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DRIS Evaluation of the Nutritional Status of Processing Tomato

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Abstract. **Diagnosis and Recommendation Integrated System (DRIS) norms were derived for processing tomato (*Lycopersicon esculentum* Mill.) from a 1993–94 survey of >100 fields in the Sacramento and San Joaquin Valleys of California. Relative foliar N, P, K, Ca, Mg, and S concentrations were expressed in ratio form, with DRIS norms calculated as the means of fields with fruit yield ≥90 Mg·ha^{-1}. Norms were developed for three growth stages: first bloom, full bloom, and 10% of fruits ripe. Optimum foliar nutrient concentration ranges were calculated by regression analysis from DRIS nutrient indices of high-yield fields. These optimum ranges were in general agreement with existing empirically derived sufficiency ranges for N and P, higher for Ca, Mg, and S, and much lower for K. The relatively low foliar K levels observed were attributed primarily to the strongly determinate growth habit of currently used cultivars. In the fields sampled, yield-limiting nutrient deficiency appeared to be rare.**

The United States is the world leader in processing tomato production, with >130,000 ha produced annually. About 90% of that total is grown in the interior valleys of California. In the past decade, improved production practices and the use of vigorous hybrid cultivars have boosted mean tomato yields in California to >75 Mg·ha^{-1}. All cultivars now in use have a determinate growth habit that concentrates fruit set to maximize yield for once-over mechanical harvest. There has been no systematic research on mineral nutrition of processing tomato under California conditions since the 1970s; given the change in cultivars, cultural practices, and yield expectations, the use of guidelines based on old data (Lorenz and Tyler, 1983) for interpreting nutrient concentrations in plant tissue has become problematic. Although a number of other sources list tomato tissue nutrient sufficiency ranges (Hochmuth et al., 1991; Jones et al., 1991; Piggott, 1986), most were not specifically developed for determinate processing cultivars.

Another limitation to the use of sufficiency range foliar nutrient guidelines is that they often have been derived from fertilizer experiments in which the supply of only one or two nutrients has been manipulated; overall nutrient balance has not been considered (Walworth and Sumner, 1988). The Diagnosis and Recommendation System (DRIS) (Beaufils, 1973) was developed to quantify the relationship of nutrient balance to crop yield. In the DRIS approach, differences in nutrient concentrations and nutrient ratios between low- and high-yielding populations are used to estimate the degree to which various nutrients may limit yield, either because of deficiency or excess (Walworth and Sumner, 1987). DRIS evaluation has provided reliable diagnosis of the nutrient status of a number of crops (Angeles et al., 1990; Beverly et al., 1984; Elwali and Gascho, 1984; Elwali et al., 1985; Parent and Granger, 1989; Walworth et al., 1986). In several studies, the DRIS approach was diagnostically superior to critical value and sufficiency range approaches (Angeles et al., 1990; Elwali and Gascho, 1984; Needham et al., 1990).

The purpose of this study was to develop DRIS nutrient norms for processing tomato grown in central California. A survey of commercial processing tomato crops was conducted to provide a broad database of foliar nutrient concentrations in low- and high-yielding crops from which to calculate DRIS norms.

Materials and Methods

A total of 105 processing tomato fields, representing >20 farming operations, were sampled during the 1993 and 1994 seasons. The fields (in which the crops were grown) were selected to represent a broad range of soil types, environmental conditions, and cultural practices. At each site, composite samples of whole, recently matured leaves (petiole plus blade) were collected at three growth stages: first bloom, full bloom, and 10% of fruits showing red color. These stages typically occurred 3 to 4 weeks apart. Tissue was oven-dried and ground to pass a 0.8-mm screen. Composite soil samples (0- to 30-cm depth) were collected concurrently with the first tissue sample.

Tissue N concentration was determined by the combustion method of Sweeney (1989), and K concentration by atomic emission spectrometry following extraction in 2% acetic acid. Phosphorus, Ca, Mg, and S concentrations were determined by inductively coupled plasma atomic emission spectrometry following microwave acid digestion (Sah and Miller, 1992). Soil exchangeable K, Ca, and Mg concentrations were measured by atomic emission spectroscopy following ammonium acetate extraction (Page, 1982). Plant available soil P was estimated by bicarbonate extraction and measured by spectrophotometry (Olsen et al., 1954). Total soil N was determined by the method of Carlson (1978) following Kjeldahl digestion (Isaac and Johnson, 1976). Soil pH was determined on a saturated paste extract.

