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Fruit Size and Yield of Mandarins as Influenced by Spray Volume and Surfactant Use in NAA Thinning

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***Abstract*. Six trials were conducted to determine whether lower spray volumes or inclusion of different surfactants would permit adequate thinning of mandarin hybrids (*Citrus reticulata* hybrids) at a much lower cost per hectare. Sprays were applied using a commercial airblast orchard sprayer during physiological drop when fruitlets averaged 8 to 16 mm in diameter. Surfactant was always included at 0.05% v/v. NAA always reduced fruit per tree, increased fruit size, and decreased production of smallest size fruit. However, in only three experiments, contrast of all NAA treatments vs. controls indicated increased production of the largest (80–100 fruit per carton) and most valuable fruit. In four of five experiments, comparison of spray volumes of 600 (only examined in three of four experiments), 1200, or 2300 L·ha^{-1} demonstrated significant fruit size enhancement from all NAA applications. Most individual NAA treatments resulted in fewer fruit per tree, but there were no statistically significant differences between NAA treatments at different spray volumes. In only one of the four experiments, there was a marked linear relationship between spray volume and fruit per tree, yield, mean fruit size, and production of largest fruit sizes. The effects of surfactants (Activator, a nonionic, Silwet L-77, and LI-700) on NAA thinning were tested in both 'Murcott' and 'Sunburst'. In comparisons between Silwet L-77 and Activator surfactant, one experiment with 'Murcott' showed greater fruit per tree and yield reduction from using Silwet, but with a smaller increase in production of largest fruit sizes, whereas in another 'Murcott' experiment, Silwet L-77 reduced numbers of smaller fruit size with no increase in production of larger fruit. Based on these findings, current recommendations for NAA thinning of Fla. mandarins are use of spray volume of ≈1100–1400 L·ha^{-1} on mature trees with proportionally lower volume on smaller trees. These data appear to support use of a nonionic surfactant rather than other tested surfactants in NAA thinning of Florida mandarins. Because experience with NAA thinning of Florida citrus is limited, it is only recommended where the disadvantages of overcropping are perceived to substantially outweigh the potential losses from overthinning.**

Some citrus cultivars are prone to alternate bearing, in which trees produce very heavy crops of small fruit in the "on" year and much smaller crops of larger fruit in the "off" year (Monselise and Goldschmidt, 1982). This often reduces cumulative fruit value, because many "on"-year fruit may have much lower or even no market value, and production may be so low in the "off" year that net commercial production is compromised. Heavy "on"-year production trees may also result in substantial tree stress, reducing growth or breaking limbs, which may adversely affect future production.

Florida citrus producers have primarily relied on hedging, topping, or skirting to reduce cropping in orchards with excessive bearing (Stover et al., 2003), but increased production of larger fruit is often modest or negligible despite substantial cropload reductions (Hilgeman et al., 1964; Monselise and Zaphris, 1960; Morales and Davies, 2000; Stover et al., 2002a, 2003). In addition, pruning for cropload reduction is likely to delay canopy development in young orchards (Stover et al., 2002a). Use of 1-naphthaleneacetic acid (NAA) during early fruit development has been reported to reduce cropload and increase fruit size for various citrus cultivars in diverse growing regions (Brar et al., 1992; Farmahan, 1992; Gallasch, 1988; Greenberg et al., 1992; Hield et al., 1962; Iwahori, 1978; Ortolá et al., 1991; Sharma et al., 1993; Wheaton, 1981). Although NAA has been labeled for thinning of many Florida citrus varieties for more than 20 years, it has received little commercial use. Published reports on citrus thinning typically involved high spray volumes (2300–4600 L·ha^{-1}). At rates of 250 to 500 ppm NAA reported to thin Florida citrus, NAA sprays at these volumes would cost US $400 per 1600 ha for NAA alone at 2004 prices. Because annual spray material costs for fresh Florida citrus currently average US $500/ha (Stover et al., 2002b), high cost is likely to be a major limitation to more widespread NAA thinning of Florida citrus. We conducted six trials to determine whether lower spray volumes or inclusion of different surfactants would permit adequate thinning at much lower cost per hectare.

