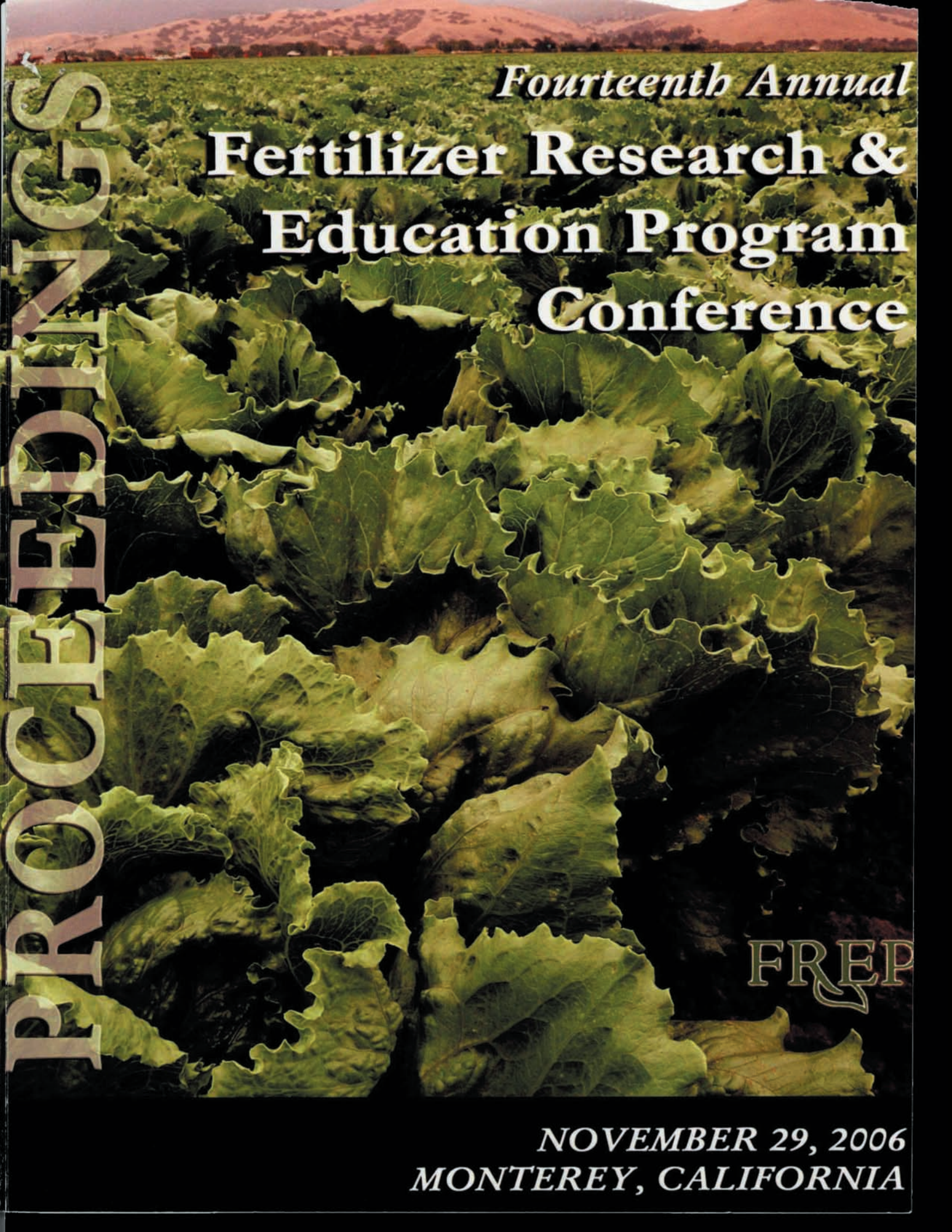
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Increasing Yield of the 'Hass' Avocado by Adding P and K to Properly Timed Soil N Applications

