The Significance of Macronutrients in Alternate Bearing ‘Nadorcott’ Mandarin Trees

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Abstract. The significance of macronutrients nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), and magnesium (Mg) in leaves was studied in relation with their possible roles in alternate bearing of ‘Nadorcott’ mandarin (*Citrus reticulata*) trees over a period of three seasons. Fruit load (“on,” a heavy fruit load, vs. “off,” a light fruit load) affected the leaf macronutrient concentrations, and the amount of macronutrients removed through the harvest of fruit, i.e., the crop removal factor ($\text{g}\cdot\text{kg}^{-1}$), was consistent in both seasons. The crop removal factors were higher for each macronutrient in “off” trees—harvest of 1 kg fruit removed $\approx 2.3 \text{ g}\cdot\text{kg}^{-1}$ N, $0.3 \text{ g}\cdot\text{kg}^{-1}$ P, $3.1 \text{ g}\cdot\text{kg}^{-1}$ K, $1.0 \text{ g}\cdot\text{kg}^{-1}$ Ca, and $0.4 \text{ g}\cdot\text{kg}^{-1}$ Mg, compared with $1.3 \text{ g}\cdot\text{kg}^{-1}$ N, $0.2 \text{ g}\cdot\text{kg}^{-1}$ P, $1.7 \text{ g}\cdot\text{kg}^{-1}$ K, $0.6 \text{ g}\cdot\text{kg}^{-1}$ Ca, and $0.2 \text{ g}\cdot\text{kg}^{-1}$ Mg in “on” trees. Fruit load per tree (kg/tree) of 84, 110, and 52 kg/tree in “on” trees, however, removed $\approx 217 \text{ g}/\text{tree}$ N, 28 g/tree P, 296 g/tree K, 100 g/tree Ca, and 35 g/tree Mg, which was 1.5–6 times more than that of fruit loads of 14, 71, and 16 kg/tree in “off” trees. In “off” trees, N, P, and K, and in “on” trees, Ca accumulated in leaves to between 20% and 30% higher concentrations in season 1, but the higher macronutrient status did not manifest in or consistently correlate with intensity of summer vegetative shoot development in the current season, or intensity of flowering in the next season, the two main determinants of fruit load in ‘Nadorcott’ mandarin. Apart from some anomalies, the concentrations of macronutrients in leaves were unaffected by de-fruiting and foliar spray applications of N and K to “on” trees, and showed no consistent relationship with treatment effects on parameters of vegetative shoot development and flowering. Leaf macronutrients in alternate bearing ‘Nadorcott’ mandarin trees, fertilized according to grower standard practice, are not related to differences in flowering and vegetative shoot development, and appear to be a consequence of fruit load and not a determinant thereof.

Alternate bearing is a problematic phenomenon that occurs in certain fruit and nut trees. It is characterized by trees flowering profusely and producing an excess amount of fruit in one season, called an “on” season,

followed by the production of a small number of flowers and fruit in the following season, called an “off” season (Monselise and Goldschmidt, 1982). In *Citrus*, the “on” crop is characterized by a large number of small fruit and the “off” crop typically consists of large and unappealing fruit (Galliani et al., 1975; Hield and Hilgeman, 1969; Monselise and Goldschmidt, 1982; Moss et al., 1974). Alternate bearing leads to costly challenges in the management of harvesting, transport, packing, and marketing of citrus fruit, as well as compromises on the quality of fruit and consistency of production practices in the orchard, such as pruning, fruit thinning, irrigation, and fertilization (Galliani et al., 1975; Hield and Hilgeman, 1969; Moss et al., 1974; Stander and Cronjé, 2016).

In commercial citriculture, fertilizers are applied annually to optimize the growth of citrus trees and to maximize the volume and quality of fruit yield (Embleton et al., 1978;

Koo et al., 1984). For those purposes, fertilizer recommendations in South African citrus production make use of a routine leaf analysis that is based on a combination of leaf mineral nutrient norms that were developed for sweet orange (*Citrus sinensis*) cultivars in the United States (Chapman, 1949; Embleton et al., 1973; Koo et al., 1984) and for sweet orange, grapefruit (*Citrus paradisi*), and lemon (*Citrus limon*) cultivars in South Africa (Du Plessis, 1977; Du Plessis and Koen, 1992; Du Plessis et al., 1992). These leaf mineral nutrient norms are used to assess the tree nutritional status, to replace the nutrients that were removed by fruit or lost to the environment in the current season, and to achieve a target fruit load in the following season (Jones and Embleton, 1969). Currently, there are no definitive leaf mineral nutrient norms for mandarin (*C. reticulata*) to guide production of cultivars such as ‘Nadorcott’ in South Africa. As part of a wider study on alternate bearing in ‘Nadorcott’ mandarin, it was shown that fruit load in “on” ‘Nadorcott’ mandarin trees inhibits summer vegetative shoot development, which manifests in poor flowering and an “off” crop (Standar et al., 2018). However, it is not clear if current fertilizer practices and the concentration of macronutrients in leaves affect this mechanism of the alternate bearing cycle of ‘Nadorcott’ mandarin.

To address this question, seasonal changes in concentrations of macronutrients, namely, N, P, K, Ca, and Mg, were determined in leaves of “on” and “off” ‘Nadorcott’ mandarin trees and correlated with vegetative shoot flush, flowering, and fruit load. In addition, leaf macronutrient concentration and phenological responses were measured in reaction to source/sink manipulations at different phenological stages, as well as in response to autumn foliar applications of N and K. To compare results from tree experiments to a representative commercial alternate bearing scenario, a survey was carried out in 15 commercial ‘Nadorcott’ mandarin orchards in South Africa showing an alternate bearing pattern, to determine whether there is a relationship between the concentrations of macronutrients in leaves and change in fruit load from one season to another.

Materials and Methods

Plant material and experimental site

Ten- to 15-year-old ‘Nadorcott’ mandarin trees budded onto ‘Carrizo’ citrange (*C. sinensis* $\times$ *Poncirus trifoliata*) rootstock and grown under commercial conditions were selected within orchards with a history of alternate bearing in De Doorns (lat. $33^{\circ}51'S$, long. $19^{\circ}52'E$) for Expt. 1, in Citrusdal (lat. $32^{\circ}81'S$, long. $19^{\circ}01'E$) for Expt. 2, and in Riviersonderend (lat. $34^{\circ}13'S$, long. $19^{\circ}89'E$) for Expt. 3. All the experimental sites are located in the Western Cape Province of South Africa. The Western Cape forms part of one of five climatically diverse citrus-growing regions in Southern Africa

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and experiences Mediterranean-type climatic conditions: summer typically occurs from December to February; autumn from March to May; winter from June to August; and spring from September to November. The region receives an annual rainfall of between 400 and 650 mm and the majority occurs from the end of autumn to the end of winter (May–August).

