viruses for higher density plantings. Proc. Fla. State Hort. Soc. 91:46-50.
4. Hutton, R. J. and B. R. Cullis. 1982. Elevated productivity from close planted dwarf orange plantings. Compact fruit tree 15:182-196.
5. Koo, R. C. J. and R. P. Muraro. 1982. Effect of tree spacings on fruit production and net return of Pineapple oranges. Proc. Fla. State Hort. Soc. 95:29-33.
6. Phillips, R. L. 1978. Tree size control. Hedging and topping citrus in high density plantings. Proc. Fla. State Hort. Soc. 91:43-46.
7. Wheaton, T. A., W. S. Castle, D. P. H. Tucker, and J. D. Whitney. 1978. Higher density plantings for Florida citrus-concepts. Proc. Fla. State Hort. Soc. 91:27-33.
8. Whitney, J. D. and S. L. Hedden. 1978. Equipment and methods for producing and harvesting citrus in higher density plantings. Proc. Fla. State Hort. Soc. 91:52-55.

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ORANGE REMOVAL WITH TRUNK SHAKERS[1,2,3]

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Abstract. **'Hamlin' and 'Valencia' oranges** [Citrus sinensis **(L.) Osb.] were removed with trunk shakers for the past 4 seasons in replicated field experiments near LaBelle. Two modes of conventional trunk shaking were compared with two modes of linear trunk shaking, with and without abscission chemicals. Fruit removal efficiency and yield data were collected on individual trees. Handpicked checks were included for yield comparisons. In 'Hamlin' oranges, neither abscission chemicals or shakers affected fruit yields. Abscission chemicals increased the fruit removal efficiency of the shakers an average of 23 percentage points from 65 to 88%. In 'Valencia' oranges, fruit yields of trees with and without abscission chemicals were 3.1 and 3.3 boxes/tree, respectively. The fruit yield averages of the shaken trees and handpicked trees were 3.1 and 3.5 boxes/tree, respectively. Abscission chemicals increased fruit removal efficiency of the shakers an average of 14 percentage points from 76 to 90%.**

Mass removal of various deciduous fruits and nuts by means of trunk shakers has been a reality for many years (1). However, application of this technique to harvesting citrus has been difficult because of poor fruit removal, bark damage, and lack of adequate tree trunk area for shaker clamp attachment in a large percentage of Florida groves (2). Previous citrus harvesting experiments with a multi-directional trunk shaker achieved 98% fruit removal in 'Queen' oranges and 86% removal in 'Valencia' oranges with the abscission chemical 5-chloro-3-methyl-4-nitro-IH-pyrazole (Release) (5). Subsequent fruit yields were reduced 15% from the effects of shaker action and abscission chemical. However, the potential for shaking a tree with a single attachment point, the advent of improved abscission chemicals for fruit loosening, and an increase in tree numbers of a size and shape adaptable for trunk shaking make this fruit removal method look increasingly attractive.

The objectives of the experiments described in this paper were to determine fruit removal efficiencies and subsequent yield effects of 4 modes of trunk shaking.

Methods and Equipment

Two identical harvest experiments were designed to collect performance data on trunk shaking 'Hamlin' oranges and 'Valencia' oranges at a location in South Florida. Initially, trees in each experiment were 15 and 8 yr old, respectively, uniform in size and density, with adequate trunk height for grasping with the shakers. These trees were representative of many younger plantings on flatwoods soils in South Florida. Each experiment was a randomized, split-plot design which included 60 trees and 6 replications. One of the two 5-tree main plots in each replication was randomly assigned to be sprayed with abscission chemicals before harvest while the other main plot was not sprayed. Within each main plot, 4 shaker and 1 handpicked check treatment were randomly assigned to each tree.

The trunk shaker and check treatments were as follows:

1. Linear shaker with 133 lb. of unbalanced mass rotating at 6 revolutions/sec with 5.5 inches eccentricity and 1010 lb. of total mass excluding the unbalanced mass.
2. Linear shaker with 200 lb. of unbalanced mass rotating at 5 revolutions/sec with 5.5 inches eccentricity and 600 lb. total mass excluding the unbalanced mass.
3. Multi-directional shaker with two 68 lb. unbalanced masses rotating at 12 revolutions/sec with 4.5 inches eccentricity rotating in opposite directions at slightly different speeds and 992 lb. of total mass, excluding the unbalanced masses.
4. Same shaker as 3 except both eccentric masses rotated in the same direction.
5. Handpicked (check).

