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INCREASING YIELD OF THE 'HASS' AVOCADO BY ADDING P AND K TO PROPERLY TIMED SOIL N APPLICATIONS

Project Leader
Carol J. Lovatt, Professor of Plant Physiology
Dept. of Botany and Plant Sciences
University of California
Riverside, CA 92521-0124
Phone: 951.827.4663; FAX: 951.827.4437
E-mail: carol.lovatt@ucr.edu

Cooperator
John Grether
Grether Farming Company, Inc.
4049 Walnut Avenue
Somis, CA 93066
Phone: 805.485.1877
E-mail: john@gretherfarming.com

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 by 70% yield of commercially valuable large size fruit. In addition, the April application significantly reduced the alternate bearing index for the 4 years of the study. In our similar, recently completed CDFA FREP-funded project on optimal timing of N fertilization, treatments producing the three numerically, but not statistically, greater cumulative yields for 2001 plus 2002 were the soil application of 3x N in April > the control > application of 2x N in November. In this study, each of the optimal times for applying N was incorporated into the control as a single dose of N (1x N, 25 lbs. N/acre). The optimal times that N was applied in the control treatment were: 1) April – anthesis, fruit set and initiation of the spring vegetative flush; 2) July – rapid increase in fruit size; 3) August – transition from vegetative to reproductive development, i.e., inflorescence initiation; and 4) November – end of the fall vegetative flush and beginning of flower initiation. No treatment significantly affected potential nitrate pollution of groundwater, but the control treatment did reduce its potential by a large numerical value. 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 three 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/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/year, except treatment A. The N treatments had been in effect for four 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/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/trees were used to calculate the total number of fruit per tree and the packout (fruit size distribution)/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 quality parameters are visually determined using a scale from 0 (none) to 4 (extensive, present in all four quarters of the fruit). All data were statistically analyzed using the General Linear Model procedures of SAS. ANOVA will be used to test for treatment effects on leaf nutrient concentrations, yield, fruit size, and fruit quality parameters. Means will be separated using Duncan's multiple range test at P=0.05.

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														
July + August N	–	–	–	25	–	–	25	–	–	–	–	–	50	–	–
July + August NPK	–	–	–	25	3.75	22.5	25	3.75	22.5	–	–	–	50	7.5	45
November N	16.7	–	–	16.7	–	–	16.7	–	–	50	–	–	100	–	–
November NPK	16.7	2.5	15	16.7	2.5	15	16.7	2.5	15	50	7.5	45	100	15	90
April N	50	–	–	16.7	–	–	16.7	–	–	16.7	–	–	100	–	–
April NPK	50	7.5	45	16.7	2.5	15	16.7	2.5	15	16.7	2.5	15	100	15	90
BMP N	25	–	–	25	–	–	25	–	–	25	–	–	100	–	–
BMP NPK	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.

In Year 3, when the second set of harvest data for which all trees received the fertilizer treatments for the full duration of the development of the crop (the 2005 and 2006 harvests), treatment effects on cumulative yield and on the alternate bearing index [ABI = (Year 1 yield - Year 2 yield) ÷ (Year 1 yield + Year 2 yield)] will be determined by ANOVA. Treatment effects across years will be determined by repeated measures analysis with year as the repeated measures factor. A cost/benefit analysis for each treatment will be calculated.

RESULTS AND CONCLUSIONS

The 2005 yield was the first in which all trees received the fertilization treatments prior to and during the initiation of floral development, flowering, fruit set, and fruit development. Trees receiving the low rate of NPK as a split application in July and August (a total of 50 lbs. N/acre, 7.5 lbs. P/acre and 45 lbs. K/acre, representing half the rate of all other trees except trees in the July + August N treatment, which received an equal amount of N without P and K) had a significantly lower yield as both kg and number of fruit per tree (Table 1). No other treatments affected total yield. No other treatment had a significant effect on total yield. The yield of trees receiving a double dose of N in April had the greatest yield (both kg and number of fruit) per tree but was not significantly different from any other treatment, despite an average of 45 to 75 more fruit per tree.

