Drip Irrigation and Fertigation Management of Celery

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The use of drip irrigation for celery production in California is increasing. At least 30% of celery acreage is now drip irrigated, mostly with surface systems. From 1996 to 1999 experiments were conducted in 11 commercial celery fields from Ventura to Salinas, comparing drip irrigation and nitrogen fertigation management techniques. The following guide summarizes the information gathered in these field trials, and outlines the basics of efficient drip irrigation and N fertigation management of celery.

A. Drip Irrigation Management

Drip system design and maintenance:

The standard approach to drip irrigating celery is to use a surface system which is installed several weeks after transplant establishment, and is removed before harvest for reuse in another field. Since these systems are portable, they cannot be engineered for a particular field. Because fields differ greatly in size, shape, row length, and slope, special consideration must be given to ensuring that the system meets basic design criteria in each field in which it is used. Among the most important design criteria are sizing of lay-flat submains to ensure minimal pressure loss, and restricting row length to the manufacturer's specification for the drip tape you are using and the slope of the field. Where tape is reused, appropriate maintenance to minimize clogging of emitters is also critical. Work closely with your system designer or irrigation supply vendor on design and maintenance issues.

Evaluating whether your drip system is delivering water with reasonable uniformity can be done by simply comparing the flow from individual emitters in different parts of the field over a standard period of time (perhaps 3-5 minutes). To calculate an approximate distribution uniformity of the system, divide the field into four quadrants. In each quadrant catch the flow from at least 3 emitters (each from a different line of tape) at the head and tail end of the tape (a total of at least 6 emitters per quadrant). Distribution uniformity is calculated as the average flow rate of the driest quadrant divided by the field average flow rate. Approximately 85-90% water distribution uniformity from a portable surface drip system is a realistic goal. With distribution uniformity below this range significant over-irrigation will be required to adequately supply the driest portion of the field.

Determining drip irrigation requirements:

There are two basic approaches to determining crop irrigation requirements:

a) Water budget calculation – estimating the amount of water the crop requires based on crop growth stage and weather conditions.
b) Soil moisture measurement – monitoring the depletion of available water in the crop root zone.

Drip irrigation is most efficiently managed by using a combination of these two systems.

Estimation of reference evapotranspiration (ETo):

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. The California Irrigation Management Information System (CIMIS) is a network of computerized weather stations that measure these environmental variables. From these measurements a daily reference evapotranspiration value (ETo) is calculated which is designed to estimate the loss of water (through both plant transpiration and soil evaporation) from a well-watered grass crop that completely covers the soil surface. The CIMIS network has weather stations in a number of the coastal celery growing areas. Daily ETo estimates can be accessed at the Department of Water Resources website:

www.dpla.water.ca.gov/cgi-bin/cimis/cimis/data/input_form

Historical average ETo values are also available for many locations. Table 1 lists average daily ETo values by month for several important celery producing areas.

Table 1. Mean CIMIS reference evaspotranspiration (ETo), in inches per day, for celery growing areas of coastal California.

	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
Salinas	.05	.07	.09	.13	.15	.16	.16	.15	.13	.09	.06	.04
Soledad	.06	.07	.11	.15	.18	.18	.21	.20	.17	.12	.07	.05
Guadalupe	.06	.08	.10	.12	.16	.15	.15	.15	.14	.11	.08	.06
Ventura	.07	.09	.10	.13	.15	.16	.18	.16	.14	.11	.08	.06

Accounting for crop growth stage:

ETo is based on the amount of water lost from a field with a complete cover of an actively growing grass crop. The actual water requirement of a celery crop is substantially less than ETo when the plants are small, and will be greater than ETo at a later growth stage. There are simple ways of adjusting ETo to estimate actual celery water requirement.

The primary force controlling crop water loss is the heating of the foliage caused by solar radiation. This provides a convenient way to account for crop growth stage – simply estimate the percentage of the field surface covered by the crop. This can best be done by estimating the width of the crop canopy per bed, and dividing by the bed width. At the time of drip installation, the plants typically cover less than 30% of the ground surface; within 2-3 weeks of harvest, nearly complete ground coverage has been achieved.

The other factor to consider is evaporation from the soil surface, which can be significant as long as wetted soil surface is not covered by foliage. During the first few days after each irrigation any exposed, wetted soil surface will lose water through evaporation nearly as fast as foliage would lose water through transpiration. Therefore, in determining an estimate of plant cover, include any exposed soil surface that is wetted by the drip tape. Once the plants shade the middle of the beds, evaporation is a minor factor, and can be ignored.

