Is Area-Wide Pest Management Useful? The Case of Citrus Greening

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Abstract

Citrus greening currently poses a severe threat to citrus production worldwide. No treatment or management strategy is yet available to cure the disease. Scientists recommend controlling the vector of the disease, and area-wide pest management has been proposed as a superior alternative to individual pest management. We analyzed a unique dataset of farm-level citrus yields that allowed us to test this hypothesis. We found that yields of blocks located in an area with higher participation in coordinated sprays were 28%, 73% and 98% percent higher in 2012/13, 2013/14, and 2014/15, respectively, compared to the yields of blocks under the same management but located in an area with lower participation; providing evidence on the efficiency of a well-performing pest management area to deal with HLB. However, participation in CHMAs has not been commensurate with this evidence. We present survey data that provide insights about producers' preferences and attitudes toward the area-wide pest management program. Despite the economic benefit we found area-wide pest management can provide, the strategic uncertainty involved in relying on neighbors seems to impose too high of a cost for most growers, who end up not coordinating sprays.

Keywords: Area-wide pest management, citrus greening, common property, externalities, pest management

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IS AREA-WIDE PEST MANAGEMENT USEFUL?
THE CASE OF CITRUS GREENING

Introduction

Citrus greening or Huanglongbing (HLB) is a bacterial disease affecting groves in major citrus production areas in the world, including the U.S., Brazil, Asia, Africa, and the Arabian Peninsula (USDA-APHIS 2015). Caused by the bacterium *Candidatus* Liberibacter asiaticus and vectored by the Asian citrus psyllid (ACP), HLB is considered to be the most devastating citrus disease worldwide (FAO 2015); it affects citrus trees' vascular system, limiting nutrient uptake, negatively affecting yield, fruit size and quality, tree mortality, and cost of production. To date, no treatment or management strategy is yet available for growers to cure the disease.

Florida is the largest orange producing state in the U.S. In fact, Florida alone is the second-largest orange juice producer in the world behind Brazil. First found in Florida in 2005, HLB has spread rapidly across the state and reached epidemic proportions. It is estimated that, on average, 90% of the acreage in a citrus operation in Florida is currently infected with HLB (Singerman and Useche 2016).

Since HLB was found in Florida, orange acreage and yield have decreased by 28% and 44%, respectively.[1] HLB has had a major impact on the profitability of orange production. Despite the fact that on-tree prices for oranges have increased from $2.89 to $9.34 a box (USDA-NASS 2016), the cost of production per box has increased by a higher percentage (CREC 2016a) because growers changed the management of their groves in an attempt to slow down the disease's progress and infection rate. The most recent estimates of aggregate economic stakes involved are by Hodges et al. (2014). They estimated that the citrus industry total output impact in Florida in 2012/13 was $10.68 billion. The authors also estimated the economic impacts of HLB over the period 2006/07 through 2013/14 at a loss of $7.80 billion in cumulative industry output, or an annual average loss of $975 million. Their estimates do not include the impact of HLB on the fresh citrus fruit market or grapefruit and specialty citrus for processing. Further, given that the impact of HLB on yield, production, and growers' profitability has been more pronounced in recent years, we expect current annual HLB-induced losses to be even higher.

The conventional protocol to manage HLB has consisted of routinely inspecting trees for symptoms, as well as controlling the ACP by means of insecticide sprays. If symptoms are found on a tree, removal of such tree has been recommended to ensure the elimination of the inoculum (Bové 2006). However, growers in Florida have been reluctant to eradicate symptomatic trees that were still productive. Therefore, as an alternative management strategy to eradication, they started applying foliar applications of nutrients in an attempt to bypass the blockage of phloem vessels HLB causes (Spann et al. 2010). Thus, sprays for the vector of the disease, the ACP, and enhanced nutritional programs for citrus trees account for the bulk of the increase in the costs of producing oranges in Florida.

Pest Mobility and Area-Wide Pest Management

Management of localized pest populations by individual farmers on a field-by-field basis has been the most widely used strategy for pest control (Klassen 2008). However, the effectiveness of individual uncoordinated treatments is compromised by the mobility of pests (Vreysen, Robinson, and Hendrichs 2007). In fact, recent work on the characteristics and mobility capabilities of the ACP call for an area-wide perspective in pest control. While it has been hypothesized that the ACP can be carried by air masses over long distances, scientists recently found the ACP is capable of traveling 2 kilometers within 12 days (Lewis-Rosenblum et al. 2015).

In contrast to individual farm pest management, area-wide pest management is based on the premise of addressing the pest population of an entire area, not just a single farm (Faust 2008). The idea underlying such efforts is that it provides a larger and more lasting effect relative to individual (uncoordinated) farm sprays. Area-wide pest management is also aimed at reducing the risk of developing pesticide resistance (Vreysen, Robinson, and Hendrichs 2007). Yu and Leung (2006) found evidence that area-wide pest management is superior to individual farm pest spraying in the presence of pest mobility.

It is due to their mobility that pests can also be viewed as common property. Neighboring growers share the pest; therefore, crop damage is dependent not only on the individual farm pest population, but also on the total pest population in the region. Because of reinfestation from neighboring farms, actions on individual farms have little effect on the density of the pest in future periods in that farm (Lazarus and Dixon 1984). Thus, individual pest management results in under-provision of pest control from a societal perspective (Yu and Leung 2006), creating a disparity between private and social optima (Reguev, Gutierrez and Federer 1976). As pointed out by Miranowski and Carlson (1986), collective pest-control may result in a higher level of welfare relative to individual optimization.

By coordinating pest control, groups may internalize externalities and increase the productivity of pest-control inputs. An example of a successful area-wide pest management program in the U.S. is the boll weevil eradication program (Dickerson and Haney 2001). However, area-wide pest management programs are not without challenges. Despite the desirable technical, economic, and environmental attributes of area-wide pest management, the implementation of such programs can encounter resistance due to concerns over methods, free riding, general public opposition, and lack of stakeholder participation, among other issues (Mumford 2000; Klassen 2000). Ostrom (1990), however, describes a number of cases of successfully governed common-pool resources that provide theoretical and empirical alternatives to the idea that multiple individuals jointly using a resource cannot avoid the problems that arise from their common use of it.