There were no significant treatment effects on the number of small size fruit (packing carton sizes 84 and 70) per tree (Table 2). However, the BMP N and BMP NPK treated trees had numerically more small fruit than all other treatments. Trees that received a double dose of N (50 lbs. N/acre) in November or April had significantly more commercially valuable large size fruit of packing carton size 60 than trees receiving the reduced rate of NPK as a split application in July and August (*P*=0.0753) and numerically more fruit of packing carton size 60 than all other treatments. Trees that received a double dose of N in April had significantly more commercially valuable large size fruit of packing carton size 48 than trees receiving the reduced amount of NPK as a split application in July and August and trees receiving the BMP N treatment (*P*=0.0232). No treatment affected the number of commercially valuable large size fruit of packing carton size 40. The total number of fruit of this size per tree was low (<20/tree). The number of fruit larger than size 40 per tree was even lower. There were significant treatment effects on the pool of all commercially valuable large size fruit, with the trees receiving the low rate of NPK as a split application in July and August having significantly fewer fruit in the combined pool of packing carton sizes 60 through 32 than all other treatments except trees receiving BMP N (*P*=0.0124). Trees receiving a double dose of N in April yielded 39 to 79 more fruit of packing carton sizes 60 through 32 than the remaining treatments, but the yield differences of large size fruit were not significantly greater.

Table 2. Effect of soil-applied N or NPK fertilizer on yield and fruit size of the 'Hass' avocado.

		Yield of packing carton sizes				
Treatment	Total yield	Σ84-70 (99-177 g)	60 (178-212 g)	48 (213-269 g)	40 (270-325 g)	Σ60-32 (178-397)
	------------------ no. of fruit ------------------					
July + August N	173 a	31	55 ab	68 ab	18	142 a
July + August NPK	40 b	2	7 b	20 c	10	38 b
November N	176 a	31	66 a	63 ab	15	145 a
November NPK	149 a	22	52 ab	65 ab	10	127 a
April N	222 a	37	89 a	82 a	12	184 a
April NPK	159 a	23	52 ab	69 ab	13	136 a
BMP N	161 a	57	53 ab	41 bc	10	105 ab
BMP NPK	177 a	60	50 ab	58 ab	9	117 a
P-value	0.0677	0.5559	0.0753	0.0232	0.5350	0.0124

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

Table 3. Effect of adding P and K to the N fertilization strategy on yield and fruit size of the 'Hass' avocado.

Treatment	Total yield	Yield of packing carton sizes Σ84-70 (99-177 g)	60 (178-212 g)	48 (213-269 g)	40 (270-325 g)	Σ60-32 (178-397)
	no. of fruit					
July + August N	173 a	31	55 a	68 a	18	142 a
July + August NPK	40 b	2	7 b	20 b	10	38 b
P-value	0.0063	0.1149	0.0169	0.0142	0.2686	0.0112
November N	176	31	66	63	15	145
November NPK	149	22	52	65	10	127
P-value	0.6299	0.5703	0.5869	0.7052	0.3393	0.7411
April N	222	37	89	82	12	184
April NPK	159	23	52	69	13	136
P-value	0.2837	0.1390	0.1554	0.6348	0.2770	0.3453
BMP N	161	57	53	41	10	105
BMP NPK	177	60	50	58	9	117
P-value	0.8984	0.9893	0.8181	0.3276	0.7152	0.7982

^{z}Means in a vertical column followed by a different letter are different at P=0.05 by Dunnett's two-tailed analysis.

To determine whether adding P and K to the N treatment had a significant positive or negative effect on total yield and fruit size, a pair-wise comparison was made where the addition of P and K was the only factor influencing yield parameters. The addition of P and K had a significant negative effect on total yield only for the low N rate split in July and August (*P*=0.0063) (Table 3). But interestingly, all total yields were numerically lower when P and K were added with N with the exception of the BMP treatment. There were no significant treatment effects on the number of small size fruit (packing carton sizes 84-70), but again the addition of P and K with the N resulted in a nonsignificant but lower number fruit in this size class with the exception of the BMP treatment. The addition of P and K had a significant negative effect on the yield of commercially valuable large size fruit of packing size 60 for the low N rate split in July and August (*P*=0.0169). In all other cases the addition of P and K with N resulted in a nonsignifcant lower number of fruit of packing carton size 60. The addition of P and K had a significant negative effect on the yield of commercially valuable large size fruit of packing carton size 48 for the low N rate split in July and August (*P*=0.0142), and adding P and K resulted in a nonsignificant lower number of fruit of packing size 48 for trees receiving a double dose of NPK in April. The number of fruit in the combined pool of commercially valuable large size fruit of packing carton sizes 60 through 32 was consistently lower with the addition of P and K with N with the exception of the BMP treatment.

