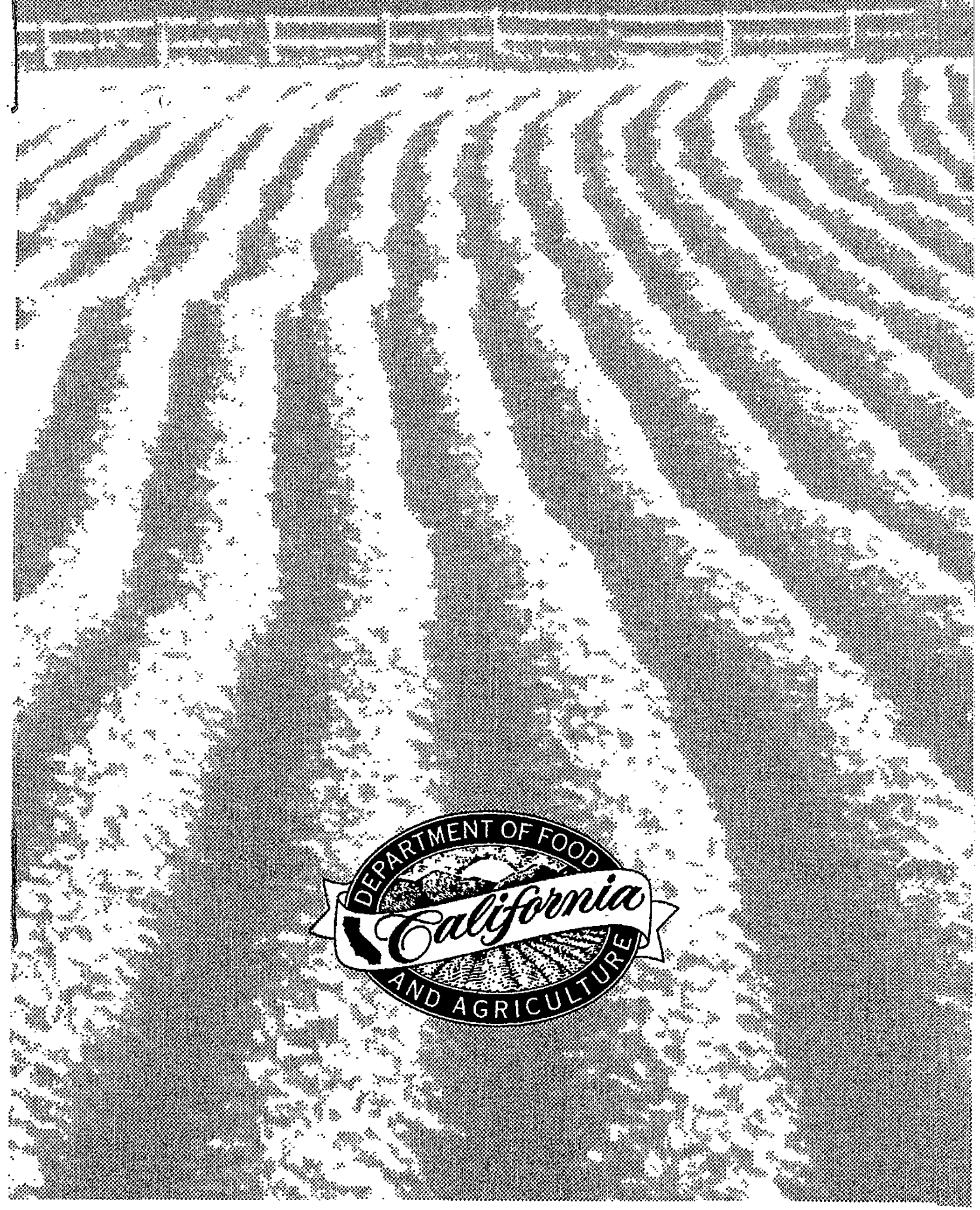
DRIP IRRIGATION AND FERTIGATION MANAGEMENT OF VEGETABLE CROPS



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DRIP IRRIGATION AND FERTIGATION MANAGEMENT OF VEGETABLE CROPS

REFERENCE BOOKLET

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INTRODUCTION

The use of drip (trickle) irrigation for vegetable production is rapidly increasing. By 1995, nearly 100,000 acres of vegetables will be drip-irrigated annually in California. There are a number of factors driving this conversion to drip irrigation; most important among them are increased crop yield potential, water conservation, and more efficient nutrient management. To realize these benefits requires careful management of both water and fertilizer inputs. This reference guide and the accompanying videotape cover the basics of drip irrigation and fertigation management for vegetable production. They are designed for individuals with limited experience with drip irrigation. Application of these management principles will set the beginner on the road to efficient use of drip irrigation technology.

SECTION 1: DETERMINING CROP IRRIGATION REQUIREMENT

A. Estimation of evapotranspiration (ET_o)

Environmental variables such as solar radiation, air temperature, relative humidity and wind speed interact to influence the rate of water loss from plants and soil. Historically, the most common technique for integrating these environmental variables and estimating evapotranspiration (ET_o, the combined water loss from plants and soil) was the Class A pan evaporometer. This device is simply an open pan of water in which the depth of daily evaporation is measured. This measurement is higher than actual crop water use, but it does provide a useful relative estimate of water need; many references use Class A pan evaporation as the primary measure of ET_o.

In California, we are fortunate to have the California Irrigation Management Information System (CIMIS), a network of computerized weather stations that measure the important environmental variables that govern water loss (solar radiation, air temperature, relative humidity and wind speed). From these measurements, a daily ET_o value is calculated which is designed to estimate the actual water loss from a well-watered grass crop. This reference ET_o value has proven to be very useful in estimating actual crop water needs. Daily CIMIS ET_o is generally only 75-80% of Class A pan evaporation.

The CIMIS network currently has over 80 reporting sites across California. ET_o values, either real-time or historical, are available at no charge through computer modem hookup; additionally, many newspapers and radio stations routinely give CIMIS ET_o values. Appendix 1 contains information on obtaining CIMIS data. California's vegetable industry is concentrated in three areas: the desert valleys (Coachella and Imperial), the Central Valley, and the Central Coast (Santa Maria to Salinas). Table 1 shows the historical mean daily ET_o values from a representative site in each area. Salinas shows less seasonal fluctuation, and generally lower values, but in all areas daily ET_o values change dramatically through the year. This accurately reflects the relative crop water needs by season. Historical ET_o values for other locations in California are listed in Appendix 2.

Table 1. Mean CIMIS evapotranspiration estimates (ET_0) in inches per day for representative sites in California vegetable production regions

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Indio	.09	.14	.20	.28	.34	.40	.40	.32	.30	.20	.12	.08
Turlock	.02	.05	.10	.16	.21	.26	.26	.23	.17	.11	.05	.02
Salinas	.05	.07	.09	.13	.15	.16	.16	.15	.13	.09	.06	.04

B. Effect of crop and growth stage on water requirement

A wide variety of vegetable crops are grown using drip irrigation, including celery, broccoli, lettuce, melons, pepper, sweet corn and tomato. There are considerable differences in growth habit, rooting depth, sensitivity to water stress, etc., among these crops. However, their water use characteristics are more similar than one might expect. By far, the most significant factor in determining water needs is crop growth stage.

The primary force controlling crop water loss is heating of the foliage caused by solar radiation. Thus, a convenient way to account for crop growth stage when calculating irrigation need is to simply estimate the percentage of the field surface covered by foliage. This can best be done by measuring the width of foliage (canopy) spread (by sighting down the row) and dividing by the row width. The calculation of crop water need is:

CIMIS ET_0 (cumulative from last irrigation)
x canopy spread (inches) ÷ row width (inches).

This canopy spread estimating procedure obviously has limitations. It is difficult to get a good estimate of cover on very young plants or those spaced widely apart. Also, depending on the soil wetting pattern of a particular field, significant evaporation from exposed soil could occur early in the season. Until substantial foliage cover is obtained, it is critical to back up this estimation procedure with a direct soil moisture measurement.

As described, this canopy coverage estimate is an appropriate way of accounting for crop growth stage. It substitutes for the use of published crop coefficients, which are intended to do the same thing. The main advantage to estimating canopy cover is that it reflects the vigor of a particular field as well as the field configuration. For example, a published crop coefficient for pepper developed for a double-row planting on 40-inch beds may not accurately reflect irrigation needs for double-row peppers on 60-inch beds. The other major problem with using published crop coefficients is that, depending on the source, these coefficients may have been developed using Class A pan evaporation rather than CIMIS ET_0.

C. Accounting for system inefficiency

Armed with reference ET_0 values and canopy coverage estimates, you need only to account for the inefficiency of your drip system. No drip system delivers equal amounts of water to all portions of the field; there is a natural tendency to irrigate based on the drier areas. Generally, an additional 10-15% should be factored in to cover system inefficiency.

A more difficult problem is the inefficiency of buried drip systems to supply shallowly rooted crops. The typical drip system now in use in California for vegetable production is buried 6-10 inches deep and is reused for multiple crops. Deep-rooted crops like tomatoes or melons can be managed efficiently but shallow-rooted crops such as celery or lettuce may not be able to reach all the applied water. This problem can be minimized by:

a) Using relatively flat beds for shallow-rooted crops, which will minimize depth of the drip tube.
b) Forming tightly pressed beds, which improves capillary water movement.
c) Irrigating often, using high-flow tape or tubing if possible. It is particularly important on heavy soils not to let the soil above the drip tape dry out because reestablishing capillary wetting will be difficult.

