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Can a Better Tool for Assessing 'Hass' Avocado Tree Nutrient Status be Developed?

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INTRODUCTION

California avocado growers must increase yield, including fruit size, and/or reduce production costs to remain competitive in the US market, which now receives fruit from Mexico, Chile, New Zealand, Australia, Dominican Republic, Peru and Ecuador and soon South Africa and Brazil. Optimizing the nutrient status of the 'Hass' avocado (*Persea americana* Mill.) is a cost-effective means to increase yield, fruit size and quality, but the California avocado industry has no reliable diagnostic tool relating tree nutrient status with yield parameters. For the 'Hass' avocado of California, experiments for only N, Zn and Fe have been conducted to determine the optimal leaf concentration for maximum yield (Crowley, 1992; Crowley and Smith, 1996; reviewed in Lovatt and Witney, 2001). Alarmingly, leaf N concentration was not related to yield (Lovatt and Witney, 2001). Optimum ranges for nutrients other than N, Zn and Fe used for interpreting leaf analyses for the 'Hass' avocado are borrowed from citrus and, thus, are not related to *any* avocado yield parameter. The project's objective is to test the feasibility of using tissues that have frequently proven more sensitive and reliable than leaves to diagnose deficiencies of the 'Hass' avocado sufficiently early that corrective measures would have a positive effect on yield parameters during the current year, not just the following year. Based on results obtained by avocado researchers in Chile (Razeto and Granger, 2001; Razeto et al., 2003; Razeto and Salgado, 2004), it is highly likely that pedicel (the stem of the fruit) and/or inflorescence tissue will meet the criteria essential for an effective diagnostic tool for 'Hass' avocado fertility management in California. However, it must be noted that additional research would be required to develop the broader database required to have confidence in the relationship between nutrient concentrations in pedicel and/or inflorescence tissue and yield or fruit size than would be provided by the two data sets that will be obtained in this proposed 2-year study. Hence, this is a feasibility study designed to determine whether a better tool for assessing 'Hass' avocado tree nutrient status can be developed.

OBJECTIVES

The specific objectives of this project are:

1. Determine the sensitivity of inflorescences and fruit pedicels (stems) to differences in tree nutrient status
2. Determine if the nutrient concentrations of the tissues above are related to fertilizer rate and to yield parameters
3. Determine if differences in tissue nutrient concentrations related to yield can be detected sufficiently early to be corrected before they impact yield, fruit size or fruit quality in the current year.

DESCRIPTION

1. Tissues were collected as follows: entire inflorescence at the cauliflower stage and at full bloom; pedicels (stems) of young fruit in June (which is before exponential increase in fruit size and June drop of the current crop, start of mature fruit drop and transition from vegetative to reproductive growth), in September at the standard time for collecting leaves for nutrient analysis, and in November at the end of the fall vegetative flush; and pedicels of mature fruit in March at the time inflorescences at the cauliflower stage were collected and in April when inflorescences were collected at full bloom. Standard leaf collection was in September each year.
2. Tissue samples were collected from 16 individual 'Hass' avocado trees on the diagonal across orchards (with different but known rootstocks) located in Pauma Valley, Irvine, Santa Paula (high N and B site), San Luis Obispo and from trees receiving BMP N

(25 lb N/acre in July, Aug., Nov. and Apr.; 100 lb N/acre/year), BMP NPK (25 lb N, 3.75 lb P, and 22.5 lb of K in July, Aug., Nov. and Apr.; 100 lb N, 15 lb P and 90 lb K/acre/year), 0.5x N (25 lb N/acre in July and Aug.; 50 lb N/acre/year) and 0.5x NPK (25 lb N, 3.75 lb P, and 22.5 lb of K in July and Aug.; 50 lb N, 7.5 lb P and 45 lb K/acre/year) at a new research site in Santa Barbara.