At the end of each season, tomato fruit yield (from machine harvest) and fertilizer application data were collected from participating growers. Crops were segregated into high- (≥90 Mg·ha^{-1}) and low-yield (≤78 Mg·ha^{-1}) groups. The mean and variance for each foliar nutrient concentration, and each possible ratio or product of each pair of nutrients (i.e., N/P, P/N, N*P), were calculated for both yield groups. For each nutrient pair, the mean of the ratio or product that maximized the variance ratio between the low- and high-yielding group was selected as the DRIS norm for that nutrient pair.

A DRIS index for each nutrient was calculated for each tomato crop using the method of Walworth and Sumner (1987). In short, the relative abundance of each nutrient was evaluated by comparing all ratios containing that nutrient (i.e., N/P, N*K, Ca/N, etc.) with the DRIS norms. In the mathematical comparison an index value of zero indicated an optimum level, negative values a relative deficiency, and positive values a relative excess of that nutrient.

Table 1. Mean foliar nutrient concentration in high- and low-yielding tomato crops at three crop growth stages.

Growth stage	Yield group	N	P	K	Ca	Mg	S
		g·kg^{-1}					
1	High[z]	47	4.1	29	30*	12	9.7
	Low[y]	49	4.3	27	23	15	7.6
2	High	39	3.2	22	30*	13	9.7
	Low	43*	3.5	24	24	13	8.5
3	High	31	3.0	16	35*	15	11
	Low	35*	3.0	16	29	15	11

[z]≥90 Mg·ha^{-1}
[y]≤78 Mg·ha^{-1}
*Group means significantly different at $P \leq 0.05$.

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Results and Discussion

Tomato crops in 43 fields had fruit yields ≥90 Mg·ha^{-1}, while crops in 40 fields yielded ≤78 Mg·ha^{-1}; group means were 104 and 61 Mg·ha^{-1}, respectively. Mean tissue nutrient concentrations were generally similar for both yield groups (Table 1). High-yield crops had higher Ca at all growth stages, and lower N at stages 2 and 3. There were no significant differences between yield groups for any soil parameter measured. Mean soil chemical characteristics were 185, 2610, and 1220 mg·kg^{-1} exchangeable K, Ca, and Mg, respectively, 704 mg·kg^{-1} total N, 18 mg·kg^{-1} extractable P, and 7.4 pH. Mean grower fertilizer applications were 223, 56, and 22 kg·ha^{-1} for N, P, and K, respectively. Fruit yield was not correlated with the rate of application of any nutrient.

N, P, and K concentrations declined significantly with advancing crop maturity, while Ca, Mg, and S concentrations increased slightly. For most nutrient pairs there was no ratio or product that consistently discriminated between yield groups, and that remained relatively constant across growth stages; therefore, DRIS norms were developed for each growth stage (Table 2). Caron and Parent (1989) also found it appropriate to calculate growth stage–specific DRIS norms for greenhouse tomatoes.

In the calculation of DRIS nutrient indices, nutrient pairs that did not have a ratio or product that discriminated between yield groups (variance ratio >1.0) were omitted. At growth stage 2 no nutrient pair containing Mg was useful, so a Mg index was not calculated. Even though a nutrient index value of zero is considered optimal, potential inaccuracies (sample size limitations, measurement error, etc.) suggested that an optimum range be used to evaluate nutrient indices. Following the precedent of Beaufils (1973), a nutrient index within 4/3 SD of the high yield population's zero index value was considered to be balanced, and sufficient for high yield production; ±4/3 SD corresponds to an 80% confidence interval in a normal distribution. By this criterion 60%, 65%, and 58% of high-yield crops showed all nutrients in balance at growth stages 1, 2, and 3, respectively, compared with 50%, 63%, and 45% for the low-yield crops.

For each nutrient monitored there was a linear relationship between the nutrient index and tissue nutrient concentration in "balanced" high-yield crops (Table 3). From these regressions an optimum range was calculated for each nutrient, defined as the foliar concentration corresponding to ±4/3 SD around the zero value of each DRIS index. Data in Table 4 compare DRIS-derived optimum nutrient ranges with empirically derived sufficiency range data previously reported. At all growth stages, DRIS-derived optimum foliar N and P ranges were intermediate to, while Ca, Mg, and S ranges higher than, published sufficiency ranges. The foliar K optimum range at growth stages 2 and 3 was much lower than previously reported values.

