OREGON STATE UNIVERSITY EXTENSION SERVICE

Postharvest Soil Nitrate Testing

for Manured Grass and Silage Corn (West of the Cascades)

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Photo: Troy Downing, © Oregon State University

Summary

This publication describes the use of postharvest soil nitrate testing as a tool to assess nitrogen (N) management in manured cropping systems west of the Cascade Mountains in Oregon, Washington and south coastal British Columbia.

The postharvest soil nitrate test measures the amount of nitrate remaining in the top 12 inches of soil in late summer or early fall following crop harvest. Corn and grass differ in their capacity to take up nitrate from the soil, so test interpretation is crop-specific.

The test looks backward in time. It evaluates the balance between N supply and crop uptake for the crops produced during the summer. Nitrate accumulates in the soil when more plant-available N is supplied than the summer crop takes up. Use the postharvest test to:

- Identify fields that are at greater risk of nitrate loss via leaching under current management.
- Identify differences in N supply among fields on a farm.

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Soil nitrate dynamics: accumulation and loss

Nitrogen from manure and soil organic matter is converted to nitrate in a two-step process (mineralization and nitrification; see Figure 1). Mineralization converts soil organic matter to ammonium-N. Nitrification converts ammonium-N to nitrate. Because nitrification proceeds more rapidly than mineralization, ammonium-N is short-lived in soil. This is why we choose to monitor soil nitrate. Crop uptake removes nitrate from soil during the growing season. Nitrate is soluble in water and moves downward in the soil with fall and winter rainfall. Most of the nitrate remaining in soil after harvest is lost via leaching by the following spring.

Agronomic rate and postharvest soil nitrate

Crops respond to plant-available nitrogen (ammonium and nitrate-N) by the "law of diminishing returns" (dotted lines in Figure 2). Without added N, some crop yield is produced from N mineralized from soil organic matter, previous crop residue and residual nitrate in soil. As N supply increases, crop N uptake also increases, until maximum yield is achieved. Maximum crop yield is determined by the environment, crop management and crop genetics.

The rate of manure or N fertilizer required to achieve near-maximum or optimum crop yield with minimal leaching of nitrate is called the *agronomic rate*. Agronomic rate is a range of values, rather than a single value (Figure 2), because crop growing conditions vary from year to year. When N supplied from all sources exceeds crop N uptake capacity (the area of the graph to the right of the "agronomic rate range" in Figure 2), soil nitrate accumulates and is subject to loss during the rainy season.

Excess soil nitrate in fall can result from:

- Excess N application.
- N application too late in the season.
- Poor crop growing conditions, usually due to drought or pests.

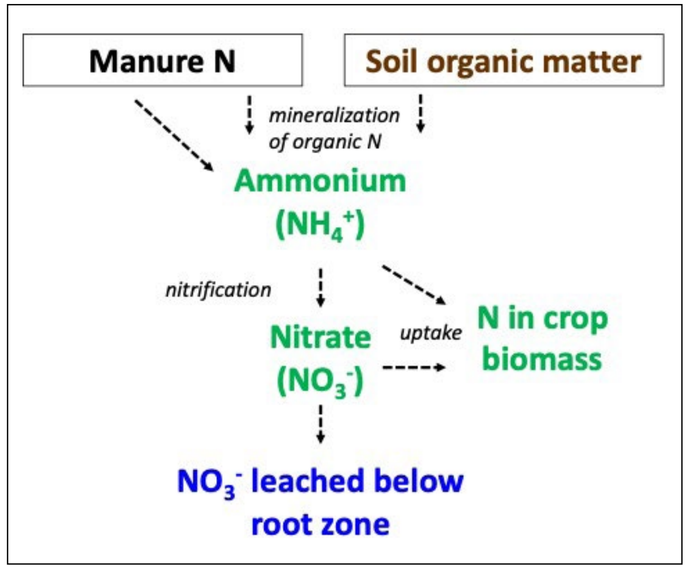

Figure 1. Nitrate is produced via a two-step process (mineralization and nitrification) from manure and soil organic matter. Crop growth and harvest removes nitrate from soil. Nitrate remaining in the soil in the fall is subject to overwinter leaching loss.

