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New Standard for the Effectiveness of Foliar Fertilizers

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INTRODUCTION

Foliar fertilization can meet a plant's demand for a nutrient at times when soil conditions (i.e. low temperature, low moisture, pH, salinity) render soil-applied fertilizers ineffective. Thus, foliar fertilization is an effective method for correcting soil deficiencies and overcoming the soil's inability to transfer nutrients to the plant. Nutrients, especially phosphate, potassium and trace elements can become fixed in the soil and unavailable to plants. Applying nutrients directly to leaves, the major organ for photosynthesis, ensures that the plant's metabolic machinery is not compromised by low availability of an essential nutrient. It is important to note that foliar applied fertilizers of phloem-mobile nutrients are translocated to all parts of the tree, including the smallest feeder roots. Foliar fertilizers reduce the potential for accumulation of nutrients in soil, run off water, surface water (streams, lakes and the ocean), and groundwater (drinking water supply), where they can contribute to salinity, eutrophication and nitrate contamination; all of these have serious consequences on the environment and human health. Therefore, foliar fertilization provides advantages over traditional soil applied fertilizer and should replace soil-applied fertilizer, at least in part, in crop best management practices (BMPs).

Three problems impede adoption of foliar fertilizers:

(1) Not all nutrients are taken up through the foliage and, even if taken up, some nutrients are not phloem-mobile. Thus, *a priori* knowledge (research) is necessary to know which nutrients are taken up through the leaves of a specific crop in order to develop a foliar fertilization program. This information is not always available to growers and the lack of information compromises a grower's ability to discern which foliar fertilizers are worth using and when to apply them.

(2) Standard leaf analyses do not always show the expected increase in nutrient concentration. This can be due to poor nutrient uptake, but also can result from excellent uptake and utilization by tissues not sampled (new shoots, stems, roots and especially fruit). Conversely, leaf analyses can give false positive information regarding foliar fertilization. Some foliar applied nutrients persist in the wax of the leaf cuticle. Thus, if the leaves analyzed are not washed properly, a false

high reading will be obtained. Frequently, it is considered sufficient to merely demonstrate that a nutrient applied as a foliar fertilizer is taken up. To do this, leaves are typically analyzed within a short period of time after the fertilizer is applied to the foliage. Whereas this approach may confirm that uptake has occurred, benefits of the application are largely presumed.

(3) Rates of foliar fertilizer are typically lower than soil applied fertilizer, but application of foliar fertilizer can be more expensive, especially if a grower does not own his own sprayer. Tank mixing multiple fertilizers and/or pesticides to save a trip through the orchard can cause negative interactions that reduce efficacy or cause negative effects on plant metabolism, such as the negative effect on yield of the avocado, due to the interaction between foliar-applied N and B (Lovatt, 1999).

Growers have been proactive in protecting the environment, but with the high cost of fertilizer in general, foliar fertilizers must be proven to be effective for growers to be willing to incur the expense of using them. An improved methodology to evaluate the effectiveness of foliar fertilizer is required. The primary investigator proposes that the only acceptable standard by which to measure effectiveness of foliar fertilizer is a resultant yield benefit and net increase in grower income. The key to achieving a yield benefit and net increase in grower income is properly timing the foliar application of fertilizer to key stages of crop phenology when nutrient demand is likely to be high or when soil conditions are known to restrict nutrient uptake. For citrus and avocado tree crops, this approach is in contrast to applying foliar fertilizers at the standard time of 1/3 to 2/3 leaf expansion (in March), which targets foliage with a thin cuticle and large surface area and only resulted in yields equal to those attained with soil applied fertilizer (Embleton and Jones, 1974; Labanauskas et al., 1969).

By demonstrating that foliar fertilization strategies can be used to increase yield parameters and grower net income, by properly timing their application (Lovatt 1999), growers have replaced soil-applied fertilizer, at least in part, with foliar fertilizer, improving fertilizer efficiency and protecting the environment. This theory is being tested with Clementine mandarin (Citrus reticulata Blanco), for which little fertilizer research has been conducted in California. Thus, the results of this project will not only establish the feasibility of using a yield benefit and net increase in grower income as a new methodology for evaluating the effectiveness of foliar fertilizers, but will also provide California Clementine mandarin growers with fertilization practices to improve crop production that are efficient and protect the environment. In addition, CDFA FREP provides the visibility required to make the benefits of this approach known to researchers and growers of other crops.

