Proc. Fla. State Hort. Soc. 122:161–165. 2009.

Managing Citrus Tree Growth with Hedging and Plant Growth Regulators: Strategies for Reducing Psyllid Feeding and Huanglongbing Infection

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Additional index words. *Diaphorina citri*, *Candidatus* Liberibacter, citrus greening, prohexadione calcium, Apogee, pruning

Reducing excessive vegetative growth that is produced annually by citrus trees in Florida would reduce the opportunities for asian citrus psyllid (*Diaphorina citri* Kuwayama) reproduction and thereby, the spread of huanglongbing. Excess tree growth is routinely removed through hedging, and branch regrowth can be reduced after hedging in the fall season under Florida conditions because of the onset of cool temperatures. Additionally, late summer hedging may synchronize a final late-season flush, and thus, reduce new flush leaves present during the winter to support overwintering psyllids. We determined timing effects of fall and early winter hedging of 'Hamlin' orange trees on vegetative growth flush and subsequent yield during a 2-year period. None of the hedging times tested stimulated a growth flush or significantly affected yield by hedging time in either year.

The plant growth regulator prohexadione calcium (pro-cal) is routinely used in apple trees to control vegetative growth and also may have the potential to reduce insect pest populations in citrus either by reducing pest-required vegetative growth, increasing pesticide efficacy, or by altering host plant metabolites or nutrition. Pro-cal reduced extension growth of shoots by more than 50% in greenhouse seedlings of 'Carrizo' citrange, but less so in 'Swingle' citrumelo seedlings. Psyllid oviposition was also reduced by approximately 50% on pro-cal treated seedlings compared to untreated control plants, but variation was large and obscured statistical differences. Based on the current data, we are confident that modifying hedging timing and/or the use of PGRs can be effective management tools to control excess vegetative growth of mature citrus trees in Florida. This will allow better management of the asian citrus psyllid and thus, reduce the spread of HLB.

Huanglongbing (HLB, citrus greening disease) is a destructive disease of citrus caused by the bacteria *Candidatus* Liberibacter spp. The disease has caused major crop and tree loss in many citrus growing areas throughout the world, and has been known to be present in Florida since Aug. 2005 (Bové, 2006). Since its discovery in Florida, HLB has quickly spread to all citrus producing areas of the state, due in large part to the prior establishment of its insect vector the asian citrus psyllid (ACP, *Diaphorina citri* Kuwayama) (Halbert and Manjunath, 2004). No natural resistance is known to exist within *Citrus* or its relatives, so long-term solutions to HLB will likely come from the development of resistant varieties. However, short-term management strategies for existing citrus groves are desperately needed until such a solution is developed.

Current HLB management strategies focus on removal of infected trees and vector control. Tree removal is an inefficient management strategy since trees may be infected for several months to a year before visible symptoms develop, during which time the vector is capable of spreading the causal pathogen of HLB. Current vector management relies on alternating use of pesticides with different modes of action as applications can be as frequent as 12 times per year. Since the ACP requires new flush (young succulent growth) for oviposition and nymph development (Chavan and Summanwar, 1993), the survival of the immature stages of ACP declines when leaves mature and harden off. Thus, one management strategy to slow the spread of HLB and improve ACP control is to reduce the number of new flushes annually and/or reduce the period of time from leaf emergence to hardening off (flush duration) of each new flush. Long-lived evergreen citrus trees in Florida produce an excess of leaves above that required to support maximum fruit yield (Yuan et al., 2005). This excess growth primarily arises from the more-or-less continuous flushing that can occur any time of the year, but especially during the warm summer rainy season. Hedging, the practice of mechanically pruning the sides and tops of tree canopies to maintain tree height and between-row spacing, is routinely used to remove excess citrus tree growth (Lewis and McCarty, 1973). Most Florida citrus growers hedge after harvest—in late winter (January–February) for 'Hamlin' trees and late spring or early summer (May–June) for 'Valencia' trees, the two primary sweet orange cultivars in the state. These times are chosen primarily to avoid removal of maturing fruit and are not based on physiology.