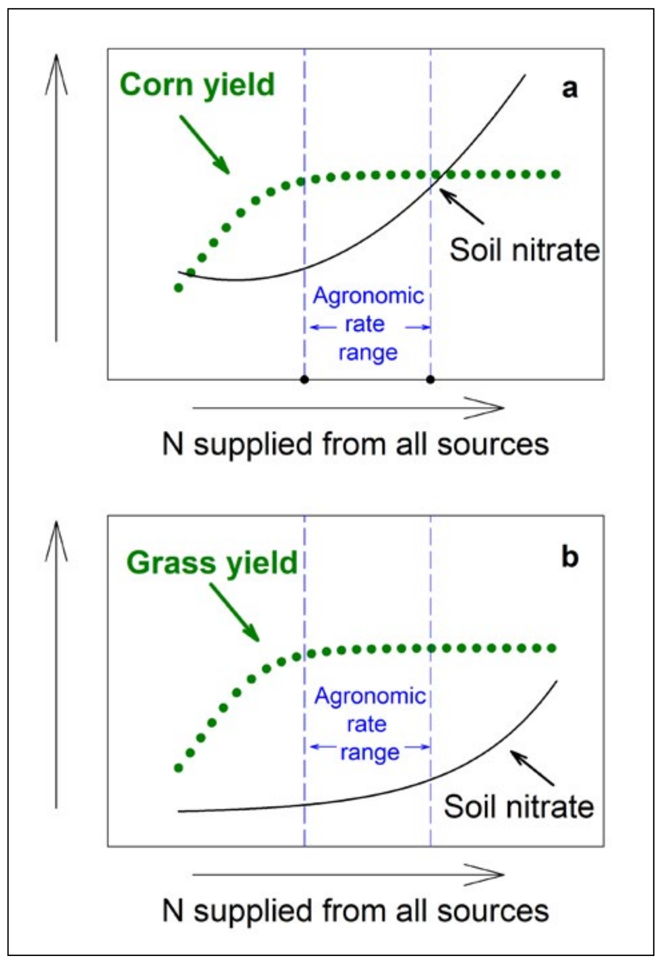

Figure 2. The effect of N supply on crop yield and postharvest soil nitrate. Grass has a greater capacity to remove nitrate from soil than corn. As a result, when nitrate supply exceeds crop demand, postharvest soil nitrate is greater with corn (a) than with grass (b).

Table 1. Average calendar date when cumulative rainfall (after Sept. 1) reaches 3–7 inches for field locations west of the Cascade mountains.[a]

Cumulative rainfall	Calendar date to reach specified cumulative rainfall							
after 1-Sep	Medford (OR)	Salem (OR)	Tillamook (OR)	Coupeville (WA)	Centralia (WA)	Lynden (WA)	Agassiz (BC)	Comox (BC)
(inches)								
3	Nov. 10	Oct. 20	Sept. 26	Oct. 31	Oct. 8	Oct. 1	Sept. 26	Oct. 10
5	Nov. 29	Nov. 1	Oct. 8	Nov. 14	Oct. 23	Oct. 15	Oct. 9	Oct. 25
7	Dec. 16	Nov. 13	Oct. 18	Dec. 15	Nov. 4	Oct. 27	Oct. 19	Nov. 6

[a]Cumulative rainfall amounts listed here are long-term averages. Updated values for many locations are available from the Western Regional Climate Center, https://wrcc.dri.edu, or from the Canadian Centre for Climate Services, https://www.canada.ca/en/environment-climate-change.

When to sample

Collect soil samples for the postharvest nitrate test as soon as possible after final harvest. Do not sample fields that have received manure or lagoon water application within the last 30 days.

