Efficient Nitrogen Management for Cool-Season Vegetables

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Introduction

Use of nitrogen (N) fertilizer is an integral part of conventional vegetable production. It has also become a serious environmental issue. Nitrate of fertilizer origin can leach into groundwater, in some cases causing that groundwater to exceed the Federal drinking water quality standard of 10 parts per million (PPM) nitrate-nitrogen (NO_3-N). N can also be lost from fields in storm runoff and irrigation tailwater; once in surface water bodies (streams, lakes, reservoirs, etc.), this N can stimulate the growth of algae and other undesirable plants, which in turn can damage aquatic ecosystems. In the coastal regions where cool-season vegetable production is centered (primarily the Salinas, Santa Maria and Ventura areas), groundwater frequently exceeds the Federal drinking water NO_3-N standard, and surface water quality monitoring often shows N concentration high enough to be of environmental concern. Therefore, efficient N fertilization has both an agronomic and environmental component.

Since the early 1990s there has been extensive research on efficient N management practices in cool-season vegetable production. This guide summarizes that research, and outlines management practices that can significantly improve N use efficiency and minimize N loss to the environment. These techniques are cost-efficient and, when employed appropriately, will maintain crop yield and quality while reducing the environmental impact of vegetable production.

NITROGEN CYCLING IN COASTAL VEGETABLE PRODUCTION

A. Current N use patterns and consequences

In the coastal vegetable production areas double cropping is the norm, with lettuce, broccoli, cauliflower and celery dominating crop rotations. N application rates vary widely by grower, season of the year, soil type and other factors; a range of 'typical' N application rates for the major crops is given in Table 1. Application rates in general are far in excess of the N removed from the field in the harvested product.

Table 1. Typical N fertilizer application rate, crop uptake and removal in harvested product for the common cool-season vegetables.

	lb N/acre		
Crop	N application	Crop uptake	Removal in harvest
Broccoli	175-250	180-220	60-80
Cauliflower	175-300	180-220	60-80
Celery	200-350	200-240	120-150
Lettuce	120-220	80-120	60-80

The table gives N uptake values for the above-ground biomass; roots generally contain 10-15% of the amount in the above-ground biomass.

There are five possible fates for fertilizer N applied but not removed with harvested product:

1) loss to the atmosphere through denitrification (conversion by soil microbes to gaseous nitrogen compounds)
2) tie-up in soil organic matter, either in decaying plant material or in the biomass of soil microbes
3) remain in the root zone in a plant-available form, available for subsequent crop uptake
4) leach below the root zone, mostly in NO_3-N form
5) leave the field in storm runoff or irrigation tailwater, either in soluble form (mostly NO_3-N), or in organic forms bound to sediment

The relative amounts of N represented by these options vary widely among fields, but a few generalizations can be made. Denitrification occurs to some extent in all soils, but generally is significant only in clay soils; industry-wide, only a small percentage of applied N is lost through denitrification. Large amounts of applied N can end up in crop residue or in soil microbial biomass in the short term, but this organic N is constantly being recycled by soil microbes in a process called mineralization, back into plant-available N; in the long term, soils in typical vegetable rotations have reasonably stable amounts of organic N, meaning that excessive N fertilization is not being 'stored' in organic forms in the soil. Similarly, soil residual NO_3-N can build up over a cropping season, as long as in-season irrigation is controlled to minimize leaching loss; however, during a typical winter, rainfall may be sufficient to leach most of the residual NO_3-N from the top several feet of soil, below the reach of shallowly-rooted vegetable crops. It is clear that, over the long term, much of the applied N not removed in harvested product is lost to the environment, either leached out of the root zone or moved off-site in runoff.

B. Annual soil nitrogen dynamics

Although ammonium-nitrogen (NH_4-N) is readily taken up by plants, it accounts for only a small percentage of crop N uptake; a microbial process called nitrification rapidly converts NH_4-N to NO_3-N in moist soil. Except for the days immediately following an NH_4-N fertilizer application, the majority of plant-available soil N will typically be in NO_3-N form. Also, since NH_4^+ is bound to soil particles by its positive charge, it is not easily leached. For these reasons N management strategies focus on NO_3-N.

