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Effect of Potassium Phosphite on Flowering, Yield, and Tree Health of 'Clementine' Mandarin

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***Abstract.* In 'Clementine' mandarin (*Citrus reticulata* Blanco) production, the number of large size fruit is the most critical parameter influencing a grower's income. Phosphorus and K play significant roles in fruit set, fruit growth, and maturation. A single foliar application of potassium phosphite (0–28–26; used at 6 mL/100 L with ≈ 10 L of spray mix per tree) to 'Nour' clementine mandarin at early green flower-bud stage of inflorescence development had no significant effect either on bud break or intensity of flowering but increased fruit set with no subsequent effect on total or export yield (i.e., fruit with equatorial diameter >51 mm). However, this application followed by a second potassium phosphate application at the beginning of the physiological fruit drop stage increased total and export yields in both kg and number of fruit per tree. Potassium phosphite applied at approximately color break did not affect fruit size but induced early fruit maturation and increased leaf P and K concentrations. When used as trunk paint on trees with visible signs of *Phytophthora gummosis*, potassium phosphite stopped the spread of the infection, caused healing of affected areas, and increased yield.**

The stages of citrus flower and fruit development have been elucidated (Bain, 1958; Lord and Eckard, 1987). During these stages yield components can be manipulated to achieve the objectives of maximizing fruit number or fruit size and fruit quality. The developmental stages from flower induction through differentiation, bloom, and fruit set require adequate supply of water, nutrients, and photoassimilates, but occur during months in which soil temperatures are low. Thus, during this time, root growth and activity (including nutrient uptake) are greatly reduced, if not completely stopped.

Nitrogen, P, and K are major elements found in large quantities in different tree organs. Deficiencies in these elements reduce vegetative growth and limit flowering and fruiting (Embleton et al., 1973). Abdalla et al. (1986) showed that P levels in the ovary are at their maximum value just prior to full bloom and are reduced by 62% after the transformation of the flower to a fruitlet. Bar Akiva et al. (1968) reported that when P is supplied to the tree to increase yield, fruit quality can also be improved. Miller and Hofman (1988) reported that K represented 44% of the mineral composition of dry matter of 'Valencia' orange fruit and that foliar supply of K as 4% KNO_3 2 to 3 months after full bloom increased fruit size. Fruit yield was increased only if leaf K concentration prior to treatment was below optimum. Furthermore, K had a significant effect on fruit quality and peel characteristics (Embleton et al., 1973).

Modern techniques of supplying nutrients to the tree, such as fertigation, have been developed to provide an optimal mineral supply. However, significant effort is being made to better target fertilizer application to periods of high nutrient demand. Consequently, use of foliar fertilization as a supplement to soil fertilization has received attention from scientists and fertilizer manufacturers (Lavon et al., 1996; Lovatt, 1999). In fact, foliar fertilization is an efficient way of supplying the tree with needed nutrients at periods of greatest demand, when deficiencies can be high and when roots may not be capable of taking up sufficient nutrients from the soil. In this paper, we present data from experiments in which potassium phosphite was supplied as a foliar fertilizer to 'Nour' clementine mandarin trees at key phenological stages and an experiment in which potassium phosphite was used as a foliar spray plus trunk paint on trees showing symptoms of gummosis due to *Phytophthora*. The overall objective was to test responsiveness of 'Nour' clementine to potassium phosphite in terms of flowering, yield, and tree health.

Materials and Methods

Plant material used and treatments tested in 1997 and 1998. Two trials were carried out on 'Nour' clementine mandarin (*Citrus reticulata* Blanco) topworked in 1990 onto 'Cadoux' clementine mandarin on sour orange rootstock (*Citrus aurantium* L.) planted in 1969 at a spacing of 5 × 5 m. Treatments consisted of potassium phosphite (Magnaphite®, Biagro Western Sales, Inc., Visalia, Calif.; 0–28–26; 6 mL/10 L per tree) applied to the foliage at different stages of tree phenology (Table 1). To improve fruit firmness and quality, Ca and microelements were included in the potassium phosphite treatment applied at fruit color break (1997) or prior to color break (1998) using Ret-Ca [composition (w/w): 15.49% N; 0.750% Fe; 0.138% Mn; 0.011% Ca; 0.002% Mo] at 25 mL/10 L per tree and Ret-Sul [composition (w/w): 15% Ca; 6.4% N; 0.4% S] at 10 mL/10 L per tree (both products are manufactured by EIBOL, Valencia, Spain). Trees were uniform in size and showed no nutrient deficiency symptoms or signs of disease or insect damage. Cultural practices used were optimal for the area.

