Drip Irrigation and Fertigation Management of Processing Tomato

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A. Drip Irrigation Management

Drip system design

The standard approach to drip irrigating tomatoes has been to use a buried system which remains in place for a period of years before field renovation. Drip tape is typically buried 10-12 inches deep, one line per 60-66 inch soil bed. In recent years some growers have used “in-furrow” drip systems in which drip tape is laid in every furrow, or every other furrow, after crop establishment. Many factors affect the choice between buried or surface drip systems: system cost, labor availability, crop rotation pattern, soil type, etc. The general experience has been that buried systems offer higher yield potential, but cost more to install and maintain. The main advantage of surface drip, beyond lower initial cost, is that it is mobile, able to be moved each year as the tomato crop is rotated.

In planning a drip installation a number of factors need to be weighed: field configuration and soil type; tape diameter, thickness, flow rate and emitter spacing; type and placement of manifolds; type of filtration and chemical injection equipment; pump capacity, etc. Some trade-off between initial cost and system performance is inevitable, but a poorly designed system is never a bargain. Engaging an experienced and trustworthy individual to design the system is strongly advised. Some general recommendations for drip systems for tomatoes are:

1) The system should be designed to meet a distribution uniformity (DU) of at least 85%, ideally 90% or more; DU is measured as the flow delivered to the driest 25% of the field divided by the average flow in the entire field. Common causes of poor uniformity are excessive length of laterals, undersizing of submains, and uneven terrain. In fields with a DU less than 85% excessive irrigation will be required to fully water the driest portion of the field; in addition to wasting water, fertilizer and energy, excessive irrigation complicates the end-of-season management for enhancing soluble solids.
2) Flow rate and emitter spacing of the drip tape should be matched to soil conditions. The wetting pattern developed around an emitter is strongly influenced by soil texture, and soil and water chemistry. To the extent practical the goal should be to achieve wide lateral spread away from the tape, and uniform moisture content between emitters. As a general rule the lower the tape flow rate, and the more widely spaced the emitters, the narrower the wetted zone and the less uniform the soil moisture content between emitters.
3) The choice of filtration equipment is constrained by the quality of water used. Clean well water can be adequately filtered by virtually any type of equipment, whereas surface water from a canal or reservoir may require one of the more expensive options. The goal is to remove both organic and inorganic contaminates without excessive backwashing of the filters, which not only creates a wastewater disposal problem, but reduces the irrigation capacity of the system.

Determining drip irrigation requirements

There are two basic elements to efficient water management with drip irrigation:

1) Water budget calculation–estimating the amount of water the crop requires based on weather conditions and crop growth stage.
2) Soil moisture measurement–monitoring soil moisture depletion as a confirmation that the water budget calculation is correct, and as a guide to determining irrigation frequency.

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

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 and compute a daily reference evapotranspiration value (ET_o) which estimates the potential loss of water (through both plant transpiration and soil evaporation) from a well-watered grass crop that completely covers the soil surface. Decades of research in California has documented the accuracy of these ET_o estimates. The CIMIS network has weather stations throughout the Central Valley. Daily ET_o estimates can be found on the Department of Water Resources website:

http://wwwcimis.water.ca.gov

or from newspapers or other media outlets. Historical ET_o values are also available for many locations. Table 1 lists average daily ET_o values by month for several Central Valley locations.

Table 1. Historical CIMIS reference evapotranspiration (ETo), in inches per day.

	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct
Five Points	.03	.06	.11	.17	.21	.26	.28	.24	.18	.11
Tracy	.03	.06	.09	.15	.20	.24	.26	.22	.18	.10
Woodland	.03	.06	.10	.16	.20	.26	.26	.23	.18	.12

Since ET_o is based on the amount of water lost from a field with a complete cover of an actively growing grass crop, this value must be adjusted to fit tomato field conditions. The actual irrigation requirement of a drip-irrigated tomato crop is substantially less than ET_o when the plants are small, and may even be slightly greater than ET_o at a later growth stage. 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, or by soil wetted by the drip system. This is easily done by estimating the average width of the crop canopy per bed, and dividing by the bed width; include in the estimate any wet soil surface not covered by foliage because evaporation from exposed, wet soil is nearly as rapid as transpiration from foliage. Once you have estimated the percentage of ground covered by foliage or exposed, wetted soil, increase this percentage by 10% to account for the slightly higher water loss characteristic of tomato compared to the grass crop on which ET_o is based. For this prediction system to work you need to update the crop canopy coverage estimate weekly, particularly during the rapid growth phase when canopy expansion is rapid.