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Materials and Methods

Trees used in this study

The characteristics of orchards used in this study are listed in Table 1. All experiments were conducted using a randomized complete-block design. Except for orchards one and two, where two-tree experimental units were used (with data taken on individual trees), single trees were used as experimental units and six to eight trees were used per treatment in each orchard. Unsprayed buffer trees were used between all treated trees. All trees were microsprinkler irrigated and received routine care for commercial production of fresh Florida mandarins.

NAA applications

Treatments were applied during early physiological drop when mean fruitlet diameter was 8 to 16 mm. NAA was applied at 250 or 500 ppm NAA (Fruitfix K-Salt 200; AmVac Chemicals, Long Beach, Calif.) plus 0.05% surfactant (Activator™ a nonionic 80% alkylarylpolyoxyethylene glycols-isopropanol, Diamond-R, Lakeland, Fla.; Silwet L-77 and LI-700, Loveland Industries, Greeley, Colo.), using an airblast sprayer (Rear's Mfg. Co., Eugene, Ore.) at 560–2340 L·ha^{-1} as indicated. Spray volumes were adjusted by changing nozzle size and adjusting travel speed (but never exceeding 4 km·h^{-1}). Sprays were made during periods of negligible wind and good spray coverage was apparent with no spray runoff observed.

Harvest data

At commercial maturity, trees were strip-harvested and all fruit were passed through an optical sorter (Autoline, Reedley, Calif.), mounted on a trailer. The number of fruit per tree and diameter was determined for all fruit, recording all data separately for each tree. Weight and diameter were determined for each fruit in a 30–50 fruit subsample, and the

Table 1. Characteristics of orchards used in this study.

Orchard	Cultivar	Location	Rootstock[z]	Year planted	Spacing (m)	Soil type[y]	NAA application parameters: Date	Fruitlet diam (mm)	High temp (°C)	Estimated Volume Full dilute spray (L·ha^{-1})[x]	Harvest date
1	Sunburst	Sebring	Cleopatra	1991	7.69 × 4.62	Astatula	20 May 1998	9.8 (97% <15)	32.2	10000	17 Nov 1998
2	Sunburst	Howey-in-the-Hills	Sour orange	1988	9.24 × 1.54	Apopka	1 June 1998	16.4 (39% <15)	33.3	7000	18 Nov 1998
3	Murcott	Palm City	Cleopatra	1993	6.86 × 3.05	Waveland	18 May 1998	9.3 (99% <15)	28.2	5000	9 Mar 1999
4	Murcott	Palm City	Cleopatra	1993	6.86 × 3.05	Waveland	23 May 1999	8.3 (100% <15)	27.9	5000	28 Feb 2000
5	Murcott	Palm City	Cleopatra	1993	6.86 × 3.05	Waveland	4 June 1999	15.0 (62% <15)	30.2	5000	28 Feb 2000
6	Sunburst	Loxahatchee	Cleopatra	1989	7.69 × 3.85	Boca	18 May 1999	15.2 (57% <15)	30.5	7000	11 Nov 1999

[z]Cleopatra = Cleopatra mandarin, *Citrus reticulata*; Sour orange = *Citrus aurantium.*

[y]Predominant soil type in each experimental orchard is listed, but inclusions of related soil types were present in all orchards. All soil types listed are fine sand soils, but Waveland and Boca include hardpans close to the surface and require bedding to achieve drainage adequate for commercial citrus production.

[x]Volume estimates for full dilute spray of 10,000 L·ha^{-1} for a citrus orchard of mature canopy 4.6 m in height.

calculated regression in each trial (r^2 for these regressions ranged from 0.93 to 0.98) was used to convert diameter data to weight estimates. No data were collected on Brix, titratable acidity, or fruit color since no effects were observed when these data were collected in earlier experiments (data not shown).

Statistical analysis

The parameters analyzed for each tree were: number of fruit per tree, weight of fruit per tree, mean fruit weight, and cartons of fruit (28.2 L per carton, ≈21.6 kg) in economic size classes. Data were analyzed using the GLM procedure of SAS (SAS Institute, Cary, N.C.); mean separation was determined using Duncan's multiple range test (DMRT) at $P \leq 0.05$ and contrast analyses were conducted.