Samples must be taken before heavy fall rains move nitrate below the 12-inch depth. Because the timing of fall rainfall is unpredictable, the best strategy is to sample fields before Oct. 1.

Consider these guidelines for the timing of soil sample collection:

- Consult Table 1 to get a general estimate for the ideal time to collect a soil sample at your location. In Table 1, Sept. 1 is used as start date for tallying fall precipitation.
- For loam, clay loam and clay soils, collect samples before 5 inches of rainfall accumulate.
- For sand, loamy sand or sandy loam soils that have a lower water-holding capacity, sample before 3 inches of rainfall accumulate.
- Late-season irrigation (after Sept. 1) is another factor in choosing a target date for soil sampling. When irrigation is applied after Sept. 1, the cutoff date for postharvest nitrate sampling will be earlier than shown in Table 1.

Table 1 shows the historic average calendar date when cumulative rainfall after Sept. 1 reaches 3–7 inches at locations west of the Cascades. For most locations, sampling before Oct. 15 in an average year is acceptable. In high rainfall areas, including coastal areas and the Cascade foothills, plan to sample earlier. A late October sampling date may be acceptable in lower rainfall areas of Southern Oregon and in the rain shadow of the Olympic Mountains (NE Olympic Peninsula, SE Vancouver Island and other nearby islands).

Soil sample collection and processing

Soil sampling

Sample the 0- to 12-inch depth. This sampling depth is a good predictor of nitrate in the rest of the soil profile when (1) in-season irrigation is not excessive, and (2) samples are taken before heavy fall rains. (Figure 3).

Photo: Dan Sullivan, © Oregon State University

Figure 3. Collect soil samples from 0–12 inch depth. Do not include organic material that is present on the soil surface in the sample.

Sample only the soil. Do not include loose crop residues or manure present on the soil surface in the sample.

Collect and composite at least 15 soil cores per field sample.

Collect soil with a probe or an auger, not a shovel, unless large rocks are present. For reliable test results, it is important to uniformly sample soil throughout the 12-inch sampling depth. A soil sample collected with a shovel contains more soil from the surface and less soil from the rest of the sampling depth. Because soil nitrate typically declines with depth, a soil sample collected with a shovel is likely to have higher soil nitrate concentration than a soil sample collected from the same location with an auger or a probe.

Choose sampling locations in a zigzag pattern across the field. Your general route of travel should be across rows, rather than down a single row. Be sure to sample the part of the field where manure is routinely applied. For grazed pastures, choose sampling locations that have average crop growth and productive forage species. Avoid atypical areas like high or low spots or field edges.

Repeat the same procedure each year. Once you are satisfied with a sampling strategy, repeat it each year. This will help you compare results across years to determine any trend.

Obtaining a representative sample from fields where manure has been injected into soil or banded on the soil surface is challenging. The depth of manure injection, the width of the injection zone and the spacing between bands depend on equipment, soil texture and the applicator. Some injection equipment can place manure below the 12-inch sampling depth. Manure may be injected or banded more than once per year, with several orientations in a field (e.g., north–south or east–west). Manure injection or banding adds variability; plan to collect a larger number of soil cores to obtain a representative composite sample. When manure is injected below 12-inch depth, consider obtaining an additional sample from the 12- to 24-inch depth.

Photo: Tom Thomson

Figure 4. Automatic hydraulic soil sampler.

Monitoring Soil Nutrients Using a Management Unit Approach (PNW 570 at https://catalog.extension.oregonstate.edu/pnw570), discusses additional soil sampling considerations.

Certified Crop Advisors (CCAs; https://www.certifiedcropadviser.org) perform contract soil sampling in some locales. Most CCAs use a probe or auger mounted on a tractor or ATV to collect samples (Figure 4). This equipment can sample soils that are too hard or clayey for efficient sampling with a hand probe or auger.