Measured variables

1997 experiment. Fruit equatorial diameter was measured on 8 July and 4 Sept. 1997 during the exponential growth phase. Ten fruit were used for each replication. Harvest was based on peel color and carried out on two dates (24 Dec. 1997 and 5 Jan. 1998). Fruit was run through a packingline. Fruit number and total weight for each commercial size class and export yield (i.e., fruit with diameter >51 mm) were obtained.

To evaluate tree nutrient status, leaf N, P, K, and Ca concentrations were quantified using methods of Chapman and Pratt (1978). In particular, N was analyzed by the Kjeldahl method, P by the Olsen method, and K and Ca by spectrophotometry. Leaf samples composed of 20 leaves each were taken on 4 Sept. 1997 from 5- to 7-month-old non-fruiting terminals. Each sample was taken at random from two trees per replication from the external portion of the canopy and at a height of ≈1.5 m.

Fifteen one-tree replications were used to determine yield parameters (kg fruit/tree, fruit number/tree, and fruit size) and six replications were used for leaf analyses. A completely randomized designed was used and data were subjected to an analysis of variance. Mean separation was performed using Newman–Keuls test at the 5% level.

Table 1. Treatments applied in the 1997 and 1998 experiments on 'Nour' clementine mandarin.

Treatment		Date of application		Phenological stage at application
Compound	(mL/10L per tree)	1997	1998	
Untreated control		–	–	–
K phosphite	6 mL/10 L	29 Feb.	4 Mar.	Early green flower bud
K phosphite	6 mL/10 L	16 May	4 May	Physiological drop
K phosphite + K phosphite	6 mL/10 L + 6 mL/10 L	29 Feb. + 16 May	4 Mar. + 4 May	Early green flower bud + Physiological drop
K phosphite + RET-Sul + RET-Ca	6 mL/10 L + 10 mL/10 L + 25 mL/10 L	14 Nov.	–	Fruit color-break
K phosphite + K phosphite	6 mL/10 L + 6 mL/10 L	– –	4 Mar. 4 May	Early green flower bud + Physiological drop
K phosphite + RET-Sul + RET-Ca	6 mL/10 L + 10 mL/10 L + 25 mL/10 L	–	4 Sept.	Prior to color-break

1998 experiment. In addition to the variables measured for the 1997 experiment, data were also taken on flowering, fruit set, and fruit growth. For this purpose, prior to flowering four shoots of the previous summer (1997) flush were tagged on each of six single-tree replications. The shoots were selected at a canopy height of ≈1.5 m from the four tree quadrants of the tree and the number of nodes on each shoot were counted and recorded. Immediately after budbreak, the number of new vegetative shoots, number and type of inflorescences, number of flower buds, open flowers, and fruit set per inflorescence were recorded weekly. From these data, the following parameters were determined:

1) Inflorescence abundance = total number of inflorescences expressed in percent relative to the total number of nodes per shoot × 100.
2) Budbreak index = number of nodes producing at least one new shoot (vegetative or generative) relative to the total number of nodes per shoot × 100.
3) Fruit set = number of fruitlets counted on 1 Apr. 1998 relative to the number of flowers counted at the date of maximum number of flowers (i.e., 9 Mar. 1998) × 100.

Fruit equatorial diameter was recorded monthly from 18 May until harvest. At each date of observation, 10 fruit were measured per tree at a canopy height of ≈1.5 m. Mature fruit were harvested once the peel reached full color on 20 Dec. 1998 and 8 Jan. 1999. Total yield, fruit size, export yield, and leaf nutrient status were determined as described for the 1997 experiment.

