Preliminary and Regional Reports

Reviewing the Commercial Potential of Hand Thinning in Citrus with a Cost-benefit Analysis of Summer Hand Thinning of ‘Nadorcott’ Mandarin

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ADDITIONAL INDEX WORDS. **alternate bearing, chemical thinning, fruit growth, fruit size, fruit value, leaf carbohydrates**

SUMMARY. **Hand thinning is not often applied as a commercial cultural practice in citriculture due to the practice’s reliance on costly manual labor. However, hand thinning could provide unique benefits such as treatment selectivity and easier control over thinning intensity, as opposed to foliar sprays of chemical thinning agents. In “on-year” ‘Nadorcott’ mandarin (*Citrus reticulata*) trees, summer (January) and autumn (April) hand-thinning treatments of removal of all fruit <20 and <40 mm diameter were evaluated for effects on leaf carbohydrates and fruit growth rate. Other factors assessed included treatments’ effects on tree total fruit yield, fruit quality, and fruit size distribution. In addition, two different summer hand-thinning treatments (removal of all fruit <20 and <25 mm) were evaluated for effects on fruit size distribution and fruit yield over two seasons to determine their potential financial implications. Summer hand thinning reduced the numbers of small fruit and increased initial growth rate of prevailing fruit. This resulted in larger numbers of premium-sized fruit per tree, without treatments reducing total fruit yield and fruit quality. Additional labor was eliminated by quicker picking of fruit during harvest, and in season 2, fruit yield was higher for summer hand-thinning treatments compared with control. A higher potential income resulted from change in fruit size distribution and the breaking of alternate bearing over the 2-year period. The results provide producers of late mandarin cultivars with an alternative to chemical thinning agents to manage crop load and improve fruit size in individual “on-year” trees.**

In recent years, plantings of late-maturing mandarin cultivars increased substantially and contribute significantly to the total annual South African citrus (*Citrus* sp.) produced (South African Citrus Growers Association, 2015). From 2014 to 2015, the total area of mandarins planted in South Africa increased by 21% from 6401 to 7722 ha, more than any other group of cultivars. Mandarin fruit generally colors well, have excellent taste, exhibit little or no seeds, and have thin rinds that are easy to peel. Major production problems in most of these cultivars include irregular flowering (Rabe and Van Rensburg, 1996) and poor fruit set (Barry and Bower, 1997; Rivas et al., 2006): events both integral to the manifestation of alternate bearing, a common phenomenon in perennial fruit trees (for general review of older literature, see Monselise and Goldschmidt, 1982). Briefly in citrus, extreme environmental conditions trigger and result in intense flowering and a subsequent season of high fruit load (“on-year”). In “on-years” the majority of fruit is of small size, high acidity, and low commercial value (Galliani et al., 1975). In return, high fruit numbers in an “on-year” impose a hormone-related inhibition on the potential of the follow-up crop (Muñoz-Fambuena et al., 2011; Shalom et al., 2012, 2014; Verreynne and Lovatt, 2009) and result in an “off-year” with no or few flowers and cropping of a low number of very large fruit.

In addition to playing an integral role in manifestation of alternate bearing and a subsequent “off-year” (García-Luis et al., 1988b; Goldschmidt et al., 1985; Goldschmidt and Golomb, 1982), carbohydrate availability has been shown as an important determinate of fruit growth and eventual size in “on-year” trees. Profuse numbers of developing fruit sinks compete for photo-assimilates and carbohydrate reserves with other sinks such as roots and vegetative flush (Martínez-Alcántara et al., 2015; Smith, 1976). Consequently, accumulation of dry-matter, of which carbohydrates comprise the majority (García-Luis et al., 1988a), is limited in fruit from “on-year” trees and fruit growth is restricted (Guardiola and García-Luis, 2000). An additional, and often neglected problem in “on-year” and late-maturing mandarins grown in South African production regions with typical Mediterranean climate, is winter rains that overlap with and further delay harvesting.