The orchard in De Doorns was used in the main experiment and was cultivated, pruned, and sprayed according to recommended agricultural practices: trees were spaced at 5 × 2 m (1000 trees/ha) and planted in a sandy soil with pH_(KCl) 4.4. Trees were watered using a drip irrigation system with four emitters per tree, and total water supply was ≈4000 L per tree per annum. All trees received consistent and standard fertilizer applications with the rate of application (kg·ha⁻¹) based on annual leaf mineral nutrient analysis and a target fruit yield of between 60 and 70 ton·ha⁻¹. For N, a leaf concentration between 22 and 26 mg·g⁻¹ leaf dry weight (DW) was considered optimum by the citrus grower. Total annual N application amounted to 240 kg·ha⁻¹, of which 25% was applied as foliar applications, 20% as soil applications, and 55% was dissolved in the irrigation solution, i.e., fertigation, and split uniformly into eight applications from September to April. The rates of annual P and K applications were targeted to maintain optimum leaf P and K concentrations of between 1.1 and 1.5 mg·g⁻¹ leaf DW for P and between 9 and 16 mg·g⁻¹ leaf DW for K. The total annual P and K applications amounted to 12 kg·ha⁻¹ P and 265 kg·ha⁻¹ K, with the majority applied via fertigation and a small fraction applied by foliar sprays. The Ca and Mg applications were targeted to maintain optimum leaf concentrations of between 35 and 50 mg·g⁻¹ leaf DW for Ca, and 3 and 5.5 mg·g⁻¹ leaf DW for Mg, and supplied as 60 and 22 kg·ha⁻¹, respectively. Calcium was applied via fertigation from August to November, whereas Mg was applied as one foliar spray in August, plus increasing portions from September to March via fertigation.

Treatments and experimental design

Expt. 1. In this experiment, the pattern of concentrations of the five major macronutrients in leaves in “on” and “off” trees were followed as independent variables over a period of two seasons and the data were used in correlation analyses with selected determinants of flowering and fruit load as dependent variables. The trees that were selected were representative of heavy- or light-fruited trees and subsequently included as single-tree replications of “on” and “off” treatments in a completely randomized design ($n = 10$). Most of the trees in the orchard bore similar fruit yields, but for the purpose of this experiment, individual trees that showed an opposite and natural alternate bearing trend were selected before harvest in season 1 (Aug. 2014). Data representing the results of leaf macronutrient analysis, as well as the

correlations between leaf macronutrients and flowering, vegetative shoot development, and fruit load made use of only eight of the respective “on” and “off” treatment replications ($n = 8$).

Expt. 2. To validate the interpretation of the results from Expt. 1 on the concentrations of macronutrients in leaves and the relationship with phenological responses, leaf N, P, K, Ca, and Mg concentrations, as well as vegetative shoot flush and flowering responses to complete fruit removal of heavy-fruited or “on” trees were determined at two phenological stages, namely, during vegetative shoot development in Summer (Jan. 2016), and during flower induction in Autumn (Apr. 2016). The “on” cycles of 12 trees were desynchronized by removing all fruit of six heavy-fruited trees in Jan. 2016, for the Summer treatment, and six heavy-fruited trees in Apr. 2016, for the Winter treatment. The experiment was set up in a completely randomized design, using whole trees as treatment replications ($n = 6$).

Expt. 3. Mineral nutrient foliar sprays were applied to heavy-fruited or “on” trees ≈210 d after full bloom on 11 May 2016, between 8:00 and 10:00 HR. The foliar sprays consisted of the following treatments that were set up in a randomized complete block design ($n = 6$): 1) an untreated control; 2) N [10 g·L⁻¹ low biuret urea (Sasol, Sandton, South Africa) containing 460 g·kg⁻¹ N]; and 3) K [30 g·L⁻¹ fully soluble, crystalline formulation of potassium nitrate (KNO₃) (Sasol, Sandton, South Africa)]. Foliar sprays were applied until the point of runoff at a rate of ≈4 L spray solution per tree, using a backpack mist-blow sprayer [Stihl SR430; Andreas Stihl (Pty), Ltd., Pietermaritzburg, South Africa] set at droplet size 2 (1—fine droplet size, 5—coarse droplet size). No surfactant was used in the foliar spray mixture. To avoid drift between different treatments, buffer trees were left untreated between treated and control trees in the same row, as well as buffer rows between treated rows. The trees were selected for uniformity in tree condition based on a dark green leaf color. All trees were similar in canopy volume with a height of between ≈3.5–4.0 m and an across-row width of 2.5–3.5 m. The trees had a trunk circumference of ≈35 cm as measured above the bud union, and a uniform and evenly distributed fruit load.

Data collection

Flowering, fruit set and vegetative shoot development. In Expt. 1, the number of flowers per tree was estimated by counting the number of flowers within the limits of a 0.5 × 0.5 × 0.5 m frame during full bloom in October. The tree canopy was divided into an eastern and western sector and an upper- and lower-half. A flower count was performed in each of these four respective quadrants per tree. The total number of flowers was estimated by extrapolating the mean number of flowers per frame to the total tree volume. The canopy volume [V (m³)] was calculated

according to the following formula (Burger et al., 1970):

$$V = r^2(\pi h - 1.046r),$$

where r = canopy radius and h = height of the fruit bearing canopy.

The same trees were used in both seasons. The same procedure was used to estimate the number of new vegetative shoots after cessation of periods of vegetative shoot flushes in spring (November), summer (February), and autumn (April).

The phenological pattern of shoots in “on” and “off” trees was followed by randomly selecting five vegetative (“off”) and five reproductive (“on”) shoots from each tree during full bloom in season 1 (Oct. 2014). All shoots were ≈12 months of age and had triangular internodes, a length of ≈15 cm and were located on the outside of the tree canopy at a height of ≈1.5 m above the orchard floor. On each shoot, the number of nodes, the number of vegetative shoots, and total number of flowers were counted. At the end of summer (February) and start of autumn (March), the numbers of persistent fruit and new vegetative shoots that developed during the subsequent vegetative shoot flushes were recorded for each shoot, and return bloom and vegetative response were determined on the same shoots during the subsequent season.

Fruit yield. In all the experiments, commercial fruit harvest commenced in mid-July, once fruit quality indices complied with specifications established by fruit export markets. Harvest was completed by the end of August. To determine the total fruit yield of the treatments, all fruit were harvested separately from individual trees on the same day, before the start of commercial harvest. A sample of 100 fruit was randomly collected from each tree replication and the transverse diameter (in mm) of each fruit was measured using an electronic fruit size measuring caliper (CD-6” C; Mitutoyo Corp, Tokyo, Japan). Each fruit was assigned to a fruit size category of which the average fruit weight was determined and fruit size distribution from each treatment replication was extrapolated for the total number of fruit per tree.

