

Comparison of Different Foliar-Fertilization Strategies on Yield, Fruit Size and Quality of 'Nules' Clementine Mandarin

Y. Zheng, T. Khuong and C.J. Lovatt
Department of Botany and Plant Sciences
University of California
Riverside, CA 92521-0124
USA

B.A. Faber
University of California
Cooperative Extension Ventura County
669 County Square Dr., #100
Ventura, CA 93003-5401
USA

Keywords: urea, boron potassium nitrate, zinc, tree nutrient status, cost:benefit analysis

Abstract

Foliar fertilizers reduce the potential for nutrients to accumulate in soil, move in run-off to surface waters (streams, lakes, ocean), and leach into the groundwater (drinking water supply), where they can contribute to salinity, eutrophication and nitrate contamination, leading to deleterious effects on the environment and human health. Thus, it is prudent to replace soil-applied fertilizer, at least in part, with foliar-applied fertilizer. Foliar fertilization is a rapid, efficient way to improve crop nutrient status during periods of high nutrient demand or when soil conditions (low temperature, salinity, pH) render soil nutrients and soil-applied fertilizers less available to the plant's roots. Foliar fertilization provides nutrients required for photosynthesis and other important metabolic functions essential to plant growth and productivity. However, not all nutrients move efficiently into leaves or other target organs. A priori knowledge (research) is necessary to develop a foliar fertilization program for a crop. Growers need this information to make cost-effective choices. Yield losses resulted when 'Nules' Clementine mandarin trees (*Citrus reticulata*) were sprayed with water containing no fertilizer. Thus, to attain yields equal to or greater than untreated control trees, foliar-fertilization strategies must compensate for the negative effect of application. For citrus, the standard time for applying foliar fertilizers is when leaves are 1/3 to 2/3 expanded (March-April) to take advantage of the thin cuticle, yet large surface area. Foliar fertilizers applied at this time to 'Nules' Clementine mandarin trees increased leaf concentrations of the applied nutrients through September (standard leaf analysis) ($P < 0.0001$); other application times had no effect on September leaf nutrient status, except boron applied at 10% anthesis. Winter prebloom foliar-applied low-biuret urea increased the 2-year cumulative yield ($P = 0.0197$) and 2-year average yield ($P = 0.0273$) of commercially valuable size fruit compared to all other treatments, except boron applied at 2/3-leaf expansion.

INTRODUCTION

Foliar-applied fertilizers provide several advantages over traditional soil-applied fertilizers. First, foliar fertilization reduces the potential for nutrients to accumulate in soil, move in run-off to surface waters (streams, lakes and the ocean), and leach into the groundwater (drinking water supply), where they can contribute to salinity, eutrophication and nitrate contamination with negative consequences on the environment and human health. Second, by providing the nutrients required for photosynthesis and other important metabolic functions essential for plant growth and productivity directly to the leaves (or other target organs), foliar fertilization can be more efficient than soil fertilization. This is especially true during periods of high nutrient demand or when soil conditions (low temperature, salinity, pH) render soil nutrients less available to the plant's roots. Foliar fertilizers supplying nutrients that are taken up by plant tissues and are phloem mobile can be 5 to 30 times more efficient than soil-applied fertilizers, depending on the nutrient, crop, and soil in which the crop is growing (PureGro, n.d.). Third, foliar fertilization can save the grower money over soil fertilization because the amount of a nutrient applied to the foliage is significantly lower than the amount that must be applied to the soil to

achieve the same yield (PureGro, n.d.). Early research with *Citrus sinensis* and *Citrus limon* provided clear evidence that foliar fertilizer applied to citrus trees at 1/3- to 2/3-leaf expansion (March-April) produced yields equal to those attained with substantially greater amounts of soil-applied fertilizer (Embleton and Jones, 1974). This application time targets foliage with a thin cuticle and large surface area. It was subsequently demonstrated that foliar fertilization could increase citrus yield parameters and grower net income reliably by properly timing the application of foliar fertilizer to key stages of crop phenology (Ali and Lovatt, 1994; Albrigo, 1999; Lovatt, 1999; Boman, 2002; El-Otmani et al., 2003; Gonzalez et al., 2010). Noting these numerous advantages, citrus growers in California and worldwide have been proactive in the use of foliar fertilization to increase yield and net profit and to protect the environment.

