2007 Annual Report

FREP Project 06-0626

Development of practical fertility monitoring tools for drip-irrigated vegetable production

Tim Hartz
Department of Vegetable Crops
University of California
Davis, CA 95616

Michelle LeStrange
Tulare County Farm Advisor
University of California Cooperative Extension

Objectives:

a) develop crop nutrient uptake and partitioning curves for drip-irrigated processing tomato across a range of field sites, and
b) evaluate and calibrate practical soil and plant monitoring tools to guide fertility management

Abstract:

Four drip-irrigated processing tomato fields were intensively monitored throughout the 2007 season to establish nutrient uptake and partitioning curves, and to evaluate a range of soil and plant monitoring tools. At harvest per acre total crop uptake ranged from 197-245 lb for N, 25-34 lb P and 159-319 lb K, with more than 70% of each nutrient contained in fruit. Rate of nutrient uptake peaked near the full bloom growth stage, at daily uptake rates of approximately 5, 0.8 and 7 lb N, P and K per acre, respectively, at the highest yielding sites. At UC Davis a replicated experiment was conducted comparing seasonal fertility treatments deficient in N, deficient in P, adequate for both nutrients, or excessive for both; two common varieties (AB 2 and Heinz 9780) were grown. At adequate or excessive fertility the varieties yielded similarly, but H 9780 was more strongly affected by limited N or P availability. Petiole analysis appeared to be flawed technique, as the two highest-yield yielding fields (58 and 59 tons of fruit per acre) were classified as deficient in both N and P based on currently established petiole concentration standards for NO_3-N and PO_4-P, while neither field was classified as deficient based on total nutrient analysis of whole leaves. NO_3-N concentration in petiole sap was typically 5-20 times higher than the concentrations in xylem exudate, with the disparity in PO_4-P between sap and xylem somewhat less. Since the vast majority of these mineral nutrient forms were clearly already stored in plant cells, environmental and physiological factors may have had more influence on petiole concentration than did current soil nutrient supply.

Introduction:

The conversion to drip irrigation is revolutionizing the California vegetable industry; at the current rate of conversion as much as half the acreage of the major fruiting crops will be in under drip irrigation within 5 years. This has important ramifications for fertility management. The higher yield potential, and the ability to respond to changing nutrient demands, makes more intensive nutrient monitoring in drip culture both useful and economically justifiable.

Optimizing nutrient management with drip irrigation will require both a detailed knowledge of crop nutrient uptake patterns, and the ability to monitor and interpret in-season nutrient status in both soil and crop. Currently, insufficient data is available on crop nutrient uptake by growth stage for these important crops under high yield, drip-irrigated conditions. Nutrient monitoring has historically centered on preplant soil testing, and in-season whole leaf or petiole analysis. With the advent of widespread drip irrigation there is interest in exploring other approaches such as soil solution monitoring, or petiole sap analysis (for both macro- and micronutrients). Unfortunately, recent research from around the country has cast doubt on the reliability of these analytical tools as in-season fertigation guides. This project was undertaken to develop accurate nutrient uptake and partitioning data under high yield drip-irrigated conditions, and to provide a critical assessment of a range of crop and soil nutrient monitoring options.

Work description:

A drip-irrigated processing tomato trial was transplanted 9 May at UC Davis. Four fertility regimes were compared:

1) low N fertility
2) low P fertility
3) adequate N and P fertility ('appropriate' fertility management)
4) excessive N and P fertility

Each fertility regime was replicated 3 times; two common processing tomato varieties (AB2 and Heinz 9780) were grown in all plots, in a split plot design. P fertility was manipulated by varying the preplant P application (from 0 to 140 lb P_2O_5/acre). N fertility was manipulated by varying weekly fertigation amounts; seasonal N application ranged among treatments from 63 - 258 lb N/acre.