The purpose of this study is twofold. The first objective consists of analyzing whether citrus blocks in area-wide ACP control management programs in Florida — known as Citrus

Health Management Areas (CHMAs) — with higher levels of participation have attained greater economic benefits. Knowing whether growers in properly functioning CHMAs obtain greater profits than growers in CHMAs with poor participation, or who do not participate in CHMAs at all, should be important for industry stakeholders and policymakers alike. Given that there is currently no cure or successful strategy to manage HLB, should properly functioning CHMAs be found to be more profitable, more growers should join and coordinate their efforts. Furthermore, policymakers should provide additional incentives for growers to join these area-wide pest management programs, and provide support for effective communication and coordination of ACP sprays among local citrus growers and grove managers.

The second objective of the study is to examine citrus growers' attitudes toward CHMAs. Rook and Carlson (1985) examined the producer's choice between group and individual pest control, and argued that if the differential benefit of joining a group is greater than the differential cost, then the farmer should join the group. In this regard, Keenan and Burgener (2008) argue that since area-wide pest management programs typically rely upon voluntary adoption, the new practices must demonstrate their economic advantage. But, is it reasonable to assume that a higher expected payoff will suffice to entice growers' participation? What should be included in the definition of cost? Is coordination with neighbors an issue? Olson (1965, p.2) argued that "unless the number of individuals is quite small, or unless there is coercion or some other special device to make individuals act in their common interest, rational, self-interested individuals will not act to achieve their common or group interests." Better information about producers' preferences and opinions regarding CHMAs should prove useful in designing incentive mechanisms to enhance grower participation in CHMAs.

In the next sections, we first describe the context of area-wide pest management in citrus production. Then, we conceptually illustrate how insects and cultural practices of neighboring producers can affect each other. The empirical part follows, first analyzing the impact of CHMAs with different levels of participation on yields and producer benefits and, second, examining grower participation decisions in CHMAs. Finally, we consider the potential impact of the 2016 Citrus Crisis Declaration on area-wide pest management efforts in Florida before presenting our conclusions.

Area-Wide Pest Management in Brazil and Florida

Florida's main competitor as orange-juice producer is Brazil. The largest orange producing area in Brazil is the state of São Paulo, where HLB was found in 2004. To date, the magnitude of the impact of HLB in Brazil has not been as dramatic as in Florida, mainly because Brazilian growers adopted tree eradication (inoculum removal) at the beginning of the outbreak. However, despite its lower spread relative to Florida, HLB still imposes a significant economic burden on Brazilian producers in terms of costs of scouting for psyllids, tree removal, and insecticide applications (Belasque et al. 2010).

Bassanezi et al. (2013) showed evidence of the ineffectiveness of combining inoculum removal and sprays for ACP in non-area-wide control areas. Contrastingly, they also found that combining those strategies in an area-wide management program was effective in reducing the disease epidemics. An interesting case study of cooperation for ACP control in Brazil was reported by Johnson and Bassanezi (2016), in which a large (corporate) grower started an ACP control program beyond his grove borders. Having noticed increasing infection rates on the edges of his groves, the grower offered neighboring small growers and backyard citrus homeowners – within a 2.5-mile radius of their operations – to spray their trees monthly. Alternatively, homeowners were also offered replacement fruit trees other than citrus. According to the authors, the grower obtained a return of $30 for every dollar spent in the program during the first two years.

The establishment of an area-wide management program for ACP in the state of Florida was proposed as part of the strategic plan for the state's citrus industry to address HLB (National Academy of Sciences 2010). Thus, CHMAs were created around 2010, as voluntary groupings of growers to work cooperatively to coordinate insecticide application timing and mode of action to control the spread of ACP across neighboring commercial citrus groves in Florida. CHMAs were originally proposed to encompass areas of 10,000 to 50,000 acres. There were 35 active CHMAs in Florida in 2012. By 2015 the number of CHMAs had increased to 55, which were distributed across 26 counties. However, only 19 of those CHMAs were estimated to be active (CREC 2016b).

Besides citrus growers, key participants in CHMAs are the University of Florida's Institute of Food and Agricultural Sciences (UF/IFAS), the Florida Department of Agriculture and Consumer Services (Division of Plant Industries), and the U.S. Department of Agriculture's Animal and Plant Health Inspections Service (USDA-APHIS) (through the Citrus Health Response Program (CHRP) under Plant Protection and Quarantine (PPQ)). The former institution is in charge of facilitating communication of information between researchers and scientists, whereas the latter two provide ACP scouting data and mapping of CHMAs. Growers, scientists, and UF/IFAS extension agents cooperated to delineate areas. The criteria included infection rates, psyllid control practices, tree removal practices, presence of abandoned groves, location of groves following organic practices, as well as target markets for the fruit (Rogers et al. 2010).

Conceptual Framework

To illustrate the pest management externality occurring across neighboring farms, consider two adjacent growers A and B, and assume all inputs other than pest control are identical. The following two equations exemplify the individual profit functions for growers A and B, respectively, and highlight that insects and cultural practices of neighboring producers can affect each other (Norgaard 1976).

(1) $\pi_A = p\, F_A(X_A, X_B) - r\, X_A,$

(2) $\pi_B = p\ F_B(X_A, X_B) - r\ X_B$,

where p is the price of output, $F_i(\cdot)$ denotes the amount produced by grower i, X_i represents the level of pest control input used by grower i, and r is the price of such input. Importantly, the amount produced by grower A ($F_A(X_A, X_B)$) depends not only on her amount of input used (X_A), but also on the amount of input used by grower B (X_B), and vice versa. Thus, even though grower A can only choose her own pest management inputs, grower B's input choice also enters into grower A's profit function.