D. Irrigation frequency

The goal of drip irrigation is to maintain soil moisture close to the optimum range. Highly sophisticated monitoring and control equipment is available that can make multiple applications per day to keep soil moisture very close to field capacity. Most growers are not set up to be that precise and therefore must accept a certain degree of drying between irrigations. The use of two easy rules will help decide how often to irrigate:

1. Deplete no more than 20-25% of available moisture in the most active root zone. This level of depletion does not adversely affect most vegetable crops.

2. Limit individual applications to less than 0.5 inches. This minimizes the portion of the root zone saturated by the application. The importance of this will be discussed later.

To apply the depletion rule, one needs to understand how water behaves in soil. There are three categories of soil water: (1) gravitational (that which will drain below the root zone, drawn by the force of gravity); (2) available (that which the soil can hold against the force of gravity and which plants are able to take up), and (3) hygroscopic (that which is held so tightly by soil particles that plants cannot extract it). The amount of hygroscopic water is basically governed by soil texture; the goal of drip irrigation management is to maximize available water content while minimizing gravitational water.

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The amount of available water a soil can hold is related to its texture, and the percentage of available water present can be estimated by tensiometers and other devices. Table 2 gives approximate values for available water-holding capacity by soil texture, and the approximate tensiometer values for field capacity and 20% depletion. With this information, CIMIS ET_0 data, and a realistic estimate of effective rooting depth of a particular crop, one can make decisions regarding irrigation frequency. Remember, *frequency will change depending on crop growth stage and site-specific factors.*

Table 2. Physical characteristics of soil: available water-holding capacity and soil matric potential (tensiometer reading) at field capacity and 20% available water depletion

Soil texture	Available water at field capacity (inches per foot)	Approximate Soil Matric Potential (centibars) at: Field capacity	20% available water depletion
Sand	0.50 - 1.00	10-15	20-25
Loam	1.00 - 1.75	15-20	20-30
Clay	1.75 - 2.25	20-25	25-35

E. Irrigation time vs. irrigation volume

There is a tendency to think of irrigation with a drip system in terms of number of hours of run time; this can lead to serious problems. The irrigation scheduling system just described calculates volume of water needed. Although you can calculate the length of time your system should run to apply that amount, you cannot always depend on that flow rate being maintained. Malfunctioning pumps and pressure regulators, clogged filters or plugged emitters on the drip tape, etc., can change actual delivery rate considerably. The only way to be sure you are applying the appropriate volume of water is by monitoring an accurate flow meter. Keeping track of actual flow rates over time is one good method of monitoring system performance and will help you to catch maintenance problems early.

F. Dangers of over-irrigation

Although row crop drip systems apply water very slowly, every application does temporarily saturate the soil around each emitter. The percentage of the root zone that is saturated depends on soil conditions, drip line emission rate, and the amount of water applied. This saturated condition, which can

last from a few hours to a day or more, excludes oxygen and puts roots under stress. This stress limits plant growth and provides an opportunity for soil pathogens like *Phytophthora* and *Pythium* to infect roots. A tensiometer reading less than 10 cb generally indicates that saturation or near-saturation conditions exist. Although some degree of saturation is inevitable with each irrigation, it is important to minimize this stress to get the full advantages of drip irrigation.

The other major problem of over-irrigation is leaching of nitrate below the crop root zone. This clearly has an economic cost, but it also has an environmental cost—nitrate pollution of groundwater. In many parts of California, nitrate of agricultural origin has reached groundwater aquifers used for domestic water supplies; hundreds of wells violate federal drinking water standard for nitrate content. The problem has become severe enough to warrant regulatory activity in several parts of the state. Although some level of nitrate leaching is unavoidable in irrigated agriculture, leaching losses can be minimized by appropriate drip irrigation management. In fact, management of water is as important as fertilizer management in controlling nitrate leaching losses.

G. Other considerations

The preceding discussion forms the framework for making decisions on drip irrigation volume and timing. As always, there are other site- and crop-specific considerations. Here are a few examples:

1. Early season irrigation scheduling

Early in the season when plants are small, it is beneficial to encourage roots to explore as much of the soil profile as possible. This maximizes nutrient uptake and maximize stress tolerance later in the season. The best approach to early season irrigation is to begin with a full soil profile and encourage deep rooting by not watering routinely but rather waiting until the 20% depletion of available water is reached at the appropriate monitoring depth. This may mean going 5-10 days between irrigations on spring plantings. Obviously, if you are establishing plantings in hot weather, the interval would be less. In this circumstance, water may be applied for its cooling effects or seedbed salinity control, as well as for plant uptake. Once the crop is established and rapidly growing, you can switch to the scheduling technique outlined.

2. Managing stress-sensitive crops

Certain crops at certain growth stages are highly sensitive to water stress. A good example is nearly mature celery, in which any significant water stress can cause black heart, a physiological disorder. In such circumstances, daily application would be appropriate to assure minimum stress. Celery also happens to be a crop with a tendency to cause root intrusion into the drip emitters,

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causing potentially serious plugging. Minimizing moisture stress by frequent late-season irrigation will minimize both root intrusion and plant moisture stress.

3. Imposing moisture stress

There are circumstances where it is desirable to withhold water at the end of the season, either to aid harvest or to improve quality. With melons and processing tomatoes, soluble solids content of the fruit is an important quality factor and a controlled degree of moisture stress as fruits ripen may be beneficial. There are no firm guidelines established, but the general rule for processing tomatoes would be to adequately supply water through fruit set, then begin deficit irrigation. Completely cut off water 15-30 days before harvest. Since melons are usually harvested over several weeks, completely cutting off water may sacrifice yield. An alternative would be to reduce applications by 50-75% starting roughly 7-10 days before initiation of harvest. For either melons or processing tomatoes, these guidelines assume that the season was begun with a full soil profile to encourage deep rooting.

Cutting back on irrigation to facilitate harvest for crops like lettuce, celery and broccoli is really a balancing act; there are no firm guidelines. Site characteristics such as soil type and prevailing ET_0 rates have to be considered, as well as machinery constraints and market considerations.

4. Accounting for rain

Drip irrigation scheduling will obviously be impacted by rain, but not always in the obvious way. In general, less than 0.10 inches of rain can be ignored since most will be evaporated from the soil surface rather than be used by the plant. Rainfall between 0.10-0.5 inches can be considered effective, in the sense that much of it will reach, and stay, in the root zone. However, there can be a hidden danger in a rain of this magnitude. With buried drip systems, the top few inches of soil will tend to collect salts (originally added by water or fertilizer inputs), sometimes to very high levels. A light rain can push this concentrated band of salts into the root zone. In such circumstances, actually irrigating during and/or immediately after the rain will help dilute this salt load and leach it away from the roots. This problem is generally confined to areas of high ET_0 and marginal water quality. Heavy precipitation (> 1.0 inch) will usually be sufficient to minimize this problem. Rain of an inch or more generally will completely recharge the soil profile, so irrigation scheduling should reflect that fact.

5. Leaching for salinity control

All experienced California growers recognize the danger of high soil- or water salinity in vegetable crop production. With the exception of asparagus and tomato, most vegetable crops are quite salt sensitive. Drip irrigation can minimize salinity problems in two ways: (1) by reducing evaporation from

wet soil surfaces (which concentrates salt) and (2) by continually moving soluble salts to the edge of the wetting pattern, away from roots. Consequently, in-season leaching requirements are minimized for most drip-irrigated vegetable crop operations in much of California. The exceptions are:

a) Areas of high initial soil salinity, poor quality water (>1200 PPM soluble salts) or poor soil structure and/or drainage.

b) Areas of high ET_0 and low annual rainfall (Kern County and the Coachella and Imperial Valleys).

In areas where salinity is a problem, it is best handled by leaching the soil profile before planting a vegetable crop, as is typically done in sprinkler- or furrow-irrigated systems.

H. Direct soil moisture monitoring

There can be several significant sources of error in the empirical irrigation scheduling just described. Each site, soil type and season is unique. Direct soil moisture measurement is the essential safeguard to avoid over- or under-watering, both of which can compromise the benefits of drip. Of the common soil moisture monitoring techniques available, the use of tensiometers is one of the best for monitoring drip irrigation. Despite substantial cost and the need for maintenance, tensiometers can provide crucial information.

The first consideration is placement. One set of instruments should be placed in the zone of most active root uptake. Depth will depend on the crop; shallow-rooted crops like celery, broccoli, or lettuce should be monitored at 6-8 inches, while tomato and vine crops are best evaluated at about 12 inches. It is also important to understand what is happening to soil moisture at deeper depths. Another set of instruments installed 8 to 12 inches below the shallow set will provide this information. To be sure that you are obtaining representative readings, several sets of instruments are needed. Remember, no irrigation system is totally uniform, nor are field soils homogeneous.

Correct interpretation of tensiometer readings is critical. To truly understand what the readings mean, one needs to know the soil moisture release curve for each field being monitored. Few growers have access to that information, so generalizations must be used. Optimum soil moisture is usually assumed to be near field capacity (the maximum amount of water a soil can hold against the force of gravity). An estimate of soil moisture tension at field capacity can be obtained by installing several tensiometers at 6-12 inches deep in the field (where no plants are growing), thoroughly watering the area, then covering a five-foot-wide area around them with heavy black plastic. Within 2 to 3 days, the tensiometer readings will stabilize, indicating that all gravitational water has drained; these readings will approximate the soil moisture tension at field capacity. In most sandy soils, field capacity values will run between 10 to 15 centibars (cb), and loam soils between 15 to 20 cb (Table 2).