3 Tissues were analyzed for N, S, P, K, Mg, Ca, Fe, Zn, Mn, B, and Cu. At harvest, yield (number and kg fruit), fruit size distribution and fruit quality were determined per tree.

RESULTS AND DISCUSSION

Relationship between tissue nutrient concentrations and yield parameters. We determined which nutrients in each tissue were significantly related to total yield and yield of commercially valuable large size fruit of packing carton sizes 60 + 48 + 40 (fruit weighing 178 to 325 g). Using stepwise regression analyses, we determined the most important combination of nutrients for each yield parameter across all orchards. ***Inflorescence tissue.*** We found significant relationships between nutrient concentrations of inflorescences at the cauliflower and full bloom stage and yield across all orchards including the trees in the fertilizer experiment in Santa Barbara. In all cases, nutrient concentrations of inflorescences collected at full bloom were more strongly related to yield and yield of commercially valuable large size fruit as both kilograms and number of fruit per tree. Cauliflower stage inflorescence tissue concentrations of Cu and Ca explained ≥ 60% of the variation in total yield (as kg/tree) and yield of fruit > 178 g per fruit (as kg and number of fruit/tree) ($P < 0.05$). Interestingly, the Cu concentration of cauliflower stage inflorescences alone predicted 54% of the variation in yield of commercially valuable large size fruit of packing carton sizes 60 + 48 + 40 (178-325 g/fruit) (as both kilograms and number of fruit per tree) ($P < 0.0001$). Cu, S, K and Zn concentrations of inflorescence tissue collected at full bloom predicted 77% of the variation in total yield, yield of fruit > 178 g per fruit and the yield of fruit in the combined pool of fruit weighing 178 to 325 g per fruit (as both Kg and number of fruit/tree) ($P < 0.01$). ***Pedicel tissue.*** P, S, B, and Ca concentrations of pedicels collected from young developing fruit in September explained 56% of the variation in yield of fruit > 178 g per fruit (packing carton size 60) as kilograms per tree ($P < 0.0009$). These nutrients plus Mg were required to predict the yield of fruit greater than packing carton size 60 as number of fruit per tree ($r^2 = 0.53$; $P = 0.0044$) and the yield of fruit in the combined pool of fruit 178 to 325 g per fruit (packing carton sizes 60 + 48 + 40) as kilograms fruit per tree ($r^2 = 0.55$; $P = 0.0039$). Note that this yield parameter as number of fruit per tree was related to P, S, B, Ca and N, not Mg ($r^2 = 0.52$; $P = 0.0138$). When pedicels of young fruit were collected in November, Zn, S, P and Mg concentrations predicted 60% of the variation in yield of fruit of packing carton sizes ≥ 40 (≥ 270 g/fruit) as both kilograms and number of fruit per tree in both years of the study ($P = 0.0244$), with Zn the most important determinant. ***Leaf tissue.*** Our results confirmed that leaf nutrient concentrations by standard leaf analyses were not related to total yield. Leaf nutrient status was also not responsive to the NPK soil fertilizer treatments. However, there was a weak, but highly significant relationship between leaf concentrations of Ca, Fe, S and Zn and yield of commercially valuable large size 'Hass' avocado fruit (packing carton sizes 60 + 48 + 40; 178-325 g/fruit) as kilograms per tree ($r^2 = 0.58$; $P = 0.0026$) and as number of fruit per tree ($r^2 = 0.51$; $P = 0.0057$) across all four orchards and the NPK soil fertilizer treatments.