The similarity in mean foliar nutrient concentrations between yield groups, and the similar percentage of crops in each yield group showing all nutrients in balance, suggested that yield-limiting nutrient deficiency was rare in the fields monitored. The lack of correlation between fruit yield and fertilizer application, and between soil test estimates of macronutrient availability and fertilizer application, suggested that participating growers used fertilization programs that, in many fields, resulted in fertilizer applications in excess of crop requirements. The importance of the relationship between foliar Ca concentration and yield, while statistically significant (r = 0.37, 0.25, and 0.26 at stages 1, 2, and 3, respectively), was unclear, since mean Ca concentrations for both yield groups met or exceeded sufficiency ranges previously reported. One possibility is that more vigorous crops would experience greater seasonal evapotranspiration than low-vigor (low-yield) crops, resulting in greater uptake of Ca, the predominate cation in both soil and irrigation water. Mean N application was similar in both yield groups, suggesting the lower foliar N concentration observed in high-yield crops at stages 2 and 3 was related to greater N demand from the larger fruit load. In high-yield crops, fruit N content exceeds the N content of the vine by growth stage 3 (Hartz, unpublished data).

The DRIS-derived optimum foliar N and P concentration ranges matched well with sufficiency ranges reported from regions as dissimilar as California, Florida, and Australia (Hochmuth et al., 1991; Jones et al., 1991; Lorenz and Tyler, 1983; Piggott, 1986), suggesting that these DRIS ranges have wide applicability. The DRIS optimum ranges for Ca, Mg, and S were substantially higher than those of any other source, undoubtedly reflecting the relative abundance of those elements in California soils and irrigation water, and high seasonal evapotranspiration, more than actual plant requirements.

Previously reported K sufficiency ranges appeared to be unrealistic for processing tomato production under the conditions encountered in this study; at stage 2 only 35% of high-yield crops had foliar K concentration >25 g·kg^{-1}, with only one crop meeting the 40 g·kg^{-1} K sufficiency standard suggested by Lorenz and Tyler (1983).

Soil K supply may have been more limited than the mean exchangeable K level (185 mg·kg^{-1}) would have indicated. On a milliequivalent basis, K represented barely 2% of base exchange. High foliar Ca and Mg concentration relative to foliar K content suggested that competing ion effects may have sup-

Table 2. Nutrient ratios, variance ratios, and coefficients of variance for three tomato growth stages.

Growth stage 1				Growth stage 2				Growth stage 3			
Nutrient ratio[z]	Ratio mean[y]	Variance ratio	CV (%)	Nutrient ratio	Ratio mean	Variance ratio	CV (%)	Nutrient ratio	Ratio mean	Variance ratio	CV (%)
N/DM	4.72	1.3	11	N	3.89	1.7	16	N	3.11	1.6	21
P/DM	0.41	1.4	26	P	0.32	1.0	34	P	0.30	0.5	33
K/DM	2.91	1.3	21	K	2.24	1.2	29	K	1.62	0.6	45
Ca/DM	2.98	0.8	33	Ca	3.02	0.6	37	Ca	3.49	1.5	26
Mg/DM	1.24	1.7	35	Mg	1.25	0.7	44	Mg	1.51	0.9	36
S/DM	0.97	0.4	42	S	0.97	0.6	47	S	1.08	0.7	32
N*P	1.93	2.4	29	N*P	1.28	2.6	42	N*P	0.94	1.3	41
N/K	1.68	2.0	20	N*K	8.85	1.8	38	K/N	0.52	1.0	37
P*K	1.18	2.4	33	P*K	0.74	2.1	49	P/K	0.21	1.4	40
N/Ca	1.81	1.3	43	N/Ca	1.52	2.0	53	N/Ca	0.98	3.3	43
Mg/N	0.27	2.9	41	Mg/N	0.33	0.9	48	Mg/N	0.51	1.3	43
N/S	5.69	1.1	40	N/S	4.92	1.6	48	N/S	3.18	1.5	38
P/Ca	0.15	2.2	44	P/Ca	0.12	3.7	47	P/Ca	0.09	3.2	41
P*Mg	0.50	2.2	41	P*Mg	0.40	0.9	57	P*Mg	0.43	0.9	42
P/S	0.48	1.7	41	P/S	3.78	3.0	38	S/P	3.83	1.5	32
Ca/K	1.08	1.7	45	K/Ca	0.86	2.2	51	Ca/K	2.54	4.4	46
Mg/K	0.46	4.6	52	K*Mg	2.75	1.0	49	Mg/K	1.19	1.6	65
K/S	3.44	1.7	37	K/S	2.75	1.3	48	K/S	1.62	1.0	52
Ca*Mg	3.59	2.5	49	Mg/Ca	0.48	0.7	56	Ca*Mg	5.08	1.8	40
Ca/S	3.22	0.8	23	Ca/S	3.34	0.5	31	Ca*S	3.98	1.0	55
Mg*S	1.18	1.5	57	Mg*S	1.17	0.7	55	Mg*S	1.61	1.1	49

[z]Selected as the highest variance ratio (variance of low-yield group/variance of high-yield group) of the three nutrient ratios possible (e.g., N/P, P/N, N*P). DM = dry matter.

