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Costs and benefits of insecticide and foliar nutrient applications to HLB-infected citrus trees

James A. Tansey¹, Pilar Vanaclocha¹, Cesar Monzo^{1,2}, Moneen Jones^{1,3}, and Philip A. Stansly¹.

¹University of Florida, Southwest Florida Research and Education Center, 2685 SR 29 N., Immokalee, FL 34142 (USA)

²Current address: Unidad Asociada IVIA-UJI, Instituto Valenciano de Investigaciones Agrarias, Moncada, Valencia, Spain.

³Current address: Department of Entomology, University of Missouri, Fisher Delta Research Center, P.O. Box 160, Portageville, MO 63873-0160 (USA)

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Abstract

BACKGROUND

The Asian citrus psyllid (ACP), *Diaphorina citri* Kuwayama (Hemiptera: Psyllidae), vectors ‘*Candidatus* Liberibacter asiaticus’ that causes huanglongbing (HLB). In Florida, HLB incidence is approaching 100% statewide. Yields have decreased and production costs have increased since 2005. Despite this, some growers are maintaining a level of production and attribute this in part to aggressive psyllid control and foliar nutrition sprays. However, the value of these practices is debated. A replicated field study was initiated in 2008 in a commercial block of ‘Valencia’ sweet orange trees to evaluate individual and combined effects of foliar nutrition and ACP control. Results from 2012-2016 are presented.

RESULTS

Insecticides consistently reduced ACP populations. However, neither insecticide nor nutrition applications significantly influenced HLB incidence nor PCR copy number in mature trees. In reset trees, infection continued to build and reached 100% in all treatments. Greatest yields (kg fruit/ ha) and production (kg s/ ha) were obtained from trees receiving both insecticides and foliar nutrition.

CONCLUSIONS

All treatments resulted in production and financial gains relative to controls. However, material and application costs associated with the nutrition component offset these gains resulting in lesser benefits than insecticides applied alone.

Key words: *Diaphorina citri*, huanglongbing, Liberibacter, citrus production

Introduction

Huanglongbing (HLB), also called citrus greening disease, is one of the most destructive diseases of citrus worldwide¹. In Florida, HLB is associated with infection by the fastidious, gram-negative, phloem-limited α -proteobacteria, *Candidatus Liberibacter asiaticus* (*Ca. Las*)^{1,2}. In the Americas and Asia, *Ca. Las* is vectored primarily by the Asian citrus psyllid (ACP), *Diaphorina citri*, Kuwayama (Hemiptera: Psyllidae). ACP was first reported in Florida in 1998 and HLB in 2005^{3,4}. HLB symptoms include foliar nutrient deficiencies and asymmetric leaf mottling, defoliation, fruit drop, misshapen and off-flavored fruit, and general tree decline^{5,6,7}. In addition to true deficiencies, foliar symptoms are attributed to callose formation and its effects on phloem transport^{8,9}. Symptoms are a result of root dysfunction and do not manifest until disease levels are advanced after which the commercial value of the tree can decline rapidly^{2,10,11,12}.

Nymphs are primarily responsible for acquiring *Ca. Las* through vascular feeding^{13,14}. The bacterium replicates and/or accumulates within the insect alimentary canal and salivary glands and is transmitted to new hosts when resulting adults move and feed¹⁵. Psyllids can remain infectious throughout their lives¹³. Local disease progression depends on ACP population prevalence, inoculum levels, grove age, citrus variety, grove management and environmental conditions^{16,17,18}. Symptoms of HLB infection can take six months to several years to develop in infected plants¹⁹, although young leaves can become infectious 15 d after inoculation²⁰.

Several HLB management strategies have been recommended or mandated in Florida. Certified HLB-free nursery stock is required^{21,22}. Although removal of symptomatic trees has been recommended to reduce HLB spread in early stages of local infection²³, removal becomes economically unsustainable when large numbers of trees are infected. Aggressive psyllid control

and area-wide insecticide spray management programs can decrease ACP populations as well as maintain profitability in spite of high HLB incidence^{24,25,26,27}. Foliar nutritional sprays are thought to reduce stress factors introduced or exacerbated by infection and are currently practiced by many growers^{18,29}.

ACP control is likely the most important measure to delay and reduce effects of HLB^{18, 23, 29}. Suppression of vector populations reduces HLB infection rates and rates of transfer in low-incidence groves²⁹. ACP control in infected groves can moderate HLB-induced decline¹⁸. However, intensive insecticide use can result in resistance in ACP populations³⁰ and have negative impacts on biological control of this and other citrus pests, increasing the probability of ACP and secondary pest outbreaks^{25,31,32,33}.

Foliar applications of macro- (N, P, and K salts) and micro- (primarily B, Mg, and Zn salts) nutrients may permit foliage to acquire essential elements that are otherwise limited by root dysfunction. Increased productivity of HLB-infected Valencia orange trees receiving foliar nutritional sprays and ACP control has been reported from the site of the current study¹⁸.

Because of the progressive nature of HLB disease incidence and symptomology, long term studies are required to understand the effects and practicality of HLB and ACP management efforts. The current work presents results of continued evaluation of foliar insecticide and nutritional applications to control ACP and mitigate HLB-induced stress. Results of the first four seasons have been reported¹⁸; here the 5th to 8th growing seasons are presented.

Experimental methods

Experimental design and ACP sampling method

Experiments were carried out on a 5.2 ha grove located in Collier Co., Florida, planted in 2001 with *Citrus sinensis* (L.) Osbeck cv. Valencia, on Swingle citrumelo, *C. paradisi* Macf. ×

Poncirus trifoliata L., rootstock. Planting density was 373 trees/ha (151 trees/ac) at 7.3 m between rows and 3.7 m within rows. Three months prior to the beginning of the study, and throughout its course, trees were micro-sprinkler irrigated and standard weed control and fertilization practices were followed³⁴. Applications of fertilizers (NPK, or as listed) were made to soil (Table 1).

Trees were defoliated in 2006 and 2007 in an attempt to eliminate citrus canker disease, so that, although the grove was planted in 2002, the effective age at the start of the study in 2008 was 4 years. Dead or missing trees were replaced with 440 young trees (resets) in 2010. The grove was divided into 16 plots in a randomized complete block (RCB) design with two factors: insecticide and foliar nutrients, each at 2 levels (with and without). Treatments included: insecticide applications when a nominal threshold (0.2 ACP adults per tap sample in 2012 and 0.1 in 2013 to 2015) was exceeded, 2-3 applications of foliar nutrition, combinations of insecticide and nutrition and an untreated control. Each treatment was replicated four times. See Monzó et al (2013) and Monzo & Stansly (2015) for a detailed description of thresholds and associated rationales.

Two dormant spray applications of broad-spectrum insecticides were made to the entire study site in the winter of 2012-2013 and to insecticide and insecticide + nutrition treatment trees in the winters of 2013-2014 to 2015-2016 (Table 2). Applications were made with an Air-O-Fan® (Reedley, Ca) air blast sprayer equipped with Albuz® ATR (Coors Tek, Golden, Co) hollow cone nozzles providing an 80° spray pattern with five nozzles (the top two delivered 2.5 L/min; the bottom three delivered 4 L/min), operating at 20.7 bar (300 PSI) and 3 km/h delivering a total of 887 L/ha. Foliar nutrition applications were applied during major flush periods (spring, summer and fall) when leaves were fully expanded but not yet hardened (Table

3). Both *Bacillus subtilis* and 3-18-20 fertilizer were removed from foliar nutrition recipe in 2011 to lower costs and reduce the amount of precipitate clogging the sprayer.

Populations of ACP adults were monitored approximately every two weeks by conducting two stem tap samples per tree over six randomly-selected trees at two randomly selected points (stops) per plot. For each stem tap sample, a white plastic clipboard (22 cm × 28 cm) was held horizontally under a randomly chosen branch that was struck three times with a 60 cm length of PVC pipe. ACP adults that fell on the clipboard were assessed visually^{32,35,36}. Flush density was evaluated at the same time by determining the number of young shoots within a 0.28 m³ (152.4 cm × 61.0 cm × 30.5 cm) volume of tree canopy from two randomly-selected points in each plot. If fewer than 10 shoots were found in a single sampling volume, additional trees were sampled until 10 young shoots were found or 10 trees were sampled. Flush density is expressed as shoots per ft³ (0.028 m⁻³). ACP juvenile populations were evaluated under a dissecting microscope by determining the proportion of flush within each sampled volume that was infested and counting the numbers of eggs and nymphs per infested flush from each sampling point. Numbers are expressed as juveniles per ft³ (0.028 m⁻³). Sampling stopped in September 2015

Real-time PCR analysis of plant samples and incidence of HLB

HLB testing was conducted one to four times per year between October 2011 and September 2015. On each sampling date, 148 mature trees and 113 reset trees were sampled. Eight randomly selected, fully expanded, hardened leaves per tree (two per each of the north, south, west and east side), were sampled and transported on ice to the Southwest Florida Research and Education Center (SWFREC), University of Florida, Immokalee for analysis.

