correlated with actual soil N mineralization.

Test	How test estimates N mineralization[a]
Total N[b]	Over 98 percent of soil total N is found in SOM. Total N is determined by combustion or Kjeldahl methods. *Nmin = total N × factor*
Organic C[c]	Combustion method or Walkley-Black method used to determine soil C. A typical soil C-to-N ratio (from 10 to 15) is assumed. *Nmin = organic C × factor*
Loss-On-Ignition (LOI)[c]	Sample weight loss at high temperature indirectly estimates SOM. A typical total N percentage in SOM is assumed. *Nmin = LOI × factor*

[a]Factor: To predict N mineralization in the field, lab results are extrapolated to field scenarios using a calibration equation or a computer simulation model. Research-based equations or models for predicting N mineralization in the field are not available for most situations.
[b]The combustion method is the most common method for soil total N analysis (Gavlak, et al., 2005).
[c]Test methods for organic C and LOI are described in Gavlak, et al. (2005) and in *Soil Organic Matter as a Soil Health Indicator: Sampling, Testing, and Interpretation*, EM 9251.

Table 5. Tests to estimate the labile or "active" N fraction present in SOM.

Test[a]	How test estimates N mineralization[b]
Hot water or hot salt water (for example, extraction with KCl or $CaCl_2$ solution)	Test extracts the portion of soil organic N that is correlated with N mineralization. *Nmin = extracted N × factor*
Illinois Soil N Test (ISNT), "amino sugar"	Organic N stored as amino sugars is an important source of N mineralized from SOM. *Nmin = extracted amino sugars × factor*
ACE protein (autoclaved citrate-extractable protein)	Soil proteins represent the largest pool of organically bound N in soil organic matter. *Nmin = extracted protein × factor*

[a]Hot water or hot salt water extraction methods: Ros, et al., 2011. Amino sugar (Illinois Soil N Test, ISNT): Khan, et al., 2001. ACE protein: Stott, 2019.
[b]Factor: To predict N mineralization in the field, lab results are extrapolated to field scenarios using a calibration equation or a computer simulation model. Research-based equations or models for predicting N mineralization in the field are not available for most situations.

Methods to estimate the "active" C fraction of SOM (Table 6)

Both N mineralization and CO_2 release accompany decomposition of organic matter. Among the most common test methods to estimate the active C fraction of SOM are: (1) measurement of CO_2 evolution upon rewetting of a dry, ground soil sample (CO_2 "burst" test) and (2) reacting soil with an oxidizing agent (for example, permanganate). The CO_2 burst test requires one to three days; the permanganate oxidation test (POXC) can be completed in less than one day.

Predictions of N mineralization rate using these tests are sometimes based on a calibration equation that incorporates other soil test data. Calibration research conducted across a wide range of soils and cropping systems has demonstrated a weak relationship between these active C tests and soil N mineralization rate (Hurisso, et al., 2016; Yost, et al., 2018). At this time, these tests are recommended only to qualitatively assess soil health. Cooperative studies to standardize laboratory methods and improve reproducibility of test results are ongoing (Stott, 2019).

Interpretation of laboratory tests for soil N mineralization: present and future

Laboratory tests for N mineralization may play a role in a soil health assessment (Figure 8) or in making N fertilizer rate decisions (Figure 9, page 10). It is important to recognize that most N mineralization tests have not been calibrated to forecast appropriate N fertilizer rates. Most of the current tests are useful only for measuring relative changes in soil health (Figure 8).

A test for N input adjustment (Figure 9, page 10) requires field-based calibration data correlating the Nmin test value to crop yield response to N inputs (fertilizer or organic N input). Calibration of an Nmin test for use in forecasting N fertilizer need is generally limited to a single crop within a specified climate and cropping system. Otherwise, too many site-specific variables affect whether the Nmin potential observed in the laboratory translates into timely nitrate availability for the crop. In general, calibration of Nmin tests across many cropping systems, soils and climates has *not* proven to be reliable.