Relationship between tissue nutrient concentrations and fruit quality parameters. We determined which combination of nutrients in each tissue had the most important effect on fruit quality across all orchards using stepwise regression analyses. The fruit quality parameters evaluated in each orchard were: number of days for fruit to ripen after harvest, peel color at maturity, fruit length, fruit width, width of the mesocarp (edible portion of the fruit), seed diameter, germination of the seed within the mesocarp, vascularization (presence of vascular tissue in the mesocarp), mesocarp discoloration, mesocarp decay. Fruit quality parameters were visually determined using a scale from 0 (none) to 4 (extensive, present in all four quarters of the fruit). ***Leaf tissue.*** Nutrient concentrations of leaves collected at the standard time were not related to any fruit quality parameter evaluated, with the exception that leaf Ca, Mn and Zn concentrations were significantly related to fruit length ($r^2 = 0.60$; $P = 0.0386$). ***Pedicel tissue.*** For pedicels collected from current year fruit, Zn, Fe, Mg, and Mn (September collection) and Zn and Mn (November collection) were also predictive of fruit length ($r^2 = 0.62$; $P = 0.0159$; $r^2 = 0.58$; $P = 0.0005$, respectively). ***Inflorescence tissue.*** Inflorescence tissues were the best predictors of fruit quality, including fruit length, fruit width, mesocarp width, seed germination within the fruit, and the number of days to ripen after harvest, across all four orchards and the NPK soil fertilizer treatments. All parameters were more strongly related to the nutrient concentrations of inflorescences collected at full bloom than at the cauliflower stage of inflorescence development. For inflorescences collected at full bloom, Cu and Mn predicted 82% of the variation in fruit length ($P = 0.0048$); Cu and K predicted 59% of the variation in fruit width ($P = 0.0055$); K and N predicted 57% of the variation in mesocarp width ($P = 0.0093$); K and Mg predicted 53% of the variation in the occurrence of seed germination within the mesocarp ($P = 0.0433$); and Cu alone predicted 51% of the variation in the number of days for fruit to ripen after harvest ($P < 0.0001$). Whereas all the relationships are statistically significant, fruit length was *strongly* influenced only by Cu and Mn nutrient status of full bloom inflorescences as reflected by the high r^2-value ($r^2 = 0.82$).

CONCLUSION

The results of this research identified the several key nutrient concentrations of inflorescence tissue related to total yield, yield of commercially valuable large size fruit (178-325 g/fruit, packing carton sizes 60 + 48 + 40) and fruit quality parameters that were statistically significant and explained in some cases ≥ 60% of the variation in yield or fruit quality. A unique finding was the potential importance of inflorescence tissue concentrations of Cu to yield parameters and Cu and Mn to fruit quality parameters across the orchards in this study. These relationships merit further testing to determine their potential capacity to serve as predictors of the effect of tree nutrient status on yield and fruit quality. Inflorescence tissue has the added advantage that it could be collected and analyzed sufficiently early in the season to mitigate the negative effect of nutrient deficiencies on the current crop and on the fruit quality of the mature crop.

The results confirmed that leaf nutrient concentrations were not related to yield or fruit quality parameters, with the exception of a weak, but highly significant relationship between leaf concentrations of Ca, Fe, S and Zn and yield of commercially valuable large size 'Hass' avocado fruit (packing carton sizes 60 + 48 + 40; 178-325 g/fruit) as kilograms per tree ($r^2 = 0.58$; $P = 0.0026$) and as number of fruit per tree ($r^2 = 0.51$; $P = 0.0057$) across all four orchards and the NPK soil fertilizer treatments. The value of this relationship could be studied further in orchards by using current leaf analyses and collecting yield data.

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Table 1.
Nutrient concentrations of 'Hass' avocado tissues collected in Irvine and Pauma Valley, California.