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Introduction

'Hass' avocado yields in California have averaged only 5,700 lbs./acre for the last 25 years (Arpaia, 1998). Experimentally determined leaf nutrient standards and replacement fertilization data related to yield and fruit size are generally lacking for the 'Hass' avocado in California. In a prior study, Lovatt tested the following hypothesis: applying N to the soil at key stages of tree phenology will improve yield parameters. The 4-year study identified key stages in the phenology of the 'Hass' avocado that benefited from a double dose (2x) N (50 lbs./acre). The optimal application times for extra N corresponded to the following phenological events: (1) April – anthesis, fruit set and initiation of the spring vegetative flush and (2) November – end of the fall vegetative flush and beginning of flower initiation. At these phenological stages, soil-applied 2x N significantly increased the 4-year average yield and the 4-year cumulative yield, and increased the yield of commercially valuable large size fruit by 70%. In addition, the April application significantly reduced the alternate bearing index for the 4 years of the study. In our recently completed CDFA FREP-funded project, which was undertaken to test the hypothesis that trees receiving their total annual N (125 lbs./acre per year) applied in equal 1x N doses each at a key stage in 'Hass' avocado phenology (multiple 1x N treatment; 25 lbs./acre x 5 key stages) will yield as well as trees receiving 2x N (50 lbs./acre) or 3x N (75 lbs./acre) at only one or two key stages. Averaged over the 4 years of the experiment, trees that received 2x N in April, 0.8x N in July and August (only 40 lbs./acre per year), and multiple 1x N had significantly more total yield in kilograms fruit per tree than trees receiving 2x N in both November and April or 3x foliar N in April ($P = 0.0178$). N treatment had no significant effect in leaf N concentration for trees in all N treatments or on the amount of N leaching past the root zone for all trees receiving N at 12 lbs./acre per year. The multiple 1x N treatment proved to be equally effective as strategies supplying 2x N in April or 2x in November, but application of 0.8x N (40 lbs./acre per year) in July and August achieved an equally high total yield and yield of large size fruit for the 4 years of the study with 85 lbs./acre per year (68%) less N than all other treatments. This N strategy is more cost-effective and has an inherently lower potential to contribute to nitrate pollution of groundwater than the other N strategies tested. These two research projects were conducted in orchards with optimal nutrition based on standard leaf analysis. Moreover, the orchards were located in two climatically and edaphically different avocado growing areas of California to develop a strategy that works across avocado-producing areas of California. With the identification of the proper time to apply N, the next logical question is whether a greater response to N soil applications would be obtained if P and K were supplied simultaneously. Due to its immobility, P is commonly limiting. K runs a close second due to its high mobility and loss by leaching. In addition, avocado trees have a high demand for K because avocado fruit are rich in K, having more K/g fresh wt. edible fruit than bananas! This project tests the following hypothesis: low available soil P or K at key stages in tree phenology will diminish the tree's response to properly timed soil-applied N.

Project Objectives

The objectives of the proposed research are: (1) to quantify the effects of properly timed soil-applied N vs. N supplemented with P and K on yield, fruit size, and alternate bearing index in a commercial 'Hass' orchard with optimal nutrition based on leaf analysis, and (2) to disseminate the results of the research to the avocado growers of California. Treatments will continue for 3 years in order to obtain the year 2 harvest.

Project Description

To meet objective (1), two fertilizer treatments (N or NPK) were applied at the following times: (A) July and August; (B) November; (C) April; and (D) July, August, November, and April [best management practice for N (BMP N)]. These application times correspond to the following key stages of 'Hass' avocado tree phenology: July – period of rapid cell division and significant increase in fruit size; August – inflorescence initiation; November – end of the fall vegetative flush and beginning of flower initiation; and April – anthesis, fruit set and initiation of the spring vegetative flush. The treatments were replicated on 20 individual trees in a randomized complete block design. N was applied as ammonium nitrate to all treatments as follows: in treatment A, trees received only 50 lbs. N/acre per year, half in July and half in August. Treatments B and C each received 50 lbs. N/acre in November and April, respectively, with the remaining 50 lbs. N/acre applied equally in April, July and August or July, August and November, respectively. Treatment D received 25 lbs. N/acre in July, August, November, and April. Thus, all treatments received 100 lbs. N/acre per year, except treatment A. The N treatments had been in effect for 4 years prior to the addition of P and K to half of the trees in each treatment (20 trees per treatment) in year 1 of this project. The rates of P and K were 15 and 90 lbs./acre per year, respectively, with trees receiving a double dose of P and K (7.5 and 45 lbs./acre, respectively) with the double dose of N (treatments B and C) and as a split application in July and August (treatment A). Treatments B and C, but not A, received the remaining P and K with the remaining N. Trees in BMP for NPK treatment received 3.75 lbs. P and 22.5 lbs. K in July, August, November, and April. The treatments are summarized in Table 1. The orchard is located in Somis, Calif. The trees are 24-year-old 'Hass' on clonal Duke 7 rootstock.

Harvest data included total kg fruit/tree. The weight of 100 randomly selected individual fruit/tree was used to calculate the total number of fruit per tree and the packout (fruit size distribution) per tree as kg and number of fruit of packing carton sizes 84 (99-134 g/fruit), 70 (135-177 g/fruit), 60 (178-212 g/fruit), 48 (213-269 g/fruit), 40 (270-325 g/fruit), 36 (326-354 g/fruit) and 32 (355-397 g/fruit). Two fruit per tree were evaluated for the length of time to ripen, peel color at maturity, and internal fruit quality (seed germination, vascularization, discoloration, decay). Fruit

Table 1. N, P and K fertilization strategies.