The pattern of growth and N uptake is similar in all the major cool-season crops. Whether planted with seed or transplants, there is a period (approximately ½ of the cropping period) in which plant growth, and N uptake, are slow (Figure 1). Once rapid vegetative growth begins, N uptake accelerates, reaching approximately 3-5 lb N per acre per day, depending on the crop and environmental conditions. More than 75% of total crop N uptake occurs in the last half of the cropping period. This is the time period in which fertilizer need is greatest.

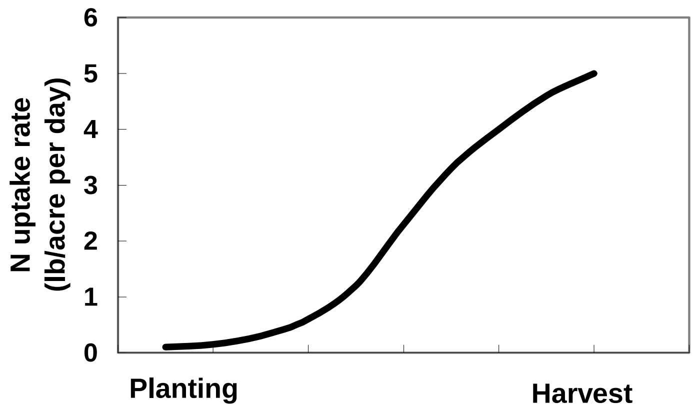

Figure 1. Seasonal N uptake pattern for cool-season vegetables in coastal production areas.

All the major cool season vegetables are shallowly rooted, with the majority of roots in the top foot of soil. Although some N uptake occurs below that level, grower management practices should be targeted toward maintaining adequate N in that top foot of soil, and minimizing the movement of NO_3-N out of that zone.

Figure 2 illustrates how soil NO_3-N typically varies in a coastal vegetable field over an annual cycle. If there has been significant winter rain, the concentration of NO_3-N in the top foot of soil in the early spring will be low because most NO_3-N carried over from the previous fall, and most NO_3-N mineralized over the winter, has been leached. As soil warms up in the spring, mineralization of soil organic N will begin to increase NO_3-N concentration in the top foot of soil. Preplant fertilization for the spring crop, plus early sidedressing, increase soil NO_3-N to significant levels. As the spring crop begins its rapid growth phase, soil NO_3-N may decline until harvest, but the incorporation of the crop residue will stimulate mineralization, increasing soil NO_3-N between the spring and summer crops. The pattern repeats itself for the summer crop; by the time that crop residue has been incorporated, and mineralization of its N begun, soil NO_3-N may be very high, and at risk of loss to winter leaching or runoff.

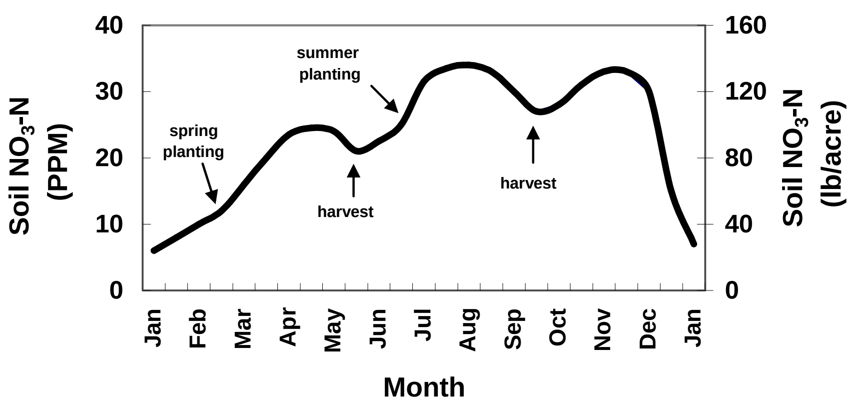

Figure 2. Typical pattern of soil NO_3-N concentration in the top foot of soil over an annual cycle in coastal vegetable production.

Figure 2 gives soil NO_3-N both in concentration (PPM) and in lb/acre. At normal bulk density, soils weigh approximately 4,000,000 lb/acre per foot depth; therefore, NO_3-N concentration x 4 = lb/acre. Clearly, the amount of soil NO_3-N commonly found in coastal vegetable fields can be both agronomically and environmentally significant.