Tissue[z]	N %	P %	K %	S %	B ppm	Ca %	Mg %	Zn ppm	Mn ppm	Fe ppm	Cu ppm
						Irvine					
Y. inflorescence	3.35 a[y]	0.52 a	2.17 a	0.35 a	54.00 a	0.60 a	0.24 a	56.30 a	38.30 a	37.60 a	19.24 a
M. fruit stem 1	0.97 b	0.19 b	1.85 b	0.06 b	30.10 b	0.22 b	0.12 b	8.10 b	4.30 b	110.40 a	4.43 b
P-value	<0.0001	<0.0001	0.0158	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	0.0845	<0.0001
M. inflorescence	2.89 a	0.38 a	2.36 a	0.37 a	57.50 a	0.59 a	0.27 a	48.90 a	31.30 a	58.90 b	15.03 a
M. fruit stem 2	1.57 b	0.29 b	1.75 b	0.07 b	19.00 b	0.20 b	0.20 b	8.50 b	5.40 b	69.20 a	3.01 b
P-value	<0.0001	0.0123	0.0039	<0.0001	<0.0001	<0.0001	0.0016	<0.0001	<0.0001	0.0426	<0.0001
M. leaf	1.85 a	0.10 a	0.88 b	0.46 a	32.80 a	1.71 a	0.82 a	37.60 a	83.60 a	69.90 a	5.96 a
Y. fruit stem	0.57 b	0.08 b	1.43 a	0.04 b	19.00 b	0.18 b	0.07 b	6.50 b	3.50 b	21.50 b	2.86 b
P-value	<0.0001	0.0461	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
						Pauma Valley					
Y. inflorescence	3.11 a	0.49 a	1.81	0.29 a	45.30 a	0.55 a	0.23 a	48.90 a	38.50 a	67.00	10.08 a
M. fruit stem 1	1.71 b	0.33 b	1.81	0.07 b	20.20 b	0.20 b	0.11 b	9.50 b	3.60 b	62.40	1.81 b
P-value	<0.0001	0.0007	0.9824	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	0.3547	<0.0001
M. inflorescence	2.60	0.42	2.04 a	0.30 a	56.80 a	0.52 a	0.26	47.00 a	30.90 a	90.70	9.94 a
M. fruit stem 2	2.88	0.49	1.55 b	0.09 b	16.30 b	0.17 b	0.23	13.80 b	5.70 b	89.60	3.66 b
P-value	0.4232	0.1618	0.0094	<0.0001	<0.0001	<0.0001	0.1784	<0.0001	<0.0001	0.917	<0.0001
M. leaf	1.86 a	0.12 b	0.69 b	0.42 a	26.60 a	2.97 a	1.03 a	41.50 a	153.10 a	128.90 a	5.04 a
Y. fruit stem	1.23 b	0.19 a	2.04 a	0.06 b	10.90 b	0.19 b	0.08 b	9.50 b	3.20 b	22.90 b	2.20 b
P-value	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001

[z] Y. inflorescence-cauliflower stage of inflorescence development (March); M. fruit stem 1-pedicel of mature fruit (March); M. inflorescence-inflorescence at full bloom (April); M. fruit stem 2-pedicel of mature fruit (April); M. leaf-mature leaf on a spring flush, non-fruiting terminal shoot (September), the standard time for leaf analysis; Y. fruit stem-pedicel of young fruit (September).

[y] Values in a vertical column followed by different letters are significantly different at *P-value* specified by Fisher's Protected LSD Test.

Table 2.
Effect of N vs. NPK fertilizer rate on tissue nutrient concentrations of 'Hass' avocado trees in Santa Barbara, California.