With fruit proven as the major inhibitor of citrus flowering in the

Units

To convert U.S. to SI, multiply by	U.S. unit	SI unit	To convert SI to U.S., multiply by
29,574	fl oz	μL	3.3814×10^{-5}
29.5735	fl oz	mL	0.0338
0.3048	ft	m	3.2808
25.4	inch(es)	mm	0.0394
28.3495	oz	g	0.0353
0.001	ppm	$mg \cdot g^{-1}$	1000
0.001	ppm	$mL \cdot L^{-1}$	1000
(°F – 32) ÷ 1.8	°F	°C	(°C × 1.8) + 32

subsequent season, a reduction in crop load to alleviate the propensity of alternate bearing in "on-year" trees would make sense. Indeed, substantial proof exists for the latter (García-Luis et al., 1995; Martinez-Fuentes et al., 2010; Verreynne and Lovatt, 2009). In terms of the previously mentioned problems associated with the current cropping season, a successful reduction of fruit numbers in "on-year" trees could reduce interfruit competition for assimilates, increase final fruit size, and improve internal fruit quality at time of harvest (Bustan et al., 1995; Galliani et al., 1975; Guardiola and García-Luis, 2000; Monselise et al., 1981). For this purpose, synthetic auxins 2,4-dichlorophenoxy propionic acid and trichlo-2-pyridinyloxyacetic acid are extensively used in the south african citrus industry as commercial chemical thinning agents when applied as foliar sprays during and directly after the physiological fruit drop period (Agustí et al., 2002).

Although not widely considered due to a heavy reliance on costly manual labor, as well as limited experimental results justifying the labor costs associated with a predetermined practice of such (Davis et al., 2004), hand thinning could be a successful alternative to chemical thinning agents, especially considering loss in potential income resulting from production of small fruit in high-value cultivars. Unfortunately, limited evidence exists for effects of different timings and intensities of hand thinning (Davis et al., 2004) due to numerous studies only reporting on hand thinning as a control for evaluating efficacy of chemical thinning agents (Hilgeman et al., 1964; Monselise et al., 1981). As opposed to chemical thinning agents, hand thinning could provide producers with unique benefits. This include control over the intensity of thinning, no risks of chemical residues, as well as a high level of selectivity by only removing fruit with unwanted characteristics from individual trees such as small fruit size and the presence of rind blemishes (Davis et al., 2004).

In an experiment preliminary to the current, a midsummer (January) hand-thinning treatment of removal of all fruit <15 mm in "on-year" 'Nadorcott' mandarin trees was unsuccessful in increasing fruit growth rate, fruit quality, and final fruit size, as well as altering leaf carbohydrate content in April, 3 months after treatment (Van der Merwe, 2012) due to suspected under-thinning (reduction in only 5% of total fruit numbers). The authors, therefore, decided on evaluating a more severe summer (January) hand-thinning treatment of removal of all fruit <20 mm diameter (10% to 15% fruit reduction) as well as a similar treatment intensity, but later timing (removal of all fruit <40 mm in April). Treatments were applied to "on-year" trees located within the same orchard as the preliminary study, and were evaluated for effects on leaf carbohydrate content (measured at more regular and shorter intervals), fruit growth rate, fruit yield, fruit quality, and fruit size distribution. In addition, two different intensities of summer hand-thinning treatments (manual removal of all fruit <20 mm and all fruit <25 mm) were evaluated for effects on fruit size distribution and fruit yield over two seasons to evaluate effects on bearing alternation, as well as for any financial implications of the practice and potential grower returns resulting from any possible change in yield and fruit size distribution.

Materials and methods

Plant material and experimental site

Adult "on-year" 'Nadorcott' mandarin trees grown under field conditions and budded on Carrizo citrange (*Citrus sinensis* × *Poncirus trifoliata*) rootstock were selected from orchards with a history of alternate bearing. Trees were planted in 2009, in a north to south row direction and a spacing of 5 m (row spacing) × 2 m (tree spacing within row). Orchards are located in the Western Cape Province of South Africa, which experiences representative 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. Experiments were conducted in 2014–15, and standard commercial cultural practices were applied as required for export-quality fruit. Trees were isolated from any possible cross-pollinators and fruit were predominantly seedless.