Soil sample handling, preservation and shipment

Homogenize the soil sample. Break up the soil cores from a single field and mix thoroughly. Send a representative 1-cup sample to the lab. If the soil cores are too hard to break apart, send the entire sample to the lab; lab technicians can pass the sample through a mechanical grinder.

Cool samples immediately. Soils kept moist and warm after sampling continue to accumulate nitrate via biological activity. The simplest way to limit biological activity is to cool the soil immediately after collection. Place the samples in plastic bags in a cooler on ice while still in the field. Refrigerate or freeze samples that must be held longer than 48 hours before analysis.

Keep the samples refrigerated or frozen until you deliver them to the lab. Contact the lab before you sample, so they will be prepared to receive the samples. Use a shipping method that will deliver the samples to the lab within 48 hours.

Table 2. Units used to report soil nitrate analyses.

Soil analysis	Interpretation	Equivalent units
nitrate-N (NO_3-N)	N present in the nitrate form, expressed on soil dry weight basis	mg/kg or ppm[a]

[a]mg/kg is equivalent to ppm on a weight to weight basis. So if the nitrate-N value is 30 mg/kg, it is also 30 ppm. Soil test units for ppm (mg/kg) are not the same as water test units for ppm (mg/L).

Measurement units used in soil nitrate testing

In this publication, soil nitrate test recommendations are based on units of parts per million (ppm, Table 2). Ask your lab to report soil test nitrate-N in units of ppm. All labs measure nitrate-N in the laboratory in units of ppm, but they may report test results in units of lb/acre. If the lab reports test results in lb/acre, verify the conversion factor (ppm to lb/acre) that was used. The appropriate conversion factor (ppm to lb/acre) varies depending on soil texture and soil sampling depth. For a soil sample collected from a 12-inch depth, a typical equivalency value is: 1 ppm nitrate-N = 3.2 to 4.0 lb nitrate-N per acre. If you do not understand the units used to report test results, ask lab personnel to explain them.

Interpreting postharvest soil nitrate test results

Data quality and variability

The first step in evaluating your soil nitrate data is to ensure data quality. Verify that the sample collection method, timing of sample collection and sample preservation methods were acceptable. Reject data that did not result from reasonable procedures.

Target soil postharvest soil nitrate concentrations

Low postharvest soil nitrate concentrations limit the loss of soil nitrate below the root zone during the winter. Crops grown for hay or silage in fields without a history of manure application can often achieve high yields with low postharvest soil nitrate-N concentrations (< 10 ppm NO_3-N). In soils that have been manured for many years, low postharvest soil nitrate concentrations are difficult to achieve because nitrate continues to be mineralized in late summer and early fall (August—October), a period when crop N uptake is limited.

The target soil test values listed in Table 3 are based on the best professional judgment of the authors, as informed by field research studies in western Oregon, Washington and British Columbia. Target values listed in Table 3 assume near-maximum crop yield, with some late-season nitrate release from soil organic matter mineralization in manured soils.

Table 3. Target postharvest soil nitrate concentrations for manured grass and silage corn fields (0—12 inch depth)[a]

Crop	Soil nitrate-N (ppm)	Range
Corn		
	< 20	target
	20-45	above target
	45+	excess
Grass		
	< 15	target
	15-30	above target
	30+	excess

[a] The postharvest test looks backward in time. It evaluates the balance between N supply and crop uptake for crops produced during the summer. Nitrate accumulates in the soil when more plant-available N is supplied than the summer crop takes up.

Because grass is more efficient at N uptake than corn (Figure 2), target postharvest soil nitrate levels given in Table 3 are lower for grass than for corn. There are two key reasons that grass is more efficient in N removal:

- Grass has a greater capacity to take up excess N than corn (Figure 2). When soil nitrate increases above what is required for maximum yield (agronomic rate range), protein increases markedly in grass but not in corn.
- With frequent harvesting and irrigation, grass can maintain vegetative growth and take up N during an entire growing season (March—October). Corn N uptake is limited after silking. As corn ears mature, the plant moves N from leaves to grain without taking up additional nitrate from the soil.