Beginning at early bloom growth stage the plots were intensively sampled every two weeks for nutrient status, with the following measurements taken:

1) whole plant macro- and micronutrient content
2) whole leaf macro- and micronutrient concentration
3) NO_3-N, PO_4-P and K concentration in petiole sap
4) NO_3-N, PO_4-P and K concentration in dry petioles
5) NO_3-N, PO_4-P, and K in plant xylem exudate (collected by a pressure apparatus)
6) Soil NO_3-N and NH_4-N in a composite sample of the 3-15 inch depth in the wetted zone
7) Soil NO_3-N, PO_4-P and K in soil solution collected in the field from suction lysimeters
8) Soil NO_3-N, PO_4-P and K in soil solution collected by centrifugation of composite samples of the 3-15 inch depth in the wetted zone

The final sampling was done a week prior to commercial harvest stage, when > 85% of fruit was red.

In addition to the UCD trial, three commercial processing tomato fields in the Sacrament Valley were monitored. In each field three areas were monitored separately for replication. Four times during the season all the fertility measurements previously described were made; the last sampling was done 7-10 days before commercial harvest. Site and management details of all fields monitored are given in Table 1.

Results and conclusions:

All fields had high total fruit yield, ranging from 45-59 tons/acre (Table 2). Total N uptake (vine and fruit) was similar in all fields, averaging approximately 220 lb/acre. P and K uptake varied substantially among fields, ranging from 25-34 lb P/acre and 159-319 lb K/acre. Differences in P uptake were due primarily to P fertilizer application (all fields had reasonably low soil test P); differences in K uptake were primarily due to soil factors (initial exchangeable K and the extent of the drip wetting pattern), since K fertilizer application was minimal in all fields.

The pattern of nutrient uptake through the season was similar in all fields; data from the UCD trial are illustrated in Fig. 1. The majority of seasonal nutrient uptake occurred during the period between early fruit set and the ripening of early fruit (approximately week 5 through week 11). In the final month of the season nutrient uptake rates declined substantially. At UCD nutrient uptake rates peaked between 4-5 lb N, 0.6-0.8 lb P and 6-7 lb K/day in the 'adequate' fertility treatment. Uptake rates in the 'excessive' fertility treatment were only marginally higher; of the extra fertilizer applied in the excessive treatment beyond that applied in the 'adequate' treatment, less than 40% of the N and 10% of the P was taken up by the plant.

At UCD fruit yield of the varieties responded differently to the nutrient regimes. AB2 showed only a minor loss of yield with low N and P fertilization, while with H 9780 yield loss to both low N and low P was substantial (Fig. 2). AB2 was apparently more effective at recovering nutrients from the soil than was H 9780, as evidenced by N and P uptake in the low fertility treatments being closer to that in the adequately fertilized plots (Fig. 3).

Partitioning of nutrients between vine and fruit showed a consistent pattern (Fig. 4). In all fields vine nutrient content peaked at about full bloom growth stage, and declined as fruits developed and ripened. Even in the excessively fertilized treatment at UCD vine N/P/K content declined substantially as the fruit load developed. Not surprisingly, nutrient concentration in all vegetative tissues declined quickly after fruit bulking began. The rate of this decline varied among fields, particularly with respect to K.

The various monitoring techniques employed gave substantially different results. Fig. 5 gives xylem and sap NO_3-N and PO_4-P concentrations over time in the adequate and excessive fertility treatments at UCD. For both nutrients xylem concentration was much lower than in sap (note the different scales for these measurements). Considering that the volume of xylem recovered from a petiole (approximately 0.1 ml on average) was much smaller than the average amount of sap (≈ 0.4 ml) it is clear that the vast majority of both mineral nutrient forms in petiole tissue have already been stockpiled inside plant cells. This suggests that, because environmental and physiological conditions affect the rate at which plants metabolize stored mineral N and P into organic compounds, a tissue measurement of these mineral nutrient forms may neither correlate with current soil nutrient supply, or crop nutrient status. Analysis of dry petiole and whole leaf tissue supported that conclusion (Table 3). The adequate and excessive fertility treatments gave equivalent fruit yield, so they were by definition adequately supplied with N and P. However, petiole analysis suggested that the adequate treatment was deficient in both nutrients at one or two growth stages, while by whole leaf analysis both treatments were adequately supplied with both nutrients. Similarly, petiole NO_3-N and PO_4-P concentrations were below current sufficiency standards in commercial field 3, and the very high yield achieved (59 ton/acre) suggested that yield-limiting nutrient deficiency was unlikely.