Typically, producers do not coordinate their use of inputs with their neighbors. That is, growers usually choose the amounts of inputs to maximize their own farm's profits. Thus, since growers do not take into account the effect of their choices on their neighbors, the individual "myopic" first-order necessary conditions for optimization for growers A and B are represented by equations (3) and (4), respectively,

(3) $$\frac{\partial \pi_A}{\partial X_A} = p\ \frac{\partial F_A}{\partial X_A} - r = 0,$$

(4) $$\frac{\partial \pi_B}{\partial X_B} = p\ \frac{\partial F_B}{\partial X_B} - r = 0.$$

Equation (3) implies that farmer A will choose the amount of input X_A so as to equate her individual marginal revenue ($p\ \partial F_A/\partial X_A$) to her individual marginal cost (r), disregarding the fact that her input choice also affects her neighbor's marginal revenue (because $F_B(X_A, X_B)$ is a function of X_A). Equation (4) has an analogous implication regarding farmer B's input choice.

Under an area-wide management plan, farmers agree on the pest management program and coordinate efforts. Thus, the following joint maximizing problem takes place:

(5) $max_{X_A,X_B}\ \pi = p\ F_A(X_A, X_B) + p\ F_B(X_A, X_B) - r\ X_A - r\ X_B - c\ X_A - c\ X_B,$

where *c* denotes the cost of the coordination efforts per unit of input. In this instance, the first order conditions are given by:

(6) $$\frac{\partial \pi}{\partial X_A} = p\ \frac{\partial F_A}{\partial X_A} - r + (p\ \frac{\partial F_B}{\partial X_A} - c) = 0,$$

(7) $$\frac{\partial \pi}{\partial X_B} = p\ \frac{\partial F_B}{\partial X_B} - r + (p\ \frac{\partial F_A}{\partial X_B} - c) = 0.$$

By comparing expressions (3) and (4) to (6) and (7), the terms in parentheses that appear in the latter two equations denote the additional marginal profits to farmer B and A, respectively, derived from the pest control actions in the neighbor's farm. Thus, if the marginal value product of the neighbor's pest control on the grower's farm is greater than the cost of coordination ($p\ \partial F_B/\partial X_A > c$, $p\ \partial F_A/\partial X_B > c$), the marginal benefit of coordination is positive. Therefore, in this case coordinating the use of inputs to control the pest as in (6)-(7) outperforms the solution obtained under individual optimization given by (3)-(4).

To achieve the joint profit maximization outcome under area-wide pest management, all (or, at least a majority) of growers may need to optimize in the same manner; that is, participate in the area-wide pest management program. Should a significant number of growers in an area use the individual maximization criterion instead – making participation fall below a minimum threshold – the resulting pest control would be lower compared to the efficient outcome, and therefore, a higher pest population should be observed in that area.

We consulted with entomologists to address the key issue regarding the percentage of adoption needed for an area-wide ACP management program to be effective, but they were not aware of any study establishing what the threshold of that majority should be. However, to the extent that our data includes CHMAs with different levels of participation, our findings allow us to empirically assess the issue.

CHMA Production Data and Analysis

In this section we test the underlying hypothesis that a CHMA with higher level of participation – where more growers coordinate their pest-control management efforts – results in a differential yield level compared to an area in which growers do not coordinate as much. Our goal is to quantify the differential economic benefit derived from a higher level of participation in CHMAs.

Data

Our production data pertain to two sets of Valencia orange blocks, each located in a different CHMA. The first set of data includes six blocks comprising 221 acres located in CHMA 1. The second set includes five blocks with a total of 161 acres located in CHMA 2. The data on annual yields include production by block for crop years 2008/09 to 2014/15, constituting a panel data set for those blocks.

The two CHMAs are located in neighboring counties in Central Florida and the blocks have comparable management and climatic conditions. A salient feature of our data is that the same grower owns all the blocks, which have been managed under the same practices (i.e., number of sprays, nutritional programs, and fertilizer applications) and have similar characteristics in terms of production region, tree age, tree density, and reset plantings.[2] However, participation of fellow growers in the two CHMAs is different. From personal communication with the grower who provided the data – and who is also the leader in both CHMAs – we learned that roughly 80% of the acreage in CHMA 2 is owned by two large corporate growers (in fact, they were formerly sister companies), a factor that certainly contributed to make coordination easier in that CHMA. Contrastingly, land ownership in CHMA 1 is divided among a higher number of large growers, and some of them are reluctant to participate in the program. The CHMA's captain estimated participation in CHMA 2 to be three to five times higher than in CHMA 1.

Given the characteristics of this data set, the differing "treatment" across blocks is the level of participation in the area-wide pest-control management program. Figure 1 shows the average number of ACPs found by the USDA-APHIS-PPQ-CHRP in the two CHMAs for which we have production data.[3] With a few exceptions, it is clear from the figure that CHMA 2 has a lower average number of ACPs through the entire series compared to CHMA 1. The production data associated with these two CHMAs is analyzed econometrically next.

Analysis

To assess whether there was any statistically significant difference in the mean level of yield attained in the two sets of blocks before CHMAs were established, we conducted a t-test using yield data for the year 2008/09. The results, reported in table 1, provide no evidence that yields were different between the two sets of blocks previous to the establishment of the CHMAs.

To determine whether yields between blocks differed after establishing the CHMAs, we performed a regression of the yield (in boxes per acre) for block j in year t as a function of dummy variables representing crop years 2009/10 through 2014/15, and dummy variables interacting crop years and CHMA 2 (CHMA2 × year). In this way, the coefficients of the crop year dummy variables encompass the overall incidence that weather, pests and disease had on that year's yield (on CHMA 1). Since there were no extreme weather events during those years, it can be sensibly argued that any effect to be found during those years is due to HLB. The interaction dummy variables (CHMA2 × year) are intended to capture the differential yield per acre of CHMA 2 through time.

We analyzed the data using two methods, a random effects model and a pooled OLS model with clustered standard errors. The implicit assumption underlying the former model is that the unobserved effects are uncorrelated with all explanatory variables. To account for the serial correlation in the errors, we computed the random effects estimator (i.e., the feasible Generalized Least Squares (GLS) estimator described on pp. 470-471 of Wooldridge 2003). For comparative purposes, we also estimated a pooled Ordinary Least Squares (OLS) regression with clustered standard errors, which provides robust standard errors to correlation among errors of the same block and heteroscedasticity over time.