All fruit was of excellent quality. The incidence of gray pulp, an internal fruit discoloration, occurred in typically less than one quarter of each individual fruit with the exception, albeit nonsignificant, of fruit from trees receiving NPK at the low rate as a split application in July and August (Table 4). There were significant treatment effects on the amount of vascularization present in the pulp of the fruit. Vascularization is the presence of xylem tissue in the pulp, making it "stringy," which is undesirable. The incidence overall was extremely low, occurring in less than 1/8 of each individual fruit, but was significantly higher in fruit from trees receiving the low rate of N as a split application in July and August than fruit from trees also receiving P and K at that time, fruit from trees receiving a double does of NPK in April, and fruit from trees receiving the BMP N treatment. Fruit from all other treatments had intermediate vascularization values that were not significantly different from fruit from the above treatments (Table 4). Fungal or bacterial decay was low and not affected by any treatment. Fruit from trees receiving a double dose of NPK in April took significantly fewer days to ripen (approx. 1.5 days

Table 4. Effect of soil-applied N or NPK fertilizer on fruit quality of the 'Hass' avocado.

	Fruit quality parameters (average value for two fruit/tree times 20 individual tree replicates) ^{z}			
Treatment	Gray pulp (scale 1-4)	Vascularization (scale 1-4)	Decay (scale 1-4)	Days to ripen (days)
July + August N	0.9	0.53 a	0.4	11.1 a
July + August NPK	1.2	0.24 b	0.7	9.9 ab
November N	0.9	0.47 ab	0.6	10.4 ab
November NPK	1.0	0.28 ab	0.6	11.3 a
April N	0.8	0.34 ab	0.4	9.9 ab
April NPK	0.8	0.21 b	0.5	9.6 b
BMP N	0.8	0.25 b	0.3	10.4 ab
BMP NPK	0.8	0.37 ab	0.5	10.6 ab
P-value	0.7776	0.0654	0.8252	0.0914

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

less) than fruit from trees receiving the low rate of N as a split application in July and August and fruit from trees receiving a double dose of NPK in November (*P*=0.0914) (Table 4). Fruit from all other treatments took an intermediate number of days to ripen that was not significantly different from the above treatments. It is interesting that fruit harvested in 2005 took only one more day to ripen than fruit harvested in 2004.

It is too early in the research to draw any conclusions. Due to alternate bearing, fertilization research with tree crops must be continued for a minimum of three years to have at least one replication of an on- or off-crop year. It is preferable to conduct such research for at least four years to have two complete cycles of on- and off-crops. This is especially true for 'Hass' avocado orchards in California, which have an alternate bearing index [ABI = (Year 1 yield - Year 2 yield) ÷ (Year 1 yield + Year 2 yield)] ranging from 0.57 to 0.92 (Lovatt, 1997). An ABI equaling zero means that alternate bearing is absent; an ABI of one means there is no crop following and an on-crop. Thus, in California, 'Hass' orchards on average undergo a 60% to 90% reduction in yield following an on-crop.

With this in mind, the results obtained this year for trees receiving the low rate of NPK as a split application in July and August must be examined in light of last year's results since these trees received their full fertilization treatment last year. Last year trees receiving the low rate of NPK as a split application in July and August yielded significantly more large size fruit (packing carton sizes 60+48+40 and fruit of packing carton sizes 60 through 32) per tree (P £ 0.10) and had numerically, but not significantly, more total yield per tree than trees receiving only N as a split application in July and August, trees receiving the BMP NPK treatment, and trees receiving a double dose of NPK in November. Thus, the relatively negative yield results observed in the 2005 harvest for trees receiving the low rate of NPK as a split application in July and August in large part likely reflects the effect of the greater overall yield and greater yield of large size fruit obtained for this treatment in the 2004 harvest.