In the future, soil Nmin tests may find semiquantitative applications within computer simulation models. Within existing simulation models such as NLEAP (Shaffer, et al., 2009), a laboratory Nmin test could be used as an "accelerator" or "decelerator"

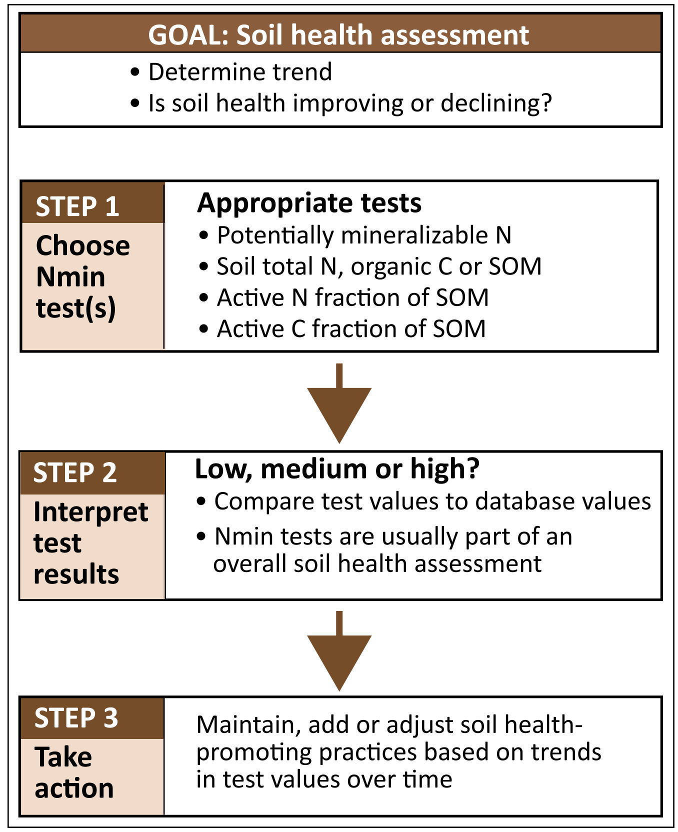

Figure 8. Process for **soil health assessment** using Nmin test(s). Interpretations are qualitative. Appropriate interpretations are often site-specific and are typically made by a grower, in consultation with a farm advisor.

Table 6. Tests that use active C as a predictor of soil N mineralization rate.

Test[a]	How test estimates Nmin[b]
CO_2 burst test: Carbon dioxide evolution after rewetting dry soil	An oven-dried, finely ground soil sample is rewetted, causing SOM to decompose via microbial respiration. CO_2 is a by-product of the respiration process. When the soil C-to-N ratio is less than 15, N mineralization accompanies CO_2 evolution. This test requires that soils be uniformly rewet to field capacity (approximately 60 percent water-filled pore space). *Nmin = CO_2 respired × factor*
Permanganate oxidizable C (POXC). Organic C extracted via wet chemical oxidation	Test extracts "easily oxidizable" fraction of SOM. *Nmin = soil C extracted × factor*

[a]Test methods: Carbon dioxide evolution: Franzluebbers, et al., 2000; Franzluebbers, 2016. Permanganate oxidizable C (POXC): Weil, et al., 2003; Stott, 2019.
[b]Factor: Calibration factors are based on empirical relationships between lab data and relevant time and soil temperatures in the field.

parameter to speed up or slow down the default soil N mineralization rate. By nesting a laboratory Nmin test variable within a larger computer simulation model, extreme overprediction or underprediction errors in forecasting N fertilizer requirement could be avoided. In the future, artificial intelligence or machine learning technologies may be useful in improving the accuracy of Nmin forecasts, based on a database of historic observations. At present, these ideas have not been validated by research.