Regression results are shown in table 2. The estimated coefficients are similar in both models, and the same variables are found to be statistically significant. However, to be conservative, we discuss the results of the random effects model because they provide somewhat less favorable results to CHMA 2 than the pooled OLS model with clustered standard errors. All of the coefficients from year 2012/13 onwards are negative and significant at standard levels. In contrast, the coefficients corresponding to the years prior to 2011/12 are not significantly different from zero. The lack of significance for the coefficients corresponding to these earlier years is not surprising, because the effects and rate of infection of HLB were not as widespread then as they have been in more recent years. In addition, CHMAs were merely starting to be organized at the time. However, it is interesting to note that the coefficient for year 2011/12 is positive and significant, denoting an increase in yield relative to the base year. This result can be explained in the light of the freezes that occurred in 2010/11, which actually ended up causing minor damage to the crop, but fears of a shortage in supply caused a 24% increase in the average season (on-tree) price. Since growers typically adjust their level of grove caretaking expenses in the same direction of price changes, it is likely that the higher yield in 2011/12 was a consequence of such behavior. As denoted by the dummy variables year 2012/13, year 2013/14, and year 2014/15, yields in CHMA 1 decreased with respect to 2008/09 by 61.0, 140.1, and

183.7 boxes per acre, respectively; all three coefficients are both statistically and economically significant.

Figure 2 illustrates the regression results reported in table 1, but in terms of total boxes per acre by CHMA. Our finding of significantly higher yields in 2011/12 but lower yields starting in 2012/13 in CHMA 1 is in line with the pattern in average Valencia oranges yield observed for the state. Figures 3 and 4 show USDA-NASS (2016a) estimates on Florida's average yield and percentage of fruit drop, as well as the number of fruit per box; two of the major symptoms of HLB are increased fruit drop and smaller fruit size.

Another key result from our regression estimation is the magnitude and significance of the coefficients corresponding to the interaction variables. The dummy CHMA2 × Year 2012/13 (CHMA2 × Year 2013/14) [CHMA2 × Year 2014/15] shows that the yield in 2012/13 (2013/14) [2014/15] was, on average, 72.5 (134.5) [137.0] boxes per acre higher in blocks located CHMA 2 compared to those located in a CHMA 1. Therefore, the partial offsetting effect of CHMA 2 against the negative impact of HLB on yields is increasing over time (at a decreasing rate). This finding is consistent with the general idea that benefits from investments in area-wide programs accrue over a multi-year time horizon (Klassen 2008).[4]

Table 3 reports the differential yields and a measure of the differential annual economic benefit accruing to CHMA 2 over CHMA 1. To compute the differential benefit, we multiply the differential annual yield obtained above by the corresponding price per box. Thus, we combine -25.8 (72.5) [134.5] {137.0} boxes per acre with the annual average on-tree price per box for processed Valencias in 2011/12 (2012/13) [2013/14] {2014/15}, which was $11 ($8.60) [$10.75] {$10.50} (USDA-NASS 2016a). By doing so, we obtain an estimated differential gross economic benefit per acre of -$284 ($624) [$1,446] {$1,439} in 2011/12 (2012/13) [2013/14] {2014/15}.

To estimate the direct cost of CHMA participation, we assume the annual program of CHMA 2 consists of 8 sprays, which in many cases can be applied aerially and cost $8 per acre each (column 6 of table 3), plus the average cost of materials at $18 (column 7 of table 3). Clearly, in this case the cumulative net benefit is positive as shown in column 8 of table 3. However, even if a grower needed to perform ground applications, which cost $25 per acre each, assuming a stand-alone application (although a tank mix with other chemicals is typically used instead to make the application cheaper), the cumulative net benefit is still positive and substantial as shown in column 9 of table 3. Note the cumulative net benefit is positive not only when considering years in which a positive statistically significant differential benefit was observed, but also when considering all years since CHMAs started in 2010/11 and assuming no yield differential during the first year. In our example, we also assume zero cost of the spray program of CHMA 1, which makes our case stronger and provides evidence of the efficiency of CHMA 2 to deal with HLB, and enhance the individual growers' profitability at a time when margins are becoming increasingly narrow

CHMA Participation

To the best of our knowledge, there are no data available about participation in CHMAs. But, as mentioned above, the majority of CHMAs across the state are not active, which is startling given the magnitude of our findings (even if they represented a best-case scenario) and the impact of the disease across the state.

The lack of state-wide participation in CHMAs is also startling given that our findings suggest that despite a high percentage of compliance is needed for spray coordination to yield significant results, participation need not be 100%. CHMAs can neither be characterized as a weakest-link public good problem. In such a case a grower's success hinges on that of the fellow grower making the least effort, which was not supported by our results. The weakest-link public good characterization of the problem is applicable to the more stringent effort needed for an eradication program (Ervin and Frisvold 2016).

Even though the CHMA program is neither of the two extreme cases just described, their analysis and policy implications can be useful for improving CHMAs participation. Perrings et al. (2002) looked at the control of invasive species in multiple countries and argue that if control is left to the uncoordinated efforts of individual countries, there will be insufficient control to protect the public interest. In their model of the weakest-link public good, Vicary and Sandler (2002) allow an agent to provide its own increments to the public good or, alternatively, bolster the provision efforts of another agent to raise the overall level of the public good. The authors found that when costs differ between agents, in-kind transfers from the low-cost agent to the high-cost agent can improve welfare.

CHMAs themselves are uniform in their cost structure and approach. The main costs involved are those of spraying and coordinating; there are no trainings involved. Since the communication for coordinating sprays is by email, its cost is given by the time and effort required. In addition, the CHMAs captains post general comments on the CHMAs websites, so there is no coordination organization establishment, and there are no fixed costs associated with it.