	Month of application														
	April			July			August			November			Total		
Treatment	N[z]	P	K	N	P	K	N	P	K	N	P	K	N	P	K
	lbs./acre														
1x N in July +August	–	–	–	25	–	–	25	–	–	–	–	–	50	–	–
1x NPK in July + August	–	–	–	25	3.75	22.5	25	3.75	22.5	–	–	–	50	7.5	45
2x N in November	16.7	–	–	16.7	–	–	16.7	–	–	50	–	–	100	–	–
2x NPK in November	16.7	2.5	15	16.7	2.5	15	16.7	2.5	15	50	7.5	45	100	15	90
2x N in April	50	–	–	16.7	–	–	16.7	–	–	16.7	–	–	100	–	–
2x NPK in April	50	7.5	45	16.7	2.5	15	16.7	2.5	15	16.7	2.5	15	100	15	90
BMP N (Control) (1x N in July, Aug., Nov. + Apr.)	25	–	–	25	–	–	25	–	–	25	–	–	100	–	–
BMP NPK (1x NPK in July, Aug., Nov. + Apr.)	25	3.75	22.5	25	3.75	22.5	25	3.75	22.5	25	3.75	22.5	100	15	90

z *Nitrogen applied as ammonium nitrate.*

Table 2. Effect of soil-applied N or NPK fertilizer on leaf total N, P and K (expressed as % dry wt.) of the 'Hass' avocado. Data for 2006 are not available, yet.

	2004			2005		
Treatment	N	P	K	N	P	K
1x N in July +August	2.31 b[z]	0.15 bc	1.23	2.13 ab	0.16 b	1.21 c
1x NPK in July + August	2.28 b	0.16 a	1.31	2.17 ab	0.16 ab	1.32 ab
2x N in November	2.37 ab	0.16 abc	1.29	2.22 a	0.18 a	1.35 a
2x NPK in November	2.35 ab	0.15 bc	1.19	2.03 b	0.16 ab	1.22 c
2x N in April	2.34 ab	0.15 bc	1.22	2.20 a	0.17 ab	1.24 bc
2x NPK in April	2.45 a	0.15 abc	1.24	2.25 a	0.17 ab	1.22 c
BMP N (Control) (1x N in July, Aug., Nov. + Apr.)	2.38 ab	0.16 ab	1.26	2.25 a	0.17 ab	1.24 bc
BMP NPK (1x NPK in July, Aug., Nov. + Apr.)	2.33 b	0.14 c	1.26	2.17 ab	0.16 ab	1.20 c
P-value	0.0417	0.0339	0.4861	0.0282	0.1078	0.0107

z *Means in a vertical column followed by a different letter are different at P = 0.05 by Duncan's Multiple Range Test.*

quality parameters are visually determined using a scale from 0 (none) to 4 (extensive, present in all four quarters of the fruit).

The severity of alternate bearing is expressed as the alternate bearing index (ABI). ABI was calculated for each sequential 2-year period using the equation: ABI = (year 1 yield minus year 2 yield) / (sum of year 1 yield plus year 2 yield), where yield is in kilograms fruit per tree. When ABI = 1.0, there is complete alternate bearing, i.e., crop one year with no crop the second year. An ABI of zero means alternate bearing is absent.

The experimental design, with 20 individual tree replications per treatment, was a randomized complete block design. Repeated measures analysis was used to test for treatment effects on yield parameters with year as the repeated measures factor. This analysis was performed using the General Linear Model procedures of the SAS statistical program (SAS Inst., Inc., Cary, N.C.). ANOVA was used to test for treatment effects on leaf nutrient concentrations, yield, cumulative yield, fruit size, and fruit quality parameters. Means were separated using Duncan's multiple range test at P = 0.05.

Results

Leaf N concentration

When leaves were collected for analysis in Sept. 2004, the trees had only been under treatment for half a year, so trees had not received their total annual N or NPK, except trees receiving 1x N or NPK in July and August only. In 2004, September leaf N concentrations were higher than the 2.1% recommended by the California Avocado Commission for the 'Hass' avocado. By Sept. 2004, trees receiving 2x NPK in April had the highest leaf N concentration, which was significantly greater than leaves from trees receiving 0.8x N or NPK in July and August and the BMP NPK treatment, but not significantly different from leaves of trees receiving 2x N in April, BMP N or 2x N or NPK in November, which had intermediate leaf N concentrations (Table 2). In 2005, leaf N concentrations for trees in all treatments were lower and closer to the recommended 2.1% N. Trees receiving 2x NPK in April again had the highest leaf N concentration obtained, but it was not significantly different from that of trees receiving BMP N, 2x N in April, or 2x N in November, all of which had leaf N concentrations significantly greater than trees receiving 2x NPK in November. Trees receiving 1x N or NPK in July and August or BMP NPK had intermediate concentrations of leaf N that were not significantly different from leaf N concentrations for all other treatments (Table 2).

Leaf P concentration

Leaf P in 2004 tended to be lower than in 2005, but within the preferred range presently in use. In addition, the 2004 leaf P concentrations exhibited more variation than in 2005 (Table 2), but keep in mind that only trees receiving 1x N or NPK in July and August had received their total annual N or NPK treatment. In 2004, trees receiving 0.8x NPK in July and August had greater leaf P concentrations than trees

receiving 1x N in July and August, 2x NPK in November, 2x N in April and BMP NPK. Trees in the BMP N treatment had leaf P concentrations that were intermediate but still significantly greater than trees in the BMP NPK treatment. Trees receiving 2x N in November and 2x NPK in April had leaf P concentrations that were intermediate and not significantly different from any other treatment. In 2005, September leaf P concentrations were optimal for all treatments. Trees receiving 2x N in November had the highest leaf P concentration, which was significantly greater than trees receiving 1x N in July and August but only at P = 0.1078 (Table 2). Leaf P concentrations for all other treatments were intermediate and not significantly different from all other treatments.