A completely randomized design was used with six single-tree replications for the study of flowering and fruit development and four 2-tree replications to determine treatment effects on yield parameters and leaf nutrient concentrations. Data were subjected to an analysis of variance and mean separation was performed using Newman–Keuls test at the 5% level.

Plant material used and treatments tested in 1999. Trees of 'Cadoux' clementine mandarin (*Citrus reticulata* Blanco) with symptoms of *Phytophthora gummosis* disease on their trunks were used to evaluate the effect of K phosphite (Magnaphite®, Biagro Western Sales, Inc.; 0–26–17) on tree health. The trees were grafted onto sour orange rootstock and planted in 1962–63 at a spacing of 6 × 6 m. Prior to treatment application, stained bark, and wood of the gummosis areas were removed to a depth that revealed healthy tissue; control trees were left undisturbed. Treatments were applied both as foliar spray and as trunk paint. Foliar treatments of Magnaphite® at a concentration of 25 mL/10 L were applied to the point of runoff using a hand gun sprayer. Trunk paint applications of 25% (v/v) Magnaphite® at 200 mL per tree were applied with a paint brush. Both foliar spray and trunk paint were applied to the same trees on three dates: 30 June (June drop), 30 July (exponential fruit growth), and 7 Sept. 1999 (end of exponential fruit growth). Untreated and undisturbed control trees were included in the trial. On 30 June, the area showing gummosis disease was marked with white paint and measured. For ease of measurement, this area was assumed to be rectangular. The total area showing lesions was measured on 15 Feb. 2000.

Mature fruit was harvested and sized as described above. Total and export yield was determined. Because trees were randomly distributed in the field, care was taken to use trees similar in size and vigor with equal gummosis lesions of similar size. A completely randomized design was used with 10 single-tree replications. Data were subjected to an analysis of variance.

Results and Discussion

Trials of 1997 and 1998 on healthy trees

Effect of K phosphite on budbreak and flower development. Application of K phosphite to the foliage of 'Nour' clementine mandarin

Table 2. Effect of potassium phosphite applied at early green flower-bud stage of inflorescence development (Mar. 1998) on budbreak, inflorescence abundance and fruit set of 'Nour' clementine mandarin.

Treatment	Bud break	Inflorescence abundance	Fruit set
		%	
Untreated control	53.6	58.0	20.3
K phosphite	46.8	47.0	31.7
Significance level	NS	NS	0

Differences are not significant (NS) or significant at 5% level (*).

Table 3. Effect of date of potassium phosphite application in 1997 on fruit diameter (mm) of 'Nour' clementine mandarin.

	Date of observation	
Treatment date	8 July 1997	4 Sept. 1997
	transverse diameter (mm)	
Untreated control	19.2 b[z]	35.9 b
Feb. 1997	19.9 ab	40.3 a
May 1997	20.0 a	40.0 a
Feb. + May 1997	22.0 a	40.1 a
Significance level	**	***

Differences are significant at 1% (**) or 0.1% (***) level. Within columns, means followed by the same letter are not significantly different, Newman-Keuls test, $P \leq 0.05$.

Table 4. Effect of date of potassium phosphite application in 1997 on yield and fruit size at harvest for 'Nour' clementine mandarin.

	Date of harvest					
	24 Dec. 1997		5 Jan. 1998			
Treatment	Yield (kg/tree)	% total yield	Yield (kg/tree)	Total yield (kg/tree)	No. fruit/tree	Fruit wt (g/fruit)
Untreated control	18.2 c[z]	64	10.1	28.3 b	296 b	96.6 bc
Feb. 1997	13.9 c	58	9.6	23.5 b	244 b	98.1 b
May 1997	11.9 d	57	9.1	21.0 b	196 c	107.6 a
Feb. + May 1997	29.4 ab	73	10.1	40.3 a	394 a	103.1 ab
Nov. 1997	25.9 bc	81	5.9	31.8 ab	340 ab	93.9 c
Significance level	***	–	NS	***	*	**

Differences are not significant (NS) or are significant at 5%(*), 1%(**), or 0.1% (***) level. Within columns, means followed by the same letter are not significantly different, Newman-Keuls test, $P \leq 0.05$.

trees at early green flower-bud stage of inflorescence development had no significant effect either on budbreak or on inflorescence abundance (Table 2). In addition, treatments had no effect on the type of inflorescence produced or on the number of flowers produced (Gousrire, 1998). However, fruit set was significantly greater for K phosphite-treated trees (Table 2).