Despite the common use of hedging to control tree size, little research has been done to examine the effects of hedging on vegetative growth. Rather, studies have focused primarily on hedging timing effects on reproductive growth and yield (Bacon, 1981; Kallsen, 2005; Morales et al., 2000). There is little doubt that improperly timed hedging can reduce flowering and yield

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during the current season, but there are also carry-over effects that can affect yield during the following season. Pruning is often mistakenly considered to be a re-invigorating practice (Harris, 1983) because it often stimulates excessive, undesirable vegetative regrowth (Phillips, 1978). Hedging removes leaves and stem growth primarily from fruiting wood, and citrus yields can decline for a year or two after intensive hedging. Summarizing numerous pruning studies across multiple tree fruit crop species, Mika (1986) concluded that pruning always induces the development of longer shoots that grow more rapidly and for a longer period of time than when pruning does not occur. Studies in citrus tend to support this generalization (Phillips, 1978). Bacon and Bevington (1978) found that hedging early in the spring, similar to current practices for 'Valencia' oranges in Florida, resulted in the production of three growth flushes during the season and that each of these flushes produced longer shoots than hedging in late summer and early fall. In addition, nearly 100% of pruned shoots sprouted new growth when hedged in early spring compared to less than 20% sprouting growth when hedged in late summer and fall (Bacon, 1981). Thus, the effect of hedging in altering the functional balance between shoots and roots can be reflected in tree regrowth and relative allocation to shoots, roots, and fruit (Eissenstat and Duncan, 1992). More recently, branch regrowth was shown to be reduced when branches are pruned in fall under Florida conditions because of the onset of cool temperatures (Chica and Albrigo, personal communication).

Plant growth regulators (PGRs) are another tool available for manipulating plant growth. In fruit crops such as apples and avocados where excessive vegetative growth can be problematic, PGRs are routinely used to limit vegetative growth. (Mandemaker et al., 2005; Petracek et al., 2003). In addition to controlling vegetative growth, PGRs have been shown to induce resistance to some diseases (Rademacher, 2004) and insect pests (Paulson et al., 2005), particularly those that take advantage of immature vegetative growth. To date, the use of PGRs in citrus has been limited to influencing fruit development and maintaining postharvest quality (El-Otmani et al., 2000), and to control rootstock sprouts on young trees (Nauer and Boswell, 1978; Stover et al., 2006).

This research was undertaken to determine if there was a time during the fall season when hedging citrus would not stimulate a late-season flush which would be sensitive to frost and serve as a host for ACP, while at the same time, would not reduce the following season's yields. We also investigated the potential for the PGR prohexadione calcium (pro-cal) (Apogee, BASF Corporation, Research Triangle Park, NC) to control vegetative growth of citrus.

Materials and Methods

Hedging study. Hedging timing studies were initiated in Fall 2007 (the 2007–08 harvest season) in a 10-acre block of commercial citrus. The block was planted in Apr. 1985 with the sweet orange 'Hamlin' [*Citrus sinensis* (L.) Osbeck] grown on 'Cleopatra' mandarin rootstock (*C. reticulata* Blanco) spaced 4.5 m (15 ft) within rows and 6.25 m (20 ft) between rows, and the rows were oriented in an east–west direction. The trees' canopies were in continuous hedgerows and had been hedged annually, usually in January or February (postharvest), to maintain between row spacing.

Hedging timings were scheduled during the fourth week of October, second and fourth weeks of November, second week of December, and during January or February (grower standard practice). An unhedged control was also included. The experiment was designed as a randomized complete block with three replications. For each treatment, three rows (46 trees per row, one row per block) were hedged. Data were collected from five contiguous uniform trees near the east and west ends of each row. The data from the east and west ends of each row were considered subsamples and pooled to create one replicate. Prior to each hedging time, all of the shoots within a 1-m^2 area at mid-height on the north and south sides of each of the data trees were tagged and their length and number of nodes recorded. After each hedging, the tagged shoots were evaluated to determine the length of growth and number of nodes removed per shoot. At the time of hedging, tarps were laid beneath the five data trees in each row, on both the north and south sides of the trees. The number and fresh weight of fruit removed were recorded and expressed on a per tree basis. The total vegetative growth removed from the five measurement trees was collected and weighed fresh. A subsample of vegetative growth was taken, weighed fresh, dried to a constant weight at 65 °C and the total dry weight of the removed vegetative growth was calculated. At harvest, the data tree plots were hand-harvested into standard 10 field-box bins (40.8 kg or 90 lb per box). Yield to the nearest half box was estimated using a calibrated pole inserted into each bin. Total yield was expressed on a per tree basis.