In light- to medium-textured soils, tensiometer readings at 20% available moisture depletion are 10 to 15 cb higher than at field capacity. This means that irrigation should commence before tensiometer readings exceed 20 to 25 cb in sandy soil, 25 to 30 cb in loam or clay loam soil. Even in heavy clay soils, tensiometer values should not exceed 35-40 cb.

The shallow tensiometers indicate the moisture status of the active root zone; the deeper instruments tell you whether the amount of water applied is correct. After an irrigation, deep tensiometers should go down to 0-10 cb. If they don't, it means the application was too light. Between irrigations the deep tensiometers should come back up to at least 10 cb, indicating that deep roots are not permanently saturated. Failure of deep tensiometers to reach 10 cb between irrigations means that either the application is too heavy, too frequent, or there is restricted drainage which is preventing percolation of gravitational water.

Another useful tool is the portable soil capacitance probe. It works by emitting a radio frequency wave and measuring the attenuation of the wave by the soil around the probe tip. The measurement made is volumetric water content in the soil, which cannot be easily compared to tensiometer reading. The instructional booklet should be studied carefully so you understand the calibration procedure and can interpret the readings correctly. This instrument is best suited to compare the relative water content of different areas or soil depths, identifying under- or over-irrigated areas. It is a tool to augment, not replace, tensiometers. The major advantages of the soil capacitance probe is its portability and quick response time. A major limitation is that it can be difficult to insert the instrument deeper than 12 inches in many field situations, particularly in multiple crop drip installations where deep tillage is not routinely practiced.

Other soil moisture monitoring techniques are available, such as resistance blocks and the neutron probe, but are not well-suited for use in drip-irrigated vegetable production. Another technique which has achieved some acceptance in scheduling irrigation of cotton and other row crops is infrared thermometry, but it also is poorly suited for use in vegetable cropping systems.

I. Sample Calculations

The following example will help integrate the preceding concepts about drip irrigation decision making:

Grower A is producing a fresh market tomato crop on a clay loam soil in Merced County. Available soil moisture capacity is 1.75 inches per foot. He plants transplants in a single row on 60-inch beds in April.

Stage 1: Establishment

A reasonable approach would be to irrigate to settle the transplants in

and to charge the soil profile if winter rains have not been sufficient. After this initial irrigation, monitor soil moisture at 10-12 inch depth, applying .25-.35 inch (about 7,000-9,000 gallons per acre) when tensiometers reach about 25 cb (~20% depletion). This pattern would continue until early bloom stage.

Stage 2: Early fruit set

By mid-May, the crop is beginning to set fruit. The grower measures the average canopy spread to be 24 inches. ET_0 is running about .22 inches per day.

a) What is the daily water use estimate?

(.22 inches/day x 24 inch canopy 60 inch bed width) + 15% (inefficiency factor) = 0.1 inch per day, or

= 2,700 gallons per acre per day

b) At this growth stage, how often is irrigation required?

Available water = 1.75 inches in top foot of soil
20% depletion = 0.35 inches, therefore
@ 0.1 inches used per day, irrigation twice per week is reasonable

Stage 3: Three weeks pre-harvest

Canopy spread average 55 inches. Daily ET_0 is 0.26 inches.

a) What is the daily water use estimate?

(.26 inches/day x 55 inch canopy 60 inch bed) + 15% (inefficiency factor)

= .27 inches per day, or

= 7,400 gallons per acre each day

b) At what interval is irrigation required?

20% depletion of top foot of soil = 0.35 inches

If daily use is 0.27 inch, daily irrigation would be required to minimize stress. Considering the fact that tomato will establish roots to 4-5 foot depth, they could probably tolerate an irrigation interval of 2-3 days without yield loss. However, that would require applications >0.5 inches, which violates our general rule.

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SECTION 2: DETERMINING NITROGEN FERTIGATION REQUIREMENT

A. Nitrogen cycling in California soils

All crops draw nitrogen from two sources: applied fertilizer and residual soil nitrogen. Most soil N is tied up in complex forms in organic matter and is unavailable for plant uptake. The rate at which these complex forms are broken down into the plant-available forms (ammonium and nitrate) is constantly changing, controlled by a series of interactions of crop residues, soil microbes, and soil moisture and temperature.

When crop residues are incorporated into the soil, they can contain substantial N. This is particularly true of heavily fertilized vegetable crops; broccoli residues, for example, can contain more than 100 lb of nitrogen per acre. After incorporation, this residue is degraded over time by soil microbes, releasing inorganic nitrogen available for uptake by the next crop. This release of available nitrogen, called mineralization, occurs rapidly from the breakdown of fresh, high-nitrogen crop residues and more slowly from the older, more stable organic matter in the soil. The result is that succeeding crops can draw a substantial portion of the nitrogen they need, perhaps 50% or more, from this pool of soil N. The wise grower will take full advantage of this 'free' nitrogen to reduce his fertilizer costs.

B. Ammonium vs. nitrate

Ammonium (NH_4^+) and nitrate (NO_3^-) are the common forms of plant-available nitrogen in the soil. Most vegetable crops will utilize both forms, although most rapid growth is usually favored by more NO_3^- than NH_4^+. This does not necessarily mean that a grower must select high-nitrate fertilizers for best results, because most soils have a high capacity to convert ammonium to nitrate. This microbial transformation process, called nitrification, proceeds rapidly in warm, moist soil. Under such conditions, a major portion of applied ammonium and urea will be converted to nitrate form before plant uptake. In winter, lower soil temperatures limit the rate of nitrification. In this situation, selection of fertilizer materials may become more important.

Ammonium and nitrate behave differently in soil. NH_4^+ is bound to soil particles by its positive charge; it will not move far from its point of application. NO_3^- is highly mobile in soil, moving freely in whatever direction soil water moves. Urea has no charge, so it is quite mobile as well. This has implications for nitrogen management and monitoring.

C. Crop nitrogen needs

Vegetable crops differ widely in their nitrogen needs, and in the pattern of uptake over the growing season. Fruiting crops such as tomatoes, peppers and melons require relatively little N until flowering begins, then increase their N uptake, reaching a peak during fruit set and early fruit bulking period. As fruits mature, N need drops again. Non-fruiting crops like broccoli, celery and lettuce show slow N uptake through the first half of the season, with N need accelerating until just before harvest.

These N uptake patterns will always hold true. To develop an efficient fertility plan, three additional factors need to be considered:

1. The contribution of residual soil N.

Preplant sampling can estimate the amount of residual ammonium and nitrate present at the start of the season, but it is difficult to estimate how much N will be mineralized as the season progresses. In general, fields in which nitrogen-rich residues (broccoli, pepper, etc.) have been incorporated will mineralize much more N than fields with incorporated residues of low N organic material (wheat or rice stubble, etc.). In fact, incorporation of low nitrogen residues may actually take up, or immobilize, inorganic soil N for a period of time.

2. The effect of temperature on the rate of crop development.

To plan fertilizer additions on the basis of daily or weekly needs one must account for the relative crop development rate, which is directly tied to temperature. Total crop N needs are relatively independent of environmental conditions. For example, an early spring cantaloupe crop will need roughly as much total N as a mid-summer crop, even though the length of the growing season (planting to harvest) will differ significantly.

3. The nitrogen content of irrigation water.

Irrigation water may have substantial amounts of nitrate; this is particularly true of well water. Some wells in the Salinas Valley and the eastern San Joaquin Valley contain more than 10 parts per million (PPM) of nitrogen, mostly in nitrate form. Over a cropping season, this can amount to a significant amount of nitrogen applied. To determine nitrogen content of water, the calculation is:

$$\text{PPM } NO_3\text{-N in water} \times 0.23 = \text{pounds N per acre inch}$$

Irrigating a crop with a total of 18 inches of water with of NO_3-N content of 10 PPM would add about 40 lb. N/acre over the cropping season.

Table 3 lists typical N fertigation programs for some major vegetable crops. This information has been drawn from many sources, much of it validated in recent drip-irrigated trials. It should be used only as a guide, to be modified as individual circumstances require. To be certain that crop needs are being met in an efficient manner, a program of soil and plant monitoring is crucial.

Table 3. Nitrogen fertigation requirements of vegetable crops under California conditions

Crop	Growth State	Approximate nitrogen requirement (Lbs. per acre per week)
Broccoli	Early growth	5 - 15[z]
	Mid season	10 - 20
	Button formation	15 - 30
	Head development	10 - 20
Cucumber	Vegetative growth	5 - 10
	Early flowering/fruit set	10 - 20
	Fruit bulking	10 - 15
	First harvest	5 - 10
Lettuce	Early growth	5 - 10
	Cupping	10 - 20
	Head filling	15 - 30
Melon	Vegetative growth	5 - 10
	Early flowering/fruit set	10 - 20
	Fruit bulking	10 - 15
	First harvest	5 - 10
Pepper	Vegetative growth	5 - 10
	Early flowering/fruit set	15 - 30
	Fruit bulking	15 - 20
	First harvest	5 - 10
Squash	Vegetative growth	5 - 10
	Early flowering	10 - 20
	First harvest	5 - 10
Tomato	Vegetative growth	5 - 10
	Early flowering/fruit set	15 - 20
	Fruit bulking	10 - 15
	First harvest	5 - 10

z Higher values represent fertigation needs in low residual N soils and/or under high temperature (rapid growth) conditions.

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D. Frequency of nitrogen applications

In furrow- or sprinkler-irrigated culture, nitrogen applications are generally large (>30 lb N/acre) and infrequent. Drip irrigation offers nearly limitless flexibility, allowing for daily N application if desired. The question of fertigation frequency has not been extensively researched, but most available information suggests that weekly additions are as effective as more frequent applications, provided that the appropriate amount is applied and that excessive irrigation does not cause significant nitrate leaching losses between fertigations.