Effect of K Phosphite on fruit growth. For the 1997 trial, K phosphite applied once at early green flower-bud stage (29 Feb.) or at physiological fruit drop (16 May) or at both stages on the same tree increased fruit diameter (Table 3). In addition, for the 1998 trial, fruitlet drop during June and July and the daily fruit growth rate (increase in fruit diameter) were not affected by treatment regardless of the date of application (Gousrire, 1998). However, the average daily growth rate of fruit diameter in June and July is greater for fruit that received K phosphite in March (i.e., early green flower-bud stage of inflorescence development) and in March plus May (physiological fruit drop).

Effect on earliness of fruit maturation. The greatest amount of fruit was harvested on the first harvest date for all of the treatments and the untreated controls (Table 4; Gousrire, 1998). The greatest fruit production at the first harvest (in terms of percent of total yield) resulted from treatments applied in Nov. 1997 and in Sept. 1998, which correspond to the end of exponential fruit growth and the beginning of fruit maturation. These treatments induced earlier maturation in terms of fruit color. Bar-Akiva et al. (1968) reported an improvement of fruit quality and, thus, an induction of early maturation of fruit as a result of P application.

Effect on total and export yield. Trees treated with K phosphite applied in February plus May 1997 had the greatest yields in kg fruit/tree compared to the other dates of application which resulted in yields which were not different from that of untreated control trees (Table 4). The yield increase was due to an increase in fruit number (Table 4). For the 1998 trial, the September treatment gave the greatest yield followed by that of March plus May (Gousrire, 1998). This increase was also due to an increase in fruit number. Albrigo (1999) also reported increased yield as a result of K phosphite applied in winter prebloom or at the beginning of bloom. Lovatt (1999) reported an increase of 24 kg/tree of commercially valuable large size fruit for 'Washington' navel orange due to K phosphite application in May and July, which corresponds to the cell division phase of fruit growth.

Table 5. Effect of date of potassium phosphite application in 1997 on export yield (i.e., fruit with diameter >51 mm) in kg/tree and in percent of total yield for the 'Nour' clementine mandarin.

Treatment[z]	kg/tree	Total yield %
Untreated control	27.0 b[z]	96.0
Feb. 1997	22.9 b	95.3
May 1997	20.3 b	96.8
Feb. + May 1997	38.8 a	96.5
Nov. 1997	29.1 b	92.0
Significance level	0	NS

[z]Within columns, means followed by the same letter are not significantly different, Newman-Keuls test, $P \leq 0.05$. Differences are not significant (NS) or are significant at 5% (*).

Export yield in kg/tree was proportional to total yield with maximum export tonnage obtained in the 1997 experiment from the February plus May treatment (Table 5) and in the 1998 experiment from the September treatment (followed by the March plus May treatment) (Gousrire, 1998). The proportion of export yield to total yield was 92% to 97% for the 1997 experiment (Table 5) and 81% to 88% for the 1998 experiment (Gousrire, 1998); however, there was no significant treatment effect. The 'Nour' clementine mandarin is an extreme alternate-bearing cultivar. Export yield represented a larger percentage in 1997 since total yield was smaller (21 to 40 kg/tree) than in 1998 and the trees had less fruit, allowing for a larger fruit size at harvest. Conversely, in 1998, yield was double that of 1997 (44 to 79 kg/tree), resulting in greater competition among fruit for photoassimilates, water, and nutrients, leading to somewhat reduced fruit size.