As previously discussed, no drip system delivers equal amounts of water to all areas of the field. To ensure that even the driest area receives adequate water, the crop water requirement calculated from ET_o and crop canopy coverage needs to be adjusted for the degree of non-uniformity of water delivery. As previously mentioned, a field-scale drip system should have a DU of 85-90%. Dividing the crop water requirement by the DU will give the depth of water to be applied.

The following example illustrates the calculation of depth of water to be applied:

Example: tomato crop at full bloom; canopy width of 45 inches on a 60-inch bed, = to a 0.75 cover factor
two days since last irrigation, cumulative ET_o of 0.52 inches
drip system distribution uniformity (DU) of 85%

Calculation: ET_o (in inches, cumulative from the last irrigation)
multiplied by the % ground cover by foliage or wet soil
multiplied by 1.1 (factor for higher transpiration of tomato compared to the ET_o reference crop)
equals the crop water requirement (in inches)

0.52 inches x (0.75 canopy cover factor) x 1.1 = 0.43 inches

Then to account for irrigation system DU:
crop water requirement (in inches)
divided by the system DU
equals the irrigation requirement (in inches)

0.43 inches ÷ 0.85 = 0.50 inches of irrigation requirement

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 approximately 12 to 26 hours of run time to apply an inch of water. Your design engineer or irrigation supply vendor can calculate the 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 in the system. A water meter is also a valuable tool to monitor the performance of the drip system. The hours of run required to apply an inch of water should not change much over the season provided the water pressure remains constant and appropriate maintenance procedures are followed to minimize emitter clogging. Monitoring the gallons applied per hour can give an early warning of problems in the system.

Irrigation frequency

Although tomato can tolerate a moderate degree of moisture stress, the goal of drip irrigation is to maintain as uniform a soil moisture regime as possible. Research has shown that tomato can tolerate a depletion of 20-30% of available soil moisture in the active root zone with no yield loss. Early in the season when plants are small, irrigation may not be required more often than once a week. Field trials in both the San Joaquin and Sacramento Valleys have shown that, in medium- to heavy-textured soils, it is seldom necessary to irrigate more often than every other day, even during the peak water demand portion of the season. In sandy soils there may be circumstances where irrigating every day is appropriate during peak demand. Table 2 provides guidance on the maximum irrigation requirement that should be allowed to accrue between irrigations.

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	0.5–0.7
clay	0.4–0.6

To help guide decisions on irrigation frequency the use of soil moisture monitoring equipment is recommended, particularly for growers new to drip irrigation, and for installations on soil types on which the grower has no experience.

Soil moisture monitoring

There can be several significant sources of error in the method of calculating irrigation requirement just described. Direct soil moisture monitoring is the essential safeguard to avoid over- or under-watering. Soil moisture sensors measure either soil moisture tension or soil moisture content. Soil moisture tension is a measure of the strength with which water is held by the soil; soil moisture content is the amount of water contained in a given volume of soil. Soil moisture tension can be monitored by tensiometers or electrical resistance blocks; soil moisture content is most often monitored by dielectric sensors, of which there are many commercial choices. Resistance blocks and dielectric sensors can be attached to low-cost electronic recorders to collect and store readings many times a day. Experience has shown that for drip irrigation, tracking soil moisture over time gives a more complete evaluation of irrigation management than simply taking readings a couple of times per week.

Sensor placement relative to the drip tape is important. Soil moisture content varies with lateral distance from the drip line and with depth below and above the drip line. The readings of sensors placed either too close or too far from the drip line may not be representative of the root zone. A rule of thumb developed from experience is to place the sensors approximately 6 inches to the side of the drip tape for most soil types. Sensor depth is important as well. A sensor at approximately 12 inch depth will monitor soil moisture in the most active root zone; a second sensor installed deeper (24-30 inches) can document whether the amount of water applied was sufficient to maintain deep moisture without either drying out or saturating the lower root zone. Installing sets of sensors in several different areas of the field is ideal to ensure that the readings are representative of the whole field.