Leaf K concentration

In 2004, there were no significant treatment effects on leaf K concentration (Table 2). Values ranged from 1.19% to 1.33%, which were within the current optimal range. By 2005, leaf K concentration was significantly affected by the fertilizer treatments (Table 2). Trees receiving 2x N in November had the highest leaf K concentration and it was significantly greater than leaf K for trees in all other treatments except trees receiving 0.8x NPK in July and August. Trees receiving 1x NPK in July and August had greater leaf K concentrations than trees receiving 1x N in July and August, but also trees in all other NPK treatments, i.e., 2x NPK in November, 2x NPK in April and BMP NPK. Leaf K was well within the current optimal range for trees in all treatments.

Relationships between leaf nutrient concentrations and yield parameters

Leaf N was not related to total yield or fruit size in either year of the study. This is consistent with results obtained in all other N fertilization studies with the 'Hass' avocado (Lovatt, C.J. and G. Witney. 2001. AvoResearch 1(3):1-4, 11). Leaf P concentration in Sept. 2004 was positively and significantly ($P < 0.0001$) related to the yield of large size fruit (packing carton sizes 60+48+40) in the harvest of 2004, the on-crop year. Leaf P concentration explained 22% of the variation in the yield of large size fruit. Sept. 2005 leaf P concentrations were not significantly related to any yield parameter. Leaf K concentration in Sept. 2004 and 2005 was not related to any yield parameter.

Leaf nutrient analyses for 2006

Leaves were collected during the second week of September but the results of the analyses are unknown at this time.

Yield 2006

Fertilizer treatment had a statistically significant effect on total yield as both kilograms (P = 0.0146) and number of fruit (P = 0.0345) per tree (Tables 3 and 4). The best treatment was 1x NPK in July and August only. It was significantly better than all other treatments except 1x N in July and August only and BMP N (control), which were intermediate to and not significantly different from any other treatment. Fertilizer strategies also significantly affected the yield of large size fruit of packing carton sizes 60 (P = 0.0028), 48 (P = 0.0044) and 40 (P = 0.0996) and the yield of fruit in the combined pool of fruit of packing

Table 3. Effect of N versus N, P and K fertilization strategies on the yield and fruit size of 'Hass' avocado harvested in 2006.

		Yield of small and large fruit based on packing carton sizes[z]						
Treatment	Total yield	84	70	Σ84-70	60	48	40	Σ60-40
	kg fruit/tree							
1x N in July +August	36.47 ab[y]	3.55	13.97	17.52	10.01 bc	7.32 b	1.51 ab	18.84 b
1x NPK in July + August	57.21 a	4.52	20.14	24.65	18.70 a	12.14 a	1.60 a	32.44 a
2x N in November	29.44 b	1.77	11.46	13.23	10.15 bc	5.74 b	0.30 b	16.20 b
2x NPK in November	25.25 b	3.40	10.17	13.57	6.59 c	3.90 b	1.11 ab	11.61 b
2x N in April	29.25 b	2.40	9.68	12.08	8.62 bc	6.92 b	1.50 ab	17.04 b
2x NPK in April	30.63 b	3.85	12.23	16.08	9.33 bc	4.45 b	0.74 ab	14.51 b
BMP N (Control) (1x N in July, Aug., Nov. + Apr.)	42.55 ab	3.42	17.73	21.15	14.22 ab	6.86 b	0.32 b	21.40 b
BMP NPK (1x NPK in July, Aug., Nov. + Apr.)	20.95 b	2.69	8.11	10.80	5.52 c	4.03 b	0.58 ab	10.13 b
P-value	0.0146	0.8340	0.1432	0.2839	0.0028	0.0044	0.0996	0.0015

z Packing carton fruit sizes include 84 (94-134 g), 70 (135-177 g), 60 (178-212 g), 48 (213-269 g) and 40 (270-325 g).
y Means in a vertical column followed by a different letter are different at P = 0.05 by Duncan's Multiple Range Test.

Table 4. Effect of N versus N, P and K fertilization strategies on the yield and fruit size of 'Hass' avocado harvested in 2006.

