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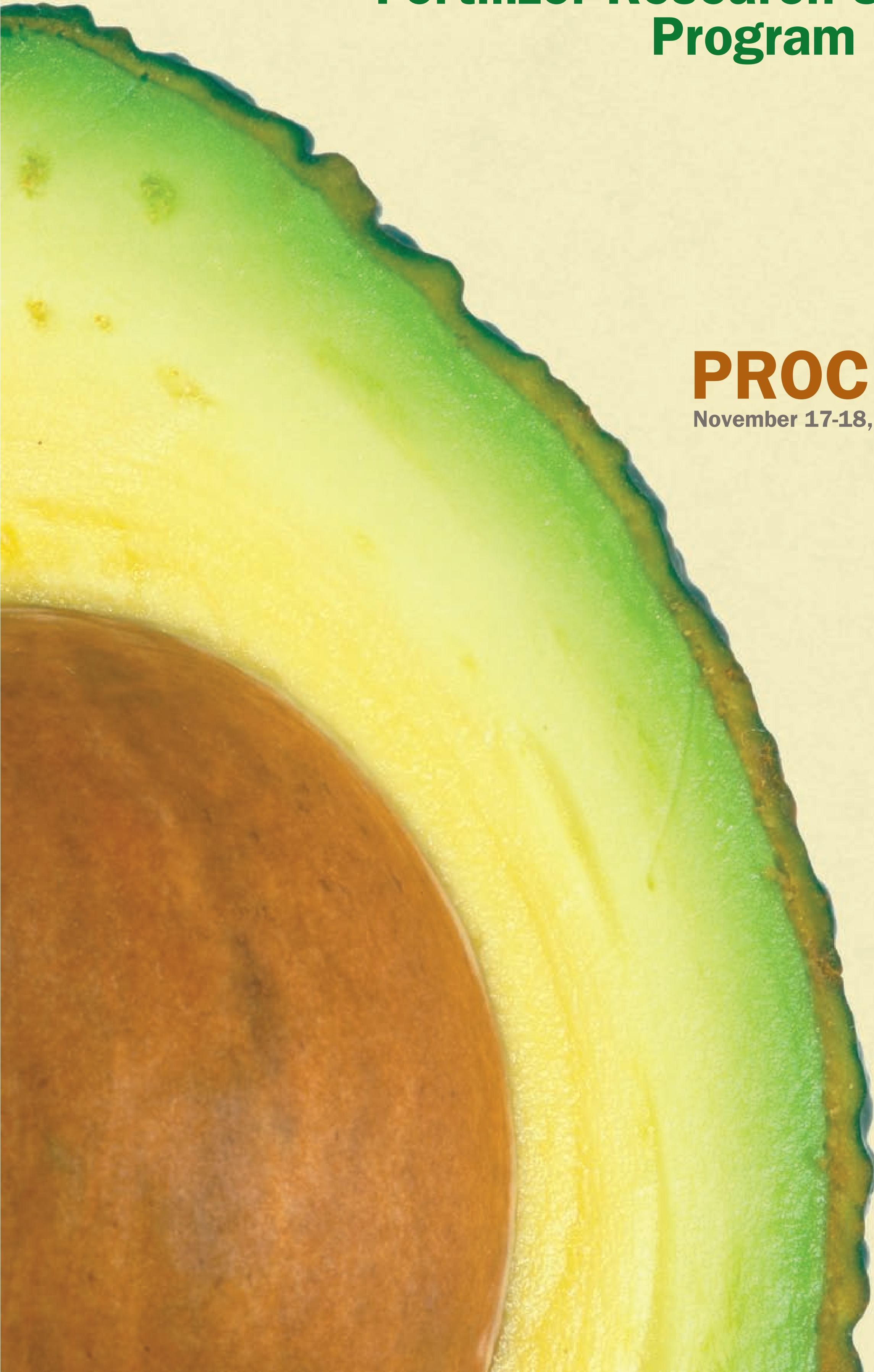

Can a Better Tool for Assessing 'Hass' Avocado Tree Nutrient Status be Developed?