Figure 2 illustrates soil NO_3-N dynamics where significant winter rain is received. In such conditions the generalization can be made that N fertilizer requirement of a crop planted in the spring will be greater than for a crop planted in the summer (when soil residual NO_3-N is likely to be high). However, in dry years, residual soil NO_3-N may carry through from the fall to the following spring; in this case, spring- and summer-planted crops may have similar N fertilizer requirements.

Vegetable crops can take up adequate N to maximize growth from soils with modest levels of NO_3-N. Root zone soil NO_3-N concentration > 20 PPM have been shown to be sufficient to maintain maximum growth rates for several weeks or more in typical field conditions. Once crop N needs are met, additional crop uptake is quite limited, regardless of soil NO_3-N level. If N fertilizer is applied to a soil with substantial NO_3-N content short-term plant N uptake is virtually unaffected. Fertilizing fields with a high level of residual NO_3-N is unnecessary and increases the risk of N loss to the environment.

C. Influence of irrigation

Cool-season vegetables are irrigated frequently, due to their shallow rooting and sensitivity to moisture stress. As they are typically employed, conventional irrigation techniques (sprinkler and furrow) are not very efficient in either distribution uniformity (how evenly water is applied across the field) or irrigation efficiency (the percentage of applied water that remains in the root zone, available for plant uptake). Crop water requirements are quite modest in the coastal production areas, varying from approximately 6 to 10 inches for lettuce, 8 to 14 inches for broccoli and cauliflower, and 12 to 18 inches for celery. The amount of irrigation applied is frequently far greater, in some cases twice as high, as actual crop need. This has significant impact on soil NO_3-N levels. In a field with 20 PPM soil NO_3-N, an inch of leaching from irrigation may carry as much as 20 lb N per acre below the root zone. In such a case, the NO_3-N concentration in the leached water can be as high as 100 PPM, or 10 times the drinking water standard. It is clear that controlling the amount of leaching from irrigation is critical to the protection of groundwater.

Irrigation water can also be the source of a significant amount of NO_3-N. Agricultural wells in coastal production areas now commonly contain 10-20 PPM NO_3-N; one foot of irrigation water at a concentration of 10 PPM would contain nearly 30 lb NO_3-N per acre. Once in soil solution that NO_3-N would be indistinguishable from fertilizer N or residual soil NO_3-N, and equally available for crop uptake.

STEPS TOWARD EFFICIENT N MANAGEMENT

A. Develop general fertilization templates

The first step toward efficient N management is to develop a general N fertilization template for each crop. These templates should be based on crop N uptake requirements by growth stage, season of the year, soil type and relative irrigation efficiency. Table 2 contains suggested ranges of seasonal N application that should ensure N sufficiency, provided the following conditions are met:

1) preplant N application is minimized, since it is most at risk for leaching before the crop reaches the stage of significant N demand.
2) early sidedress application is limited to no more than about 60 lb N/acre each (again, to minimize leaching losses), and the majority of seasonal N is applied after rapid crop growth has begun
3) irrigation is delivered with reasonably high distribution uniformity and irrigation efficiency.

Table 2. General guidelines for seasonal N application.

	Seasonal total N application (lb/acre)	
Crop	Winter-Spring	Summer-Fall
Broccoli	180-240	150-180
Cauliflower	180-240	150-180
Celery	220-260	180-220
Lettuce	150-180	100-140

Crops produced from late fall through early spring will generally require more fertilizer N than crops grown from late spring through early fall. The level of residual soil NO_3-N tends to be lower over the winter and spring, and the chance of significant leaching from rainfall is greater during this period. Similarly, crops grown in very sandy soils may require more fertilizer than in heavier textured soils, due to the higher likelihood of leaching in sandy soil, together with the fact that the amount of soil organic N mineralization will tend to be lower in a sandy soil.

Few situations should require seasonal N application rates greater than those listed in Table 2. The obvious exception may be where several heavy rains occur, particularly if received within days of sidedress N applications. The use of modest rates of slow-release N fertilizer on winter-grown crops can help ensure continuous N availability and limit winter leaching losses. It may be tempting to use higher N rates on fields that are difficult to irrigate efficiently, but the more environmentally sound approach would be to upgrade the irrigation system rather than compensate for its inefficiency by applying more fertilizer.