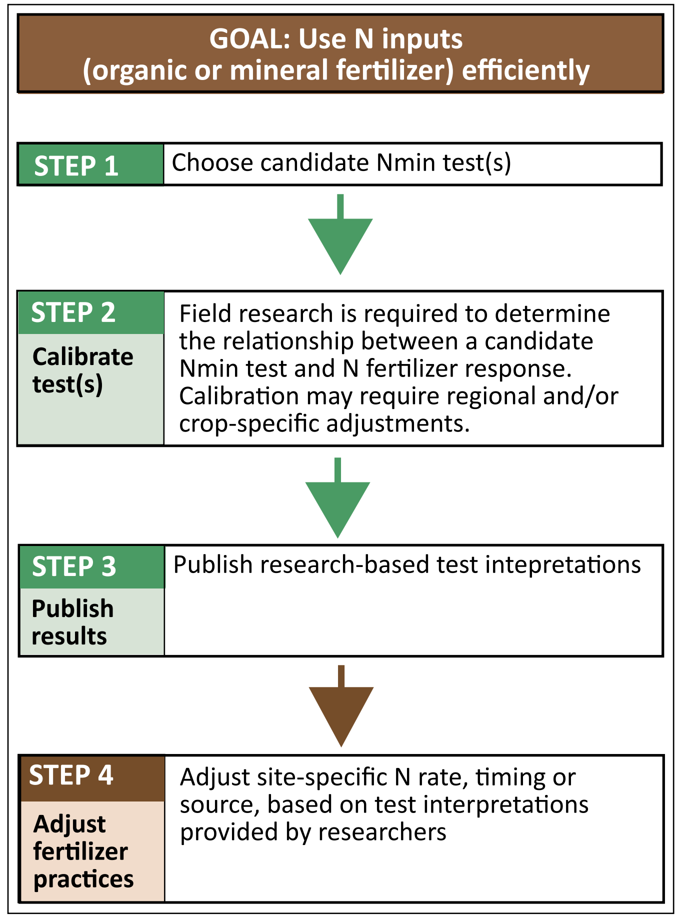

Figure 9. Process for development of reliable research-based Nmin tests for the purpose of **N input adjustment**. This process requires the expertise of soil science professionals in conducting research and developing reliable quantitative interpretations of the test (Steps 1–3, green) for use by growers to adjust site-specific N management practices (Step 4, brown).

Field measurements of N mineralized

This section describes two methods to relate N mineralization estimates determined by laboratory tests (Table 2, page 6) to actual N mineralization observed in the field. These methods are valid only to measure baseline N mineralization when soils have not been fertilized with organic N inputs or inorganic N fertilizers during the previous three to six months. See Schepers and Meisinger (1994) for additional method details.

Field method: Buried bag

Description. The buried bag method is used to measure N mineralization at in-field soil temperature (Westermann and Crothers, 1980). It has been employed in Oregon (Figure 10) and in Idaho.

For the buried bag method, moist soil is collected at rooting depth within one to two weeks of planting. Ideally, soil is at or near field capacity when the sample is collected, as this is the optimum moisture content for N mineralization processes to occur. Well-mixed field-moist composite soil samples are sieved through a coarse screen (6–8 mm). The soil sample is divided and placed into polyethylene bags. Polyethylene is ideal for the buried bag method, as it allows for enough oxygen and CO_2 exchange to support microbial processes such as N mineralization but does not allow water or nutrient loss.

Figure 10. In-field aerobic incubation using the buried bag method: (1) Polyethylene bags are filled with moist soil. (2 and 3): Bags are placed vertically in auger holes, after the crop has been planted. (4) Soil temperatures in bags reflect actual field soil temperatures, including shading by the crop. See *Nutrient Management for Sustainable Vegetable Cropping Systems in Western Oregon* (EM 9165) for additional method explanation and N mineralization data for Willamette Valley soils.

Photos: Aaron Heinrich

The bags are buried in the field after the crop has been planted. Bags installed prior to planting may be destroyed during the planting process. At prescribed intervals during the growing season, bags are removed from the field for determination of soil nitrate-N concentration. Mineralized N is the net increase in soil nitrate-N from the date of bag burial.

Researchers have used many variations of the buried bag approach to evaluate N mineralization in the field. For example, an open-cylinder method uses a cylinder (PVC pipe or aluminum) as the vessel for holding soil (instead of a bag). Using this method, soil is packed into open-ended cylinders, with a granular anion exchange resin pillow at the bottom (Kolberg, et al., 1997; Eghball, 2000; Moberg, et al., 2013). The exchange resin captures nitrate in leachate passing through the soil in the cylinder. When cylinders are removed from the field, both the soil in the cylinder and the resin pillow are extracted to measure nitrate. The open-cylinder variation of the buried bag method was used to collect data shown in Figure 6 (page 5).

Limitations. Soil moisture in buried bags is static, while soil moisture in the field changes throughout the growing season. Also, soil aggregation in bags is generally less than soil aggregation in the field. The process of N mineralization in the bags is mediated solely by soil microorganisms (bacteria and fungi) because crop roots and macrofauna (for example, earthworms) are excluded from the buried bags. Soil nitrate also accumulates to atypically high concentrations in the bags, because plant roots are not taking up N and nitrate leaching is prevented. In spite of these issues, a strong relationship between cumulative N mineralized in buried bags and crop N uptake was demonstrated in a field study with sugar beet (Figure 11).

Field method: crop N uptake from a zero N plot

Description. Nitrogen uptake by an unfertilized crop is a practical method for estimating baseline N mineralization, provided a few precautions are observed (Schepers and Meisinger, 1994). This method has the advantage of being conducted under field temperature, moisture and aeration conditions, and it incorporates the rooting characteristics of a specific crop (rooting depth, root density and root exudates) into the N mineralization measurement.