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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 nitrogen, zinc and iron (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 two-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 best management practices (BMP) N (25 pounds N/acre in July, August, November and April; 100 pounds N/acre/year), BMP NPK (25 pounds N, 3.75 pounds P, and 22.5 pounds of K in July, August, November and April; 100 pounds N, 15 pounds P and 90 pounds K/acre/year), 0.5x N (25 pounds N/acre in July and August; 50 pounds N/acre/year) and 0.5x NPK (25 pounds N, 3.75 pounds P, and 22.5 pounds of K in July and August.; 50 pounds N, 7.5 pounds P and 45 pounds K/acre/year) at a new research site in Santa Barbara.

3 Tissues were analyzed for nitrogen, sulfur, phosphorus, potassium, magnesium, calcium, iron, zinc, manganese, boron and copper (N, S, P, K, Mg, Ca, Fe, Zn, Mn, B and Cu). At harvest, yield (number and kilogram fruit), fruit size distribution and fruit quality were determined per tree.

RESULTS AND DISCUSSION

The research was initiated with the start of funding in July 2007. Due to the freeze on January 18, 2007, orchards we had planned to use had to be replaced with new ones. This included the trees in Year 4 of an experiment comparing rates of N versus NPK soil-applied fertilizers. As a result, we did not have the benefit of using trees that had received fertilizer treatments at different rates of N, P, and K for multiple years. Instead, the fertilizer treatments were initiated with the start of the project. In addition, temperatures exceeded 100°F on June 20, 21, and 22, 2008, causing a significant proportion of the setting fruit to abscise from trees in our research orchards located in San Luis Obispo, Santa Barbara and Santa Paula. Despite these constraints, the results we obtained have proven adequate for meeting the objectives of the research.

Nutrient concentrations of cauliflower stage (Young inflorescences, March) and full bloom stage (Mature inflorescences, April) collected from 'Hass' avocado trees in Irvine were significantly greater than pedicels (stems) of mature fruit collected in March and April, respectively, (Table 1). Similarly, for 'Hass' avocado trees in Pauma Valley, cauliflower stage inflorescence had significantly greater nutrient concentrations than the pedicels of mature fruit collected from the same trees in March, with the exception of K and Fe (Table 1). For inflorescences collected from these same trees at full bloom (April), only concentrations of K, S, B, Ca, Zn, Mn, and Cu, but not N, P, Mg or Fe, were greater than those of pedicels of mature fruit also collected in April. It is of great interest that for all trees in the fertilizer experiment in Santa Barbara, regardless of NPK treatment, inflorescences collected at the cauliflower stage (Y. inflorescences) and at full bloom (M. inflorescences) had significantly greater nutrient concentrations for all nutrients (except K in a few cases) than the pedicels of mature fruit collected from the same trees at the same time in March and April, respectively (Table 2).

For the five orchards in which we collected inflorescences at both the cauliflower and full bloom stage of inflorescence development, cauliflower stage inflorescences always had significantly greater concentrations of N, P, Zn, and Cu, but significantly lower concentrations of K and Fe than full bloom inflorescences (data not shown). The results in Santa Barbara were similar. For each fertilizer treatment cauliflower stage inflorescences had significantly greater concentrations of N, P, K, Zn and S, and a significantly lower concentration of Fe. Neither tissue showed differences in concentrations of N, P or K related to the soil fertilization treatments.

Mature leaves (M. leaf) on spring flush, non-fruiting terminal shoots collected in September, the standard time for avocado leaf analysis, had significantly greater concentrations of nutrients than pedicels collected from young fruit (Y. fruit stem) that developed contemporaneously on spring flush, fruiting terminal shoots (Table 1). For avocado trees in Irvine, all nutrient concentrations were greater in leaves than pedicels, but for trees at Pauma Valley and trees in the fertilizer experiment in Santa Barbara, P and/or K concentrations were not significantly greater in leaves (Tables 1 and 2). In Santa Barbara, the N, P, and K concentrations of pedicels from young fruit collected in September did not reflect the NPK fertilization rates in Year 1 or Year 2. Regardless of fertilizer treatment, N, P and K concentrations of the pedicels from young fruit were greater in Year 1 of the experiment than in Year 2 (data not shown).