In the case of HLB, however, other aspects of grower heterogeneity should be taken into account when designing and implementing a program such as CHMAs. Scientific evidence suggests it would be important to take into account grove heterogeneity. Bassanezi (2010) found that when HLB symptoms start to be visible in young trees, they can already affect up to 30% of the tree canopy, whereas in mature trees they affect less than 5% of the canopy at the onset. In addition, Bassanezi and Bassanezi (2008) found that, without HLB control, young trees experience a yield reduction two to three years after the onset of symptoms, while for mature trees the timeframe is five to ten years after onset. As Bassanezi (2010) points out, the different impact of the disease on trees of different ages can present a challenge for HLB management; owners of mature groves might be reluctant to adopt control measures and, therefore, impose an externality (e.g.: source of inoculum) on neighboring growers willing to plant new trees. Caplat, Coutts and Buckley (2012) argue that subsidizing the control efforts of the players with the least incentive to control increases the confidence of the whole group regarding the usefulness of their efforts, and this becomes a self-fulfilling belief. Their results, together with Vicary and Sandler (2002), justify the in-kind transfers occurring in Brazil described by Johnson and Bassanezi (2016).

As pointed out by a reviewer, the existence of small-scale "lifestyle farmers", who could be less motivated by profit incentives, may be a challenge for CHMAs participation. In this regard, one could (arbitrarily) assume that citrus growers with less than 5 acres represent such "lifestyle farmers". In 2012, 26% of Florida citrus producers (955 out of 3,639) had operations with less than 5 acres, but accounted for only 0.3% of the acreage (1,546 out of 539,181 total acres) (USDA-NASS 2012). However, the experience with the Boll Weevil Eradication program discussed next strongly suggests that abandoned citrus acreage in Florida, which is currently estimated at 130,684 acres (USDA-NASS 2016b), constitutes at present a much more serious problem.

The success of the Boll Weevil Eradication program resided in the identification of cotton stalks as the major diapausing (overwintering) habitat for the insect (Carlson, Sappie and Hammig 1989). In fact, with the exception of the extreme southern Texas area, the only host plant for the boll weevil in the U.S. is American cotton. Thus, the coordinated diapause control treatments that were part of the eradication effort were directed to destroy overwintering weevil populations in cotton plants. The treatments were estimated to suppress 90-95% of the weevil population (Smith 1998). The ACP, on the other hand, has multiple host plants (Martini et al. 2013). So, despite the effectiveness of insecticide applications during the winter for reducing ACP populations, they do not prevent resurgence in the Spring. However, there is some evidence that suggests that citrus is the primary host during winter, at least in central Florida. Therefore, commercial groves with little or no ACP management, such as abandoned groves, may be significant overwintering sites and a haven for the ACP (Martini, Pelz-Stelinski and Stelinski

2016). There is an initiative from the Florida Department of Agriculture and Consumer Services that provides incentives for growers to remove abandoned groves, but it is estimated that the funds available will cover the removal of only 15,000 acres.[5]

CHMA Participation Survey

Given the dearth of information about grower participation in CHMAs, we recently conducted a paper-based survey with Florida citrus growers to learn more about their behavior related to CHMAs and their attitudes toward the area-wide pest management program. The survey took place at a meeting of Florida citrus growers in April 2016. The purpose of the meeting was to summarize the scientific advances and recommended practices to manage HLB. There were 310 attendees to the event, including growers, researchers, extension agents, media, and state officials. The number of growers in the audience was estimated at 140.

The morning session of the day-long meeting in which growers were surveyed was divided into two; the first half was devoted to rootstock tolerance to HLB, after which there was a 15-minute break. The second half of the morning session included three talks, one on scion tolerance and two on ACP management. The surveys were distributed as people entered the room after the coffee break, just before the second half of the morning session started. Thus, participants filled out the forms on their own, (mostly) before and in between the talks – as they sat waiting for the next talk to start – but perhaps some participants filled them out at the end of that second half. The moderator reminded the audience several times during the session to complete the survey. Participants handed back the survey once that set of talks was over and exited the room to go for lunch. It is unlikely that the sessions had any significant influence on their responses because the questions asked in the survey were about the practices growers had already been doing and their reasons for doing so (e.g., whether a grower participated in CHMAs and the reasons for doing so are unlikely to be influenced by any information provided).

The number of completed surveys by growers was 123, giving a response rate of 88%. The high response rate was likely due to the fact that a University of Florida merchandise clipboard was given to all respondents as a token of appreciation. The growers who responded to the survey represented 153,278 acres, which accounts for approximately one-third of the citrus acreage in Florida.

The survey form is reproduced in the Appendix. Succinctly, questions were designed to gather information on the following. First, whether the grower was participating in CHMAs at the time of the survey. Second, if not participating, growers had to rank their level of agreement with statements describing their reasons for not participating. And, if they did participate, growers had to rank their level of agreement with statements describing what they thought were the main obstacles to increase CHMAs effectiveness. Third, CHMA participants were also asked about the level of participation in coordinated sprays.

When asked about CHMA participation, we obtained 120 responses; 45 (37.5%) of the growers stated they do not currently participate, whereas 75 (62.5%) stated they do. Out of the 75 CHMA participants, 57 answered the question asking the extent to which they participate in coordinated sprays. Only 23 growers (40% of those who responded to the question) self-reported that they participated in coordinated sprays 100% of the time. The majority of growers (60%) stated that they participated less than 100% of the time: 14 (25%) growers participated between 76 to 99% of the time, 10 (18%) participated between 51 to 75% of the time, and 10 (17%) participated less than 50% of the time (see figure 5).[6]

The lack of participation in coordinated sprays can be explained, to some extent, by the current lack of profitability in citrus production; during the last three seasons, the average Florida citrus grower was only able to break even (see figure 6). Moreover, the comparison of annual citrus production budgets shows that growers are reducing caretaking inputs, particularly insecticide applications (CREC 2016a). However, given the evidence we presented above, reducing coordinated sprays might end up imposing a compounding cost, rather than savings, on those growers as well as on their neighbors. In this regard, larger operations might be at an advantage compared to smaller operations, since the former are less dependent upon the willingness of neighboring growers to participate in CHMAs.