Using this method, a crop is grown without added N fertilizer, organic amendments or any other N inputs during the growing season. Aboveground crop N uptake is calculated using the N concentration of the plant tissue and the dry weight of the aboveground crop biomass.

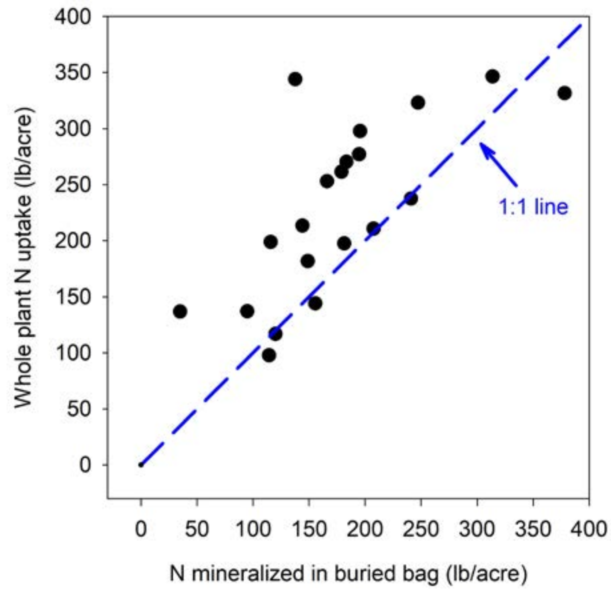

Figure 11. Soil N mineralized (0- to 24-inch depth) versus whole-plant N uptake by a sugar beet crop. Mineralized inorganic N was measured using the in-situ buried bag incubation method (Figure 10; Westermann and Crothers, 1980). Soil for buried bag incubation was collected in the spring near the time of beet seeding. Source: A. Moore and A. Leytem, Kimberly, ID (unpublished).

The zero N plot method has been used successfully with summer vegetable crops grown in western Oregon, where winter rainfall is sufficient to leach virtually all of the residual soil nitrate from the previous year (EM 9165, Figure 5). In this situation, almost all of the nitrate that is available to a spring-seeded crop comes from mineralization of SOM, provided no additional N inputs are applied in spring. The zero N plot method may also be useful east of the Cascades, provided that early spring residual soil nitrate concentrations are less than 5 ppm NO_3-N throughout the crop rooting depth.

Limitations. Nitrogen supplied from sources other than soil N mineralization can sometimes compromise zero-N plot measurements. Examples include N supplied in irrigation water, N from accidental fertilizer application and gaseous ammonia-N that drifts onto the field from a nearby source. A wet crop canopy can trap gaseous ammonia, and leaves can absorb it. In very infertile soils, poor root system development may limit access to all of the nitrate present in the soil.

Before-and-after soil nitrate testing is recommended with zero N plot measurements. Ideally, soil nitrate concentrations are low both when the crop is seeded and when the crop is harvested, demonstrating that N present in the crop came from baseline N mineralization during the growing season.

For most crops, only aboveground biomass collection is feasible. For root and tuber crops, the below-ground biomass also needs to be measured. See EM 8949-E for a description of the zero N plot method for potatoes.

Questions and answers: Nmin tests

Why isn't there a reliable soil test to predict baseline N mineralization?

Nitrogen is the nutrient applied in greatest quantity to boost crop yields. A soil test to estimate crop N need would have economic and environmental benefits. Soil scientists have tried many approaches to estimating N mineralization from a soil test, but they have made only slight progress in finding a method that is universally acceptable. Many factors affect baseline N mineralization test results, including SOM quality and quantity, soil temperature, soil moisture, tillage and microbial community composition and activity.

The soil test report from a commercial soil testing laboratory reports a value for estimated nitrogen release. What is this measurement? Is it reliable?

Some soil test reports list estimated nitrogen release (ENR). The ENR value is usually based on an assumed relationship between SOM concentration and nitrate-N release via mineralization. It rarely represents data collected via an additional laboratory test. Instead, the ENR (lb/acre) = soil OM percentage multiplied by a constant (usually ENR = SOM × 20). This equates to approximately 1 percent of SOM mineralized per year. Using this equation, N mineralized from SOM is estimated as 20 lb N/acre for a soil with 1 percent SOM and 100 lb N/acre for a soil with 5 percent SOM. Often, the same constant conversion factor is applied to all soil test data, regardless of field history, soil sampling depth, heat units in the field or other scenario-specific factors.