The current research was undertaken to test three foliar fertilization strategies for their capacity to increase yield and fruit size of *Citrus reticulata* Blanco ('Nules' Clementine mandarin). These strategies have been used widely on annual crops and tree fruit and nut crops, including citrus, but limited foliar fertilization research has been conducted on mandarins in California. In the first strategy, boron (B as Solubor) and zinc (Zn as ZnSO₄) were applied directly to developing flowers at 10% anthesis in the southwest tree quadrant (SWTQ). Application of B to floral buds or flowers is well known for its ability to increase pollen germination and pollen tube growth, resulting in increased syngamy and greater fruit set and yield of both deciduous (apple, peach, pear, almond, pecan, pistachio) and evergreen (avocado, citrus, date, mango) tree fruit and nut crops (Brown et al., 1995; Cowgill and Compton, 1999; Jaganth and Lovatt, 1998; Khayyat et al., 2007; Lovatt, 1999; Saran and Kumar, 2011; Sotomayor et al., 2002; Stover et al., 1999; Wells et al., 2008). Boron also has well known roles in cell division, cell expansion, and carbohydrate metabolism that could make this element essential to fruit set beyond its role in enhancing syngamy (Waqar et al., 2009). Thus, the capacity of foliar-applied B to increase fruit set and yield of 'Nules' Clementine mandarin, a parthenocarpic fruit, was of interest. Pre-anthesis foliar applications of Zn have been used to counter the reduced availability of Zn in cold soils to successfully increase flower retention, fruit set and yield of deciduous and evergreen tree fruit crops (Cowgill and Compton, 1999; Stover et al., 1999; Gonzalez et al., 2010).

For comparison, in the second strategy, B and Zn were applied to leaves at 1/3- to 2/3-expansion (i.e., before the cuticle was fully formed but the leaf had sufficient surface area for nutrient uptake). For citrus in California, 1/3- to 2/3-leaf expansion occurs 2 to 4 weeks before 10% anthesis in the SWTQ. Comparison of the results obtained with the first two strategies will provide critical information regarding the need to apply B or Zn directly to the developing flowers versus simply increasing tree B or Zn nutrient status prior to bloom.

In the third strategy, potassium nitrate was applied to the foliage at quiescence (February), postbloom (75% petal fall in the northeast tree quadrant [NETQ], May) and during exponential fruit growth (July) to increase the yield of commercially valuable large size fruit, as achieved by Boman (2002) with 'Sunburst' mandarin. Winter prebloom foliar-applied low-biuret urea was also tested for comparison and to replicate a previous experiment in which this treatment increased the 2-year cumulative yield of commercially valuable fruit of 'Nules' Clementine mandarin (Gonzalez et al., 2010).

Herein, we also report the results of a separate experiment testing the impact of foliar-applied water on yield parameters of 'Nules' Clementine mandarin. It has long been suspected that foliar sprays might reduce yield by increasing flower or fruit abscission, depending on application time and force of the spray. Thus, to achieve an increase in yield, a foliar-applied fertilizer would have to overcome the negative effect of the application process. Further, we wanted to determine whether the putative crop thinning effect resulting from a foliar spray was the basis for the increase in fruit size attributed to foliar-applied fertilizers.