Once you have estimated the percentage of ground cover by foliage and/or wetted soil, increasing this percentage by 10-20% will account for the higher water loss characteristic of celery, compared to the grass crop on which ETo is based.

Accounting for system inefficiency:

As previously discussed, no drip system delivers equal amounts of water to all portions of the field. To ensure that even the driest portion of the field receives adequate water, the crop water requirement calculated from ETo and crop canopy coverage needs to be increased by 10-15% (or more, if the field system has poor distribution uniformity).

A more difficult problem is to account for irrigation water that leaches below the active crop root zone. Because celery is a shallowly rooted crop, it draws most of its water from the top foot of soil. Drip systems, unlike sprinkler systems, usually wet only a portion of the soil profile. If irrigation frequency is not adjusted correctly to fit soil water holding characteristics, a substantial percentage of applied water can leach below the top foot. Even where irrigation frequency is carefully matched to field conditions, a leaching loss of 10-15% of applied water would not be uncommon. Combining these two sources of drip system inefficiency, it may be necessary to increase estimated crop water requirement by 25-30%.

Calculation of drip irrigation requirement

The following formulas calculates the actual amount of water needed to meet crop requirements, and to account for the irrigation system inefficiencies:

ETo (in inches, cumulative from the last irrigation)
x % ground cover by foliage or wet soil
x 1.2 (factor for higher transpiration of celery than the reference crop)
= crop water requirement (in inches)

Then to account for irrigation system inefficiency:

crop water requirement (in inches)
x 1.3 (system inefficiency factor)
= irrigation requirement (in inches)

A busy grower may view these measurements and calculations as too time consuming to use. Figure 1 integrates the effect of growth stage and system inefficiency into a single factor, called a crop coefficient.

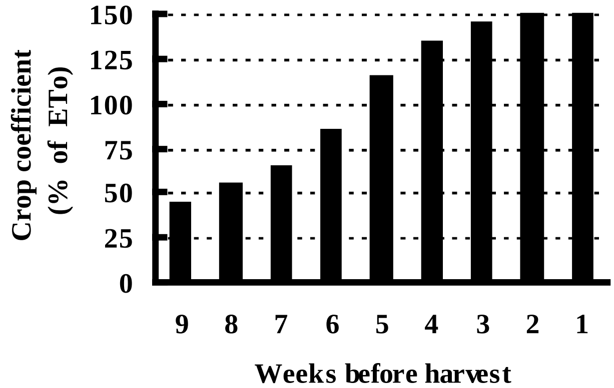

Figure 1. Approximate crop coefficients for drip irrigated celery grown under warm weather conditions

This figure gives the normal seasonal pattern of crop coefficients, based on a typical field situation in which the drip system is installed about 60 days before harvest. (This figure relates to fields maturing from late spring through fall; overwinter crops grow more slowly, so the time period represented by this figure would be 10-14 weeks.) The following formula calculates irrigation requirement:

ETo (cumulative since the last irrigation, in inches)
x crop coefficient for that period of the growing season
= irrigation requirement (in inches)

Although using real-time ETo will be most accurate, using historical mean ETo and adjusting where necessary for abnormally hot or cool weather is a reasonable alternative. If you apply irrigation in compliance with the crop coefficients given in this graph, seasonal water application during the drip-irrigated portion of the season would be approximately 110-120% of Eto; during the final month before harvest water application will be 140-150% of ETo.

Irrigation volume vs. hours of run:

So far we have discussed irrigation requirement in terms of inches of water. Depending on the emitter flow rate, distance between emitters, and operating pressure, it may take from 5 to 15 hours of run time to apply an inch of water. Your design engineer or irrigation supply vendor can calculate an approximate flow rate for your system, but the actual flow rate may be quite different, particularly if you do not maintain the design pressure. The only way to be sure of the water volume applied is to have a water meter on the system. If you do not have a water meter, a reasonable estimate of application rate can be calculated from the timed capture of the flow from individual emitters in different parts of the field. This can be done easily early in the season while the plants are small and the drip tape is readily accessible. After that, the hours of run required to apply an inch of water should not change much, as long as pressure is constant and appropriate maintenance minimizes emitter clogging.

