CALIFORNIA DEPARTMENT OF FOOD AND AGRICULTURE
FERTILIZER RESEARCH AND EDUCATION PROGRAM
(FREP)

FINAL REPORT (Received 1/31/12)

Project Title: New Standard for the Effectiveness of Foliar Fertilizers

CDFA Agreement No. 07-0667

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
Jim Bates, CPA
Chief of Financial Operations
Fowler Packing Company
Phone: 559-834-5911, Cell: 559-281-8446
Fax: 559-834-5272
E-mail: cfo@fowlerpacking.com

MANDARIN ORCHARD SITE
David Johnson, Ranch Manager
Rustigian Ranch
Corner of Clovis and Central
Fresno, CA 93725
(559) 217-0890
davidjohnson@fowlerpacking.com

STATEMENT OF OBJECTIVE:

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

PROJECT OBJECTIVES:

1. To test the efficacy of the following fertilizers applied to the foliage at the times specified:

a. N [23 lb/acre, urea (46% N, 0.25% biuret)] applied winter prebloom (Nov, Dec, Jan) to increase flower number, fruit set and yield, without reducing fruit size, and to increase total soluble solids (TSS) and TSS:acid;
b. 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 (Nov, Dec) to increase flower number, fruit set and yield, without reducing fruit size, and to increase total soluble solids (TSS) and TSS:acid;
c. 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;
d. Zn [1 lb/acre, $ZnSO_4$ (36% Zn)] at 2/3-leaf expansion, the standard time for applying foliar fertilizers to citrus;
e. 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;
f. B [1.3 lb/acre, Solubor (20.5% B)] at 2/3-leaf expansion, the standard time for applying foliar fertilizers to citrus;
g. 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;
h. K and P [0.49 gal/acre, potassium phosphite (0-28-26)] at 2/3-leaf expansion, the standard time for applying foliar fertilizers to citrus;
i. 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.

2. To analyze the cost:benefit of the above foliar-fertilizer strategies.

EXECUTIVE SUMMARY:

1. Problem: To develop **"an improved methodology for verifying effectiveness of foliar fertilizer".** The PI proposed that the only acceptable standard by which to measure effectiveness of foliar fertilizer is a resultant yield benefit and net increase in grower income and proposed to demonstrate that this standard is attainable. Foliar fertilizers reduce the potential accumulation of nutrients in soil, run-off water, surface water (streams, lakes, ocean), and groundwater (drinking water supply), where they can contribute to salinity, eutrophication and nitrate contamination, which have deleterious effects on the environment and humans. Soil-applied fertilizer should be replaced at least in part with foliar-applied fertilizer in BMPs. Foliar fertilizers can meet the crop's demand for a nutrient when soil conditions (low temperature, low soil moisture, soil pH, salinity) render soil-applied fertilizers ineffective or when nutrients (e.g., phosphate, potassium and trace elements) become fixed in the soil and unavailable to plants. Foliar fertilization is a rapid and efficient method for overcoming the soil's inability to transfer nutrients to the plant. Applying nutrients directly to leaves, site of 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 plant, even feeder roots. However, not all nutrients are taken up through leaves and, even if taken up, some nutrients are not phloem mobile. *A priori* knowledge (research) is necessary to develop a foliar fertilization program for a crop. Growers need this information to make cost-effective choices. Foliar fertilizer rates are typically lower than soil fertilizer rates, but application can be more expensive. Thus, a goal of the PI's research program has been to identify the role that essential nutrients play in the physiology of a tree crop and then to apply a nutrient as a foliar fertilizer at the appropriate time in the phenology of the tree, i.e., a time when the demand for the nutrient is likely to be high, in order to stimulate a specific physiological process that increases yield, fruit size or fruit quality, such that the foliar application of the fertilizer results in a net increase in grower income even when the tree is NOT deficient in the nutrient by standard leaf analysis. The approach of timing foliar-applied fertilizers to key stages of citrus and avocado tree phenology has proven superior to applying foliar fertilizers at the standard 2/3-leaf expansion (April), which targets a thin cuticle and large surface area, and achieves yields equal to soil fertilization.

2. Project objective. To test the efficacy of properly timed foliar- applied $ZnSO_4$, B, urea-N and phosphite-P+K fertilizers to increase Clementine mandarin fruit number, size, and quality and increase grower net income. Foliar fertilizers have the potential to solve low fruit set and small fruit size problems, but little research has been conducted in California to optimize Clementine mandarin nutrition for maximum yield of valuable large size fruit.

a. Specific objectives. To test the efficacy of foliar-applied: (1) N [23 lb/acre, urea (46% N, 0.25% biuret)] alone (Nov, Dec and Jan applications were tested) or with K and P [0.64 gal/acre, potassium phosphite (0-28-26)] (Nov and Dec applications were tested) applied in 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; and (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.

b. Describe research approach. Treatments (1-5) above, soil-fertilized control (standard grower practice) (6) and a foliar-fertilized (2/3-leaf expansion) control for each fertilizer above (7-11) were applied to 16 individual 'Nules' Clementine mandarin trees per treatment in a randomized complete block design (224 data trees) in a commercial orchard. Treatment effects on yield, fruit size distribution (packout) and fruit quality (peel thickness, fruit weight, juice weight, % juice, TSS, % acidity, TSS:acid, external peel quality) were determined ($P \leq 0.05$) and a cost-benefit analysis calculated. Cumulative treatment effects on yield parameters and alternate bearing were analyzed.

c. Identify criteria to evaluate project success. A net increase in grower income resulting from foliar fertilization indicates success.

3. Audience. Mandarin growers of California (> 25,000 acres), for whom little nutrition/fertilizer research has been conducted, will benefit directly from the research. The approach is applicable to other crops.

WORK DESCRIPTION:

The research was conducted in a commercial orchard of bearing 'Nules' Clementine mandarins trees located in Fresno, CA. Treatments above (1-5), a soil-fertilized control (standard grower practice) (treatment 6) and a foliar-fertilized (2/3-leaf expansion) control for each fertilizer ($ZnSO_4$, low-biuret urea-N with potassium phosphite-P+K, and Solubor-B above (treatments 7-11) were applied to 16 individual 'Nules' Clementine mandarin trees (replications) per treatment in a randomized complete block design (224 data trees). Fertilizer rates (listed above in the objectives and below in the tasks) were based on application in 250 gallons water per 100 trees per acre so they could be easily adjusted for application to individual trees. There were buffer trees between treated trees within rows and buffer rows between treated rows. The project was initiated in October, the orchard was visited every two weeks to monitor and record tree phenology in order to apply the foliar fertilizer treatments at the proper time each year. Starting at the beginning of June, five average size fruit were collected from around each of 20 randomly selected trees in the buffer rows every two weeks. Fruit diameter and peel thickness were measured to determine when maximum peel thickness occurred each year. Maximum peel thickness occurred on 1 July, 7 July and 9 July in Years 1, 2 and 3 of the research, respectively. In September, 40 spring flush leaves from non-fruiting terminals were collected from around each data tree at a height of 1.5 m. Samples were immediately stored on ice, taken to UCR, washed thoroughly, oven- dried at 60 ºC, ground to pass through a 40-mesh screen and sent to the UC-DANR Laboratory at UC- Davis for analysis. Tissue was analyzed for N, P, K, S, Ca, Mg, Fe, Mn, B, Zn, and Cu by atomic absorption spectrometry and inductively coupled plasma atomic emission spectrometry. Annually, at harvest in November or December, treatment effects on yield, fruit size distribution (packout) were determined using an in field fruit sizer. A subsample of 100 fruit per tree will be used to determine fruit diameter, peel thickness, color and external peel quality by my lab. A second subsample of 25 fruit per tree were used to determine fruit weight, juice weight, % juice, TSS, % acidity, TSS:acid by the UC Lindcove REC analytical lab. A cost-benefit analysis was calculated. Cumulative treatment effects on yield parameters were determined with each successive harvest. The effectiveness of the treatments averaged across the 3 years of the experiment was also determined. With each successive set of harvest data, alternate bearing index [ABI = (year 1 yield - year 2 yield) / (year 1 yield + year 2 yield)] was calculated for each treatment. In year 3, treatment effects on ABI for the 3 years of the experiment were determined. All data were statistically analyzed using the General Linear Model procedure of SAS.

YEAR 1 – TASK 1: To test the efficacy of the following fertilizers applied to the foliage at the times specified: (1) N [23 lb/acre, urea (46% N, 0.25% biuret)] alone or 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; and (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. Fertilizer rates are based on application in 250 gallons water per 100 trees per acre so that can be adjusted for application to individual trees.

NOTE: The starting date of the project was delayed until October 2008 for the following reasons. (1) First, the original start date in February 2008 was after the first treatment needed to be applied, i.e., winter prebloom foliar application of urea in January. Thus, I would have had no data for this treatment for year 1 and, thus, this treatment could never have been compared with the other treatments for effects on cumulative yield or effects on yield averaged across the years of the study by repeated measures analyses, an important analysis in an alternate bearing crop which 'Nules' is, ~500 fruit in the off-crop year to >1200 fruit in the on-crop year. I also would not have been able to compare the effects of treatments on the alternate bearing index (the calculated measure of the severity of alternate bearing). (2) In evaluating potential orchards that growers were willing to make available in February for the initiation of the research, the setting crop yields were very low due to the freeze the previous winter and, thus, would not have provided a good test of the treatments. (3) Based on results obtained with foliar- applied urea in an on-going experiment in Grapevine, CA, that suggested that December might be the optimal time apply a winter prebloom treatment instead of January as I had proposed, I thought our CDFA-FREP project would be best served by applying the urea to separate sets of trees in November, December, and January to make sure we had the optimal application time for this cultivar. This new CDFA-FREP project was the perfect time and place to obtain three years of yield data to identify the optimal time for winter prebloom foliar applications of low biuret urea-N and phosphite-P+K to increase flowering and yield. The leadership of the CDFA-FREP agreed. Please note that I covered the expense of the extra trips to make the additional applications, as described above, to conduct the research in the way that would provide the greatest amount of information of value to the growers.

Month of initiation: 10/08 Month of completion: 12/09

Subtask 1.1: Lay out experiment, select trees of similar size, crop load and health, and label data trees. Subtask 1.1 was be initiated and completed in October 2008.

Subtask 1.2: Monitor tree phenology, apply foliar fertilizer treatments at proper stage of tree phenology or at 2/3-leaf expansion, collect tissue samples at appropriate times and measure fruit diameter and peel thickness, and determine peel color and TSS:acid. Wash, dry, grind leaf samples and send to the UC- DANR Laboratory for analysis.
Subtask 1.2 was initiated in March 2009 and completed in November 2009; mid-year report sent July 2009

Subtask 1.3: Harvest mature crop and obtain all yield data, including fruit quality data (samples taken to the Lindcove REC Analytical Lab.
Subtask 1.3 was initiated in November 2009 and completed in November 2009**.**

Subtask 1.4: Statistically analyze yield data and nutrient analyses.
Subtask 1.4 was initiated in November 2009 and completed in December 2009.

Subtask 1.5: Prepare and send annual report to FREP.
Subtask 1.5 was initiated in December 2009 and completed in January 2010.

YEAR 2 – TASK 2: To test the efficacy of the following fertilizers applied to the foliage at the times specified: (1) N [23 lb/acre, urea (46% N, 0.25% biuret)] alone or 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; and (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. Fertilizer rates are based on application in 250 gallons water per 100 trees per acre so that can be adjusted for application to individual trees.

Month of initiation: 2/10 Month of completion 12/1

Subtask 2.1: Monitor tree phenology, apply foliar fertilizer treatments at proper stage of tree phenology or at 2/3-leaf expansion, collect tissue samples at appropriate times and measure fruit diameter and peel thickness, and determine peel color and TSS:acid. Wash, dry, grind leaf samples and send to the UC-DANR Laboratory for analysis.
Subtask 2.1 was be initiated in March 2010 and completed in November 2010; mid-year report sent July 2010

Subtask 2.2: Harvest mature crop and obtain all yield data, including fruit quality data (samples taken to the Lindcove REC Analytical Lab.
Subtask 2.2 was initiated in November 2010 and completed in November 2010.

Subtask 2.3: Statistically analyze yield data and nutrient analyses.
Subtask 2.3 was initiated in November 2010 and completed in December 2010.

Subtask 2.4: Prepare and send annual report to FREP.
Subtask 2.4 was initiated in December 2010 and completed in January 2011.

YEAR 3 – TASK 3: To test the efficacy of the following fertilizers applied to the foliage at the times specified: (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; and (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. Fertilizer rates are based on application in 250 gallons water per 100 trees per acre so that can be adjusted for application to individual trees.

Month of initiation: 2/11 Month of completion: 12/11

Subtask 3.1: Monitor tree phenology, apply foliar fertilizer treatments at proper stage of tree phenology or at 2/3-leaf expansion, collect tissue samples at appropriate times and measure fruit diameter and peel thickness, and determine peel color and TSS:acid. Wash, dry, grind leaf samples and send to the UC- DANR Laboratory for analysis.
Subtask 3.1 was initiated in March 2011 and completed in November 2011; mid-year report sent July 2011

Subtask 3.2: Harvest mature crop and obtain all yield data, including fruit quality data (samples taken to the Lindcove REC Analytical Lab.)
Subtask 3.2 was initiated in November 2011 and completed in November 2011.

Subtask 3.3: Statistically analyze yield data and nutrient analyses.
Subtask 3.3 was initiated in November 2011 and completed in December 2011.

Subtask 3.4: Prepare and send annual report and final reports to FREP. Subtask 3.4 was initiated in December 2011 and completed in December 2011.