The treatments were repeated on the same trees, and data collected as described above during the fall of 2008 (2008–09 harvest season).

Plant growth regulator study. Five-month-old seedlings of 'Carrizo' citrange were obtained from a commercial citrus nursery in May 2008. The seedlings were planted into 164-mL Cone-tainers (Stuewe & Sons, Inc., Corvallis, OR), using Fafard 2 soilless potting medium (Conrad Fafard, Inc., Agawam, MA), and allowed to recover from transplant for 2 weeks. On 30 May 2008, the 120 seedlings were randomly assigned to one of four treatments. Treatments consisted of two foliar applications of pro-cal, one soil drench application, and an untreated control. Foliar applications were applied at 100 and 200 $mg{\cdot}L^{-1}$ (ppm) a.i. mixed with 2.5 $mL{\cdot}L^{-1}$ (0.32 oz/gal) nonionic surfactant (Induce®, Helena Chemical Co., Collierville, TN), and 5 $mL{\cdot}L^{-1}$ (0.64 oz/gal) of 0.5% citric acid (per manufacturer's recommendation). Seedlings were sprayed to thoroughly wet upper and lower leaf surfaces while the soil surface was covered during application and until the product dried to avoid soil contamination. Soil drench applications were applied at 100 $mg{\cdot}L^{-1}$ (ppm) a.i. mixed with 5 $mL{\cdot}L^{-1}$ (0.64 oz/gal) of 0.5% citric acid. Each container received a total of 40 mL (1.4 oz) of solution applied as two 20-mL (0.7 oz) applications. Some leaching occurred following the second 20-mL (0.7 oz) application. Foliar-treated seedlings and control seedlings all received 40 mL (1.4 oz) of deionized water at the time of treatment.

On 2 June, the initial height of each seedling was recorded. All seedlings were watered on Monday, Wednesday, and Friday each week with 40 mL of a dilute nutrient solution (8N–2P–8K plus minors) so that each seedling received 15 mg of N per week. Final seedling heights were recorded on 7 July.

On 2 Sept. the experiment was repeated using 5-month-old seedlings of 'Swingle' citrumelo (*C. paradisi* Macfad. x *P. trifoliata*). Final seedling heights were recorded on 3 Oct.

For the evaluation of the effect of pro-cal on psyllid oviposition, 10 additional 'Carizzo' seedlings were treated as previously described for each of the treatments. Seedlings were selected to

Table 1. Effect of different fall and winter hedging times on fruit removal, shoot removal, and yield of 'Hamlin' sweet orange during the 2007–08 harvest season.

			Growth/yield parameter			
Hedging date	No. fruit removed/tree	Fruit removed (kg, FW)	Vegetative growth removed (kg, DW)	Avg shoot length removed (cm)	Avg no. nodes removed per shoot	Yield (kg/tree)
23 Oct.	40 b[z]	5.09 b	1.81 c	4.9 d	3.3 d	242.2 NS
7 Nov.	40 b	5.21 b	2.28 bc	11.1 c	7.3 c	246.3
19 Nov.	65 a	8.86 a	4.48 a	18.4 ab	11.3 a	219.0
12 Dec.	61 a	8.99 a	3.12 b	19.7 a	12.2 a	214.9
2 Feb.	ND[y]	ND	1.91 bc	16.4 b	9.8 b	246.3
Control[x]	N/A	N/A	N/A	N/A	N/A	242.2

[z]Means within a column followed by different letters were significantly different by Tukey's test, $P < 0.05$; NS = nonsignificantly different.
[y]ND = no data. The 2 Feb. hedging took place after harvest was complete; thus, no fruit removal data were collected.
[x]This treatment was not hedged for the 2-year duration of the study; thus, only yield data were collected.

Table 2. Effect of different fall and winter hedging times on fruit removal, shoot removal and yield of 'Hamlin' sweet orange during the 2008/2009-harvest season.