[y]High yield group (≥90 Mg·ha^{-1}).

Table 3. Relationship between foliar nutrient concentration and DRIS[z] indices for "balanced" high-yield tomato crops.

Growth stage	Nutrient	Regression equation[y] y =	r^{2x}
1	N	48.5 + 0.4 x	0.38
	P	4.1 + 0.1 x	0.71
	K	28.5 + 0.8 x	0.84
	Ca	30.2 + 1.1 x	0.85
	Mg	13.5 + 0.4 x	0.90
	S	9.4 + 0.4 x	0.89
2	N	40.0 + 0.9 x	0.75
	P	3.3 + 0.1 x	0.80
	K	23.4 + 0.7 x	0.90
	Ca	27.3 + 1.2 x	0.75
	S	8.6 + 0.3 x	0.83
3	N	32.6 + 0.7 x	0.84
	P	3.0 + 0.1 x	0.73
	K	13.9 + 0.5 x	0.82
	Ca	32.4 + 0.9 x	0.61
	Mg	16.0 + 0.5 x	0.88
	S	9.9 + 0.3 x	0.60

[z]Diagnosis and Recommendation Integrated System.

[y]y = Foliar nutrient concentration ($g \cdot kg^{-1}$), x = DRIS index.

[x]All regressions significant at $P \leq 0.01$.

pressed K uptake. One might expect higher rates of K fertilization to be warranted. However, under typical California conditions, fruit yield response of processing tomatoes to K fertilization was limited to sites with ammonium acetate exchangeable soil K <125 $mg \cdot kg^{-1}$ (Hartz et al., 1996), supporting the low levels of K fertilization encountered in this study.

The growth characteristics of determinate tomato cultivars also limited foliar K concentration, particularly during fruit development (stages 2 and 3). Determinate cultivars develop smaller root systems, and partition a higher percentage of absorbed K into fruit, than do semideterminate cultivars, resulting in lower foliar K concentration (Widders and Lorenz, 1979). Using a soil with 200 $mg \cdot kg^{-1}$ exchangeable K, Widders and Lorenz (1982) found that tomato leaf K concentration declined ≈40% during fruit development, close to the 44% decrease in foliar K concentration observed in high-yield crops between growth stages 1 and 3 in the present study.

The DRIS-derived foliar nutrient optimum ranges should have wide applicability. Major Mediterranean, South American, and Asian tomato production areas have climatic and soil conditions similar to those of central California, and similar determinate tomato cultivars dominate production in these regions.

Table 4. Comparison of DRIS[z]-derived optimum foliar nutrient concentration ranges for tomato with published nutrient sufficiency ranges.

Growth stage	Source of data	Foliar nutrient sufficiency range ($g \cdot kg^{-1}$) N	P	K	Ca	Mg	S
1	DRIS optimum	46–52	3.2–4.9	22–35	19–41	10–18	5.0–13
	Hochmuth et al. (1991)	28–40	2.0–4.0	25–40	10–20	3.0–5.0	3.0–8.0
	Piggott (1986)	55–60	4.0–6.0	30–50	15–25	4.0–6.0	---
2	DRIS optimum	35–45	2.5–4.1	16–31	18–36	---	5.0–12
	Hochmuth et al. (1991)	25–40	2.0–4.0	25–40	10–20	2.5–5.0	3.0–6.0
	Jones (1991)	40–60	2.5–7.5	29–50	10–30	4.0–6.0	4.0–12
	Lorenz and Tyler (1983)	≥30	≥3.5	≥40	---	---	---
3	DRIS optimum	27–38	2.3–3.7	8.0–20	24–41	10–22	7.0–13
	Hochmuth et al. (1991)	20–30	2.0–4.0	15–25	10–20	2.5–5.0	3.0–6.0
	Lorenz and Tyler (1983)	≥25	≥2.5	≥30	---	---	---
	Piggott (1986)	40–60	4.0–8.0	30–50	14–40	4.0–9.0	---

[z]Diagnosis and Recommendation Integrated System.

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