RESULTS

Year 1. The first harvest was in December 2009. All trees produced uniformly good yields (an average of 94 kg of fruit per tree, with a range of 87-100 kg of fruit per tree and an average of 950 fruit per tree, with a range of 863-1016) (Tables 1 and 2). No treatment significantly increased total yield above that of the untreated control trees. The highest yields as kilograms and number of fruit per tree were obtained with foliar-applications of low-biuret urea in November or January (100 kg per tree and 1016 and 1010 fruit per tree, respectively, compared to 93 kg and 921 fruit per tree for the untreated control trees). Prebloom foliar application of low-biuret urea in January significantly increased fruit set, resulting in a significant increase in the number of commercially marketable fruit per tree of packing carton sizes 18 to 32 (55-71 mm fruit transverse diameter) compared to untreated control trees ($P = 0.0413$) (Table 2). The net increase was 100 fruit per tree more than the untreated control. The January application of urea also resulted in the highest yield as kilograms per tree of commercially marketable fruit of packing carton sizes 18-32, but it was not significantly different from the yield of the untreated control trees ($P = 0.0982$) (Table 1). All three winter prebloom foliar-applications of low-biuret urea (Nov., Dec. or Jan.) and zinc applied to the foliage at 10% anthesis in the SWTQ significantly increased the yield of commercially marketable fruit in the combined pool of fruit of packing carton sizes 18 to 32 as kilograms fruit per tree compared to trees receiving foliar-applied urea combined with potassium phosphite in December and foliar-applied potassium nitrate at dormancy (Feb.), postbloom (75% petal fall in the NETQ) (~May) and during summer fruit growth (July-Aug.). Trees treated with foliar-applied urea in January also produced significantly more kilograms fruit per tree than trees treated with boron applied to the foliage at 10% anthesis in the SWTQ ($P = 0.0982$). In addition, the three winter prebloom foliar-applications of low-biuret urea (Nov., Dec. or Jan.) and zinc applied to the foliage at 10% anthesis in the SWTQ significantly increased the yield of fruit in the combined pool of commercially valuable fruit of packing carton sizes 28 + 24 (58-63 mm fruit transverse diameter) as kilograms and number of fruit per tree compared to trees receiving foliar-applied urea combined with potassium phosphite in December, foliar-applied potassium nitrate at dormancy (Feb.), postbloom (75% petal fall in the NETQ) (~May) and during summer fruit growth (July-Aug.), and boron applied to the foliage at 10% anthesis in the SWTQ ($P = 0.0223$ and $P = 0.0214$ for kg and number of fruit per tree, respectively) (Data not shown). All other treatments had an intermediate effect on the yield of fruit of packing carton sizes 28 + 24 that was not significant.

All fruit were of excellent quality and had a high sugar to acid ratio (~ 14) at harvest in December (Table 3). Several foliar fertilizer treatments significantly increased the percentage of juice in the fruit above that of fruit from untreated control trees. The foliar fertilizer treatments that increased juice content of the fruit above that of the untreated control trees were: low-biuret urea applied in November or January, potassium nitrate at dormancy (Feb.), postbloom (75% petal fall in the NETQ) (~May) and during summer fruit growth (July-Aug.), zinc applied at 10% anthesis, zinc applied at 2/3-leaf expansion, and potassium phosphite applied in early May and again in July. There were no significant treatment effects on peel thickness, total soluble solids (TSS), percent acidity or the ratio of total soluble solids to acid (Table 3).

The highest US$ return per tree was attained with the foliar application of low-biuret urea in November or January, which resulted in a net increase of $1,961 and $1,932 per acre above that of the control trees not receiving foliar-fertilization, but the result was not statistically significant (Table 4).

Year 2. The second harvest was in December 2010. All trees produced uniform yields that were lower than in Year (an average of 91 kg of fruit per tree across all treatments, with a range of 83-95 kg of fruit per tree, and an average of 860 fruit per tree, with a range of 735-884 per tree) (Tables 5 and 6). No treatment significantly increased total yield above that of the untreated control trees. The highest yields as kilograms and number of fruit per tree were obtained with the foliar application of boron at 10% anthesis (~April): 94.7 kg and 884 fruit per tree, which was equal in kilograms per tree but 24 more fruit per tree than the untreated control trees. The next best treatment was low-biuret urea in January at 94.1 kilograms per tree and 864 fruit per tree. No treatment had a significant effect on the yield of large size fruit or the yield of commercially marketable fruit (packing carton sizes 18-32).

There were several significant effects due the fertilizer treatments on fruit quality in Year 2 (Table 7). Foliar application of boron or low-biuret urea combined with potassium phosphite at 2/3-leaf expansion, the standard application time for citrus foliar fertilization (Embleton and Jones, 1974), significantly reduced the average weight of individual fruit below that of the untreated control trees (P = 0.0786). Low-biuret urea combined with potassium phosphite applied at 2/3-leaf expansion significantly increased the TSS:acid ratio of the juice above that of the untreated control trees and all other fertilizer treatments, except low-biuret urea combined with potassium phosphite applied in November, low-biuret urea applied in January, and zinc applied at 2/3-leaf expansion (P = 0.0782). The increase in juice TSS:acid ratio for fruit from trees treated with low-biuret urea combined with potassium phosphite at 2/3-leaf expansion with was due to the fruit having a high concentration of TSS than trees receiving other fertilizer treatments, but not the untreated control trees.

In year 2, the greatest income was derived from the untreated control trees, which produced US$137 and US$546 more than the next best treatments - boron applied at 10% anthesis and low-biuret urea applied in January (Table 8).

Year 3. The third harvest was in November 2011. The average yield in 2011 was significantly greater than in the previous 2 years as both kilograms and number of fruit per tree (an average of 107 kg of fruit per tree across all treatments, with a range of 97-115 kg of fruit per tree, and an average of 1268 fruit per tree, with a range of 1156-1366 per tree) (Tables 9 and 10). The heavy yield in Year 3 resulted in a much greater number of fruit of packing carton size 32, 36 and 40 (< or = 57 mm in diameter) than in the prior 2 years (Tables 2, 6, and 10). No treatment significantly increased total yield above that of the untreated control trees, which produced the greatest yields as both kilograms and number of fruit per tree and significantly more fruit of packing size 28 (both kilograms and number of fruit per tree) than trees receiving foliar-applied low-biuret urea in November, low-biuret urea combined with potassium phosphite in December, low-biuret urea in January, potassium nitrate at dormancy (Feb.), postbloom (75% petal fall in the NETQ) (~May) and during summer fruit growth (July-Aug.), and low-biuret urea combined with potassium phosphite at 2/3-leaf expansion (P = 0.0918 for both kilograms and number of fruit per tree) (Tables 9 and 10). All other treatments produced intermediate yields of fruit of packing carton size 28 as both kilograms and number of fruit per tree that were not significantly different from the untreated control. Trees receiving a winter prebloom foliar application of low-biuret urea in January and the untreated control trees produced a significantly greater total number of fruit per tree than trees receiving zinc at 10% anthesis, boron at 2/3-leaf expansion and low-biuret urea combined with potassium phosphite at 2/3-leaf expansion.

There were no significant treatment effects on the following fruit quality parameters analyzed: peel thickness, percent juice content per fruit, the ratio of TSS:acidity (Table 11). The greatest average fruit weight was for trees receiving foliar-applied low-biuret urea in December and the average fruit weight for this treatment was significantly greater than fruit from trees receiving foliar applications of low- biuret urea in January, potassium phosphite in May and July, or low-biuret urea in July (P = 0.0173). The average fruit weight for other treatments was intermediate and not significantly different. Trees treated with boron at 10% anthesis produced the highest concentration of TSS in the fruit juice, which was significantly greater than the TSS value for fruit in all other treatments, except foliar-applied low- biuret urea in December, potassium nitrate at dormancy (Feb.), postbloom (75% petal fall in the NETQ) (~May) and during summer fruit growth (July-Aug.), and low-biuret urea in July (P = 0.0194). Interestingly, trees treated with boron at 10% anthesis also produced the highest percent acidity in the fruit juice, which was significantly greater than trees treated with low-biuret urea in December, low- biuret urea combined potassium phosphite in December or at 2/3-leaf expansion, and the untreated control (P = 0.0699).

Untreated control trees produced the greatest income per acre, US$537 more than the next best treatment
- foliar-applied potassium phosphite in May and July (Table 12). The greater income for the untreated control trees was due to the value of fruit of packing carton size 28 (P = 0.0918) and 32 (non- significant).

Tree Nutrient Status After 3 Years of Foliar Fertilization. Nutrition in this orchard was generally optimal over the 3 years of the experiment with the exception that several micronutrients fell below the optimum range by Year 3 (Table 13). Leaf Zn concentrations ranged from 13.2 to 21.8 ppm (optimum is 25-100 ppm, 16-24 ppm is low and < 16 ppm is deficient) (Embleton et al., 1978). Mn ranged from 17.1 to 20.0 ppm (optimum is 25-200 ppm, 16-24 is low). Leaf Fe concentrations ranged from 58.9 to 79.6 ppm. Most were at the low end of the optimum range (60-120 ppm). Trees treated with potassium nitrate at dormancy (Feb.), postbloom (75% petal fall in the NETQ) (~May) and during summer fruit growth (July-Aug.) or with low-biuret urea plus potassium phosphite at 2/3-leaf expansion had leaf Fe concentrations of 58.9 and 59.1 ppm, respectively, which is considered low. Cu ranged from 3.1 to 4.1 ppm (optimum is 5-16 ppm, 3.6-4.9 is low and less than 3.6 is deficient). Leaf N (2.4%-2.6%) and K (1.2%) concentrations were consistent with levels recommended for sweet oranges by Embleton for larger fruit size rather than a greater total number of fruit per tree (Embleton, personal communication). The foliar fertilization treatments resulted in statistically significant differences in leaf nutrient concentrations for all nutrients, except calcium and magnesium. All differences were small and of little apparent physiological significance. Significant differences in leaf nutrient concentrations could not be linked in many cases to the nutrient(s) in the fertilizer applied or to effects on yield or fruit size. For example, Low-biuret urea plus potassium phosphate applied at 2/3-leaf expansion and low-biuret urea applied in July significantly increased percent leaf N to values greater than all other treatments including the untreated control, but did not result in yields (kilograms or fruit number) greater than the untreated control in Year 3 (Tables 9,10, 13, 14 and 15). Similarly for leaf P concentrations, trees treated with low-biuret urea plus potassium phosphite in December, low-biuret urea in January, zinc at 10% anthesis, boron at 2/3-leaf expansion, low-biuret urea plus potassium phosphite at 2/3-leaf expansion, or low- biuret urea in July had significantly greater leaf concentrations of P than trees in the untreated control and several other treatments (Table 13). For trees in these treatments, the total kilograms of fruit per tree in Year 3 were not significantly different, whereas total fruit number per tree was significantly greater for trees receiving low-biuret urea in January and the control trees than trees receiving zinc at 10% anthesis, boron at 2/3-leaf expansion, or low-biuret urea plus potassium phosphite at 2/3-leaf despite the fact that all trees in these treatments had greater leaf P concentrations. Further, review of leaf concentrations revealed additional anomalies (Table 13).

Of interest is the fact that untreated control trees had leaf concentrations of N, P, K, S, B, Zn, Mn, and Cu that were significantly lower than trees in other treatments with no effect on yield or fruit size relative to trees in treatments with greater leaf concentrations of theses nutrients. Further, foliar-applied boron at 2/3-leaf expansion or at 10% anthesis resulted in leaf B concentrations that were significantly greater than all other treatments ($P < 0.0001$) (Table 13). Increasing the leaf B concentration to the mid- part of the optimal range (31-100 ppm is the optimal range; Embleton et al., 1978) did not increase yield or fruit size. Pair-wise analysis of total yield and fruit size distribution as kilograms and number of fruit per tree, using Dunnett's two-tailed t-test at $P = 0.05$, indicated no significant differences in yield between foliar application of boron at 10% anthesis or 2/3-leaf expansion (Data not shown). Foliar application of zinc at 2/3-leaf expansion resulted in the greatest leaf concentration of Zn compared to all other treatments ($P < 0.0001$). However, there were no significant differences in yield or fruit size between trees treated with zinc at 10% anthesis or 2/3-leaf expansion (Dunnett's t-test at $P = 0.05$) (Data not shown).

3-Year Average Yield. Averaged across all treatments, trees produced significantly more total kilograms of fruit per tree in Year 3 than in Years 1 and 2 ($P < 0.0001$), with no significant differences in total kilograms in Year 1 versus 2 (Table 14). Fruit number per tree was also significantly greater in Year 3 than in Years 1 and 2, with fruit number in Year 1 significantly greater than in Year 2 ($P < 0.0001$) (Table 15). Averaged across the 3 years of the research, the greatest number of fruit per tree was attained with the January foliar-application of low-biuret urea, but the treatment effect was neither dramatically nor significantly different from the untreated control (Table 15). A similar effect on total kilograms per tree was not attained.

Year (crop load) significantly affected the yield of fruit in all packing carton size categories. The effect of crop load on fruit size distribution is easily seen in Tables 14 and 15. The high yield in Year 3 resulted in significantly more small fruit of packing carton sizes 40, 36 and 32 than the other two years. The lowest yield (Year 2) resulted in more fruit of packing carton sizes 21, 18 and 15 compared to the two other years. Trees in Year 1, the intermediate yield year, produced more fruit of packing carton size 28 than in the other two years. Averaged across the 3 years of the experiment, two foliar-applied fertilizer treatments reduced the yield of fruit of packing carton size 28 (kilograms per tree, *P* = 0.1008; number of fruit per tree, *P* = 0.101) with no significant effect on the yield of commercially valuable fruit (packing carton sizes 18-32) (Tables 14 and 15). There were no significant interactions between treatment and year that affected total yield or fruit size. Revenue generated annually was consistent across all 3 years of the research (Tables 4, 8, and 12).