Results and Discussion

Comparing NAA treatments vs. nontreated controls

In contrast analyses of all NAA treatments vs. nonthinned controls, NAA thinning treatments decreased fruit number per tree and increased mean fruit size compared with nonthinned controls in all six experiments (Tables 2–7). However, using DMRT for mean separation, several individual treatments were not significantly different from the controls in two of the six experiments, both with 'Sunburst' (Tables 2 and 7). Considering all experiments, NAA treatment reduced fruit number per tree from 73% (Table 6) to as little as 12% (not significant; Table 7) compared with nonthinned controls. Mean fruit size increase in NAA-treated trees ranged from 8% (not significant; Table 6) to as much as 39% (Table 2).

In four of the experiments, contrast analyses of all NAA treatments vs. controls showed a significant reduction in kg of fruit per tree (Tables 3–6). Interestingly, the experiment in orchard 1 (Table 2), which displayed among the largest fruit size increases, was one of two experiments with no significant reduction in yield after NAA thinning. In this experiment, yield was numerically reduced by 4% to 14% when NAA treated trees were compared with nontreated controls. This was also the only orchard in this report in which nonthinned trees were clearly overcropped with some breakage of limbs through excessive fruit weight, and yet no breakage was observed on thinned trees (data not shown). The other experiment in which yield reduction was not significant after NAA thinning was in orchard 6 (Table 7), in which cropload (fruit per tree) reductions of 12% to 30% resulted in 9% to 16% increases in mean fruit weight. The two experiments with no cropload reduction were also the only experiments in which controls had high percentages of unmarketable small fruit (Tables 2 and 7).

Effect of NAA treatments on production of different fruit sizes varied widely among the six experiments. In three of the six experiments, contrast of all NAA treatments vs. controls showed a significant increase in production of fruit in the largest sizes classes (size 80–100, meaning 80–100 fruit are required to fill a 21.6-kg carton). In one additional experiment, the contrast P value was 0.09 (Table 3) for increase in production of size 80 to 100 fruit. All six experiments showed numeric increases in production of size 80 to 100 fruit, ranging from 29% (not significant; Tables 6 and 7) to 71% (Table 2) more than the respective nonthinned control in each experiment. In all six experiments, NAA induced reductions in cartons of the smallest fruit sizes (210 fruit per 21.6-kg carton or smaller size), and in five of six experiments (Tables 2–6), the reduction extended to medium-sized fruit (150 fruit per 21.6-kg carton). Contrast between nonthinned controls and all NAA treatments showed an increase of production in size 80 to 120 (36% increase) and size 80 to 150 (17% increase) fruit in one experiment (Table 2),

Table 2. Effect of spray volume and surfactant on cropping parameters of 'Sunburst'/Cleopatra mandarin at different spray volumes and with different surfactant after NAA thinning: Sebring, Fla. 1997. All NAA applications were at 500 ppm in spray solution. All surfactants (nonionic was Diamond-R Activator 80% alkylarylpolyoxyethylene glycols-isopropanol, Diamond-R, Lakeland, Fla.; Silwet L-77, Greeley, Colo.) were used at 0.5% (v/v).

Treatment	Fruit per tree	Fruit size (g)	Yield/ tree (kg)	Cartons[y] per tree at indicated fruit sizes by numbers of fruit/carton: Smaller	210s	176s	150s	120s	100s	80s	80–150	80–120	80–100
1 Control	1939 a[z]	115 d	221 a	2.64 a	0.69 a	1.76 a	1.99 a	3.03 a	1.07 c	0.70 b	6.8 a	4.8 b	1.8 c
2 Nonionic, 610 L·ha^{-1}	1626 ab	134 c	212 a	1.44 b	0.46 b	1.51 ab	1.71 ab	3.53 a	1.57 bc	0.83 b	7.6 a	5.9 ab	2.4 bc
3 Nonionic, 1170 L·ha^{-1}	1320 b	150 ab	196 a	0.58 b	0.28 bc	0.93 c	1.45 bc	3.78 a	2.00 ab	1.00 ab	8.2 a	6.8 a	3.0 ab
4 Nonionic, 2340 L·ha^{-1}	1232 b	161 a	191 a	0.61 b	0.21 c	0.69 c	1.07 c	3.25 a	2.47 a	1.44 a	8.2 a	7.2 a	3.9 a
5 Silwet L-77, 610 L·ha^{-1}	1358 b	144 bc	193 a	0.80 b	0.34 bc	1.05 bc	1.53 a-c	3.47 a	1.85 b	0.90 ab	7.8 a	6.2 ab	2.8 bc
Contrast analyses													
All NAA vs. control (1 vs. 2, 3, 4, and 5)	0.0041	0.0001	0.1842	0.0006	0.0003	0.0014	0.0057	0.0884	0.0004	0.1038	0.0785	0.007	0.0044
610 L·ha^{-1} vs. 1170 L·ha^{-1} (2 vs. 3)	0.1504	0.0189	0.4601	0.1068	0.0795	0.0208	0.2418	0.45	0.0974	0.5046	0.4562	0.2298	0.2112
1170 L·ha^{-1} vs. 2340 L·ha^{-1} (3 vs. 4)	0.6632	0.099	0.7926	0.9563	0.4356	0.2999	0.0886	0.1292	0.0716	0.0915	0.9939	0.572	0.0644
Nonionic vs. Silwet (2 vs. 5)	0.2034	0.1121	0.3859	0.2147	0.2212	0.0554	0.4139	0.8534	0.2652	0.7556	0.8798	0.6685	0.4454