E. Monitoring soil nitrogen status

Soil testing for inorganic (available) nitrogen has usually been limited to preplant sampling. Now that drip irrigation provides the ability to add nitrogen on demand, more extensive monitoring is justified. Traditional soil sampling and laboratory analysis offer the most complete, accurate information, but growers are not likely to go to the trouble and expense of this technique on an ongoing basis through a cropping cycle.

There are several alternatives for on-farm soil nitrogen measurement. One is the use of soil solution access tubes (SSAT), also called suction lysimeters. This device is simply a porous ceramic cup, similar to a tensiometer cup, attached to a hollow access tube. The unit is installed in the field with the ceramic tip in the active root zone. To collect a sample, a vacuum draws water from the surrounding soil into the tube. This soil water sample is collected and usually analyzed only for nitrate content, since only a fraction of NH_4^+ will be in soil solution, the majority being tied up on soil particles. It is important to recognize that the vast majority of inorganic nitrogen is usually in the nitrate form.

The use of SSATs has serious limitations. There can be a high degree of spatial variability in nitrate distribution in commercial fields, but this can be minimized by using at least 4 SSATs per management unit. The greater problem is interpreting the analysis. The nitrate in soil solution tends to concentrate toward the edges of the wetted zone, so tube placement can radically alter the result. Most importantly, by mid-season, most crops have developed extensive root systems and are capable of taking up enormous quantities of nitrogen, far in excess of their needs; low nitrate values in this situation would not necessarily reflect nitrogen deficiency.

Clearly, using SSATs to determine N deficiency would not be appropriate. However, they do provide a simple and inexpensive method for determining when soil N is clearly *sufficient*. This is particularly true during the first half of the growing season, when crop nitrogen needs are low and substantial residue N may be present. Monitoring soil solution nitrate concentration can help minimize early season fertigation and maximize use of residual

soil N. Extensive field data is lacking, but in general soil solution NO_3^-N concentrations in excess of 50-75 PPM indicate that sufficient N is available to meet immediate plant needs. It is not uncommon for residual N in soil solution to remain at or above these levels for the first 4 to 6 weeks of the season. As soil solution values drop and/or the crop reaches a stage of high nitrogen demand, greater reliance on some form of plant tissue testing should take precedence.

There are several methods of analyzing nitrate content of soil solution samples. Colorometric test kits and a portable nitrate-selective electrode meter are available for on-farm use; both methods can be quite accurate. The fastest, cheapest technique is the use of nitrate-sensitive test strips. Although only semi-quantitative, these colorometric strips can effectively discriminate NO_3-N concentration above and below the 50-75 PPM level.

Another simple technique for estimating soil nitrate concentration is the 'quick test' procedure described in Appendix 3. This test has the advantage of measuring nitrate in a composite soil sample representative of the major root zone, compared to the site-specific measurement of an SSAT. Soil and the nitrate extracting solution are measured volumetrically, eliminating the need to dry or weigh soil. The moisture content of soil will affect the test, but moisture content of drip-irrigated soils will generally fall in a relatively narrow range so the impact will be minor, in most cases. In general, soil NO_3-N values above 20 PPM indicate sufficient available nitrogen to meet immediate plant needs. As was the case with SSATs, low 'quick test' soil nitrate values late in the cropping season may not indicate insufficient soil nitrogen, but rather highly efficient plant uptake. Tissue testing would be required to confirm low N status.

F. Monitoring crop nitrogen status

Conventional plant tissue analysis, in which tissue is dried, ground and chemically analyzed in a laboratory, is the most accurate way to determine crop N status. Through decades of experience N sufficiency guidelines have been developed for most important vegetable crops. Although not specifically developed for drip irrigation, these standards are still generally applicable. Unfortunately, laboratory analysis of dry tissue is relatively costly, and the time lag between sampling and obtaining results can be significant. In the past several years, there has been increasing interest in on-farm tissue testing methods for analyzing the nitrate content of fresh petiole sap. Regardless of approach, tissue analysis can provide invaluable information. To get the most useful data, the following points must be considered.

1. Plant sampling technique

Selecting the correct tissue for analysis is crucial because tissues of different ages have radically different nitrogen concentrations. For most crops, the youngest fully expanded leaf is used; this is usually 3 to 4 leaves back from the growing point. When analyzing for nitrate content, usually only the leaf petiole or midrib is used; nitrate content of this tissue is regarded as an indicator of the current availability of nitrogen for assimilation into organic compounds. In contrast, total tissue nitrogen content gives an estimate of overall N status. This determination is performed on leaf blades or whole leaves (blades and petioles). For drip-irrigated vegetable crops, analysis of NO_3^-N is by far the most common measurement of crop N status.

To ensure that a tissue sample is representative of the area surveyed, at least 30 petioles should be collected from throughout the field. Each management unit should be sampled separately.

2. Determination of growth stage

Most vegetable crops show a distinct pattern of nitrate accumulation in the petioles. Highest values are seen during early vegetative growth, with declining nitrate concentrations thereafter. The decline is particularly steep for fruiting crops; as fruits begin to set and grow, they form a sink into which the plant pumps large amounts of nitrogen, limiting the amount of nitrate stored in leaf petioles. It is therefore important to correctly note growth stage at sampling to know what sufficiency standard to apply.

3. Handling and preparation of samples

Traditionally, samples are rinsed with distilled water to remove dust and other residues; this is more important for accurate analysis of minor elements than for nitrate analysis. Once removed from the plant, tissue will respire (lose CO_2) and transpire (lose water) at a rapid rate. To minimize these functions, samples should be placed in plastic bags on ice in a cooler until they are put into a drying oven or pressed for fresh sap. This is particularly important for fresh sap analysis because water loss can significantly affect results.

Fresh sap analysis is a relatively new technique which has become more popular with the introduction of a portable nitrate-selective meter than can analyze plant sap directly without the need for dilution or volume measurement. Although the meter costs several hundred dollars, there are virtually no recurring expenses, so with frequent usage per sample costs are modest.

Petioles are crushed in a garlic press or other simple device. After the meter has been calibrated, several drops of the sap are placed directly on the electrode pad, which generates a digital readout value in PPM NO_3^-; to convert to PPM NO_3^-N, this value must be divided by 4.43. Once a fresh sap sample has been obtained, it should be tested immediately. The meter is sensitive to temperature changes, so it is best used in an office or farm building, with petiole samples brought to this central location. A complete petiole sap test protocol is presented in Appendix 4.

Test kits are also available which can measure nitrate content of fresh sap. Sap samples are diluted and mixed with chemical reagents; nitrate concentration is determined by colorometric reaction. These kits can be reasonably accurate, but the processing of samples is more laborious than for use of the nitrate-selective meter.

A major difficulty with either technique for analyzing fresh sap is the interpretation of results. All currently accepted standards for tissue nitrate concentration are based on conventional laboratory analysis of dried tissue and it is difficult to account for the dilution effects of fresh sap, which is mostly water. Recent studies have correlated fresh sap and dry tissue values. The correlation has been generally good across a wide range of nitrogen levels with each crop having a characteristic relationship between fresh sap and dry tissue. Laboratory analysis of dry tissue remains the standard of accuracy, but fresh sap analysis can be a valuable tool for on-farm decision-making. The wise grower will periodically check the accuracy of fresh sap values by comparison with lab analysis of duplicate samples.

Table 4 gives petiole nitrate sufficiency ranges by crop and growth stage, both for dry tissue and fresh sap.

Table 4. Petiole NO_3-N sufficiency values for drip-irrigated vegetables

Crop	Growth stage	Petiole NO_3-N concentration (PPM) Dry tissue	Fresh sap
Broccoli	Mid growth	10,000 - 20,000	1,000 - 1,600
	Button formation	8,000 - 15,000	800 - 1,200
	Preharvest	5,000 - 8,000	600 - 1,000
Cantaloupe	Early flower	12,000 - 15,000	1,000 - 1,200
	Fruit bulking	8,000 - 10,000	800 - 1,000
	First harvest	4,000 - 6,000	700 - 800
Celery	Mid growth	7,000 - 10,000	300 - 500
	Preharvest	6,000 - 8,000	300 - 400
Lettuce	Early head formation	7,000 - 12,000	400 - 600
	Preharvest	6,000 - 10,000	300 - 500
Pepper	Vegetative growth	7,000 - 10,000	900 - 1,200
	Early flower/fruit	5,000 - 8,000	700 - 1,000
	Fruit bulking	5,000 - 8,000	700 - 1,000
	Preharvest	5,000 - 7,000	700 - 900
Tomato	Vegetative growth	10,000 - 14,000	700 - 900
	Early flower/fruit	9,000 - 12,000	600 - 800
	Fruit bulking	6,000 - 8,000	500 - 700
	Preharvest	4,000 - 6,000	400 - 600
Watermelon	Early flowering	12,000 - 15,000	900 - 1,100
	Fruit bulking	8,000 - 15,000	700 - 900
	Fruit harvest	5,000 - 8,000	500 - 700

Appendix 1

Accessing CIMIS ET_0 Information

CIMIS (California Irrigation Management Information System) weather data is available via computer modum hookup. You must establish an account with the Department of Water Resources (no charge) to obtain an ID and password to call up the system. To obtain information on establishing an account, contact the DWR office nearest you.