Averaged across all treatments, it is clear that crop load also influenced all fruit quality parameters analyzed in this experiment (Table 16). Year 3, the highest yielding year, resulted in significantly thinner peels, greater percent acidity and the lowest total soluble solids to acid ratio in the juice compared to the other two years. In contrast, Year 2, which had the lowest yield, resulted in the thickest peels, greatest fruit weight, and highest TSS to acid ratio (Table 16). Averaged across the 3 years of the research, foliar fertilizer treatments significantly affected the total soluble solids to acid ratio (TSS:acid) (*P* = 0.0328). Trees treated with low-biuret urea in January or zinc at 10% anthesis produced fruit with higher TSS:acid ratios than trees treated with low-biuret urea in November, potassium nitrate at dormancy (Feb.), postbloom (75% petal fall in the NETQ) (~May) and during summer fruit growth (July-Aug.), and boron at 2/3-leaf expansion, but no treatments resulted in TSS:acid ratios significantly different from the untreated control trees. There was no significant treatment by year interaction on any of the yield or fruit quality parameters analyzed in this experiment.

Alternate Bearing Index. Despite significant differences in annual crop load for the 3 years of the research, the alternate bearing index (ABI) for the orchard was very low, less than 0.08 for 2009 and 2010 and less than 0.2 for 2010 and 2011. Only when ABI values exceed 0.5 is alternate bearing considered an economic problem. The foliar fertilizer treatments had no significant effect on ABI for either 2-year period.

3-Year Cumulative Yield. There were no significant effects resulting from foliar-applied fertilizer treatments on 3-year cumulative total yield (kilograms and number of fruit per tree) (Tables 17 and 18). The greatest 3-year cumulative yields were attained with the January foliar application of low-biuret urea, but the difference was only 0.9 kilogram and 66 fruit per tree more than the untreated control. Trees treated with low-biuret urea in November or January or boron at 2/3-leaf expansion and untreated control trees produced significantly more fruit of packing carton size 28 than trees treated with low- biuret urea plus potassium phosphite in December or trees treated with potassium nitrate at dormancy (Feb.), postbloom (75% petal fall in the NETQ) (~May) and during summer fruit growth (July-Aug.) (*P* = 0.0991). However, there were concomitant effects on the yield of commercially valuable fruit of packing carton sizes 18-32. Subtle non-significant differences in fruit size distribution resulted in the untreated control trees having a crop value that was US$687 greater than the next best crop value, which was for trees receiving foliar-applied low-biuret urea in January; the difference was not significant (Table 19). The reduced value and utilization rate for fruit of packing carton size 15 in the current pricing system had a negative effect on the crop value of trees treated with low-biuret urea in January.

DISCUSSION

The lack of a statistically significant increase in yield, fruit size or grower income in response to a foliar- applied fertilizer treatment was both surprising and disappointing. Whereas this was the first time that many of the treatments included in this research were tested on Clementine mandarins in California, foliar-applications of low-biuret urea, potassium phosphite and potassium nitrate have previously been shown to increase yield, fruit size and quality of citrus cultivars in several different growing areas. Winter prebloom foliar applications of low-biuret urea or potassium phosphite (a form of P [HPO_3^{-2}] readily taken up by leaves and translocated through trees to the roots [Lovatt and Mikkelsen, 2006]) have been shown to increase yield, yield of commercially valuable large size fruit and total soluble solids (TSS) of sweet oranges (*C. sinensis*) in California and Florida (Albrigo, 1999; Ali and Lovatt, 1992, 1994; Lovatt, 1999); when combined, the yield effects are additive (Albrigo, 1999). Use of urea and potassium phosphite in Clementine mandarin (*C. reticulata*) production in Morocco produced similar beneficial yield results (El-Otmani et al., 2003a, b). Application of potassium phosphite in May (during the cell division stage of fruit development) and again in July (at maximum peel thickness, which marks the end of the cell division stage of citrus fruit development) or a single application of low- biuret urea in July increased the yield of large size 'Frost nucellar' navel orange fruit in California (*C. sinensis*) (Lovatt, 1999). Fruit size of ‘Sunburst’ tangerine (*C. reticulata* x *C. paradisi*) was increased with three foliar applications of potassium nitrate (KNO_3) made at dormancy (February), post-bloom (~April) and during exponential fruit growth (July-August) (Boman, 2002). The foliar-fertilizer treatment in the study with ‘Sunburst’ tangerine resulted in a significant increase in grower income because a greater number of fruit reached the minimum size and quality for early harvest and netted a higher market price than fruit on the untreated control trees. In our research, early harvest by size was not possible. In previous research in California, a single winter (December) prebloom foliar application of low-biuret urea to ‘Nules’ Clementine mandarin trees in an alternate bearing orchard significantly increased fruit size in both the ON- and OFF crop years and increased the 2-year cumulative yield of commercially valuable fruit (transverse diameter 64-76 mm, packing carton sizes 21-15) as both kilograms and number of fruit per tree with no effect on total yield or fruit quality (Gonzalez et al., 2010). Whether alternate bearing was a factor in attaining positive effects on fruit size in this earlier experiment is unknown. The results of the research presented herein provided clear evidence that crop load (Year) affected fruit size and quality.

Pairwise statistical analysis confirmed that there were no significant differences in total yield and fruit size as either kilograms or number of fruit per tree when boron or zinc was applied at 10% anthesis versus at 2/3-leaf expansion (Data not shown).

The results of the leaf analyses provided evidence of nutrient deficiencies in Year 3 of the research, possibly resulting from the heavy crop set in Year 3. Zinc was low in all trees except those receiving foliar-applied zinc at 2/3-leaf expansion. These trees did not have greater total yield or yield of commercially valuable fruit (packing carton sizes 18-32) in Year 3, or as 3-year cumulative yield, than the untreated control trees or trees in any other treatment. Thus, zinc alone was not limiting to yield or fruit size. Leaf Fe concentration was significantly lower than that of the untreated control trees for trees receiving foliar-applied potassium nitrate at dormancy (Feb.), postbloom (75% petal fall in the NETQ) (~May) and during summer fruit growth (July-Aug.) and trees receiving low-biuret urea plus potassium phosphite at 2/3-leaf expansion. These trees had lower 3-year cumulative total yields and/or yields of commercially valuable fruit of packing carton size 18-32. Thus, it is possible that low Fe availability might have limited yield and/or fruit size. The interaction between crop load and fruit size makes it difficult to diagnose the true effect of low Fe, as reduced fruit number can result in increased fruit size, which increases total kilograms per tree. The effect of Cu deficiency on yield and fruit size is also difficult to determine. Trees in treatments having leaf Cu concentrations considered deficient also had leaf Fe concentrations in the optimal range, i.e., trees receiving low-biuret urea in November or January. Trees in these treatments yielded well and were among the higher crop values per acre, suggesting that Cu was not limiting to yield or fruit size. The yield results of this research were surprising. In year 3, foliar-fertilizer treatments that mitigated the low nutrient status of the tree (based on leaf nutrient analyses) for a specific nutrient, e.g., boron and zinc, early in the season (10% anthesis in the SWTQ and at 2/3-leaf expansion) did not increase yield or fruit size. Thus, it cannot be ruled out that the low levels of Mn, Fe and Cu available in the trees in Year 3 prevented the trees from fully responding to the foliar-applied fertilizers in Year 3.

Over the 3 years of the research there were significant differences in the average kilograms and number of fruit per tree across all treatments. However, the differences in total yield from year to year were not large enough to be considered alternate bearing. Despite this fact, the annual differences in yield had a significant effect on fruit size distribution (packout) (tables 14 and 15). Importantly, we are learning that crop load influences the efficacy of foliar-applied plant growth regulator treatments and, likely, foliar- applied fertilizer treatments in citrus, in particular Clementine mandarin (Chao et al., 2011). When yield exceeded 1,000 fruit per tree, foliar-applied GA_3 (even multiple applications) could not increase yield, fruit size or grower income. At lower yields, GA_3 could be used successfully to increase yield, fruit size and grower income. These results suggest that when flowering is intense, fruit set is high and the system is “saturated”. The few sites remaining for which fruit set can be increased, result in marginal increases in yield that are not statistically significant. Further, the large number of fruit on the tree makes it difficult to increase fruit size. In years in which floral intensity is low, increasing fruit set for the few flowers present does not significantly increase yield. Further, in a low crop year fruit size is already large, increasing it further is counterproductive as it leads to fruit that are too large and of lower dollar value. Thus, when floral intensity is neither too low nor too high, PGRs, and likely foliar fertilizers, can significantly increase fruit set and fruit size.

During the first 2 years of the research, ‘Nules’ Clementine mandarin annual yield was less than 1,000 fruit per tree annually. The January foliar application of low-biuret urea resulted the greatest 2-year cumulative yield as kilograms and number of fruit per tree (not significant) and significantly increased both the kilograms and number of commercially valuable fruit per tree of packing carton size 28 (P = 0.0275 for kilograms; P = 0.0273 for fruit number) (Tables 20 and 21) and in the combined pool of packing carton sizes 28 and 24 (P = 0.0641 for kilograms; P = 0.0547 for fruit number) (Data not shown). This resulted in a net increase of US$1,386 per 200 trees per acre at the end of the first 2 years of the research (Table 22). No other foliar fertilizer treatment produced a net increase in revenue over the untreated control trees at the end of the second or third year of this experiment.

CONCLUSION

Foliar-applied fertilizer treatments were unsuccessful in increasing yield, fruit size and grower income in a dramatic and statistically significant manner in this 3-year study. There were consistent numeric increases in yield and significant increases in yield of commercially valuable size fruit in response to the January foliar application of low-biuret urea in Year 1 and as 2-year cumulative yield when yields were less than 1,000 fruit per tree per year and trees had adequate nutrition. Whether the yield results in Year 3 were compromised by the large crop (> 1,000 fruit per tree) or by the low leaf concentrations of B, Mn, Fe, Zn and Cu in Year 3 remains unresolved. A winter prebloom foliar application of low-biuret urea is an inexpensive treatment (~$21/acre cost of material only) that can ensure maximum yield in years when yield would fall short of 1,000 fruit per tree and no negative effect in years in which yield is greater than 1,000 fruit per tree.

PROJECT EVALUATION:

We have completed three full years of foliar-fertilizer treatment applications, harvested the crop for all three years and completed the statistical analysis of the yield data, including fruit size distribution (pack out), fruit quality parameters and leaf analyses.

OUTREACH ACTIVITIES SUMMARY:

During the 3-years of this project the PI gave presentations, which included information related to this project to growers, industry people and other researchers at the following venues: (1) Kern County Citrus Growers Meeting, "Plant Growth Regulators on Mandarins", March 25, 2008 (invited); (2) Tulare County Citrus Growers Meeting, "Plant Growth Regulators on Mandarins", April 17, 2008 (invited); (3) VI International Symposium on Mineral Nutrition of Fruit Crops, University of Algarve, Faro, Portugal, "Properly Timed Foliar Fertilization Can and Should Result in a Yield Benefit and Net Increase in Grower Income", May 19-23, 2008; (4) CDFA-FREP Annual Meeting, "Gauging the Effectiveness of Foliar Fertilizers on Citrus", November 12-13, 2008 (invited); (5) California and Plant and Soil Science Conference, Fertilization of Perennial Tree Crops: *Timing is everything!*, February 3-4, 2009 (invited);
(6) Friends of Citrus at the USDA Citrus and Date Germplasm Repository, UCR, "Phenology and Physiology of Citrus Productivity", February 17, 2010 (invited); (7) INIFAP-Campo Experimental Santiago Ixcuintla, Santiago Ixcuintla, Nayarit, MÉXICO, "Impact of Climate Change on Citrus and Avocado Flowering and Yield in California and Mexico", March 12, 2010 (invited); (8) University of Arizona, Tuscon, AZ, "Phenology and Physiology of Citrus and Avocado Productivity", April 27, 2010 (invited); (9) citrus grower education meeting sponsored by Citrus Research Board, Auburn, CA, "Phenology and Physiology of Citrus Productivity", October 29, 2010 (invited); (10) citrus grower education meeting sponsored by Citrus Research Board, Pala, CA, "Phenology and Physiology of Citrus Productivity", February, 2011 (invited); and (11) Ojai Valley 'Pixie' Growers Association, I organized a seminar with the help of Dr. Ben Faber, Ventura County Farm Advisor, to discuss alternate bearing in mandarins and available strategies for mitigating it, which included a discussion of foliar fertilization, August 10, 2011.

References:

Albrigo, L. G. 1999. Effects of foliar applications of urea or Nutri-Phite on flowering and yields of Valencia orange trees. Proc. Fla. State Hort. Soc.

Ali, A.G. and C.J. Lovatt. 1992. Winter application of foliar urea. Citrograph 78:7–9.

Ali, A. G. and C. J. Lovatt. 1994. Winter application of low-biuret urea to the foliage of ‘Washington’ navel orange increased yield. J. Amer. Soc. Hort. Sci. 119:1144-1150.

Boman, B.J. 2002. KNO_3 foliar application to 'Sunburst' tangerine. Proc. Fla. State. Hort. Soc. 115:6-9.

Chao, C.-C.T., T. Khuong, Y. Zheng, and C.J. Lovatt, 2011. Response of evergreen perennial tree cropsto gibberellic acid is crop load-dependent: I. *GA_3 increases the yield of commercially valuable 'Nules' Clementine Mandarin fruit only in the off-crop year of an alternate bearing orchard.* Sci. Hortic. 130:753-761.

El-Otmani, M., A. Ait-Oubahou, F.-Z. Taibi, B. Lmfoufid, M. El-Hila, and C. J. Lovatt. 2003a. Prebloom foliar urea application increases fruit set, size, and yield of Clementine mandarin. Proc. Intl. Soc. Citriculture 1:559–562.