Table 3 gives approximate soil tension values (in centibars, cb) for field capacity (the amount of water the soil can hold against the force of gravity, commonly thought of as the “ideal” water status), and for 20-30% available moisture depletion (the maximum “safe” level of depletion between irrigations). The goal of drip irrigation management is to keep soil water tension between field capacity and 20-30% depletion as much as possible. Immediately after an irrigation, cb readings may go down near zero, but they should rebound to near or above field capacity before the next irrigation. Until fruit begin to ripen, allowing soil tension to rise above the 20-30% depletion level, even for a day or two, may be enough to induce yield loss or blossom end rot of fruits.

Table 3. Approximate soil water tension at field capacity, and at 20-30% available moisture depletion.

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

Interpreting soil moisture content data from dielectric sensors is complicated by the fact that the optimum range of soil water content varies considerably by soil texture, so a field-specific calibration is needed. Often readings from these sensors are used more to show wetting/drying trends at various soil depths rather than to directly quantify soil moisture availability.

End of season water management

The proceeding discussion describes irrigation management practices from planting until the early fruits begin to ripen. From that point forward irrigation should be reduced, for several reasons. Once fruit begin to ripen, the plants begin to senesce, and water use declines. By harvest, crop water use is about 25-30% lower than at mid-season. Also, some degree of moisture stress may be necessary to increase fruit soluble solids concentration (SSC) to a level acceptable to the processor. In a fully-watered crop SSC will seldom be greater than 5.0° brix, and may be as low as 4.0, depending on variety and field conditions. The goal of end-of-season water management is to induce sufficient moisture stress to achieve acceptable SSC with minimum yield loss. Since increasing SSC is accomplished primarily by excluding water from fruit rather than increasing the amount of solids in the fruit, some yield loss is inevitable.

Recent research has documented that after a tomato fruit reaches the “pink” stage of maturity (color change on 30% of the fruit surface), its SSC is essentially unaffected by irrigation management; regardless of subsequent soil moisture stress, SSC of that fruit will slowly decline (typically about 0.2° brix by harvest). However, the SSC of green fruit is greatly affected by irrigation. Therefore, in order to have a significant influence on overall SSC, some moisture stress must be imposed while the majority of fruits are still green. Since fruit ripening typically begins 5-6 weeks before harvest, and proceeds at a relatively constant rate, deficit irrigation may need to be initiated at least a month before the projected harvest date, perhaps even earlier in fields with high soil water holding capacity.

To significantly increase fruit SSC the moisture content of the top 2-3 feet of soil must be reduced below field capacity. An average soil moisture tension of 40-50 cb should be a sufficient stress to increase SSC of green fruit; this level of stress should not reduce brix yield (tons of solids/acre), but rather simply limit the amount of water in the fruit; this represents the minimum yield sacrifice for increased SSC. A more severe soil moisture deficit will further increase SSC, but may also reduce brix yield. As a general guideline, application of 30-70% of ET_o over the last 4-5 weeks before harvest is a reasonable compromise between maximizing yield and achieving acceptable SSC. The lower end of that range would be appropriate for soils with high water holding capacity, the higher end of that range would apply to lighter soils with limited water storage.

Both soil moisture monitoring and brix measurement of ripening fruit can help guide end-of-season irrigation management. Dielectric sensors are not ideal for this purpose, since the readings cannot be related directly to soil moisture tension (cb) without a field-specific calibration curve. Tensiometers can be used, but they can accurately read only up to approximately 70-80 cb, and if this level of soil moisture tension is reached the instrument will need to be serviced before accurate readings are restored. Resistance blocks calibrated in cb are a good choice because they are relatively inexpensive and have acceptable accuracy throughout the soil tension range of interest. Measuring the brix of early-ripening fruit at the pink stage can estimate the amount of SSC increase necessary to meet processor standards; subsequent monitoring of later-ripening fruit can determine the effectiveness of the deficit irrigation strategy. Accurate SSC determination of pink-stage fruit will require a composite juice sample from at least 20 fruit representing all areas of the field. If there are significant soil texture differences within the field, or any factor causing uneven water distribution (variable slope, excessively long row lengths, etc.), sampling different sections of the field separately may be appropriate. Inexpensive, hand-held refractometers can give reasonably accurate brix estimates, provided the readings are compensated for the temperature of the juice. Providing fruit samples to Processing Tomato Advisory Board (PTAB) grading stations for brix measurement may be the most accurate method of SSC determination.