Leaf and fruit sampling for mineral nutrient analysis. The leaf sampling protocol for the analysis of mineral nutrients is different for the major citrus-producing countries. In California (Chapman, 1968; Embleton et al., 1973), Florida (Koo and Sites, 1956; Koo et al., 1984; Smith, 1966), and Australia (Jorgensen and Price, 1978), leaves are sampled from 4- to 10-month-old, nonfruiting, and purely vegetative shoots. Citrus growers in Brazil (Quaggio et al., 1996), Israel (Raveh, 2013), and South Africa (Du Plessis, 1977; Du Plessis and Koen, 1992; Du Plessis et al., 1992) sample leaves from 4- to 6-month-old fruiting shoots. The use of fruiting shoots though, may not be wholly reliable as the characteristics of fruit on different trees and shoots might be different and cause variation in leaf nutrient analysis results. Also, results from mineral nutrient analyses

of leaves sampled from fruiting shoots cannot necessarily be used to predict what will happen in the future, as it is not guaranteed that fruit will remain on the tree during the period between sampling and timing of the next fertilizer application. More importantly, nonfruiting and purely vegetative shoots are those on which the majority of the next season's flowers and fruit will develop from (Verreyne and Lovatt, 2009), which is of direct interest in this experiment because results from such leaf mineral nutrient analyses could be used in validating predictions of flowering and fruit load.

In the present study, only mature leaves were sampled from the third to fifth position on fully hardened, nonfruiting, and purely vegetative shoots. All shoots had triangular internodes, a length of ≈ 15 cm, and were located on the outside of the tree canopy at a height of ≈ 1.5 m above the orchard floor. In Expt. 1, the spring leaf samples were collected in September, from vegetative shoots that developed during the previous season's vegetative shoot flushes; the summer leaf samples were collected in December, from vegetative shoots that developed during the current season's spring vegetative shoot flush, and autumn and winter leaf samples were collected in March and June, from vegetative shoots that developed during the current season's summer vegetative shoot flush (Fig. 1). In Expt. 2, leaf samples were collected from vegetative shoots that developed during the current season's summer vegetative shoot flush, starting on the day of treatment in January and continued at monthly intervals until commercial harvest commenced in July. In Expt. 3, leaf samples were collected on the day of treatment, and again 2 weeks thereafter.

One leaf sample consisted of eight leaves that were collected from each of four shoots from each treatment replication, between 0800 and 1000 HR on each sampling date. After sampling, the leaves were kept cool and washed with distilled water, before being

frozen at -80°C and freeze-dried (Christ Beta 1–8 LD Freeze Dryer; Martin Christ Gefriertrocknungsanlagen GmbH, Osterode am Harz, Germany). The leaves were ground to a fine powder with an analytical grinder (Yellow line, A10; IKA-Werke, Staufen, Germany) and stored at -80°C until analysis.

In Expt. 1, fruit samples were collected from different canopy positions at the time of commercial harvest to determine the macronutrient concentration of fruit (rind and pulp combined) from each of three distinct fruit size categories. For each sampled fruit, the transverse diameter was measured with an electronic caliper, and the mass (g) of each fruit was determined with an electronic scale (W22 Series; UWE Co., Hsin Tien, Taiwan). Fruit were subsequently assigned to a fruit size category, namely, small (≈ 50 mm and 71 g), medium (≈ 63 mm and 131 g), and large (≈ 76 mm and 203 g). From each fruit size category, six fruit samples consisting of 12 fruit were analyzed for macronutrient concentrations.

The concentrations of the macronutrients in the fruit tissue (rind and pulp combined) were used to calculate the total mass of the respective macronutrients removed by the total fruit loads in “on” and “off” trees by using the total fruit yield in kg fruit per tree and fruit size distribution data for each of the treatment replications.

Analysis of macronutrient concentrations. Macronutrient analyses in leaf and fruit samples were conducted by an accredited commercial chemical and microbiology analytical laboratory [Bemlab (Pty) Ltd., Strand, South Africa] according to published protocols (Hou and Jones, 2000). Briefly, 1 g of fruit or dried leaf tissue was ashed at 800°C and made up to a volume of 50 mL with a 50:50 hydrochloric acid (50%) solution for extraction through filter paper. The P, K, Ca, and Mg concentrations were analyzed using inductively coupled plasma-emission spectroscopy (Varian PRX-OEX; Varian Inc., Palo Alto, CA) against suitable standards

and after a nitric–hydrochloric total acid digestion step. For analysis of total N, 0.15 g of each sample was combusted at 850°C and analyzed using a LECO N analyzer (LECO FP528 Nitrogen analyzer; LECO cooperation, St. Joseph, MI) by thermal conductivity. The concentrations of the macronutrients in the leaf and fruit were expressed as $\text{mg}\cdot\text{g}^{-1}$ leaf DW or $\text{mg}\cdot\text{g}^{-1}$ fruit fresh weight.

Commercial fruit load and leaf macronutrient data. To compare the results from the tree experiments with representative commercial alternate bearing scenarios, a survey was carried out in 15 commercial ‘Nadorcott’ mandarin orchards in South Africa showing an alternate bearing pattern. Fruit load and leaf nutrient analyses of at least three consecutive seasons were collected between 2013 and 2017. Each orchard covered an area of at least two hectares and showed an alternate bearing pattern across three consecutive harvests [an alternate bearing index (I) higher than 0.15 (Monselise and Goldschmidt, 1982)]. The alternate bearing index of each orchard was calculated using the following formula (Gur et al., 1969):

$$I = \frac{1}{(n-1)} \left[\frac{(a_2 - a_1)}{(a_2 + a_1)} + \frac{(a_3 - a_2)}{(a_3 + a_2)} + \dots \right],$$

where n = number of seasons and a = fruit yield (as kg/tree) in the corresponding seasons, with the difference in yield between two seasons expressed as an absolute value.

The total area of orchards used in the survey was ≈ 65 ha. The orchards are located in Clanwilliam (lat. $32^{\circ}33'S$, long. $18^{\circ}83'E$), De Doorns, and Graafwater (lat. $32^{\circ}16'S$, long. $18^{\circ}59'E$) in the Western Cape Province; in Kirkwood (lat. $33^{\circ}46'S$, long. $25^{\circ}56'E$) and Addo (lat. $33^{\circ}48'S$, long. $25^{\circ}56'E$) in the Eastern Cape Province; and in Mbombela (lat. $25^{\circ}40'S$, long. $31^{\circ}01'E$) in Mpumalanga Province. The orchards were cultivated according to good agricultural practices, and the commercial harvest of

Fig. 1. Spring leaf samples for macronutrient analyses in alternate bearing ‘Nadorcott’ mandarin trees were collected in September (A_1 and A_2), from vegetative shoots that developed during the previous season's vegetative shoot flushes; the summer leaf samples were collected in December (B_1 and B_2), from vegetative shoots that developed during the current season's spring vegetative shoot flush, and autumn and winter leaf samples were collected in March [C_1 and C_2 (* = also commercial time of sampling)] and June (D_1 and D_2), from vegetative shoots that developed during the current season's summer vegetative shoot flush.

orchards commenced in June and finished by the end of August. Fruit load per tree (kg/tree) for each orchard was calculated using the fruit yield (ton·ha⁻¹) of each orchard for each commercial harvest, the tree spacing (trees/ha), and the orchard area (ha).