Real-time PCR analysis of 100 mg of petiole tissue was conducted following methodology described in Stansly et al. (2014), to obtain the cycle threshold (Ct-value)

representing the minimum number of DNA amplification cycle necessary to detect a signal. The Ct value is considered indicative of target DNA titer³⁷ and allows direct comparison on specific sampling dates. Samples were processed and analyzed with Applied Biosystems 7500 system SDS software version 1.2¹⁸. A sample was considered positive for HLB when Ct values were less than 36.

Fruit yield, drop and quality

Ripe fruit was harvested March of 2013, 2014, 2015, and 2016. Fruit mass per plot per harvest year was assessed by weighing all collected fruit per plot in commercial 10-box bins with a Gator Deck scale (Scale Systems, Novi, MI) and corrected for the mean mass of four bins. Fruit drop was evaluated for 10 randomly-selected trees per plot just prior to harvest in 2013 and 2015. Ripe fruit samples (17.6 L) were taken from approximately ten randomly selected trees per plot each year. Juice quality was measured for each sample at the citrus quality laboratory of the Citrus Research and Education Center, University of Florida, Lake Alfred. Juice was de-aerated under vacuum for 2-3 minutes. Soluble solids content was measured by hydrometer, brix by refractometer and titratable acidity as citric acid (pH endpoint 8.2).

Economic analysis

Yield (kg s per ha) was calculated for each treatment and untreated plots. Relative costs and benefits of treatments was assessed by multiplying yield (kg s /ha) by the published values of marketable solids per ha for each growing season. Mean delivered-in prices for Valencia oranges for processing in Florida were \$3.53/kg (\$1.60/lb) solids 2012-2013³⁸, \$3.79/kg (\$1.72/lb) solids for 2013-2014³⁹ and \$4.62/kg (\$2.10/lb) solids for 2014-2015⁴⁰. No published value for 2016 was available at the time this work was prepared, so 2015 values were used for that year's evaluation. Costs of each treatment in each year and cumulatively were subtracted from the gross

values per ha for each treatment. These costs included the materials for insecticide and/or foliar nutrition applications and the costs of applying these treatments per growing season (Tables 2, 3, 4, 5). Untreated plots received two dormant sprays in 2012-2013 at \$342.34 ha⁻¹, due to grower concerns over high ACP numbers. Dormant sprays were not applied to untreated plots during the following growing seasons. Costs of materials were based on quotes from chemical supply companies in 2014 and 2016. Applications costs for treatments were \$68.92 per ha for 378.54 L per 0.405 ha (100 gallon per acre) air-blast insecticide applications⁴¹. Costs also included transport and picking costs of harvested oranges (\$2.82 per 40.82 kg)⁴². All values are in US Dollars.

Data analysis

All analyses were conducted with the SAS Version 9.3 analysis package⁴³. Effects of treatments and main components (insecticides and nutrition applications) on ACP adult counts per tap sample over the course of the study period were evaluated using a repeated measures analysis of variance (ANOVA), employing the SAS Mixed procedure and specifying a variance components covariance structure. When treatment effects or interactions of factors were significant, pairwise comparisons were made using the pdiff statement specifying the Tukey adjustment. These data were log 10 ($x + 0.05$)-transformed to satisfy normality and homoscedasticity assumptions. Correlations of ACP adult and juvenile counts and their relationship with flush densities were evaluated by treatment using a Spearman rank correlation (SAS Proc Corr, specifying the Spearman option). Comparisons of correlations were conducted using Z-tests. Effects of applications on Ct-values were assessed as repeated measures ANOVAs. Treatment and main effects on Ct-values and HLB incidence throughout the study period for mature and reset trees were assessed. An autoregressive covariance structure was selected based on Akaikei and

Bayesian information criteria. Treatment and main effects on yields, fruit drop and fruit quality parameters were analyzed by growing season and in the case of yields, for cumulative values of the four harvests combined, using the SAS GLM procedure. Fruit drop for 2013 and 2015 growing seasons was similarly evaluated. Block was considered a random factor in all applicable analyses.

Results

Asian citrus psyllids

Overall and annual ACP adult counts were influenced by treatment, with no significant interactions between main effects. Insecticides significantly reduced ACP numbers in all years with no significant differences between insecticide alone and insecticide + nutrient treatments (Table 6). Nutrition had a significant effect on ACP numbers the first two years, but more were found in 2012-2013 on untreated trees than those receiving nutrition treatments, whereas the opposite was true in 2013-2014, resulting in a significant interaction between treatment and growing season ($F_{2, 1185} = 12.58$; $P < 0.001$).

Numbers of ACP adults differed by year ($F_{3, 1408} = 129.99$; $P < 0.001$) with significantly ($P < 0.05$) more found in the 2012-2013 growing season than in each subsequent season (Figure 1). Seasonal differences were seen in ACP population in all years, with most found in June, August, and November-December 2012, March-April 2013, plus small peaks in June, July-August and November 2013 (Figure 1). Greater peaks were apparent April to September 2014, April to September 2015 on untreated trees and trees treated with nutrients alone (Figure 1). A significant interaction of year and insecticide was also apparent ($F_{3, 1408} = 49.43$; $P < 0.001$). Although the effect of insecticide application was significant ($P < 0.001$) in all years, ACP

populations were reduced most during the 2012-2013 growing season when populations were highest (Table 6).

As with adults, insecticide applications significantly reduced annual and overall juvenile ACP counts (Table 6). Significantly more juvenile ACP were seen on trees receiving foliar nutrition in 2014-2015 and overall; marginally more juveniles were found on trees treated with foliar nutrition in 2015-2016 (Table 6). Numbers of juveniles increased dramatically, particularly relative to adult numbers from 2014 to 2016 (Table 6).

Neither insecticides nor nutrient applications influenced flush density ($F_{1,1408} = 3.40$; $P = 0.065$, $F_{1,1408} = 1.26$; $P = 0.264$). ACP juvenile counts and flush densities were correlated on untreated ($R = 0.458$; $n = 356$; $P < 0.001$) nutrition-treated ($R = 0.598$; $n = 356$; $P < 0.001$), insecticide-treated ($R = 0.133$; $n = 336$; $P = 0.012$), and insecticide + nutrition-treated trees ($R = 0.162$; $n = 336$; $P = 0.002$). However, the strengths of correlations were as follows: nutrition > untreated > insecticide = insecticide + nutrition (Z-test; $\alpha = 0.05$). Greater correlation of ACP adult and nymph counts were seen on trees with foliar nutrition (alone) treatments than those with nutrition + insecticide ($Z = 1.49$; $n = 336$; $P = 0.006$).

For reset trees, ACP adult counts were as follows: unsprayed trees > foliar nutrition-treated trees > insecticide + nutrition = insecticide treated trees (Table 6). Insecticide significantly reduced ACP counts (Table 6). Foliar nutrition also decreased counts, though much less than insecticides and in only two growing seasons (Table 6). ACP counts on reset trees decreased from 2012-2013 to 2013-2014 ($t_{1,1151} = 3.02$; $P = 0.014$) but increased to greater-than-2012-2013 levels by 2015-2016 ($t_{1,1151} = 5.36$; $P < 0.001$). Juvenile counts were not conducted on reset trees.

PCR analysis of plant samples and incidence of HLB

For mature trees, HLB incidence was approximately 100% throughout the study period. No significant treatment effect was apparent ($P > 0.05$). An overall trend of increasing Ct values with time was apparent among all treatments. Any differences among treatments disappeared by study's end ($P > 0.05$ for all comparisons).

HLB incidence increased on resets from $41 \pm 7\%$ in October 2011 to $99 \pm 1\%$ by November 2013 and continued at ca. 100% thereafter; Ct-values decreased from a mean of 32.31 ± 1.32 in April 2012 to 23.70 ± 1.22 in March 2015. Ct values did not differ by treatment ($F_{3,107} = 1.72$; $P = 0.166$) (Figure 2).

Fruit yield, drop and quality

Yields (kg fruit per tree) increased significantly ($P < 0.01$) over all treatments from 2012 to 2015: 2013 (59.23 ± 3.14); 2014 (80.28 ± 3.00); 2015 (96.72 ± 2.99). However overall yields decreased ($P < 0.01$) from 2015 to 2016 (71.42 ± 2.76). Yields were greater for trees with insecticide applications (Table 7). Mean and cumulative yields also increased with foliar nutrition; increases with foliar nutrition were seen for the 2013, 2014 and 2016 harvests (Table 7).