Since red fruits are unaffected by soil moisture status, from a SSC perspective there is no requirement to completely cut off irrigation; assuming that sufficient moisture stress has been applied to achieve acceptable SSC, some level of irrigation to maintain vine cover can be continued up to harvest. The main limitations are the need to keep the bed tops dry to minimize fruit rot, and the need to have the soil profile dry enough at harvest to minimize soil compaction by the harvesting equipment.

Whenever deficit irrigation is practiced, the possibility of root intrusion into the drip emitters exists. However, due to the strongly determinate growth habit of processing cultivars, root growth has nearly stopped by the time fruit begin to ripen. To date, growers practicing end-of-season deficit irrigation have generally not encountered root intrusion, but monitoring and/or preventive action is advised. Monitoring the water delivery rate of the system (gallon/acre/hour of run) can help spot the first sign of root intrusion. Chlorine or acid injection can be used as a preventative practice. The legality of the injection of herbicides into the drip system to prevent root intrusion is not clear, so growers are advised to consult their county Agriculture Commissioners before making such applications.

Drip irrigation under saline, shallow groundwater conditions

Drip irrigation can be used to great benefit in fields with a shallow, saline groundwater table. The soil salinity near the drip line will be primarily affected by the salinity of the irrigation water, whereas soil salinity beyond this zone will reflect the influence of the saline ground water. Applying irrigation water at the full calculated irrigation requirement will generally be sufficient to maintain root zone salinity at an appropriate level. Under-irrigating to induce the plant to use water from the shallow water table is not recommended, as that can increase root zone salinity. Periodic leaching of salt accumulated above the buried drip lines with sprinklers may be necessary for stand establishment if winter and spring rainfall is insufficient to leach the salts. The influence of soil salinity may be sufficient stress to increase fruit SSC without intentional deficit irrigation. Brix testing of early-ripening fruit can provide guidance; if the brix level is undesirably low, a deficit irrigation approach similar to that outlined may be necessary.

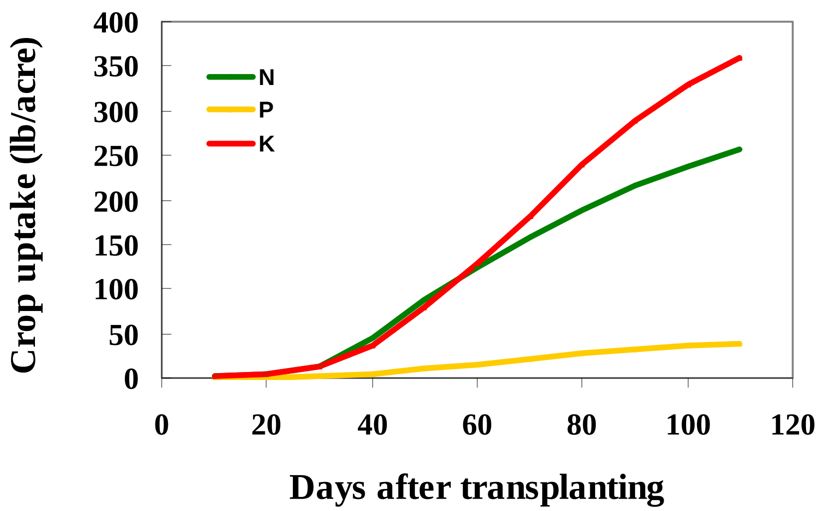
B. Fertility Management

While growers recognize that drip irrigation requires radical changes in water management strategies, the impact of drip on soil fertility management is less obvious. The most frequently discussed effect of drip irrigation on fertilizer needs is the potential for reduced N leaching losses through greater irrigation efficiency. There are a number of other ways in which the conversion to drip irrigation may require adjustments of fertilizer programs. The following discussion highlights some of those issues.