MATERIALS AND METHODS

The research was conducted with 10-year-old and 6-year-old 'Nules' Clementine mandarin trees (*C. reticulata* Blanco) on 'Carrizo citrange' rootstock (*C. sinensis* 'Washington' navel × *P. trifoliata* L. Raf.) in commercial orchards in Grapevine (35°N, 119°W) and Fresno, California (36°N and 119°W), respectively. In both orchards a randomized complete block design with 16 individual tree replications per treatment was used. Treatments in the Grapevine orchard were: (1) water applied at bloom (late April early-May), postbloom (75% petal fall in the NETQ, late May) and during exponential fruit growth (July); and (2) untreated control, receiving no foliar application, only grower standard soil-applied fertilizer. Water (pH 6.5) was applied with a 2758 KPa handgun sprayer at 1869 L/ha. Treatments in the Fresno orchard were: (1) N (26 kg/ha, urea [46% N, 0.25% biuret]) prebloom (quiescence) in January; (2) B (1.5 kg/ha, Solubor® US Borax Inc. [20.5% B]) at 2/3-leaf expansion in April and (3) at 10% anthesis in the SWTQ in late April-early May; (4) Zn (91.1 kg/ha, ZnSO₄ [36% Zn]) at 2/3-leaf expansion and (5) at 10% anthesis in the SWTQ; (6) K (28 kg KNO₃/ha) at quiescence (February), post-bloom (75% petal fall in the NETQ, late May) and exponential fruit growth (July); and (7) untreated control, receiving no foliar application, only grower standard soil-applied fertilizer. Fertilizers were applied with a 2758 KPa handgun sprayer in 1869 L of water per ha, adjusted to pH 5.5; 0.05% Silwett L77® (General Electric Co.) was included in the B and Zn solutions.

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 the laboratory, washed thoroughly, oven-dried at 60°C, ground to pass through a 40-mesh screen and sent to the Analytical Laboratory at UC-Davis for analysis of N, P, K, S, Ca, Mg, Fe, Mn, B, Zn, and Cu by atomic absorption spectrometry and inductively coupled plasma atomic emission spectrometry.

At annual harvest in December, yield (kg and number of fruit per tree) was determined. A sub-sample of 100 fruits per tree was used to determine fruit diameter and fruit mass to calculate fruit size distribution. A sub-sample of 25 fruits per tree was used to determine fruit quality (peel thickness, fruit mass, juice mass, % juice [juice fresh mass/fruit fresh mass], total soluble solids [TSS, °brix], % acidity, and TSS:acid) by the UC Lindcove Analytical Laboratory. Fruit were mechanically juiced with a commercial juice extractor; TSS concentration was determined with a refractometer and percent acidity was determined by titration to pH 8.2 ± 0.1 with 1M NaOH.

Fisher's Protected LSD Test at $P \leq 0.05$ was used to test for treatment effects. Analyses were performed using the SAS statistical program (SAS Instit., Cary, NC).

RESULTS

Foliar application of water at bloom (late April-early May), 75% petal fall (late May) and exponential fruit growth (July) significantly reduced 2-year cumulative total yield by 22 kg per tree compared to the untreated control (Table 1). There was a general reduction of yield across all fruit size categories, except colossal (transverse fruit diameters 76.21-82.55 mm). This resulted in significant reductions in yield for fruit of packing carton sizes small (fruit diameters 44.45-50.80 mm), the combined pool of fruit of packing carton sizes tiny plus small (fruit diameters ≤ 50.80 mm), and commercially valuable fruit in the combined pool of packing carton sizes large, jumbo and mammoth (fruit diameters 57.16-76.20 mm) (Table 1). Thus, the crop-thinning effect of foliar-applied water did not result in a significant increase in fruit size or yield of commercially valuable large size fruit. Foliar-applied water had no effect on any fruit quality parameter quantified in this experiment.

In the second experiment, no foliar fertilizer treatment increased 2-year cumulative total yield per tree compared to untreated control trees (Table 2). The winter prebloom (January) foliar application of low-biuret urea significantly increased the 2-year cumulative yield of commercially valuable fruit of packing carton size 28 (fruit diameter 58-60 mm) as both kilograms and number of fruit per tree compared to untreated control

trees and trees in all other foliar fertilizer treatments ($P = 0.0197$ and $P = 0.0237$, respectively), except trees receiving B at 2/3-leaf expansion. Trees receiving foliar-applied boron at 2/3-leaf expansion had yields of commercially valuable fruit of packing carton size 28 that were intermediate to and not significantly different from trees receiving low-biuret urea in January and trees in all other treatments. The winter prebloom foliar application of low-biuret urea resulted in a net increase of 7.5 kilograms (66 fruits; data not shown) of fruit 58 to 60 mm in diameter per tree for 2 years compared to the untreated control trees ($P = 0.0197$). Repeated measures analysis with year as the repeated measure provided evidence that this treatment was effective across both years of the experiment ($P = 0.0273$). Trees receiving multiple applications of potassium nitrate had the lowest yield of fruit of packing carton size 28, but it was not significantly different from that of the untreated control trees and trees receiving Zn at 2/3-leaf expansion, B at 10% anthesis or Zn at 10% anthesis.