Treatments and experimental design

Healthy 'Nadorcott' trees representative of an "on-year"-crop and with uniform canopy sizes were selected. Before treatment, the fruit size distribution within each replicate tree was established by measuring the diameters of 150 randomly distributed fruit within the canopy with an electronic caliper (CD-6" C; Mitutoyo, Tokyo, Japan). A fruit growth curve representing the historical daily growth rate for 'Nadorcott' fruit from the area was used to predict the fruit size at harvest for the different fruit size ranges as measured in January. Accordingly, all fruitlets expected to develop into fruit with diameters <50 mm at time of commercial maturity in August, were removed as part of hand-thinning treatments. In season 1, three treatments were replicated six times (n = 6) in a randomized complete block design, where an individual tree represented a single replicate: 1) control (no thinning); 2) summer hand thinning: removal of all fruit <20 mm, 65 d after full bloom (DAFB); and 3) autumn hand thinning: removal of all fruit <40 mm, 175 DAFB. Fruit were individually excised from shoots by hand, with 75 and 86 fruit removed per replicate tree, for each of the latter two treatments, respectively. In a separate experiment, the following treatments were replicated six times: 1) control (no thinning); 2) removal of all fruit <20 mm, 80 DAFB; and 3) removal of all fruit <25 mm, 80 DAFB. For the latter hand-thinning treatments, 72 and 151 fruit were removed per replicate tree.

Data collection

FRUIT GROWTH RATE. Ten fruit with similar diameters and distributed within the outer tree canopy of each replicate tree, were tagged and their diameters measured at ± 2-week intervals, from day of treatment, until 6 weeks after respective treatments to calculate treatment effect on fruit growth rate (millimeters per day).

FRUIT QUALITY. Representative samples consisting of 12 fruit were collected from each replicate tree at

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We thank Doepie Van Zyl and C.P. Mouton for providing access to their orchards at Kanetvlei in De Doorns and Tienrivieren in Citrusdal, as well as to Citrus Research International, for financial support. The comments and suggestions by Tim Grout and Lynn Hoffman to improve the manuscript are gratefully acknowledged.

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the time of harvest. Fruit diameter and fruit height (millimeters) were measured with electronic calipers to determine treatment effects on fruit shape by calculating a fruit diameter: height ratio. Thereafter, fruit were cut in half along the equatorial plane and rind thickness (flavedo and albedo combined) was measured with electronic calipers in the equatorial region of opposite sides of each fruit, and the values averaged. Fruit were then individually juiced using a citrus juicer (Sunkist®, Chicago, IL). The juice was strained through a muslin cloth and weighed to express juice content [percent (wt/wt)] as a percentage of the weight of the extracted juice and total fruit fresh weight. Total soluble sugars (TSS) of the juice were determined using a refractometer (PR-32; Atago, Tokyo, Japan). Titratable acidity (TA) was determined by titrating 20 mL of the extracted juice against 0.1 N sodium hydroxide using phenolphthalein as an indicator. The TSS:TA ratios were subsequently calculated.

LEAF CARBOHYDRATE ANALYSIS. Samples consisting of eight leaves were collected from each of the treatment replicates between 9:00 and 10:00 AM, starting on the day of treatments, and continued at ± 2-week intervals, for a period of 6 weeks. Samples were washed with distilled water, frozen at –80 °C, and freeze dried (Christ Beta 1–8 LD Freeze Dryer; Martin Christ Gefriertrocknungsanlagen, Osterode am Harz, Germany), before being ground to a fine powder with an analytical grinder (Yellow line, A10; IKA-Werke, Staufen, Germany). From 100 mg leaf powder, TSS were extracted three times with 5 mL of 80% ethanol at 80 °C for 1 h. The pellets were then extracted three times with 5 mL de-ionized water at 80 °C for 24 h for the determination of total water-soluble polysaccharides. Starch content was determined from the pellet by quantifying the glucose released following an enzymatic digestion for 17 h at 60 °C, with the amyloglucosidase enzyme (AMG; Sigma Aldrich, Aston Manor, South Africa).

The various extracts were analyzed for TSS, using the phenol–sulphuric acid assay (Brummer and Cui, 2005). Briefly, a volume of 20 μL of each of the respective extracts, was added to 180 μL de-ionized water, 200 μL phenol (5 $\text{mL}\cdot\text{L}^{-1}$), and 1000 μL concentrated sulphuric acid. Absorbances were determined on a spectrophotometer (Cary® 50 Bio; Varian, Mulgrave, Australia) at 490 nm against a blank prepared for the standard. The sugar concentrations are expressed as milligrams per gram leaf dry weight and are referred to as leaf soluble sugars, leaf polysaccharides, and leaf starch, respectively. The sum values of the latter are referred to as leaf total carbohydrates.