Nutrient uptake pattern

Drip-irrigated processing tomato crops exhibit a characteristic nutrient uptake pattern; Fig. 1 shows the typical macronutrient uptake of a 50 ton/acre crop.

Figure 1. Pattern of macronutrient uptake in high-yield processing tomato.



At harvest the total macronutrient content of the whole crop (vine and fruit) averages approximately 250 lb nitrogen (N) and 40 lb phosphorus (P) per acre, respectively. Potassium (K) uptake varies depending on soil K availability, but generally ranges between 300-400 lb/acre. The macronutrient content of processing tomatoes averages about 3-4 lb N, 0.4-0.5 lb P, and 4-6 lb K per ton of fruit. Nutrient uptake is slow until fruit set begins, and then accelerates significantly; from early fruit set until fruit begin to ripen nutrient uptake remains relatively constant at approximately 5 lb N, 0.5 lb P and 6 lb K per acre per day. It is in this period of time that fertigation management is critical. Crop nutrient uptake slows in the final 4-5 weeks before harvest, with the fruit drawing nutrients out of the vine; in most cases it is unnecessary to apply fertilizer during this final period.

Phosphorus management

Although P fertilizers can be applied through drip irrigation (with proper safeguards to prevent chemical precipitation), fertigation may not be the best way to apply P. Normally, P supply is most limiting early in the season, when the soil is colder, and the limited root system of the crop reaches only a small volume of soil. This argues for most or all of the season's P requirement to be applied preplant, or at planting. Placement of P close to the young plants maximizes availability. When P is applied through buried drip lines, the extent of movement away from the point of injection is governed by soil texture and pH; in alkaline soil of medium to heavy texture, fertigated P may move only a few inches from the tape, making it less available than if banded close to the plant row or applied in a transplant drench. Once the crop has developed a large, vigorous root system soil P is more readily accessible to the crop, and in-season P applications are seldom necessary.

P management should be based on soil test P level. When sampling a drip-irrigated field, particularly one in which buried lines have been in place for several years, it is important to sample in the zone wetted by the drip tape because this is the area from which the crop will draw most of its nutrients during the season. Because of the concentrated root feeding, the available soil P level in that zone can decline substantially below the level in the rest of the soil profile. Fields with bicarbonate (Olsen) soil test P > 20 PPM will have minimal preplant or at-transplanting P requirement, and are unlikely to require in-season P application; fields with lower soil test levels are likely to respond to preplant or at-transplanting P application.

When determining your P application strategy it is important to remember that high-yield processing tomato is a reasonably heavy feeder, and most of the P taken up by the plant is removed in the fruit; with a 50 ton/acre crop approximately 25-30 lb of elemental P/acre will be removed from the field in the fruit, the equivalent of 60-70 lb P_2O_5/acre. Therefore, applications less than that amount “mine” the root zone and reduce soil P availability for future crops. A reasonable P management strategy would be to apply the “fruit replacement” amount in fields with soil Olsen P between 10-20 PPM, and somewhat more than that in fields with < 10 PPM. Fields with Olsen P > 20 PPM may require no P for the current crop, but annual soil testing should be done to assess the draw-down of available soil P in the root zone.

A final word on P management. In transplant production it is a common practice to withhold P fertilization to control transplant height and growth rate in the greenhouse; when they come to the field transplants may be highly P-deficient. Even if they are to be transplanted into a field with high soil test P, a pre-transplanting drench or at-transplanting “starter” P application is prudent.

Nitrogen management

Many field trials in California have shown that conventionally-irrigated processing tomatoes generally require no more than 100-150 lb of fertilizer N to achieve maximum yield; the remaining N the crop requires comes from soil sources, namely residual soil NO_3-N and soil organic N that is mineralized (made plant-available) during the season. Since tomato is a moderately deep-rooted crop, NO_3-N leaching loss during the season is seldom large. Switching to drip irrigation is unlikely to reduce N fertilizer requirement, and may actually increase it; growers who are able to dramatically decrease N fertilization after switching to drip were probably overfertilizing their conventionally-irrigated fields. With drip, the higher yield potential may require greater N availability, and since the surface soil often remains dry, the mineralization of soil organic N may be limited.