OBJECTIVES

1 Test the efficacy of properly timed foliar applied $ZnSO_4$, Solubor B, urea N and phosphate P+K fertilizers to increase Clementine mandarin fruit number, size, and/or quality and increase grower net income.

2 Demonstrate that a yield benefit and net increase in grower income should be the only acceptable standard for evaluating the effectiveness of foliar applied fertilizers.

DESCRIPTION

1 Test the efficacy of the following fertilizers applied to the foliage at the times specified below in comparison with fertilizers applied at 2/3 leaf expansion:

(1) N [23 lb/acre, urea (46% N, 0.25% biuret)] with K and P [0.64 gal/acre, potassium phosphite (0-28-26)] applied winter prebloom to increase flower

number, fruit set and yield, without reducing fruit size, and to increase total soluble solids (TSS) and TSS:acid.

(2) Zn [1 lb/acre, $ZnSO_4$ (36% Zn)] at 10% anthesis in the southwest tree quadrant (SWTQ) to increase fruit set and yield, without reducing fruit size.

(3) B [1.3 lb/acre, Solubor (20.5% B)] at 10% anthesis in the SWTQ to increase total yield and yield of commercially valuable large size fruit.

(4) K and P [0.49 gal/acre, potassium phosphite (0-28-26)] in May and July to increase yield of commercially valuable large size fruit, without reducing total yield, and to increase TSS and TSS:acid.

(5) N [23 lb/acre, urea (46% N, 0.25% biuret)] at maximum peel thickness to increase yield of commercially valuable large size fruit, without reducing yield, and to increase TSS and TSS:acid.

(6) K (25 lb KNO3/acre) at dormancy (February), post bloom (approximately April) and summer fruit growth (July to August) to increase the yield of commercially valuable large size fruit (Boman 2002).

(7) N [23 lb/acre, urea (46% N, 0.25% biuret)] with K and P [0.64 gal/acre, potassium phosphite (0-28-26)] applied at 2/3 leaf expansion.

(8) Zn [1 lb/acre, ZnSO4 (36% Zn)] at 2/3 leaf expansion.

(9) B [1.3 lb/acre, Solubor (20.5% B)] at 2/3 leaf expansion.

2 Determine the best time to apply the winter prebloom treatments to Clementine mandarin in the San Joaquin Valley, the winter prebloom foliar-applied urea-N and winter prebloom foliar-applied phosphite-P+K were expanded to five treatments as follows:

(1) N [23 lb/acre, urea (46% N, 0.25% biuret)] in November.

(2) N [23 lb/acre, urea (46% N, 0.25% biuret)] in December.

(3) N [23 lb/acre, urea (46% N, 0.25% biuret)] in January.

(4) N [23 lb/acre, urea (46% N, 0.25% biuret)] with K and P [0.64 gal/acre, potassium phosphite (0-28-26)] in November.

(5) N [23 lb/acre, urea (46% N, 0.25% biuret)] with K and P [0.64 gal/acre, potassium phosphite (0-28-26)] in December.

3 In all treatments, fertilizer rates are based on application in 250 gallons water per 100 trees per acre so that they can be adjusted for application to individual trees.

RESULTS AND DISCUSSION

The first harvest for our CDFA FREP project was in December 2009. All trees produced uniformly heavy on-crop yields (an average of 207 lbs of fruit per tree, with a range of 196 to 220 lbs of fruit per tree and an average of 950 fruit per tree, with a range of 863 to1016 fruit per tree) (Tables 1 and 2). No treatment significantly increased total yield above that of the untreated control trees. The highest yields by lb and number of fruit per tree were obtained with foliar applications of low biuret urea in November or January (220 lbs per tree and 1016 and 1010 fruit per tree, respectively, compared to 206 lbs and 921 fruit per tree for the untreated control trees).