Tissue[z]	N %	P %	K %	S %	B ppm	Ca %	Mg %	Zn ppm	Mn ppm	Fe ppm	Cu ppm
	BMP N July, August, November and April[y]										
Y. inflorescence	3.77 a[x]	0.60 a	2.13	0.35 a	44.25 a	0.55 a	0.33 a	62.75 a	161.13 a	63.00 a	27.69 a
M. fruit stem 1	1.37 b	0.22 b	1.83	0.07 b	18.75 b	0.22 b	0.14 b	7.38 b	20.50 b	51.88 b	2.41 b
P-value	<0.0001	<0.0001	0.2368	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	0.0014	0.0307	<0.0001
M. inflorescence	3.01 a	0.46 a	1.84	0.31 a	43.13 a	0.51 a	0.32 a	43.13 a	140.25 a	105.75 a	19.40 a
M. fruit stem 2	1.60 b	0.28 b	1.87	0.08 b	18.75 b	0.22 b	0.16 b	8.50 b	29.75 b	58.75 b	3.23 b
P-value	<0.0001	<0.0001	0.8978	<0.0001	<0.0001	<0.0001	0.0003	<0.0001	0.0093	<0.0001	<0.0001
M. leaf	1.91 a	0.12 a	0.73	0.31 a	17.38 a	1.38 a	0.71 a	18.13 a	240.25 a	70.50 a	5.70 a
Y. fruit stem	0.59 b	0.08 b	1.04	0.04 b	13.00 a	0.18 b	0.08 b	5.20 b	11.60 b	29.40 b	2.48 b
P-value	<0.0001	<0.0001	0.176	<0.0001	0.0663	<0.0001	<0.0001	0.0012	0.0106	0.0007	<0.0001
	BMP NPK July, August, November and April										
Y. inflorescence	3.65 a	0.58 a	2.16 a	0.34 a	49.38 a	0.56 a	0.29 a	59.25 a	142.88 a	60.25 a	25.46 a
M. fruit stem 1	1.20 b	0.19 b	1.61 b	0.07 b	21.13 b	0.23 b	0.14 b	7.13 b	20.25 b	50.50 b	2.51 b
P-value	<0.0001	<0.0001	0.0305	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	0.0055	0.0257	<0.0001
M. inflorescence	2.87 a	0.45 a	1.95 a	0.30 a	47.13 a	0.48 a	0.28 a	39.63 a	107.00 a	103.38 a	18.14 a
M. fruit stem 2	1.36 b	0.28 b	1.46 b	0.07 b	17.88 b	0.22 b	0.16 b	7.38 b	25.38 b	55.75 b	2.75 b
P-value	<0.0001	0.0017	0.0126	<0.0001	<0.0001	<0.0001	0.0003	<0.0001	0.0075	<0.0001	<0.0001
M. leaf	1.72 a	0.11	0.62 b	0.32 a	16.75	1.42 a	0.71 a	16.25 a	252.00 a	74.50 a	5.16 a
Y. fruit stem	0.57 b	0.10	1.37 a	0.04 b	15.25	0.17 b	0.07 b	6.00 b	7.00 b	23.50 b	2.93 b
P-value	<0.0001	0.6	<0.0001	<0.0001	0.3959	<0.0001	<0.0001	<0.0001	0.0121	<0.0001	0.0057
	0.5x N July + August										
Y. inflorescence	3.74 a	0.60 a	2.20 a	0.36 a	44.00 a	0.53 a	0.32 a	59.50 a	156.00 a	64.38 a	25.96 a
M. fruit stem 1	1.41 b	0.21 b	1.62 b	0.07 b	20.13 b	0.24 b	0.14 b	7.25 b	27.88 b	51.75 b	2.65 b
P-value	<0.0001	<0.0001	0.0041	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	0.0005	0.0088	<0.0001
M. inflorescence	2.87 a	0.45 a	1.91	0.30 a	44.00 a	0.49 a	0.29 a	40.00 a	138.50 a	100.50 a	18.04 a
M. fruit stem 2	1.51 b	0.25 b	1.77	0.08 b	16.38 b	0.24 b	0.15 b	8.13 b	25.00 b	55.25 b	3.26 b
P-value	<0.0001	<0.0001	0.5153	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	0.0001	<0.0001	<0.0001
M. leaf	1.85 a	0.11 a	0.67 b	0.29 a	17.00 a	1.38 a	0.74 a	15.88 a	208.75 a	78.50 a	5.58 a
Y. fruit stem	0.60 b	0.08 b	1.20 a	0.04 b	12.88 b	0.16 b	0.08 b	5.00 b	10.00 b	25.38 b	2.29 b
P-value	<0.0001	<0.0001	0.0025	<0.0001	0.0021	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
	0.5x NPK July + August										
Y. inflorescence	3.82 a	0.61 a	2.25 a	0.35 a	52.38 a	0.64 a	0.31 a	61.25 a	194.75 a	62.50 a	27.26 a
M. fruit stem 1	1.23 b	0.22 b	1.72 b	0.07 b	23.75 b	0.24 b	0.13 b	7.00 b	25.13 b	47.25 b	2.46 b
P-value	<0.0001	<0.0001	0.0444	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	0.0033	0.0007	<0.0001
M. inflorescence	2.90 a	0.47 a	1.97	0.31 a	44.63 a	0.51 a	0.29 a	41.63 a	126.88 a	104.50 a	19.08 a
M. fruit stem 2	1.55 b	0.30 b	1.74	0.07 b	21.38 b	0.23 b	0.15 b	7.38 b	27.38 b	54.00 b	2.76 b
P-value	<0.0001	0.0039	0.3576	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	0.0008	<0.0001	<0.0001
M. leaf	1.76 a	0.11 a	0.73 b	0.31 a	18.25	1.48 a	0.66 a	16.50 a	187.50 a	73.88 a	5.73 a
Y. fruit stem	0.58 b	0.09 b	1.28 a	0.04 b	14.00	0.18 b	0.07 b	5.25 b	11.50 b	26.75 b	2.38 b
P-value	<0.0001	0.0002	0.0007	<0.0001	0.155	<0.0001	<0.0001	<0.0001	<0.0001	0.0002	<0.0001