Treatments 1 and 2 were conducted with the linear shaker (Fig. 1) with theoretical shaking amplitudes of 0.7 and 1.8 inches, respectively, under no-load conditions. Treatments 3 and 4 were conducted with a commercially available multi-directional shaker with a theoretical shaking amplitude of 0.6 inches (Fig. 1) (3).

Four to 5 days prior to harvest, main plots receiving abscission chemicals were treated in an amount dependent upon fruit and tree condition and cultivar. The normal abscission mixture was 75 ppm Release, 1.5 ppm cycloheximide (Acti-aid), and 0.1% Ortho X-77 surfactant applied at the rate of 4 gal of mix per tree.

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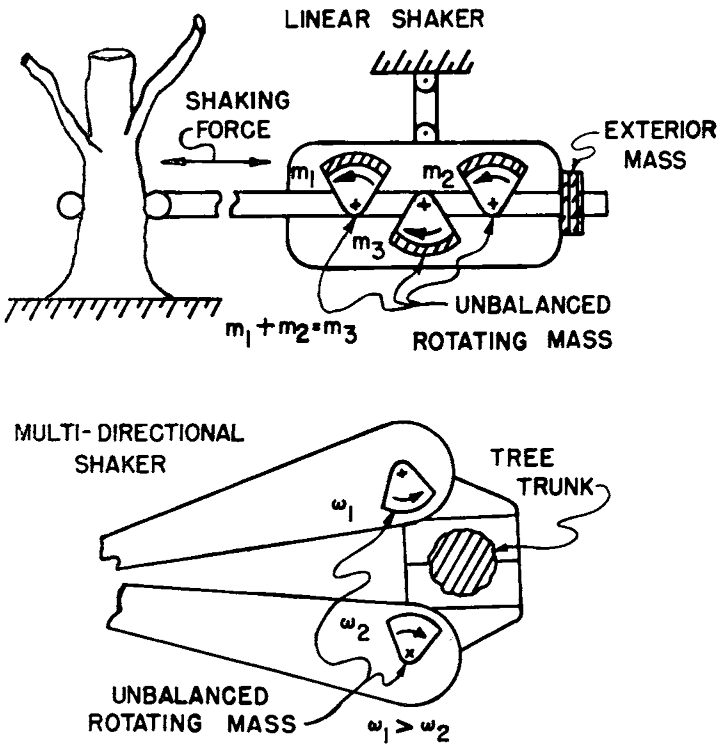

Fig. 1. Schematic diagram of the linear and multi-directional trunk shakers used in these experiments. Shown are mass configurations for treatments 1 and 3. Treatment 2 had added rotating mass and no exterior mass. Treatment 4 had both masses rotating in same direction.