Another question asked in the survey to non-CHMA participants concerned their reasons for not participating in coordinated sprays. Figure 7 shows graphically their responses on a Likert scale. The top reason growers mentioned for not participating in CHMAs was that other growers do not participate. That is, most growers perceive (correctly or not) that other growers are reluctant to coordinate efforts to control the pest. Similarly, Ervin and Frisvold (2016) report that for the case of managing resistance of mobile weeds, growers believe such a management to be beyond their control and instead dependent on neighbors' actions, which discourages them from proactively managing resistance. This (lack of) assurance that an individual's actions will be matched by fellow growers is what Ostrom (2009) referred to as norms/social capital; that is, sharing norms of reciprocity, which is one of the variables Ostrom identified as affecting the likelihood of self-organization to achieve sustainable Social-Ecological Systems. The second top reason growers mentioned for not participating in CHMAs was "I prefer to spray on my own timing," implying growers' own reluctance to coordinate efforts with other growers. In addition, "too much effort to coordinate" was the reason receiving the third-largest percentage of "agree" responses from non-CHMA participants.

The responses from CHMA participants regarding obstacles to increase CHMAs effectiveness are summarized in figure 8. Like non-participants, CHMA participants stated neighbors not participating as the top obstacle to increase CHMAs effectiveness. Interestingly, as depicted in figures 7 and 8, other than their agreement on neighbors' participation, CHMA participants and non-participants diverged on their opinions on whether it is too much effort to coordinate; it is too costly to spray; the usefulness of spraying; and the benefit of CHMAs. Of course, participants have actual experience regarding spray coordination, have incurred in the cost of CHMAs' sprays, and are aware of the effectiveness of spraying and its benefits.

However, the divergence of opinion between participants and non-participants makes the latter's motives for not joining stand out even further.

An additional reason argued by some growers for not participating in CHMAs is that, given the current widespread level of infection across the state, they do not believe in the usefulness of spraying for the ACP. Survey results included in figure 7 help illustrate this point; the figure shows that a total of 37% of non-CHMA participants agree or somewhat agree with the statement that it is no longer useful to spray for the ACP.

Overall, it is clear from the survey responses that (lack of) coordination has been a major obstacle for the establishment and correct operation of CHMAs. Our hypothesis is that strategic uncertainty — defined as uncertainty regarding the actions and beliefs of others — also plays a key role in undermining CHMAs participation. As Morris and Shin (2002, p. 2) put it, "the idea is that even a small seed of doubt concerning the ability of the players to close ranks to achieve the good outcome will start to undermine the resolve of an individual player to stick to the cooperative strategy, and opt out". In another manuscript we are working on, we have analyzed data of a choice experiment that shows that the coordination requirement (i.e.: percentage of growers needed to coordinate) as well as the number of growers in a CHMA adversely affect their participation decisions. Thus, we think there is a behavioral component involved.

Potential Impact on CHMAs of the 2016 Citrus Crisis Declaration

The cultural practices of Florida citrus growers have changed significantly in the last 10 years in an attempt to deal with HLB, but none has worked so far. It is highly unlikely that solely improving area-wide spray coordination efforts on groves that already show severe HLB-induced tree decline would change the outlook for those groves. In March 2016, the Florida Commissioner of Agriculture declared a citrus crisis under the Emergency Exemptions provisions of the Federal Insecticide, Fungicide, and Rodenticide Act (FDACS 2016). The main goal of the declaration was to allow growers across the state to use streptomycin and oxytetracycline in foliar applications to attempt to enhance the health of trees infected with HLB. Given that the expected enhancement of streptomycin and oxytetracycline on HLB-infected trees is not yet proven — particularly given that most of the compound sprayed is not absorbed by the tree but lost in the environment or leeched into the soil — the citrus crisis declaration provides yet more evidence of the dire situation faced by Florida citrus growers due to HLB. It is precisely due to the gravity of the situation growers are facing that they are willing to try any alternative that they believe shows promise. So it was growers, through their associations, that were pushing to obtain approval for the use of streptomycin and oxytetracycline in Florida groves.

Quite interestingly, ACP population data suggest that the declaration has had the unintended effect of increasing the ACP infestation. As shown in figure 1, the two CHMAs analyzed above experienced a substantial spike in the average number of ACP per block in 2016, reaching record levels in both CHMAs. More importantly, figure 9 shows that this spike occurred statewide, and that the average ACP population in Florida achieved an all-time high in 2016. Significantly, such spike occurred shortly after the citrus crisis announcement allowing for the use of streptomycin and oxytetracycline in Florida, which suggests that growers are likely substituting insecticide applications with streptomycin and oxytetracycline. This substitution would imply that growers are getting away from the strategic uncertainty that CHMAs pose, and taking instead the risky/uncertain outcome that the self-managed strategy of applying streptomycin and oxytetracycline present (which they evidently perceive to be lower).

The basic tenet of allowing for the use of streptomycin and oxytetracycline to manage HLB (i.e., that they might improve the condition of the trees infected with HLB) requires little coordination among growers. Thus, if streptomycin and oxytetracycline are eventually found unable to enhance the health of HLB-infected trees, encouraging its use now may severely hamper the chances to control HLB, not only because of the compounds' ineffectiveness, but also because of their lack of reliance on the coordination required for CHMAs' success.

Conclusions and Policy Implications

In our analysis of data on yields of Valencia oranges from blocks located in two CHMAs with different levels of participation, we found that the number of boxes per acre decreased significantly from 2012/13 through 2014/15. Since there were no extreme weather events such as hurricanes or freezes during those years, we argue that those variables capture mainly the increasing negative impact of HLB on yields. We also found that the yields of blocks located in the CHMA with higher participation were 73 (28%), 135 (73%) and 137 (98%) boxes per acre (percent) higher in 2012/13, 2013/14, and 2014/15, respectively compared to the yields of the blocks located in the CHMA with lower participation during those same years. This translates into a gross differential benefit per acre of $624, $1,446, and $1,439 in 2012/13, 2013/14, and 2014/15, respectively. Thus, the partial offsetting effect found in the higher participation CHMA against the negative impact of HLB on yields has increased over time.