The failure of pedicels collected from young fruit in June, September and November or mature fruit in March and April to reflect soil-applied fertilizer treatments can be seen in Figure 1. There was a dramatic increase in the P and Mg concentrations of pedicels from young fruit sampled in June in the 0.5x NPK treatment that was not related to a fertilizer application, as trees in this treatment receive NPK fertilizer only in July and August. It was of interest that nutrient concentrations of pedicles increased in most cases over the six-month period from October 2007 (pedicels from young fruit) to April 2008 (pedicels of mature fruit) and by April were typically greater for each treatment than the nutrient concentrations of pedicels from young fruit collected two months later in June (Figure 1). A notable exception was boron. Pedicel boron concentrations were greatest in mature pedicels collected in March. Surprisingly, these relationships, though less pronounced, were evident in the four other avocado orchards, with the exceptions of pedicel S concentrations at Irvine and Pauma Valley and pedicel zinc at Pauma Valley (Figure 2). From our data we cannot tell whether the differences in nutrient concentrations in pedicels from mature fruit in April and young fruit in June reflect the effect of the heavy 2007-2008 on-crop of mature fruit on the lighter 2008-2009 off-crop of young developing fruit in all orchards or whether most nutrients accumulate in the pedicel of fruit throughout their development from June through April the following year; both are intriguing and potentially useful possibilities.

We determined which nutrients in each tissue significantly influenced total yield and yield of commercially valuable large size fruit of packing carton sizes 60 + 48 + 40 (fruit weighing 178 to 325 grams). Using stepwise regression analyses, we determined the most important combination of nutrients for each yield parameter across all orchards. 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 cauliflower stage inflorescences were more strongly related to yield and yield of commercially valuable large size fruit. In this tissue, Cu, Mg and P explained 67% of the variation in yield of fruit of packing carton sizes 60 + 48 + 40 ($P = 0.0049$). However, since the project started in July 2007, we only have one set of tissue samples and corresponding yield data. Using pedicels from young fruit collected in September or November for which we have tissue samples and yield data for two years at four of five sites, we found no significant relationships between tissue nutrient concentrations and yield parameters. The strongest relationships were found with leaf samples, for which we had two years of samples and corresponding yield data at Santa Barbara, Santa Paula, Pauma Valley and Irvine. There was no relationship between leaf nutrient concentrations and total yield. Leaf Ca, Fe, S and Zn concentrations predicted 50% of the variation in yield of commercially valuable large size fruit of packing carton sizes 60 + 48 + 40 ($P = 0.0003$). These same nutrients predicted the yield of all fruit greater than packing carton size 60, accounting for 51% of the variation in yield ($P = 0.0002$).

CONCLUSION

We had a sufficient number of sampling dates, orchards and corresponding yield data, to be able to conclude that pedicels from young or mature fruit of the 'Hass' avocado in California had low nutrient concentrations that were not responsive to the soil fertilizer treatments. However, if it could be determined whether the mature fruit on the tree impact pedicel nutrient concentrations of the setting young crop of fruit or whether pedicel nutrient concentrations increase throughout fruit development, valuable information might be obtained from pedicel nutrient analysis. The nutrient status of the cauliflower stage inflorescence was also not responsive to the NPK soil fertilizer treatments. In addition, we only had one year of paired tissue analysis and yield, but these results were promising. 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 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 (178-325 grams per fruit) ($r^2 = 0.50$; $P = 0.0003$) across all five orchards and fertilizer treatments.

Now that we have identified this relationship, we are looking forward to testing it further with existing data sets. For the final report, we will also analyze all data with yield expressed as number of fruit per tree to compare with the present analyses based on kilograms of fruit per tree. We will also complete the analysis of the huge data set relating tissue nutrient concentrations and fruit quality.

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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).