[z]Means within a column not followed by the same letter were found significantly different by DMRT at $P \leq 0.05$.

[y]28.2 L per carton estimated at 21.6 kg.

Table 3. Effect of spray volume and NAA concentration on cropping parameters of 'Sunburst'/Sour Orange after NAA thinning: Howey-in-the-Hills, Fla. 1997. Values for NAA are ppm in spray solution. Nonionic surfactant (Diamond-R Activator 80% alkylarylpolyoxyethylene glycols-isopropanol, Diamond-R, Lakeland, Fla.) was used at 0.5% (v/v) in all sprays.

Treatment	Fruit per tree	Fruit size (g)	Yield/ tree (kg)	Cartons[y] per tree at indicated fruit sizes by numbers of fruit/carton									
				Smaller	210s	176s	150s	120s	100s	80s	80–150	80–120	80–100
1 Control	654 a[z]	151 c	99 a	0.26 a	0.13 a	0.46 a	0.78 a	1.86 a	0.89 a	0.59 a	4.1 a	3.3 a	1.5 a
2 500 ppm NAA, 1120 L·ha^{-1}	389 b	188 ab	73 ab	0.02 b	0.02 b	0.08 b	0.21 b	1.10 b	1.44 a	0.57 a	3.6 a	3.4 a	2.3 a
3 500 ppm NAA, 2240 L·ha^{-1}	310 b	198 a	61 b	0.01 b	0.01 b	0.02 b	0.09 b	0.72 b	1.32 a	0.90 a	3.3 a	2.9 a	2.2 a
4 250 ppm NAA, 2240 L·ha^{-1}	377 b	183 b	69 b	0.01 b	0.02 b	0.07 b	0.18 b	1.09 b	1.50 a	0.80 a	3.0 a	3.1 a	2.0 a
Contrast analyses													
All NAA vs. control (1 vs. 2, 3, and 4)	0.0004	0.0001	0.0127	0.0001	0.0001	0.0001	0.0001	0.0002	0.0465	0.5999	0.1408	0.7052	0.0884
1120 L·ha^{-1} vs. 2240 L·ha^{-1} (2 vs. 3)	0.2594	0.0856	0.3554	0.8887	0.4683	0.3195	0.2289	0.0745	0.5389	0.6703	0.3867	0.4537	0.8499
250 ppm vs. 500 ppm (3 vs. 4)	0.8563	0.2956	0.7225	0.7271	1.000	0.7764	0.7025	0.9788	0.8631	0.3195	0.6874	0.6539	0.5593

[z]Means within a column not followed by the same letter were found significantly different by DMRT at $P \leq 0.05$.
[y]28.2 L per carton estimated at 21.6 kg.

Table 4. Effect of surfactant, spray volume, and NAA concentration on cropping parameters of 'Murcott'/Cleopatra mandarin after NAA thinning: Palm City, Fla. 1998–1999. Values for NAA are ppm in spray solution. All surfactants (nonionic was Diamond-R Activator 80% alkylarylpolyoxyethylene glycols-isopropanol, Diamond-R, Lakeland, Fla.; Silwet L-77, Loveland Industries, Greeley, Colo.) were used at 0.5% (v/v).