Leaf mineral nutrient analyses were conducted in March. The sampling of leaves was carried out according to the South African citrus industry standard, namely, leaves were sampled from 4- to 6-month-old fruiting shoots (Du Plessis, 1977; Du Plessis and Koen, 1992; Du Plessis et al., 1992).

Statistical analysis

STATISTICA data analysis software version 14 (Dell, Inc. 2017, Round Rock, TX) was used to analyze the data. Analysis of variance (ANOVA) or repeated measures ANOVA was performed when responses were repeated on the same respondent. Mean separations were carried out using Fisher's least significant difference test where applicable, at $P \leq 0.05$. The relationships between the concentrations of individual macronutrients and vegetative shoot development, flowering and fruit load, respectively, are indicated by Spearman's coefficient of correlation (r). The fruit load of commercial orchards in each season was tested for normality distribution. The relationship between fruit load in the current season and fruit load

in the following season was analyzed by regression analysis; as well as the relationship between fruit load and the concentrations of the various macronutrients in leaves. The strength of the relationships is indicated by Spearman's r . The median and mean values for fruit load of all commercial orchards were determined using descriptive statistics. The average value for the median and the mean of the fruit loads (47 kg/tree) were used to classify fruit load of trees in every orchard as "on" (a fruit load > 47 kg/tree) or "off" (a fruit load < 47 kg/tree). These categories were used to do frequency counts and calculate the probability of "on" or "off" trees to experience an "on" or "off" year in the following season. The categorization of fruit load data were used to perform an ANOVA for the leaf macronutrient concentrations of "off" or "on" trees in commercial orchards.

Results and Discussion

The amount of macronutrients removed through the harvest of fruit, i.e., the crop removal factor (g·kg⁻¹), was higher for each macronutrient in "off" trees compared with "on" trees; the harvest of 1 kg fruit per tree removed ≈ 2.3 g·kg⁻¹ N, 0.3 g·kg⁻¹ P, 3.1 g·kg⁻¹ K, 1.0 g·kg⁻¹ Ca, and 0.4 g·kg⁻¹ Mg in "off" trees vs. 1.3 g·kg⁻¹ N, 0.2 g·kg⁻¹ P, 1.7

g·kg⁻¹ K, 0.6 g·kg⁻¹ Ca, and 0.2 g·kg⁻¹ Mg in "on" trees. Total fruit load (kg/tree), though, was 6-fold higher in "on" trees in season 1, almost 2-fold higher in "on" trees in season 2, and almost 3-fold higher in "on" trees in season 3 ($P < 0.01$) (Table 1). In season 1, season 2, and season 3, fruit loads of 84, 110, and 52 kg/tree in "on" trees (Table 1) removed on average 217 g/tree N, 28 g/tree P, 296 g/tree K, 100 g/tree Ca and 35 g/tree Mg, which were two to seven times more than that removed by fruit loads of 14, 71, and 16 kg/tree in "off" trees ($P < 0.01$) (Table 2). This is in agreement with studies in 'Michal', 'Murcott', and 'Wilking' mandarins, where up to 32%, 44%, and 58% more N, P, and K were removed by the harvesting of heavy-fruited trees, compared with harvesting of light-fruited trees (Golomb and Goldschmidt, 1987; Monselise et al., 1983; Smith, 1976). In the present study, "off" trees, on the other hand, sprouted two to three times more new vegetative shoots than "on" trees (Tables 3 and 4). Similar to what has been reported in other mandarin trees (Golomb and Goldschmidt, 1987; Monselise et al., 1983; Smith, 1976), N, P, and K accumulated in leaves of "off" trees, and Ca in leaves of "on" trees to between 20% and 30% higher concentrations in season 1 ($P < 0.01$) (Fig. 2).

Despite the differences in macronutrient concentrations between "on" and "off"

Table 1. Fruit yield, return bloom, and vegetative response over 3 years of 10-year-old alternate bearing 'Nadorcott' mandarin trees used in Expt. 1.

Tree fruiting status	Fruit yield in current yr (kg/tree)	Fruit per tree in current yr	Return bloom and vegetative response in the following yr			
			Flowers	New spring vegetative shoots	New summer vegetative shoots	Total new vegetative shoots
			(no./tree)			
Season 1						
“Off” tree	14 b	126 b	51,097 a	163 b	144 b	306 b
“On” tree	84 a	918 a	30,034 b	493 a	369 a	863 a
<i>P</i> value	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Season 2						
“On” tree	110 a	1,225 a	165 b	1,018 a	420 a	1,439 a
“Off” tree	71 b	657 b	32,712 a	598 b	167 b	766 b
<i>P</i> value	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Season 3						
“Off” tree	16 b	144 b				
“On” tree	52 a	621 a				
<i>P</i> value	<0.01	<0.01				

Different letters in the same column within a given season denote significant differences between values ($P < 0.05$; Fisher's least significant difference test; $n = 10$).

Table 2. The total amount nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), and magnesium (Mg) removed by the total number of fruit in "on" and "off" 'Nadorcott' mandarin trees at harvest, respectively, over three seasons in Expt. 1.

Tree fruiting status	Amount of macronutrients removed by fruit load				
	N	P	K	Ca	Mg
(g/tree)					
Season 1					
"Off" tree	32 b	4 b	43 b	14 b	5 b
"On" tree	106 a	14 a	145 a	49 a	17 a
<i>P</i> value	<0.01	<0.01	<0.01	<0.01	<0.01
Season 2					
"On" tree	217 a	28 a	296 a	100 a	35 a
"Off" tree	152 b	19 b	204 b	68 b	23 b
<i>P</i> value	<0.01	<0.01	<0.01	<0.01	<0.01
Season 3					
"Off" tree	38 b	5 b	52 b	17 b	6 b
"On" tree	93 a	12 a	127 a	43 a	15 a
<i>P</i> value	<0.01	<0.01	<0.01	<0.01	<0.01

Different letters in the same column within a given season denote significant differences between values ($P < 0.05$; Fisher's least significant difference test; $n = 10$).

Table 3. The effect of tree fruit load (“on” or “off”) on vegetative shoot growth, flowering, and fruit set in alternate bearing ‘Nadorcott’ mandarin trees, over two seasons in Expt. 1.

Tree fruiting status	Nodes (no./shoot)	New spring vegetative shoots (no./shoot)	Flowers (no./shoot)	Fruit (no. per shoot)	Fruit set (%)	New summer vegetative shoots (no./shoot)
Response to fruit load in season 1						
“On” tree season 1	11.1	1.7 b	6.7 a	0.9	22.4	1.3 b
“Off” tree season 1	10.6	2.8 a	3.5 b	0.7	29.4	1.7 a
<i>P</i> value	0.07	0.04	<0.01	0.37	0.49	0.04
Response to fruit load in season 2						
“Off” tree season 2	14.1 b	3.3	6.6 b	1.4	26.8	4.1 a
“On” tree season 2	19.8 a	2.6	12.6 a	1.4	22.2	2.4 b
<i>P</i> value	0.03	0.29	0.02	0.90	0.46	<0.01

Different letters in the same column within a given season denote significant differences between values ($P < 0.05$; Fisher’s least significant difference, $n = 10$).