Drip-irrigated field trials have shown that high fruit yields (50-60 tons/acre) can consistently be achieved with a seasonal application of approximately 200 lb N/acre or less. A reasonable N fertigation plan would be to make multiple applications concentrated just before and during the rapid uptake phase of the crop (Table 4). N fertigation after fruit ripening begins is seldom necessary. The rates given in Table 4 should be sufficient to maximize fruit yield in nearly all field conditions, provided that irrigation is efficiently managed, with little in-season leaching. In fields with significant residual soil nitrate-nitrogen (NO_3-N) somewhat lower rates should be adequate. Residual soil NO_3-N should be sampled after transplant establishment. Fields with > 10 PPM NO_3-N in the top two feet of soil should require no more than 160 lb/acre of fertigated N, while fields with very low residual NO_3-N (< 5 PPM) may require 200 lb N/acre or slightly more to ensure sufficiency.

Table 4. General N fertigation template for processing tomato.

Growth stage	Duration (weeks)	Maximum N fertigation rate* (lb/acre/week)
2 weeks post-transplant-early fruit set	2-3	10
Early fruit set-full bloom	3-4	30-35
Full bloom-early red fruit	2-3	20-25

* in fields with substantial residual NO_3-N lower rates may be adequate

Potassium management

K management is a complicated issue. Fertilizer trials in conventionally-irrigated fields have shown that a tomato yield response to K fertilization is unlikely if soil test K is > 130 PPM exchangeable K (based on ammonium acetate extraction). However, there are a number of reasons why this rule of thumb does not hold for drip-irrigated fields. The higher yield expectations and the more limited root zone from which to draw mean that the soil K availability threshold is higher with drip irrigation. On the positive side, drip irrigation provides a way to effectively deliver K to the root zone, minimizing the soil K fixation that can limit the effectiveness of conventional preplant or sidedress K application.

Based on limited research data, yield response to K fertilization is likely in drip fields with exchangeable K up to 200 PPM, and possible in fields up to 300 PPM. Soil K availability depends not only on the exchangeable K level, but also on the percentage of all cations that K represents (other cations compete for plant uptake). Most commercial soil testing laboratories report soil calcium (Ca), magnesium (Mg), sodium (Na) and K both as PPM and as percent cation saturation (on a milliequivalent basis). In soils in which K represents > 3% of cation saturation this cation competition is of little importance; in soils in which K represents < 2% of cation saturation K uptake may be significantly impeded by cation competition. As with P, sampling the concentrated root zone is essential in getting an accurate picture of soil K status.

Where K fertilization is appropriate, fertigation during fruit set will be the most effective application technique. Even in soil of limited K availability tomato plants can usually take up enough K to support early vine growth, but when fruit set begins crop uptake quickly exceeds the soil supply; the result is that the vine is stressed to maintain the developing fruit, and later-setting fruit are aborted. Concentrating K fertigation during fruit set minimizes this vine stress and maximizes fruit set. There is limited research information on K fertigation rates. Fruit K content at harvest is typically 200-250 lb/acre (240-300 lb K_2O equivalent), so application rates less than that represents “mining” of soil K. However, on the basis of maximizing the economic return on the current crop, the first 100 lb K_2O/acre would probably achieve most of the potential yield benefit; the economic return on additional fertigation would decline.

K availability also affects fruit color uniformity; the disorder called “yellow shoulder” (in which the tissue around the stem scar remains yellow after a fruit has ripened) is directly related to low

K fertility. Preventing or reducing yellow shoulder often requires a substantially higher level of soil K fertility than is required to achieve maximum yield. However, since growers are not usually compensated for reducing yellow shoulder, K fertigation management is usually directed toward yield maximization. Contrary to a widely held belief, fruit SSC is unlikely to be affected by K fertigation.