El-Otmani, M., A. Ait-Oubahou, H. Gousrire, Y. Hamza, A. Mazih, and C. J. Lovatt. 2003b. Effect of potassium phosphite on flowering, yield, and tree health of ‘Clementine’ mandarin. Proc. Intl. Soc. Citriculture 1:428–432.

Embleton, T.W. and W.W. Jones. 1974. Foliar-applied nitrogen for citrus fertilization. J. Environ. Quality 3:388-392.

Embleton, T.W., W.W. Jones, and R.G. Platt. 1978. Leaf analysis as a guide to citrus fertilization. In: H.M. Reisenauer (ed.). Soil and plant-tissue testing in California. Div. Agr. Sci. Univ. Calif. Bul. 1879.

Gonzalez, C., Zheng, Y., Lovatt, C. 2010. Properly timed foliar fertilization can and should result in a yield benefit and net increase in grower income. Acta Hort. 868:273-286.

Lovatt, C. J. 1999. Timing citrus and avocado foliar nutrient applications to increase fruit set and size. HorTechnology 9:607-612.

Lovatt, C. J., Y. Zheng, and K. D. Hake. 1988. Demonstration of a change in nitrogen metabolism influencing flower initiation in citrus. Israel J. Bot. 37:181-188.

Lovatt, C.J and R.L. Mikkelsen. 2006. Phosphite fetilizers: What are they? Can you use them? What can they do? Better Crops 90:11-13.

Table 1. Effects 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 - prebloom; February - dormancy; April - 10% anthesis or 2/3-leaf expansion as indicated; May - postbloom (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								
			40 49-51mm	36 52-54mm	32 55-57mm	28 58-60mm	24 61-63mm	21 64-67mm	18 68-71mm	15 72-75mm	18-32 55-71mm
		kg per tree									
Urea	12 Nov	99.8 a[z]	3.1 a	10.9 a	15.7 a	23.3 a	17.6 a	17.0 a	6.5 a	3.1 a	80.1 ab
Urea + Potassium phosphite	12 Nov	93.7 a	3.2 a	9.6 a	17.0 a	18.5 abcd	18.6 a	14.7 a	6.6 a	3.6 a	75.3 abcd
Urea	18 Dec	96.5 a	3.3 a	7.9 a	15.5 a	18.8 abcd	19.4 a	16.2 a	7.7 a	3.9 a	77.6 abc
Urea + Potassium phosphite	18 Dec	87.2 a	3.2 a	9.2 a	13.8 a	16.0 cd	13.5 a	15.2 a	7.6 a	4.5 a	66.1 d
Urea	9 Jan	99.9 a	3.4 a	8.2 a	19.0 a	22.6 a	17.6 a	17.8 a	5.7 a	2.8 a	82.5 a
Potassium nitrate	19 Feb + 6 May + 1 Jul	94.2 a	5.1 a	13.6 a	16.5 a	17.2 bcd	12.9 a	14.3 a	7.6 a	2.3 a	68.4 cd
Zinc	24 Apr (10% anthesis)	95.2 a	3.5 a	10.1 a	18.6 a	21.8 ab	17.2 a	14.8 a	5.2 a	1.9 a	77.5 abc
Zinc	14 Apr (2/3-leaf expansion)	94.7 a	3.0 a	10.3 a	16.2 a	20.6 abc	15.9 a	15.6 a	6.3 a	2.6 a	74.5 abcd
Boron	24 Apr (10% anthesis)	91.4 a	4.5 a	10.0 a	15.7 a	15.5 d	15.7 a	17.3 a	7.2 a	2.3 a	71.3 bcd
Boron	14 Apr (2/3-leaf expansion)	97.3 a	4.1 a	9.4 a	16.9 a	19.5 abcd	15.4 a	17.6 a	6.7 a	3.7 a	76.1 abc
Urea + Potassium phosphite	14 Apr (2/3-leaf expansion)	89.0 a	1.8 a	7.3 a	14.1 a	18.7 abcd	18.1 a	14.7 a	7.5 a	4.6 a	73.1 abcd
Potassium phosphite	6 May +1 Jul	94.0 a	4.3 a	9.8 a	17.5 a	18.7 abcd	16.7 a	13.8 a	8.2 a	2.5 a	75.0 abcd
Urea	1 Jul	90.3 a	2.3 a	9.0 a	15.8 a	18.6 abcd	17.0 a	14.2 a	7.9 a	2.5 a	73.5 abcd
Control		93.3 a	3.7 a	8.7 a	12.3 a	18.4 abcd	17.4 a	18.0 a	8.2 a	4.0 a	74.2 abcd
P-value		0.4956	0.7000	0.7861	0.6096	0.0931	0.2931	0.9092	0.9343	0.7116	0.0982

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

Table 2. Effects 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 - prebloom; February - dormancy; April - 10% anthesis or 2/3-leaf expansion as indicated; May - postbloom (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								
			40 49-51mm	36 52-54mm	32 55-57mm	28 58-60mm	24 61-63mm	21 64-67mm	18 68-71mm	15 72-75mm	18-32 55-71mm
		no. of fruit per tree									
Urea	12 Nov	1016 a[z]	48 a	145 a	179 a	237 a	164 a	141 a	47 a	19 a	768 ab
Urea + Potassium phosphite	12 Nov	946 a	50 a	127 a	194 a	188 abcd	173 a	122 a	47 a	23 a	724 abc
Urea	18 Dec	950 a	52 a	105 a	176 a	192 abcd	181 a	134 a	55 a	25 a	737 abc
Urea + Potassium phosphite	18 Dec	882 a	49 a	122 a	157 a	163 cd	126 a	126 a	54 a	28 a	626 d
Urea	9 Jan	1010 a	53 a	108 a	216 a	230 a	164 a	147 a	40 a	18 a	797 a
Potassium nitrate	19 Feb + 6 May + 1 Jul	980 a	80 a	180 a	188 a	175 bcd	120 a	118 a	54 a	15 a	655 cd
Zinc	24 Apr (10% anthesis)	980 a	55 a	134 a	212 a	222 ab	160 a	123 a	37 a	12 a	753 ab
Zinc	14 Apr (2/3-leaf expansion)	970 a	46 a	136 a	184 a	210 abc	148 a	129 a	45 a	17 a	716 abcd
Boron	24 Apr (10% anthesis)	926 a	70 a	133 a	178 a	158 d	147 a	143 a	51 a	14 a	677 bcd
Boron	14 Apr (2/3-leaf expansion)	991 a	63 a	124 a	192 a	199 abcd	144 a	146 a	48 a	24 a	728 abc
Urea + Potassium phosphite	14 Apr (2/3-leaf expansion)	863 a	28 a	96 a	160 a	191 abcd	168 a	122 a	53 a	29 a	695 bcd
Potassium phosphite	6 May + 1 Jul	960 a	67 a	130 a	199 a	191 abcd	156 a	114 a	59 a	16 a	719 abc
Urea	1 Jul	902 a	36 a	120 a	179 a	190 abcd	158 a	118 a	56 a	16 a	701 bcd
Control		921 a	58 a	116 a	140 a	187 abcd	162 a	149 a	59 a	25 a	697 bcd
P-value		0.5960	0.7000	0.7861	0.6096	0.0931	0.2931	0.9092	0.9343	0.7116	0.0413

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

Table 3. Effects of applying foliar fertilizers at key stages of tree phenology on the fruit quality of 'Nules' Clementine mandarin trees. Application times refer to the following phenological stages: November, December, and January - prebloom; February - dormancy; April - 10% anthesis or 2/3-leaf expansion as indicated; May - postbloom (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	Peel thickness (mm)	Fruit weight (g)	Juice content (%)	TSS (°brix)	Acidity (%)	TSS: acid
Urea	12 Nov	2.7 a[z]	77.3 a	39.5 a	11.0 a	0.8 a	14.3 a
Urea + Potassium phosphite	12 Nov	3.1 a	81.6 a	37.1 abc	11.0 a	0.8 a	14.7 a
Urea	18 Dec	2.8 a	79.7 a	37.7 abc	11.3 a	0.8 a	14.2 a
Urea + Potassium phosphite	18 Dec	3.0 a	88.6 a	35.1 bc	11.3 a	0.8 a	14.9 a
Urea	9 Jan	2.9 a	81.0 a	38.8 ab	11.2 a	0.8 a	14.8 a
Potassium nitrate	19 Feb + 6 May + 1 Jul	2.7 a	78.8 a	38.8 ab	11.3 a	0.8 a	14.2 a
Zinc	24 Apr (10% anthesis)	2.9 a	81.2 a	39.2 a	11.1 a	0.7 a	15.4 a
Zinc	14 Apr (2/3-leaf expansion)	3.1 a	85.7 a	39.5 a	10.9 a	0.8 a	14.6 a
Boron	24 Apr (10% anthesis)	3.1 a	83.3 a	36.2 abc	11.4 a	0.8 a	14.6 a
Boron	14 Apr (2/3-leaf expansion)	2.9 a	79.8 a	37.2 abc	11.3 a	0.8 a	14.1 a
Urea + Potassium phosphite	14 Apr (2/3-leaf expansion)	3.0 a	83.5 a	36.6 abc	11.2 a	0.8 a	14.6 a
Potassium phosphite	6 May + 1 Jul	2.6 a	74.8 a	39.5 a	11.4 a	0.8 a	14.9 a
Urea	1 Jul	3.3 a	83.5 a	36.0 abc	11.3 a	0.8 a	13.8 a
Control		3.0 a	88.2 a	34.8 c	11.3 a	0.8 a	14.3 a
P-value		0.5083	0.1462	0.0738	0.9284	0.3337	0.1919

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

Table 4. Effects of applying foliar fertilizers at key stages of tree phenology on the crop value in US dollars per acre of 'Nules' Clementine mandarin trees. Application times refer to the following phenological stages: November, December, and January - prebloom; February - dormancy; April - 10% anthesis or 2/3-leaf expansion as indicated; May - postbloom (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.) The number of cartons of fruit produced per tree in each size category was calculated by dividing the total number of fruit harvested in each size category by the number of fruit packed per carton by size, i.e., packing carton size 40 contains 40 fruit per carton. Price by packing carton size is based on recent FOB pricing data as follows: 40, $3.00 with 70% utilization; 36, $3.60; 32, 28, 24, 21, and 18, $4.10; and 15, $3.90 with 60% utilization.

Treatment	Application time	Total	Packing carton size							
			40 49-51mm	36 52-54mm	32 55-57mm	28 58-60mm	24 61-63mm	21 64-67mm	18 68-71mm	15 72-75mm
		US$/200 trees/acre								
Urea	12 Nov	28771 a[z]	506 a	2897 a	4579 a	6951 a	5611 a	5494 a	2126 a	608 a
Urea + Potassium phosphite	12 Nov	27061 a	523 a	2538 a	4959 a	5520 abcd	5912 a	4756 a	2139 a	713 a
Urea	18 Dec	27455 a	541 a	2096 a	4504 a	5614 abcd	6188 a	5241 a	2492 a	779 a
Urea + Potassium phosphite	18 Dec	24338 a	516 a	2443 a	4024 a	4777 cd	4300 a	4926 a	2467 a	886 a
Urea	9 Jan	28742 a	559 a	2168 a	5523 a	6745 a	5590 a	5755 a	1840 a	562 a
Potassium nitrate	19 Feb + 6 May + 1 Jul	26021 a	840 a	3598 a	4807 a	5137 bcd	4092 a	4614 a	2474 a	460 a
Zinc	24 Apr (10% anthesis)	27499 a	575 a	2690 a	5421 a	6506 ab	5474 a	4788 a	1677 a	368 a
Zinc	14 Apr (2/3-leaf expansion)	26726 a	487 a	2723 a	4711 a	6145 abc	5054 a	5037 a	2048 a	522 a
Boron	24 Apr (10% anthesis)	25958 a	731 a	2665 a	4556 a	4638 d	5008 a	5585 a	2328 a	448 a
Boron	14 Apr (2/3-leaf expansion)	27403 a	665 a	2486 a	4908 a	5817 abcd	4912 a	5700 a	2178 a	736 a
Urea + Potassium phosphite	14 Apr (2/3-leaf expansion)	25761 a	295 a	1928 a	4110 a	5596 abcd	5755 a	4753 a	2423 a	901 a
Potassium phosphite	6 May + 1 Jul	26940 a	705 a	2591 a	5108 a	5595 abcd	5317 a	4452 a	2683 a	490 a
Urea	1 Jul	25989 a	375 a	2390 a	4585 a	5558 abcd	5402 a	4607 a	2569 a	503 a
Control		26810 a	611 a	2321 a	3576 a	5491 abcd	5539 a	5814 a	2670 a	789 a
P-value		0.3157	0.7000	0.7861	0.6096	0.0931	0.2931	0.9092	0.9343	0.7116

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

Table 5. Effects 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 - prebloom; February - dormancy; April - 10% anthesis or 2/3-leaf expansion as indicated; May – postbloom (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 2: 2009- 2010; the orchard is located in Fresno, CA.)