Fruit size peaked on packing carton sizes 28 to 24 (fruit 2.28 to 2.5 inches in transverse diameter). The three pre bloom foliar applications of low biuret urea (November, December and January), the pre bloom application of low biuret urea combined with potassium phosphite (November), and zinc applied to the foliage at 10% anthesis in the SWTQ significantly increased the yield of fruit in these two size categories; as lb per tree compared to trees receiving foliar applied urea combined with potassium phosphite in December, foliar applied potassium nitrate at dormancy (February), post bloom (75% petal fall in the NETQ) (approximately May) and during summer fruit growth (July-Aug.), and boron applied to the foliage at 10% anthesis in the SWTQ (P = 0.0223) (Table 1). All other treatments had an intermediate effect on the yield of fruit of packing carton sizes 28 + 24 that was not significant. Interestingly, only the pre bloom foliar application of low biuret urea (November, December and January) and foliar zinc applied at 10% anthesis in the SWTQ increased the number of fruit of packing carton sizes 28 + 24 per tree.

The result is compared to trees receiving foliar-applied urea combined with potassium phosphite in December, foliar potassium nitrate applied at dormancy (February), post bloom (approximately May) and during summer fruit growth (July to Aug.), and foliar boron applied at 10% anthesis in the SWTQ (P = 0.0214) (Table 2). Despite the significant positive effect of several treatments on the yield of fruit of packing carton sizes 28 + 24, there was no concomitant effect on the yield of commercially valuable large size fruit in the combined pool of fruit of packing carton sizes 28 to 15 (2.25 to 2.95 inches in transverse diameter). Although not significant, the highest yield of fruit of packing carton sizes 28 to15 was achieved with the foliar application of low biuret urea in November (150 lbs fruit per tree, 608 fruit per tree) (Tables 1 and 2). The lowest yield of fruit of packing carton sizes 28 to15 resulted from foliar application of potassium nitrate at dormancy (February.), post bloom (approximately May) and during summer fruit growth (July through Aug.).

All fruit were of excellent quality and had a high sugar to acid ratio (approximately 14). There were no significant treatment effects on any fruit quality parameter analyzed, including rind thickness, average fruit weight, average juice weight per fruit, average juice volume per fruit, total soluble solids (TSS as °brix), acidity (%), or the ratio of TSS:acidity (Table 3).

CONCLUSIONS

The pre bloom foliar application of low biuret urea in November not only resulted in the highest total yield, but also the highest yield of commercially valuable large size fruit in the combined pools of fruit of packing carton sizes 28 and 24 and 28 to 15 both as lb and number of fruit per tree, but the month (November, December and January), in which the winter pre bloom low biuret urea application was made did not have a significant effect on yield or fruit size. The November low biuret urea application, resulted in total yields and yields of commercially valuable large size fruit that were significantly greater than those produced by trees receiving several other treatments, but not the untreated control trees. Yield and fruit size of the untreated control trees were not significantly different from those of any treatment.

The yield results for the harvest of December 2010 will be very important to determine. Of key importance is the following: (1) whether November is really a better time to apply low biuret urea and especially low biuret urea combined with potassium phosphite rather than December as the Year 1 data suggest; (2) whether application of potassium nitrate applied at dormancy (February), post bloom (75% petal fall in the NETQ) (approximately May) and during summer fruit growth (July to Aug.) or boron at 10% anthesis in the SWTQ reduce fruit size of 'Nules' Clementine mandarin in California; and (3) whether treatments having a positive effect on total yield this year will have

Table 1
Effect of applying foliar fertilizers at key stages of tree phenology on yield (kg per tree) of 'Nules' Clementine mandarin trees. Application times refer to the following phenological stages: November, December, and January-pre bloom; February-dormancy; April-10% anthesis or 2/3 leaf expansion as indicated; May-post bloom (75% petal fall in the Northeast tree quadrant); and July-exponential increase in fruit growth (Stage II of fruit development, the start of which is identified by maximum peel thickness). (Year 1: 2008-2009; the orchard is located in Fresno, CA)