Northern District
Red Bluff
Clyde Muir
(916) 529-7355

San Joaquin District
Fresno/Bakersfield
Dave Scruggs
(805) 395-2815

Central District
Sacramento
Mark Rivera
(916) 445-8976

Southern District
Los Angeles
Linda Brainard
(818) 543-4621

Current CIMIS information is also available from various media outlets throughout the state. The following list contains newspapers, radio stations and telephone recording services that disseminate CIMIS ET_0 data.

Newspapers

Ag Alert
Stations 7,
30,31,37,38,41,48,61,62,70
Published in Sacramento, CA

Chico Enterprise Record
Station 8
Published in Chico, CA
(weekly ET for pasture/turfgrass, alfalfa, olives, orchard - 3 clean tilled leafing dates and one for grass cover crop, beets, corn and grain)

Chula Vista News
Station 66
Published in Chula Vista, CA

Claremont Courier
Station 82
Published in Claremont, CA

Corning Daily Observer
Station 8
Published in Corning, CA
(weekly ET for 7 crops)

Dos Palos Star
Stations 7, 56
Published in Merced, CA

Fallbrook Enterprise
Stations 49,62,66,74
Published in Fallbrook, CA

Fresno Bee
Station 80
Published in Fresno, CA

Gridley Herald
Station 8
Published in Gridley, CA
(weekly ET for 11 crops)

Gustine Standard
Stations 56,70
Published in Gustine, Crows Landing, and Newman, CA

Hanford Sentinel
Stations 2,15,21
Kings County, CA

Imperial Valley Press
Stations 41,87,88
Published in Brawley, CA

Intermountain News
Station 43
Published in Burney, CA

Lodi News Sentinel
Stations 42, 70
Published in Lodi, CA

Los Banos Enterprise
Stations 7,56
Published in Los Banos, CA

Mendota Journal
Stations 7,40
Published in Firebaugh, CA

Modoc Record
Stations 43,90
Published in Cedarville, CA

Red Bluff Daily News
Station 8
Published in Red Bluff, CA
(weekly ET for 7 crops 3 times/wk)

Register Pajaronian
stations 16,19,95,104
Published in Watsonville, CA

Turlock Journal
Station 71
Published in Modesto, CA

Visalia Times Delta
Stations 33, 86
Published in Visalia, CA

Telephone Recordings

Alameda County Water District
Station 100
510-659-1970, Ext. 200

Coachella Valley Water District
Stations 50,55
619-398-7211

Contra Costa Water District
Stations 47,65
415-603-8304

East Bay Municipal Utilities District
Station 65
415-820-7750
Data is provided from April to November

Marin Municipal Water District
Station 63
415-924-1067

Mission Resource Conservation District
(San Diego County)
Stations 49,62,66,74
800-339-9954

North Marin Water District
Station 63
415-892-1418, Ext. 555
ET for mature cool season turf

Rancho California Water District
Station 62
714-676-4435

Santa Clara Valley Water District
Station 69
408-267-3127

UC Cooperative Extension/ San Diego
Stations 49,62,66,74
800-336-3023

UC Cooperative Extension/ Santa Maria
English/Spanish
Stations 38,64,76,88
805-934-6328

Ventura County Resource Conservation District
Stations 97,101
805-386-4686

Western Municipal Water District
Station 44
714-780-2809

Radio Stations

KIEV, 870 AM - Los Angeles
The information is broadcast at 7:00 a.m. on Saturdays and 5:00 a.m. to 7:00 a.m. on Sundays by Burnell Yarick, a retired farm advisor.

KKIG, 780 AM - Coachella Valley
The information is broadcast during the weather forecast.
Stations 50,55

KROP, 1300 AM - Imperial Valley
The information is broadcast during the agriculture forecast.
Stations 41,68,87

KSNI, 102 FM - Santa Maria
The information is broadcast at 6:00 a.m., noon, and 5:00 p.m. during the agricultural forecast.
Stations 38,64,76,88

D—039649

KCNO, 570 AM - Cedarville
The information is broadcast at 6:00 a.m., 12:30 p.m., and 2:30 p.m. during the agricultural forecast.
Stations 43,90

KSUE, 1240 AM & 93.3 FM - Susanville
The information is broadcast during the agricultural program conducted by a local cooperative extension person.

The National Weather Service is now broadcasting CIMIS Et_o data on the NOAA Weather Radio Stations. CIMIS Et_o data can be heard weekdays, March through October, during the Agricultural Weather Advisory report on the following radio frequencies:

Bakersfield	162.550
Coachella	162.400
Fresno	162.400
Lindsay	162.500
Redding	162.550
Sacramento	162.550

California State University

California State University, Fresno
Agricultural Technology Information Network
All Stations - Information is available at 20 access points. See attached for access points and instructions.
Jeff Ennen (209) 278-4872

CIMIS Alert

CIMIS Alert was begun for California water agencies, conservation district, and other interested public agencies to promote improved irrigation management by water users.

The Cimis Alert program enables public agencies to provide a daily telephone recording of local evapotranspiration (Et_o). Contact your local water agency and/or cooperative extension office to see if CIMIS Et_o information is available.

Appendix 2

Historical Average Daily Et_o for Selected California Locations

County	City	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
Alameda	Livermore	0.04	0.06	0.09	0.15	0.19	0.22	0.24	0.20	0.18	0.10	0.05	0.03
	Oakland	0.05	0.06	0.09	0.13	0.17	0.18	0.19	0.18	0.16	0.10	0.05	0.03
Alpine	Markleeville	0.02	0.03	0.06	0.12	0.16	0.20	0.24	0.20	0.15	0.08	0.04	0.02
Amador	Jackson	0.04	0.06	0.09	0.15	0.19	0.24	0.26	0.23	0.18	0.10	0.05	0.03
Butte	Chico	0.04	0.06	0.09	0.16	0.20	0.25	0.28	0.24	0.18	0.12	0.06	0.03
	Gridley	0.04	0.06	0.10	0.16	0.20	0.26	0.28	0.23	0.18	0.12	0.06	0.03
	Oroville	0.04	0.06	0.09	0.16	0.20	0.25	0.28	0.24	0.18	0.12	0.06	0.03
Calaveras	San Andreas	0.04	0.06	0.09	0.15	0.19	0.24	0.26	0.23	0.18	0.10	0.05	0.02
Colusa	Colusa	0.04	0.06	0.09	0.16	0.21	0.25	0.26	0.22	0.19	0.11	0.06	0.03
	Williams	0.04	0.06	0.09	0.15	0.20	0.24	0.28	0.24	0.18	0.11	0.05	0.03
Contra Costa	Brentwood	0.03	0.06	0.09	0.15	0.20	0.24	0.26	0.22	0.17	0.10	0.05	0.02
	Concord	0.04	0.05	0.08	0.13	0.18	0.20	0.22	0.19	0.16	0.10	0.04	0.02
	Martinez	0.04	0.05	0.09	0.13	0.17	0.19	0.22	0.18	0.16	0.10	0.04	0.02
	Pittsburg	0.03	0.06	0.09	0.14	0.18	0.21	0.24	0.20	0.17	0.10	0.04	0.02
Del Norte	Crescent City	0.02	0.03	0.06	0.10	0.12	0.12	0.14	0.12	0.10	0.06	0.03	0.02
El Dorado	Camino	0.03	0.06	0.08	0.13	0.19	0.24	0.25	0.22	0.17	0.10	0.05	0.03
Fresno	Clovis	0.03	0.06	0.10	0.16	0.11	0.26	0.28	0.24	0.18	0.11	0.05	0.02
	Coalinga	0.04	0.06	0.10	0.15	0.20	0.24	0.28	0.24	0.18	0.11	0.05	0.02
	Five Points	0.03	0.06	0.11	0.17	0.21	0.26	0.28	0.24	0.18	0.11	0.05	0.03
	Fresno	0.03	0.06	0.11	0.16	0.22	0.26	0.27	0.23	0.17	0.10	0.05	0.02
	Friant	0.04	0.06	0.10	0.16	0.20	0.26	0.28	0.24	0.18	0.11	0.05	0.02
	Kerman	0.03	0.05	0.10	0.16	0.21	0.26	0.27	0.23	0.18	0.11	0.05	0.02
	Kingsburg	0.03	0.06	0.11	0.16	0.21	0.26	0.27	0.23	0.18	0.11	0.05	0.02
	Reedley	0.04	0.06	0.10	0.16	0.20	0.26	0.28	0.24	0.18	0.11	0.05	0.02
Glenn	Orland	0.04	0.06	0.10	0.16	0.22	0.25	0.28	0.24	0.19	0.12	0.06	0.04
	Willows	0.04	0.06	0.09	0.16	0.20	0.24	0.28	0.24	0.18	0.12	0.06	0.03
Humboldt	Eureka	0.02	0.04	0.06	0.10	0.12	0.12	0.12	0.12	0.10	0.06	0.03	0.02
	Ferndale	0.02	0.04	0.06	0.10	0.12	0.12	0.12	0.12	0.10	0.06	0.03	0.02
	Garbervill	0.02	0.04	0.07	0.10	0.15	0.17	0.18	0.16	0.13	0.08	0.03	0.02
	Hoopa	0.02	0.04	0.07	0.10	0.14	0.18	0.20	0.17	0.13	0.08	0.03	0.02