Suggested management actions to reduce postharvest soil nitrate

For both crops, consider all sources of N in developing a nutrient management plan for your fields. Sources of N may include manure slurry, lagoon water, fertilizer, soil organic matter or previous crop residues. At some locations, atmospheric deposition of N is a significant input. Annual atmospheric deposition of N totals 10—20 lb N/acre in most dairy farming locales west of the Cascades (AIPPACT-5; http://lar.wsu.edu/airpact/monthly_depo_ap5.php). Some wells used for irrigation water supply nitrate. An inch of irrigation water with nitrate-N concentration of 10 ppm (mg N/L) supplies 2.3 lb N per acre.

Corn: *suggested management practices*

- Keep records to document crop yield, dry matter and crop N removal.
- Eliminate or reduce the amount of manure and N fertilizer applied to fields where corn follows grass. Corn grown after grass sod plowdown usually does not respond to additional N from manure or fertilizer.
- In situations where grass can take up additional N, consider reallocating manure application from corn to grass.
- Grow a grass or cereal cover crop between corn crops. Harvest the cover crop by grazing or by cutting for silage. Consider relay cropping or interseeding the cover crop when corn is 6—12 inches tall. When seeding a winter cover crop after corn harvest, do not fertilize with N at planting time.
- Use the presidedress nitrate test (PSNT) to determine the need for in-season N fertilizer or lagoon water application. Apply lagoon water or N fertilizer at sidedress time only when PSNT indicates a need. When PSNT is above 30 ppm nitrate-N (0—12 inch depth), sidedress N fertilizer or lagoon water application is unlikely to increase silage yield.
- Apply lagoon water at a rate designed to meet crop N requirement. An inch of lagoon water with an analysis of 4 lb N per thousand gallons (480 ppm N) contains approximately 100 lb N/acre.
- Remember that the economic optimal rate of N input for corn is almost always lower than the rate required for maximum crop yield. Reducing N fertilizer input is often a better economic decision than it first appears.
- Consult with agricultural professionals to find out how to improve whole-farm nutrient balance. Reducing imports of N to the farm as fertilizer or feed without lowering milk production will reduce costs, reduce nitrate leaching and reduce the risk of nitrate toxicity to cows.

Photo: Troy Downing, © Oregon State University

Figure 5. Cover crops seeded after silage corn protect soil from erosion. However, their capacity for N uptake in fall is limited. Cereal or grass cover crops seeded before Sept. 15 can take up 50 lb/acre by late November. Cover crops seeded after Oct. 15 take up less than 20 lb N/acre by late November.

Grass: *suggested management practices*

- Keep records to document crop yield, dry matter and crop N removal. When yields are low, consider improved soil/crop management practices.
- Manage grass to maintain high yields for as many years as possible to reduce nitrate leaching and forage production cost. This can be done by carefully choosing proven varieties, avoiding overharvesting and controlling weed encroachment. Keep manure spreader and silage wagon traffic off wet fields to avoid soil compaction.
- When grass yield is limited by poor stand or weeds, consider reseeding or interseeding with an improved species or variety and improving management practices.
- Establish new perennial grass fields in early autumn following a short-season corn variety. Till lightly, then seed the grass as soon as possible after corn harvest. Do not apply N fertilizer at planting. Make the first N application after the grass is well established in spring.
- Increase grass N removal by increasing management intensity and by improving harvest management practices. Grass takes up N during vegetative growth when leaves are green and expanding. When grass is allowed to head out, grass N uptake from soil slows.
- Monitor forage protein. Grass crude protein greater than 21 percent is associated with a greater risk for nitrate toxicity to cows. High concentrations of nitrate in grass typically occur under poor growing conditions that limit photosynthesis, such as a sudden drought or very cloudy weather. Photosynthesis provides the energy needed to convert nitrate to protein.
- Use the T-Sum 200 method described in *Nutrient Management for Pastures: Western Oregon and Western Washington* (EM 9224, at catalog.extension.oregonstate.edu/em9224), to schedule an early spring manure application on fields with low risk of runoff.
- When possible, avoid manure application late in the growing season.
- For a late-summer manure application, apply lagoon water instead of thicker slurry. Lagoon water contains most of the N in ammonium form, the same form of N that is present in fertilizers. The N present in lagoon water is immediately available for grass uptake, and so it is not mineralized later in the fall when it is not needed by the grass.
- Consult with agricultural professionals to improve whole farm nutrient balance.