Irrigation frequency:

Celery is extremely sensitive to water stress; pithiness of petioles, a common quality problem in drip-irrigated fields, can result from even short-term water stress. Maximizing growth rate and quality of celery requires that no more than 20-30% of available water in the primary root zone (the top foot of soil) be depleted between irrigations. Since drip irrigation does not wet the entire soil volume, irrigation must be applied more frequently than with sprinklers. Table 2 lists the approximate amount of irrigation requirement that can be accumulated between irrigations without inducing water stress. Soil texture influences water holding capacity, so the ranges are quite different among soil types. Using this information and the daily irrigation requirement (daily ETo x crop coefficient) one can determine the most appropriate irrigation frequency. Irrigation may be needed no more than once a week on young plants in heavy soil under low ETo conditions; conversely, nearly mature plants on light soil under summer (high ETo) conditions may require daily irrigation to maximize growth and prevent pithiness. Following this approach to determining irrigation frequency will also limit the amount of water applied during each irrigation to approximately the amount that the soil can hold without significant leaching.

Table 2. Range of cumulative irrigation requirement allowable between irrigations without inducing crop water stress.

Soil texture	Cumulative irrigation requirement* allowable between irrigations (inches)
sand	0.2 – 0.3
sandy loam	0.3 – 0.5
silt loam	0.5 – 0.7
clay loam	0.5 – 0.6
clay	0.5 – 0.6

* ETo x crop coefficient

Soil moisture monitoring:

There can be several significant sources of error in the approach to irrigation management just described. Direct soil moisture monitoring is the essential safeguard to avoid over- or under-watering. Of the common soil moisture monitoring techniques available, the use of tensiometers is among the best options for monitoring drip-irrigated celery. Tensiometers measure soil water tension (the degree to which soil water is attracted to soil particles, measured in centibars); as available soil water is depleted, tensiometer readings increase. Tensiometers should be installed in the plant row, approximately 10-12 inches deep. Installing instruments in several different parts of the field is ideal, to ensure that the readings are representative of the whole field.

Table 3 gives approximate centibar values for field capacity (the ‘ideal’ water status) and 20-30% available moisture depletion (the maximum ‘safe’ level of depletion between irrigations). The goal of drip irrigation management is to keep tensiometers between field capacity and 20-30% depletion. Immediately after an irrigation, tensiometer readings may go down to near zero, but they should rebound to about field capacity within 24 hours. Allowing tensiometer readings to rise above the 20-30% depletion level, even for a day or two, may be enough to induce pithiness of petioles. Celery is most sensitive to water stress during the last 4-5 weeks before harvest, and particularly during high ETo conditions. Celery maturing from late fall through early spring seldom develops significant levels of pithiness, even if some degree of transient water stress is encountered.

Table 3. Approximate soil matric potential (tensiometer reading) at field capacity, and at 20-30% available moisture depletion.

	Approximate soil matric potential (centibars)	
Soil texture	Field capacity	20-30 % available water depletion
sand	8-12	20-25
loam	12-16	25-30
clay	15-20	25-35

B. Nitrogen Fertigation Management

Crop N requirement:

Celery has traditionally been the most heavily fertilized vegetable crop grown in California. Under conventional irrigation seasonal N application rates of 300-350 lb/acre have been common, with some growers exceeding 400 lb N/acre. These fertilization rates reflect not only the fact that celery is a heavy N feeder (high yield celery typically takes up 200-280 lb N/acre), but the high irrigation volume commonly applied on sprinkler-irrigated celery leaches a significant percentage of the applied N. If one limits the amount of in-season leaching with well-managed drip irrigation N, fertility rates can be reduced correspondingly.

Fig. 2 shows the approximate rate of N uptake by celery over the final 9 weeks before harvest, corresponding to the drip-irrigated portion of the season. (This figure relates to fields maturing from late spring through fall; overwinter crops grow more slowly, so the time period represented by this figure would be 10-14 weeks.) Before drip irrigation is installed plant N uptake is minimal; at drip installation total crop N content averages only about 20-30 lb N/acre. Thereafter, the crop growth rate increases, reaching a maximum N uptake of about 35 lb N/acre per week just before harvest.