Greater numbers of dropped fruit per tree were seen in 2015 (58.47 ± 1.92) than 2013 (28.99 ± 2.99) ($F_{1,21} = 72.52$; $P < 0.001$). No treatment effect on mean or cumulative fruit dropped per tree or interaction of treatment and date were detected (Table 7). There were no significant main or treatment effects (at $\alpha = 0.05$) for any of the juice quality measures from these harvests (Table 7).

Economic analysis

Insecticide costs decreased from \$996.68 in the 2012-2013 season to \$584.91 ha⁻¹ during the 2014-2015 season (Table 5) due to reduced ACP pressure (Figure 1). Cost of the nutritional

program was \$1,498.68 ha⁻¹ in the 2012-2013 growing season; costs were reduced to \$776.17 ha⁻¹ for 2013-2014 and \$345.53 ha⁻¹ for the following growing seasons by eliminating one nutrient spray and substituting spray program 1 for spray program 2 (Tables 3, 4, 5).

Marginal production gains (kg solids per ha; hereafter referred to as kg s ha⁻¹) for each treatment, relative to untreated plots, were found for trees that received insecticides in all years. However, because differences were not significant (Table 9), mean values among all treatments were incorporated into economic analyses. Because fruit yields were higher, sum production was greater for all treatments compared to untreated trees (Table 9). Greater yields for treated trees resulted in greater gross values of the fruit harvested from treated trees; however, these gains were offset by the costs of treatments (Table 9). Although revenue generated from harvested fruit was greater than the calculated costs for all treatments in all years, improvements in revenue relative to untreated trees were seen consistently only for insecticide-alone-treated trees.

Discussion and Conclusions

Insecticide applications consistently reduced ACP counts below nominal thresholds, with differences between treated and untreated plots generally persisting for several months. The combined effects of growing-season applications and dormant sprays²⁵ contributed to limited population resurgence on this site. Numbers of applications required were reduced from four at the beginning of the study period to two per growing season. In addition to control exerted by on-site insecticide treatments, insecticide applications in the groves immediately around the study site likely limited numbers of local ACP.

Although insecticide was the only significantly influential main factor on ACP adult counts overall, fewer ACP were also found on trees sprayed with foliar nutrition in 2012 when populations were high. ACP adults are reported to actively move among host plants⁴⁵ and may be

stimulated to disperse by crowding or resource shortage^{18,46}. Our result suggests limited movement of ACP and/or reduced alightment on insecticide and nutrition-treated trees. Foliar nutrition recipes included a horticultural mineral oil (HMO) component (applied at 46.77 L ha⁻¹) as an adjuvant. HMO has been attributed with repelling ACP adults^{47,48,49}. However, effects of HMO applications on ACP alightment are likely low, given the infrequency of application. Greater numbers of ACP juveniles on nutrition-treated trees may have also dissuaded and reduced ACP adult alightment. Evaluating the mechanism of this apparent repellence from nutrition-treated trees requires more work.

The correlation of ACP juvenile counts and flush density was greater for nutrient-treated than untreated trees. Leaf nitrogen was significantly higher in these trees from 2008-2012, after nutrition and lower after insecticide applications⁵⁰. Citrus trees are efficient absorbers of foliar nutrient sprays and leaf nitrogen levels increase more quickly in response to foliar than to soil application⁵¹. Young leaves absorb more nitrogen than older, hardened leaves⁵². Female ACP target new flush for oviposition²⁵. The plant vigor hypothesis⁵³ posits that the nutritional status of hosts influences colonization and that these effects are most apparent for herbivores that are closely associated with growth processes. However, this effect should have also influenced adult numbers. Another potential explanation includes the effect of nutrition on nymph survivorship.

Despite significant reductions in ACP densities with insecticide treatments, HLB incidence was sustained in mature trees and continued to increase in reset trees. All sampled reset trees were *Ca. Las*-positive by November 2013, little more than 3 years after planting.

Importantly, nutrition-treated trees yielded more than untreated. Both the foliar nutrition and insecticide components of treatments resulted in consistent, significant improvements in kg fruit per tree. The use of foliar applications of nutrition by plants is influenced by phloem and

symplastic nutrient mobility: micronutrient requirements can be met by foliar applications and potassium and nitrogen are highly mobile and rapidly distribute throughout the plant⁵⁴. Although foliar nutrition improved yields, only insecticides influenced all of 2013, 2014, 2015, 2016 and cumulative yields. This result supports the importance of ACP control for continued citrus production in a context of widespread HLB prevalence and effects of local ACP reductions seen on the study site. Another study by our research team (currently under review) indicated decreases in tree productivity of infected trees were more apparent with ACP densities increases between 0.0-0.2 than 0.2-0.4 adults per stem tap (see also Monzo and Stansly, 2015). It also suggests the importance of regional, coordinated, multi-grower control like the Citrus Health Management Areas (CHMA) program⁵⁵. Combined foliar nutrition and insecticide treatments resulted in numerically greater yields than insecticides or foliar nutrition applied individually in all years. This result suggests an additive effect of these treatment components.

It is likely that, in addition to effects of insecticide applications on ACP populations, other arthropods were affected. We found that insecticides also significantly reduced damage by citrus leaf miner, *Phyllocnistis citrella* (Stainton) (Lepidoptera: Gracillariidae) (Stansly unbl. data). However, direct damage associated with this insect is near-negligible. Its association with citrus canker is of greater concern. We did not see obvious differences in canker incidence among treatments. Losses of ACP natural enemies because of insecticide applications have also been documented⁵⁶. Although elucidating effects of insecticide applications on the complex of herbivorous arthropods that feed on citrus and their natural enemies and effects of modifying these populations on agronomic performance of trees warrants further work, the most influential insect in this system, by far, is ACP.

All treatments including controls saw successive increases in yields every year except the last. Foliar nutrition was applied to run-off and a proportion may have found its way to the soil and therefore neighboring trees. However, accumulation is generally limited to the area below the canopy⁵⁷. Soil analysis from this site (2008-2012) did not suggest leaching of nutrients among treatments⁵⁰. Successive increases in yields in control trees were likely associated trees maturing to their expected peak production age⁵⁸, possibly with combined effects of fertilization applied to, and decreased ACP numbers over the entire site.

In a context of ubiquitous HLB, effects of ACP feeding and potential interactions of vector and pathogen are likely important. Phloem-feeding insects like ACP introduce salivary secretions with effector molecules that can influence defense signaling, host development and symptoms of pathogens they vector⁵⁹. Insecticide and foliar nutrition influence leaf nutrition status in different ways⁵⁰. Understanding these interactions requires much more work.

Costs of applications and increases in picking and transport costs associated with greater yields offset the relative benefits of these treatments. Although all treatments resulted in improved yields, costs were necessarily lower for trees receiving insecticide-alone than combined insecticide + nutrition treatments. While yields were improved by the addition of foliar nutrition, the increase was generally not sufficient to cover the extra cost of the nutritional program employed here. Thus, economic benefits of reducing ACP populations were apparently greater than those for applying foliar nutrition. Foliar nutritional programs would benefit economically from finer tuning to the actual needs of the tree as indicated by leaf nutrient analysis (Morgan et al., in review).

In conclusion, foliar nutrition increased yields but the benefits of these treatments were offset by costs of treatments and ironically, increased costs of picking and harvesting the

improved crop. Best results were obtained with combined insecticide + nutrition treatments but again these treatment costs exceeded benefits. Improved yields, relatively low cost and effects on ACP populations indicated that insecticide treatments were the best strategy for improving the performance of citrus trees infected with HLB. The apparent importance of ACP nymphs suggests that they should also be monitored and specifically targeted for control.

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Table 1. Fertilizers applied to the entire study site. The period reported is 2012-2016. Please see Stansly et al. (2014) for a synopsis of 2008-2011 results.