COST-BENEFIT ANALYSIS. Time (minutes) to complete the hand-thinning treatments, as well as the total time to pick all fruit at time of fruit maturity (harvest) was recorded. The percentage distribution of the different commercial fruit size classes within each replicate tree was determined by measuring diameters of 150 fruit collected from randomly distributed positions within the canopy of each replicate tree. By using the percentage fruit size distribution for each replicate tree, the actual numbers of fruit within each of the eight commercial size classes for each replicate tree were calculated by dividing the kilograms per tree values by the average weight of a specific size class. For the latter, 12 fruit from each of eight commercial size classes were collected from six replicate trees to establish an average fruit fresh weight (grams) for each. The value of fruit in each commercial size class was calculated using commercial prices for the 2-year period. Prices were obtained from a group of industry exporters. The prices were used to generate the potential grower return per tree over the 2-year period, where fruit size was the only criterion affecting grade.

STATISTICAL ANALYSIS. Analysis of variance was performed using PROC GLM of SAS software (version 9.1; SAS Institute, Cary, NC). Mean separations were carried out using the least significant difference test, where applicable, at $P \leq 0.05$.

Results and discussion

Summer hand thinning significantly increased the numbers of large to premium-sized fruit (size classes 1×, 1, and 2) and significantly reduced the number of small fruit (size classes 4, 5, and <5) per tree at time of harvest (Fig. 1), without significantly reducing total fruit yield (Table 1) or internal fruit quality attributes (not shown, due to nonsignificance). This implies that less small fruit were prevalent due to a removal thereof at an early stage, and in reaction to the latter, prevailing fruit increased in size and a larger proportion of fruit could be exported at a higher premium from summer hand-thinned trees, than from control and autumn hand-thinning

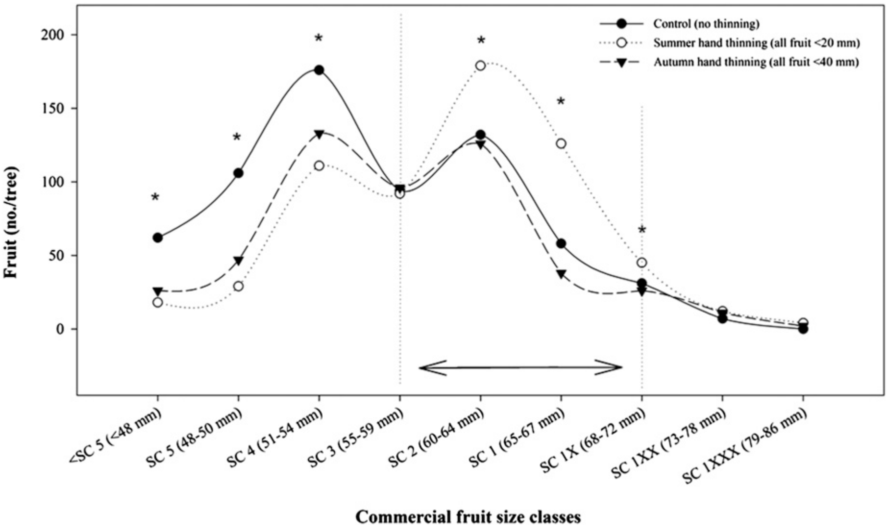

Fig. 1. The distribution of the different commercial fruit size classes (SC) within control and hand-thinned trees at time of fruit maturity (harvest) in 'Nadorcott' mandarin. The arrows indicate the preferred and highest value fruit size classes, as determined from prices obtained from a group of industry exporters, where fruit size was the only criterion affecting grade. Data are expressed as means of six replicates (n = 6); * indicates significant difference at the 5% level (least significant difference); 1 mm = 0.0394 inch.

Table 1. **Different timings of hand-thinning treatments of "on-year" 'Nadorcott' mandarin trees were replicated six times (n = 6) in a randomized complete block design, and total fruit yield per tree determined at time of commercial harvest.**

Treatments[z]	Fruit removed (no./tree)	Total wt of removed fruit (kg/tree)[z]	Fruit yield (kg/tree)
Control (no thinning)	0 b[y]	0.00 c	48.00 NS
Summer hand thinning (<20 mm)[x]	72 a	0.24 b	56.00
Autumn hand thinning (<40 mm)[w]	81 a	2.96 a	41.00
P value	0.0000	0.0000	0.1653

[z] 1 mm = 0.0394 inch, 1 kg = 2.2046 lb.

