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This REFERENCE SHEET is part of the **Farm Water Quality Planning (FWQP)** series, developed for a short course that provides training for growers of irrigated crops who are interested in implementing water quality protection practices. The short course teaches the basic concepts of watersheds, nonpoint source pollution (NPS), self-assessment techniques, and evaluation techniques. Management goals and practices are presented for a variety of cropping systems.

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Reference:
Nutrient Management in Cool-Season Vegetables

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Although many factors have contributed to the nutrient load in surface and ground waters, fertilizer use has been one of the significant influences. The Fertilizer Research and Education Program, an industry-funded program administered by the California Department of Food and Agriculture, has sponsored extensive research on efficient nutrient management practices in vegetable production. This Fact Sheet summarizes that research. For techniques to help improve nutrient use efficiency and minimize nutrient leaching, refer to FWQP Fact Sheet 3.4, *Management Goals and Recommended Practices for Nutrient Management in Cool-Season Vegetables* (UC ANR Publication 8097).

Fertilizer use is an integral part of conventional vegetable production. It has also become a serious environmental issue. The two nutrients having the greatest potential to harm water quality are nitrogen (N) and phosphorus (P). Nitrogen and phosphorus loading in surface water bodies contributes to an *eutrophic* environment. Eutrophication is the process by which a body of water becomes enriched in nutrients that stimulate the growth of aquatic plants (e.g., algae), which in turn lead to the depletion of dissolved oxygen in the water. Nitrate pollution of ground water is the more serious potential problem because of its effect on drinking water quality.

The federal Clean Water Act's Section 303 sets a drinking water standard for nitrogen but not phosphorus. Drinking water standards for nitrogen have been set at 10 parts per million (ppm) for nitrogen from nitrates (NO_3-N), also expressed as 45 ppm of nitrates (NO_3). In coastal areas of California where vegetable production is concentrated (Monterey, San Luis Obispo, Santa Barbara, and Ventura Counties), ground water frequently exceeds 10 ppm NO_3-N (Pettygrove et al. 1998). It is becoming harder for urban and rural water users in these areas to obtain drinking water that is in compliance with this standard. No specific standards have been set for phosphorus in fresh water. To prevent eutrophication, dissolved phosphates should not exceed 25 parts per billion (ppb) in lakes, 50 ppb in streams flowing into lakes, and 100 ppb in streams that do not flow into lakes.

NITROGEN IN COASTAL VEGETABLE PRODUCTION

Current nitrogen use patterns and consequences. Vegetable farming practice in California's coastal regions has characteristic features that result in the overuse of nitrogen . Double- or triple-cropping a field in a single year is the norm, with lettuce, broccoli, cauliflower, and celery dominating crop rotations. All of these are shallow-rooted crops with yields and quality levels that are sensitive to even short-term water stress or unavailability of N. Consequently, irrigation and N fertilizer are applied frequently and liberally to ensure maximum yield and quality.

Nitrogen 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 are generally far greater than the amount of N removed from the field in the harvested product.

Table 1. Typical nitrogen (N) application, crop uptake, and removal in cool-season vegetable production in aboveground biomass (roots contain approximately 10% as much N)

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

(*Hartz, personal communication) (†Hartz et al. 2000)

There are six possible fates for N that remains in the field:

- *Leached below the root zone.* Nitrate moves readily with water that percolates through the root zone. Most of the N leached below the root zone of the crop is in the NO_3 form. Over the long term, much of the applied N that is not removed in harvested product leaches out of the root zone and becomes a potential contaminant of ground water.
- *Soilborne erosion losses.* Nitrogen in soil aggregates can be moved by water or wind. Both ammonium (NH_4) and NO_3 will move with sediments. Erosion control practices such as cover cropping, contour farming, the use of benches, vegetative buffer strips, and vegetated waterways can significantly reduce soil erosion losses.
- *Denitrification.* Soil microbes can convert NO_3 into nitrogen gas, which is lost to the atmosphere. This denitrification occurs to some extent in all soils when oxygen levels are low: for example, after irrigation or rainfall has saturated soils. In heavy clay soils with poor drainage or in soils with restrictive layers that prevent drainage, N losses through denitrification may be 15 to 50% of applied fertilizer N. In typical vegetable fields, only a small percentage of applied N is lost through denitrification.
- *Immobilization in and mineralization from organic matter.* Applied N may be tied up (*immobilized*) in soil organic matter or in the biomass of soil microbes as they work to decompose crop residues. Large amounts of applied N can be immobilized temporarily into organic N by the soil microbes, for example, when low-N plant material is incorporated into the soil. Organic N is slowly and constantly being recycled back into plant-available N through a process called *mineralization.* The loss of soil organic matter reduces the capacity of the soil to retain applied N.
- *Residual soil nitrogen.* Nitrogen may remain in the root zone as residual soil N, available for uptake by subsequent crops. This residual soil N generally builds up over a cropping season, as long as in-season irrigation is controlled to minimize leaching loss. During a typical winter, however, rainfall is sufficient to leach most of the residual NO_3 from the top several feet of soil.
- *Ammonia volatilization.* When animal manure, urea, or ammonium-containing fertilizers are left on the surface of the soil, N can be lost to the air as gaseous

ammonia. This loss can be significant in alkaline (high pH), sandy soils. If manure or fertilizers are incorporated within a few hours after application, this loss is negligible.