There were no significant treatment effects on any fruit quality parameter in either year of the experiment. When averaged across the 2 years of research by repeated measures analysis with year as the repeated measure, trees treated with winter prebloom foliar-applied urea or Zn at 10% anthesis produced fruit with significantly greater TSS: acid ratios than fruit from trees treated with B at 2/3-leaf expansion; all other foliar fertilizer treatments had TSS: acid that were intermediate and not significantly different ($P = 0.0862$) (data not shown). The differences were not only marginally significant, but also unlikely to have an impact on the commercial value or consumer acceptability of the fruit. The TSS: acid ratios ranged from 15.9 (B at 2/3-leaf expansion) to 17.2 (winter prebloom low-biuret urea), all well above 12, which defines the sweet fruit preferred by consumers.

Leaf nutrient concentrations optimal for maximum yield of commercially valuable 'Nules' Clementine mandarin fruit have not been established for California. However, leaf nutrient standards developed by Embleton et al. (1973) for sweet oranges (*Citrus sinensis*) are generally used. By these standards, all trees had optimal concentrations of N, P, Ca, Mg, S, B and Fe, but were in the low range for Mn and Cu (Table 3). All trees were Zn deficient except trees receiving a foliar-application of Zn at 2/3-leaf-expansion. To achieve larger fruit size, Embleton (personal communication) recommended that leaf K concentrations be slightly above optimal at 1.1% to 1.2% with leaf N concentrations maintained in the optimal range. The leaf K and N concentrations of all trees in the experiment reflected this recommendation, ranging from 1.13% to 1.23% for K and 2.52% and 2.56% for N, with no significant differences among treatments. Surprisingly, trees treated with prebloom foliar-applied urea or Zn at 10% anthesis had significantly greater leaf P concentrations than untreated control trees and trees receiving Zn at 2/3-leaf expansion or three applications of potassium nitrate; P values for all trees were within the optimal range. Trees receiving a winter prebloom foliar application of low-biuret urea had significantly greater leaf S concentrations than all other trees except those receiving foliar-applied Zn at 10% anthesis; all S concentrations were within the optimal range. Trees in the two foliar B treatments had significantly greater leaf B concentrations than trees in all other treatments; foliar-application of B at 2/3-leaf expansion was more effective than application at 10% anthesis for increasing tree B status. Trees treated with foliar-applied Zn at 2/3-leaf expansion had significantly greater leaf Zn concentrations than trees in all other fertilizer treatments, placing these trees within the low range for Zn, whereas trees in all other treatments were Zn deficient. Surprisingly, three foliar applications of potassium nitrate at quiescence (February), post-bloom (75% petal fall in the NETQ, late May) and exponential fruit growth (July) did not increase leaf N or K concentrations compared to any treatment.

DISCUSSION

The results of this research provide clear evidence that the physical effect of applying water with a 2758 KPa handgun sprayer to mandarin trees at bloom, 75% petal fall and exponential fruit growth significantly reduced total yield ($P = 0.0463$) and yield

of commercially valuable fruit in the combined pool of large, jumbo and mammoth (fruit diameters 57.16-76.20) ($P = 0.0432$). Overall yield was reduced by 22 kilograms per tree (13%), with a loss of 13.2 kilograms of commercially valuable large size fruit per tree. There was no increase in fruit size due to the reduction in yield. The increase in yield of very large fruit (colossal, fruit diameter 76.21-82.55 mm) was only 2.9 kilograms per tree and not significant.