			Growth/yield parameter			
Hedging date	No. fruit removed/tree	Fruit removed (kg, FW)	Vegetative growth removed (kg, DW)	Avg shoot length removed (cm)	Avg no. nodes removed per shoot	Yield (kg/tree)
22 Oct.	17[z]	3.30	1.38	21.9	10.4	165.9
5 Nov.	24	3.94	1.64	18.7	10.4	151.7
19 Nov.	48	7.30	1.87	26.5	15.3	145.6
9 Dec.	21	3.80	2.63	26.2	13.7	161.9
21 Jan.	ND[y]	ND	1.70	25.7	13.8	172.1
Control[x]	N/A	N/A	N/A	N/A	N/A	178.9

[z]Mean separation within columns by Tukey's test, $P < 0.05$; there were no significant differences.
[y]ND = no data. The 21 Jan. hedging took place after harvest was complete; thus, no fruit removal data were collected.
[x]This treatment was not hedged for the 2-year duration of the study; thus, only yield data were collected.

have young, newly expanded flush. Two pairs of psyllids were caged on each seedling using transparent plastic cylinder cages [33 cm (13 inch) long × 7 cm (2.75 inch) diameter] with their tops covered with thin muslin. The seedlings were placed in growth chambers (Percival, Boone, IA) at 25 °C, 65% to 75% RH, and a 12-h photoperiod. After 10 d, all pairs were removed and the laid eggs were counted.

Results

Hedging study. None of the hedging times reported here stimulated a growth flush (data not shown). Hedging during October through December (preharvest) removed 40–65 fruit per tree in 2007 and 20–50 fruit in 2008 (Tables 1–2). This equated to 3–9 kg (7–20 lb) of fruit per tree on average across the two seasons. In general, the number of fruit removed per tree increased as hedging was done closer to harvest. The amount of vegetative growth removed per tree as assessed by dry weight, shoot length and number of nodes removed per shoot, also tended to increase as hedging was done later and closer to harvest (Tables 1–2). Although yield was not significantly affected by hedging time in either year, late November and early December hedging tended to have a greater negative effect on yield than late October and early November timings.

All applications of pro-cal significantly reduced the height growth of 'Carrizo' seedlings, although the 200 $mg \cdot L^{-1}$ foliar and soil drench applications were more effective than the 100 $mg \cdot L^{-1}$ foliar application (Table 3). 'Swingle' seedlings were unaffected by the 100 $mg \cdot L^{-1}$ foliar application, but the 200 $mg \cdot L^{-1}$ foliar and soil drench applications significantly reduced shoot growth.

Table 3. Effect of prohexadione calcium (Apogee®) foliar spray and soil drench application on shoot growth of 'Carrizo' citrange and 'Swingle' citrumelo seedling shoot growth. PGR applications were made one time and plant height data were recorded 30 d after treatment.

	Plant ht (cm)	
Treatment	Carrizo	Swingle
Control	24.3 a[z]	36.7 a
Apogee spray 100 ppm	16.4 b	38.3 a
Apogee spray 200 ppm	10.3 c	33.1 b
Apogee soil drench 100 ppm	10.2 c	33.4 b

[z]Means within a column followed by different letters were significantly different by Tukey's test, $P < 0.05$.

All application rates and methods of pro-cal numerically reduced psyllid oviposition by more than 50%; however, variability was high and no treatments were statistically different (Fig. 1).

Discussion

This research was undertaken to determine if annual maintenance hedging could be performed during the fall and early winter, prior to harvest, without stimulating a vegetative growth flush and without significantly reducing yield. A new growth flush during the late season is undesirable because it is sensitive to winter frost damage. Additionally, this new growth is the preferred host tissue for the asian citrus psyllid, the vector of HLB, and a late-season flush would allow psyllid populations to build prior to the spring flush. None of the fall hedging