Our findings provide evidence on the efficiency of a well-performing CHMA to deal with HLB. However, participation in CHMAs has not been commensurate with this evidence; CHMAs present growers with strategic uncertainty. We found that the top reason stated by growers for not participating in CHMAs was their belief about their neighbors not participating. The second most important reason given for not participating in CHMAs was the grower's preference for self-reliance in spraying. These results help explain why participation in CHMAs and, therefore, their success is not as widespread across Florida as one would expect. Despite the relatively high benefit we found CHMAs can provide, the strategic uncertainty involved in relying on neighbors seems to impose too high of a cost for most growers, who end up not coordinating sprays. Florida's recent approval of the use of streptomycin and oxytetracycline to manage HLB presented growers with a new alternative to combat the disease. It is still unclear whether such compounds will prove effective against HLB, but it seems they might have had an unfortunate side effect on CHMAs, the one strategy for which we found evidence that works to manage HLB. Thus, efforts should be made at the state level not only to prevent the cooperation among growers achieved in some areas from vanishing, but also to increase coordination to threshold levels that make cooperation among producers efficient against HLB across all citrus growing regions in Florida.

A mandatory component in CHMAs – that replaces its current voluntary character – along with some form of enforcement seems crucial to overcome the issues of heterogeneity of growers and their groves, abandoned acreage, as well as the side effect of streptomycin and oxytetracycline on CHMAs. Faust (2008) summarizes the characteristics of an area-wide pest management program envisioned by Edward F. Knipling – a strong proponent of regional pest management; it included a mandatory component to ensure the success of the program due to the suboptimal level of pest management observed under voluntary programs. Ostrom (1990) identified eight design principles that characterized robust common-pooled resource institutions; monitoring and graduated sanctions are two of them. Thus, users who violate the rules are assessed a sanction. In this context, Levi (1988) argues that strategic actors comply with rules when they can expect others to comply as well, because those who do not are subject to coercion.

As suggested by a reviewer, a possible way to ensure sufficient levels of participation to achieve the highest social welfare is the implementation of a smart regulatory approach, e.g., one based on performance. While such an approach might potentially have the added advantage of decreasing the growth in use of chemicals in citrus production, it would require growers to disclose and self-report how good (or not) they are doing (i.e., report yields) to be able to establish the subsidies and payments based on performance. The introduction of this change to CHMAs is likely to be resisted by growers; it would require a high degree of coercion (to collect the data) and a significant monitoring effort (to prevent growers from understating their self-reported performance). A performance-based approach may also be difficult to implement because CHMAs are not the only strategy growers are taking against HLB. Thus, the scheme would need to be very elaborate to avoid confounding the effects of different strategies and penalizing adopters of those other strategies. For example, if a grower decides to stop replanting trees, as some are already doing – e.g., until an HLB-resistant tree variety is released – his/her yields will start to decrease. So assessing performance assuming only a CHMA effect would penalize the grower who is replanting.

Based on our findings and the existing related literature, we recommend the CHMA scheme to be modified as follows. First, we propose CHMAs to become mandatory in commercial citrus groves across the state. Growers would be assessed charges for the sprays on a per acre basis. As it was the case for the Boll Weevil Eradication Program, the use of subsidies may contribute to reduce the potential controversy that mandatory CHMA sprays may generate. Second, we also recommend the introduction of monitoring and sanctions for non-complying growers. Third, the introduction of in-kind transfers among growers seems a plausible approach to complement CHMAs and achieve appropriate levels of participation. Such an approach has demonstrated economic benefits in Brazil, and would be useful to complement governmental efforts in the removal of abandoned acreage. The government could further incentivize growers to make such transfers by declaring them eligible for some form of tax-break or other appropriate subsidies. Fourth, as suggested by Pretty et al. (2001), we recommend the use of processes that support communication and learning among farmers as an incentive for them to adopt sustainable practices more permanently, rather than only during the duration of the program. In addition, according to Klassen (2000), successful adoption of an area-wide pest management scheme may also enable producers to pool resources to use technologies, information systems, and expertise that are otherwise too expensive for individual producers. The pooling of resources would, for example, enable improved specialized analysis of pest immigration patterns and help implement approaches to prevent or retard the development of insecticide resistance

The above policy changes would benefit not only Florida citrus growers but also all Florida residents. The impact of the significant increase in chemical use in the last few years across the industry has not yet been measured nor analyzed. Less-intensive ACP control programs applied area-wide have been found to be as efficient as, or more efficient than, more intensive programs in non-area-wide control areas (Bassanezi et al. 2013). There are long-term environmental benefits derived from reducing insecticides applications (Ervin and Frisvold 2016). Furthermore, CHMAs success may lower the overall use of other chemicals, including nutritionals and fertilizer.

Finally, our survey findings suggest that additional research is needed to learn more about the transaction costs of implementing the CMHA approach. We hypothesize that strategic uncertainty plays a key role on growers' participation decisions in area-wide pest management programs. When describing the processes of organizing and governing Common Pool Resources, Ostrom (1990) pointed out that uncertainty reduction is costly and never fully accomplished. She also noted that the uncertainty derived from strategic behavior remains even after acquiring knowledge about the resource system. Over time, agents increase their understanding of the physical world and what to expect from the behavior of other agents. Given the devastating effect of HLB in Florida and its incipient spread to other U.S. citrus producing regions, further research is needed to help speed up the learning process regarding the factors that influence the strategic behavior of agents in the context of area-wide pest management areas.