These results lend support to the idea that to increase total yield or yield of commercially valuable large size fruit, a foliar-applied fertilizer must have a beneficial effect that is in addition to overcoming the negative effect of the application process. Whereas the water treatment and foliar fertilizer treatments were conducted in two separate orchards, the foliar application methods were identical. Of the foliar-fertilizers tested in this research, no foliar fertilizer treatment increased 2-year cumulative total yield and only the winter prebloom foliar application of low-biuret urea significantly increased the 2-year cumulative yield (and 2-year average yield) of commercially valuable fruit (packing carton size 28, diameters 58-60 mm). The increased yield of larger fruit was not due to a reduction in total yield. Trees receiving the winter prebloom foliar application of low-biuret urea retained more total fruit and had more marketable size fruit (packing carton sizes 32-18, fruit diameters 55-71 mm) per tree than the untreated control trees over the 2 years of the experiment (not significant). The winter prebloom foliar application of low-biuret urea is made when trees are quiescent (January) and this experiment the trees had been harvested in December. Therefore, the treatment was unlikely to cause flower or fruit abscission compared to foliar fertilizer applications made at 10% anthesis, 75% petal fall or even during exponential fruit growth in July. For comparison, potassium nitrate was applied to the foliage at quiescence (February) and also at 75% petal fall in the NETQ (May) and again during exponential fruit growth (July). Trees receiving this treatment had the lowest yield of fruit of packing carton size 28 ($P = 0.0197$) and of commercially marketable fruit (packing carton sizes 32-18) (not significant).

Foliar application of B and Zn at 2/3-leaf expansion increased tree B and Zn status to a greater degree than foliar applications at 10% anthesis. Trees treated with foliar-applied B at 2/3-leaf expansion had a 2-year cumulative yield of commercially valuable fruit of packing carton size 28 (fruit diameters 58-60 mm) equal to, but not significantly different from, trees treated with a winter prebloom foliar application of low-biuret urea. However, trees receiving foliar-applied B at 2/3-leaf expansion had a significantly greater yield of fruit of packing carton size 28 than trees receiving three applications of potassium nitrate. The effect of foliar-application of boron at 2/3-leaf expansion on the yield of commercially valuable size mandarin fruit was promising. Further research to optimize the use of this inexpensive fertilizer strategy in mandarin production should be undertaken. Foliar application of Zn at 2/3-leaf expansion significantly increased tree Zn status from deficient to low compared to trees in all other treatments, which were Zn deficient. There was no concomitant effect on yield or fruit size. Based on Von Liebig's law of the minimum, the capacities of the foliar-applied fertilizers tested in this research to increase yield and fruit size were likely compromised by Zn deficiency and the low Mn and Cu status of the trees, even when the leaf Zn concentration was increased from deficient to low in trees treated with foliar-applied Zn at 2/3-leaf expansion.

CONCLUSIONS

The results of this research confirmed the efficacy of a winter prebloom foliar-application of low-biuret urea to increase the yield of commercially valuable size fruit in a second orchard in a more northern mandarin-growing area of California. At standard planting densities of 480 to 900 trees per ha, the net increase of 7.5 kg (66 fruits) of commercially valuable large size fruit per tree per 2 years translates to 3,600 kg (31,680 fruits) and 6,500 kg (59,400 fruits) per ha for 2 years, respectively, resulting in a net increase in grower income of US\$3,250 and US\$6,090 per ha for the 2 years, respectively. A winter prebloom foliar application of low-biuret urea is a cost effective strategy for increasing grower net income.

ACKNOWLEDGEMENTS

This research was supported in part by the California Department of Food and Agriculture Fertilizer Research and Education Program and the Citrus Research Center and Agricultural Experiment Station of the University of California, Riverside. The authors thank Jim Bates, CPA, Chief of Financial Operations, Fowler Packing Company, and David Johnson, Ranch Manager, Rustigian Ranch, Fresno, CA, for use of the orchard and assistance with harvests, and Eric Jorgenson for his technical assistance.