Photo: Shabtai Bittman

Figure 6. Cover crop establishment in November in Aggasiz, British Columbia. Fall-seeded cover crop (left), relay cover crop (center), no cover crop (right).

Response of postharvest soil nitrate to changes in management

Reductions in fall soil nitrate are most likely to be measured when:

- Commercial N fertilizer inputs are reduced or eliminated.
- Cropping systems that maximize N removal in late summer and fall (August to October) are used.
- Late-summer manure application is reduced or eliminated.

Improved management will likely not result in reduced fall soil nitrate test values for three to five years on fields with a long-term history of manure application. Compared to unmanured soils, soils with a manure application history will support greater rates of mineralization from soil organic matter for a decade or more.

Success in N management is indicated by long-term trends in postharvest soil nitrate. Sampling methods and timing must be consistent to compare results across years. Weather complicates interpretation of trends in postharvest nitrate test values. For example, increased late-season N mineralization (and higher postharvest soil nitrate) usually results from a September that is wetter than normal.

It is important to recognize the **limitations of the postharvest test** as a diagnostic tool. The values given in Table 3 for postharvest soil nitrate are:

- Valid only for the Pacific Northwest, west of the Cascades.
- Designed for fields with more than three consecutive years of manure application. Lower postharvest soil nitrate test values can be can be obtained in fields where manure is not routinely applied.
- Based on good management of the crop and normal yields. Crop stressors such as moisture deficiency, insect damage, weeds or plant disease will reduce crop yield and crop uptake of nitrogen, thus increasing postharvest soil nitrate test levels.
- Provided only for silage corn and grass production. The values in Table 3 are based on field research with these crops.
- Based on the assumption that summer irrigation does not exceed evapotranspiration, so that nitrate is retained in the top 12 inches of soil during the growing season. Fields where soil moisture is maintained at a high level in August and September are more prone to leaching and must be sampled early in fall.

The postharvest nitrate test will not:

- Detect a shortage of plant-available nitrogen for the summer crop.
- Determine source(s) of excess plant-available N. Sources of N may include manure slurry, lagoon water, fertilizer, soil organic matter or previous crop residues. At some locations, irrigation water or deposition of N from the atmosphere can supply N.
- Predict crop response to fall manure or N fertilizer applications. The test does not predict the amount of plant-available N that will be mineralized from soil organic matter or crop residues in the fall.
- Predict groundwater nitrate concentrations.

Common questions and answers about postharvest nitrate testing

Why is it difficult to achieve postharvest nitrate-N less than 15–20 ppm with organic sources such as manure?

The timing of crop N uptake usually does not match the timing of N mineralized in the soil from manure and other organic sources. Soil temperature and moisture often support continued mineralization of N after crop N uptake has stopped.

How much postharvest nitrate-N can be removed by a fall-seeded grass or cereal cover crop?

Cover crop growth responds strongly to daylength and temperature, which decrease rapidly in the fall. Early seeding or relay cropping is required to achieve significant fall crop N uptake. Grass or cereal cover crops seeded before Sept. 15 can take up 50 lb/acre by late November. Cover crops seeded after Oct. 15 usually take up less than 20 lb N/acre by late November.