Year	Month	N	P	K	Form	Rate	Special applications
2008	September	13	0	21	Dry	336 kg	
2009	January	12	4	16	Dry	448 kg	
	May	8	0	24	Dry	448 kg	
	October				Dry	224 kg	K-Mag® (22 % K ₂ O, 11 % Mg and 22 % S)
	October				Liquid	1861 l	UN-32 (45 % NH ₄ NO ₃ , 35 % urea and 20 % water)
2010	January				Liquid	1861 l	UN-32 (45 % NH ₄ NO ₃ , 35 % urea and 20 % water)
	March	0	0	42	Dry	224 kg	
	March	9	0	0	Liquid	931 l	
	April				Liquid	1861 l	UN-32 (45 % NH ₄ NO ₃ , 35 % urea and 20 % water)
	May				Dry	1,120 kg	Granulite (heat dried biosolids)
	August				Dry	224 kg	K-Mag® (22 % K ₂ O, 11 % Mg and 22 % S)
	September	14	0	22	Dry	336 kg	
2011	January	16	4	16	Dry	336 kg	
	May	0	0	42	Dry	224 kg	
	May	20	0	0	Liquid	961 l	5% Ca
	August	0	0	42	Dry	224 kg	
	August	20	0	0	Liquid	961 l	5% Ca
2012	January	0	0	42	Dry	224 kg	
	January	30	0	0	Liquid	561 l	
	February	20	0	5	Liquid	1,122 l	
	March	15	0	22	Dry	393 kg	
	April	20	0	5	Liquid	795 l	
	April	20	0	5	Liquid	795 l	
	May	20	0	5	Liquid	374 l	
	June	20	0	5	Liquid	700 l	
	July	5	3	0	Dry	1,120 kg	Granulite (heat dried biosolids)
	August	8	0	11	Liquid	700 l	
	September	8	0	11	Liquid	700 l	
	October	8	0	11	Liquid	700 l	
	November	0	0	0	Dry	1,120 kg	Gypsum
2013	January	15	0	20	Dry	336 kg	
	February	9	0	9	Liquid	935 l	
	March	15	0	20	Dry	280 kg	
	March	9	0	9	Liquid	935 l	
	May	20	0	5	Liquid	1,870 l	
	July	0	0	42	Dry	225 kg	
	August	8	0	11	Liquid	1,403 l	
	September	20	2	5	Liquid	1,122 l	
	November	20	0	5	Liquid	935 l	
2014	January	15	0	18	Dry	448 kg	
	February	9	3	9	Liquid	935 l	
	March	12	3	6	Liquid	935 l	
	April	12	3	6	Liquid	935 l	
	May	15	0	20	Dry	336 kg	
	May	8	0	11	Liquid	561 l	
	June	8	0	11	Liquid	1122 l	
	July	9	3	9	Liquid	468 l	
	July	3	3	0	Dry	1,120 kg	Granulite
	August	8	0	11	Liquid	561 l	
	October	8	0	11	Liquid	561 l	
	November	9	0	9	Liquid	935 l	
2015	January	10	2	16	Dry	448 kg	
	January	8	0	8	Liquid	925 l	
	February	9	3	9	Liquid	468 l	
	March	14	2	16	Dry	336 kg	
	April	8	0	11	Liquid	935 l	
	June	15	3	18	Dry	336 kg	
	June	8	3	11	Liquid	935 l	
	July	8	0	11	Liquid	468 l	
	August	8	0	11	Liquid	468 l	
	September	16	0	18	Dry	336 kg	
	October	0	0	0	Dry	560 kg	Iron Humate
	November	9	0	9	Liquid	468 l	
2016	January	10	0	12	Dry	381 kg	

February	7	0	9	Liquid	468 l
March	12	0	17	Dry	381 kg
March	11	37	0	Liquid	281 l
April	11	37	0	Liquid	281 l
May	12	0	17	Dry	381 kg
May	8	0	11	Liquid	936 l

Table 2. Insecticide treatments conducted in the insecticide and insecticide + nutrition plots during the growing season (Mar - Oct), when ACP populations were over 0.2 adults per tap sample in 2012 and 0.1 adults per tap sample from 2013 to 2016, and the dormant season (Nov – Feb) between 2012 and 2015 Insecticide treatments are grouped by growing season from end of harvest through beginning of harvest the next year.

Date	Brand Name	Active Ingredient	Company	Rate/ha	Cost/ha	HMO ₁	HMO cost/ha
1-May-12	Movento [®] MPC ²	Spirotetramat	Bayer CropScience LP	1.17 L	\$126.18	2%	\$28.82
15-Jun-12	Imidan [®] 70-W	Phosmet	Gowan Company	1.12 kg	\$27.16	1%	\$14.41
16-Aug-12	Dimethoate 4EC ²	Dimethoate	Helena Chemical	1.75 L	\$23.75	2%	\$28.82
8-Nov-12	Delegate [®] WG ²	Spinetoram	Dow AgroSciences LLC	0.37 kg	\$115.11	1%	\$14.41
5-Dec-12	Danitol [®] 2.4 EC ³	Fenpropathrin	Valent	1.17 L	\$49.50	-	\$0
24-Jan-13	Movento [®] MPC ³	Spirotetramat	Bayer CropScience LP	1.17 L	\$126.18	2%	\$28.82
10-Apr-13	VoliamFlexi [®] ²	Thiamethoxam + Chlorantraniliprole	Syngenta	0.51 kg	\$115.57	1%	\$14.41
31-Oct-13	Closer [™] SC Insecticide ²	Sulfoxaflor	Dow AgroSciences LLC	0.37 L	\$77.37	3%	\$43.23
19-Dec-13	Imidan [®] 70-W ³	Phosmet	Gowan Company	1.12 kg	\$27.18	1%	\$14.41
22-Jan-14	Danitol [®] 2.4 EC ³	Fenpropathrin	Valent	1.17 L	\$49.50	-	\$0
22-Mar-14	Mustang [®] ²	Zeta-Cypermethrin	FMC Corporation	0.31 L	\$13.57	-	\$0
7-Jul-14	Exirel [®] ²	Cyantraniliprole	Du Pont	1.46 L	\$215.34	-	\$0
19-Dec-14	Lorsban [®] Advanced ³	Chlorpyrifos	Dow AgroSciences LLC	5.85 L	\$56.83	1%	\$14.41
14-Jan-15	Baythroid [®] XL ³	Fenpropathrin	Bayer CropScience LP	0.44 L	\$23.49	-	\$0
1-May-15	Agri-Flex [®] ²	Thiamethoxam + Abamectin	Bayer CropScience LP	0.62 L	\$67.92	1%	\$14.41
27-Jul-15	Apta [®] ²	Tolfenpyrad	Ninchino America Inc	1.82 L	\$86.54	-	\$0

¹ HMO: Horticultural Mineral Oil.

² Additional sprays conducted during the growing seasons (ACP populations in insecticide plots exceeded threshold).

³ Dormant spray applications.

Table 3. Components of the nutritional programs used in the experiment from 2012 to 2015.

		Product	Function	Company	Rate/ha	Cost/ha
2012-Sept 2013	Nutrition program 1	Serenade Max WP (<i>Bacillus subtilis</i> 26.2%)	SAR inducer	AgraQuest, Inc.	2.52 kg	\$65.33
		Saver TM (Potassium salicylate)	SAR inducer	Plant Food Systems	2.34 L	\$13.59
		3-18-20 w/K-Phite [®]	Macronutrient	Plant Food Systems	74.83 L	\$237.22
		13-0-44 fertilizer (KNO ₃)	Macronutrient	Diamond R Fertilizer	9.53 kg	\$15.12
		Techmangan (MnSO ₄)	Micronutrient	Diamond R Fertilizer	9.53 kg	\$15.75
		Zinc Sulfate	Micronutrient	Diamond R Fertilizer	3.14 kg	\$6.23
		Sodium Molybdate	Micronutrient	Diamond R Fertilizer	0.06 kg	\$3.15
		Epsom Salts (MgSO ₄)	Micronutrient	Diamond R Fertilizer	9.53 kg	\$6.30
		Purespray Green [®] (435 Oil)	Adjuvant	Petro-Canada Lubricants, Inc.	46.77 L	\$67.95
Oct 2013-Sep 2015	Nutrition program 2	Saver TM (Potassium salicylate)	SAR inducer	Plant Food Systems	9.35 L	\$54.34
		13-0-44 fertilizer (KNO ₃)	Macronutrient	Diamond R Fertilizer	9.53 kg	\$15.62
		Techmangan (MnSO ₄)	Micronutrient	Diamond R Fertilizer	9.53 kg	\$14.46
		Zinc Sulfate	Micronutrient	Diamond R Fertilizer	3.14 kg	\$6.23
		Sodium Molybdate	Micronutrient	Diamond R Fertilizer	0.06 kg	\$3.17
		Epsom Salts (MgSO ₄)	Micronutrient	Diamond R Fertilizer	9.53 kg	\$6.30
		Purespray Green [®] (435 Oil)	Adjuvant	Petro-Canada Lubricants, Inc.	46.77 L	\$67.95
		Beau-Ron [®] D (Boron)	Micronutrient	Drexel Chemical Co.	1.68 kg	\$5.00
		K-Phite [®]	Macronutrient	Plant Food Systems	4.68 L	\$34.62

Table 4. Summary of annual numbers of insecticide and nutritional applications, application costs and material costs based on Tables 1 and 2, and total costs for each growing season. All costs are in US Dollars.