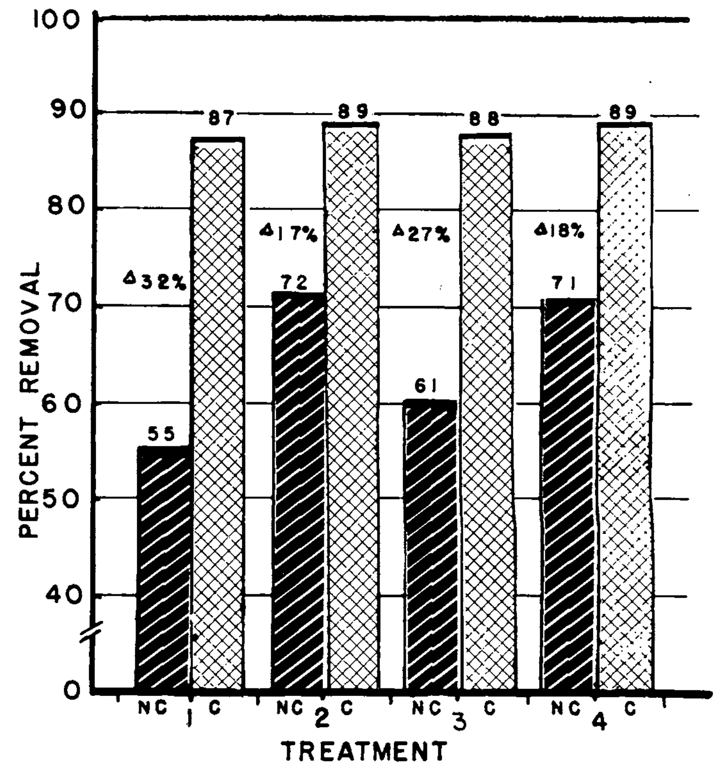

Fig. 2. Trunk shaker removal of 'Hamlin' oranges with (C) and without (NC) abscission chemical. Average of 1981-84 data. Treatments 1 and 2 are linear shaking with 133 lb. and 200 lb. of unbalanced mass, respectively. Treatments 3 and 4 were multi-directional shaking with unbalanced masses rotating in opposite directions and same direction, respectively.

The shaker treatment trees were shaken for 7 sec. Data were collected on fruit removal and yield for 4 seasons (1981-84). Bark damage was observed as each plot was harvested. Trunk circumference at 8 inches above ground level was measured on the trunk shaker treatment trees during the 1982-84 seasons as well as shaker clamp height above ground level.

All data were statistically analyzed and significant differences refer to F values at the 0.05 level. Fruit yield data of all 5 treatments were included in the statistical analysis. Since fruit removal efficiencies of treatment 5 (handpicked check) were 100%, these data were not included in the statistical analysis. Fruit harvesting efficiency (6) was calculated to determine treatment effect on subsequent yields and total fruit recovery that could be expected.

Results and Discussion

'Hamlin' oranges

Fruit removal. Fruit removal data of the 4 shaker treatments for all 4 seasons are presented in Fig. 2. In descending order of magnitude the removal efficiencies of the shaker treatment were 2, 4, 3, and 1. Fruit removal efficiency was significantly greater each season with the abscission chemicals. The increases for treatments 1, 2, 3, and 4 were 32, 17, 27, and 18 percentage points, respectively. The experiment average was 65% without abscission chemicals and 88% with abscission chemicals or a 23 percentage point increase. In general, the difference in removal efficiencies between treatments with abscission chemicals was small. The removal efficiencies of all shaker treatments without abscission chemicals increased slightly from 1981 to 1982 and then decreased somewhat in 1983 and 1984 with the greatest reduction in removal efficiency occurring in treatments 1 and 3.

This decrease in removal efficiency for the 1983 season might be explained by the reduction in trunk amplitudes during shaking from 1.0 inch (1982) to 0.75 inch (1983). This was thought to be due in part to the fact that in 1983 the ground was thoroughly saturated with water by heavy rains just prior to harvest, and may have increased the trunk resistance to movement. Removal efficiencies for all shaker treatments with abscission chemicals were highest in the 1981 season and lowest in the 1984 season. The lower removal efficiencies in the last 3 seasons were due to 1) rainy and cool weather decreasing the effectiveness of the abscission chemicals, 2) lesser amounts of chemicals were applied as compared to the 1981 season because of freeze damage to the trees in 1982 and 1983, and 3) reduced trunk amplitude in 1983 as described above. Averaged over the abscission chemical effects, fruit removal efficiencies of the shaker treatments were significantly different for all 3 seasons. Treatment 1 was lowest and treatment 2 was the highest.

Fruit yields. The fruit yield data of all treatments are shown in Fig. 3. In 1981, the first year of harvest, the yields of each plot were very uniform. The chemical and/or shaker effects on the fruit yielding potential of the trees appeared in subsequent seasons (1982, 83, 84). The chemical effect was not significant for 1982, 1983, or 1984, although in 1983 and 1984 the mean yields of the chemically treated trees were higher than those without chemical.

The shaker effect on fruit yields harvested in 1982 and 1984 was not significant but was in 1983. However, when averaged over the 4 seasons of the experiment, there was no appreciable difference in yield due to shaker or chemical treatments. This can be more clearly seen in Table 1 where the average yield for the last 3 yr (1982-84) was divided by the initial yield (1981).