Is there a relationship between soil organic matter content and potential N mineralization?

Field research west of the Cascades has demonstrated that soil organic matter content does not accurately predict N mineralization potential. Soil testing methods to quantitatively predict N mineralization from soil organic matter are unreliable. See *Baseline Soil Nitrogen Mineralization: Measurement* *and Interpretation* (EM 9281 at catalog.extension.oregonstate.edu/em9281) for a full explanation.

What other soil tests can provide information to guide N management for corn?

Test soil nitrate when corn is at the four- to six-leaf growth stage to determine the need for sidedress N application to corn. See *Nutrient Management for Silage Corn in Western Oregon* (EM 8978, at https://catalog.extension.oregonstate.edu/em8978) for additional guidance.

How much variability should I expect in postharvest nitrate-N test values for the same grass field sampled between Aug. 15 and Oct. 15?

Postharvest nitrate test values depend on weather, soil biology and crop management. A good stand of actively growing grass can maintain nitrate-N concentrations of less than 15 ppm throughout the postharvest sampling period. However, if soil is dry in late summer, increased N availability may occur for two or three weeks following the first heavy rain, when grass growth has slowed. It may be useful to take several soil nitrate tests from the same field in the fall to document changes in nitrate concentration with time. Soil nitrate interpretive values given in Table 3 are for typical precipitation and sampling dates west of the Cascades.

Ammonium-N is plant available. Why doesn't the postharvest test include ammonium-N analysis?

Postharvest analyses for ammonium in soil usually do not provide useful information. Ammonium does not accumulate in soils because it is rapidly converted to nitrate by soil microbes. Soil samples taken at least 30 days after manure application usually have negligible ammonium-N concentrations unless the soil remained dry after the application. Some of the ammonium measured in the laboratory may not have been present in the field. Soil sample drying prior to analysis can increase extractable ammonium measured in the laboratory.

Should postharvest nitrate tests be used for fields with muck or peat soils?

No. Soils that contain high levels of soil organic matter (muck or peat soils) were formed in landscape depressions with poor drainage. Soil organic matter decomposition and N mineralization are greatly accelerated when these soils are drained and cultivated. Postharvest soil nitrate test values for these soils are usually very high relative to the values given in Table 3, regardless of crop or management practices.

Appendix: Historical perspective on the postharvest nitrate test

Postharvest nitrate testing (originally called a "report card" or a "residual soil nitrate" test) was introduced in the Pacific Northwest in the 1990s, based on monitoring studies and concurrent research in Washington (D. Sullivan, C. Cogger, A. Bary), British Columbia (B. Zebarth, J. Paul, S. Bittman) and Oregon (E. Marx, N. Christensen, J. Hart). Many field studies have included postharvest nitrate testing, but the validation and calibration of the postharvest test was not the primary focus of the research. Most of the postharvest test data over the years originated from studies conducted on manured fields overlying shallow groundwater (Abbotsford-Sumas and Abbotsford-Blaine aquifers) near the U.S.-Canadian border. The reference section in this publication, "Research and monitoring of N management for forage production west of the Cascades," lists relevant research that includes postharvest nitrate testing and estimates of soil N mineralization in dairy manure application fields. All of the referenced studies were conducted west of the Cascades in Oregon, Washington, and British Columbia.