[y] Means with a different letter within a column differ significantly at the 5% level (least significant difference); NS = no significant differences.

[x] 5 Jan. [65 d after full bloom (DAFB)].

[w] 21 Apr. (175 DAFB).

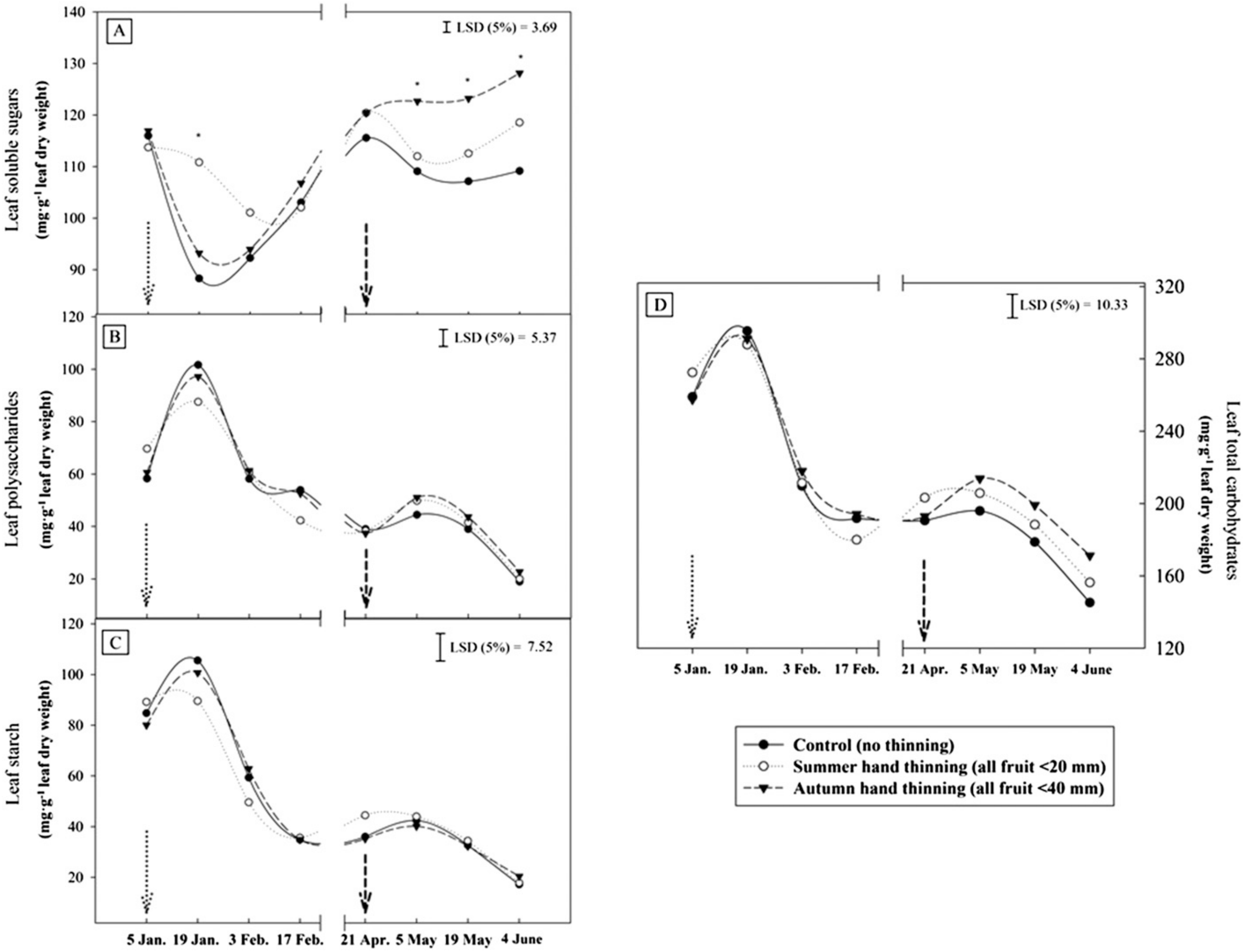

Fig. 2. **Effects of two different timings of hand-thinning treatments (summer vs. autumn) in 'Nadorcott' mandarin on leaf carbohydrate concentration, expressed as (A) total soluble sugars, (B) total water-soluble polysaccharides, and (C) starch. (D) Leaf total carbohydrates represent the sum of the individual components (A–C). Data were expressed as means of six replicates (n = 6); * indicates significant difference at the 5% level [least significant difference (LSD)]; 1 mg·g^{-1} = 1000 ppm, 1 mm = 0.0394 inch.**