Treatment	Fruit per tree	Fruit size (g)	Yield/ tree (kg)	Cartons[y] per tree at indicated fruit sizes by numbers of fruit/carton								
				Smaller	176	150	120	100	80	80–150	80–120	80–100
1 Control	275 a[z]	147 c	39 a	0.18 a	0.22 a	0.55 a	0.66a	0.17 b	0.26 a	1.6 a	1.1 a	0.4 b
2 500 ppm NAA + nonionic, 610 L·ha^{-1}	172 b	171 b	29 b	0.03 b	0.05 b	0.19 bc	0.57 a	0.38 a	0.25 a	1.4 a	1.2 a	0.6 ab
3 500 ppm NAA + nonionic, 1170 L·ha^{-1}	192 b	167 b	32 ab	0.06 b	0.07 b	0.27 b	0.58 a	0.37 a	0.25 a	1.5 a	1.2 a	0.6 ab
4 500 ppm NAA + nonionic, 2340 L·ha^{-1}	154 b	173 b	26 b	0.03 b	0.05 b	0.21 bc	0.50 ab	0.30 ab	0.22 a	1.2 a	1.0 a	0.5 ab
5 250 ppm NAA + nonionic, 2340 L·ha^{-1}	152 b	171 b	26 b	0.05 b	0.04 b	0.16 bc	0.50 ab	0.34 a	0.21 a	1.2 a	1.0 a	0.6 ab
6 500 ppm NAA + Silwet, 1170 L·ha^{-1}	128 b	188 a	24 b	0.01 b	0.02 b	0.09 c	0.36 b	0.39 a	0.35 a	1.2 a	1.1 a	0.7 a
Contrast analyses												
All NAA vs. control (1 vs. 2, 3, 4, 5, and 6)	0.0001	0.0001	0.0013	0.0001	0.0001	0.0001	0.0459	0.001	0.9575	0.0426	0.824	0.0449
610 L·ha^{-1} vs. 1170 L·ha^{-1} (2 vs. 3)	0.4823	0.4649	0.6125	0.3816	0.4894	0.2234	0.8953	0.8389	0.9787	0.7196	0.9868	0.8928
1170 L·ha^{-1} vs. 2340 L·ha^{-1} (3 vs. 4)	0.2019	0.2946	0.2172	0.3318	0.3964	0.3678	0.3807	0.2876	0.7937	0.2632	0.3174	0.4379
500 ppm 1170 L·ha^{-1} vs. 250 ppm 2340 L·ha^{-1} (3 vs. 5)	0.1810	0.5352	0.1880	0.6975	0.3234	0.0824	0.4032	0.6313	0.6015	0.2121	0.396	0.5627
Nonionic vs. Silwet (3 vs. 6)	0.0342	0.0021	0.0924	0.1117	0.075	0.0057	0.025	0.8001	0.1287	0.1648	0.5395	0.3071

[z]Means within a column not followed by the same letter were found significantly different by DMRT at $P \leq 0.05$.
[y]28.2 L per carton estimated at 21.6 kg.

no effect in two experiments (Tables 3 and 7), and significant reductions in cumulative marketable sizes in three experiments (Table 4, size 80–150 reduced by 20%; Table 5, size 80–120 reduced by 25% and size 80–150 reduced by 38%; Table 6, size 80–120 reduced by 34% and size 80–150 reduced by 45%). It may be noteworthy that these NAA-induced reductions in production of marketable fruit occurred in the three experiments on 'Murcott', which tend to produce somewhat larger fruit than 'Sunburst'.

Effects of spray volume and NAA rate

All six experiments included comparisons between treatments in which total NAA applied per hectare was varied through changing spray volume at the same NAA concentration or changing NAA concentration at the same spray volume. DMRT indicated only two experiments in which differences between these treatments were significant at $P \leq 0.05$, despite two- to fourfold differences in the amount of NAA applied per hectare among these treatments. In orchard one 'Sunburst' (Table 2), there was a marked linear increase in cropload reduction and mean fruit size increase as spray volume and associated g NAA applied per hectare increased. In orchard five 'Murcott' (Table 6), doubling NAA use per hectare by using 500 vs. 250 ppm at the same spray volume increased both cropload reduction (from 63% to 73% thinning) and mean fruit size (from 178 to 197 g), although both treatments were somewhat excessive in cropload reduction. Contrast analyses between NAA treatments suggested an effect of the amount of NAA applied per hectare in only one other experiment: in orchard two 'Sunburst' (Table 3), 1120 L·ha^{-1} produced a mean fruit size smaller than 2240 L·ha^{-1} (188 vs. 198 g), but the contrast was only significant at P = 0.09. Overall, the most remarkable outcome was that in most experiments, substantial reductions in fruit number per tree or increases in mean fruit size occurred even at moderate levels of NAA per hectare using spray volumes of 600 to 1200 L·ha^{-1}.