There is a widespread belief in the industry that additional N fertilizer can help overcome other forms of stress affecting a crop, or can successfully ‘push’ a field (or variety) that lacks vigor. However, research has consistently shown that, if soil N supply is sufficient for unrestricted plant growth, applying additional fertilizer N does not result in more vigorous growth, nor does it overcome other limiting factors (cold weather, root disease, etc.).

B. Modifying fertilization templates for field-specific factors

General crop fertilization templates should be adjusted based on specific field conditions. Consideration of variables such as soil organic matter content, previous crop, and NO_3-N content of irrigation water can help determine whether the N application target for a specific field should be toward the top or bottom of the ranges given in Table 2. In general, the higher the soil organic matter content, the greater the potential contribution from N mineralization to crop available N.

Soil with < 1% organic matter in the top foot of soil will likely contribute relatively little to crop N supply, while soil with organic matter content > 1.5% may contribute a significant quantity of N. Similarly, net N mineralization in fields in which the prior crop was broccoli or cauliflower (which may have >120 lb N/acre in crop residue) is likely to be higher than a field coming out of lettuce (<40 lb N/acre in residue), or a fallow season.

The NO_3-N concentration of agricultural wells varies widely, from near zero to >30 PPM. Since one acre foot of water at 10 PPM NO_3-N contains nearly 30 lb N, it is clear that irrigation can be a significant source of N. The following formula calculates the N content of irrigation water based on water NO_3-N concentration and the seasonal irrigation volume:

___ irrigation water NO_3-N (PPM) x ___ total inches of irrigation applied x 0.23 = ___lb N/acre

The percentage of NO_3-N in irrigation water that would remain in the root zone can be estimated using the irrigation efficiency of the field. Sprinkler and furrow irrigation typically have irrigation efficiencies in the 60-80% range, drip irrigation in the 80-90% range.

C. Monitor soil and crop N status

Soil monitoring:

While generalizations about crop N requirements, season, soil texture and organic matter content, and irrigation efficiency can be made, the only way to ensure appropriate field-specific N management is to monitor soil and/or plant N status during the season. The monitoring techniques available to growers have expanded in recent years with the introduction of on-farm ‘quick tests’ of N status; regardless of the techniques employed, monitoring is a crucial element of efficient N management.

Soil nitrate concentration has traditionally been measured by standard laboratory techniques on samples taken before planting. The value of preplant soil test in determining N requirements in cool season vegetables is limited, since NO_3-N concentration can change considerably (through N mineralization or NO_3-N leaching) by the time the crop is established and actively growing. Measuring soil NO_3-N just prior to sidedressing can tell whether the scheduled application can be delayed or reduced.

Extensive field trials in coastal production areas have shown that soil NO_3-N concentration at or above 20 PPM in the top foot of soil is sufficient to meet immediate crop requirements; in the absence of leaching, 20 PPM NO_3-N (equivalent to approximately 80 lb N/acre in the top 12 inches of soil) could supply a crop for at least 2 weeks, even at peak N demand. As a management guide, a soil test >20 PPM NO_3-N would indicate that no additional N should be applied for at that time. Retesting 2-3 weeks later would show whether or not the combined action of leaching and crop uptake has significantly reduced NO_3-N concentration.

Soil NO_3-N concentration between 10-20 PPM indicates that only a limited amount of sidedress N (no more than 50 lb N/acre) was justified at that time. Soil NO_3-N below 10 PPM indicates that soil N availability is limited, and a significant sidedress application is warranted; if the crop is at or near the rapid growth phase as much as 80-100 lb N may be appropriate. However, if the crop is at the seedling stage, 40-60 lb would be sufficient to carry the crop for weeks.