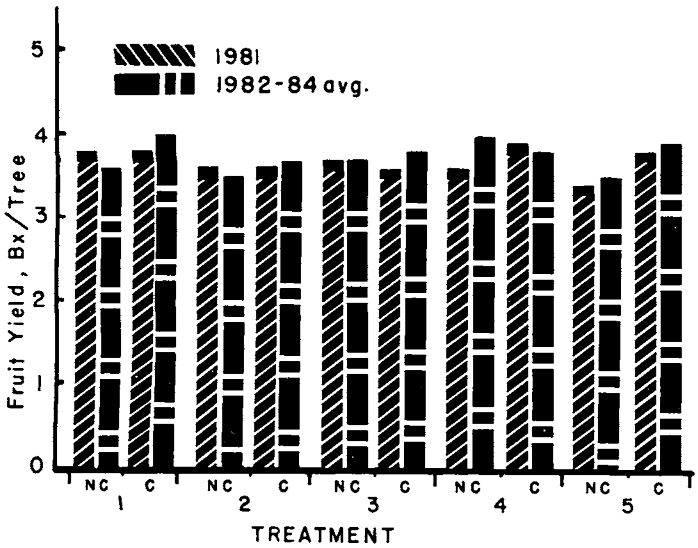

Fig. 3. 'Hamlin' orange yields for 4 trunk shaker harvest treatments and handpicked check with (C) and without (NC) abscission chemical. Treatments 1 and 2 are linear shaking with 133 lb. and 200 lb. unbalanced rotating mass, respectively. Treatments 3 and 4 are multi-directional shaking with unbalanced mass rotating in opposite directions and same direction, respectively. Treatment 5 was handpicked.

Harvesting efficiency (6) based on the mean average yield and removal figures over the entire experiment (Table 1) show that treatments 1, 2 and 3 with abscission chemical all had harvest efficiencies of 95%. Treatment 1 without abscission chemical was the least efficient at 52%.

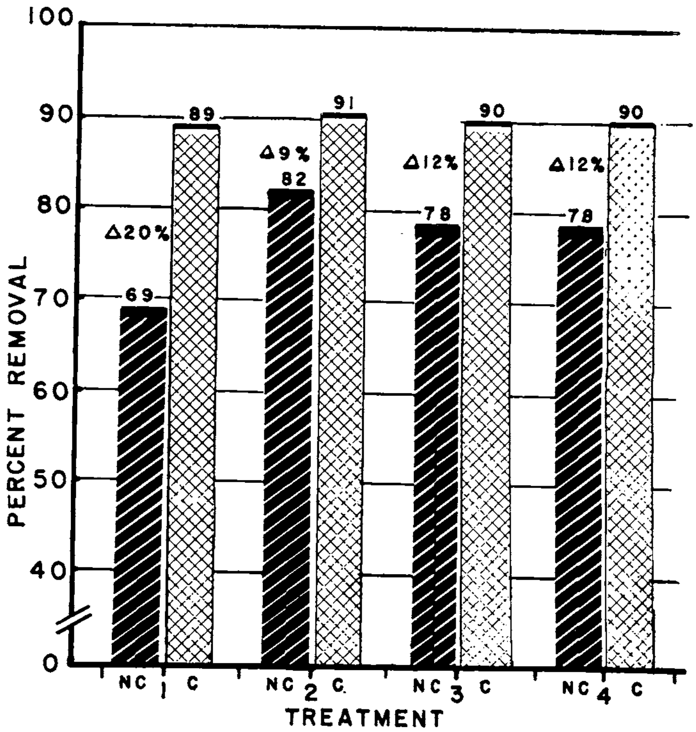

Fig. 4. Average trunk shaker removal of 'Valencia' oranges (4 yr avg.) with (C) and without (NC) abscission chemical. Treatments 1 and 2 are linear shaking with 133 lb. and 200 lb. unbalanced rotating mass, respectively. Treatments 3 and 4 are multi-directional shaking with unbalanced masses rotating in opposite directions and same direction, respectively.

'Valencia' oranges

Fruit removal. Fruit removal data for all shaker treatments are presented in Fig. 4. Abscission chemicals increased removal efficiency significantly in all four harvest seasons, the average increase being 13 percentage points. This increase, however, was not as great as the increase of 24 percentage points realized in 'Hamlin' oranges. Fruit loosening by the abscission chemicals was lowest in the second (1982) season, partially because the fruit was in a non-responsive period (4) to the chemical when harvested. The effect of the shaker treatment on fruit removal efficiency was significant only for the 1982 season.