Table 4. The relationship between measurements of tree phenological events and the concentrations of leaf nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), and magnesium (Mg) in alternate bearing ‘Nadorcott’ mandarin trees in seasons 1 and 2 of Expt. 1.

Mo.	Leaf macronutrient concn (mg·g ⁻¹ leaf DW ²)	Flowers (season 1)	New spring vegetative shoots (season 1)	New summer vegetative shoots (season 1)	Total vegetative shoots (season 1)	Fruit yield (season 1)	Flowers (season 2)	New spring vegetative shoots (season 2)
Spearman’s correlation coefficient								
September	N	-0.21	0.35	0.49*	0.35	-0.45	0.62*	-0.40
	P	-0.55*	0.26	0.17	0.15	-0.16	0.28	-0.41
	K	-0.47	-0.20	-0.29	-0.25	0.19	-0.25	-0.14
	Ca	0.06	-0.13	-0.19	-0.17	0.26	-0.15	0.11
	Mg	0.05	0.15	0.17	0.18	-0.22	0.28	0.07
December	N	-0.11	0.01	0.21	0.16	-0.18	0.24	-0.07
	P	-0.46	-0.01	0.04	-0.08	0.10	-0.08	-0.29
	K	-0.20	-0.06	-0.22	-0.22	0.22	-0.18	0.00
	Ca	0.00	-0.19	-0.23	-0.21	0.14	-0.28	-0.01
	Mg	0.15	0.02	0.07	0.03	-0.16	0.15	0.06
March	N	—	—	0.23	0.14	-0.31	0.20	-0.45
	P	—	—	0.51*	0.41	-0.59*	0.48	-0.70**
	K	—	—	0.45	0.40	-0.58*	0.45	-0.76**
	Ca	—	—	-0.57*	-0.48	0.62*	-0.61*	0.61
	Mg	—	—	0.14	0.08	-0.19	0.27	0.00
June	N	—	—	—	—	-0.62*	0.66*	-0.51
	P	—	—	—	—	-0.63*	0.52*	-0.62*
	K	—	—	—	—	-0.60*	0.67**	-0.50*
	Ca	—	—	—	—	0.63*	-0.68**	0.45
	Mg	—	—	—	—	-0.28	0.34	-0.05

²Dry weight.

The strength of the relationship is indicated by Spearman’s correlation coefficient. * and ** indicate significance at $P < 0.05$ and $P < 0.01$, respectively.

‘Nadorcott’ mandarin trees, the concentrations of macronutrients in leaves showed no consistent relationship with vegetative shoot development, or with flowering and fruit load in the subsequent season, in any of the treatments, or in commercial alternate bearing ‘Nadorcott’ mandarin orchards, over three seasons. Nitrogen concentration in leaves during spring was positively but weakly correlated with summer vegetative shoot development in both seasons; spring of season 1 ($r = 0.49$, $P = 0.05$) and spring of season 2 ($r = 0.51$, $P = 0.049$) (Tables 4 and 5). In season 1, the concentrations of N and P in leaves during winter (June) correlated positively with flowering during spring of season 2 (N: $r = 0.66$, $P = 0.01$; P: $r = 0.52$, $P = 0.04$), but in the following season, leaf N concentration had a strong negative correlation with flowering ($r = -0.79$, $P < 0.01$), whereas leaf P concentration showed no correlation with flowering ($r = 0.10$, $P = 0.75$) (Tables 4 and 5).

Leaf Ca and Mg concentrations during spring and summer were not related to total new vegetative shoots in season 1 (Ca: spring: $r = -0.17$, $P = 0.52$ and summer: $r =$

-0.21 , $P = 0.44$; Mg: spring: $r = 0.18$, $P = 0.51$ and summer: $r = 0.03$, $P = 0.92$), nor in season 2 (Ca: spring: $r = 0.33$, $P = 0.21$ and summer: $r = 0.22$, $P = 0.40$; Mg: spring: $r = -0.18$, $P = 0.54$ and summer: $r = -0.05$, $P = 0.86$) (Tables 4 and 5). Leaf Ca concentration during winter correlated negatively with return bloom in season 1 ($r = -0.68$, $P < 0.01$), and leaf Ca and Mg concentrations during winter were not correlated to return bloom in season 2 (Ca: $r = -0.12$, $P = 0.90$ and Mg: $r = -0.15$, $P = 0.84$) (Tables 4 and 5).

During flower induction, leaf K concentration was positively correlated with return bloom in both seasons (season 1: $r = 0.67$, $P < 0.01$; season 2: $r = 0.65$, $P < 0.01$) (Tables 4 and 5), but foliar spray treatments of “on” trees with N and K during flower induction at the end of season 1, to validate these positive correlations, failed to improve flowering (data not shown). De-fruiting experiments substantiated the lack of a relationship between leaf macronutrient concentrations and vegetative shoot development, or flowering and fruit load. Apart from some anomalies, e.g., a lower leaf N concentration of summer de-fruiting trees compared with “on”

trees in February (21.3 vs. 22.9 mg·g⁻¹ leaf DW; $P = 0.02$), there were no differences in the concentrations of any of the leaf macronutrients that were induced by the de-fruiting treatments in “on” trees (Table 6). Those that differed were not related to any vegetative or flowering responses (Table 7). A de-fruiting treatment of “on” trees in summer, for example, increased vegetative shoot development almost 9-fold compared with the control or “on” trees (Table 7), but the treatment had no effect on leaf macronutrient concentrations (Table 6). Similarly, there were no differences in the concentrations of N, P, and K in leaves in any of the treatments following autumn de-fruiting in April, but “off” trees and “on” trees that were de-fruiting in summer sprouted more flowers compared with “on” trees, and “on” trees that were de-fruiting in autumn (Tables 7 and 8).