Forms of fertilizer nitrogen. Fertilizer N may be applied in the urea, NH_4, or NO_3 forms. Urea is rapidly converted to NH_4 in the soil. Although NH_4 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 to NO_3 in warm, moist soils. The majority of N taken up by plants will typically be in the form of NO_3. Also, since NH_4 is bound to soil particles by its positive charge, it is not easily leached. For these reasons, growers focus their N management strategies on NO_3.

Nitrogen dynamics within a cropping season. Most cool-season vegetables grown on California's central coast are shallow rooted, with most of their roots in the top 12 to 18 inches of soil. Although some N uptake occurs below the top foot of soil, growers should target their management practices on maintaining adequate mineral N in the top foot of soil and minimizing the leaching of NO_3 below that zone.

Spring planting. With normal winter rainfall (12 inches or more in most coastal vegetable production areas), a field that has been fallow throughout the winter will usually have a low level of plant-available N prior to planting in the spring. At this time the soil is cool and microbial activity is low. The rate of mineralization of N from the residue of the previous crop is relatively slow. Winter rains are likely to leach the majority of any N fertilizer applied in the fall or residual soil NO_3 to beyond the root zone of shallow-rooted vegetable crops. Consequently, the need for fertilizer N for an early spring-planted crop may be relatively high. By contrast, during dry winters with little leaching or when spring planting follows the last significant rain by more than a month, mineralization may make NO_3 more abundant.

Summer planting. By contrast, N fertilizer requirements for summer-planted crops are frequently much lower. Substantial soil NO_3 may have accumulated in spring from soil N mineralization and fertilizers that were not taken up by the spring crop. Freshly incorporated vegetable crop residue releases N reasonably quickly. This is particularly significant following broccoli, cauliflower, and celery crops since the amount of N in their residues is much greater than in lettuce residues. Additionally, warm soil temperatures increase the N mineralization rate. Unless N fertilizer applications are adjusted to make use of these other sources of available N, high levels of soil residual NO_3 may be present in the fall when there is a greater risk that it will be leached by winter rain.

Crop growth stage and nitrogen requirements. The pattern of growth and N uptake is similar in all of the major cool-season vegetable crops, whether planted as seed or as transplants. In the initial growth stage (approximately one-half of the cropping period), both growth and N uptake are slow (Figure 1). During that period, net soil N mineralization may actually be greater than crop N uptake. The crop does not deplete the soil NO_3, and fertilizer requirements are minimal. Once rapid vegetative growth begins, N uptake accelerates, reaching approximately 3 to 5 lb N per acre per day, depending on the crop and environmental conditions. More than 75% of total crop N requirement and uptake occurs in the latter half of the cropping period. Of course, fertilizer need is greatest during this period.