treatments. Reducing fruit numbers by summer hand thinning seemingly resulted in a transient buildup of leaf photosynthate, and leaf soluble sugar content was significantly higher 2 weeks after treatment (5 to 19 Jan.) than for the control and autumn hand-thinning treatments (Fig. 2A). Shortly thereafter (19 Jan. to 3 Feb.), fruit growth rate was significantly higher for the summer hand-thinning treatment compared with control and autumn hand-thinning treatments in the corresponding time period (Fig. 3). After the latter time period, leaf soluble sugar content again decreased to a level similar to that of control and autumn hand-thinning treatments (Fig. 2A). Potential for fruit growth is determined at an early stage of fruit development (Guardiola, 1988) and fruit removal in January seemingly reduced the limitation of fruit intersink competition on fruit growth rate in a period when competition has been shown to be maximal (Van Rensburg et al., 1996).

Autumn hand thinning had no effects on fruit growth rate (Fig. 3) and fruit quality (not shown, due to nonsignificance) and as a result, a significant accumulation of photoassimilates occurred in response to the autumn treatment, which could most probably be ascribed to a reduced activity of major sinks during time of autumn hand thinning (Guardiola and García-Luis, 2000). Neither summer, nor autumn hand-thinning treatments had a significant effect on leaf polysaccharides and leaf starch (storage carbohydrates), nor leaf total carbohydrates content throughout the rest of the monitoring period (Fig. 2B–D).

In Expt. 2 alternate bearing was eliminated, and season 2 total fruit yield of trees subjected to summer hand thinning in season 1 was significantly higher (increase of 22% and 67%, respectively) than those of control "on-year" trees, which did experience alternate bearing and a drop of 17% in total fruit yield from season 1 to season 2 (Table 2). Taking into consideration that no significant differences in leaf total carbohydrates between hand-thinned and control trees were observed throughout the rest of the monitoring period in Expt. 1, the authors theorize the reduction in fruit yield of control trees in Expt. 2 was due to a hormonal inhibition imposed by an excess number of fruit in season 1, on the potential of return bloom and yield of season 2, as opposed to a carbohydrate effect. Fruit are major sources of endogenous hormones auxin and gibberellin (GA) (Ben-Cheikh et al., 1997; Yuan et al., 2003). In "on-year" shoots, high endogenous auxin has been shown to inhibit sprouting of new flower-bearing units during summer (Verreynne and Lovatt, 2009) and inhibit flowering in the following season, whereas high endogenous GA relates to the inhibition of flower-gene expression and a lack of return bloom in "on-year" shoots (Goldberg-Moeller et al., 2013; Koshita et al., 1999; Muñoz-Fambuena et al., 2012). Fruit removal can increase return bloom and encourage regular fruiting (Goldschmidt and Golomb, 1982; Monselise et al., 1981). Early crop reduction could stimulate the development of new vegetative shoots with potential to flower (Safael-Nejad et al., 2015), whereas a lower crop load during flower development could reduce the inhibition imposed by fruit on flower induction and return bloom (Martinez-Fuentes et al., 2010).

Pertaining to a lower number of small fruit requiring manual picking during harvest, additional labor associated with hand thinning was eliminated by a quicker picking of fruit during harvest and a resultant lower total required labor time (time for one person to thin and harvest a tree) than the control, "on-year" trees (Fig. 4). In addition to higher potential income resulting from change in fruit size distribution in season 1 (Fig. 1) and breaking of alternate bearing in season 2 (Table 3), the results also show that additional labor is canceled out by a reduced labor requirement to pick