The lack of a relationship between the concentration of macronutrients in leaves and the subsequent flowering and fruit load responses in alternate bearing ‘Nadorcott’ mandarin trees suggests that macronutrient concentration in leaves are not the decisive

Fig. 2. The concentrations of leaf nitrogen (A), phosphorus (B), potassium (C), calcium (D), and magnesium (E) determined at 3-month intervals over two seasons in alternate bearing 'Nadorcott' mandarin trees. The line graph corresponds to the left Y-axis and represents the concentration of the mineral elements in the leaf expressed as mg·g⁻¹ leaf dry weight (DW), whereas the bar graph corresponds to the right Y-axis and represents the rate and distribution of the annual nutrient application as a percentage of the total annual application. The arrows indicate the time of harvest. Bars denote standard error of the mean and different letters indicate significant differences between values over time ($P < 0.05$; Fisher's least significant difference test; $n = 8$).

factor of vegetative shoot development, flowering, and fruit load of adequately fertilized and alternate bearing 'Nadorcott' mandarin trees. To support a maximum fruit yield of between 60 and 70 ton·ha⁻¹ in mandarins,

Raveh (2013) recommended that the optimum concentrations of the macronutrients in mandarin leaves should be between 20 and 24 mg·g⁻¹ leaf DW for N, 0.9 and 1.2 mg·g⁻¹ leaf DW for P, 5.5 and 6.9 mg·g⁻¹ leaf DW for K,

and 1.9 and 2.6 mg·g⁻¹ leaf DW for Mg. Alva et al. (2006) reported that optimum N, P, and K concentrations in 4–6-month-old spring flush leaves of mandarins are 26–30 mg·g⁻¹ leaf DW for N, 0.8–2.4 mg·g⁻¹ leaf

Table 5. The relationship between measurements of tree phenological events and the concentrations of leaf nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), and magnesium (Mg) in alternate bearing 'Nadorcott' mandarin trees in seasons 2 and 3 of Expt. 1.

Mo.	Leaf macronutrient concn (mg·g ⁻¹ leaf dry weight)	Flowers (season 2)	New spring vegetative shoots (season 2)	New summer vegetative shoots (season 2)	Total vegetative shoots (season 2)	Fruit yield (season 2)	Flowers (season 3)	New spring vegetative shoots (season 3)
Spearman's correlation coefficient								
September	N	-0.51*	0.32	0.51*	0.37	-0.44	0.51*	-0.35
	P	0.23	-0.50*	-0.46	-0.49	0.30	0.10	-0.20
	K	0.01	-0.17	-0.22	-0.21	0.12	0.01	0.10
	Ca	-0.51*	0.25	0.34	0.33	-0.51*	-0.25	0.25
	Mg	0.24	-0.06	-0.19	-0.17	0.37	0.15	0.27
December	N	-0.25	-0.10	0.15	0.02	-0.09	0.04	0.02
	P	-0.49	-0.12	0.01	-0.04	-0.32	0.02	-0.24
	K	-0.57*	0.05	0.15	0.11	-0.32	-0.08	0.12
	Ca	0.00	0.06	0.23	0.22	-0.02	0.08	-0.11
	Mg	0.21	-0.01	0.00	-0.05	0.35	0.05	0.06
March	N	—	—	-0.80**	-0.68**	0.78**	-0.69**	0.65*
	P	—	—	-0.35	-0.40	0.05	0.20	-0.15
	K	—	—	-0.09	-0.31	0.08	0.18	-0.20
	Ca	—	—	0.16	0.17	0.24	-0.12	0.20
	Mg	—	—	-0.25	-0.26	0.37	-0.21	0.11
June	N	—	—	—	—	0.79**	-0.79**	0.69*
	P	—	—	—	—	-0.07	0.10	-0.05
	K	—	—	—	—	-0.50*	0.65*	-0.51*
	Ca	—	—	—	—	-0.03	-0.12	0.14
	Mg	—	—	—	—	0.12	-0.15	0.21

The strength of the relationship is indicated by Spearman's correlation coefficient. * and ** indicate significance at $P < 0.05$ and $P < 0.01$, respectively.

Table 6. The concentrations of leaf nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), and magnesium (Mg) in "on" and "off" 'Nadorcott' mandarin trees, and in response to de-fruiting of "on" trees applied in the Summer (January) and Autumn (April) of 2016 in Expt. 2.

Treatments	January	February	March	April	May	June
N mg·g ⁻¹ leaf dry weight						
"On" trees	22.2	22.9 a	23.7	24.8	26.4	23.9
"Off" trees	22.9	22.8 a	23.8	25.1	26.0	22.5
"On" trees de-fruiting in January	22.2	21.3 b	21.4	23.0	23.6	22.3
"On" trees de-fruiting in April	22.6	23.0 a	23.8	24.3	25.5	22.4
<i>P</i> value	0.53	0.02	0.13	0.23	0.33	0.58
P mg·g ⁻¹ leaf dry weight						
"On" trees	1.08	1.16	0.98	1.18	1.26	1.20
"Off" trees	1.24	1.16	1.14	1.30	1.34	1.14
"On" trees de-fruiting in January	1.10	1.02	0.94	1.20	1.18	1.16
"On" trees de-fruiting April	1.14	1.14	1.02	1.22	1.34	1.20
<i>P</i> value	0.11	0.07	0.33	0.48	0.27	0.76
K mg·g ⁻¹ leaf dry weight						
"On" trees	12.4 b	11.4	10.5	10.9 b	11.0	7.6
"Off" trees	15.0 a	13.1	12.5	13.7 a	13.3	9.8
"On" trees de-fruiting January	12.0 b	9.5	9.5	11.1 b	10.7	8.9
"On" trees de-fruiting April	12.2 b	11.6	10.3	10.3 b	11.9	8.7
<i>P</i> value	<0.01	0.10	0.20	0.02	0.39	0.26
Ca mg·g ⁻¹ leaf dry weight						
"On" trees	31.8	29.5	28.8 ab	31.9 a	33.4 ab	33.2
"Off" trees	27.0	27.5	24.5 b	22.5 b	27.0 b	30.3
"On" trees de-fruiting January	35.9	34.5	36.1 a	30.6 a	38.8 a	36.2
"On" trees de-fruiting April	35.5	35.7	33.4 a	32.6 a	34.1 ab	30.7
<i>P</i> value	0.06	0.20	0.02	0.02	0.03	0.32
Mg mg·g ⁻¹ leaf dry weight						
"On" trees	4.1	3.6	3.2	3.6	4.0	3.6 ab
"Off" trees	3.6	3.4	3.4	3.1	3.6	3.2 bc
"On" trees de-fruiting January	4.0	4.2	4.0	3.7	4.0	4.1 a
"On" trees de-fruiting April	3.8	3.6	3.5	3.8	3.5	2.8 c
<i>P</i> value	0.22	0.15	0.26	0.08	0.53	0.01

Different letters in the same column within a given nutrient denote significant differences between values ($P < 0.05$; Fisher's least significant difference test; $n = 6$).