As with the 'Hamlin' experiment, treatments 1 and 2 generally gave the lowest and highest removal efficiencies, respectively. Fruit removal efficiencies for the 4 shaker treatments were within one percentage point of each other in the abscission chemical treatments when averaged over the experiment duration. The linear shaker in treatment 2 produced the highest removal efficiency, with and without the use of abscission chemical.

Fruit yields. The effect of abscission chemicals on subsequent fruit yields was not significant for the last 3 yr of the experiment which would be affected by the previous years' chemical application (Fig. 5).

The effect of shaker treatment was significant with an overall average reduction in fruit yield of 14% between the shaker harvested trees and handpicked trees. When considering fruit removal and chemical effects on yield together (Table 2), the total harvest efficiency among the shaker treatments was highest for treatment 1 with abscission chemical (91%) and lowest with treatment 3 without abscission chemical (69%).

Table 1. 'Hamlin' orange yield and harvest efficiency.

Treatment		Yield (boxes/tree)				
Shaker[z]	Chem.[y]	1981	1982-84	82-84 / 81 (Y)	Removal (%) (R) 1981-83 avg.	Harvesting Efficiency (R x Y)
1	NC	3.8	3.6	.95	55	52
1	C	3.8	4.0	1.05	90	95
2	NC	3.6	3.5	.95	74	95
2	C	3.6	3.7	1.03	92	95
3	NC	3.7	3.7	1.0	61	61
3	C	3.6	3.8	1.05	90	95
4	NC	3.6	4.0	1.11	70	78
4	C	3.9	3.8	.97	91	88
5	NC	3.4	3.5	1.03	100	—
5	C	3.8	3.9	1.03	100	—

[z]Treatment 1=linear shaker, 133 lb. unbalance rotating mass; 2=linear shaker, 200 lb. unbalance rotating mass; 3=multidirectional shaker, unbalanced masses rotating opposite direction, 4=multidirectional shaker, unbalanced masses rotating same direction; 5=handpicked.
[y]NC=no abscission chemicals applied; C=abscission chemicals applied.

Table 2. 'Valencia' orange yield and harvest efficiency.

Treatment		Yield (boxes/tree)				Harvesting
Shaker[z]	Chem.[y]	1981	1982-84	82-84 / 81 (Y)	Removal (%) (R) 1981-83 avg.	Efficiency (R x Y)
1	NC	3.7	3.8	1.04	75	82
1	C	2.9	2.9	.99	92	91
2	NC	3.7	3.2	.87	87	76
2	C	3.8	3.2	.86	93	80
3	NC	3.6	3.1	.86	80	69
3	C	3.9	3.3	.84	92	77
4	NC	3.2	3.0	.95	80	76
4	C	3.3	2.6	.79	93	73
5	NC	3.5	3.6	1.03	100	—
5	C	3.7	3.4	.93	100	—

[z]Treatment 1=linear shaker, 133 lb. unbalance rotating mass; 2=linear shaker, 200 lb. unbalance rotating mass; 3=multidirectional shaker, unbalanced masses rotating opposite direction; 4=multidirectional shaker, unbalanced rotating same direction; 5=handpicked.
[y]NC=no abscission chemicals applied; C=abscission chemicals applied.

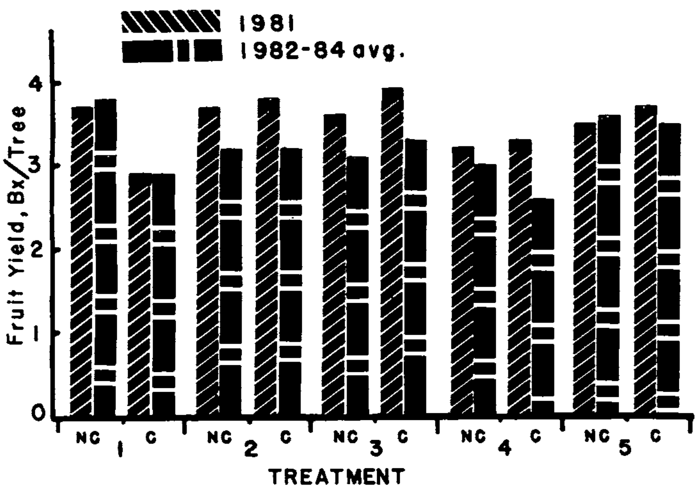

Fig. 5. 'Valencia' orange yields for 4 shaker treatments and handpicked check. NC=no chemical, C=abscission chemical. Treatments 1 and 2 are linear shakers with 133 lb. and 200 lb. unbalanced rotating mass, respectively. Treatments 3 and 4 are multi-directional shakers with unbalanced masses rotating in opposite directions and same direction, respectively. Treatment 5 was randpicked.