	2012-2013	2013-2014	2014-2015	2015-2016	Sum
Growing season insecticide applications	4	2	2	2	10
Dormant sprays	2	2	2	0	6
Nutritional applications	3	2	2	2	9
Cost per application (\$/ha)	\$68.92	\$68.92	\$68.92	\$68.92	\$275.68
Material costs: growing season insecticides (\$/ha)	\$378.66	\$250.58	\$228.90	\$168.87	\$1,027.01
Material costs: dormant spray insecticides (\$/ha)	\$204.50	\$91.09	\$80.32		\$375.91
Material costs: nutritional program 1 (\$/ha)	\$1,291.92	\$430.64			\$1,722.56
Material costs: nutritional program 2 (\$/ha)		\$207.69	\$207.69	\$207.69	\$623.07
Total cost for growing season insecticide applications (\$/ha)	\$654.34	\$388.42	\$366.74	\$306.71	\$1,716.21
Total cost for dormant insecticide applications (\$/ha)	\$342.34	\$228.93	\$218.16		\$789.43
Total cost for nutritional program (\$/ha)	\$1,498.68	\$776.17	\$345.53	\$345.53	\$2,965.91

Table 5. Total cost (applications + materials) for each treatment per season (USD per ha).

Treatment	2012-2013	2013-2014	2014-2015	2015-2016	Sum
Insecticide + Nutrition	\$2,495.36	\$1,393.52	\$930.43	\$652.24	\$5,471.55
Insecticide	\$996.68	\$617.35	\$584.91	\$306.71	\$2,505.64
Nutrition	\$1,498.68	\$776.17	\$345.53	\$345.53	\$2,965.91
Untreated	\$342.34	0	0	0	\$342.34

Table 6. Mean $\pm$ SEM ACP adults and juveniles per bi-weekly stem tap samples by year for the interval between harvest (2012-2013, 2013-2014, 2014-2015, and 2015-2016) and the means of four growing seasons (2012-2016). (A) Main effects, (B) Treatment effects.

		Mature Trees									
ACP adults		2012-2013		2013-2014		2014-2015		2015-2016		2012-2016	
(A) Main Effects	Insecticide	0.08 $\pm$ 0.01	*	0.03 $\pm$ 0.01	*	0.04 $\pm$ 0.01	*	0.10 $\pm$ 0.02	*	0.06 $\pm$ 0.01	*
	No Insecticide	2.30 $\pm$ 0.23		0.24 $\pm$ 0.03		0.32 $\pm$ 0.03		0.59 $\pm$ 0.09		0.91 $\pm$ 0.08	
	Nutrition	0.68 $\pm$ 0.09	*	0.17 $\pm$ 0.02	*	0.19 $\pm$ 0.03		0.37 $\pm$ 0.09		0.35 $\pm$ 0.03	*
	No Nutrition	1.70 $\pm$ 0.23		0.10 $\pm$ 0.01		0.17 $\pm$ 0.02		0.31 $\pm$ 0.05		0.62 $\pm$ 0.07	
(B) Treatment Effects	Insecticide + Nutrition	0.08 $\pm$ 0.01	c	0.03 $\pm$ 0.01	c	0.02 $\pm$ 0.00	b	0.03 $\pm$ 0.01	c	0.04 $\pm$ 0.01	b
	Insecticide	0.09 $\pm$ 0.02	c	0.03 $\pm$ 0.01	c	0.05 $\pm$ 0.01	b	0.13 $\pm$ 0.04	c	0.07 $\pm$ 0.01	b
	Nutrition	1.26 $\pm$ 0.15	b	0.31 $\pm$ 0.04	a	0.35 $\pm$ 0.05	a	0.84 $\pm$ 0.16	a	0.68 $\pm$ 0.06	a
	Untreated	3.32 $\pm$ 0.41	a	0.18 $\pm$ 0.02	b	0.30 $\pm$ 0.04	a	0.36 $\pm$ 0.04	b	1.15 $\pm$ 0.14	a
ACP juveniles		2012-2013		2013-2014		2014-2015		2015-2016		2012-2016	
(A) Main Effects	Insecticide	0.55 $\pm$ 0.09	*	0.43 $\pm$ 0.09	*	2.53 $\pm$ 1.01	*	20.15 $\pm$ 4.12	*	3.67 $\pm$ 0.69	*
	No Insecticide	4.39 $\pm$ 0.66		4.47 $\pm$ 1.22		25.74 $\pm$ 5.05		80.43 $\pm$ 9.06		20.21 $\pm$ 2.09	
	Nutrition	2.00 $\pm$ 0.38		3.57 $\pm$ 1.21		20.48 $\pm$ 4.84	*	54.91 $\pm$ 8.49		14.45 $\pm$ 1.89	*
	No Nutrition	2.94 $\pm$ 0.58		1.33 $\pm$ 0.28		7.79 $\pm$ 2.02		45.66 $\pm$ 6.88		9.43 $\pm$ 1.21	
(B) Treatment Effects	Insecticide + Nutrition	0.44 $\pm$ 0.09	b	0.42 $\pm$ 0.10	c	3.67 $\pm$ 1.95	b	12.55 $\pm$ 3.30	b	2.93 $\pm$ 0.72	c
	Insecticide	0.63 $\pm$ 0.14	b	0.40 $\pm$ 0.15	c	1.40 $\pm$ 0.52	b	27.74 $\pm$ 7.88	b	4.41 $\pm$ 1.17	c
	Nutrition	3.42 $\pm$ 0.70	a	6.51 $\pm$ 2.28	a	37.29 $\pm$ 9.20	a	97.27 $\pm$ 14.29	a	25.95 $\pm$ 3.60	a
	Untreated	5.13 $\pm$ 1.05	a	2.04 $\pm$ 0.50	b	14.19 $\pm$ 3.91	a	63.59 $\pm$ 10.75	a	14.46 $\pm$ 2.10	b
		Reset Trees									
ACP adults		2012-2013		2013-2014		2014-2015		2015-2016		2012-2016	
(A) Main Effects	Insecticide	0.24 $\pm$ 0.05	*	0.09 $\pm$ 0.03	*	0.15 $\pm$ 0.03	*	0.14 $\pm$ 0.04	*	0.14 $\pm$ 0.02	*
	No Insecticide	1.12 $\pm$ 0.12		0.51 $\pm$ 0.07		0.52 $\pm$ 0.09		2.12 $\pm$ 0.51		0.96 $\pm$ 0.10	
	Nutrition	0.55 $\pm$ 0.08	*	0.32 $\pm$ 0.06		0.21 $\pm$ 0.04	*	0.99 $\pm$ 0.25		0.46 $\pm$ 0.06	*
	No Nutrition	0.76 $\pm$ 0.12		0.25 $\pm$ 0.05		0.46 $\pm$ 0.09		1.15 $\pm$ 0.44		0.59 $\pm$ 0.09	
(B) Treatment Effects	Insecticide + Nutrition	0.25 $\pm$ 0.07	c	0.13 $\pm$ 0.06	b	0.08 $\pm$ 0.02	c	0.06 $\pm$ 0.02	b	0.13 $\pm$ 0.03	c
	Insecticide	0.23 $\pm$ 0.08	c	0.05 $\pm$ 0.01	b	0.12 $\pm$ 0.04	c	0.21 $\pm$ 0.08	b	0.14 $\pm$ 0.03	c
	Nutrition	0.85 $\pm$ 0.13	b	0.50 $\pm$ 0.10	a	0.34 $\pm$ 0.08	b	1.91 $\pm$ 0.48	a	0.79 $\pm$ 0.10	b
	Untreated	1.47 $\pm$ 0.22	a	0.53 $\pm$ 0.10	a	0.91 $\pm$ 0.18	a	2.41 $\pm$ 1.01	a	1.19 $\pm$ 0.20	a

Mature Trees

ACP Adults: Main effects: * indicates significant effect ($P > 0.05$). Overall: Insecticide $F_{1, 1408} = 691.39$; $P < 0.001$. Nutrition $F_{1, 1340} = 5.29$; $P = 0.022$. Insecticide x Nutrition $F_{1, 1408} = 4.17$; $P = 0.041$. 2012-2013: Insecticide $F_{1, 409} = 639.57$; $P < 0.001$. Nutrition $F_{1, 409} = 18.29$; $P < 0.001$. Insecticide x Nutrition $F_{1, 409} = 16.16$; $P < 0.001$. 2013-2014: Insecticide $F_{1, 409} = 161.92$ $P < 0.001$. Nutrition $F_{1, 409} = 7.40$; $P = 0.007$. Insecticide x Nutrition $F_{1, 409} = 2.72$; $P = 0.999$. 2014-2015: Insecticide $F_{1, 361} = 134.08$; $P < 0.001$.

Nutrition $F_{1,361} = 0.00$; $P = 0.956$. Insecticide x Nutrition $F_{1,361} = 2.25$; $P = 0.135$. 2015-2016: Insecticide $F_{1,156} = 74.64$; $P < 0.001$. Nutrition $F_{1,156} = 1.15$; $P = 0.285$. Insecticide x Nutrition $F_{1,156} = 1.45$; $P = 0.230$.