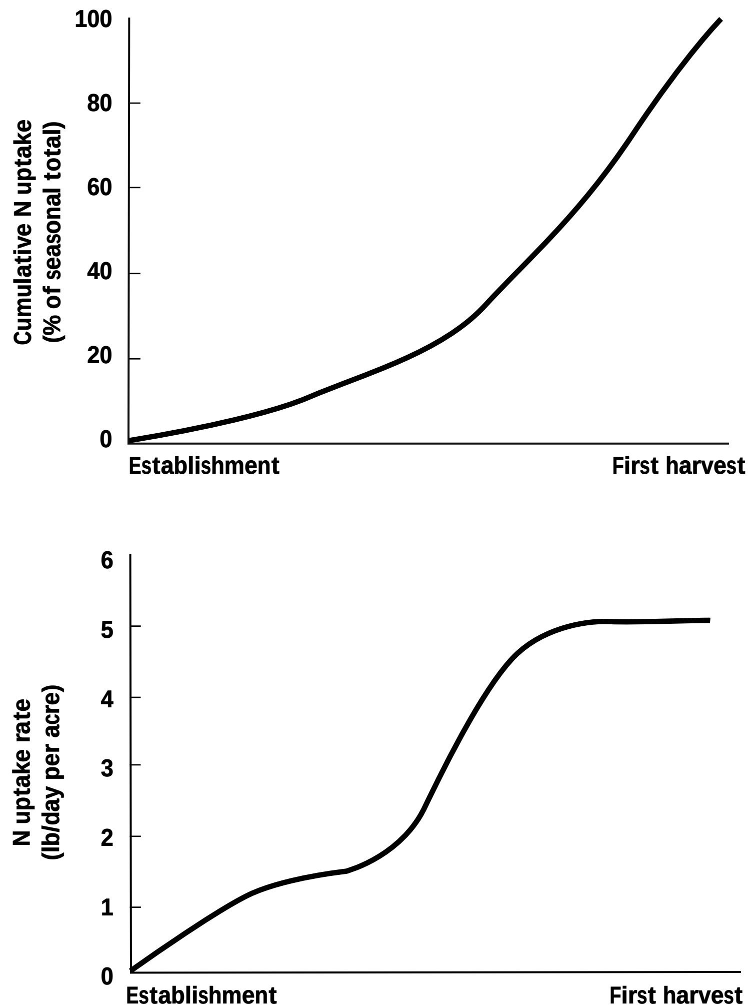

Figure 1. Seasonal N uptake pattern for cool-season vegetables in coastal production areas of California.

Soils with modest levels of NO_3-N can support the immediate needs of vegetable crops for maximum growth rate. (A *modest level* is generally more than 10 ppm [also written as mg/kg of dry soil; 1 ppm of NO_3-N = 2 lb/acre] in the top 6 to 8 inches of the root zone.) Soil NO_3-N can drop quickly, however, as a result of the combined action of crop uptake and leaching by rain or irrigation. A higher level of soil NO_3 may be needed to ensure sufficient N availability to meet short-term requirements. Under typical field conditions, a soil NO_3-N concentration of 20 or more ppm is sufficient to maintain maximum growth rates for several weeks or longer.

When crops are fertilized with N at a rate beyond their requirement, they continue to take up luxury amounts. At these excessive N rates, however, the crop uptake efficiency is lower, leading to a large increase in the amount of NO_3 left in the soil, potentially to be leached. In-season soil NO_3 testing provides a convenient way to determine short-term need for a sidedressed application of N. As a rule of thumb, whenever soil NO_3-N exceeds 20 ppm N, you can delay or reduce the rates of sidedress N applications. Frequent testing can ensure that adequate soil NO_3 levels are maintained and unnecessary fertilizer applications are avoided.

As a result of N inputs from fertilizer, crop residues, soil mineralization, and irrigation water, NO_3 pools can build up to high levels at the end of the growing season in fall and winter. This NO_3 can easily be leached by winter rains. Cereal cover crops have the capacity to capture and trap much of this N and make it available for subsequent crops. Cover crops should be included as much as possible in crop plans to reduce NO_3 leaching and provide other benefits to the soil.

Influence of Irrigation

Crop water requirements are modest in California's coastal production areas. If irrigation is applied in a timely and efficient manner, lettuce requires 6 to 10 inches (acre-inches per acre), broccoli and cauliflower 8 to 14 inches, and celery 12 to 18 inches of water. Cool-season vegetables require frequent irrigation, due to their shallow rooting and sensitivity to moisture stress.

Distribution uniformity (how evenly the irrigation water is applied across the field) and irrigation efficiency (the percentage of applied water that remains in the root zone, available for plant uptake) can vary drastically from field to field. The greater the distribution uniformity, the greater the potential maximum irrigation efficiency. Irrigation system performance is dependent upon system design and maintenance, proper or improper redesigns or retrofits, equipment age, pressure variability, and various management practices. The distribution uniformity of a sprinkler irrigation system can also be affected significantly by wind conditions.

Conventional sprinkler or furrow irrigation systems often have poor distribution uniformity or irrigation efficiency. Microirrigation (drip tape, drip emitters, microsprayers, and microsprinklers) has the potential for higher distribution uniformity than other irrigation methods, but such systems often are not designed and maintained to meet this potential. These conditions were noted in irrigation system evaluations in San Luis Obispo and Santa Barbara Counties (Pitts et al. 1996). Low distribution uniformity and low efficiencies often lead to overirrigation, with excessive amounts of water lost to deep percolation (drainage) below the crop root zone.

Excessive irrigations can have significant impact on soil NO_3-N levels. Even in a field with 20 ppm soil NO_3-N, an inch of water leaching from an irrigation may carry as much as 20 lb N per acre below the root zone.