[z] Y. inflorescence-cauliflower stage of inflorescence development (March); M. fruit stem 1-pedicel of mature fruit (March); M. inflorescence-inflorescence at full bloom (April); M. fruit stem 2-pedicel of mature fruit (April); M. leaf-mature leaf on a spring flush, non-fruiting terminal shoot (September), the standard time for leaf analysis; Y. fruit stem-pedicel of young fruit (September).

[y] BMP N (25 lb N/acre in July, Aug., Nov. and Apr.; 100 lb N/acre/yr), BMP NPK (25 lb N, 3.75 lb P, 22.5 lb K in July, Aug., Nov. and Apr.; 100 lb N, 15 lb P, 90 lb K/acre/yr), 0.5x N (25 lb N/acre in July and Aug.; 50 lb N/acre/yr), 0.5x NPK (25 lb N, 3.75 lb P, 22.5 lb K in July and Aug.; 50 lb N, 7.5 lb P, 45 lb K/ acre/yr).

[x] Values in a vertical column followed by different letters are significantly different at P-value specified by Fisher's Protected LSD Test.

Figure 1.
Nutrient concentrations of pedicels of young fruit (Oct., Nov., June, Sept.) and mature fruit (Mar., Apr.) from ‘Hass’ avocado trees in Santa Barbara, California, receiving soil-applied fertilizer: BMP N (-•-) (25 lb N in July, Aug., Nov. and Apr. /acre/yr); BMP NPK (-○-) (25 lb N, 3.75 lb P, 22.5 lb K in July, Aug., Nov. and Apr./acre/yr); 0.5x N (-▲-) (25 lb N in July and Aug./acre/yr); 0.5x NPK (-△-) (25 lb N, 3.75 lb P, 22.5 lb K in July and Aug./acre/yr).