Rarely does research demonstrate a strong predictive relationship between measured SOM and predicted baseline Nmin. Therefore, we recommend ignoring ENR values on soil test reports.

Are Nmin tests explicitly used to guide N fertilizer application rates in OSU nutrient management guides?

A soil Nmin test has not been calibrated for use with most agronomic crops. One exception is the anaerobic Nmin test, which has been calibrated only for soft white winter wheat production in *western* Oregon (EM 8963 and EM 9020). Soil samples are collected during the last two weeks in January, when wheat is at the tillering growth stage. The laboratory Nmin test (anaerobic incubation at 104°F, table 3, page 7) requires 7 days. Spring N fertilizer application for winter wheat typically occurs in March in western Oregon, allowing sufficient time for completion of the laboratory Nmin test to guide a decision on N fertilizer rate based on test values.

Midseason soil nitrate tests, such as the pre-sidedress nitrate test (PSNT), are an indicator of soil N mineralization rates. Recommendations for sidedress N fertilizer application, based on a midseason nitrate test, are given in OSU nutrient management guides for vegetable crops (EM 9221 and EM 9272). A soil sample for a midseason soil nitrate test is typically collected four to six weeks after planting. The midseason (PSNT) test is not a "pure" baseline Nmin test. It measures carry-over nitrate from the previous crop, plus any preplant N fertilizer, plus additional nitrate mineralized from SOM during the early growth of a vegetable crop.

Is there a standardized method and interpretation for the CO_2 "burst" respiration test?

Laboratory test protocols can strongly affect test results. The CO_2 burst test method has not been sufficiently standardized (Wade, et al., 2018). Soil sample collection and preparation, labware used to perform the test, soil moisture content, method of soil moisture addition, duration of incubation and the method used for measuring CO_2 evolution can all affect test results. Therefore, we recommend great caution when comparing CO_2 "burst" test values from one laboratory to those from another laboratory.

Glossary

Active fraction of SOM. A fraction of total SOM that has a half-life of a few years. Soil tests to quantify active SOM are under development (Table 5, page 8).

Baseline N mineralization. The conversion of N present in SOM to nitrate via microbial activity (Figure 1, page 2).

Denitrification. Loss of nitrate to the atmosphere as a gas (N_2 or N oxides — there are a number of forms). In aerobic soils, loss of nitrate via denitrification is typically insignificant.

Nitrogen mineralization. The conversion of N from an organic form to inorganic forms (ammonium and nitrate) as a result of microbial activity. Ammonium is usually a short-lived intermediate in the conversion of organic N to nitrate. In this publication, we refer to the overall biological process that converts SOM to nitrate as "baseline N mineralization." Ammonium N can sometimes persist in acid soils below pH 5.5, when soils are cold (less than 45°F) or when soil is saturated.

Nmin tests. Laboratory tests that may be useful in predicting baseline N mineralization from SOM in the field. Major categories of Nmin tests are listed in Table 2 (page 6).

Organic inputs. Includes crop residues, manures, composts, biosolids and other organic materials.

Plant-available nitrogen (PAN). The inorganic forms of N (nitrate and ammonium) that can be taken up by plant roots.

Potentially mineralizable N (PMN). Another name for an aerobic or anaerobic soil incubation that quantifies N mineralization. "Potentially" recognizes that laboratory incubations are only rough indicators of N mineralization rate and amount under field conditions.

Saturated soil. All pores in saturated soils are filled with water. As soil nears saturation, the net amount of nitrate produced by N mineralization is reduced. Some of the nitrate is lost to the atmosphere via the process of denitrification.

Soil health (or soil quality). Soil health is the continued capacity of soil to function as a vital living ecosystem to support plants, animals and humans (Chessman, et al., 2019). "Soil health" and "soil quality" are often used interchangeably in the literature.

Soil health test. A test used to evaluate soil function(s). Typically, a battery of biological, chemical and physical soil health tests is required to assess overall soil function. Mineralization is an important biological soil function. A recent NRCS publication describes recommended soil health test methods (Stott, 2019).

Soil incubation. A research method used to quantify soil N mineralization or other soil biological processes under specified soil temperature and moisture conditions.