		Yield of small and large fruit based on packing carton sizes[z]						
Treatment	Total yield	84	70	Σ84-70	60	48	40	Σ60-40
	No. fruit/tree							
1x N in July +August	207 ab[y]	31	90	120	51 bc	30 b	5.1 ab	87 b
1x NPK in July + August	320 a	39	129	168	96 a	50 a	5.4 a	152 a
2x N in November	166 b	15	73	89	52 bc	24 b	1.0 b	77 b
2x NPK in November	148 b	29	65	94	34 c	16 b	3.7 ab	54 b
2x N in April	161 b	21	62	83	44 bc	29 b	5.0 ab	78 b
2x NPK in April	180 b	33	78	111	48 bc	18 b	2.5 ab	69 b
BMP N (Control)	245 ab	29	114	143	73 ab	28 b	1.1 b	102 ab
(1x N in July, Aug., Nov. + Apr.) BMP NPK	122 b	23	52	75	28 c	17 b	2.0 ab	47 b
(1x NPK in July, Aug., Nov. + Apr.) P-value	0.0345	0.8340	0.1432	0.3307	0.0028	0.0044	0.0996	0.0014

z Packing carton fruit sizes include 84 (94-134 g), 70 (135-177 g), 60 (178-212 g), 48 (213-269 g) and 40 (270-325 g).

y Means in a vertical column followed by a different letter are different at P = 0.05 by Duncan's Multiple Range Test.

carton sizes 60, 48 and 40 (P = 0.0015) as kilograms fruit per tree (Table 3). In all cases, the best treatment was 1x NPK in July and August only. The same was true when yield was determined in number of fruit per tree (Table 4). Thus, 1x NPK applied in July and August not only increased fruit retention, but also increased fruit growth. Comparison of the BMP N treatment with the BMP NPK treatment in Tables 3 and 4 provides clear evidence that supplying P and K this frequently at the rate used in this study has a negative effect on yield. There were no fertilizer treatment effects on the number of days required for fruit to ripen after harvest, fruit length, fruit width or seed size, but treatments influenced the width of the flesh (edible portion of the fruit) (P = 0.0046) (Table 5). Trees treated with BMP NPK produced fruit with significantly wider flesh than fruit from trees treated with 1x N in July and August, 2x N in April and BMP N (control) (Table 5). Fruit from all other treatments had flesh that was intermediate in width and not significantly different from any other treatment. Fertilizer strategies had no significant effect on peel color, flesh quality, or seed germination.

Three-year average yield

When averaged across the 3 years of the study, fertilizer strategies had significant effects on total yield as kilograms (P = 0.0020) and number of fruit (P = 0.0060) per tree (Tables 6 and 7). Trees treated with 1x NPK in July and August had a significantly greater 3-year average total yield in kilograms per tree than trees treated with 2x N in November, 2x NPK in November, 2x NPK in April and BMP NPK. Trees receiving other treatments had 3-year average total yields that were intermediate and not significantly different from any other treatment (Table 6). The BMP N (control) treatment resulted in a 3-year average yield of small fruit of packing carton size 70 that was significantly greater as both kilograms and number of fruit per tree than trees receiving 2x N in November, 2x NPK in November, 2x NPK in April or BMP NPK (P = 0.0221) (Tables 6 and 7). Trees receiving 1x NPK in July and August or BMP N (control) had a significantly greater 3-year average yield of large size fruit of packing carton size 60 as both kilograms (P = 0.0133) and number of fruit (P = 0.0133) per tree compared to trees receiving 2x NPK in November and BMP NPK (Tables 6 and 7). Trees receiving 1x NPK in July and August or 2x N in April had the highest 3-year average yields of fruit in the combined pool of fruit of packing carton sizes 60, 48 and 40 as both kilograms (P = 0.0223) and number of fruit (P = 0.0170) per tree (Tables 6 and 7). All other treatments produced yields that were intermediate and not significantly different from any other treatment. Year had a statistically significant effect on every yield parameter except the kilograms and number of fruit of packing carton size 60 (Tables 6 and 7). Year 1 was an on-crop year followed by two off-crop years. Note that the first off-crop was characterized by the production of large size fruit at the expense of small size fruit. In contrast, the subsequent off-crop was comprised predominantly of small size fruit with few large size fruit (Tables 6 and 7). Treatment by year interactions affected the yield (as both kilograms and number of fruit per tree) of fruit of packing carton sizes 60 (P = 0.0385) and 48 (P = 0.0143) and yield

Table 5. Effect of N versus N, P and K fertilization strategies on fruit quality of the 'Hass' avocado harvested in 2006.

Treatment	Days to ripen	Fruit length	Fruit width	Seed diameter	Flesh width	Peel color	Seed germination	Flesh quality[z]		
								Vascularization	Discoloration	Decay
1x N in July +August	11.1	89.29	62.98	34.40	28.82 bc[y]	3.7	0.4	0.6	0.8	0.3
1x NPK in July + August	10.4	89.79	63.41	34.38	29.03 abc	3.6	0.5	0.4	0.4	0.2
2x N in November	10.4	92.49	64.98	35.19	29.55 abc	3.6	0.2	0.8	0.9	0.6
2x NPK in November	10.0	91.15	64.06	34.83	29.11 abc	3.6	0.2	0.5	0.7	0.2
2x N in April	10.7	90.95	64.27	35.90	27.85 c	3.7	0.4	0.8	0.6	0.3
2x NPK in April	9.6	89.79	64.71	34.30	30.53 ab	3.5	0.3	0.4	0.4	0.3
BMP N (Control) (1x N in July, Aug., Nov. + Apr.)	10.8	89.58	62.92	34.23	28.56 c	3.7	0.3	0.5	0.7	0.2
BMP NPK (1x NPK in July, Aug., Nov. + Apr.)	9.8	93.78	65.44	34.78	30.66 a	3.6	0.2	0.4	0.5	0.2
P-value	0.1082	0.1081	0.2326	0.8166	0.0046	0.6754	0.7276	0.1554	0.5717	0.3153