Young fruit size at time of harvest is also an important factor in subsequent yields of mature fruit. Young fruit size of the 1983 and 1984 crops was larger (0.4 inch diameter) when the trees were shaken in 1982 and 1983, and a significant number of young fruit were removed by shaking. In contrast, the young fruit size in 1981 was much smaller (petal bloom) when the trees were shaken, hence subsequent 1982 yields were not affected.

The difference in average trunk circumference between the 'Hamlin' and 'Valencia' cultivars (25.7 inches vs. 19.3 inches) did not affect the operating frequency of the respective shaker treatments. Tree height and trunk circumference were larger for the 'Hamlin' orange trees and resulted in lower fruit removal. However, there was some difference due to their mode of shaking. The linear shaker (treatments 1 and 2) operated from 5-6 revolutions/sec while the multi-directional shaker (treatments 3 and 4) operated at 10-12.5 revolutions/sec or twice as fast as the linear shaker. This means that in the 7 sec shaking duration, the multi-directional shaker moved the trees through twice as many oscillations.

Bark damage is a factor in operating any shaking equipment, particularly on Valencia orange trees which are in a growth period at time of harvest. However, in these experiments, observed bark damage was minimal in all treatments.

Static forces on the shaker clamping pads were 3300 lb. and 11,240 lb., respectively, for the linear and multi-directional shakers and total clamp pad contact areas were 36 inches and 63 inches, respectively, as measured on a 20-inch circumference cylinder, representing the average tree circumference. Clamping pressures were 93 psi for the linear shaker and 177 psi for the multi-directional shaker. The average difference in clamp pad height between the two shakers was 3 inches when clamped on a tree; the smaller height being on the linear shaker. For this reason, the linear shaker could grasp the limited area or height of most tree trunks more easily.

Fruit yield and removal data from the 'Hamlin' orange experiment indicates that all 4 trunk shaker treatments were comparable when used with an abscission chemical. Treatments 2 and 4, without abscission chemical, were superior to treatments 1 and 3 but the respective harvest efficiencies of 72 and 78% are below current commercially acceptable levels.

Data from the 'Valencia' orange experiment show that the combination of abscission chemical and shaker treatment affected fruit yields except for the linear shaker in treatment 1. Shaker treatment 1, with abscission chemical, had a substantially higher harvest efficiency (91%) than the other treatments and could provide a viable harvest method for 'Valencia' oranges in South Florida.

Further research on timing 'Valencia' harvest before the young fruit reach 0.4 inches in diameter and abscission chemical improvement should enhance the harvesting efficiency of trunk shakers.

Literature Cited

1. Brown, G. K. (ed). 1983. Status of harvest mechanization of horticultural crops. Amer. Soc. Agr. Eng. Special Publ. 0383, 78 pp.
2. Hedden, S. L., G. E. Coppock, and J. D. Whitney. 1983. Citrus harvest mechanization in Florida-current situation. Trans. Amer. Soc. Agr. Eng. 26:397-398.
3. Hedden, S. L., J. D. Whitney, and D. B. Churchill. 1984. Trunk shaker removal of oranges. Trans. Amer. Soc. Agr. Eng. 27:372-374.
4. Wheaton, T. A., W. C. Wilson, and R. E. Holm. 1977. Abscission response and color changes of 'Valencia' oranges. J. Amer. Soc. Hort. Sci. 102:580-583.
5. Whitney, J. D. 1975. Orange yield and removal studies with air and trunk shakers using two abscission chemicals. Proc. Fla. State Hort. Soc. 88:120-124.
6. Whitney, J. D. 1976. Air shaker harvest trials in 'Valencia' oranges with two rates of abscission chemical. Proc. Fla. State Hort. Soc. 89:41-43.