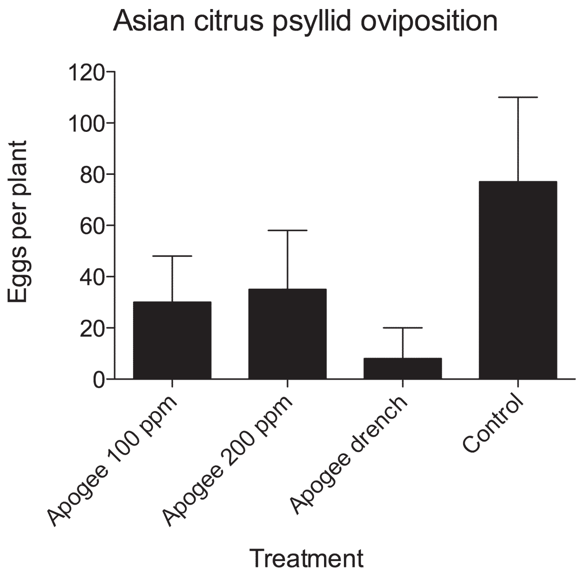

Fig. 1. The effect of prohexadione-calcium (pro-cal, Apogee) on oviposition of the asian citrus psyllid on citrus rootstock seedlings. Pro-cal was applied as a single foliar spray or as a soil drench as described.

times studied stimulated a vegetative flush. This is similar to results reported for fall hedging of 'Valencia' trees in Australia (Bevington, 1980).

All preharvest hedging times studied removed a portion of the current season's crop. However, during the 2007–08 harvest season, the 23 Oct. and 7 Nov. timings had no effect on total yield per tree. The 19 Nov. and 12 Dec. timings removed about 50% more fruit, on both a number and weight basis, and reduced yield (although not statistically significant) compared to postharvest hedged trees and unhedged control trees. During the 2008–09 harvest season, yields were lower compared to the 2007–08 harvest season, suggesting a slight alternate bearing. Similar to the 2007–08 harvest season, none of the 2008–09 hedging times statistically reduced yield, but the 19 Nov. timing reduced yield by about 30 kg or about 0.74 boxes. However, this was likely due to hedging error, as the hedging was somewhat more severe on this date than the other times.

The lack of yield reduction, particularly at the two earliest hedging times, suggests that the remaining fruit were able to compensate for the hedging loss by an increase in relative growth rate. Stover et al. (2003) showed a similar growth compensation effect when 'Murcott' tangerine trees were topped during August. Grossman and DeJong (1995) showed that peach relative growth rates increased significantly when previously unthinned trees were thinned as little as 8 weeks before harvest. There is a well-known negative relationship between fruit size and yield in citrus, so larger fruit can be expected to follow partial fruit removal (Syvertsen et al., 2003).

The removal of significant amounts of vegetative shoot growth (Table 1), as measured by length and number of nodes removed, had no affect on yield the following season (Table 2). This indicates that the remaining basal buds of pruned shoots were able to sufficiently respond to winter floral-inductive conditions to produce an adequate bloom. In a pruning study of individual shoots, Chica and Albrigo (personal communication) showed that basal buds of vegetative shoots could be induced to flower and set fruit when the terminal buds were removed prior to 15 Nov. However, these results were in contrast to those reported by Bacon (1981) and Bevington and Bacon (1978) in which no flowering occurred the following spring when 'Valencia' trees were pruned after mid-summer.

The application of pro-cal reduced the growth of 'Carrizo' seedlings by approximately 50% at all concentrations and application methods. However, 'Swingle' seedlings showed a response only at the highest foliar application rate or the soil drench, and the magnitude of this effect was considerably less than that measured for 'Carrizo'. It should be noted that the 'Swingle' seedlings grew poorly during this experiment, and the apparent lack of response to pro-cal may actually have been a lack of vigorous growth in the control seedlings.

The reduction in oviposition by asian citrus psyllid, although not statistically significant in this study, indicates the potential use of the pro-cal treatments described to impact the reproductive biology of this insect pest. Whether this effect on psyllid biology is a direct one, due to reduced flush growth and oviposition sites, or indirect, through some change in plant chemistry, is unknown. In a similar study of pear psyllid, Paulson et al. (2005) found that psyllid nymph populations continued increasing after the application of the pesticide imidacloprid, but declined when imidacloprid was combined with pro-cal. Thus, pro-cal and other PGRs may increase the efficacy of systemic pesticides, like imidacloprid, by reducing their dilution within the plant by reducing growth. Likewise, the fall hedging treatments studied in the present work may allow for more effective control of the asian citrus psyllid by reducing total tree growth and/or by allowing for better canopy penetration of foliar applied pesticides.

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