Literature Cited

- 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. 112:1-4.
- Ali, A.G. and Lovatt, C.J. 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. KNO₃ foliar application to 'Sunburst' tangerine. Proc. Fla. State Hort. Soc. 115:6-9.
- Brown, P.H., Ferguson, L. and Picchioni, G. 1995. Boron boosts pistachio yields. Fluid Journal 3:11-13.
- Cowgill, W. and Compton, J. 1999. Foliar nutrient suggestions on apples and peaches. Rutgers Coop. Exten. Plant & Pest Advisory Fruit Ed. 3:3.
- El-Otmani, M., Ait-Oubahou, A., Taibi, F.-Z., Lmfoufid, B., El-Hila, M. and Lovatt, C.J. 2003. Prebloom foliar urea application increases fruit set, size, and yield of Clementine mandarin. Proc. Intl. Soc. Citriculture 1:559-562.
- Embleton, T.W. and Jones, W.W. 1974. Foliar-applied nitrogen for citrus fertilization. Environ. Quality 3:388-392.
- Embleton, T.W., Jones, W.W., Labanauskas, C.K. and Reuther, W.J. 1973. Leaf analysis as a diagnostic tool and guide to fertilization, p.183-211. In: W.J. Reuther (ed.), The Citrus Industry. Vol. 3. Univ. of California, Div. of Agr. Sci., Berkeley.
- Gonzalez, C., Zheng, Y. and Lovatt, C.J. 2010. Properly timed foliar fertilization can and should result in a yield benefit and net increase in grower income. Acta Hort. 868:273-286.
- Jaganath, I. and Lovatt, C.J. 1998. Efficacy studies on prebloom canopy applications of boron and/or urea to 'Hass' avocado. Acta Hort. 1:181-184.
- Khayyat, M., Tafazoli, E., Eshghi, S. and Rajaei, S. 2007. Effect of nitrogen, boron, potassium and zinc sprays on yield and fruit quality of date palm. American-Eurasian J. Agric. & Environ. Sci. 2:289-296.
- Lovatt, C.J. 1999. Timing citrus and avocado foliar nutrient applications to increase fruit set and size. HortTechnology 9:607-612.
- PureGro Company. n.d. Soil vs. foliar. PureGro Co., Sacramento, Calif.
- Saran, P.L. and Kumar, R. 2011. Boron deficiency disorders in mango (*Mangifera indica*): Field screening, nutrient composition and amelioration by boron application. Indian J. Agric. Sci. 81:506-510.
- Sotomayor, C., Silva, H. and Castro, J. 2002. Effectiveness of boron and zinc foliar sprays on fruit setting of two almond cultivars. Acta Hort. 591:437-440.
- Stover, E., Fargione, M., Risio, R., Stiles, W. and Iungerman, K. 1999. Prebloom foliar boron, zinc and urea applications enhance cropping of some 'Empire' and 'McIntosh' apple orchards in New York. HortScience 34:210.
- Waqar, A., Niaz, A., Kanwal, S., Rahmatullah, M. and Rasheed, M.K. 2009. Role of boron in plant growth: A review. J. Agric. Res. 47:329-338.
- Wells, M.L., Conner, P.J., Funderburk, J.F. and Price, J.G. 2008. Effects of foliar-applied boron on fruit retention, fruit quality, and tissue boron concentration of pecan. HortScience 43:696-699.

Tables

Table 1. Effect of foliar-applied water on 2-year cumulative yield and fruit size of *Citrus reticulata* ('Nules' Clementine mandarin) trees in a commercial orchard in Grapevine, CA.

Treatment	Total	Categories based on transverse fruit diameter (mm) ^z								
		T <44.45	S 44.45-50.80	T+S ≤50.80	M 50.81-57.15	L 57.16-63.50	J 63.51-69.85	MA 69-86-76.20	L+J+MA 57.16-76.20	C 76.21-82.55
		kg fruit per tree								
Control ^y	171.5 a ^x	0.65 a	13.0 a	13.7 a	44.4 a	41.7 a	31.3 a	23.9 a	96.9 a	9.7 a
Water	149.6 b	0.39 a	8.5 b	8.9 b	39.8 a	38.8 a	24.4 a	20.5 a	83.7 b	12.6 a
<i>P</i> -value	0.0463	NS	0.0350	0.0262	NS	NS	NS	NS	0.0432	NS

^z T-Tiny, S-Small, M-Medium, L-Large, J-Jumbo, MA-Mammoth, and C-Colossal.

^y Untreated, receiving no foliar application, only grower standard soil-applied fertilizer.

^x Means followed by different letters are significantly different by Fisher's Protected LSD Test at $P \leq 0.05$. NS-Not significant.

Table 2. Effect of applying foliar fertilizers at key stages of tree phenology on 2-year cumulative yield and fruit size of *Citrus reticulata* ('Nules' Clementine mandarin) trees in a commercial orchard in Fresno, CA. Application times refer to the following phenological stages: January-prebloom (quiescence); February-quiescence; April-2/3 leaf expansion; late April-early May-10% anthesis; late May-75% petal fall; and July-exponential fruit growth.