Treatment	Application time	Total	Packing carton size							
			≤ 32 ≤ 2.2 in	28 2.3-2.4 in	24 2.4-2.5 in	21 2.5-2.6 in	18 2.7-2.8 in	15 2.8-3.0 in	28-24 2.3-2.5 in	28-15 2.3-3.0 in
		lbs. per tree								
Urea	Nov	220.02	68.78	51.37 a[z]	38.80	37.48	14.33	6.83	90.17 a	148.81
Urea + Potassium phosphite	Nov	206.57	67.24	40.79 abcd	41.01	32.41	14.55	7.94	81.57 ab	136.46
Urea	Dec	212.74	60.19	41.45 abcd	42.77	35.71	16.98	8.60	84.22 a	145.50
Urea + Potassium phosphite	Dec	192.24	62.61	35.27 cd	29.76	33.51	16.75	9.92	65.04 d	125.22
Urea	Jan	220.24	69.67	49.82 a	38.80	39.24	12.57	6.17	88.40 a	146.39
Potassium nitrate	Feb + May + Jul	207.67	80.91	37.92 bcd	28.44	31.53	16.75	5.07	66.14 cd	119.49
Zinc	Apr 24									
(10% anthesis)	209.88	73.19	48.06 ab	37.92	32.63	11.46	4.19	85.98 a	134.04	
Zinc	Apr 13									
(2/3 leaf expansion)	208.78	69.44	45.41 abc	35.05	34.39	13.89	5.73	80.25 abc	134.26	
Boron	Apr 24									
(10% anthesis)	201.50	68.34	34.17 d	34.61	38.14	15.87	5.07	69.00 bcd	127.65	
Boron	Apr 13									
(2/3 leaf expansion)	214.51	70.99	42.99 abcd	33.95	38.80	14.77	8.16	76.94 abcd	138.67	
Urea + Potassium phosphite	Apr 13									
(2/3 leaf expansion)	196.21	51.37	41.23 abcd	39.90	32.41	16.53	10.14	81.13 abc	139.99	
Potassium phosphite	May + Jul	207.23	71.87	41.23 abcd	36.82	30.42	18.08	5.51	78.04 abcd	132.06
Urea	Jul	199.08	61.29	41.01 abcd	37.48	31.31	17.42	5.51	78.48 abcd	132.72
Control		205.69	56.00	40.56 abcd	38.36	39.68	18.08	8.82	78.92 abcd	145.28
P-value		0.4956	0.8149	0.0931	0.2931	0.9092	0.9343	0.7116	0.0223	0.4204

[z] Values in a column followed by different letters are significantly different by Fisher's Protected LSD test at $P = 0.05$.

Table 2
Effect of applying foliar fertilizers at key stages of tree phenology on yield (number of fruit per tree) of 'Nules' Clementine mandarin trees. Application times refer to the following phenological stages: November, December, and January pre bloom; February-dormancy; April-10% anthesis or 2/3 leaf expansion as indicated; May post bloom (75% petal fall in the Northeast tree quadrant); and July exponential increase in fruit growth (Stage II of fruit development, the start of which is identified by maximum peel thickness). (Year 1: 2008-2009; the orchard is located in Fresno, CA)

Treatment	Application time	Total	Packing carton size							
			≤ 32 ≤ 2.2 in.	28 2.3-2.4 in.	24 2.4-2.5 in.	21 2.5-2.6 in.	18 2.7-2.8 in.	15 2.8-3.0 in.	28-24 2.3-2.5 in.	28-15 2.3-3.0 in.
			no. of fruit per tree							
Urea	Nov	1016	402	237 a[z]	164	141	47	19	402 a	608
Urea + Potassium phosphite	Nov	946	386	188 abcd	173	122	47	23	362 ab	553
Urea	Dec	950	345	192 abcd	181	134	55	25	373 a	587
Urea + Potassium phosphite	Dec	882	374	163 cd	126	126	54	28	289 c	498
Urea	Jan	1010	400	230 a	164	147	40	18	394 a	600
Potassium nitrate	Feb + May + Jul	980	479	175 bcd	120	118	54	15	295 bc	482
Zinc	Apr 24									
(10% anthesis)	980	420	222 ab	160	123	37	12	382 a	554	
Zinc	Apr 13									
(2/3 leaf expansion)	970	409	210 abc	148	129	45	17	358 ab	548	
Boron	Apr 24									
(10% anthesis)	926	399	158 d	147	143	51	14	305 bc	513	
Boron	Apr 13									
(2/3 leaf expansion)	991	420	199 abcd	144	146	48	24	342 abc	560	
Urea + Potassium phosphite	Apr 13									
(2/3 leaf expansion)	863	288	191 abcd	168	122	53	29	360 ab	563	
Potassium phosphite	May + Jul	960	417	191 abcd	156	114	59	16	347 abc	535
Urea	Jul	902	351	190 abcd	158	118	56	16	348 abc	538
Control		921	328	187 abcd	162	149	59	25	350 abc	582
P-value		0.5960	0.8015	0.0931	0.2931	0.9092	0.9343	0.7116	0.0214	0.2288

[z] Values in a column followed by different letters are significantly different by Fisher's Protected LSD test at $P = 0.05$.