Xylem exudate nutrient concentrations were generally lower in NO_3-N and higher in PO_4-P and K, than would have been expected based on measured crop nutrient uptake and transpirational water volume. Part of the disparity in NO_3-N concentration may be due to the uptake of other N forms. The higher than expected xylem concentrations of PO_4-P and K may have been associated with contamination from cytoplasm of cells ruptured at the cut surface of the petiole. Greenhouse experiments are currently underway to refine the xylem measurement technique, and investigate the effect of different N fertilizers on the forms of N in xylem exudate.

Additional field monitoring will be done in 2008. Commercial fields in the San Joaquin Valley will be included, and the UCD experiment will be repeated.

Outreach:

The information and insight gained in this first season has been and will continue to be disseminated to industry audiences through print and personal presentations. A newsletter article has been prepared (see appendix 1) for publication in County UCCE newsletters for industry clientele to be published in spring, 2008. In addition to a presentation at the FREP conference in Tulare I have made presentations at UCCE-sponsored grower meetings in Bakersfield (December 12) and Yuba City (December 18). Additional 2008 grower meetings have been scheduled for January 8 (Woodland), January 31 (Modesto) and February 21 (Fresno).

Table 1. Site and management details for 2007 fields.

	Transplant			Soil fertility (PPM)		Seasonal fertilizer rate (lb/acre)		
Field	date	Variety	Soil texture	Olsen P	Exchange K	N	P_2O_5	K_2O
UCD	9 May	AB2, H9780	loam	11	220			
Low N						80	70	0
Low P						167	0	0
Adequate fertility						190	70	0
Excessive fertility						294	140	0
1	4 April	H2601	loam	4	114	169	14	24
2	1 May	AB5	clay loam	16	138	181	14	18
3	10 May	AB2	clay loam	11	110	186	90	33

Table 2. Crop productivity and nutrient uptake in 2007 fields.

Field	Biomass dry wt (tons/acre)	Total fruit yield (tons/acre)	Biomass nutrient content (lb/acre)		
			N	P	K
UCD[z]	10,100	58	208	34	319
1	7,150	45	197	25	159
2	9,530	51	243	27	194
3	9,670	59	245	34	227

[z] mean of AB 2 and H 9780 varieties, ‘adequate’ nutrient regime

Table 3. Tissue analysis of ‘adequate’ and ‘excessive’ fertility treatments, UCD trial.

Fertility treatment	Growth stage	PPM in petioles NO_3-N	PPM in petioles PO_4-P	% petiole K	% in whole leaves N	% in whole leaves P	% in whole leaves K
adequate fertility	Early bloom [y]	9,600	2,800	6.3	4.7	0.39	3.4
excessive fertility		10,600	3,300	6.0	4.9	0.43	3.5
Sufficiency level [z]		*9,000*	*3,000*	*6.0*	*4.6*	*0.32*	*2.2*
adequate fertility	Full bloom [x]	1,700	1,600	5.4	3.6	0.27	3.5
excessive fertility		5,000	2,400	6.0	4.1	0.30	3.5
Sufficiency level		*6,000*	*2,500*	*4.0*	*3.5*	*0.25*	*2.0*