Treatment effects. Different letters indicated differences ($P < 0.05$). Overall $F_{3,1408} = 129.99$; $P < 0.001$. 2012-2013: $F_{3,393} = 43.63$; $P < 0.001$. 2013-2014: $F_{3,393} = 37.29$; $P < 0.001$. 2014-2015: $F_{3,380} = 27.07$; $P < 0.001$. 2015-2016: $F_{3,156} = 59.10$; $P < 0.001$.

ACP Juveniles: Main effects: * indicates significant effect ($P > 0.05$). Overall: Insecticide $F_{1,1408} = 327.60$; $P < 0.001$. Nutrition $F_{1,1408} = 4.05$; $P = 0.044$. Insecticide x Nutrition $F_{1,1408} = 3.18$; $P = 0.075$. 2012-2013: Insecticide $F_{1,377} = 121.51$; $P < 0.001$. Nutrition $F_{1,377} = 2.00$; $P = 0.158$. Insecticide x Nutrition $F_{1,377} = 0.48$; $P = 0.487$. 2013-2014: Insecticide $F_{1,377} = 96.82$; $P < 0.001$. Nutrition $F_{1,377} = 9.37$; $P = 0.002$. Insecticide x Nutrition $F_{1,377} = 2.26$; $P = 0.134$. 2014-2015: Insecticide $F_{1,380} = 77.59$; $P < 0.001$. Nutrition $F_{1,380} = 1.79$; $P = 0.181$. Insecticide x Nutrition $F_{1,380} = 1.84$; $P = 0.176$. 2015-2016: Insecticide $F_{1,144} = 129.47$; $P < 0.001$. Nutrition $F_{1,144} = 1.46$; $P = 0.229$. Insecticide x Nutrition $F_{1,144} = 2.02$; $P = 0.157$.

Treatment effects. Different letters indicated differences ($P < 0.05$). Overall: $F_{3,1408} = 111.61$; $P < 0.001$. 2012-2013: $F_{3,377} = 41.33$; $P < 0.001$. 2013-2014: $F_{3,377} = 36.15$; $P < 0.001$. 2014-2015: $F_{3,108} = 9.71$; $P < 0.001$. 2015-2016: $F_{3,144} = 44.32$; $P < 0.001$.

Reset Trees

ACP Adults: Main effects: * indicates significant effect ($P > 0.05$). Overall: Insecticide $F_{1,1151} = 91.41$; $P < 0.001$. Nutrition $F_{1,1151} = 4.49$; $P = 0.0343$. Insecticide x Nutrition $F_{1,1151} = 3.63$; $P = 0.057$. (2012-2013): Insecticide $F_{1,281} = 126.14$; $P < 0.001$. Nutrition $F_{1,281} = 3.63$; $P = 0.058$. Insecticide x Nutrition $F_{1,281} = 7.94$; $P = 0.005$. (2013-2014): Insecticide $F_{1,385} = 96.96$; $P < 0.001$. Nutrition $F_{1,385} = 0.29$; $P = 0.593$. Insecticide x Nutrition $F_{1,385} = 0.31$; $P = 0.579$. (2014-2015): Insecticide $F_{1,295} = 31.29$; $P < 0.001$. Nutrition $F_{1,295} = 4.95$; $P = 0.027$. Insecticide x Nutrition $F_{1,295} = 6.84$; $P = 0.009$. (2015-2016): Insecticide $F_{1,151} = 24.01$; $P < 0.001$. Nutrition $F_{1,151} = 0.61$; $P = 0.435$. Insecticide x Nutrition $F_{1,151} = 0.17$; $P = 0.680$.

Treatment effects. Different letters indicated differences ($P < 0.05$). Overall: $F_{1,1151} = 31.14$; $P < 0.001$. (2012-2013): $F_{3,279} = 43.27$; $P < 0.001$. (2013-2014): $F_{3,384} = 33.10$; $P < 0.001$. (2014-2015): $F_{3,294} = 23.03$; $P < 0.001$. (2015-2016): $F_{3,151} = 8.04$; $P < 0.001$.

Table 7. Mean $\pm$ SEM of yields and fruit drop of oranges (kg) per tree for harvests associated with insecticide and foliar nutrition inputs (in the 2012-2013, 2013-2014, 2014-2015 and 2015-2016 growing seasons) and these years combined: A) Main effects, B) Treatment effects.

Yield												
Factor	2012-2013		2013-2014		2014-2015		2015-2016		Mean (all seasons)		Cumulative (all seasons)	
Insecticide	66.75 ± 3.71	*	89.39 ± 2.77	*	102.45 ± 4.47	*	77.50 ± 3.15	*	84.02 ± 2.94	*	336.10 ± 10.27	*
No Insecticide	51.70 ± 3.52		71.16 ± 2.68		90.99 ± 3.00		65.34 ± 3.49		69.80 ± 2.96		279.19 ± 11.00	
Nutrition	64.22 ± 3.39	*	82.73 ± 4.72	*	97.66 ± 2.78		77.02 ± 3.31	*	80.41 ± 2.76	*	321.63 ± 12.93	*
No Nutrition	54.23 ± 4.86		77.83 ± 3.82		95.78 ± 5.51		65.82 ± 3.57		73.41 ± 3.50		293.66 ± 15.33	
Insecticide + Nutrition	70.52 ± 1.42	a	93.38 ± 3.66	a	103.27 ± 3.42	a	84.40 ± 2.30	a	87.89 ± 3.36	a	351.57 ± 6.37	a
Insecticide	62.99 ± 7.25	a	85.41 ± 3.43	a	101.64 ± 9.00	ab	70.59 ± 3.05	ab	80.16 ± 4.73	a	320.62 ± 17.10	ab
Nutrition	57.92 ± 5.03	ab	72.07 ± 3.84	b	92.05 ± 1.88	ab	69.64 ± 3.09	b	72.92 ± 3.56	b	291.69 ± 11.89	bc
Untreated	45.48 ± 2.59	b	70.25 ± 4.25	b	89.92 ± 6.14	b	61.04 ± 5.91	b	66.67 ± 4.70	b	266.69 ± 17.86	c
Fruit Drop												
Factor	2012-2013		2013-2014		2014-2015		2015-2016		Mean (all seasons)		Cumulative (all seasons)	
Insecticide	34.76 ± 4.20		-		57.00 ± 3.09		-		45.88 ± 3.82		91.76 ± 4.50	
No Insecticide	23.21 ± 3.34		-		59.94 ± 2.38		-		41.58 ± 5.14		83.15 ± 3.93	
Nutrition	26.95 ± 3.06		-		57.73 ± 3.14		-		42.34 ± 4.50		84.64 ± 3.58	
No Nutrition	31.03 ± 5.27		-		59.21 ± 2.41		-		45.12 ± 4.59		90.24 ± 5.09	
Insecticide + Nutrition	33.90 ± 1.96	a	-		54.20 ± 5.36	a	-		44.05 ± 4.66	a	88.10 ± 4.77	a
Insecticide	35.63 ± 8.82	a	-		59.80 ± 3.26	a	-		47.71 ± 8.02	a	95.43 ± 7.93	a
Nutrition	20.00 ± 2.79	a	-		61.25 ± 3.01	a	-		40.63 ± 8.02	a	81.25 ± 5.42	a
Untreated	26.43 ± 6.13	a	-		58.63 ± 4.03	a	-		42.53 ± 6.97	a	85.05 ± 6.35	a

Yield

Overall mean main effects: Date - $F_{3,54} = 72.31$; $P < 0.001$; Insecticide - $F_{1,54} = 58.81$; $P < 0.001$; Nutrition - $F_{1,54} = 14.21$; $P < 0.001$; Nutrition x Insecticide - $F_{1,54} = 0.16$; $P = 0.691$.

Overall treatment effects: Date - $F_{3,54} = 24.39$; $P < 0.001$.

Cumulative main effects: Insecticide - $F_{1,9} = 33.21$; $P < 0.001$; Nutrition - $F_{1,9} = 8.02$; $P = 0.020$; Nutrition x Insecticide - $F_{1,9} = 0.09$; $P = 0.770$. Cumulative treatment effect: $F_{3,9} = 13.77$; $P = 0.001$.

2013: Insecticide - $F_{1,9} = 12.28$; $P = 0.007$; Nutrition - $F_{1,9} = 5.41$; $P = 0.045$; Nutrition x Insecticide - $F_{1,9} = 0.33$; $P = 0.582$. Treatment effect - $F_{3,9} = 6.01$; $P = 0.016$.