z When ripe, internal fruit quality was evaluated for abnormalities and discoloration. Vascularization (presence of vascular bundles and associated fibers) of the flesh was also determined. The internal fruit quality parameters were visually rated on a scale from 0 (normal) to 4 (high incidence of abnormalities, discoloration, or vascularization).

y Means in a vertical column followed by a different letter are different at P = 0.05 by Duncan's Multiple Range Test.

Table 6. Effect of N versus N, P and K fertilization strategies on the 3-year average yield and fruit size of 'Hass' avocado harvested in 2004, 2005 and 2006.

	Total yield	Yield of small and large fruit based on packing carton sizes[z]						
		84	70	Σ84-70	60	48	40	Σ60-40
	kg fruit/tree							
Treatment								
1x N in July +August	39.11 abc[y]	2.48	9.32 abc	11.79 ab	10.16 abc	12.44	4.28	26.87 ab
1x NPK in July + August	46.23 a	2.77	12.31 ab	15.08 ab	12.58 a	12.27	4.36	29.22 a
2x N in November	36.24 bc	1.08	7.43 bc	8.51 b	10.72 abc	11.82	4.13	26.67 ab
2x NPK in November	33.00 c	1.89	7.23 c	9.12 b	8.87 bc	10.25	2.99	22.11 b
2x N in April	42.57 ab	2.87	8.87 abc	11.74 ab	12.27 ab	13.62	4.17	30.06 a
2x NPK in April	36.74 bc	2.34	8.16 bc	10.50 ab	10.21 abc	11.75	3.72	25.67 ab
BMP N (Control) (1x N in July, Aug., Nov. + Apr.)	45.07 ab	2.52	13.52 a	16.04 a	13.60 a	11.30	3.15	28.06 ab
BMP NPK (1x NPK in July, Aug., Nov. + Apr.)	32.28 c	1.72	8.44 bc	10.17 ab	8.50 c	10.10	3.01	21.62 b
Year								
2004	49.58 a	3.06 a	10.72 a	13.77 a	11.91	14.70 a	6.70 a	33.31 a
2005	33.29 b	0.40 b	4.61 b	5.01 b	10.35	14.04 a	3.55 b	27.95 a
2006	33.97 b	3.21 a	12.94 a	16.14 a	10.38	6.41 b	0.96 c	17.76 b
P-value								
Treatment (T)	0.0020	0.6343	0.0221	0.0866	0.0133	0.3228	0.3972	0.0223
Year (Y)	0.0005	<0.0001	<0.0001	<0.0001	0.5946	<0.0001	<0.0001	<0.0001
T x Y	0.0624	0.8580	0.5486	0.6964	0.0385	0.0143	0.6663	0.0143

z Packing carton fruit sizes include 84 (94-134 g), 70 (135-177 g), 60 (178-212 g), 48 (213-269 g) and 40 (270-325 g).

y Means in a vertical column followed by a different letter are different at P = 0.05 by Duncan's Multiple Range Test.

Table 7. Effect of N versus N, P and K fertilization strategies on the 3-year average yield and fruit size of 'Hass' avocado harvested in 2004, 2005 and 2006.

		Yield of small and large fruit based on packing carton sizes[z]						
	Total yield	84	70	Σ84-70	60	48	40	Σ60-40
	No. fruit/tree							
Treatment								
1x N in July +August	200 ab[y]	21	60 abc	81	52 abc	52	14	118 abc
1x NPK in July + August	235 a	24	79 ab	103	65 a	51	15	130 a
2x N in November	178 b	9	48 bc	57	55 abc	49	14	118 abc
2x NPK in November	163 b	16	46 c	63	45 bc	43	10	98 bc
2x N in April	217 ab	25	57 abc	82	63 ab	57	14	133 a
2x NPK in April	188 ab	20	52 bc	72	52 abc	49	13	114 abc
BMP N (Control) (1x N in July, Aug., Nov. + Apr.)	238 a	22	87 a	108	70 a	47	11	127 ab
BMP NPK (1x NPK in July, Aug., Nov. + Apr.)	166 b	15	54 bc	69	44 c	42	10	96 c
Year								
2004	245 a	26 a	69 a	95 a	61	61 a	23 a	145 a
2005	157 b	3 b	30 b	33 b	53	58 a	12 b	123 a
2006	194 ab	28 a	83 a	110 a	53	27 b	3 c	83 b
P-value								
Treatment (T)	0.0060	0.6343	0.0221	0.1172	0.0133	0.3228	0.3972	0.0170
Year (Y)	0.0041	<0.0001	<0.0001	<0.0001	0.5946	<0.0001	<0.0001	<0.0001
T x Y	0.1513	0.8580	0.5486	0.7269	0.0385	0.0143	0.6663	0.0137

z Packing carton fruit sizes include 84 (94-134 g), 70 (135-177 g), 60 (178-212 g), 48 (213-269 g) and 40 (270-325 g)

y Means in a vertical column followed by a different letter are different at P = 0.05 by Duncan's Multiple Range Test.

of fruit in the combined pool of packing carton sizes 60, 48 and 40 (P = 0.0143) (Tables 6 and 7).