In soil sampling for NO_3-N analysis it is crucial to collect a composite sample of the active root zone that represents the field variability. For cool season vegetables the active root zone is roughly the top foot of soil, although at early seedling stage a sample of the top 8 inches may be more appropriate. Since NO_3-N can vary considerably with depth, a standard soil probe should be used to collect the sample; in samples collected with a shovel the top few inches are usually over-represented. Soil NO_3-N can also vary by position in the bed. When taking soil samples avoid the furrow bottom and any zone where N fertilizer was banded. In furrow-irrigated fields the top several inches of the bed can accumulate NO_3-N by evaporation from the soil surface. Since the surface soil may be too dry for root activity it should be discarded so NO_3-N availability is not overestimated. This is not a concern in sprinkler-irrigated fields. In drip-irrigated fields soil samples should be drawn only from the zone wetted by the tape.

Differences in soil texture and irrigation patterns can result in significant variability in soil NO_3-N. Sampling areas of a field separately may be justified if large differences in soil texture or irrigation volume exist. Regardless of whether a field is sampled whole or divided into subunits, each composite sample should contain a minimum of 12 soil cores, which should be blended thoroughly before analysis.

Commercial laboratories throughout the state offer soil NO_3-N analysis. The major drawback to laboratory analysis is the delay between sampling and receiving results, typically at least several days. There is an on-farm 'quick test' technique which can give same-day results. It is not as accurate as laboratory analysis, but if done with care it can reliably distinguish between low NO_3-N fields and those with substantial residual NO_3-N concentration. The test protocol is given in Appendix 1.

The results of soil NO_3-N analysis are usually reported in PPM. The following formula converts PPM NO_3-N into an estimate of lb NO_3-N/acre:

____ PPM NO_3-N x ____ depth of sample (inches) depth x 0.33 = ____ lb NO_3-N/acre

Plant monitoring:

Total N and NO_3-N concentration in plant tissue can both be used as indicators of N sufficiency. The total N concentration of whole leaves gives the best overall view of crop N status; however, this technique has not been widely used in the California vegetable industry, which has focused almost exclusively on monitoring NO_3-N in leaf petioles or midribs. Since leaf total N changes only slowly with time it provides a longer term view of N availability. Petiole NO_3-N represents only NO_3-N that has not yet been assimilated into organic compounds in the plant; because petiole NO_3-N can fluctuate quickly it is widely regarded as the plant analysis technique that best reflects current conditions.

There are some significant limitations of tissue analysis as a tool for in-season N management. Whole leaf total N can document whether N availability has been adequate to date; leaf N concentration below a 'sufficiency' level suggests that soil N availability may be limited, and fertilization warranted. However, when leaf N is at or above the sufficiency level, one cannot infer soil N availability from the leaf N concentration. This is because, as long as soil N supply is sufficient to achieve the maximum plant growth rate, there is relatively little additional N uptake regardless of soil NO_3-N concentration; whole leaf N concentration may be similar in fields with soil NO_3-N ranging from 10 to 50 PPM or higher.

This same limitation applies to petiole testing. NO_3-N values below the 'sufficiency' range is a valid indicator of low soil NO_3-N availability, and suggests that fertilization may be warranted; however, values at or above the sufficiency level are poorly correlated with current soil NO_3-N supply, and cannot reliably be used to determine future fertilization requirements. As with whole leaf N, this is partly due to the limited crop N uptake beyond that needed for maximum growth rate, regardless of soil N availability. Additionally, the speed with which plants convert NO_3-N into organic N compounds varies based on environmental conditions, particularly light and temperature. Therefore, high petiole NO_3-N is often more indicative of environmental conditions than of soil N availability.

These observations suggest that plant tissue analysis may help indicate when additional N fertilization is necessary, but it should not be used alone to identify fields where sidedress N application can be reduced or delayed. In-season soil testing is the most useful diagnostic for that purpose.

Plant tissue testing, whether whole leaf total N or petiole NO_3-N, has traditionally been done by drying and grinding the samples and analyzing by standard laboratory techniques. Laboratory analysis remains the standard of accuracy, but on-farm measurement of petiole sap NO_3-N was made possible by the introduction of a battery operated NO_3-N meter. This device, called the Cardy meter, uses a nitrate-selective electrode to measure NO_3-N in fresh sap; the protocol for sap NO_3-N measurement is given in Appendix 2. As with the soil NO_3-N 'quick test', a degree of accuracy is sacrificed for more timely results; unless care is taken in sample handling and meter calibration, results are unreliable.