2014: Insecticide - $F_{1,9} = 75.25$; $P < 0.001$; Nutrition - $F_{1,9} = 5.44$; $P = 0.045$; Nutrition x Insecticide - $F_{1,9} = 2.14$; $P = 0.178$. Treatment effect - $F_{3,9} = 27.61$; $P < 0.001$.

2015: Main effects - Insecticide - $F_{1,9} = 6.78$; $P = 0.029$; Nutrition - $F_{1,9} = 0.18$; $P = 0.679$; Nutrition x Insecticide - $F_{1,9} = 0.00$; $P = 0.955$. Treatment effect - $F_{3,9} = 2.32$; $P = 0.144$.

2016: Main effects - Insecticide - $F_{1,9} = 13.80$; $P = 0.005$; Nutrition - $F_{1,9} = 11.73$; $P = 0.008$; Nutrition x Insecticide - $F_{1,9} = 0.63$; $P = 0.446$. Treatment effect - $F_{3,9} = 8.72$; $P = 0.005$.

Fruit Drop

Overall mean main effects: Date - $F_{1,21} = 75.52$; $P < 0.001$; Insecticide - $F_{1,21} = 1.55$; $P = 0.227$; Nutrition - $F_{1,21} = 0.65$; $P = 0.431$; Nutrition x Insecticide - $F_{1,21} = 0.06$; $P = 0.802$. Insecticide x Date - $F_{1,21} = 4.38$; $P = 0.049$. Overall treatment effects: Date - $F_{3,21} = 0.75$; $P = 0.533$. Treatment x Date $F_{3,21} = 1.80$; $P = 0.179$.

Cumulative main effects: Insecticide - $F_{1,9} = 1.28$; $P = 0.287$; Nutrition - $F_{1,9} = 0.33$; $P = 0.580$; Nutrition x Insecticide - $F_{1,21} = 2.51$; $P = 0.147$. Cumulative treatment effect: $F_{3,9} = 1.37$; $P = 0.312$.

2013: Insecticide - $F_{1,9} = 4.50$; $P = 0.063$; Nutrition - $F_{1,9} = 0.56$; $P = 0.473$; Nutrition x Insecticide - $F_{1,9} = 0.19$; $P = 0.676$. Treatment effect - $F_{3,9} = 1.75$; $P = 0.227$.

2015: Insecticide - $F_{1,9} = 1.28$; $P = 0.287$; Nutrition - $F_{1,9} = 0.33$; $P = 0.580$; Nutrition x Insecticide - $F_{1,9} = 2.51$; $P = 0.147$. Treatment effect - $F_{3,9} = 1.37$; $P = 0.312$.

Table 8. Mean $\pm$ error of juice quality measures of fruit collected at random at each harvest (2013, 2014, 2015, and 2016) from experimental plots: A) Main factors, B) Treatment effects.

		Factor	Juice (kg/box)	Solids (kg/box)	Acid (%w/w)	Brix (TSS)	Ratio
(A) Main Effects	2013	Insecticide	25.85 ± 0.62	2.69 ± 0.08	0.75 ± 0.01	10.4 ± 0.13	13.92 ± 0.29
		No Insecticide	25.08 ± 0.48	2.68 ± 0.07	0.79 ± 0.03	10.71 ± 0.25	13.58 ± 0.46
		Nutrition	25.41 ± 0.54	2.65 ± 0.08	0.78 ± 0.01	10.41 ± 0.16	13.44 ± 0.41
		No Nutrition	25.51 ± 0.61	2.72 ± 0.06	0.77 ± 0.03	10.7 ± 0.23	14.06 ± 0.33
	2014	Insecticide	24.42 ± 0.17	2.48 ± 0.03	0.65 ± 0.03	10.15 ± 0.12	15.81 ± 0.47
		No Insecticide	24.86 ± 0.14	2.53 ± 0.06	0.64 ± 0.01	10.18 ± 0.23	15.95 ± 0.35
		Nutrition	24.71 ± 0.20	2.46 ± 0.04	0.65 ± 0.03	9.96 ± 0.15	15.40 ± 0.45
		No Nutrition	24.57 ± 0.15	2.55 ± 0.05	0.64 ± 0.01	10.37 ± 0.17	16.36 ± 0.27
	2015	Insecticide	23.79 ± 0.39	2.65 ± 0.05	0.73 ± 0.01	11.16 ± 0.12	15.28 ± 0.22
		No Insecticide	23.84 ± 0.35	2.64 ± 0.08	0.72 ± 0.02	11.07 ± 0.24	15.36 ± 0.33
		Nutrition	23.85 ± 0.33	2.71 ± 0.07	0.74 ± 0.01	11.35 ± 0.20	15.45 ± 0.23
		No Nutrition	23.78 ± 0.41	2.59 ± 0.06	0.72 ± 0.02	10.88 ± 0.12	15.18 ± 0.31
	2016	Insecticide	24.90 ± 0.23	2.45 ± 0.04	0.62 ± 0.02	9.85 ± 0.12	16.10 ± 0.51
		No Insecticide	24.64 ± 0.24	2.40 ± 0.04	0.66 ± 0.02	9.73 ± 0.14	14.85 ± 0.40
		Nutrition	24.90 ± 0.24	2.41 ± 0.05	0.63 ± 0.01	9.69 ± 0.14	15.47 ± 0.48
		No Nutrition	24.65 ± 0.23	2.44 ± 0.04	0.64 ± 0.02	9.89 ± 0.12	15.47 ± 0.51
(B) Treatment Effects	2013	Insecticide + Nutrition	25.01 ± 0.84	2.57 ± 0.12	0.77 ± 0.01	10.26 ± 0.15	13.37 ± 0.25
		Insecticide	26.63 ± 0.83	2.80 ± 0.06	0.73 ± 0.02	10.55 ± 0.20	14.46 ± 0.37
		Nutrition	25.76 ± 0.76	2.72 ± 0.11	0.79 ± 0.03	10.56 ± 0.29	13.5 ± 0.84
		Untreated	24.40 ± 0.43	2.65 ± 0.10	0.8 ± 0.05	10.86 ± 0.43	13.66 ± 0.53
	2014	Insecticide + Nutrition	24.44 ± 0.23	2.48 ± 0.04	0.67 ± 0.05	10.14 ± 0.22	15.28 ± 0.86
		Insecticide	24.40 ± 0.28	2.48 ± 0.04	0.62 ± 0.02	10.16 ± 0.12	16.33 ± 0.27
		Nutrition	24.98 ± 0.28	2.44 ± 0.07	0.63 ± 0.01	9.77 ± 0.18	15.52 ± 0.42
		Untreated	24.74 ± 0.07	2.62 ± 0.07	0.65 ± 0.02	10.59 ± 0.30	16.39 ± 0.52
	2015	Insecticide + Nutrition	23.62 ± 0.50	2.67 ± 0.09	0.74 ± 0.02	11.31 ± 0.20	15.41 ± 0.30
		Insecticide	23.96 ± 0.66	2.64 ± 0.06	0.73 ± 0.01	11.01 ± 0.13	15.15 ± 0.35
		Nutrition	24.09 ± 0.46	2.74 ± 0.10	0.70 ± 0.01	11.39 ± 0.39	15.49 ± 0.41

	Untreated	23.60 ± 0.57	2.54 ± 0.10	0.71 ± 0.04	10.75 ± 0.20	15.22 ± 0.57
2016	Insecticide + Nutrition	24.97 ± 0.47	2.44 ± 0.09	0.61 ± 0.02	9.75 ± 0.21	16.04 ± 0.72
	Insecticide	24.83 ± 0.11	2.47 ± 0.03	0.62 ± 0.03	9.95 ± 0.14	16.16 ± 0.83
	Nutrition	24.83 ± 0.22	2.39 ± 0.05	0.65 ± 0.02	9.63 ± 0.21	14.91 ± 0.58
	Untreated	24.46 ± 0.22	2.40 ± 0.07	0.67 ± 0.03	9.83 ± 0.21	14.79 ± 0.65

2013,

Juice (kg/box); $F_{6,9} = 1.31$; $P = 0.344$ (model); 0.079 (Interaction); $P = 0.894$ (Nutrition); $P = 0.326$ (Insecticide);
Solids (kg/box); $F_{6,9} = 1.83$; $P = 0.200$ (model); 0.112 (Interaction); $P = 0.386$ (Nutrition); $P = 0.950$ (Insecticide);
Acid; $F_{6,9} = 0.57$; $P = 0.745$ (model); $P = 0.461$ (Interaction); $P = 0.710$ (Nutrition); $P = 0.200$ (Insecticide);
Brix; $F_{6,9} = 1.10$; $P = 0.431$ (model); $P = 0.982$ (Interaction); $P = 0.313$ (Nutrition); $P = 0.289$ (Insecticide);
Ratio; $F_{6,9} = 0.38$; $P = 0.873$ (model); $P = 0.470$ (Interaction); $P = 0.335$ (Nutrition); $P = 0.600$ (Insecticide).