Conversely, it is interesting to note that trees that received a double dose of N in April have the highest 2-year cumulative total yield per tree and highest cumulative yield per tree of commercially valuable large size fruit (combined pool of packing carton sizes 60 through 32), having had higher yields last year and the highest yields this year in the these two categories. This result is consistent with the fact that the double dose of N in April is a treatment that has proven to be one of the best of two treatments identified in two previous studies, a treatment that significantly increased total yield, increased the yield of commercially valuable large size fruit (packing carton size 60+48+40), and reduced the severity of alternate bearing for the four years of the study (P £ 0.05) (Lovatt, 2001). However, additional years of yield data are required to determine the long-term effect of this treatment on yield, fruit size and alternate bearing in this study.

I would like to express my sincere appreciation to Mr. John Grether. Without special individuals like Mr. Grether, who make their orchards available for the type of research reported herein, FREP-funded projects would not be possible. This is Mr. Grether's second such project with me and I am extremely grateful.

EXPLORING AGROTECHNICAL AND GENETIC APPROACHES TO INCREASE THE EFFICIENCY OF ZINC RECOVERY IN PEACH AND PISTACHIO ORCHARDS

Project Leaders
R. Scott Johnson
U.C. Kearney Agricultural Center
9240 S. Riverbend Avenue
Parlier, CA 93648
(559) 646-6547; FAX (559) 646-6593
sjohnson@uckac.edu

Steven A. Weinbaum
Professor of Pomology
Dept. of Pomology
One Shields Avenue
Davis, CA 95616
(530) 752-0255
saweinbaum@ucdavis.edu

Robert H. Beede
UCCE Kings County
680 North Campus Drive, Suite A
Hanford, CA 93230
(559) 582-3211, Ext. 2737; FAX (559) 582-516
bbeede@ucdavis.edu

INTRODUCTION

Zinc (Zn) is an essential plant micronutrient, and Zn deficiency is widespread, causing economic losses throughout the world. Among fruit crops, pecan, peach, citrus and avocado seem to be particularly sensitive to this disorder. Zinc is the most widely limiting micronutrient for tree fruit production in California, and deficiencies are worse in sandy and alkaline soils. Inadequate zinc availability in soils and limited responses to soil applications of fertilizer zinc has resulted in the large-scale adoption of foliar applications. Recent studies suggest that foliar-applied zinc remains in or on treated leaves and is not transported to other plant parts. As a result, zinc accumulates in the soil because much of the foliar-applied Zn is carried to the orchard floor in leaf litter following leaf fall.

Multiple approaches are proposed to increase the efficiency of fertilizer zinc recovery following both soil and foliar applications. The first approach is to modify soil pH in small areas of the root system to increase soil zinc availability. A second approach is to use cover crops efficient at mobilizing soil Zn, thus making it more available to the trees. The third approach rests upon preliminary data suggesting that other Prunus rootstocks may be more efficient soil zinc scavengers than “Nemaguard,” the rootstock currently in use for most peach and nectarine orchards. Finally, we will use labeled zinc (^{68}Zn) and tree excavations to study the efficiency of zinc uptake and its distribution throughout the tree from a fall foliar application.

OBJECTIVES

1. Assess the feasibility of alternative zinc application methodologies to increase the efficiency of zinc recovery by using soil applications to acidify and stimulate root proliferation in a limited portion of the soil volume.
2. Evaluate the potential of using zinc-efficient cover crops to mobilize soil zinc and make it more available to tree roots.
3. Evaluate an experimental peach rootstock that appears to have greater capacity for zinc uptake from soil than rootstocks currently in commercial usage.
4. Compare the efficiency of zinc uptake into the woody tissues of peach trees before, during and after leaf abscission in the fall.
5. Evaluate the distribution of zinc throughout young peach trees (especially to the roots) from a fall foliar application.

RESULTS AND DISCUSSION

This project was started in 2005 so there are few conclusions to report thus far. Many individual experiments were initiated and some preliminary results have been obtained. Most of the experiments will continue for several years. Below is a brief summary of each set of experiments.