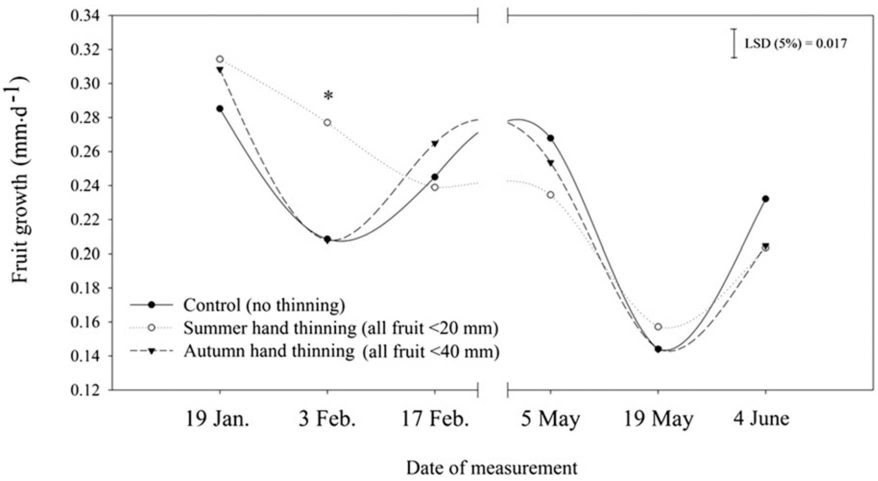

Fig. 3. The fruit growth rate of 'Nadorcott' mandarin following two hand-thinning treatments, applied either in summer [5 Jan.; 65 d after full bloom (DAFB)] or autumn (22 Apr.; 175 DAFB) along with a control treatment (no thinning). Data were expressed as means of six replicates (n = 6). * indicates significant difference at the 5% level [least significant difference (LSD)]; 1 mm = 0.0394 inch.

Table 2. Different intensities of summer hand-thinning treatments in "on-year" 'Nadorcott' mandarin were replicated six times (n = 6) in season 1, and total fruit yield determined over a 2-year period, each year at time of commercial harvest.

Treatments[z]	Fruit removed (no./tree)	Total wt of removed fruit (kg/tree)[z]	Fruit yield (kg/tree)
Season 1			
Control (no thinning)	0 c[y]	0.00 c	78.64 NS
Summer hand thinning (<20 mm)[x]	72 b	0.26 b	67.90
Summer hand thinning (<25 mm)	151 a	0.63 a	68.58
P value	0.0000	0.0000	0.2847
Season 2			
Control (no thinning)	—[w]	—	65.00 c
Summer hand thinning (<20 mm)	—	—	83.00 b
Summer hand thinning (<25 mm)	—	—	115.00 a
P value			0.0171

[z] 1 mm = 0.0394 inch, 1 kg = 2.2046 lb.

[y] Means with a different letter within a column differ significantly at the 5% level (least significant difference); NS = no significant differences.

[x] 24 Jan. (80 d after full bloom).

[w] Season 1 replicate trees were left untreated in season 2.