Three-year cumulative yield

The fertilizer strategies significantly affected 3-year cumulative total yield as both kilograms (P = 0.0035) and number of fruit (P = 0.0111) per tree (Tables 8 and 9). Trees receiving 1x NPK in July and August produced a significantly greater 3-year cumulative total yield (in kilograms and number of fruit per tree) than trees receiving 2x N in November, 2x NPK in November, 2x NPK in April and BMP NPK. All other treatments resulted in intermediate 3-year cumulative total yields that were not significantly different from any other treatment (Tables 8 and 9). Trees receiving 1x NPK in July and August or BMP N (control) had marginally greater 3-year cumulative yields of fruit of packing carton size 60 (as kilograms and number of fruit per tree) than trees receiving BMP NPK, but not any other treatment (P = 0.0661) (Tables 8 and 9). Trees receiving 1x NPK in July and August and 2x N in April had significantly higher yields of fruit in the combined pool of packing carton sizes 60, 48 and 40 as both kilograms (P = 0.0109) and number of fruit (P = 0.0105) per tree than trees receiving 2x NPK in November and BMP NPK (Tables 8 and 9). Yields for all other treatments were intermediate and not significantly different from any other treatment.

Three-year average fruit quality

Averaged over the 3 years of the experiment, fertilizer treatment had a significant effect only on vascularization, the presence of vascular bundles, and associated fibers in the flesh (P = 0.0405) (Table 10). The lowest amount of vascularization was in fruit from trees receiving 1x NPK in July and August and 2x NPK in April. Year was a significant factor influencing the number of days required for fruit to ripen, vascularization, flesh discoloration, and decay. There was, however, no significant treatment by year interactions (Table 10).

Alternate bearing

The alternate bearing index (ABI) for 2004-2005 ranged from 0.54 to 0.66 (Table 11). For 2005-2006, alternate

Table 8. Effect of N versus N, P and K fertilization strategies on the 3-year cumulative yield and fruit size of 'Hass' avocado harvested in 2004, 2005 and 2006.

		Yield of small and large fruit based on packing carton sizes[z]						
Treatment	**Total yield**	**84**	**70**	**Σ84-70**	**60**	**48**	**40**	**Σ60-40**
	kg fruit/tree							
1x N in July +August	115.78 abc[y]	7.02	26.57 ab	33.60	28.81 ab	37.20	14.33	80.33 abc
1x NPK in July + August	138.58 a	7.86	35.14 a	43.00	37.83 a	39.26	15.60	92.68 a
2x N in November	108.61 bc	3.21	20.56 b	23.77	29.65 ab	36.46	14.78	80.88 abc
2x NPK in November	99.10 c	4.84	21.28 b	26.12	27.26 ab	32.21	10.58	70.05 bc
2x N in April	127.55 ab	7.96	25.68 ab	33.64	34.32 ab	41.67	15.09	91.08 a
2x NPK in April	110.16 bc	6.52	22.81 ab	29.33	29.55 ab	36.20	13.19	78.93 abc
BMP N (Control) (1x N in July, Aug., Nov. + Apr.)	133.26 ab	6.18	33.31 ab	39.48	37.50 a	37.87	14.09	89.47 ab
BMP NPK (1x NPK in July, Aug., Nov. + Apr.)	96.68 c	5.11	24.65 ab	29.76	25.66 b	30.11	9.63	65.40 c
P-value	0.0035	0.5359	0.0969	0.1854	0.0661	0.1586	0.3758	0.0109

z Packing carton fruit sizes include 84 (94-134 g), 70 (135-177 g), 60 (178-212 g), 48 (213-269 g) and 40 (270-325 g).

y Means in a vertical column followed by a different letter are different at P = 0.05 by Duncan's Multiple Range Test.

Table 9. Effect of N versus N, P and K fertilization strategies on the 3-year cumulative yield and fruit size of 'Hass' avocado harvested in 2004, 2005 and 2006.