[z] from Western Fertilizer Handbook

[y] 5 weeks post-transplant

[x] 9 weeks post-transplant

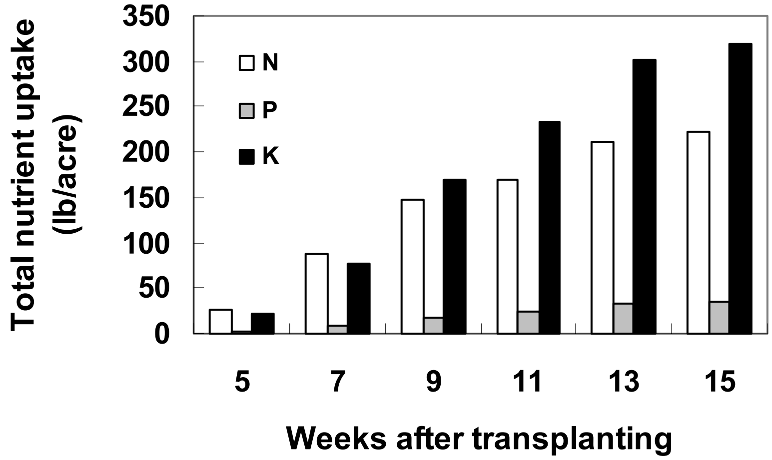

Fig. 1. Pattern of nutrient uptake over the 2007 season; mean of AB2 and H9780 varieties grown at UCD in the adequate fertility treatment.

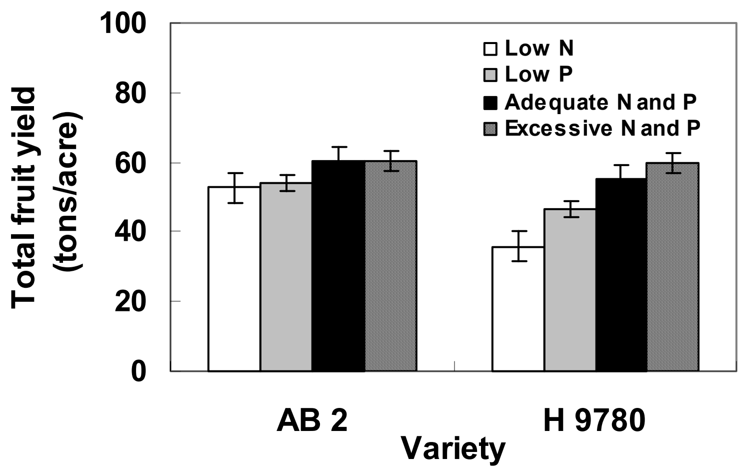

Fig. 2. Effect of fertility treatment on total fruit yield, UCD trial.

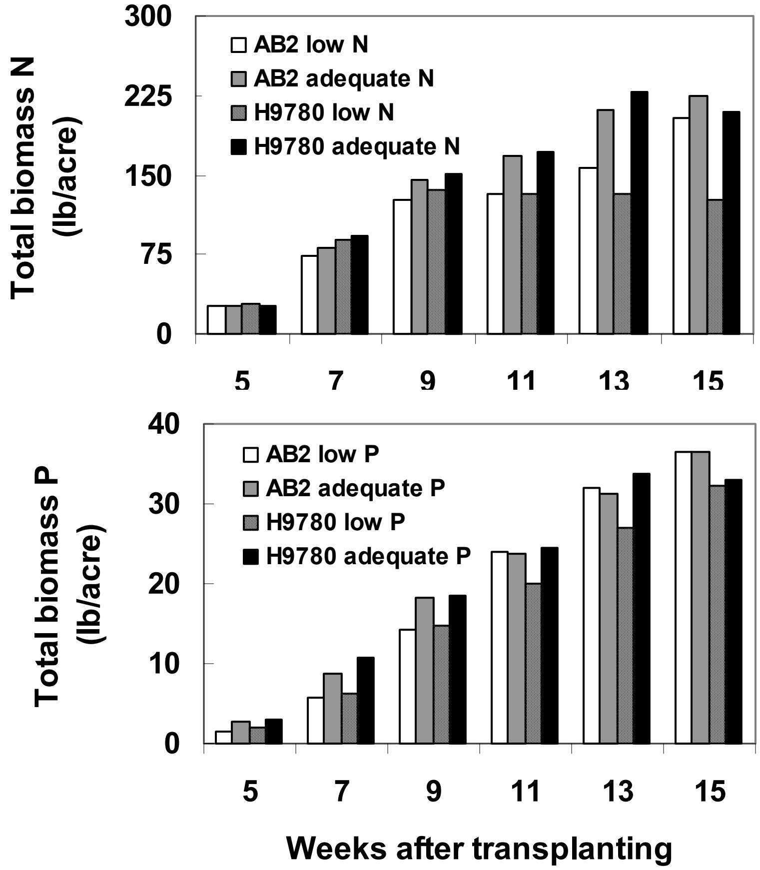

Fig. 3. Effect of fertility treatments on N and P uptake in the UCD trial.