Irrigation water can also be a source of NO_3. Many agricultural wells now contain 10 or more ppm NO_3-N. One foot of irrigation water at a concentration of 10 ppm would contain 27 lb NO_3-N per acre-foot of water. Once in soil solution, that NO_3 would be indistinguishable from residual soil NO_3, and equally available for crop uptake. Irrigation water should be tested for NO_3 content before it is applied. If you know how much irrigation water is being applied and the concentration of NO_3-N in that irrigation water, you can also determine the amount of NO_3-N that will be applied in that irrigation by using this equation:

$$\text{Pounds of N/acre} = 0.23 \times \text{ppm } NO_3\text{-N in irrigation water} \times \text{inches of water}$$

If the water analysis is expressed as NO_3 rather than NO_3-N, use a different conversion factor:

$$\text{Pounds of N/acre} = 0.051 \times \text{ppm } NO_3 \times \text{inches of water}$$

In summary, N requirements of cool season vegetables vary by crop, season, soil type, and cropping history. Efficient N fertilizer management is a necessity to minimize further NO_3 pollution of ground water, and requires a grower to take into account field-specific factors. Techniques that minimize unnecessary N application include soil and irrigation water monitoring for NO_3, cover cropping, and achievement of high application efficiency and distribution uniformity of irrigation water. Irrigation with minimal loss of nutrients and moisture from the root zone translates into reduced fertilizer and irrigation water costs.

PHOSPHORUS IN COASTAL VEGETABLE PRODUCTION

Phosphorus is present in soil in a number of chemical forms: a very small amount of soluble P (mostly PO_4-P) in the soil water, P adsorbed onto soil particles, chemical precipitates, and P as a constituent of organic matter. These different P sources establish an equilibrium in the soil; as plants remove soluble P, the other forms replenish the soluble P supply. Common laboratory soil test procedures provide an estimate of the amount of P in the soil that is available to plants. Unlike soil nitrate testing, which measures the actual amount of nitrate present, soil testing for P as carried out by most laboratories gives an index value or ranking of the relative P supply. Researchers over many years have calibrated these soil test procedures in greenhouse and field trials so that the results can be used to predict whether a vegetable crop is likely to respond to additional P fertilization.

It has been traditional practice to fertilize with P before and sometimes during each vegetable crop, regardless of soil test P level. Since the common coastal vegetable crops use a relatively small amount of P (and even less is removed from the field in harvested product), residual soil P levels have risen dramatically. Currently, it is not uncommon to find a soil that tests for P far in excess of the level required for optimum plant growth.While this generally does not present a significant agronomic problem, it does create a potential environmental hazard. The growth of algae in surface waters is often limited by the low concentration of P. Runoff from highly fertilized vegetable fields can carry with it a significant amount of P, stimulating algae growth in the receiving water body. Increased algae growth can be a nuisance for human recreational activities, but more importantly it can cause serious problems in aquatic ecosystems (low dissolved oxygen, high pH, etc.). The higher the soil test P level, the greater the P pollution hazard. Unlike surface water, leaching of P to ground water does not occur, due to the ease with which soil minerals immobilize P.

You can reduce the movement of P from your farm to the environment by following these guidelines:

1. *Fertilize only when soil testing suggests that plants are likely to respond to fertilization.* For soils with pH > 6.2, the most appropriate soil test is the Olsen (*bicarbonate*) procedure. Soils with Olsen P > 80 ppm contain sufficient available P for optimum vegetable crop production. Continued fertilization of these soils wastes money and increases the potential for P pollution. Soils testing in the range of 40 to 80 ppm may under some circumstances (low soil temperature, for example) respond to P applications, but only a small amount of P would be required. Small, at-planting “starter” applications would be sufficient. For summer-planted fields, no P fertilization should be necessary for soils that test > 40 ppm.
2. *Maximize the efficiency of P fertilizer applications.* Injected bands of P fertilizer are generally more available to plants than are broadcast applications. Where you use a broadcast application, immediately incorporate the fertilizer. Apply P fertilizer as close to the time of planting as possible, since P fertilizer becomes less available to plants the longer it is in contact with the soil. This timing will allow you to use a lower application rate and still achieve the same agronomic effect.
3. *Minimize the amount of tailwater leaving the farm during the irrigation season through the use of a tailwater return system and by following the recommendations of a mobile irrigation lab.* Even tailwater from fields with only moderate soil P levels can contain significant quantities of P. It may be impractical to eliminate runoff from winter storms, but during the winter the water temperature is low enough to minimize algae growth, regardless of P concentration.

4. *Institute erosion control practices.* Soil particles contain significant amounts of P in non-soluble forms; erosion moves those P-rich soil particles into waterways where they will continually release P in soluble form, available to support algae growth. Cover cropping is an excellent practice for erosion control. Additional erosion control practices are detailed in other publications in the Farm Water Quality Planning series.

For more information visit the UC Davis Vegetable Research and Information Center at http://www.vric.ucdavis.edu.

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