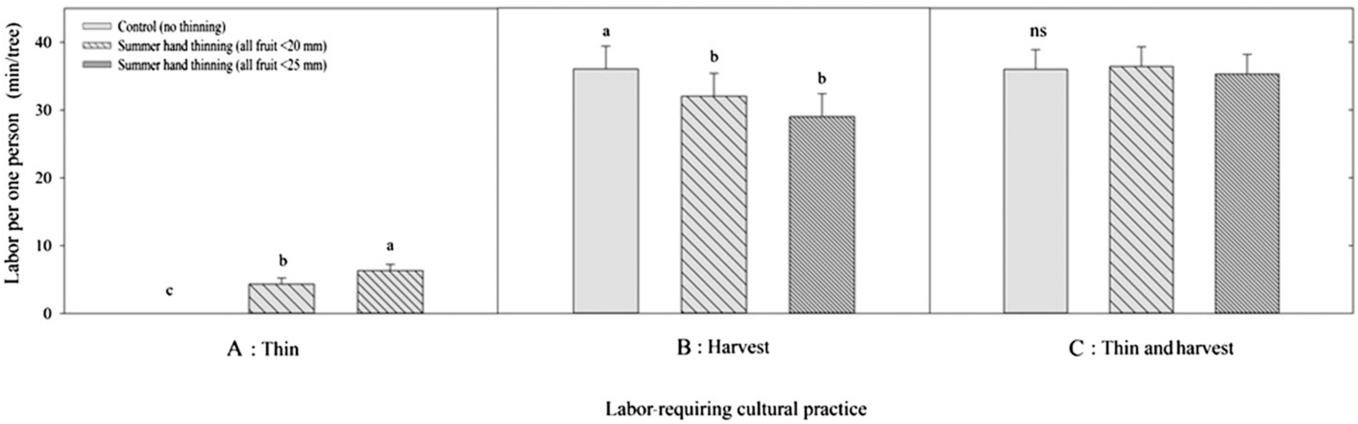

Fig. 4. Labor time required for one person to either (A) thin or (B) pick (harvest) all fruit, respectively, from "on-year" 'Nadorcott' mandarin trees, following two summer hand-thinning treatment intensities. (C) Total time (thin and harvest) represents the sum value of the time for one person to thin and harvest one replicate tree. Data were expressed as means of six replicates (n = 6). Means with a different letter within a treatment differed significantly at the 5% level (least significant difference), whereas "ns" indicated no significant differences; 1 mm = 0.0394 inch.

Table 3. Potential grower return per tree and hectare over the 2-year period, as calculated from average fruit size distribution and total fruit yield, in response to summer hand thinning of 'Nadorcott' mandarin in season 1. The value of fruit in each commercial size class was calculated using commercial prices obtained from a group of industry exporters for the 2-year period. Fruit size was the only criterion affecting grade.

		Potential income (80% packout)		
Treatments[z]	Avg fruit yield (kg/tree)[z]	R/tree[y]	R/ha[y]	Difference from control (R/ha)
2-yr cumulative (seasons 1 and 2)				
Control (no thinning)	71.50	491.44	491,444.11	0.00
Summer hand thinning (all fruit <20 mm)	76.00	634.23	634,229.52	142,785.41
Summer hand thinning (all fruit <25 mm)	91.50	509.64	509,640.79	18,196.68

[z] 1 mm = 0.0394 inch, 1 kg = 2.2046 lb.

[y] 1 South African Rand (R) = $0.070 on 23 Nov. 2015, 1 R/ha = 0.4047 R/acre.

"on-year" fruit at time of harvest and therefore challenges the perception that hand thinning is a costly practice. A quicker harvesting of "on-year" trees is beneficial, particularly if long rain spells prevail during time of commercial maturity and delay harvesting of fruit beyond the time of optimal maturity as well as beyond the window of optimal financial returns. Furthermore, a delay of, or extended harvest time has been shown to have a negative effect on return bloom and reduce potential of the follow-up crop (Verreynne and Lovatt, 2009).

Conclusions

Summer hand thinning increased the numbers of large- to premium-sized fruit and reduced numbers of small fruit per tree without reducing total fruit yield or fruit quality. At harvest, less small fruit was prevalent due to removal thereof at an early stage and in reaction to the latter, prevailing fruit increased in size and a larger proportion of fruit could be exported at a higher premium. As opposed to summer hand thinning, autumn hand thinning was seemingly applied too late and had no effects on fruit growth rate and fruit quality. Neither summer, nor autumn hand-thinning treatments had a significant effect on leaf storage carbohydrates, nor on leaf total carbohydrates content throughout the monitoring period. Alternate bearing was eliminated by summer hand thinning and season 2 total fruit yield was significantly higher than control, nonthinned trees. Taking into consideration that no significant differences in leaf total carbohydrates were observed throughout the rest of the monitoring period, the authors theorize the reduction in fruit yield of control trees were due to a hormonal inhibition imposed by an excess numbers of fruit in season 1 on the potential of return bloom and yield of season 2. Additional labor associated with hand thinning was compensated for by a quicker picking of fruit during harvest. In addition, higher potential income resulted from change in fruit size distribution and breaking of alternate bearing and therefore challenges the perception that hand thinning is a costly practice. This research is one of a few, if not the only that reports on the effects of different timings and intensities of hand thinning on yield and fruit size over a 2-year period, and how it affects potential financial grower returns. The results provide producers of late-maturing mandarin cultivars in typical Mediterranean-type production regions with an alternative to chemical thinning agents to manage crop load and improve fruit size of individual "on-year" trees by hand thinning all fruit smaller than 20 mm diameter in summer, 65–80 DAFB.

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