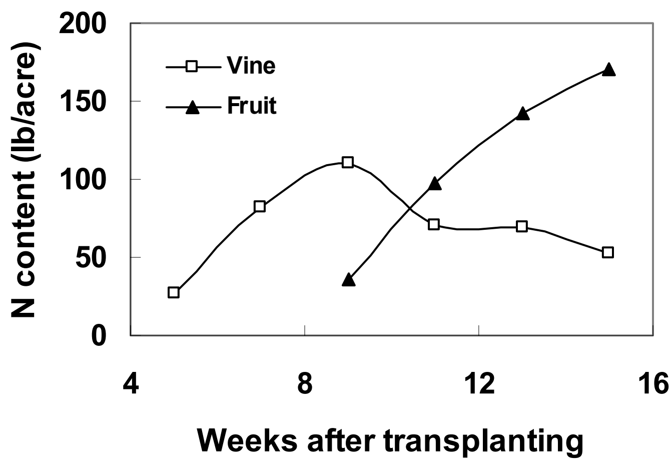

Fig. 4. Partitioning of nutrients between vine and fruit, AB2 variety at UCD.

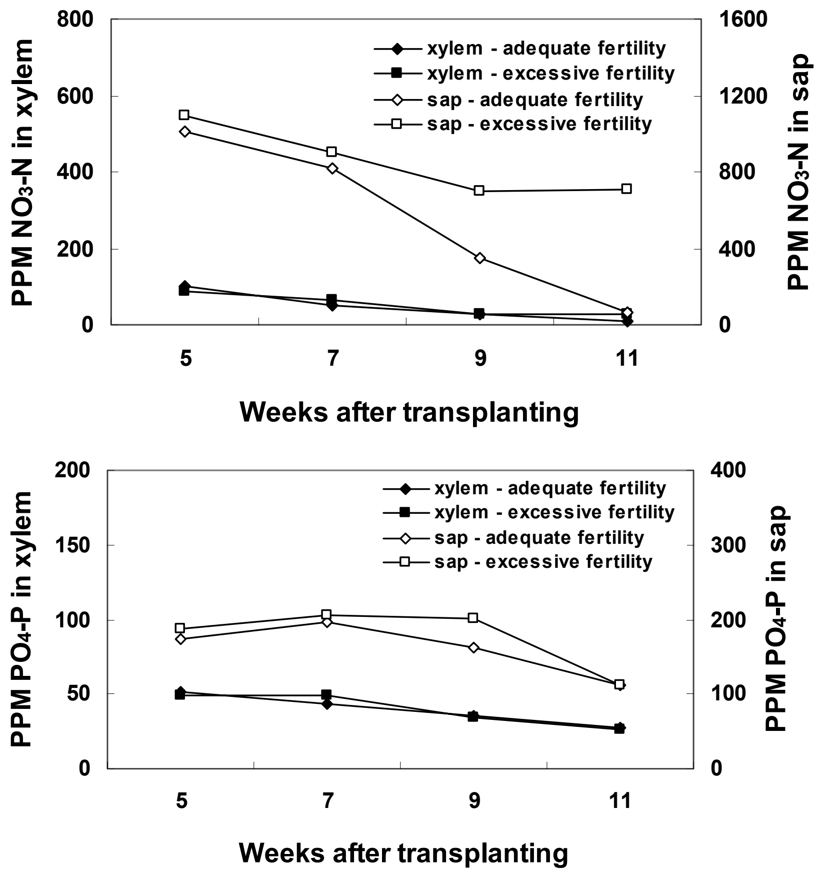

Fig. 5. Comparative NO_3-N and PO_4-P concentrations in xylem exudate and petiole sap of the adequate and excessive fertility treatments at UCD, AB 2 variety.