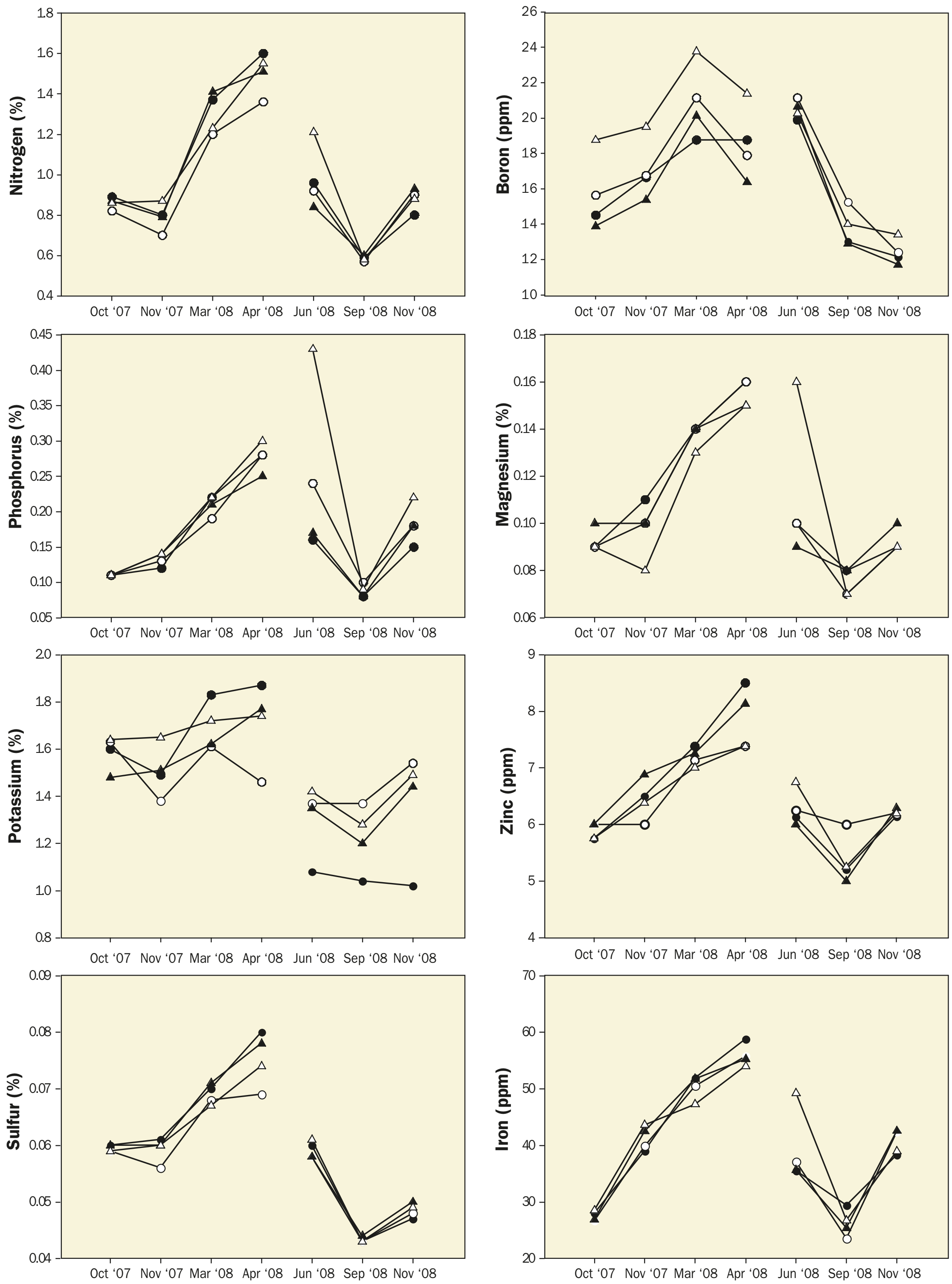

Figure 2.
Nutrient concentrations of pedicels of young fruit (Oct., Nov., June, Sept.) and mature fruit (Mar., Apr.) from 'Hass' avocado trees in Irvine (-•-), Pauma Valley (-○-), Santa Paula (-▲-), San Luis Obispo (-△-), and Santa Barbara (-X-) in the BMP NPK treatment (25 lb N, 3.75 lb P, 22.5 lb K July, Aug., Nov. and Apr./acre/yr).