Nutrient monitoring

As in conventionally-irrigated fields, soil availability of P and K are best assessed by preplant sampling. As already discussed, in fields with buried drip systems soil samples should be drawn from the primary rooting zone (6-18 inch depth, within the area wetted by the drip system). In-season soil NO_3-N testing is useful mainly to determine the amount of residual NO_3-N present after crop establishment; this information can be used to modify the general N fertigation template, as previously described. Once rapid growth begins, and N fertigations are initiated, soil NO_3-N sampling is of limited value because: a) NO_3-N becomes stratified in the soil profile, and collecting a sample that is truly representative of soil N availability is difficult, and b) crop N uptake is sufficiently high that soil NO_3-N concentration can change quickly.

Plant tissue testing can help identify growth-limiting nutrient deficiency. The traditional analytical methods are petiole sampling for analysis of NO_3-N, PO_4-P, and K, and whole leaf sampling for total N/P/K analysis. It is important to understand the differences between these techniques. Petiole analysis is considered to be a measure of recent crop nutrient uptake, since the measurement is made on the tissue that transports nutrients to the leaves, and the measurement is of “unassimilated” N and P forms (NO_3-N and PO_4-P are the common chemical forms that are taken up from the soil, and have not yet been assimilated by the plant into organic compounds). Unfortunately, factors other than soil nutrient availability can significantly affect petiole nutrient concentration, and therefore this measurement is of limited practical value in managing in-season fertilization. Values above the guidelines given in Table 5 can be reliably interpreted to mean that crop nutrient status is currently adequate, but because petiole nutrient concentrations can change greatly within just a few days that measurement is not a sound basis on which to make future fertigation decisions. Values below these “sufficiency” levels do not necessarily indicate nutrient deficiency, particularly with regard to N; in a management system in which multiple N fertigations are made to keep pace with crop uptake, one would not necessarily see a large accumulation of petiole NO_3-N during the rapid growth phase. Low petiole nutrient concentrations alone are not sufficient information on which to change a fertigation template.

Laboratory analysis of dried petiole tissue provides the most accurate information. An alternative approach is petiole sap analysis. This can be done either in a laboratory using standard analytical equipment, or on-farm using ion-selective electrode meters (“Cardy” NO_3-N or K meters). The advantage of sap analysis is speed; some labs offer next day service, and Cardy meter readings take only minutes to obtain. However, sap analysis is inherently less accurate, because the values vary with tissue water content. Both the water status of the petioles at sampling, and any drying that occurs during handling and transport, can affect the results. Additionally, Cardy meters are less reliable than well-maintained laboratory equipment, and their readings should be considered only as an approximation of NO_3-N or K concentration.

Table 5. Petiole nutrient sufficiency guidelines.

		Sufficiency level by growth stage	
Sample type	Nutrient	First flower	Full bloom
Dry petiole	PPM NO_{3}-N	> 8,000	> 4,000
	PPM PO_{4}-P	> 2,500	> 2,000
	% K	> 4.5	> 3.0
Petiole sap	PPM NO_{3}-N	> 600	> 300
	% K	> 3,000	> 2,500

Whole leaf analysis provides a more reliable estimate of crop nutrient status than petiole analysis because it measures all forms of N and P. Leaf nutrient concentrations also change more slowly than petioles, and therefore provide a more stable basis upon which to modify the crop fertigation template. Table 6 gives the ranges of leaf nutrient concentration typical of high-yield processing tomatoes; this information was developed from a survey of more than 100 commercial fields so it is broadly relevant to the industry. Leaf nutrient concentrations within these ranges can be considered sufficient for the growth stage; the farther outside these ranges a leaf analysis falls, the more likely it is to reflect nutrient deficiency of excess availability.

Table 6. Whole leaf nutrient sufficiency ranges.

	Sufficiency range by growth stage	
Nutrient	First flower	Full bloom
% N	4.6-5.2	3.5-4.5
% P	0.32-0.49	0.25-0.41
% K	2.2-3.5	1.6-3.1

Tissue analysis is most useful from early flowering through full bloom. Nutrient deficiency is rare before flowering (with the possible exception of P); after full bloom tissue nutrient concentration, particularly for K, is heavily influenced by fruit load; low tissue values may not reflect nutrient deficiency as much as nutrient export to the fruit.