County	City	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
Imperial	Brawley	0.09	0.13	0.19	0.27	0.33	0.38	0.38	0.32	0.28	0.20	0.12	0.07
	Calipatria	0.09	0.14	0.20	0.28	0.34	0.39	0.39	0.33	0.29	0.21	0.13	0.07
	El Centro	0.09	0.13	0.18	0.26	0.33	0.37	0.37	0.31	0.28	0.20	0.11	0.06
	Holtville	0.09	0.14	0.19	0.26	0.33	0.39	0.38	0.32	0.29	0.20	0.12	0.07
	Yuma	0.10	0.15	0.21	0.29	0.35	0.41	0.41	0.35	0.30	0.21	0.13	0.08
Inyo	Bishop	0.06	0.09	0.15	0.22	0.26	0.36	0.31	0.31	0.25	0.15	0.08	0.05
	Death Valley	0.07	0.12	0.17	0.26	0.31	0.37	0.37	0.33	0.28	0.17	0.10	0.06
	Independence	0.06	0.09	0.11	0.22	0.28	0.32	0.31	0.28	0.24	0.13	0.07	0.05
	Lower Haiwee Res.	0.06	0.09	0.14	0.24	0.28	0.32	0.31	0.28	0.24	0.13	0.09	0.05
Kern	Arvin	0.04	0.06	0.11	0.16	0.21	0.25	0.26	0.24	0.18	0.11	0.06	0.03
	Bakersfield	0.03	0.06	0.11	0.16	0.21	0.26	0.28	0.24	0.18	0.11	0.05	0.03
	Buttonwillow	0.03	0.06	0.10	0.16	0.21	0.32	0.28	0.24	0.18	0.11	0.05	0.03
	China Lake	0.07	0.11	0.17	0.26	0.30	0.33	0.35	0.31	0.24	0.16	0.09	0.06
	Delano	0.03	0.06	0.11	0.16	0.21	0.26	0.28	0.24	0.18	0.11	0.05	0.02
	Grapevine	0.04	0.06	0.10	0.15	0.18	0.23	0.24	0.22	0.20	0.11	0.06	0.03
	Inyokern	0.06	0.11	0.16	0.24	0.28	0.32	0.35	0.30	0.24	0.17	0.09	0.06
	Isabella Dam	0.04	0.05	0.09	0.15	0.19	0.24	0.26	0.22	0.17	0.10	0.06	0.03
	Lost Hills	0.02	0.04	0.08	0.15	0.22	0.26	0.28	0.23	0.17	0.13	0.03	0.01
	Shafter	0.03	0.06	0.11	0.17	0.21	0.26	0.27	0.24	0.18	0.11	0.05	0.03
	Taft	0.04	0.06	0.10	0.14	0.20	0.24	0.28	0.24	0.19	0.11	0.06	0.03
	Tehachapi	0.05	0.06	0.10	0.17	0.20	0.26	0.26	0.24	0.20	0.11	0.07	0.04
Kings	Corcoran	0.03	0.06	0.11	0.17	0.23	0.26	0.27	0.24	0.19	0.11	0.05	0.02
	Hanford	0.03	0.06	0.11	0.16	0.21	0.26	0.27	0.23	0.18	0.11	0.05	0.02
	Kettleman City	0.03	0.06	0.11	0.18	0.23	0.26	0.27	0.24	0.20	0.12	0.06	0.03
	Lemoore	0.03	0.06	0.11	0.17	0.21	0.26	0.27	0.24	0.18	0.11	0.05	0.02
Lake	Lakeport	0.04	0.05	0.08	0.12	0.17	0.20	0.24	0.20	0.16	0.09	0.04	0.03
	Lower Lake	0.04	0.05	0.09	0.15	0.17	0.21	0.24	0.21	0.17	0.10	0.04	0.03
Lassen	Ravendale	0.02	0.04	0.07	0.14	0.18	0.22	0.26	0.24	0.16	0.09	0.04	0.02
	Susanville	0.02	0.04	0.07	0.14	0.18	0.22	0.25	0.22	0.15	0.09	0.04	0.02
Los Angeles	Burbank	0.07	0.10	0.12	0.16	0.17	0.20	0.21	0.22	0.18	0.13	0.09	0.06
	Glendora	0.06	0.09	0.12	0.15	0.17	0.20	0.24	0.22	0.19	0.13	0.09	0.06
	Gorman	0.05	0.08	0.11	0.15	0.18	0.25	0.25	0.23	0.20	0.12	0.08	0.04
	Lancaster	0.07	0.11	0.15	0.19	0.28	0.32	0.35	0.31	0.24	0.15	0.09	0.06
	Long Beach	0.07	0.09	0.11	0.13	0.15	0.16	0.17	0.16	0.15	0.11	0.08	0.06
	Los Angeles	0.07	0.09	0.12	0.16	0.18	0.19	0.20	0.19	0.17	0.13	0.09	0.06
	Palmdale	0.06	0.09	0.13	0.17	0.24	0.28	0.32	0.31	0.22	0.13	0.09	0.06

County	City	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
Los Angeles con't.	Pasadena	0.07	0.09	0.12	0.16	0.17	0.20	0.23	0.22	0.19	0.13	0.09	0.06
	Pearblossom	0.06	0.09	0.12	0.16	0.24	0.26	0.32	0.26	0.21	0.13	0.09	0.05
	Redondo Beach	0.07	0.09	0.11	0.13	0.15	0.16	0.17	0.15	0.15	0.09	0.08	0.06
	San Fernando	0.06	0.09	0.11	0.15	0.18	0.20	0.24	0.22	0.18	0.13	0.09	0.06
Madera	Chowchilla	0.03	0.05	0.10	0.16	0.12	0.26	0.28	0.24	0.18	0.11	0.05	0.02
	Madera	0.03	0.05	0.10	0.16	0.21	0.26	0.28	0.24	0.18	0.11	0.05	0.02
	Raymond	0.04	0.06	0.10	0.15	0.20	0.25	0.27	0.24	0.17	0.11	0.05	0.02
Marin	Novato	0.04	0.06	0.08	0.12	0.14	0.20	0.19	0.17	0.15	0.09	0.05	0.02
	San Rafael	0.04	0.05	0.08	0.11	0.13	0.16	0.16	0.16	0.14	0.09	0.04	0.02
Mariposa	Coulterville	0.04	0.06	0.09	0.15	0.19	0.24	0.27	0.22	0.18	0.11	0.05	0.02
	Mariposa	0.04	0.06	0.09	0.15	0.19	0.25	0.27	0.23	0.17	0.11	0.05	0.02
	Yosemite Village	0.02	0.04	0.07	0.16	0.17	0.22	0.23	0.20	0.15	0.09	0.04	0.02
Mendocino	Fort Bragg	0.03	0.05	0.07	0.10	0.12	0.12	0.12	0.12	0.10	0.07	0.04	0.02
	Hopland	0.04	0.05	0.08	0.11	0.16	0.20	0.21	0.19	0.15	0.09	0.04	0.02
	Point Arena	0.03	0.05	0.07	0.10	0.12	0.13	0.12	0.12	0.10	0.07	0.04	0.02
	Ukiah	0.03	0.05	0.08	0.11	0.16	0.19	0.22	0.19	0.15	0.09	0.04	0.02
Merced	Los Banos	0.03	0.06	0.10	0.16	0.20	0.25	0.26	0.23	0.18	0.11	0.05	0.02
	Merced	0.03	0.06	0.10	0.16	0.21	0.26	0.27	0.23	0.18	0.11	0.05	0.02
Mono	Bridgeport	0.02	0.03	0.07	0.13	0.18	0.22	0.24	0.22	0.16	0.09	0.04	0.02
Monterey	Castroville	0.05	0.06	0.09	0.12	0.14	0.15	0.15	0.13	0.13	0.09	0.06	0.04
	King City	0.06	0.07	0.11	0.15	0.14	0.19	0.20	0.21	0.22	0.17	0.07	0.04
	Long Valley	0.05	0.07	0.10	0.14	0.19	0.22	0.24	0.22	0.18	0.12	0.07	0.04
	Monterey	0.06	0.06	0.09	0.12	0.13	0.14	0.14	0.13	0.12	0.09	0.06	0.05
	Salinas	0.05	0.07	0.09	0.13	0.15	0.16	0.16	0.15	0.13	0.09	0.06	0.04
	Soledad	0.06	0.07	0.11	0.15	0.18	0.18	0.21	0.20	0.17	0.12	0.07	0.05
Napa	St. Helena	0.04	0.06	0.09	0.13	0.17	0.20	0.22	0.20	0.16	0.10	0.05	0.03
	Yountville	0.04	0.06	0.09	0.13	0.17	0.20	0.23	0.20	0.16	0.10	0.05	0.03
Nevada	Grass Valley	0.04	0.06	0.08	0.13	0.19	0.24	0.26	0.23	0.18	0.10	0.05	0.03
	Nevada City	0.04	0.06	0.08	0.13	0.19	0.23	0.26	0.22	0.18	0.10	0.05	0.03
	Soda Springs	0.02	0.02	0.06	0.10	0.14	0.18	0.20	0.18	0.14	0.08	0.02	0.02
	Truckee	0.02	0.02	0.06	0.11	0.14	0.18	0.20	0.19	0.14	0.08	0.03	0.02
Orange	Laguna Beach	0.07	0.09	0.11	0.13	0.15	0.15	0.16	0.16	0.15	0.11	0.08	0.06
	Santa Ana	0.07	0.09	0.12	0.15	0.15	0.18	0.20	0.20	0.16	0.12	0.08	0.06