DW for P, and 15–18 mg·g⁻¹ leaf DW for K. South African citrus growers use leaf macro-nutrient norms of between 20 and 28 mg·g⁻¹ leaf DW for N, 1.1 and 1.6 mg·g⁻¹ leaf DW for P, 9 and 16 mg·g⁻¹ leaf DW for K, 35 and 55 mg·g⁻¹ leaf DW for Ca, and 3.3 and 5.5 mg·g⁻¹ leaf DW for Mg (Du Plessis and Koen, 1992). Throughout all the experiments in this study, however, "on" or "off" trees

with leaf N, P, K, Ca, and Mg concentrations within these ranges did not consistently flower or sprout new vegetative shoots, despite "on" and "off" trees receiving the same amount of fertilizer (Tables 2 and 3; Fig. 2). Very few new vegetative shoots developed from parent shoots in "on" trees compared with "off" trees, and from season 2 to season 3, flower intensity was lower and

fruit load decreased from 110 kg/tree to 16 kg/tree, whereas the concentrations of leaf N, P, K, Ca, and Mg in "on" trees during summer, before harvest, at harvest, and during flowering were between 21 and 24 mg·g⁻¹ leaf DW for N, 0.8 and 1.3 mg·g⁻¹ leaf DW for P, 10 and 15 mg·g⁻¹ leaf DW for K, 26.0–45.0 mg·g⁻¹ leaf DW for Ca, and 2.8–3.4 mg·g⁻¹ leaf DW for Mg, and within the

industry norm (Tables 2 and 3; Fig. 2). The same inconsistent relationships between the change in fruit load from one season to another, and that of the leaf macronutrient concentrations occurred in “off” trees, as well as in the 15 commercial ‘Nadorcott’ mandarin orchards, across three seasons.

In commercial ‘Nadorcott’ mandarin orchards, fruit load in the current season correlated negatively with fruit load in the following season ($r = -0.55$, $P < 0.01$). There was a moderately strong (68%) probability for orchards with a light fruit load (“off”), i.e., orchards with an average tree fruit load lower than the mean and median of all commercial fruit load data, namely, 47 kg/tree in the current year, to have a heavy fruit load (“on”), i.e., a fruit load higher than 47 kg/tree in the following year. For orchards in an “on” season to experience a subsequent “off” season, the probability was 62%. The analyses, together with the calculated alternate bearing index (Table 8), confirmed that all the selected commercial orchards were in a definitive alternate bearing cycle. In concurrence with results from experiments using single-tree replications (Fig. 2), K concentration was greater in leaves of trees in “off” commercial orchards (10.5 vs. 9.4 mg·g⁻¹ leaf DW; $P = 0.04$) and Ca concentration was greater in leaves of trees in “on” commercial orchards (42.7 vs. 34.8 mg·g⁻¹ leaf DW; $P < 0.01$) (Table 9). Despite this, no relationships

were found between fruit load in the current season and the concentration of any macronutrients in the standard leaf analyses of commercial orchards in March, or between the concentration of any of the macronutrients from the current season and fruit load of the next (Table 1). There were no correlations between fruit load and concentrations of macronutrients in leaves in the current season (except for Ca) (N: $r = -0.23$, $P = 0.06$; P: $r = 0.01$, $P = 0.94$; K: $r = -0.12$, $P = 0.32$; Ca: $r = 0.48$, $P < 0.01$; Mg: $r = -0.07$, $P = 0.58$); or between leaf N, P, K, Ca, and Mg concentrations in the current season, and fruit load in the next (N: $r = -0.18$, $P = 0.15$; P: $r = 0.02$, $P = 0.15$; K: $r = 0.30$, $P = 0.20$; Ca: $r = 0.08$, $P = 0.49$; Mg: $r = -0.19$, $P = 0.13$).

Tree nutrient status as measured by foliar analysis may influence fruit load via fruit size or an alteration of fruit set potential in mandarin cultivars such as ‘Nules Clementine’ mandarin and sweet orange cultivars such as ‘Valencia’ and ‘Washington Navel’ (Lovatt, 1999, 2013). However, the factor limiting fruit load and causing an “off” season in ‘Nadorcott’ mandarin trees was not poor fruit set but a lack of vegetative shoot development and flowers (Stander et al., 2018). In fact, percentage of fruit set in “off” ‘Nadorcott’ mandarin trees was similar to “on” trees, but because flower number was almost 2-fold lower, it did not manifest in a larger fruit yield compared with heavy-flowering “on” trees (Tables 1 and 3).

These results question the pertinence of current nutritional guidelines or leaf mineral nutrient norms that are used for ‘Nadorcott’ mandarin orchards in an alternate bearing cycle in South Africa, where the purpose of fertilization should be different during an “on” vs. an “off” season in terms of manipulating vegetative shoot flush, flowering, and fruit load (Stander et al., 2018). Similar to what has been reported for avocado (*Persea americana*) (Campisi-Pinto et al., 2017), it could be possible that leaf analysis is not sensitive enough to detect changes in macronutrient status of ‘Nadorcott’ mandarin trees, or differences in fertilization rates that may affect fruit load or result in the manifestation of alternate bearing. For example, in other evergreen fruit trees such as avocado, coffee (*Coffea arabica*), and olive (*Olea europaea*), organs such as flowers, petioles of leaves, and stems of flowers and fruit are alternative tree organs from which nutrient analyses provide valuable supplemental information to leaf nutrient analyses (Campisi-Pinto et al., 2017; Castillo-Gonzalez et al., 2000; Khelil et al., 2010; Martinez et al., 2003; Razeto and Salgado, 2004). Indeed, studies on mineral nutrients and alternate bearing in other mandarin cultivars, e.g., ‘Kinnow’ (Mirsoleimani et al., 2014) and ‘Michal’, ‘Wilking’, and ‘Murcott’ (Monselise et al., 1983), have shown that the effects of fruit load in the current season on bud responses in the following season are also closely related to the nutrient concentration in stems. The relationship between macronutrient concentration in stems or buds, and vegetative shoot development and flowering should, therefore, be investigated in ‘Nadorcott’ mandarin as a mean to predict flowering and fruit load and to fertilize accordingly.

Although these results on the relationship between leaf macronutrients and alternate bearing are in contrast to some of those obtained in deciduous fruit and nut trees, e.g., apple (*Malus domestica*) (Neilsen et al., 1990) and pistachio (*Pistachia vera*) (Rosecrance et al., 1998), they are consistent with results

Table 7. Vegetative shoot development and flowering in “on” and “off” ‘Nadorcott’ mandarin trees, and “on” trees in reaction to de-fruiting in the Summer (January) and Autumn (April) of 2016 in Expt. 2.

Tree fruiting status (season 1)	New summer vegetative shoots (season 1)	Spring floral intensity (season 2)
	(no./tree)	(no./tree)
“On” trees	9 c	18,942 c
“Off” trees	34 b	43,110 a
“On” trees de-fruited in January	79 a	32,324 b
“On” trees de-fruited in April	11 c	22,991 c
P value	<0.01	<0.01

Different letters in the same column denote significant differences between values ($P < 0.05$; Fisher’s least significant difference test; $n = 6$).

Table 8. The summary of a survey carried out in 15 commercial alternate bearing ‘Nadorcott’ mandarin orchards in South Africa. Fruit load per tree (kg/tree) for each orchard was calculated using the fruit yield (ton·ha⁻¹) of each orchard for each commercial harvest, the tree spacing (trees/ha), and the orchard area (ha).