Regardless of analytical method used, sample collection and handling are critical to accurate tissue testing. Recently matured leaves, typically 3-4 nodes down from the growing point, are used for both whole leaf and petiole analysis. A minimum of 20 leaves or petioles should be collected, each from a different healthy plant of representative vigor. Sampling should cover the entire field. As with soil sampling, if you suspect large differences in plant N status in different areas of a field sample them separately. Collecting more than 20 leaves or petioles may be required when plants are small to obtain a large enough sample to test. It is important to accurately note the crop growth stage since both total N and NO_3-N concentration decline as crop maturity advances. Once tissue samples are collected they should be dried as quickly as possible (for laboratory analysis) or kept cool in plastic bags until analysis (for sap testing).

Whole leaf total N is reported as % of tissue dry weight. Petiole NO_3-N is given in PPM. Table 3 lists the minimum tissue N sufficiency level for the common coastal vegetable crops.

Table 3. Approximate tissue N sufficiency ranges for cool-season vegetables.

			Petiole NO_3-N (PPM)	
Crop	Growth stage	Total leaf N (%)	Dry tissue	Fresh sap
Broccoli	head initiation	3.0	8,000	700
	preharvest	3.0	4,000	500
Cauliflower	head initiation	3.0	6,000	700
	preharvest	3.0	4,000	400
Celery	midgrowth	2.5	7,000	600
	preharvest	2.0	4,000	300
Lettuce	cupping	3.0	5,000	400
	preharvest	2.5	3,500	300

Appendix 1
Soil NO_3-N 'Quick Test'

Procedure:

1) Collect at least 12 soil cores representative of the area surveyed. In furrow-irrigated fields don't include the top 2 inches of soil, which may be too dry for root activity. Do not sample furrow bottoms or where fertilizer bands are placed. Blend the sample thoroughly.

2) Fill a volumetrically marked tube or cylinder to the 30 ml level with .01 M calcium chloride. Any accurately marked tube or cylinder will work, but 50 ml plastic centrifuge tubes with screw caps are convenient and reusable.
3) Add the field moist soil to the tube until the level of the solution rises to 40 ml; cap tightly and shake vigorously until all clods are thoroughly dispersed. It is critical that the soil you test is representative of the sample; for moist clay soils that are difficult to blend pinch off and test several small pieces of each soil core. Testing duplicate samples will minimize variability.
4) Let the sample sit until the soil particles settle out and a clear zone of solution forms at the top of the tube. This may take only a few minutes for sandy soils, an hour or more for clay soils.
5) Dip a Merckquant® nitrate test strip into the clear zone of solution, shake off excess solution, and wait 60 seconds. Compare the color that has developed on the strip with the color chart provided.

Interpretation of results:

The nitrate test strips are calibrated in parts per million (PPM) NO_3^-. Conversion to PPM NO_3-N in dry soil requires dividing the strip reading by a correction factor based on soil texture and moisture:

$$\text{strip reading} \div \text{correction factor} = \text{PPM } NO_3\text{-N in dry soil}$$

	Correction factor	
Soil texture	Moist soil	Dry soil
Sand	2.3	2.6
Loam	2.0	2.4
Clay	1.7	2.2

Soil less than 10 PPM NO_3-N have limited N supply and may require fertilization soon. Soils between 10-20 PPM NO_3-N have enough N to meet immediate plant needs but a modest amount of sidedress N may be appropriate. Soil NO_3-N greater than 20 PPM indicates that additional N application should be postponed until retesting shows that residual soil NO_3-N has declined.

NO_3-N test strips can be purchased from Ben Meadows Co., 3589 Broad Street, Atlanta, GA 30314, (800) 241-6401, www.benmeadows.com . University of California Cooperative Extension Farm Advisors can help you source the volumetric tubes and calcium chloride extracting solution.

Appendix 2
Petiole Sap NO_3-N Determination

Sample collection:

Twenty or more petioles from different plants throughout a field are required for a representative sample. Where there are obvious or suspected differences in fertility within a field, separate samples should be collected and analyzed.