		Yield of small and large fruit based on packing carton sizes[z]						
Treatment	**Total yield**	**84**	**70**	**Σ84-70**	**60**	**48**	**40**	**Σ60-40**
	No. fruit/tree							
1x N in July +August	586 abc[y]	60	170 ab	231	148 ab	154	48	350 ab
1x NPK in July + August	710 a	67	225 a	293	194 a	163	52	409 a
2x N in November	524 bc	28	132 b	159	152 ab	151	50	353 ab
2x NPK in November	493 c	42	136 b	178	140 ab	134	36	309 b
2x N in April	641 abc	68	165 ab	233	176 ab	173	51	400 a
2x NPK in April	554 abc	56	146 ab	202	152 ab	150	44	346 ab
BMP N (Control) (1x N in July, Aug., Nov. + Apr.)	676 ab	53	214 ab	267	192 a	157	47	397 a
BMP NPK (1x NPK in July, Aug., Nov. + Apr.)	495 c	44	158 ab	202	132 b	125	32	289 b
P-value	0.0111	0.5359	0.0969	0.2142	0.0661	0.1586	0.3758	0.0105

z Packing carton fruit sizes include 84 (94-134 g), 70 (135-177 g), 60 (178-212 g), 48 (213-269 g) and 40 (270-325 g).

y Means in a vertical column followed by a different letter are different at P = 0.05 by Duncan's Multiple Range Test.

Table 10. Effect of N versus N, P and K fertilization strategies on 3-year average fruit quality of the 'Hass' avocado harvested in 2004, 2005 and 2006.

	Days to ripen	Flesh quality[z]		
		Vascularization	Discoloration	Decay
Treatment				
1x N in July +August	10.4	0.4 ab[y]	0.60	0.30
1x NPK in July + August	9.8	0.3 b	0.60	0.30
2x N in November	10.0	0.5 a	0.70	0.40
2x NPK in November	10.2	0.3 ab	0.70	0.30
2x N in April	10.2	0.4 ab	0.50	0.30
2x NPK in April	9.4	0.3 b	0.50	0.20
BMP N (Control) (1x N in July, Aug., Nov. + Apr.)	10.2	0.4 ab	0.60	0.20
BMP NPK (1x NPK in July, Aug., Nov. + Apr.)	10.0	0.3 ab	0.50	0.30
Year				
2004	9.3 b	0.2 c	0.3 c	0.1 c
2005	10.4 a	0.3 b	0.9 a	0.5 a
2006	10.3 a	0.5 a	0.6 b	0.3 b
P-value				
Treatment (T)	0.2949	0.0405	0.5376	0.5915
Year (Y)	<0.0001	<0.0001	<0.0001	<0.0001
T x Y	0.3373	0.2257	0.7116	0.5253

z When ripe, internal fruit quality was evaluated for abnormalities and discoloration. Vascularization (presence of vascular bundles and associated fibers) of the flesh was also determined. The internal fruit quality parameters were visually rated on a scale from 0 (normal) to 4 (high incidence of abnormalities, discoloration, or vascularization).

y Means in a vertical column followed by a different letter are different at P = 0.05 by Duncan's Multiple Range Test.

bearing was more severe, i.e., ABIs ranged from 0.62 to 0.70 (Table 11). The fertilizer treatments had no significant effect on alternate bearing (Table 11).

Conclusions

Supplementing the 1x N in July and August with P and K had a consistent beneficial, though not significant, effect on total yield and yield of commercially valuable large size fruit (packing carton sizes 60, 48 and 40; fruit weighing 178-325 g/fruit) compared to trees receiving only 1x N in July and August. Trees treated with 1x NPK in July and August produced total yields and yields of large size fruit (178-325 g/fruit) equal to or better than trees receiving all other treatments, including the BMP N (control) or BMP NPK treatments. Note that trees receiving 1x NPK in July and August received 50% less N, P, and K than trees in all other treatments. Yield results obtained in two separate CDFA FREP-funded projects identified the fertilizer application time of July and August, combined with a significantly reduced rate of fertilizer, as equal to or better than other strategies requiring more frequent applications and a higher total annual rate of fertilizer (N or NPK). July and August correspond to the following phenological and physiological events: July – period of "June" drop for the current crop (Garner, 2004), rapid N and K uptake by mature fruit from the previous spring bloom (Rosecrance and Lovatt, personal communication), and development of the summer vegetative flush (Salazar-García et al., 1998) and August – period of exponential increase in fruit size for the current crop and abscission of mature fruit (Garner, 2004), and inflorescence initiation for next year's crop (Salazar-García et al., 1998).

Table 11. Effect of N versus N, P and K fertilization strategies on the alternate bearing index of 'Hass' avocado harvested in 2004, 2005 and 2006.

	Alternate bearing index		
Treatment	**2004-2005**	**2005-2006**	**2-year average**
1x N in July +August	0.60	0.63	0.61
1x NPK in July + August	0.66	0.66	0.66
2x N in November	0.58	0.70	0.64
2x NPK in November	0.61	0.64	0.60
2x N in April	0.59	0.70	0.65
2x NPK in April	0.55	0.68	0.61
BMP N (Control) (1x N in July, Aug., Nov. + Apr.)	0.59	0.66	0.63
BMP NPK (1x NPK in July, Aug., Nov. + Apr.)	0.54	0.62	0.60
P-value	0.9286	0.9927	0.9922

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