Orchard no.	Fruit load (kg/tree)			AB index (<i>I</i>) ^z	Leaf macronutrient concn (mg·g ⁻¹ leaf dry weight)														
					N			P			K			Ca			Mg		
	Yr 1	Yr 2	Yr 3		Yr 1	Yr 2	Yr 3	Yr 1	Yr 2	Yr 3	Yr 1	Yr 2	Yr 3	Yr 1	Yr 2	Yr 3	Yr 1	Yr 2	Yr 3
1	18	66	15	0.60	24.7	27.0	19.8	1.3	1.2	1.2	10.4	13.6	7.1	44.6	33.5	30.9	5.0	5.6	6.4
2	28	96	23	0.58	22.2	21.3	20.6	1.5	1.5	1.7	9.5	9.4	12.0	41.7	44.7	43.4	4.6	4.3	4.7
3	18	61	20	0.52	25.7	24.1	20.7	1.3	1.3	1.2	8.8	9.3	7.2	48.4	37.2	29.0	4.8	4.8	5.6
4	49	103	42	0.39	22.9	21.9	22.6	1.5	1.3	2.0	9.0	8.1	15.9	43.5	48.9	47.2	4.6	4.0	3.9
5	49	91	34	0.38	24.1	24.6	25.1	1.3	1.5	1.0	17.4	15.9	15.5	19.7	27.0	21.6	5.2	5.9	6.2
6	18	57	41	0.34	27.8	24.3	27.7	1.7	2.5	1.4	11.1	8.6	10.8	27.5	44.9	32.7	4.4	5.6	3.6
7	43	27	72	0.34	25.1	22.15	24.5	1.5	1.4	1.3	9.0	10.4	9.8	42.5	36.8	41.5	3.9	4.9	4.2
8	48	28	63	0.32	25.1	21.2	21.2	1.8	1.4	1.3	7.1	8.7	6.9	37.9	28.6	46.5	6.4	5.5	5.6
9	31	67	40	0.31	23.6	26.0	24.5	1.6	1.6	1.5	12.7	10.0	10.9	30.0	42.5	30.6	4.3	5.2	4.3
10	31	64	37	0.30	23.7	23.1	20.5	1.3	1.5	0.9	10.7	10.5	9.2	30.3	23.8	23.2	5.0	6.1	5.8
11	35	73	45	0.29	21.9	25.7	23.0	1.5	1.4	1.4	11.3	10.8	10.6	40.9	45.3	36.5	4.6	4.2	4.0
12	43	87	56	0.27	22.5	23.7	22.1	1.2	1.0	0.9	12.5	10.9	11.3	44.8	42.8	50.9	4.4	4.7	4.0
13	28	53	35	0.25	27.0	26.4	27.7	1.3	1.7	1.4	10.5	6.9	10.8	36.9	51.5	32.7	4.1	4.7	3.6
14	77	47	76	0.24	20.6	20.3	20.9	1.2	1.5	1.0	9.0	10.4	9.3	43.6	45.3	49.8	4.3	4.4	5.3
15	33	53	46	0.19	27.0	26.4	27.7	1.3	1.7	1.4	10.5	6.9	10.8	36.9	51.5	32.7	4.1	4.7	3.6

^aThe alternate bearing index (I) was calculated using the following formula: $I = \frac{1}{(n-1)} \left[\frac{(a_2-a_1)}{(a_2+a_1)} + \frac{(a_3-a_2)}{(a_3+a_2)} + \dots \right]$,

n = number of seasons; a = fruit yield (as kg/tree) in the corresponding seasons, with the difference in yield between two seasons expressed as an absolute value.

Table 9. The effect of fruit load in 15 commercial 'Nadorcott' mandarin orchards on the concentration of leaf macronutrients.

Orchard fruiting status ^z	N	P	K	Ca	Mg
	(mg·g ⁻¹ leaf dry weight)				
"Off" (<47 kg/tree)	23.1	1.4	10.5 a	34.8 b	4.9
"On" (>47 kg/tree)	22.6	1.4	9.4 b	42.7 a	4.9
P value	0.18	0.65	0.04	<0.01	0.39

^zThe median and mean values for fruit load of all commercial orchards were determined using descriptive statistics.

Different letters in the same column denote significant differences between values ($P < 0.05$; Fisher's least significant difference test; $n = 34$).

from research in other evergreen tree crops, e.g., olive (Jiménez-Moreno and Fernández-Escobar, 2017). More significantly, the results presented herein are in agreement with results from research in other mandarin cultivars. In 'Satsuma' mandarin (*Citrus unshiu*), Mudau et al. (2004) demonstrated that despite a wide range in annual N application rates and varying methods of application, no different effects were recorded for fruit load or any other horticultural responses between any of the treatments. In 'Moncada' mandarin, it was shown that N is not a limiting factor for vegetative shoot development in alternate bearing trees (Martínez-Alcántara et al., 2015), and in 'Murcott' (Smith, 1976) and 'Nadorcott' mandarins (Stander et al., 2017), leaf N, P, and K concentrations and leaf N concentration in "off" trees were shown to be a result, not a cause, of alternate bearing. There may be a minimum level for each respective macronutrient required by a citrus tree to maintain metabolism and general physiological function, but all the orchards used as experimental sites in this study were well fertilized as reflected by the high macronutrient concentration in leaves. The trees were never subject to any nutrient deficiency that may have affected primary metabolism and contributed to alternate bearing in such a manner.

In this study, macronutrient concentrations in the leaf appeared not to have played a role in the perpetuation of alternate bearing in 'Nadorcott' mandarin trees, and adequate nutrient content did not alter the alternate bearing cycle. Alternate bearing occurred in 'Nadorcott' mandarin trees that were well fertilized. Alternative factors such as a hormonal regulation of vegetative shoot development, root growth, and flowering may be of more relevance to alternate bearing cycles (Goldberg-Moeller et al., 2013; Shalom et al., 2012, 2014; Ulger et al., 2004).

Conclusions

In this study, the concentration of macronutrients in leaves did not play a role in the perpetuation of alternate bearing in 'Nadorcott' mandarin trees. Fruit load affected the concentration of the macronutrients in leaves in some cases but not to the detriment of vegetative shoot development, flowering, or

fruit load of the following season. The crop removal factor was higher for each macronutrient in "off" trees, but the harvest of an ≈ 8 -fold higher fruit load in "on" trees removed 1.5–7 times more macronutrients than the harvest of fruit in "off" trees. In "off" trees, N, P, and K, and in "on" trees, Ca accumulated in leaves in season 1 to between 20% and 30% higher concentrations, but the higher macronutrient status did not manifest in or consistently correlate with intensity of summer vegetative shoot development in the current season, flowering in the next season, or both—the two main determinants of fruit load in 'Nadorcott' mandarin. Apart from some anomalies, concentrations of macronutrients in leaves were unaffected by defruiting and foliar spray applications of N and K to "on" trees, and showed no consistent relationship with treatment effects on parameters of vegetative shoot flush, flowering, and fruit load. This study, therefore, does not support a role for leaf macronutrients in the regulation of vegetative shoot development, flowering, and fruit load in alternate bearing 'Nadorcott' mandarin trees. Changes in leaf macronutrient concentration in leaves can be considered a consequence of, rather than a cause of, differences in fruit load from one season to another.

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