			Packing carton size								
Treatment	Application Time	Total	40 49-51mm	36 52-54mm	32 55-57mm	28 58-60mm	24 61-63mm	21 64-67mm	18 68-71mm	15 72-75mm	18-32 55-71mm
		kg per tree									
Urea	11 Nov	90.6 a[z]	3.1 a	6.5 a	11.7 a	17.1 a	14.3 a	16.9 a	11.2 a	5.1 a	71.2 a
Urea + Potassium phosphite	11 Nov	93.0 a	2.4 a	6.6 a	12.2 a	15.4 a	15.3 a	18.3 a	11.7 a	6.3 a	72.8 a
Urea	22 Dec	91.9 a	2.1 a	5.7 a	10.3 a	14.8 a	16.7 a	19.2 a	13.3 a	6.7 a	74.3 a
Urea + Potassium phosphite	22 Dec	93.4 a	3.9 a	8.0 a	9.9 a	15.2 a	14.5 a	18.6 a	10.5 a	7.3 a	68.6 a
Urea	13 Jan	94.1 a	1.5 a	6.5 a	12.1 a	18.7 a	16.9 a	17.5 a	10.3 a	6.8 a	75.6 a
Potassium nitrate	11 Feb + 20 May + 16 Jul	89.9 a	3.2 a	6.8 a	11.3 a	12.3 a	15.3 a	18.8 a	13.1 a	4.9 a	70.8 a
Zinc	4 May (10% anthesis)	83.0 a	2.1 a	4.9 a	7.8 a	11.8 a	15.9 a	19.0 a	11.5 a	4.7 a	66.0 a
Zinc	7 Apr (2/3-leaf expansion)	88.2 a	1.9 a	5.8 a	12.1 a	13.9 a	17.0 a	12.5 a	11.9 a	7.5 a	67.4 a
Boron	4 May (10% anthesis)	94.7 a	2.5 a	8.1 a	11.7 a	17.8 a	17.9 a	18.3 a	10.0 a	5.7 a	75.7 a
Boron	7 Apr (2/3-leaf expansion)	92.6 a	2.8 a	6.4 a	14.0 a	18.1 a	17.0 a	16.9 a	9.1 a	4.9 a	75.0 a
Urea + Potassium phosphite	7 Apr (2/3-leaf expansion)	88.9 a	2.6 a	6.3 a	11.7 a	17.2 a	16.5 a	17.4 a	9.6 a	4.2 a	72.4 a
Potassium phosphite	20 May + 16 Jul	92.8 a	2.0 a	6.9 a	10.0 a	15.5 a	16.7 a	17.5 a	13.0 a	5.8 a	72.6 a
Urea	16 Jul	90.2 a	1.8 a	5.2 a	9.7 a	14.6 a	16.4 a	20.1 a	9.3 a	7.6 a	70.0 a
Control		94.7 a	1.8 a	5.3 a	10.8 a	16.4 a	22.6 a	19.4 a	10.2 a	4.6 a	79.4 a
P-value		0.9765	0.7404	0.8804	0.7618	0.1656	0.3402	0.4925	0.7067	0.5506	0.7862

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

Table 6. Effects 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 - prebloom; February - dormancy; April - 10% anthesis or 2/3-leaf expansion as indicated; May – postbloom (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 2: 2009-2010; the orchard is located in Fresno, CA.)

Treatment	Application Time	Total	Packing carton size 40 49-51mm	36 52-54mm	32 55-57mm	28 58-60mm	24 61-63mm	21 64-67mm	18 68-71mm	15 72-75mm	18-32 55-71mm
		no. of fruit per tree									
Urea	11 Nov	837 a[z]	46 a	82 a	131 a	171 a	128 a	135 a	78 a	31 a	644 a
Urea + Potassium phosphite	11 Nov	852 a	35 a	83 a	137 a	154 a	137 a	146 a	82 a	39 a	656 a
Urea	22 Dec	827 a	31 a	72 a	116 a	148 a	150 a	153 a	93 a	42 a	660 a
Urea + Potassium phosphite	22 Dec	864 a	59 a	101 a	111 a	152 a	130 a	148 a	73 a	46 a	614 a
Urea	13 Jan	864 a	23 a	81 a	137 a	187 a	152 a	140 a	72 a	42 a	688 a
Potassium nitrate	11 Feb + 20 May + 16 Jul	822 a	48 a	86 a	127 a	123 a	138 a	150 a	92 a	30 a	629 a
Zinc	4 May (10% anthesis)	735 a	31 a	62 a	87 a	118 a	143 a	152 a	81 a	29 a	581 a
Zinc	7 Apr (2/3-leaf expansion)	801 a	29 a	73 a	136 a	139 a	153 a	100 a	83 a	47 a	611 a
Boron	4 May (10% anthesis)	884 a	38 a	102 a	131 a	178 a	161 a	146 a	70 a	35 a	687 a
Boron	7 Apr (2/3-leaf expansion)	871 a	42 a	80 a	157 a	181 a	153 a	135 a	63 a	31 a	689 a
Urea + Potassium phosphite	7 Apr (2/3-leaf expansion)	830 a	39 a	79 a	131 a	172 a	149 a	139 a	67 a	26 a	658 a
Potassium phosphite	20 May + 16 Jul	839 a	30 a	87 a	112 a	155 a	150 a	139 a	91 a	36 a	648 a
Urea	16 Jul	804 a	27 a	65 a	109 a	146 a	147 a	160 a	65 a	47 a	627 a
Control		860 a	27 a	66 a	122 a	164 a	203 a	155 a	71 a	29 a	715 a
P-value		0.9314	0.7404	0.8804	0.7618	0.1656	0.3402	0.4925	0.7067	0.5506	0.6898

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

Table 7. Effects of applying foliar fertilizers at key stages of tree phenology on the fruit quality of 'Nules' Clementine mandarin trees. Application times refer to the following phenological stages: November, December, and January - prebloom; February - dormancy; April - 10% anthesis or 2/3-leaf expansion as indicated; May - postbloom (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 2: 2009-2010; the orchard is located in Fresno, CA.)

Treatment	Application Time	Peel thickness (mm)	Fruit weight (g)	Juice content (%)	TSS (°brix)	Acidity (%)	TSS: acid
Urea	11 Nov	3.2 a[z]	110.6 bcd	30.8 a	10.2 d	0.6 a	17.9 de
Urea + Potassium phosphite	11 Nov	3.6 a	111.7 bcd	30.0 a	10.1 d	0.5 a	19.6 ab
Urea	22 Dec	3.2 a	109.2 bcd	32.1 a	10.5 abcd	0.6 a	18.7 bcde
Urea + Potassium phosphite	22 Dec	3.2 a	111.1 bcd	30.9 a	10.7 abc	0.6 a	18.5 bcde
Urea	13 Jan	3.2 a	112.4 abcd	31.4 a	10.5 abcd	0.6 a	19.0 abcd
Potassium nitrate	11 Feb + 20 May + 16 Jul	3.4 a	123.1 a	28.1 a	10.8 ab	0.6 a	18.2 cde
Zinc	4 May (10% anthesis)	3.3 a	115.0 abcd	31.7 a	10.5 abcd	0.6 a	18.8 bcde
Zinc	7 Apr (2/3-leaf expansion)	3.2 a	120.0 ab	28.7 a	10.5 abcd	0.5 a	19.2 abc
Boron	4 May (10% anthesis)	3.0 a	108.5 cd	32.0 a	10.4 cd	0.6 a	18.6 bcde
Boron	7 Apr (2/3-leaf expansion)	3.1 a	105.6 d	32.1 a	10.4 bcd	0.6 a	17.8 e
Urea + Potassium phosphite	7 Apr (2/3-leaf expansion)	3.1 a	105.8 d	30.0 a	10.9 a	0.6 a	20.0 a
Potassium phosphite	20 May + 16 Jul	3.0 a	112.0 abcd	31.0 a	10.5 abcd	0.6 a	18.8 bcde
Urea	16 Jul	3.2 a	108.1 cd	33.0 a	10.5 abcd	0.6 a	18.5 bcde
Control		3.3 a	117.4 abc	31.1 a	10.7 abc	0.6 a	18.4 bcde
P-value		0.9682	0.0786	0.1977	0.0787	0.2952	0.0782

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

.

Table 8. Effects of applying foliar fertilizers at key stages of tree phenology on the crop value in US dollars per acre of ‘Nules’ Clementine mandarin trees. Application times refer to the following phenological stages: November, December, and January - prebloom; February - dormancy; April - 10% anthesis or 2/3-leaf expansion as indicated; May - postbloom (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 2: 2009-2010; the orchard is located in Fresno, CA.) The number of cartons of fruit produced per tree in each size category was calculated by dividing the total number of fruit harvested in each size category by the number of fruit packed per carton by size, i.e., packing carton size 40 contains 40 fruit per carton. Price by packing carton size is based on recent FOB pricing data as follows: 40, $3.00 with 70% utilization; 36, $3.60; 32, 28, 24, 21, and 18, $4.10; and 15, $3.90 with 60% utilization.

Treatment	Application time	Total	Packing carton size							
			40 49-51mm	36 52-54mm	32 55-57mm	28 58-60mm	24 61-63mm	21 64-67mm	18 68-71mm	15 72-75mm
		US$/200 trees/acre								
Urea	11 Nov	24698 a[z]	479 a	1634 a	3361 a	5015 a	4383 a	5274 a	3573 a	979 a
Urea + Potassium phosphate	11 Nov	25389 a	372 a	1663 a	3508 a	4512 a	4686 a	5706 a	3716 a	1226 a
Urea	22 Dec	25713 a	325 a	1442 a	2968 a	4344 a	5118 a	5976 a	4240 a	1301 a
Urea + Potassium phosphite	22 Dec	24914 a	615 a	2015 a	2847 a	4448 a	4438 a	5780 a	3348 a	1424 a
Urea	13 Jan	26108 a	240 a	1623 a	3500 a	5485 a	5198 a	5467 a	3281 a	1313 a
Potassium nitrate	11 Feb + 20 May + 16 Jul	24766 a	502 a	1721 a	3257 a	3593 a	4709 a	5865 a	4169 a	950 a
Zinc	4 May (10% anthesis)	22668 a	326 a	1242 a	2239 a	3467 a	4886 a	5921 a	3677 a	909 a
Zinc	7 Apr (2/3-leaf expansion)	23689 a	303 a	1467 a	3494 a	4066 a	5217 a	3895 a	3795 a	1452 a
Boron	4 May (10% anthesis)	26517 a	397 a	2032 a	3367 a	5223 a	5510 a	5710 a	3178 a	1101 a
Boron	7 Apr (2/3-leaf expansion)	25700 a	440 a	1608 a	4033 a	5308 a	5211 a	5256 a	2886 a	958 a
Urea + Potassium phosphite	7 Apr (2/3-leaf expansion)	24758 a	412 a	1585 a	3367 a	5044 a	5082 a	5409 a	3053 a	806 a
Potassium phosphite	20 May + 16 Jul	25305 a	319 a	1734 a	2882 a	4537 a	5135 a	5439 a	4127 a	1133 a
Urea	16 Jul	24372 a	283 a	1305 a	2800 a	4270 a	5022 a	6250 a	2960 a	1482 a
Control		26654 a	280 a	1320 a	3128 a	4807 a	6927 a	6043 a	3254 a	895 a
P-value		0.8821	0.7404	0.8804	0.7618	0.1656	0.3402	0.4925	0.7067	0.5506

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

Table 9. Effects 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 - prebloom; February - dormancy; April - 10% anthesis or 2/3-leaf expansion as indicated; May – postbloom (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 3: 2010- 2011; the orchard is located in Fresno, CA.)

Treatment	Application Time	Total	Packing carton size								
			40 49-51mm	36 52-54mm	32 55-57mm	28 58-60mm	24 61-63mm	21 64-67mm	18 68-71mm	15 72-75mm	18-32 55-71mm
		------ *kg per tree* ------									
Urea	16 Nov	105.5 a[z]	14.2 a	21.4 a	22.2 a	13.9 bcd	9.8 a	7.6 a	3.3 a	1.1 a	56.9 a
Urea + Potassium phosphite	16 Nov	108.6 a	15.4 a	24.8 a	19.0 a	20.0 ab	9.5 a	5.4 a	1.8 a	1.6 a	55.7 a
Urea	31 Dec	105.3 a	17.5 a	21.3 a	21.2 a	15.9 abcd	7.4 a	5.5 a	2.4 a	0.7 a	52.4 a
Urea + Potassium phosphite	31 Dec	108.1 a	15.2 a	21.5 a	17.7 a	14.0 bcd	12.0 a	7.3 a	3.4 a	0.6 a	54.4 a
Urea	14 Jan	109.6 a	16.6 a	24.9 a	22.6 a	14.5 bcd	9.1 a	4.9 a	2.4 a	1.1 a	53.4 a
Potassium nitrate	15 Feb + 5 May + 18 Jul	104.4 a	16.8 a	19.9 a	20.8 a	13.4 cd	10.7 a	8.3 a	2.8 a	0.6 a	56.0 a
Zinc	19 Apr (10% anthesis)	101.8 a	12.4 a	20.0 a	19.9 a	15.5 abcd	12.1 a	6.7 a	4.1 a	1.2 a	58.3 a
Zinc	7 May (2/3-leaf expansion)	107.2 a	15.0 a	23.7 a	20.7 a	16.0 abcd	11.6 a	9.0 a	1.4 a	0.7 a	58.6 a
Boron	19 Apr (10% anthesis)	108.5 a	16.9 a	22.5 a	19.4 a	17.6 abcd	9.3 a	5.9 a	2.6 a	1.1 a	54.8 a
Boron	7 May (2/3-leaf expansion)	102.8 a	15.6 a	19.1 a	21.6 a	18.6 abcd	11.1 a	8.5 a	1.2 a	0.4 a	61.1 a
Urea + Potassium phosphite	7 May (2/3-leaf expansion)	97.1 a	14.5 a	19.7 a	19.3 a	12.8 d	12.6 a	5.2 a	1.8 a	0.8 a	51.7 a
Potassium phosphite	13 May +18 Jul	111.3 a	15.5 a	20.4 a	25.6 a	19.4 abc	9.0 a	7.1 a	2.3 a	0.8 a	63.3 a
Urea	18 Jul	106.4 a	15.5 a	22.6 a	18.2 a	19.8 ab	10.6 a	7.3 a	2.7 a	0.9 a	58.6 a
Control		114.6 a	13.4 a	22.1 a	23.2 a	21.0 a	11.9 a	6.6 a	2.4 a	0.0 a	65.1 a
P-value		0.1647	0.8570	0.7887	0.4977	0.0918	0.5638	0.8658	0.9375	0.9593	0.5924

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

Table 10. Effects 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 - prebloom; February - dormancy; Apri l - 10% anthesis or 2/3-leaf expansion as indicated; May – postbloom (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 3: 2010-2011; the orchard is located in Fresno, CA.)