Effect of surfactant type

There were no treatments in which surfactant was not included with NAA, because previous experience in Florida demonstrated the value of including surfactant for NAA-thinning of citrus (Adair Wheaton, personal communication, 1996), Florida extension recommendations on NAA thinning recommended inclusion of surfactant (e.g., Davies et al., 1998), and virtually all published NAA thinning trials on citrus noted inclusion of surfactant, whereas none directly tested their influence on NAA thinning. The effect of Activator nonionic vs. Silwet L-77 surfactants on NAA thinning was compared in four experiments and the additional surfactant LI-700 was included in two of these experiments. Inclusion of Silwet L-77 vs. nonionic surfactant in the NAA spray resulted in greater cropload reduction in two of the four experiments (63% vs. 46%, Table 4, significant by contrast analysis but not DMRT; 53% vs. 30%, Table 6), both in 'Murcott' but in 2 separate years. In 1 year (Table 4), difference in cropload reduction from inclusion of Silwet L-77 vs. nonionic surfactant also translated into a significant increase in mean fruit size (188 g vs. 167 g) but not an increase in production of fruit in the size 80 to 100 range. In the next year (Table 6), mean fruit size was numerically lower in the trees

Table 5. Effect of spray volume and NAA concentration on cropping parameters of 'Murcott'/Cleopatra mandarin after NAA thinning: Palm City, Fla. 1999–2000. Values for NAA are ppm in spray solution. Silwet L-77 surfactant (Loveland Industries, Greeley, Colo.) was used at 0.5% (v/v) in all sprays.

	Treatment	Fruit per tree	Fruit size (g)	Yield/ tree (kg)	Cartons[y] per tree at indicated fruit sizes by numbers of fruit/carton								
					Smaller	176	150	120	100	80	80–150	80–120	80–100
1	Control	836 a[z]	161 b	134 a	0.09 a	0.69 a	1.35 a	2.75 a	1.21 b	0.15 a	5.45 a	4.1 a	1.4 b
2	250 ppm NAA, 560 L·ha^{-1}	430 b	180 a	77 b	0.02 b	0.10 b	0.30 b	1.29 b	1.64 a	0.24 a	3.47 b	3.2 b	1.9 a
3	250 ppm NAA, 1120 L·ha^{-1}	387 b	181 a	70 b	0.02 b	0.07 b	0.24 b	1.17 b	1.49 ab	0.25 a	3.15 b	2.9 b	1.7 ab
4	250 ppm NAA, 2340 L·ha^{-1}	446 b	179 a	80 b	0.02 b	0.12 b	0.34 b	1.33 b	1.58 a	0.32 a	3.57 b	3.2 b	1.9 a
5	500 ppm NAA, 1120 L·ha^{-1}	412 b	178 a	74 b	0.03 b	0.13 b	0.31 b	1.20 b	1.44 ab	0.30 a	3.25 b	2.9 b	1.7 ab
	Contrast analyses												
	All NAA vs. control (1 vs. 2, 3, 4, and 5)	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0115	0.0487	0.0001	0.0001	0.0099
	560 L·ha^{-1} vs. 1120 L·ha^{-1} (2 vs. 3)	0.298	0.8273	0.2565	0.6717	0.781	0.538	0.4503	0.3128	0.8102	0.2216	0.249	0.5144
	1120 L·ha^{-1} vs. 2340 L·ha^{-1} (3 vs. 4)	0.1609	0.5352	0.1263	0.8107	0.5532	0.3108	0.3123	0.5547	0.4062	0.1093	0.1538	0.4504
	250 ppm vs. 500 ppm NAA (3 vs. 5)	0.413	0.7059	0.3184	0.5581	0.8757	0.7258	0.4308	0.3501	0.8055	0.2134	0.1945	0.435

[z]Means within a column not followed by the same letter were found significantly different by DMRT at $P \leq 0.05$.
[y]28.2 L per carton estimated at 21.6 kg.