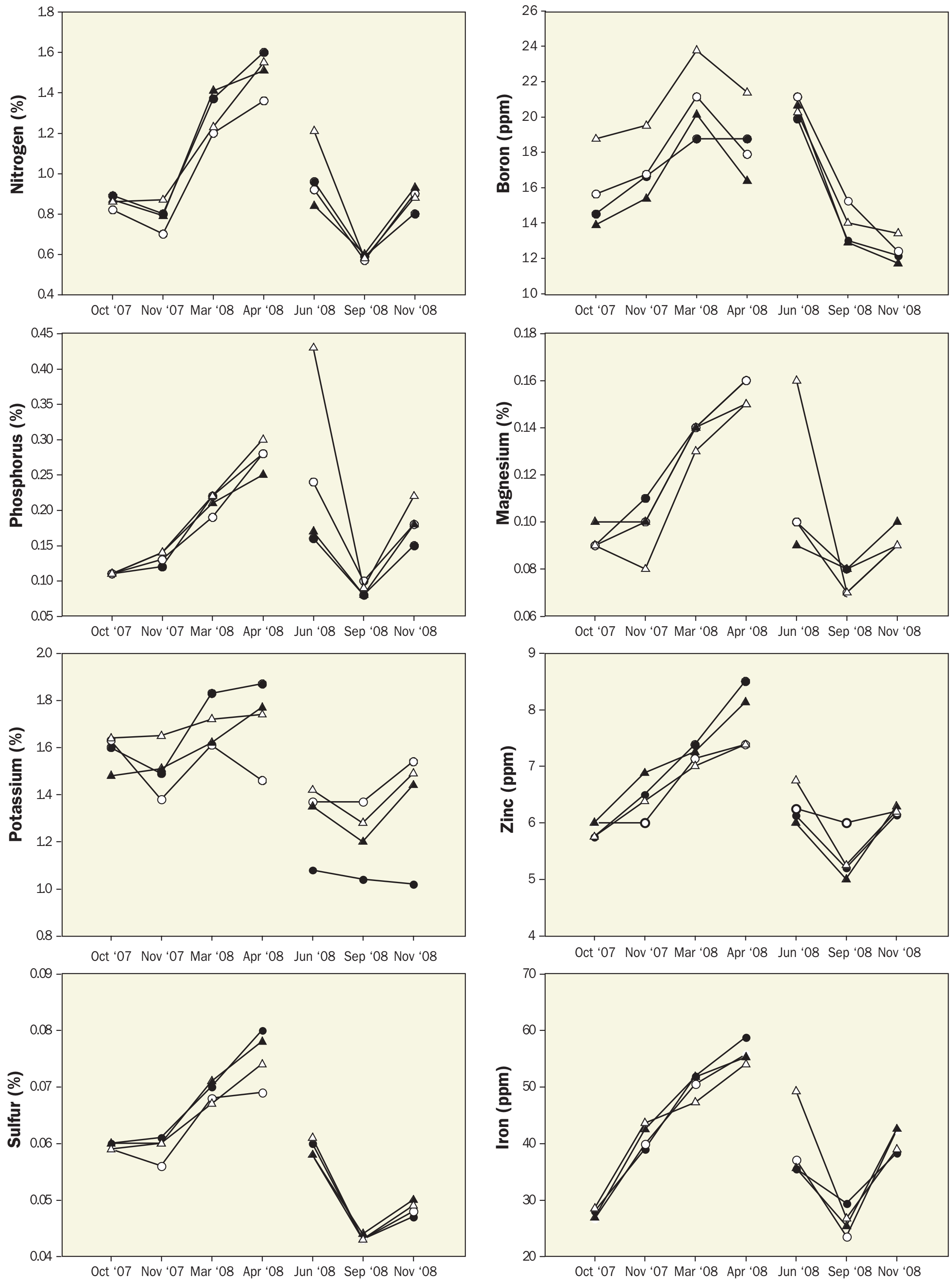

Figure 2.
Nutrient concentrations of pedicels of young fruit (Oct., Nov., June, Sept.) and mature fruit (Mar., Apr.) from 'Hass' avocado trees in Irvine (-•-), Pauma Valley (-○-), Santa Paula (-▲-), San Luis Obispo (-△-), and Santa Barbara (-X-) in the BMP NPK treatment (25 lb N, 3.75 lb P, 22.5 lb K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