County	City	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
Placer	Auburn	0.04	0.06	0.09	0.15	0.20	0.25	0.27	0.24	0.18	0.11	0.05	0.03
	Blue Canyon	0.02	0.04	0.07	0.11	0.15	0.20	0.23	0.20	0.15	0.09	0.03	0.02
	Colfax	0.04	0.06	0.08	0.13	0.19	0.24	0.26	0.23	0.18	0.10	0.05	0.03
	Lincoln	0.04	0.06	0.09	0.16	0.20	0.25	0.27	0.24	0.18	0.12	0.06	0.04
	Roseville	0.04	0.06	0.10	0.16	0.20	0.16	0.28	0.24	0.19	0.12	0.06	0.03
	Tahoe City	0.02	0.02	0.06	0.10	0.14	0.18	0.20	0.18	0.14	0.08	0.03	0.02
Plumas	Portola	0.02	0.03	0.06	0.12	0.16	0.20	0.24	0.19	0.14	0.09	0.03	0.02
	Quincy	0.02	0.03	0.07	0.12	0.16	0.20	0.24	0.19	0.15	0.09	0.04	0.02
Riverside	Beaumont	0.06	0.08	0.11	0.15	0.20	0.24	0.24	0.26	0.20	0.13	0.09	0.06
	Blythe	0.10	0.15	0.22	0.30	0.36	0.41	0.41	0.36	0.30	0.22	0.13	0.09
	Coachella	0.09	0.16	0.20	0.28	0.34	0.40	0.40	0.33	0.30	0.20	0.13	0.08
	Desert Center	0.09	0.15	0.20	0.28	0.35	0.40	0.39	0.36	0.30	0.20	0.13	0.08
	Elsinore	0.07	0.10	0.13	0.15	0.19	0.24	0.25	0.23	0.18	0.13	0.09	0.06
	Indio	0.09	0.14	0.20	0.28	0.34	0.40	0.40	0.32	0.30	0.20	0.13	0.08
	Oasis	0.09	0.10	0.19	0.27	0.33	0.39	0.37	0.32	0.28	0.20	0.11	0.07
	Palm Desert	0.06	0.13	0.16	0.26	0.28	0.35	0.31	0.30	0.28	0.20	0.09	0.06
	Palm Springs	0.06	0.10	0.16	0.24	0.27	0.28	0.37	0.27	0.24	0.19	0.09	0.06
	Riverside	0.07	0.10	0.13	0.14	0.20	0.24	0.26	0.24	0.20	0.13	0.09	0.06
Sacramento	Courtland	0.03	0.06	0.09	0.15	0.20	0.23	0.26	0.22	0.18	0.10	0.05	0.02
	Sacramento	0.03	0.06	0.10	0.16	0.20	0.26	0.27	0.23	0.18	0.12	0.06	0.03
San Benito	Hollister	0.05	0.17	0.10	0.14	0.18	0.19	0.21	0.19	0.16	0.11	0.06	0.04
San Bernardino	Baker	0.09	0.14	0.20	0.28	0.33	0.39	0.39	0.35	0.30	0.20	0.11	0.07
	Barstow	0.08	0.13	0.19	0.26	0.33	0.39	0.39	0.33	0.29	0.19	0.11	0.07
	Chino	0.07	0.10	0.13	0.15	0.19	0.22	0.24	0.23	0.20	0.13	0.09	0.06
	Crestline	0.05	0.07	0.11	0.15	0.18	0.22	0.25	0.23	0.18	0.11	0.07	0.05
	Lucerne Valley	0.07	0.10	0.17	0.22	0.30	0.37	0.37	0.32	0.25	0.16	0.10	0.06
	Needles	0.10	0.15	0.21	0.30	0.35	0.41	0.41	0.35	0.30	0.21	0.13	0.09
	San Bernadino	0.06	0.09	0.12	0.15	0.19	0.23	0.26	0.24	0.20	0.13	0.09	0.06
	Twentynine Palms	0.08	0.13	0.19	0.26	0.33	0.37	0.36	0.33	0.29	0.19	0.11	0.07
	Victorville	0.07	0.11	0.16	0.22	0.30	0.33	0.36	0.31	0.25	0.17	0.09	0.06
San Diego	Chula Vista	0.07	0.09	0.11	0.13	0.16	0.16	0.18	0.16	0.15	0.11	0.08	0.06
	Escondido	0.07	0.10	0.12	0.16	0.18	0.20	0.22	0.21	0.18	0.12	0.08	0.06
	Fallbrook	0.07	0.09	0.12	0.16	0.18	0.20	0.22	0.21	0.18	0.12	0.08	0.06
	Oceanside	0.07	0.09	0.11	0.13	0.16	0.16	0.16	0.17	0.14	0.11	0.08	0.06
	Pine Valley	0.05	0.06	0.09	0.14	0.18	0.23	0.26	0.24	0.20	0.13	0.07	0.05
	Ramona	0.07	0.09	0.13	0.16	0.18	0.22	0.24	0.22	0.19	0.13	0.09	0.06

County	City	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
San Diego con't.	San Diego	0.07	0.09	0.11	0.13	0.16	0.16	0.17	0.16	0.15	0.11	0.08	0.06
	Santee	0.07	0.09	0.12	0.15	0.18	0.20	0.22	0.20	0.18	0.12	0.09	0.06
	Warner Springs	0.15	0.08	0.12	0.16	0.19	0.26	0.27	0.25	0.21	0.13	0.08	0.05
San Francisco	San Francisco	0.05	0.05	0.08	0.10	0.12	0.15	0.16	0.15	0.14	0.09	0.04	0.02
San Joaquin	Farmington	0.05	0.05	0.09	0.16	0.20	0.25	0.26	0.22	0.18	0.11	0.05	0.02
	Lodi	0.03	0.06	0.09	0.17	0.21	0.23	0.25	0.25	0.17	0.10	0.04	0.02
	Manteca	0.05	0.05	0.10	0.16	0.20	0.25	0.26	0.22	0.18	0.11	0.05	0.02
	Stockton	0.03	0.06	0.09	0.16	0.20	0.25	0.26	0.22	0.18	0.10	0.05	0.02
	Tracy	0.03	0.06	0.09	0.15	0.20	0.24	0.26	0.22	0.18	0.10	0.04	0.02
San Luis Obispo	Arroyo Grande	0.06	0.08	0.10	0.13	0.14	0.16	0.14	0.15	0.13	0.10	0.08	0.06
	Atascadero	0.04	0.06	0.09	0.13	0.15	0.20	0.22	0.20	0.16	0.10	0.06	0.03
	Morro Bay	0.06	0.08	0.10	0.12	0.14	0.15	0.15	0.15	0.13	0.11	0.07	0.06
	Paso Robles	0.05	0.07	0.10	0.14	0.18	0.11	0.24	0.22	0.17	0.12	0.07	0.05
	San Luis Obispo	0.06	0.08	0.10	0.14	0.16	0.18	0.15	0.18	0.15	0.11	0.08	0.06
	San Miguel	0.05	0.07	0.10	0.14	0.16	0.21	0.24	0.12	0.17	0.12	0.07	0.05
	San Simeon	0.06	0.07	0.09	0.12	0.13	0.15	0.15	0.14	0.12	0.10	0.07	0.06
San Mateo	Half Moon Bay	0.05	0.06	0.08	0.10	0.13	0.14	0.14	0.13	0.12	0.19	0.04	0.03
	Redwood City	0.05	0.06	0.09	0.13	0.17	0.18	0.20	0.18	0.16	0.11	0.06	0.03
Santa Barbara	Carpenteria	0.06	0.09	0.10	0.13	0.15	0.17	0.18	0.19	0.15	0.11	0.08	0.06
	Guadaulupe	0.06	0.08	0.10	0.12	0.16	0.15	0.15	0.15	0.14	0.11	0.08	0.06
	Lompoc	0.06	0.08	0.10	0.12	0.15	0.15	0.16	0.15	0.13	0.10	0.08	0.06
	Los Alamos	0.06	0.07	0.10	0.14	0.16	0.18	0.19	0.18	0.15	0.12	0.08	0.05
	Santa Barbara	0.06	0.09	0.10	0.13	0.15	0.17	0.18	0.14	0.11	0.08	0.06	0.06
	Santa Maria	0.06	0.08	0.10	0.13	0.16	0.17	0.17	0.17	0.15	0.11	0.08	0.06
	Solvang	0.06	0.07	0.11	0.14	0.16	0.19	0.20	0.18	0.15	0.12	0.07	0.05
Santa Clara	Gilroy	0.04	0.06	0.10	0.14	0.17	0.19	0.20	0.18	0.16	0.11	0.06	0.04
	Los Gatos	0.05	0.06	0.09	0.13	0.16	0.19	0.20	0.18	0.16	0.10	0.06	0.04
	Palo Alto	0.05	0.06	0.09	0.13	0.17	0.18	0.20	0.18	0.16	0.10	0.06	0.03
	San Jose	0.05	0.06	0.10	0.14	0.18	0.19	0.21	0.19	0.17	0.11	0.06	0.03
Santa Cruz	Santa Cruz	0.05	0.06	0.08	0.12	0.14	0.15	0.15	0.14	0.13	0.09	0.06	0.04
	Watsonville	0.05	0.06	0.08	0.12	0.15	0.15	0.16	0.13	0.13	0.09	0.06	0.04
Shasta	Burney	0.02	0.04	0.07	0.12	0.16	0.20	0.24	0.21	0.15	0.09	0.03	0.02
	Fall River Mills	0.02	0.04	0.07	0.12	0.16	0.10	0.25	0.22	0.15	0.09	0.03	0.02
	Glenburn	0.02	0.04	0.07	0.12	0.16	0.21	0.25	0.22	0.16	0.09	0.03	0.02
	Redding	0.04	0.05	0.08	0.14	0.18	0.24	0.28	0.24	0.18	0.10	0.05	0.03