Table 6. Effect of surfactant and NAA concentration on cropping parameters of 'Murcott'/Cleopatra mandarin after NAA thinning: Palm City, Fla. 1999–2000. Values for NAA are ppm in spray solution. All surfactants (nonionic was Diamond-R Activator 80% alkylarylpolyoxyethylene glycols-isopropanol, Diamond-R, Lakeland, Fla.; Silwet L-77 and LI-700, Loveland Industries, Greeley, Colo.) were used at 0.5% (v/v). All sprays were applied at 1870 L·ha^{-1}.

	Treatment	Fruit per tree	Fruit size (g)	Yield/ tree (kg)	Cartons[y] per tree at indicated fruit sizes by numbers of fruit/carton								
					Smaller	176	150	120	100	80	80–150	80–120	80–100
1	Control	787 a[z]	160 d	126 a	0.11 a	0.65 a	1.24 a	2.53 a	1.22 a-c	0.10 b	5.1 a	3.9 a	1.3 b
2	250 ppm NAA+ LI-700	486 b	173 c	84 b	0.04 b	0.21 b	0.50 b	1.5 b	1.44 ab	0.20 b	3.6 b	3.1 ab	1.6 ab
3	250 ppm NAA+ nonionic	429 b	183 b	79 b	0.02 b	0.12 bc	0.28 c	1.08 c	1.69 a	0.47 a	3.5 b	3.2 ab	2.2 a
4	250 ppm NAA + Silwet	291 c	178 bc	52 c	0.02 b	0.12 bc	0.21 c	0.78 cd	1.04 bc	0.24 b	2.3 c	2.1 c	1.3 b
5	500 ppm NAA + Silwet	213 d	197 a	42 c	0.01 b	0.03 c	0.10 c	0.37 d	0.86 c	0.57 a	1.9 c	1.8 c	1.4 b
	Contrast analyses												
	All NAA vs. control (1 vs. 2, 3, 4, and 5)	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.7255	0.0005	0.0001	0.0002	0.1244
	250 vs. 500 ppm NAA (4 vs. 5)	0.1656	0.0001	0.2881	0.4068	0.0949	0.235	0.0550	0.4515	0.0012	0.3841	0.5133	0.5805
	LI-700 vs. Silwet (2 vs. 4)	0.0016	0.2016	0.0023	0.2883	0.0949	0.0035	0.0016	0.0860	0.6554	0.0028	0.0087	0.1966
	Nonionic vs. Silwet (3 vs. 4)	0.0188	0.2052	0.0087	1.000	0.9266	0.446	0.1554	0.0083	0.0177	0.0061	0.005	0.0038
	LI-700 vs. nonionic (2 vs. 3)	0.3092	0.015	0.5824	0.2883	0.0793	0.0215	0.0480	0.2899	0.0062	0.7541	0.8156	0.0735

[z]Means within a column not followed by the same letter were found significantly different by DMRT at $P \leq 0.05$.
[y]28.2 L per carton estimated at 21.6 kg.

Table 7. Effect of surfactant, NAA concentration, and spray volume on cropping parameters of 'Sunburst'/Cleopatra mandarin after NAA thinning: Loxahatchee, Fla. 1999. Values for NAA are ppm in spray solution. All surfactants (nonionic was Diamond-R Activator, 80% alkylarylpolyoxyethylene glycols-isopropanol, Diamond-R, Lakeland, Fla.; Silwet L-77 and LI-700, Loveland Industries, Greeley, Colo.) were used at 0.5% (v/v).