The USDA Natural Resources Conservation Service (NRCS) in Washington state formally adopted postharvest nitrate testing guidance as WA Agronomy Technical Note 35 in 1993, and recommended a 0—24 inch sampling depth. Subsequent research and monitoring of postharvest soil nitrate showed that the highest nitrate concentration in the soil profile was almost always in the 0- to 12-inch depth, and that the nitrate concentration at 0- to 12-inch depth strongly correlated with the total quantity of nitrate present in the soil profile (Marx, 1995; Sullivan et al., 2000; Cogger et al., 2001). In 2003, Extension guidelines for postharvest soil nitrate testing — *Post Harvest Soil Nitrate Testing for Manured Cropping Systems West of the Cascades* (EM 8832 at catalog.extension.oregonstate.edu/em8832) — were published following a series of facilitated meetings with clientele. The authors of this publication reviewed the published and unpublished soil nitrate data from west of the Cascades. The guidance in the 2003 publication and in this publication is based on a 0- to 12-inch soil sample depth. The interpretive ranges in this publication (Table 3) are the same as the ranges given in the 1993 publication. The "target," "above target" and "excess" interpretive ranges given in this publication correspond with those presented in the 2003 publication.

Note that the postharvest test is not intended to predict groundwater nitrate concentrations. Recent studies by Washington Department of Ecology have demonstrated that the postharvest soil nitrate test is only a rough indicator of the risk of nitrate leaching (Carey, 2002; Carey and Harrison, 2014; Carey et al., 2017).

A number of studies have shown that presidedress nitrate test (PSNT) values are strongly correlated with postharvest soil nitrate values in silage corn fields (Marx, 1995; Cogger et al., 2000; Zebarth et al., 2001). Therefore, we strongly recommend collecting PSNT samples as part of a soil nitrate monitoring program for silage corn.

Research has consistently shown that mineralization of N from soil organic matter plays a major role in determining postharvest soil nitrate concentrations (Sullivan et al., 1999; Cogger et al., 2001; Bittman et al., 2007; Moberg et al., 2013; Zhang et al., 2020). For that reason, we consider it important to include postharvest nitrate test data in the context of historic field management practices and soil organic matter content. Real-time computer simulation models (e.g., Adapt-N; NLOS) show promise for improving N management. The models can help interpret PSNT and postharvest test results by taking into account multiple factors such as temperature, rainfall and crop growth (Hirsch, 2007).

For more information

Extension and Outreach publications

Nutrient management planning

Estimating Plant-Available Nitrogen from Manure (EM 8954). 2020. https://catalog.extension.oregonstate.edu/em8954

Interpreting Compost Analyses (EM 9217). 2018. https://catalog.extension.oregonstate.edu/em9217

Manure Application Rates for Forage Production: Western Oregon (EM 8585). 2020. https://catalog.extension.oregonstate.edu/em8585

Monitoring Soil Nutrients Using a Management Unit Approach (PNW 570). 2003. https://catalog.extension.oregonstate.edu/pnw570

Nutrient Management for Pastures: Western Oregon and Western Washington (EM 9224). 2019. https://catalog.extension.oregonstate.edu/em9224

Nutrient Management for Silage Corn: Western Oregon (EM 8978). 2021. https://catalog.extension.oregonstate.edu/em8978

Sampling Dairy Manure and Compost for Nutrient Analysis (PNW 673). 2015. https://catalog.extension.oregonstate.edu/pnw673

Monitoring and recordkeeping

Calculating Dairy Manure Nutrient Application Rates (EM 8768). 2015. https://catalog.extension.oregonstate.edu/em8768

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Keeping Track of Manure Nutrients in Dairy Pastures (PNW 549). 2001. https://catalog.extension.oregonstate.edu/pnw549

Other Extension and Outreach publications

AIRPACT-5 (Air-quality forecasting for the Pacific Northwest). Imagery showing monthly deposition of nitrogen and sulfur. Civil & Environmental Engineering (WSU-Pullman). http://lar.wsu.edu/airpact/monthly_depo_ap5.php

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Research and monitoring of N management for forage production west of the Cascades

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Carey B. 2002. Effects of land application of manure on groundwater at two dairies over the Sumas–Blaine surficial aquifer: implications for agronomic rate estimates. Washington State Department of Ecology, Olympia, Washington. Publication Number 02-03-007. https://fortress.wa.gov/ecy/publications/documents/0203007.pdf

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