County	City	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
Sierra	Downieville	0.02	0.04	0.07	0.12	0.16	0.20	0.24	0.20	0.16	0.09	0.03	0.02
	Sierraville	0.02	0.04	0.07	0.11	0.15	0.20	0.24	0.20	0.14	0.08	0.03	0.02
Siskiyou	Happy Camp	0.02	0.03	0.06	0.10	0.14	0.17	0.20	0.17	0.14	0.08	0.03	0.02
	Mt. Shasta	0.02	0.03	0.06	0.10	0.15	0.18	0.22	0.19	0.13	0.07	0.02	0.02
	Tulelake	0.02	0.03	0.07	0.11	0.17	0.20	0.26	0.22	0.15	0.09	0.03	0.02
	Weed	0.01	0.03	0.06	0.08	0.15	0.18	0.22	0.18	0.12	0.06	0.03	0.02
	Yreka	0.02	0.03	0.07	0.10	0.16	0.19	0.24	0.11	0.14	0.08	0.03	0.02
Solano	Benicia	0.04	0.05	0.09	0.13	0.16	0.17	0.20	0.18	0.15	0.09	0.04	0.02
	Fairfield	0.04	0.06	0.09	0.13	0.18	0.20	0.25	0.19	0.16	0.10	0.05	0.03
	Rio Vista	0.03	0.06	9.06	0.15	0.19	0.22	0.26	0.21	0.17	0.10	0.04	0.02
Sonoma	Cloverdale	0.04	0.05	0.08	0.11	0.16	0.20	0.20	0.18	0.15	0.09	0.05	0.02
	Fort Ross	0.04	0.05	0.07	0.10	0.12	0.15	0.13	0.14	0.11	0.08	0.04	0.02
	Healdsburg	0.04	0.06	0.08	0.12	0.16	0.20	0.20	0.18	0.15	0.09	0.05	0.02
	Petaluma	0.04	0.06	0.09	0.12	0.15	0.19	0.15	0.19	0.15	0.09	0.05	0.03
	Santa Rosa	0.04	0.06	0.09	0.12	0.16	0.20	0.20	0.19	0.15	0.09	0.05	0.02
Stanislaus	La Grange	0.04	0.06	0.10	0.16	0.20	0.26	0.28	0.24	0.18	0.11	0.05	0.02
	Modesto	0.03	0.05	0.10	0.16	0.21	0.26	0.26	0.22	0.17	0.11	0.05	0.02
	Newman	0.03	0.06	0.10	0.15	0.20	0.25	0.26	0.22	0.17	0.11	0.05	0.02
	Oakdale	0.04	0.05	0.10	0.16	0.20	0.26	0.26	0.23	0.17	0.11	0.05	0.02
	Turlock	0.03	0.05	0.10	0.16	0.21	0.26	0.26	0.23	0.17	0.11	0.05	0.02
Sutter	Yuba City	0.04	0.07	0.09	0.15	0.19	0.24	0.23	0.20	0.16	0.10	0.04	0.03
Tehama	Corning	0.04	0.06	0.09	0.15	0.20	0.24	0.26	0.23	0.18	0.12	0.06	0.04
	Red Bluff	0.04	0.06	0.09	0.15	0.19	0.25	0.28	0.24	0.18	0.11	0.06	0.03
Trinity	Hayfork	0.02	0.04	0.07	0.12	0.16	0.20	0.22	0.19	0.15	0.09	0.03	0.02
	Weaverville	0.02	0.04	0.07	0.11	0.16	0.20	0.24	0.19	0.15	0.09	0.03	0.02
Tuolumne	Groveland	0.04	0.06	0.09	0.14	0.19	0.24	0.26	0.21	0.17	0.11	0.05	0.02
	Sonora	0.04	0.06	0.09	0.14	0.19	0.24	0.26	0.22	0.17	0.10	0.05	0.02
Tulare	Alpaugh	0.03	0.06	0.11	0.16	0.21	0.26	0.26	0.24	0.18	0.11	0.05	0.02
	Badger	0.03	0.05	0.09	0.14	0.19	0.24	0.25	0.22	0.16	0.11	0.05	0.02
Tulare con't.	Dinuba	0.04	0.06	0.10	0.16	0.20	0.26	0.28	0.24	0.18	0.11	0.05	0.02
	Porterville	0.04	0.06	0.11	0.16	0.21	0.26	0.28	0.24	0.18	0.11	0.05	0.02
	Visalia	0.03	0.06	0.11	0.18	0.22	0.27	0.27	0.23	0.19	0.12	0.06	0.03
Ventura	Concord	0.07	0.09	0.10	0.12	0.14	0.15	0.17	0.15	0.13	0.11	0.08	0.06
	Thousand Oaks	0.07	0.09	0.11	0.15	0.17	0.20	0.22	0.20	0.18	0.13	0.09	0.06
	Ventura	0.07	0.09	0.10	0.13	0.15	0.16	0.18	0.16	0.14	0.11	0.08	0.06

County	City	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
Yolo	Davis	0.03	0.07	0.11	0.16	0.20	0.25	0.26	0.23	0.18	0.13	0.06	0.03
	Winters	0.06	0.06	0.09	0.15	0.19	0.24	0.26	0.22	0.18	0.11	0.05	0.03
	Woodland	0.03	0.06	0.10	0.16	0.20	0.26	0.26	0.23	0.18	0.12	0.06	0.03
Yuba	Brownsville	0.04	0.05	0.08	0.13	0.19	0.23	0.26	0.22	0.18	0.11	0.05	0.03

Appendix 3

SOIL NO_3-N 'QUICK TEST' PROTOCOL

Procedure

1. Collect a composite soil sample representative of the main root zone of the crop; blend thoroughly in a container. Don't include the top 2 inches of soil since it may be high in N but too dry for active root growth.
2. Fill a volumetrically marked tube or cylinder to the 30 ml level with .025M aluminum sulfate [$Al_2(SO_4)_3$] solution.
3. Add field moist soil to the tube until the liquid level rises to 40ml; cap tightly and shake vigorously until soil is thoroughly dispersed. Let sit until soil particles settle out.
4. When solution is reasonably clear, dip a Merckquant nitrate test strip into the solution, shake off excess solution, and wait 60 seconds. Compare color with the color chart provided.

To minimize the variability inherent in soil sampling, run duplicate tubes for each field soil evaluated.

Interpretation

The test strips are calibrated in parts per million (PPM) PPM NO_3. The approximate conversion to PPM NO_3-N on a dry soil basis is:

$$\text{PPM } NO_3 \div 2 = \text{PPM } NO_3\text{-N in dry soil}$$

Soil less than 10 PPM NO_3-N would be considered quite low; levels above 20 PPM NO_3-N have enough available nitrogen to meet immediate crop needs.

Caution: Low soil NO_3-N values late in the cropping season may not indicate insufficient nitrogen; it may just indicate highly efficient crop uptake. Tissue testing would be required to confirm low nitrogen status.

Appendix 4

PROTOCOL FOR NITRATE TESTING OF PETIOLE SAP

The following describes the procedure for measuring the nitrate concentration of fresh petiole sap using the 'Cardy' nitrate selective electrode meter.

A. Sample collection

1. Number of leaves

At least 20 petioles from different plants throughout a management unit 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.

2. Leaf age

As with standard petiole sampling, recently expanded mature leaves should be used for most crops.

3. Time sampling

There is some disagreement among printed references regarding the best time of day to collect petiole samples. Most sources would agree that most consistent results will be obtained by collecting samples after 8 a.m. but before 2 p.m.

4. Sample Storage

Immediately upon collection, leaf blades should be stripped away and petioles 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 as long as six to eight hours without appreciable change in sap nitrate readings. Always 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 must be analyzed immediately.

B. Use of the Cardy meter

Although it can be used in the field, the Cardy meter is better suited to use indoors. It is sensitive to temperature changes, so frequent recalibration is necessary through the day if used in the field. Also, the readings tend to drift for the first few minutes after it is turned on. From the standpoint of accuracy and efficiency, it is better to collect a number of petiole samples and bring them to a central location for analysis.

1. Calibration

The Cardy Meter is calibrated on a set point with a 'standard' solution and an electronic gain function with a 'slope' solution. It should be calibrated with these standard solutions each time it is turned on, and periodically as samples are analyzed. Generally, the calibration is quite stable, even from one day to the next. If the calibration continually drifts badly, it is a sign that the electrode pad may be wearing out; replacement electrodes can be purchased separately and are easily installed.

2. Sap extraction

Extracting sap from fresh petioles is not a high-tech procedure; whatever you can rig to conveniently press petioles is fine. To ensure maximum accuracy, one should collect as much sap as is reasonably possible from all petioles in the sample, then mix the collected sap before it is analyzed.

3. When to read

The Cardy electrode takes at least 20 seconds to stabilize each time a new sample is analyzed. Make it a rule to take readings at a standard time (perhaps 30 seconds) after putting each sample on the electrode.

4. NO_3 vs. NO_3-N

The calibration solutions that come with the Cardy meter are listed as PPM NO_3; most reference material on plant and soil nutrition refer to PPM NO_3-N. The conversion is:

$$\text{PPM } NO_3 \div 4.43 = \text{PPM } NO_3\text{-N}$$

It should be emphasized that, despite careful attention to these rules, fresh sap analysis with the Cardy meter does not have the accuracy of conventional laboratory analysis of dry tissue. I believe the usefulness of fresh sap analysis is strengthened where it is used on a regular basis, with good record keeping; this allows a grower to follow the trend of NO_3-N concentration over the season. Not only does this provide insight on the N dynamics of the crop, it also allows one to pinpoint a suspect value which needs retesting.

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