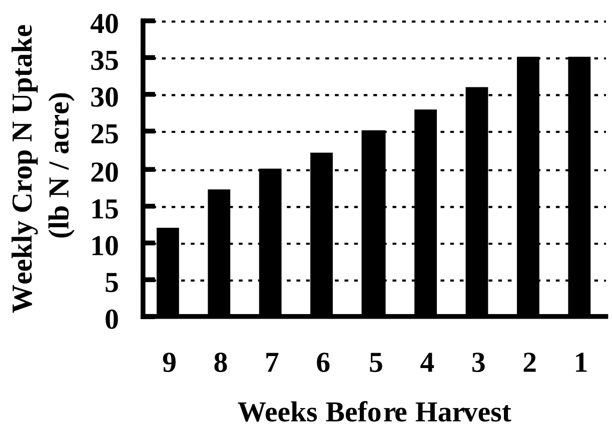

Figure 2. Seasonal N uptake pattern of drip-irrigated celery grown under warm weather conditions.

A maximally efficient N fertigation plan would match this seasonal crop uptake rate. It is currently a standard practice to top-dress a substantial amount of N (80-120 lb N/acre) under the drip tape just prior to drip installation, the theory being that the drip irrigation will carry this N into the crop root zone. However, it will be several weeks before the crop can utilize this amount of N, and any leaching in those first few weeks of drip irrigation can flush much of this fertilizer below the root zone. A better approach would be to either eliminate the practice of top-dressing, or top-dress only a token amount (20-50 lb N/acre), concentrating instead on applying more N through fertigation later in the season, when the crop is better able to utilize it.

Determining N fertigation rate and timing:

There are two major factors that determine appropriate fertigation rate. The first factor is what level of residual soil nitrate-nitrogen (NO_3-N) is present in the field when the drip irrigation phase of the season begins. Extensive research in the coastal vegetable growing regions has shown that high levels of residual NO_3-N are commonly present, coming from fertilizer carry-over from previous crops, the mineralization of N from prior crop residue, and the addition of NO_3-N in irrigation water from nitrate-rich well water. In-season soil testing, through conventional laboratory analysis or by the ‘quick test’ procedure outlined in Appendix 1, can determine the amount of soil residual NO_3-N. As long as residual NO_3-N in the wetted root zone is >15-20 PPM, little or no additional fertigated N is necessary.

In most field conditions a seasonal fertigation total of between 150-225 lb N/acre (200-275 lb total N/acre, including preplant and/or top-dress N) should be adequate to maximize celery yield and quality. The effectiveness of fertigated N will be maximized if it is injected at the end of the irrigation run, with only a 30-40 minute period of clear water to flush the fertilizer from the system. With good irrigation control, fertigation once a week can be as effective as fertigation with each irrigation.

The other major factor in determining N fertigation rate is the degree of leaching expected. In a typical field situation, each inch of leaching would remove between 10-25 lb NO_3-N/acre from the crop root zone. In fields in which leaching is difficult to control (very sandy soils, for example) or where excessive irrigation is deliberately applied (to overcome poor water distribution uniformity, or to control salinity) one may need to compensate for NO_3-N leaching losses. In such fields, fertigation frequency as well as the amount applied may need to be increased to prevent transient N deficiency. Obviously, NO_3-N leaching from heavy rain may also require additional fertigation.

Monitoring N status:

Monitoring crop N status through petiole NO_3-N analysis is a common practice for many growers. Petiole sampling can help identify fields in which N availability is low, and corrective action necessary. Petiole NO_3-N in excess of 6,000 PPM indicates adequate N availability. As values decrease below 6,000 PPM, the likelihood of restricted N availability affecting plant growth increases. A major limitation of petiole NO_3-N testing is that it does not reliably show when soil NO_3-N availability is very high, and planned fertigation can be reduced. That is because celery does not continue to take up large amounts of N beyond what is required for maximum growth. The only way to be sure that your next N fertigation is actually required is through in-season soil NO_3-N testing.

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 solution. (To make the solution dissolve 5.6 grams of calcium chloride (about 1/5 ounce) in a gallon of distilled water). 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 respond to immediate fertilization. Soils between 10-20 PPM NO_3-N have enough N to meet immediate plant needs but a modest amount of sidedress N is 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.

Supply vendors:

centrifuge tubes and calcium chloride	Univ. of Calif. Cooperative Extension offices in Monterey, Santa Barbara, and Ventura Counties can help you local these items
Merckquant® nitrate test strips (0-500 PPM nitrate test range)	Ben Meadows Co. 3589 Broad Street Atlanta, GA 30314 (800) 241-6401