Treatment	Application Time	Total	Packing carton size								
			40 49-51mm	36 52-54mm	32 55-57mm	28 58-60mm	24 61-63mm	21 64-67mm	18 68-71mm	15 72-75mm	18-32 55-71mm
		no. of fruit per tree									
Urea	16 Nov	1253 abcd[z]	213 a	275 a	248 a	140 bcd	87 a	58 a	23 a	7 a	556 a
Urea + Potassium phosphite	16 Nov	1293 abcd	231 a	318 a	213 a	201 ab	84 a	41 a	12 a	10 a	551 a
Urea	31Dec	1290 abcd	262 a	273 a	238 a	160 abcd	65 a	42 a	16 a	4 a	521 a
Urea + Potassium phosphite	31Dec	1305 abc	228 a	276 a	198 a	141 bcd	106 a	56 a	23 a	3 a	524 a
Urea	14 Jan	1339 a	248 a	319 a	253 a	146 bcd	81 a	37 a	16 a	6 a	532 a
Potassium nitrate	15 Feb + 5 May + 18 Jul	1239 abcd	252 a	255 a	233 a	135 cd	95 a	63 a	19 a	3 a	545 a
Zinc	19 Apr (10% anthesis)	1183 cd	185 a	256 a	223 a	156 abcd	107 a	51 a	28 a	7 a	565 a
Zinc	7 May (2/3-leaf expansion)	1262 abcd	225 a	304 a	231 a	162 abcd	102 a	69 a	9 a	4 a	573 a
Boron	19 Apr (10% anthesis)	1308 abc	254 a	288 a	217 a	177 abcd	82 a	45 a	18 a	6 a	539 a
Boron	7 May (2/3-leaf expansion)	1188 bcd	233 a	245 a	242 a	187 abcd	98 a	65 a	8 a	3 a	601 a
Urea + Potassium phosphite	7 May (2/3-leaf expansion)	1156 d	217 a	252 a	217 a	128 d	111 a	39 a	12 a	5 a	508 a
Potassium phosphite	13 May + 18 Jul	1321 ab	233 a	261 a	286 a	195 abc	80 a	54 a	15 a	5 a	631 a
Urea	18 Jul	1249 abcd	232 a	289 a	204 a	199 ab	94 a	56 a	18 a	5 a	571 a
Control		1366 a	202 a	284 a	259 a	211 a	105 a	51 a	16 a	0 a	643 a
P-value		0.1005	0.8570	0.7887	0.4977	0.0918	0.5638	0.8658	0.9375	0.9593	0.4766

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

Table 11. Effects of applying foliar fertilizers at key stages of tree phenology on the fruit quality of 'Nules' Clementine mandarin trees. Application times refer to the following phenological stages: November, December, and January - prebloom; February - dormancy; April - 10% anthesis or 2/3-leaf expansion as indicated; May – postbloom (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 3: 2010-2011; the orchard is located in Fresno, CA.)

Treatment	Application Time	Peel thickness (mm)	Fruit weight (g)	Juice content (%)	TSS (°brix)	Acidity (%)	TSS: acid
Urea	16 Nov	2.4 a[z]	93.0 ab	34.6 a	10.5 bcd	1.0 abc	10.3 a
Urea + Potassium phosphite	16 Nov	2.5 a	91.5 ab	35.3 a	10.4 d	1.0 abc	10.2 a
Urea	31 Dec	2.4 a	95.4 a	35.7 a	10.7 abcd	1.0 bc	10.5 a
Urea + Potassium phosphite	31 Dec	2.5 a	88.8 abc	36.5 a	10.4 cd	1.0 c	10.2 a
Urea	14 Jan	2.3 a	86.5 bcd	38.7 a	10.5 bcd	1.0 abc	10.3 a
Potassium nitrate	15 Feb +13 May + 18 Jul	2.3 a	88.6 abc	36.7 a	10.7 ab	1.0 abc	10.4 a
Zinc	19 Apr (10% anthesis)	2.4 a	90.7 abc	36.4 a	10.5 bcd	1.0 abc	10.3 a
Zinc	7 May (2/3-leaf expansion)	2.4 a	89.0 abc	37.4 a	10.6 bcd	1.0 abc	10.3 a
Boron	19 Apr (10% anthesis)	2.3 a	90.0 abc	36.8 a	10.9 a	1.1 a	10.4 a
Boron	7 May (2/3-leaf expansion)	2.5 a	91.9 ab	36.6 a	10.7 bcd	1.1 ab	10.1 a
Urea + Potassium phosphite	7 May (2/3-leaf expansion)	2.3 a	90.3 abc	36.2 a	10.6 bcd	1.0 bc	10.4 a
Potassium phosphite	13 May + 18 Jul	2.3 a	79.5 d	39.0 a	10.5 bcd	1.0 abc	10.2 a
Urea	18 Jul	2.3 a	83.4 cd	38.7 a	10.7 abc	1.1 ab	10.1 a
Control		2.5 a	89.4 abc	37.3 a	10.5 bcd	1.0 c	10.4 a
P-value		0.6965	0.0173	0.2405	0.0194	0.0699	0.7631

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

Table 12. Effect of applying foliar fertilizers at key stages of tree phenology on the crop value in US dollars per acre of 'Nules' Clementine mandarin trees. Application times refer to the following phenological stages: November, December, and January - prebloom; February - dormancy; April - 10% anthesis or 2/3-leaf expansion as indicated; May - postbloom (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 3: 2010-2011; the orchard is located in Fresno, CA.) The number of cartons of fruit produced per tree in each size category was calculated by dividing the total number of fruit harvested in each size category by the number of fruit packed per carton by size, i.e., packing carton size 40 contains 40 fruit per carton. Price by packing carton size is based on recent FOB pricing data as follows: 40, $3.00 with 70% utilization; 36, $3.60; 32, 28, 24, 21, and 18, $4.10; and 15, $3.90 with 60% utilization.

Treatment	Application time	Total	Packing carton size							
			40 49-51mm	36 52-54mm	32 55-57mm	28 58-60mm	24 61-63mm	21 64-67mm	18 68-71mm	15 72-75mm
		US$/200 trees/acre								
Urea	16 Nov	24691 a[z]	2238 a	5496 a	6364 a	4099 bcd	2968 a	2283 a	1034 a	209 a
Urea + Potassium phosphite	16 Nov	25483 a	2427 a	6370 a	5462 a	5894 ab	2855 a	1612 a	558 a	306 a
Urea	31 Dec	23714 a	2755 a	5455 a	6091 a	4679 abcd	2232 a	1636 a	742 a	125 a
Urea + Potassium phosphite	31 Dec	24091 a	2397 a	5516 a	5073 a	4119 bcd	3630 a	2185 a	1064 a	109 a
Urea	14 Jan	24867 a	2607 a	6381 a	6477 a	4262 bcd	2752 a	1448 a	745 a	197 a
Potassium nitrate	15 Feb + 13 May + 18 Jul	24360 a	2649 a	5103 a	5961 a	3963 cd	3239 a	2463 a	876 a	106 a
Zinc	19 Apr (10% anthesis)	24503 a	1947 a	5126 a	5711 a	4560 abcd	3656 a	1995 a	1282 a	227 a
Zinc	7 May (2/3-leaf expansion)	25822 a	2361 a	6080 a	5929 a	4731 abcd	3482 a	2688 a	423 a	129 a
Boron	19 Apr (10% anthesis)	24754 a	2666 a	5764 a	5571 a	5197 abcd	2793 a	1765 a	800 a	199 a
Boron	7 May (2/3-leaf expansion)	25387 a	2449 a	4894 a	6194 a	5480 abcd	3350 a	2551 a	385 a	83 a
Urea + Potassium phosphite	7 May (2/3-leaf expansion)	22686 a	2278 a	5043 a	5549 a	3760 d	3807 a	1541 a	551 a	157 a
Potassium phosphite	13 May + 18 Jul	26403 a	2442 a	5222 a	7334 a	5715 abc	2723 a	2119 a	704 a	144 a
Urea	18 Jul	25653 a	2433 a	5786 a	5229 a	5824 ab	3207 a	2190 a	824 a	161 a
Control		26940 a	2116 a	5670 a	6649 a	6190 a	3597 a	1977 a	741 a	0 a
P-value		0.4821	0.8570	0.7887	0.4977	0.0918	0.5638	0.8658	0.9375	0.9593

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

Table 13. Effects of applying foliar fertilizers at key stages of tree phenology in Year 3 on leaf nutrient concentrations of 'Nules' Clementine mandarin trees. Application times refer to the following phenological stages: November, December, and January - prebloom; February - dormancy; April - 10% anthesis or 2/3-leaf expansion as indicated; May - postbloom (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). (The orchard is located in Fresno, CA.)

Treatment	Application time	N	P	K	Ca	Mg	S	B	Zn	Mn	Fe	Cu
		%						*ppm*				
Urea	16 Nov	2.54 b[z]	0.137 abc	1.17 abcd	4.1 a	0.43 a	0.248 cdef	41.6 c	13.44 bc	18.2 bcd	64.8 bcd	3.07 d
Urea + Potassium phosphite	16 Nov	2.53 b	0.139 abc	1.14 cd	4.1 a	0.44 a	0.258 abc	40.6 c	13.73 bc	19.6 ab	74.2 ab	3.52 bcd
Urea	31 Dec	2.55 b	0.139 abc	1.14 cd	4.1 a	0.45 a	0.257 bcd	41.6 c	13.16 c	19.5 ab	74.3 ab	3.41 cd
Urea + Potassium phosphite	31 Dec	2.54 b	0.141 ab	1.15 abcd	4.0 a	0.44 a	0.258 abc	41.0 c	13.44 bc	20.0 a	79.6 a	3.62 abc
Urea	14 Jan	2.53 b	0.143 a	1.13 cd	4.1 a	0.44 a	0.262 ab	39.0 c	13.25 c	18.6 abcd	66.2 bcd	3.59 bc
Potassium nitrate	15 Feb + 13 May + 18 Jul	2.52 b	0.135 bc	1.22 ab	4.1 a	0.43 a	0.243 ef	41.8 c	14.64 bc	17.1 d	58.9 d	3.56 bc
Zinc	19 Apr (10% anthesis)	2.56 b	0.143 a	1.13 cd	4.1 a	0.44 a	0.251 bcdef	41.9 c	15.20 bc	18.1 bcd	65.5 bcd	3.73 abc
Zinc	7 May (2/3-leaf expansion)	2.54 b	0.132 c	1.16 abcd	4.0 a	0.43 a	0.240 f	40.2 c	21.81 a	18.5 abcd	67.2 bcd	3.66 abc
Boron	19 Apr (10% anthesis)	2.56 b	0.137 abc	1.23 a	4.0 a	0.44 a	0.245 def	72.6 b	15.46 b	17.5 cd	62.5 cd	4.09 a
Boron	7 May (2/3-leaf expansion)	2.56 b	0.142 ab	1.20 abc	4.0 a	0.45 a	0.248 cdef	82.4 a	14.62 bc	18.8 abcd	71.8 abc	3.73 abc
Urea + Potassium phosphite	19 Apr (2/3-leaf expansion)	2.62 a	0.144 a	1.18 abc	4.0 a	0.43 a	0.270 a	42.4 c	13.47 bc	17.6 cd	59.1 d	3.70 abc
Potassium phosphite	13 May +18 Jul	2.53 b	0.134 bc	1.18 abc	4.1 a	0.44 a	0.246 cdef	41.2 c	14.30 bc	19.0 abc	69.1 abcd	3.74 abc
Urea	18 Jul	2.64 a	0.141 ab	1.08 d	4.0 a	0.43 a	0.255 bcde	39.2 c	13.91 bc	17.8 cd	62.0 cd	3.89 ab
Control		2.52 b	0.131 c	1.14 bcd	4.1 a	0.45 a	0.244 ef	41.2 c	13.38 c	18.1 bcd	70.3 abc	3.54 bcd
P-value		0.0002	0.0112	0.0946	0.6660	0.2745	<0.0001	<0.0001	<0.0001	0.0191	0.0027	0.0313

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

Table 14. Effects of applying foliar fertilizers at key stages of tree phenology on yield (kg/tree) of 'Nules' Clementine mandarin trees averaged across the 3 years of the research. Application times refer to the following phenological stages: November, December, and January - prebloom; February - dormancy; April - 10% anthesis or 2/3-leaf expansion as indicated; May - postbloom (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). (The orchard is located in Fresno, CA.)