Treatment	Application time	Total	Categories based on transverse fruit diameter (mm)						
			36 52-54	32 55-57	28 58-60	24 61-63	21 64-67	18 68-71	32-18 55-71
			kg fruit per tree						
Control ^z		188.0 a ^y	14.0 a	23.1 a	34.8 bc	39.9 a	37.4 a	18.4 a	153.6 a
Urea	January	194.0 a	14.6 a	31.1 a	41.3 a	34.5 a	35.3 a	16.0 a	158.2 a
Potassium nitrate	Feb + late May + Jul	184.1 a	20.4 a	27.8 a	29.5 c	28.2 a	33.1 a	20.7 a	139.2 a
Boron	Apr (2/3-leaf expansion)	189.8 a	15.8 a	30.8 a	37.6 ab	32.4 a	34.5 a	15.8 a	151.0 a
Zinc	Apr (2/3-leaf expansion)	182.8 a	16.1 a	28.3 a	34.4 bc	32.9 a	28.1 a	18.2 a	141.9 a
Boron	Late April-early May (10% anthesis)	186.1 a	18.1 a	27.3 a	33.4 bc	33.7 a	35.6 a	17.1 a	147.0 a
Zinc	Late April-early May (10% anthesis)	178.2 a	15.1 a	26.4 a	33.6 bc	33.1 a	33.8 a	16.7 a	143.6 a
<i>P</i> -value		NS	NS	NS	0.0197	NS	NS	NS	NS

^z Untreated, receiving no foliar application, only grower standard soil-applied fertilizer.

^y Values in a column followed by different letters are significantly different at the specified *P*-values by Fisher's Protected LSD test. NS-Not significant.

Table 3. Effect of applying foliar fertilizers at key stages of tree phenology on leaf nutrient concentrations of *Citrus reticulata* ('Nules' Clementine mandarin) trees in a commercial orchard in Fresno, CA. Application times refer to the following phenological stages: January-prebloom (quiescence); February-quiescence; April-2/3 leaf expansion; late April-early May-10% anthesis; late May-75% petal fall; and July-exponential fruit growth.

Treatment	Application Time	N	P	K	Ca	Mg	S	B	Zn	Mn	Fe	Cu	
		%						$\mu\text{g g}^{-1}$					
Control ^z		2.5 a ^y	0.131 c	1.1 a	4.1 a	0.45 a	0.244 bc	41.2 c	13.38 b	18.1 a	70.3 a	3.5 a	
Urea	Jan	2.5 a	0.143 a	1.1 a	4.1 a	0.44 a	0.262 a	39.0 c	13.25 b	18.6 a	66.2 a	3.6 a	
Potassium nitrate	Feb + late May + Jul	2.5 a	0.135 bc	1.2 a	4.1 a	0.43 a	0.243 bc	41.8 c	14.64 b	17.1 a	58.9 a	3.6 a	
Boron	April (2/3-leaf expansion)	2.6 a	0.142 ab	1.2 a	4.0 a	0.45 a	0.248 bc	82.4 a	14.62 b	18.8 a	71.8 a	3.7 a	
Zinc	April (2/3-leaf expansion)	2.5 a	0.132 c	1.2 a	4.0 a	0.43 a	0.240 c	40.2 c	21.81 a	18.5 a	67.2 a	3.7 a	
Boron	Late April-early May (10% anthesis)	2.6 a	0.137 abc	1.2 a	4.0 a	0.44 a	0.245 bc	72.6 b	15.46 b	17.5 a	62.5 a	4.1 a	
Zinc	Late April-early May (10% anthesis)	2.6 a	0.143 a	1.1 a	4.1 a	0.44 a	0.251 ab	41.9 c	15.20 b	18.1 a	65.5 a	3.7 a	
<i>P</i> -value		NS	0.0072	NS	NS	NS	0.0047	<0.0001	<0.0001	NS	NS	NS	

^z Untreated, receiving no foliar application, only grower standard soil-applied fertilizer.

^y Values in a column followed by different letters are significantly different at the specified *P*-values by Fisher's Protected LSD test. NS-Not significant.