2014,

Juice (kg/box); $F_{6,9} = 1.62$; $P = 0.247$ (model); 0.653 (Interaction); $P = 0.5220$ (Nutrition); $P = 0.071$ (Insecticide);
Solids (kg/box); $F_{6,9} = 1.57$; $P = 0.260$ (model); 0.155 (Interaction); $P = 0.156$ (Nutrition); $P = 0.384$ (Insecticide);
Acid; $F_{6,9} = 1.53$; $P = 0.271$ (model); $P = 0.220$ (Interaction); $P = 0.542$ (Nutrition); $P = 0.740$ (Insecticide);
Brix; $F_{6,9} = 1.67$; $P = 0.236$ (model); $P = 0.096$ (Interaction); $P = 0.087$ (Nutrition); $P = 0.889$ (Insecticide);
Ratio; $F_{6,9} = 1.29$; $P = 0.353$ (model); $P = 0.862$ (Interaction); $P = 0.105$ (Nutrition); $P = 0.788$ (Insecticide).

2015

Juice (kg/box) - Insecticide: $F_{6,9} = 0.37$; $P = 0.879$ (model); 0.650 (Interaction); $p = 0.900$ (Nutrition); $p = 0.930$ (Insecticide);
Solids (kg/box); $F_{6,9} = 0.37$; $P = 0.882$ (model); 0.435 (Interaction); $P = 0.268$ (Nutrition); $P = 0.901$ (Insecticide);
Acid; $F_{6,9} = 0.34$; $P = 0.898$ (model); $P = 0.731$ (Interaction); $P = 0.527$ (Nutrition); $P = 0.731$ (Insecticide);
Brix; $F_{6,9} = 0.70$; $P = 0.656$ (model); $P = 0.548$ (Interaction); $P = 0.120$ (Nutrition); $P = 0.752$ (Insecticide);
Ratio; $F_{6,9} = 1.11$; $P = 0.424$ (model); $P = 0.987$ (Interaction); $P = 0.496$ (Nutrition); $P = 0.837$ (Insecticide)

2016

Juice (kg/box) - Insecticide: $F_{6,9} = 1.20$; $P = 0.388$ (model); $P = 0.716$ (Interaction); $P = 0.434$ (Nutrition); $p = 0.426$ (Insecticide);
Solids (kg/box); $F_{6,9} = 0.37$; $P = 0.882$ (model); $P = 0.435$ (Interaction); $P = 0.268$ (Nutrition); $P = 0.901$ (Insecticide);
Acid; $F_{6,9} = 1.10$; $P = 0.429$ (model); $P = 0.840$ (Interaction); $P = 0.547$ (Nutrition); $P = 0.110$ (Insecticide);
Brix; $F_{6,9} = 0.70$; $P = 0.656$ (model); $P = 0.548$ (Interaction); $P = 0.120$ (Nutrition); $P = 0.752$ (Insecticide);
Ratio; $F_{6,9} = 86$; $P = 0.557$ (model); $P = 0.873$ (Interaction); $P = 1.00$ (Nutrition); $P = 0.119$ (Insecticide)
(B):

2013,

Juice (kg/box); $P = 0.241$ (Treatment); **Solids (kg/box);** $P = 0.330$ (Treatment); **Acid;** $P = 0.484$ (Treatment), **Brix;** $P = 0.521$ (Treatment); **Ratio;** $P = 0.612$ (Treatment).

2014,

Juice (kg/box); $P = 0.253$ (Treatment); **Solids (kg/box);** $P = 0.203$ (Treatment); **Acid;** $P = 0.548$ (Treatment); **Brix;** $P = 0.136$ (Treatment); **Ratio;** $P = 0.392$ (Treatment)

2015,

Juice (kg/box); $P = 0.897$ (Treatment); **Solids (kg/box);** $P = 0.473$ (Treatment); **Acid;** $P = 0.850$ (Treatment); **Brix;** $P = 0.302$ (Treatment); **Ratio;** $P = 0.906$ (Treatment)

2016,

Juice (kg/box); $P = 0.388$ (Treatment); **Solids (kg/box);** $P = 0.314$ (Treatment); **Acid;** $P = 0.429$ (Treatment); **Brix;** $P = 0.259$ (Treatment); **Ratio;** $P = 0.558$ (Treatment)

Table 9. Marginal economic analysis of insecticide, nutrition and insecticide + nutrition treatments costs and benefits on citrus trees.

Production was calculated as the kg solids per box (the mean value per year was used), multiplied by the numbers of boxes per tree and assuming 377 trees per ha. Transport/picking costs were calculated based on the mass of fruit harvested from each treatment and assuming \$2.82 per 40.82 kg (Muraro, 2012a). Gross income was based on the average delivered-in price per year (NASS, 2014¹, NASS, 2015²; Spreen, 2015³) and the mean delivered-in price for cumulative estimates. Net income is the gross income minus input costs per ha.

Year	Treatment	boxes/ha	kg s/ha	Treatments	Transport/picking	Sum	Average delivered-in price \$/kg s ^{1,2,3}	Gross income \$/ha	Net income \$/ha
2013	Insecticide + Nutrition	644.39	1730.18	\$2,426.44	\$1,817.18	\$4,243.62	\$3.53	\$6,107.55	\$1,795.01
	Insecticide	575.58	1545.44	\$996.68	\$1,623.14	\$2,619.82	\$3.53	\$5,455.40	\$2,835.58
	Nutrition	529.25	1421.05	\$1,429.76	\$1,492.50	\$2,922.26	\$3.53	\$5,016.30	\$2,025.12
	Untreated	415.58	1115.84	\$342.34	\$1,171.94	\$1,514.28	\$3.53	\$3,938.90	\$2,424.62
2014	Insecticide + Nutrition	853.28	2137.46	\$1,393.52	\$2,406.24	\$3,799.76	\$3.79	\$8,100.96	\$4,301.20
	Insecticide	780.45	1955.02	\$617.35	\$2,200.87	\$2,818.22	\$3.79	\$7,409.54	\$4,591.33
	Nutrition	658.55	1649.67	\$776.17	\$1,857.12	\$2,633.29	\$3.79	\$6,252.26	\$3,618.98
	Untreated	641.92	1608.01	\$0.00	\$1,810.22	\$1,810.22	\$3.79	\$6,094.37	\$4,284.15
2015	Insecticide + Nutrition	943.65	2498.31	\$930.43	\$2,661.09	\$3,591.52	\$4.62	\$11,542.18	\$7,742.97
	Insecticide	928.75	2458.88	\$584.91	\$2,619.09	\$3,204.00	\$4.62	\$11,360.00	\$8,156.01
	Nutrition	841.12	2226.87	\$345.53	\$2,371.97	\$2,717.50	\$4.62	\$10,288.16	\$7,570.66
	Untreated	821.66	2175.34	\$0.00	\$2,317.08	\$2,317.08	\$4.62	\$10,050.09	\$7,733.01
2016	Insecticide + Nutrition	771.22	1870.21	\$652.24	\$2,174.84	\$2,827.08	\$4.62	\$8,640.36	\$5,813.28
	Insecticide	645.03	1564.19	\$306.71	\$1,818.98	\$2,125.69	\$4.62	\$7,226.58	\$5,100.89
	Nutrition	636.35	1543.14	\$345.53	\$1,794.50	\$2,140.03	\$4.62	\$7,129.32	\$4,989.29
	Untreated	557.76	1352.58	\$0.00	\$1,572.89	\$1,572.89	\$4.62	\$6,248.91	\$4,676.01
Cumulative	Insecticide + Nutrition	3212.53	8236.16	\$4,750.39	\$6,884.50	\$11,634.89	\$4.14	\$34,097.70	\$27,827.77
	Insecticide	2929.81	7523.53	\$2,198.94	\$6,443.09	\$8,642.03	\$4.14	\$31,147.43	\$28,146.98
	Nutrition	2665.28	6840.74	\$2,551.46	\$5,721.58	\$8,273.04	\$4.14	\$28,320.66	\$25,412.59

Untreated	2436.93	6251.77	\$342.34	\$5,299.24	\$5,641.58	\$4.14	\$25,882.34	\$25,882.34
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Figure caption

Figure 1. Mean $\pm$ SEM ACP adults per tap sample taken at two week intervals from May 2012 to March 2015. ▽ Insecticide application based on threshold ACP levels of 0.2 ACP/tap in 2013 and 0.1 in 2014 and 2015. ▾ Dormant season (winter) insecticide applications. ΔFoliar nutrition applications.

Figure 2. Mean ($\pm$ SEM) Ct values and incidence of HLB in reset trees by treatment as indicated by real-time PCR analysis.