			Packing carton size								
Treatment	Application Time	Total	40 49-51mm	36 52-54mm	32 55-57mm	28 58-60mm	24 61-63mm	21 64-67mm	18 68-71mm	15 72-75mm	18-32 55-71mm
		kg per tree									
Urea	Nov	98.6 a[z]	6.8 a	13.0 a	16.5 a	18.1 a	13.9 a	13.9 a	7.0 a	3.1 a	69.4 a
Urea + Potassium phosphite	Nov	98.4 a	7.0 a	13.7 a	16.1 a	18.0 ab	14.4 a	12.8 a	6.7 a	3.9 a	67.9 a
Urea	Dec	97.9 a	7.6 a	11.6 a	15.7 a	16.5 abc	14.5 a	13.6 a	7.8 a	3.8 a	68.1 a
Urea + Potassium phosphite	Dec	96.2 a	7.4 a	12.9 a	13.8 a	15.1 bc	13.3 a	13.7 a	7.2 a	4.1 a	63.0 a
Urea	Jan	101.2 a	7.2 a	13.2 a	17.9 a	18.6 a	14.5 a	13.4 a	6.1 a	3.6 a	70.5 a
Potassium nitrate	Feb + May + Jul	96.2 a	8.4 a	13.4 a	16.2 a	14.3 c	13.0 a	13.8 a	7.8 a	2.6 a	65.1 a
Zinc	Apr-May (10% anthesis)	93.4 a	6.0 a	11.7 a	15.4 a	16.4 abc	15.1 a	13.5 a	6.9 a	2.6 a	67.3 a
Zinc	Apr-May (2/3-leaf expansion)	96.7 a	6.6 a	13.3 a	16.3 a	16.8 abc	14.8 a	12.4 a	6.5 a	3.6 a	66.8 a
Boron	Apr-May (10% anthesis)	98.2 a	8.0 a	13.5 a	15.6 a	17.0 abc	14.3 a	13.8 a	6.6 a	3.0 a	67.3 a
Boron	Apr-May (2/3-leaf expansion)	97.5 a	7.5 a	11.6 a	17.5 a	18.7 a	14.5 a	14.3 a	5.7 a	3.0 a	70.7 a
Urea + Potassium phosphite	Apr-May (2/3-leaf expansion)	91.7 a	6.3 a	11.1 a	15.0 a	16.2 abc	15.8 a	12.4 a	6.3 a	3.2 a	65.7 a
Potassium phosphite	May + Jul	99.3 a	7.3 a	12.3 a	17.7 a	17.9 ab	14.2 a	12.8 a	7.8 a	3.0 a	70.3 a
Urea	Jul	95.7 a	6.5 a	12.3 a	14.6 a	17.6 ab	14.7 a	13.9 a	6.6 a	3.7 a	67.3 a
Control		100.9 a	6.3 a	12.0 a	15.4 a	18.6 a	17.3 a	14.7 a	6.9 a	2.9 a	72.9 a
Year											
Year 1		94.0 b	3.5 b	9.6 b	16.0 b	19.1 a	16.6 a	15.8 b	7.1 b	3.2 b	74.7 a
Year 2		91.3 b	2.4 c	6.4 c	11.1 c	15.6 b	16.6 a	17.9 a	11.0 a	5.9 a	72.3 a
Year 3		106.5 a	15.3 a	21.7 a	20.8 a	16.6 b	10.5 b	6.8 c	2.5 c	0.8 c	57.2 b
P-value											
Treatment		0.6900	0.5976	0.7726	0.2749	0.1008	0.5786	0.9818	0.8686	0.7862	0.5919
Year		<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
T x Y		0.9212	0.9868	0.9388	0.9296	0.1300	0.3463	0.6948	0.9618	0.8405	0.7182

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

Table 15. Effects of applying foliar fertilizers at key stages of tree phenology on yield (fruit number/tree) of 'Nules' Clementine mandarin trees averaged across the 3 years of the research. Application times refer to the following phenological stages: November, December, and January - prebloom; February - dormancy; April - 10% anthesis or 2/3-leaf expansion as indicated; May - postbloom (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). (The orchard is located in Fresno, CA.)

Treatment	Application Time	Total	Packing carton size								
			40 49-51mm	36 52-54mm	32 55-57mm	28 58-60mm	24 61-63mm	21 64-67mm	18 68-71mm	15 72-75mm	18-32 55-71mm
		no. of fruit per tree									
Urea	Nov	1035 a[z]	102 a	167 a	186 a	183 a	126 a	111 a	49 a	19 a	656 a
Urea + Potassium phosphite	Nov	1030 a	105 a	176 a	181 a	181 ab	131 a	103 a	47 a	24 a	644 a
Urea	Dec	1022 a	115 a	150 a	176 a	167 abc	132 a	110 a	55 a	24 a	640 a
Urea + Potassium phosphite	Dec	1017 a	112 a	166 a	155 a	152 bc	121 a	110 a	50 a	26 a	588 a
Urea	Jan	1071 a	108 a	170 a	202 a	188 a	132 a	108 a	43 a	22 a	673 a
Potassium nitrate	Feb + May + Jul	1014 a	127 a	174 a	182 a	144 c	117 a	110 a	55 a	16 a	610 a
Zinc	Apr-May (10% anthesis)	966 a	90 a	151 a	174 a	165 abc	137 a	108 a	49 a	16 a	633 a
Zinc	Apr-May (2/3-leaf expansion)	1011 a	100 a	171 a	184 a	170 abc	134 a	99 a	46 a	22 a	633 a
Boron	Apr-May (10% anthesis)	1039 a	120 a	174 a	176 a	171 abc	130 a	111 a	46 a	19 a	634 a
Boron	Apr-May (2/3-leaf expansion)	1017 a	113 a	150 a	197 a	189 a	131 a	115 a	40 a	19 a	673 a
Urea + Potassium phosphite	Apr-May (2/3-leaf expansion)	950 a	95 a	143 a	169 a	164 abc	143 a	100 a	44 a	20 a	620 a
Potassium phosphite	May + Jul	1040 a	110 a	159 a	199 a	180 ab	129 a	103 a	55 a	19 a	666 a
Urea	Jul	985 a	98 a	158 a	164 a	178 ab	133 a	111 a	46 a	23 a	633 a
Control		1049 a	95 a	155 a	174 a	188 a	157 a	118 a	49 a	18 a	685 a
Year											
Year 1		950 b	54 b	127 b	182 b	195 a	155 a	131 b	50 b	20 b	714 a
Year 2		835 c	36 c	80 c	125 c	156 b	150 a	143 a	77 a	36 a	651 b
Year 3		1268 a	230 a	278 a	233 a	167 b	93 b	52 c	17 c	5 c	561 c
P-value											
Treatment		0.4158	0.5917	0.7706	0.2741	0.1010	0.5765	0.9807	0.8697	0.7827	0.3649
Year		<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
T x Y		0.8479	0.9870	0.9387	0.9302	0.1294	0.3418	0.7025	0.9617	0.8395	0.6671

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

Table 16. Effects of applying foliar fertilizers at key stages of tree phenology on the fruit quality of ‘Nules’ Clementine mandarin trees averaged across the 3 years of the research. Application times refer to the following phenological stages: November, December, and January - prebloom; February - dormancy; April - 10% anthesis or 2/3-leaf expansion as indicated; May - postbloom (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). (The orchard is located in Fresno, CA.)

Treatment	Application Time	Peel thickness (mm)	Fruit weight (g)	Juice content (%)	TSS (°brix)	Acidity (%)	TSS: acid
Urea	Nov	2.7 a[z]	93.1 a	35.0 a	10.5 a	0.8 a	14.0 cd
Urea + Potassium phosphite	Nov	3.0 a	93.0 a	34.1 a	10.6 a	0.8 a	14.3 abcd
Urea	Dec	2.8 a	94.0 a	35.0 a	10.8 a	0.8 a	14.4 abcd
Urea + Potassium phosphite	Dec	2.9 a	95.8 a	35.3 a	10.7 a	0.8 a	14.4 abcd
Urea	Jan	2.8 a	93.3 a	36.5 a	10.8 a	0.8 a	14.8 a
Potassium nitrate	Feb + May + Jul	2.7 a	97.7 a	34.1 a	10.8 a	0.8 a	14.2 bcd
Zinc	Apr-May (10% anthesis)	2.8 a	94.6 a	35.5 a	10.7 a	0.8 a	14.8 a
Zinc	Apr-May (2/3-leaf expansion)	2.9 a	97.7 a	35.6 a	10.7 a	0.8 a	14.7 ab
Boron	Apr-May (10% anthesis)	2.8 a	94.8 a	34.9 a	10.8 a	0.8 a	14.3 abcd
Boron	Apr-May (2/3-leaf expansion)	2.8 a	92.1 a	35.2 a	10.8 a	0.8 a	13.8 d
Urea + Potassium phosphite	Apr-May (2/3-leaf expansion)	2.7 a	92.0 a	35.0 a	10.9 a	0.8 a	14.7 ab
Potassium phosphite	May + Jul	2.6 a	91.9 a	35.9 a	10.7 a	0.8 a	14.6 abc
Urea	Jul	2.9 a	92.5 a	35.7 a	10.9 a	0.8 a	14.2 abcd
Control		2.9 a	99.3 a	34.2 a	10.8 a	0.8 a	14.4 abcd
Year							
Year 1		2.9 b	80.4 c	37.2 a	11.2 a	0.8 b	14.3 b
Year 2		3.2 a	112.2 a	30.9 b	10.5 b	0.6 c	18.7 a
Year 3		2.3 c	89.4 b	37.4 a	10.6 b	1.0 a	10.3 c
P-value							
Treatment		0.2033	0.2307	0.5760	0.6741	0.1025	0.0328
Year		<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
T x Y		0.5504	0.3204	0.2380	0.9173	0.5863	0.6162

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

Table 17. Effects of applying foliar fertilizers at key stages of tree phenology on 3-year cumulative yield (kg per tree) of 'Nules' Clementine mandarin trees. Application times refer to the following phenological stages: November, December, and January - prebloom; February - dormancy; April - 10% anthesis or 2/3-leaf expansion as indicated; May-postbloom (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). (The orchard is located in Fresno, CA.)

Treatment	Application Time	Total	Packing carton size								
			40 49-51mm	36 52-54mm	32 55-57mm	28 58-60mm	24 61-63mm	21 64-67mm	18 68-71mm	15 72-75mm	18-32 55-71mm
		kg per tree/ 3 years									
Urea	Nov	295.8 a[z]	20.4 a	38.8 a	49.6 a	54.3 a	41.7 a	41.6 a	21.1 a	9.2 a	208.2 a
Urea + Potassium phosphite	Nov	295.3 a	21.0 a	41.0 a	48.2 a	53.9 ab	43.3 a	38.4 a	20.0 a	11.6 a	203.8 a
Urea	Dec	293.7 a	22.9 a	34.9 a	47.0 a	49.5 abc	43.5 a	40.9 a	23.4 a	11.3 a	204.2 a
Urea + Potassium phosphite	Dec	288.6 a	22.3 a	38.7 a	41.4 a	45.1 bc	40.0 a	41.1 a	21.5 a	12.4 a	189.1 a
Urea	Jan	303.5 a	21.5 a	39.5 a	53.7 a	55.8 a	43.6 a	40.2 a	18.4 a	10.7 a	211.5 a
Potassium nitrate	Feb + May + Jul	288.5 a	25.1 a	40.3 a	48.6 a	42.9 c	38.9 a	41.3 a	23.5 a	7.8 a	195.2 a
Zinc	Apr-May (10% anthesis)	280.1 a	17.9 a	35.1 a	46.3 a	49.1 abc	45.2 a	40.5 a	20.8 a	7.8 a	201.9 a
Zinc	Apr-May (2/3-leaf expansion)	290.0 a	19.9 a	39.8 a	49.0 a	50.5 abc	44.4 a	37.1 a	19.6 a	10.8 a	200.5 a
Boron	Apr-May (10% anthesis)	294.6 a	23.9 a	40.6 a	46.7 a	51.0 abc	42.9 a	41.5 a	19.7 a	9.0 a	201.8 a
Boron	Apr-May (2/3-leaf expansion)	292.6 a	22.4 a	34.8 a	52.4 a	56.2 a	43.5 a	43.0 a	17.0 a	9.1 a	212.1 a
Urea + Potassium phosphite	Apr-May (2/3-leaf expansion)	275.0 a	18.9 a	33.2 a	45.1 a	48.7 abc	47.2 a	37.2 a	18.8 a	9.5 a	197.1 a
Potassium phosphite	May + Jul	298.0 a	21.8 a	37.0 a	53.1 a	53.6 ab	42.4 a	38.3 a	23.5 a	9.1 a	210.9 a
Urea	Jul	287.0 a	19.6 a	36.8 a	43.7 a	52.9 ab	44.0 a	41.6 a	19.8 a	11.0 a	202.0 a
Control		302.6 a	19.0 a	36.1 a	46.3 a	55.8 a	51.9 a	44.0 a	20.8 a	8.6 a	218.7 a
P-value		0.6835	0.6248	0.7938	0.2603	0.0991	0.5877	0.9819	0.8719	0.7650	0.5960

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

Table 18. Effects of applying foliar fertilizers at key stages of tree phenology on 3-year cumulative yield (fruit number per tree) of 'Nules' Clementine mandarin trees. Application times refer to the following phenological stages: November, December, and January - prebloom; February - dormancy; April - 10% anthesis or 2/3-leaf expansion as indicated; May- postbloom (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). (The orchard is located in Fresno, CA.)