The general rule when sampling crops for NO_3-N testing is to take the most recently fully expanded mature leaf. For broccoli and cauliflower this would be the leaf 3-4 nodes down from the growing point. For lettuce the youngest wrapper leaf is best. For celery the youngest leaf that has the dark green color of exposed leaves is ideal. Collect samples from healthy plants, of representative vigor, where the plant stand is uniform. Since the NO_3-N level can vary somewhat throughout the day the most consistent results will be obtained by collecting samples between 8 AM and 2 PM; in very hot weather sample collection before noon is advisable.

Immediately upon collection, leaf blades should be stripped away and petioles or midribs put in plastic bags on ice in a cooler until they are analyzed; water loss can occur very rapidly in hot field conditions, leading to inaccurate readings. Once on ice, samples can be held six to eight hours without appreciable change in sap nitrate readings. Allow petioles to warm up to the temperature of the meter before analysis; once the field heat is removed, petioles in a plastic bag can be held at room temperature for one to two hours without harm. Once sap is pressed from the petioles, it should be analyzed within a few minutes.

Sample preparation:

Sap can be pressed from petioles or midribs in a variety of ways. Any device, from a hand-held kitchen garlic press to table mounted hydraulic press, will work; the main criteria are convenience and the ability to obtain a truly representative sap sample. Press as much sap as practical from each petiole into a common container, then blend thoroughly. Clean and dry the press carefully between samples from different fields.

The procedure for preparing petioles or midribs for sap extraction vary somewhat by crop:

Broccoli and Cauliflower

When plants are young use the entire petiole or midrib. As plants mature the petioles and midribs can get quite large, so a subsample of each can be taken. Line them up on a cutting board and subsample a center section from each.

Celery

When the plant is young, sample the whole petiole. When the leaves are larger, take only the portion of the petiole above the first node. Later, when the leaves are very large, take the section between the first and second node. Line up the petioles on a cutting board and cut a center section from each.

Lettuce

The midrib on young leaves will be about 1 inch long and on more mature plants the midrib will be from 2-3 inches in length. When the plants are large, a subsample can be cut from the center of the midribs as previously described.

Sap testing:

The Cardy meter can measure petiole sap NO_3-N over the entire range of concentration commonly encountered. Maximum accuracy requires careful calibration of the meter each day it is used, and periodic calibration checks during any day that many samples are analyzed. Despite these precautions, sap NO_3-N measurements with the Cardy meter do not have the accuracy of conventional laboratory analysis of dry tissue; results should be considered approximate values.

Although it can be used in the field, the Cardy meter is better suited for use indoors because it is sensitive to temperature changes. From the standpoint of accuracy and efficiency it is best to collect petiole samples from all fields of interest and bring them to a central, indoor location for analysis.

The Cardy meter must be calibrated using the 'two point' method described in the instructions. Before calibration turn the meter on and let stand for several minutes with several drops of distilled water on the sensor membrane to ensure that it is fully hydrated. The meter may be calibrated either in PPM NO_3^- or PPM NO_3-N; since the sufficiency levels in Table 3 are given in PPM NO_3-N it is easiest to make your readings in those units. The conversion between these units is:

$$\text{PPM } NO_3^- \times .226 = \text{PPM } NO_3\text{-N}$$
$$\text{PPM } NO_3\text{-N} \times 4.43 = \text{PPM } NO_3^-$$

The calibration solutions that come with the meter are marked 2000 PPM and 150 PPM NO_3^-; if you calibrate the meter to these numerical values you will need to convert all sap readings to PPM NO_3-N. However, if you calibrate the meter with these solutions to read 450 and 34 (2000 and 150, respectively, multiplied by .226) the meter will measure sap directly in PPM NO_3-N.

The meter takes at least 20 seconds to stabilize each time a sample is placed on the sensor; make it a rule to take readings at a standard time (perhaps 30 seconds) after putting each sample on the sensor. Be sure to rinse the sensor with distilled water and pat dry between each sample. While rinsing the sensor take care not to get water in the crack between the sensor pad and the main body of the meter, as this can cause erratic readings.

The sensor pads will wear out, usually after 50-200 samples. They can easily be replaced; the meter itself will last for years. Failure to hold calibration is a sign of sensor wear.

Cardy meters and accessories can be purchased from a number of vendors, including Spectrum Technologies, 23839 W. Andrew Road, Plainfield, IL 60544, (800) 248-8873, www.specmeters.com .