Table 3

Effect of applying foliar fertilizers at key stages of tree phenology on the quality of fruit of 'Nules' Clementine mandarin trees. Application times refer to the following phenological stages: November, December, and January pre bloom; February-dormancy; April-10% anthesis or 2/3 leaf expansion as indicated; May-post bloom (75% petal fall in the Northeast tree quadrant); and July-exponential increase in fruit growth (Stage II of fruit development, the start of which is identified by maximum peel thickness). (Year 1: 2008-2009; the orchard is located in Fresno, CA)

Treatment	Application time	Rind thickness (inches)	Fruit weight (ounces)	Juice weight (ounces)	Juice volume (pints)	TSS: acid
Urea	Nov	0.106	5.46	10.57	0.61	14.3
Urea + Potassium phosphite	Nov	0.122	5.76	10.59	0.62	14.7
Urea	Dec	0.110	5.62	10.56	0.61	14.2
Urea + Potassium phosphite	Dec	0.118	6.26	10.77	0.63	14.9
Urea	Jan	0.114	5.72	10.80	0.63	14.8
Potassium nitrate	Feb + May + Jul	0.106	5.57	10.55	0.62	14.2
Zinc	Apr 24					
(10% anthesis)	0.114	5.73	11.20	0.65	15.4	
Zinc	Apr 13					
(2/3 leaf expansion)	0.122	6.05	11.60	0.68	14.6	
Boron	Apr 24					
(10% anthesis)	0.122	5.88	10.57	0.62	14.6	
Boron	Apr 13					
(2/3 leaf expansion)	0.114	5.64	10.41	0.61	14.1	
Urea + Potassium phosphite	Apr 13					
(2/3 leaf expansion)	0.118	5.90	10.64	0.62	14.6	
Potassium phosphite	May + Jul	0.102	5.28	10.28	0.60	14.9
Urea	Jul	0.130	5.90	10.61	0.62	13.8
Control		0.118	6.23	10.78	0.63	14.3
P-value		0.5083	0.1462	0.6843	0.6907	0.1919

[z] Values in a column followed by different letters are significantly different by Fisher's Protected LSD test at $P = 0.05$.

the same effect next year or whether yield next year will be proportionally lower due to the effects of alternate bearing (or, conversely, be proportionally greater for treatments causing lower yields this year).

For citrus, it is difficult to increase yield further in the on crop year. The goal for an on crop year is typically to increase fruit size; the winter pre bloom foliar application of low biuret urea (November, December and January), which tended to do both during this first on-crop, is therefore of interest. However, an optimal time of this application or any treatment cannot be determined based on one year of yield data. No conclusions can be made at this time, especially in an alternate bearing orchard.

ACCOMPLISHMENTS

The primary investigator made presentations at the following venues that included information related to this project to educate growers, industry people and other researchers regarding the need to reduce soil-applied fertilizers and the benefits that can be attained using properly timed foliar fertilization:

1. "Phenology and Physiology of Citrus Productivity" at the Tulare County Citrus Growers Meeting, October 7, 2009;
2. "Phenology and Physiology of Citrus Productivity - *The basis for developing and using plant growth regulators and foliar fertilizers in commercial citrus production*" at the Friends of Citrus meeting, February 17, 2010;
3. "Effect of Climate Change on Citrus and Avocado Flowering and Productivity," to researchers at INIFAP, Tepic, Nayarit, Mexico, March 12, 2010; and
4. "Phenology and Physiology of Citrus and Avocado Productivity", University of Arizona, April 28, 2010.
5. "Phenology and Physiology of Citrus Productvity – *The basis for developing and using PGRs and foliar fertilizers in commercial citrus production*" to Australian visitors in citrus research and production at UCR, August 26, 2010.

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