Soil Acidification

A technique developed in Germany called CULTAN (Controlled Uptake Long Term Ammonium Nutrition) has been used successfully to treat Fe and Zn deficiencies in crop plants. The idea is to add Fe or Zn, together with ammonium fertilizer (to stimulate root growth), to a small acidified portion of the soil. This increases the uptake of these metals since they are much more available at lower pH. We tried the technique with some mature peach trees by adding soil sulfur, urea and varying rates of zinc sulfate to an 18" deep hole near the tree. Leaf samples several months later showed higher zinc levels with high rates of zinc sulfate. Over time, we hope to see increased leaf zinc with the lower zinc sulfate rates as well.

To newly planted peach trees we tried a modification of this approach. Within each planting hole we added a "root bag" containing 100g urea, 100g sulfur and 0, 10 or 50g zinc sulfate. Each bag was wrapped with cheesecloth for easy handling. Leaf samples were taken in mid-summer but have not yet been analyzed.

Companion Crops

Barley and other graminaceous species are very efficient at taking up Zn and Fe under conditions where these metals are low in the soil. They do this by releasing molecules called phytosiderophores that help extract these nutrients from the soil. When another crop is planted with the barley, its Zn and Fe uptake can also be improved if its roots are in close proximity to the barley roots. On our first attempt we planted winter barley in the rows next to some 3-year-old peach trees, but could not measure any increase in leaf Zn. We felt it was probably because the roots of the two species were not close enough together. This year we will plant the barley right under the tree to maximize root interaction.

We have also obtained seed from a barley variety that is reported to be even more zinc-efficient than normal varieties. It is not commercially grown in the USA so only a small amount was available. A preliminary trial will be conducted around a few trees to see if it stimulates zinc uptake better than standard varieties.

Rootstocks

Rootstocks can have a very substantial effect on the uptake of nutrients in fruit trees. We have a 3-year-old peach orchard at the Kearney Ag Center planted on four different rootstocks. The trees have never been fertilized with zinc in any form. One of these rootstocks, Hiawatha, has considerably more zinc in the leaves, and especially in dormant shoots, compared to the standard rootstock Nemaguard (Table 1). The three rootstocks other than Hiawatha would all be considered Zn-deficient based on the current recommendations for mid-summer leaf samples. They have all shown some degree of zinc-deficiency symptoms. This raises the possibility of completely eliminating zinc sprays with certain rootstocks. These data also suggest that it may be possible to store large amounts of zinc in the dormant wood. Perhaps such trees would not need to be fertilized with zinc for at least several years. We have some trees in the sand tank experiment (see our other FREP report), which have zinc concentrations in dormant shoots as high as 75 ppm. We will monitor these trees carefully to see how efficiently the zinc is recycled and supplied to growing shoots and fruits over several years. We will also be investigating methods, other than rootstocks, of substantially elevating the zinc levels in dormant tissues.

Table 1. Zinc concentrations in leaves (July 2004) and dormant shoots (January 2005) of O'Henry and Springcrest peach trees as influenced by four different rootstocks. The two cultivars are combined, as there were no differences between them.

Tissue Sampled			Rootstock	
	Nemaguard	Controller 9	Controller 5	Hiawatha
Leaves (7/04)	10.9 bc	11.9 b	9.4 c	21.6 a
Shoots (1/05)	25.8 b	28.4 b	18.9 c	90.3 a

ZN68 Studies

The stable isotope Zn68 has proved to be a valuable tool for addressing many questions regarding zinc uptake efficiency and distribution in the tree. In one experiment, we have been able to show about 7% of the zinc applied to peach leaves in late fall is taken into the perennial parts of the trees before leaf fall. Of the amount taken up, nearly half is transported to the roots, but is then remobilized in the spring and mostly ends up in new growth. This suggests zinc is much more mobile than we originally thought. We have a series of experiments planned to further study the distribution of zinc throughout the tree and test several approaches (rates, timing, additives, etc.) of increasing the amount of zinc that ends up in the tree from foliar applications.

CONCLUSION

Although this project has just begun, we already have promising leads on several approaches to increasing the efficiency of zinc applications to fruit and nut trees. Over the next two years we hope to better understand aspects of zinc uptake, movement, and storage in the tree and focus on the most efficient and environmentally sound way to supply this nutrient to the plant.