Treatment effect on leaf N, P, K, and Ca concentrations. Table 6 shows that in leaves of untreated trees, N concentration was relatively low, Ca was optimal, and K was high compared to the standard levels

Table 6. Effect of date of potassium phosphite application in 1998 on leaf mineral concentration (% dry matter) of 'Nour' clementine mandarin leaves sampled on 20 Oct. 1998.

Treatment	Element			
	N	P	K	Ca
Untreated control	1.98	0.10 c[z]	2.31 c	3.97
Mar. 1998	2.07	0.12 b	2.53 b	4.03
May 1998	2.03	0.12 b	2.53 b	4.03
Mar. + May 1998	2.05	0.14 a	2.59 a	4.04
Sept. 1998	2.01	0.14 a	2.54 a	4.11
Significance level	NS	**	0	NS

[z]Within columns, means followed by the same letter are not significantly different, Newman-Keuls test, $p \leq 0.05$. Differences are not significant (NS) or are significant at 5% (*) or 1% (**).

Table 7. Effect of potassium phosphite on total and export yields (fruit with diameter >51 mm) and average fruit weight of 'Cadoux' clementine mandarin.

Treatment	Total yield		Export yield		
	kg/tree	fruit/tree (no)	kg/tree	% of total	Fruit wt (g/fruit)
Untreated	124 ± 23	2185 ± 434	49 ± 9	40	65.7 ± 1.2
K phosphite	157 ± 24	2703 ± 404	67 ± 15	42	58.0 ± 1.8
Significance level	0	0	0	–	NS

Differences are not significant (NS) or are significant at 5% (*).

Table 8. Effect of potassium phosphite on the surface of trunk lesions (cm^2) caused by *Phytophthora* gummosis of 'Cadoux' clementine mandarin trees.

Treatment	Date of observation		Difference	Significance level
	30 June 1999	15 Feb. 2000		
Untreated control	4272	6314	+ 2042 (+48%)	***
K phosphite	5989	6140	+ 151 (+2.5%)	NS

Differences are not significant (NS) or are significant at 0.1 % (***) level.

used in most citrus-producing countries (du Plessis and Koen, 1996; Embleton et al., 1996; Gallasch, 1996; Lekchiri, 1996; Tucker et al., 1995). Foliar applications of K phosphite in 1998 increased leaf P and K regardless of the time of application. Inclusion of RET-Sul and RET-Ca in the K phosphite spray in Sept. 1998 had no effect on leaf N or Ca. Potassium phosphite treatments in 1997 significantly increased leaf P but not K (Gousrire, 1998). It is noteworthy that pH of the treatment solutions was 6.5; the pH of the water used to prepare the treatment solutions was 7.6.

Effect of potassium phosphate on trees with phytophthora gummosis lesions. Potassium phosphite applied to trees with gummosis symptoms increased total and export yield (Table 7). This increase was due to an increased number of fruit since fruit weight was not affected. In addition, Table 8 shows that K phosphite reduced the growth of *Phytophthora* lesions. In fact, for treated trees, the lesions healed completely and persistent gumming was observed only one tree out of 10, whereas it continued in the untreated control trees. This result has prompted further investigation and additional experiments are underway.

Conclusions

Effect of potassium phosphite applied as a foliar spray on 'Nour' clementine mandarin varied with the time of application, but in general, increased fruit set, fruit yield, and average fruit weight, and thus, increased export yield. It induced earliness of fruit coloring and increased leaf P and K levels. It also improved health of *Phytophthora* gummosis-affected 'Cadoux' trees and increased their yield; an effect which is under further investigation.

Foliar application of potassium phosphite can be used to supplement the supply of P and K to trees, particularly in situations where absorption by the root system is restricted. This is the case in fall, winter, and early spring months when soil temperatures are low and root activity is stopped or reduced or in groves where nematodes limit absorption of nutrients through the root system (Hamid et al., 1988). By targeting the stages of tree phenology when P and/or K needs are greatest, foliar fertilization programs can increase yield and reduce the quantity of these nutrients applied to soils, thus, reducing the risk of environmental pollution of soil and water.

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