Appendix 1: Newsletter article

Efficient fertigation management for drip-irrigated processing tomatoes
Tim Hartz
UC Davis

Drip irrigation is revolutionizing processing tomato production. Many growers now routinely achieve 50 ton yields, and 60 ton yields are not uncommon. In light of these higher yield expectations, and given the differences in rooting patterns and wetted zone in drip-irrigated fields, a reevaluation of soil fertility management is appropriate.

Crop nutrient uptake in high-yield fields:

In 2007 I intensively monitored two drip-irrigated fields, a commercial field in Yolo County, and a fertigation experiment at UC Davis; in both fields 'AB 2' transplants were planted in early May. In these fields the crop was sampled repeatedly over the season, with whole plants (vine and fruit) harvested so that total nutrient uptake could be tracked, and rates of nutrient uptake at different growth stages determined. Total fruit yield in both fields approached 60 tons/acre.

The pattern of N uptake was quite similar in both fields; at harvest the total N contained in the crop (vine and fruit) averaged 230 lb/acre. The seasonal pattern of N uptake at the UCD site is given in Fig. 1. N uptake prior to early fruit set stage (week 5) was slow, but accelerated quickly until full bloom (week 9). During fruit development N uptake slowed, and much of the N was moved out of the vine to support fruit growth. The data given was for plots receiving a seasonal total of 190 lb N/acre, of which 170 was fertigated during the growing season. An 'excessive' N treatment that received a seasonal total of 290 lb N/acre was also monitored, and the N uptake pattern was very similar; at harvest the total crop N uptake had only increased about 30 lb/acre, with no fruit yield advantage over the lower N treatment.

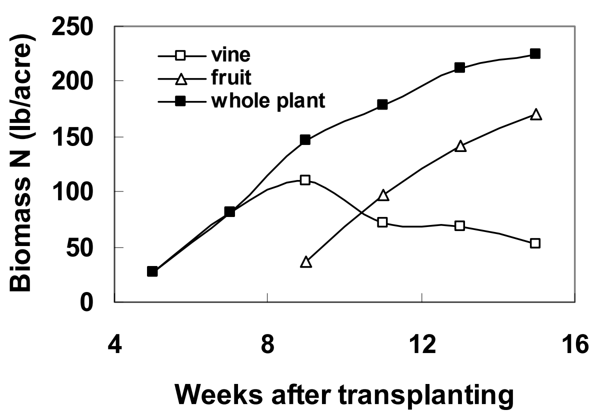

Fig. 1. Pattern of crop N uptake over the season, UCD trial.

By measuring the change in crop N content between sampling dates the weekly rate of N uptake was calculated. Table 1 gives the approximate N uptake rates observed. The pattern of phosphorus uptake was similar to N, but at a much lower level; at harvest total crop P content averaged 35 lb/acre. The pattern of K uptake was also similar between fields, but the total amount of K taken up was highly dependent on soil K supply. At UCD, with exchangeable soil K of 220 PPM, total uptake was 320 lb/acre; the commercial field had much lower soil K (110 PPM), and had only 230 lb K/acre in the crop at harvest.

Table 1. Rate of N uptake by growth stage.

Growth stage	Duration (weeks)	N uptake (lb/acre/week)
transplant - early fruit set	4-5	5-10
early fruit set - full bloom	3-4	20-35
full bloom - early red fruit	2-3	20-25
early red fruit - harvest	4-5	10-20

Nutrient management:

From these 2007 trials and a variety of experiments conducted over the last decade some general guidelines for high-yield, drip-irrigated management can be formulated. Fields with soil test P (Olsen extraction) > 25 PPM are unlikely to require P fertilization for maximum yield, particularly if transplants are used and the transplants come to the field with a high P status (> 0.4% P). Below 25 PPM soil P, or where the transplant grower has used P deficiency as a tool to manage transplant size, preplant P banding or at-planting P application in a transplant drench should give a growth response. With adequate preplant or at-planting P application, in-season P fertigation is seldom necessary.