	Treatment	Fruit per tree	Fruit size (g)	Yield/ tree (kg)	Cartons[y] per tree at indicated fruit sizes by numbers of fruit/carton									
					Smaller	210s	176s	150s	120s	100s	80s	80–150	80–120	80–100
1	Control	1221a[z]	106 b	130 a	1.4 a	0.87 a	1.20 a	1.59 a	1.21 a	0.36 a	0.28 a	3.4 a	1.9 a	0.6 a
2	NAA 500 ppm + LI-700, 1680 L·ha^{-1}	1027 ab	118 ab	121 a	0.99 ab	0.65 b	0.96 a-c	1.52 ab	1.56 a	0.53 a	0.30 a	3.9 a	2.4 a	0.8 a
3	NAA 500 ppm + nonionic, 1680 L·ha^{-1}	865 b	124 a	108 a	0.82 b	0.64 b	1.00 ab	1.60 a	1.55 a	0.51 a	0.21 a	3.9 a	2.3 a	0.7 a
4	NAA 500 ppm + Silwet, 1680 L·ha^{-1}	781 b	120 ab	93 a	0.70 b	0.47 b	0.75 bc	1.18 ab	1.35 a	0.58 a	0.58a	3.7 a	2.5 a	1.2 a
5	NAA 500 ppm + Silwet, 1120 L·ha^{-1}	949 b	119 ab	111 a	0.66 b	0.46 b	0.72 c	1.13 b	1.22 a	0.42 a	0.24a	3.0 a	1.9 a	0.7 a
6	NAA 250 ppm + Silwet, 1680 L·ha^{-1}	1072 ab	116 ab	124 a	0.87 b	0.57 b	0.78 bc	1.30 ab	1.51 a	0.63 a	0.17 a	3.6 a	2.3 a	0.8 a
	Contrast analyses													
	All NAA vs. control (1 vs. 2, 3, 4, 5, and 6)	0.0129	0.0053	0.1684	0.0029	0.0006	0.0004	0.1071	0.2328	0.1862	0.9227	0.7433	0.3321	0.5156
	250 vs. 500 ppm NAA (4 vs. 6)	0.0430	0.5108	0.0740	0.1692	0.0616	0.0492	0.0485	0.1711	0.5133	0.8002	0.1900	0.3508	0.6496
	LI-700 vs. Silwet (2 vs. 4)	0.0833	0.7978	0.1020	0.5058	0.0725	0.0242	0.02	0.1857	0.5948	0.9025	0.2140	0.4801	0.8818
	Nonionic vs. Silwet (3 vs. 4)	0.5448	0.4570	0.3920	0.8857	0.8835	0.8301	0.7772	0.6155	0.3344	0.1907	0.3214	0.2607	0.1884
	LI-700 vs. nonioinic (2 vs. 3)	0.2452	0.3201	0.4164	0.6008	0.0965	0.0387	0.0373	0.4021	0.6597	0.1544	0.7943	0.6681	0.2406

[z]Means within a column not followed by the same letter were found significantly different by DMRT at $P \leq 0.05$.
[y]28.2 L per carton estimated at 21.6 kg.

that included Silwet in the thinning spray, although not statistically significant, but production of larger fruit was significantly reduced (cartons per tree of size 80–100 fruit was 1.3 for Silwet vs. 2.2 for nonionic surfactant). No statistically significant differences were seen between Silwet and nonionic surfactant-containing treatments in the two 'Sunburst' experiments. In the two experiments that included LI-700, inclusion of this surfactant resulted in less NAA thinning than inclusion of Silwet (Tables 6 and 7), although production of the largest fruit sizes was not influenced. Use of nonionic surfactant in the NAA solution resulted in somewhat greater mean fruit size than use of LI-700 in one experiment (183 vs. 173 g; Table 6).

Practical significance. Based on these findings, current recommendations for NAA thinning of Florida mandarins are use of spray volume of ≈1100 to 1400 $L \cdot ha^{-1}$ on mature trees with proportionally lower volume on smaller trees (Stover et al., 2001). It is clear that higher NAA rate per hectare sometimes increases thinning and fruit size enhancement but may also result in excessive thinning. Although cost of NAA application remains high, use of lower rates appears to be a prudent approach.

These data appear to support use of a nonionic surfactant rather than other tested surfactants in NAA thinning of Florida mandarins. Inclusion with NAA of organosilicone surfactant sometimes increased thinning effect and mean fruit size when compared with nonionic surfactant, but the instances in which production of larger fruit sizes was reduced or unaffected despite greater thinning make use of an organosilicone surfactant less attractive. However, it is possible that use of even lower rates of NAA with the organosilicone may give adequate thinning with increased production of larger fruit. Interestingly, there is a recent report that Silwet L-77 transiently suppresses photosynthesis when applied to citrus (Orbovic et al., 2001), and this phenomenon may explain the results reported here.

It has been reported that the greatest benefit of thinning Florida mandarins is often observed the following year from reducing alternate bearing rather than from higher value within the year of thinning (Stover et al., 2002a), so it is unfortunate that return cropping data were not collected for the experiments reported here. Because experience with NAA thinning of Florida citrus is limited, it is only recommended where the disadvantages of overcropping are perceived to substantially outweigh the potential losses from overthinning.

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