Soil moisture at field capacity. The amount of water held in soil pores against the force of gravity. Field capacity occurs a day or two after heavy rain or irrigation. When soil moisture is at field capacity, soil moisture tension is approximately 0.1 bar for loamy sands and 0.3 bar for loams; about 60 percent of soil pores are water filled, and the remaining 40 percent are air filled.

Soil organic matter (SOM). The organic fraction of the soil, excluding undecayed plant and animal residues. We consider organic materials (for example, manure, compost and crop residues) part of baseline soil organic matter (SOM) after they have been in the soil for at least three months in spring or summer, or for at least six months after a fall application. Soil organic matter is 50–60 percent C by weight. SOM is expressed as a percentage on a dry weight basis: SOM/soil (w/w) × 100.

Soil test calibration. The process of validating soil test results to plant performance in the field to determine crop nutrient need. Nitrogen management recommendations are valid only when accompanied by relevant field calibration data. To be considered reliable, soil test calibration studies must be performed over a number of years and within crop rotations of local interest.

Soil total carbon (C) and organic C. In acid soils, total C = organic C. In alkaline soils, a portion of total C is contained in carbonates (inorganic C). In alkaline soils with carbonates, organic C = (total C − inorganic C).

Soil total nitrogen (N). The sum of all forms of nitrogen present in soil, including organic and inorganic forms. Typically, over 98 percent of the soil total N is contained within SOM.

Water-filled pore space (%) = (volumetric water content/total volume of soil pores) × 100. Soil bulk density and soil moisture measurements are required to estimate water-filled pore space. A soil particle density of 2.65 g/cm^3 and a water density of 1 g/cm^3 is assumed. Water-filled pore space is used in computer simulation models to estimate the effect of soil moisture on baseline N mineralization rate.

For more information

Extension publications

Analytical Laboratories Serving Oregon. EM 8677, https://catalog.extension.oregonstate.edu/em8677, Oregon State University.

Estimating Plant-available Nitrogen from Manure. EM 8954, catalog.extension.oregonstate.edu/em8954, Oregon State University.

Estimating Plant-available Nitrogen Release from Cover Crops. PNW 636, https://catalog.extension.oregonstate.edu/em8954, Oregon State University.

Estimating Nitrogen Mineralization in Organic Potato Production. EM 8949-E. https://catalog.extension.oregonstate.edu/sites/catalog/files/project/pdf/em8949.pdf, Oregon State University.

Fertilizing with Biosolids. PNW 508, https://catalog.extension.oregonstate.edu/pnw508, Oregon State University.

Fertilizing with Manure and Other Organic Amendments. PNW 533, https://catalog.extension.oregonstate.edu/pnw533, Oregon State University.

Interpreting Compost Analyses. EM 9217, https://catalog.extension.oregonstate.edu/em9217, Oregon State University.

Nitrogen Uptake and Utilization by Pacific Northwest Crops. PNW 513, https://catalog.extension.oregonstate.edu/pnw513, Oregon State University.

Nutrient and Soil Health Management for Sweet Corn. EM 9272, https://catalog.extension.oregonstate.edu/EM9272, Oregon State University.

Nutrient Management for Sustainable Vegetable Cropping Systems in Western Oregon. EM 9165, https://catalog.extension.oregonstate.edu/em9165, Oregon State University.

OSU Organic Fertilizer and Cover Crop Calculator: Predicting Plant-available Nitrogen. EM 9235, https://catalog.extension.oregonstate.edu/em9235, Oregon State University.

Soft White Winter Wheat (Western Oregon) Nutrient Management Guide. EM 8963, https://catalog.extension.oregonstate.edu/em8963, Oregon State University.

Soil Nitrate Testing for Willamette Valley Vegetable Production. EM 9221, https://catalog.extension.oregonstate.edu/em9221, Oregon State University.

Soil Organic Matter as a Soil Health Indicator: Sampling, Testing and Interpretation. EM 9251, https://catalog.extension.oregonstate.edu/em9251, Oregon State University.

Understanding and Measuring Organic Matter in Soil. EM118E, https://pubs.extension.wsu.edu/understanding-and-measuring-organic-matter-in-soil, Washington State University.

Using the Nitrogen Mineralization Soil Test to Predict Spring Fertilizer N Rate for Soft White Winter Wheat Grown in Western Oregon. EM 9020, https://catalog.extension.oregonstate.edu/em9020, Oregon State University.

Worksheet for Calculating Biosolids Application Rates in Agriculture. PNW 511, https://catalog.extension.oregonstate.edu/pnw511, Oregon State University.

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