Regarding N, seasonal fertilization rates should not exceed crop N uptake, and in many fields may be significantly less. All soils will mineralize some N from organic matter during the growing season, and many fields begin the season with significant residual nitrate-nitrogen (NO_3-N). With efficient irrigation management, a seasonal total of 160-220 lb N/acre should be sufficient for high-yield production, provided it is applied in sync with crop demand. Table 2 contains an N fertigation template that should ensure N sufficiency under most normal field conditions. It assumes early season N availability from residual NO_3-N or at-planting application. N fertigation in the final month before harvest is seldom necessary.

Table 2. Nitrogen fertigation template for high-yield processing tomato production.

Growth stage	Duration (weeks)	N fertigation rate should be no more than: (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

Although N can be applied with each irrigation, in most cases there is no benefit in fertigating more often than once a week. The fertigation amounts given in Table 2 can be reduced in fields where significant residual soil NO_3-N is present.

In drip-irrigated fields the demand for potassium can be substantially higher than for furrow-irrigated production. This is due not only to the increased yield potential, but also to the smaller, more concentrated root zone from which the plants draw nutrients. This is particularly the case with buried drip because the roots are concentrated in a band around the drip tape (typically 8-12 inches deep). Since available soil K decreases with soil depth, this means that soil K availability is lower than would be suggested by a soil test of a sample of the top foot of soil. *For buried systems that have been in place for multiple years, both P and K availability in the zone around the drip tape can drop considerably, and it is important to soil test this zone to get an accurate assessment of soil fertility.*

In-season fertility monitoring:

In the past the most common way to monitor fertility during the season was petiole analysis. Petiole NO_3-N and phosphate-phosphorus (PO_4-P) concentration have been thought to indicate recent crop uptake of these nutrients from the soil, which was assumed to be primarily a function of soil nutrient supply. Unfortunately, it is not that simple. Most of the NO_3-N and PO_4-P in petiole tissue is already stored in plant cells; the rate at which these inorganic ions are assimilated into organic compounds is strongly influenced by environmental conditions in the field, so the connection between petiole concentration and soil nutrient supply is confounded. Recent research from across the country, and on a range of vegetable crops, had shown that petiole NO_3-N and PO_4-P are poor measures of current soil supply, and cannot be reliably used to guide fertigation. Furthermore, current 'sufficiency' levels appear to be too high, particularly for drip-irrigated culture in which fertigation, particularly for nitrogen, continues through most of the season. For N and P, the more reliable measure of crop nutrient status is total N and P concentration of whole leaves.

To illustrate the limitations of petiole analysis, Table 3 gives the petiole and whole leaf nutrient analysis for two fertility treatments in the 2007 UCD trial. The 'adequate' fertility treatment received a seasonal total of 190 lb N and 70 lb P_2O_5 per acre; it had equivalent fruit yield and quality to the 'excessive' nutrient treatment, which received 290 and 140 lb/acre of N and P_2O_5, respectively. By whole leaf analysis both treatments were adequately supplied for all nutrients (the correct diagnosis), while petiole analysis wrongly suggested inadequate N at full bloom, and inadequate P at both growth stages.

Table 3. Tissue analysis of 'adequate' and 'excessive' fertility treatments, UCD trial.

		PPM in petioles		% petiole	% in whole leaves		
Fertility treatment	Growth stage	NO_3-N	PO_4-P	K	N	P	K
adequate fertility	Early bloom	9,600	2,800	6.3	4.7	0.39	3.4
excessive fertility		10,600	3,300	6.0	4.9	0.43	3.5
Sufficiency level		*9,000*	*3,000*	*6.0*	*4.6*	*0.32*	*2.2*
adequate fertility	Full bloom	1,700	1,600	5.4	3.6	0.27	3.5
excessive fertility		5,000	2,400	6.0	4.1	0.30	3.5
Sufficiency level		*6,000*	*2,500*	*4.0*	*3.5*	*0.25*	*2.0*