Treatment	Application Time	Total	Packing carton size								
			40 49-51mm	36 52-54mm	32 55-57mm	28 58-60mm	24 61-63mm	21 64-67mm	18 68-71mm	15 72-75mm	18-32 55-71mm
		no. of fruit per tree/3 years									
Urea	Nov	3106 a[z]	307 a	501 a	558 a	549 a	379 a	334 a	148 a	58 a	1968 a
Urea + Potassium phosphite	Nov	3090 a	316 a	529 a	544 a	544 ab	394 a	309 a	141 a	72 a	1931 a
Urea	Dec	3066 a	345 a	450 a	529 a	500 abc	396 a	329 a	164 a	71 a	1919 a
Urea + Potassium phosphite	Dec	3051 a	336 a	499 a	466 a	456 bc	362 a	330 a	151 a	78 a	1765 a
Urea	Jan	3213 a	324 a	509 a	605 a	563 a	396 a	324 a	129 a	66 a	2018 a
Potassium nitrate	Feb + May + Jul	3041 a	380 a	521 a	547 a	433 c	352 a	331 a	165 a	49 a	1830 a
Zinc	Apr-May (10% anthesis)	2899 a	271 a	453 a	522 a	496 abc	410 a	325 a	146 a	48 a	1899 a
Zinc	Apr-May (2/3-leaf expansion)	3033 a	300 a	514 a	552 a	510 abc	403 a	298 a	138 a	67 a	1899 a
Boron	Apr-May (10% anthesis)	3118 a	361 a	523 a	527 a	514 abc	390 a	334 a	138 a	56 a	1903 a
Boron	Apr-May (2/3-leaf expansion)	3050 a	338 a	449 a	591 a	567 a	394 a	346 a	120 a	57 a	2018 a
Urea + Potassium phosphite	Apr-May (2/3-leaf expansion)	2849 a	284 a	428 a	508 a	492 abc	429 a	300 a	132 a	60 a	1861 a
Potassium phosphite	May + Jul	3121 a	330 a	477 a	598 a	541 ab	386 a	308 a	165 a	57 a	1997 a
Urea	Jul	2954 a	294 a	474 a	492 a	534 ab	399 a	334 a	139 a	69 a	1899 a
Control		3147 a	286 a	466 a	521 a	563 a	470 a	354 a	146 a	54 a	2055 a
P-value		0.4203	0.6189	0.7913	0.2597	0.0994	0.5854	0.9809	0.8727	0.7608	0.3667

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

Table 19. Effects of applying foliar fertilizers at key stages of tree phenology on 3-year cumulative crop value in US$per acre of 'Nules' Clementine mandarin trees. Application times refer to the following phenological stages: November, December, and January - prebloom; February - dormancy; April - 10% anthesis or 2/3-leaf expansion as indicated; May-postbloom (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). (The orchard is located in Fresno, CA.) The number of cartons of fruit produced per tree in each size category was calculated by dividing the total number of fruit harvested in each size category by the number of fruit packed per carton by size, i.e., packing carton size 40 contains 40 fruit per carton. Price by packing carton size is based on recent FOB pricing data as follows: 40, $3.00 with 70% utilization; 36, $3.60; 32, 28, 24, 21, and 18, $4.10; and 15, $3.90 with 60% utilization.

Treatment	Application Time	Total	Packing carton size							
			40 49-51mm	36 52-54mm	32 55-57mm	28 58-60mm	24 61-63mm	21 64-67mm	18 68-71mm	15 72-75mm
		US$/200 trees/acre/3 years								
Urea	Nov	78160 a[z]	3223 a	10027 a	14305 a	16064 a	12961 a	13050 a	6734 a	1797 a
Urea + Potassium phosphite	Nov	77932 a	3322 a	10571 a	13929 a	15925 ab	13453 a	12074 a	6412 a	2246 a
Urea	Dec	76883 a	3621 a	8993 a	13563 a	14637 abc	13538 a	12853 a	7474 a	2205 a
Urea + Potassium phosphite	Dec	73343 a	3528 a	9974 a	11943 a	13343 bc	12368 a	12891 a	6879 a	2418 a
Urea	Jan	79717 a	3405 a	10172 a	15501 a	16491 a	13540 a	12670 a	5866 a	2072 a
Potassium nitrate	Feb + May + Jul	75147 a	3990 a	10422 a	14025 a	12692 c	12040 a	12942 a	7519 a	1517 a
Zinc	Apr-May (10% anthesis)	74670 a	2847 a	9058 a	13371 a	14534 abc	14016 a	12704 a	6636 a	1504 a
Zinc	Apr-May (2/3-leaf expansion)	76237 a	3151 a	10270 a	14133 a	14941 abc	13753 a	11621 a	6265 a	2103 a
Boron	Apr-May (10% anthesis)	77229 a	3793 a	10460 a	13494 a	15057 abc	13311 a	13060 a	6306 a	1748 a
Boron	Apr-May (2/3-leaf expansion)	78489 a	3554 a	8987 a	15136 a	16605 a	13474 a	13508 a	5449 a	1778 a
Urea + Potassium phosphite	Apr-May (2/3-leaf expansion)	73205 a	2985 a	8555 a	13026 a	14400 abc	14644 a	11703 a	6027 a	1865 a
Potassium phosphite	May + Jul	78647 a	3466 a	9546 a	15325 a	15846 ab	13175 a	12010 a	7513 a	1766 a
Urea	Jul	76014 a	3091 a	9481 a	12613 a	15652 ab	13632 a	13047 a	6353 a	2145 a
Control		80404 a	3007 a	9311 a	13352 a	16488 a	16063 a	13834 a	6665 a	1684 a
P-value		0.6945	0.6189	0.7913	0.2597	0.0994	0.5854	0.9809	0.8727	0.7608

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

Table 20. Effects of applying foliar fertilizers at key stages of tree phenology on 2-year cumulative yield (kg per tree) of ‘Nules’ Clementine mandarin trees. Application times refer to the following phenological stages: November, December, and January - prebloom; February - dormancy; April - 10% anthesis or 2/3-leaf expansion as indicated; May-postbloom (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). (The orchard is located in Fresno, CA.)

Treatment	Application Time	Total	Packing carton size 40 49-51mm	36 52-54mm	32 55-57mm	28 58-60mm	24 61-63mm	21 64-67mm	18 68-71mm	15 72-75mm	18-32 55-71mm
		kg per tree/2 years									
Urea	Nov	190.3 a[z]	6.1 a	17.4 a	27.4 a	40.4 ab	31.9 a	33.9 a	17.7 a	8.1 a	151.3 a
Urea + Potassium phosphite	Nov	186.7 a	5.6 a	16.2 a	29.2 a	33.9 cde	33.8 a	33.0 a	18.2 a	9.9 a	148.1 a
Urea	Dec	188.4 a	5.4 a	13.6 a	25.8 a	33.6 cde	36.1 a	35.4 a	21.0 a	10.6 a	151.8 a
Urea + Potassium phosphite	Dec	180.5 a	7.1 a	17.2 a	23.7 a	31.2 de	28.0 a	33.8 a	18.1 a	11.8 a	134.7 a
Urea	Jan	194.0 a	4.9 a	14.6 a	31.1 a	41.3 a	34.5 a	35.3 a	16.0 a	9.6 a	158.2 a
Potassium nitrate	Feb + May + Jul	184.1 a	8.3 a	20.4 a	27.8 a	29.5 e	28.2 a	33.1 a	20.7 a	7.2 a	139.2 a
Zinc	Apr-May (10% anthesis)	178.2 a	5.6 a	15.1 a	26.4 a	33.6 cde	33.1 a	33.8 a	16.7 a	6.5 a	143.6 a
Zinc	Apr-May (2/3 leaf expansion)	182.8 a	4.9 a	16.1 a	28.3 a	34.4 bcde	32.9 a	28.1 a	18.2 a	10.1 a	141.9 a
Boron	Apr-May (10% anthesis)	186.1 a	7.0 a	18.1 a	27.3 a	33.4 cde	33.7 a	35.6 a	17.1 a	7.9 a	147.0 a
Boron	Apr-May (2/3 leaf expansion)	189.8 a	6.9 a	15.8 a	30.8 a	37.6 abc	32.4 a	34.5 a	15.8 a	8.7 a	151.0 a
Urea + Potassium phosphite	Apr-May (2/3 leaf expansion)	177.9 a	4.4 a	13.6 a	25.8 a	36.0 abcd	34.6 a	32.1 a	17.0 a	8.7 a	145.4 a
Potassium phosphite	May + Jul	186.7 a	6.3 a	16.7 a	27.5 a	34.2 bcde	33.4 a	31.2 a	21.2 a	8.3 a	147.6 a
Urea	Jul	180.6 a	4.1 a	14.2 a	25.5 a	33.2 cde	33.3 a	34.3 a	17.2 a	10.2 a	143.4 a
Control		188.0 a	5.5 a	14.0 a	23.1 a	34.8 bcde	39.9 a	37.4 a	18.4 a	8.6 a	153.6 a
P-value		0.8707	0.5862	0.6235	0.5238	0.0275	0.2938	0.8823	0.8358	0.6083	0.4142

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

Table 21. Effects of applying foliar fertilizers at key stages of tree phenology on 2-year cumulative yield (fruit number per tree) of 'Nules' Clementine mandarin trees. Application times refer to the following phenological stages: November, December, and January - prebloom; February - dormancy; April - 10% anthesis or 2/3-leaf expansion as indicated; May- postbloom (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). (The orchard is located in Fresno, CA.)

Treatment	Application Time	Total	Packing carton size								
			40 49-51mm	36 52-54mm	32 55-57mm	28 58-60mm	24 61-63mm	21 64-67mm	18 68-71mm	15 72-75mm	18-32 55-71mm
		no. of fruit per tree/2 years									
Urea	Nov	1853 a[z]	94 a	227 a	310 a	409 ab	292 a	276 a	125 a	51 a	1412 a
Urea + Potassium phosphite	Nov	1798 a	85 a	210 a	330 a	343 cde	310 a	268 a	129 a	62 a	1380 a
Urea	Dec	1776 a	82 a	177 a	292 a	340 cde	331 a	287 a	148 a	67 a	1398 a
Urea + Potassium phosphite	Dec	1746 a	108 a	223 a	268 a	315 de	256 a	274 a	128 a	74 a	1241 a
Urea	Jan	1873 a	76 a	190 a	352 a	418 a	316 a	287 a	112 a	60 a	1485 a
Potassium nitrate	Feb + May + Jul	1802 a	128 a	266 a	315 a	298 e	258 a	268 a	146 a	45 a	1285 a
Zinc	Apr-May (10% anthesis)	1715 a	86 a	197 a	299 a	341 cde	303 a	274 a	118 a	41 a	1335 a
Zinc	Apr-May (2/3 leaf expansion)	1771 a	75 a	210 a	320 a	349 bcde	301 a	229 a	128 a	63 a	1326 a
Boron	Apr-May (10% anthesis)	1810 a	107 a	235 a	309 a	337 cde	308 a	289 a	121 a	50 a	1364 a
Boron	Apr-May (2/3 leaf expansion)	1863 a	105 a	205 a	349 a	380 abc	296 a	281 a	111 a	54 a	1417 a
Urea + Potassium phosphite	Apr-May (2/3 leaf expansion)	1694 a	67 a	176 a	292 a	363 abcd	317 a	260 a	120 a	55 a	1353 a
Potassium phosphite	May + Jul	1799 a	98 a	216 a	312 a	346 bcde	306 a	253 a	149 a	52 a	1366 a
Urea	Jul	1705 a	63 a	185 a	288 a	336 cde	305 a	278 a	121 a	64 a	1328 a
Control		1781 a	85 a	182 a	262 a	352 bcde	365 a	304 a	130 a	54 a	1412 a
P-value		0.7696	0.5869	0.6250	0.5232	0.0273	0.2930	0.8868	0.8380	0.6102	0.2455

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

Table 22. Effects of applying foliar fertilizers at key stages of tree phenology on 2-year cumulative crop value in US$per acre of ‘Nules’ Clementine mandarin trees. Application times refer to the following phenological stages: November, December, and January - prebloom; February - dormancy; April - 10% anthesis or 2/3-leaf expansion as indicated; May-postbloom (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). (The orchard is located in Fresno, CA.) The number of cartons of fruit produced per tree in each size category was calculated by dividing the total number of fruit harvested in each size category by the number of fruit packed per carton by size, i.e., packing carton size 40 contains 40 fruit per carton. Price by packing carton size is based on recent FOB pricing data as follows: 40, $3.00 with 70% utilization; 36, $3.60; 32, 28, 24, 21, and 18, $4.10; and 15, $3.90 with 60% utilization.

Treatment	Application Time	Total	Packing carton size 40 49-51mm	36 52-54mm	32 55-57mm	28 58-60mm	24 61-63mm	21 64-67mm	18 68-71mm	15 72-75mm
		US$/200 trees/acre/2 years								
Urea	Nov	53469 a[z]	985 a	4531 a	7941 a	11965 ab	9993 a	10767 a	5700 a	1587 a
Urea + Potassium phosphite	Nov	52449 a	895 a	4201 a	8467 a	10032 cde	10598 a	10461 a	5855 a	1939 a
Urea	Dec	53169 a	866 a	3538 a	7472 a	9958 cde	11306 a	11217 a	6732 a	2080 a
Urea + Potassium phosphite	Dec	49252 a	1131 a	4458 a	6870 a	9225 de	8738 a	10706 a	5815 a	2310 a
Urea	Jan	54850 a	799 a	3792 a	9023 a	12229 a	10788 a	11223 a	5121 a	1875 a
Potassium nitrate	Feb + May + Jul	50787 a	1342 a	5319 a	8063 a	8729 e	8802 a	10479 a	6643 a	1411 a
Zinc	Apr-May (10% anthesis)	50167 a	900 a	3932 a	7660 a	9974 cde	10360 a	10709 a	5354 a	1277 a
Zinc	Apr-May (2/3 leaf expansion)	50415 a	790 a	4191 a	8205 a	10210 bcde	10271 a	8933 a	5842 a	1974 a
Boron	Apr-May (10% anthesis)	52475 a	1127 a	4696 a	7923 a	9861 cde	10518 a	11295 a	5506 a	1549 a
Boron	Apr-May (2/3 leaf expansion)	53102 a	1104 a	4093 a	8942 a	11125 abc	10124 a	10956 a	5064 a	1695 a
Urea + Potassium phosphite	Apr-May (2/3 leaf expansion)	50519 a	707 a	3513 a	7477 a	10640 abcd	10837 a	10162 a	5476 a	1708 a
Potassium phosphite	May + Jul	52245 a	1024 a	4324 a	7991 a	10132 bcde	10452 a	9890 a	6809 a	1623 a
Urea	Jul	50362 a	659 a	3695 a	7385 a	9828 cde	10425 a	10857 a	5529 a	1985 a
Control		53464 a	891 a	3641 a	6703 a	10298 bcde	12466 a	11857 a	5924 a	1684 a
P-value		0.6720	0.5869	0.6250	0.5232	0.0273	0.2930	0.8868	0.8380	0.6102

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