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Appendix

2016 Florida Growers Survey

1) Which of the following best describes your current responsibilities? (choose all that apply)

☐ Grove owner ☐ Production manager/Foreman ☐ Caretaker ☐ Other:___________________

2) Do you currently participate in CHMAs sprays? ☐ Yes ☐ No

If you answered NO, indicate which of the following explain your reasons for not participating:

(circle one number per row)

	Disagree		Somewhat Agree		Agree	
Neighbors do not participate	1	2	3	4	5	N/A
Too much effort to coordinate sprays	1	2	3	4	5	N/A
It is too costly to spray	1	2	3	4	5	N/A
No longer useful to spray for ACP	1	2	3	4	5	N/A
I prefer to spray on my own timing	1	2	3	4	5	N/A
Plan on exiting the industry soon	1	2	3	4	5	N/A
Benefit (yield) not worth it	1	2	3	4	5	N/A

If you answered YES, indicate what you think are the main obstacles to increase CHMAs effectiveness against HLB:

(circle one number per row)

	Disagree		Somewhat Agree		Agre	
Neighbors do not participate	1	2	3	4	5	N/A
Too much effort to coordinate sprays	1	2	3	4	5	N/A
It is too costly to spray	1	2	3	4	5	N/A
Decreasingly effective to spray for ACP	1	2	3	4	5	N/A
Benefit (yield) decreasing	1	2	3	4	5	N/A

3) How many times did you spray for ACP during 2015/16 (without including CHMAs sprays)?_________

4) How many times did you participate in coordinated sprays as part of CHMAs during 2015/16?_________

5) What percentage of times did you participate in coordinated sprays when an email from the CHMAs captain was sent during 2015/16?___________%

Endnotes

1. Even though HLB was first found in Florida in 2005, the initial figures we use next to illustrate its impact on the industry correspond to 2004 because they provide a better estimate of the scale of the industry prior to HLB. Florida was hit by four hurricanes between August and September of 2004. A little over a year later, in October 2005, another hurricane hit the state. Those hurricanes had a significant negative impact on yield and, therefore, production of oranges statewide in 2005, 2006, and 2007.

2. Characteristics for which we do not have data include soil quality and soil pH. We are not aware of differing biophysical conditions that might influence the incidence of ACP between the two areas. The major factors (i.e., cultural practices) are controlled for by blocks having identical management.

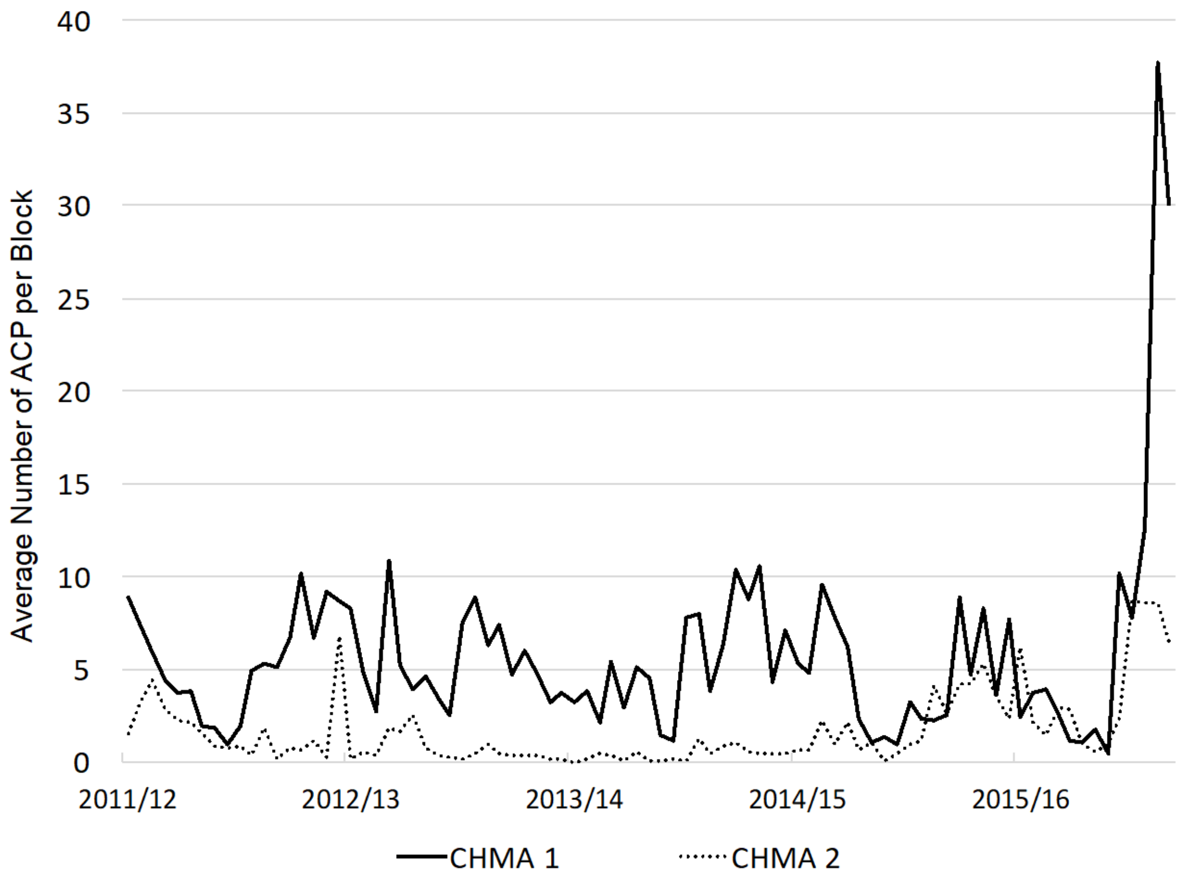
3. The USDA-APHIS-PPQ-CHRP started scouting and monitoring ACPs within CHMAs in August 2011.

4. The differential yield of CHMA 2 with respect to CHMA 1 is increasing through time, likely due to the biophysical phenomenon that higher populations of ACP result in bacterial re-infection of trees by ACP (therefore, the higher level of bacteria in trees makes their yield decrease more sharply through time). While area-wide ACP management reduces ACP populations, it does not eliminate HLB. Thus, despite the bacterial load in trees located in CHMA 2 being presumably lower, HLB still causes those trees to decline, though at a lower rate.

5. Personal communication with the person in charge of the program. See also: http://www.freshfromflorida.com/Divisions-Offices/Plant-Industry/Agriculture-Industry/Citrus-Health-Response-Program/Abandoned-Grove-Initiative

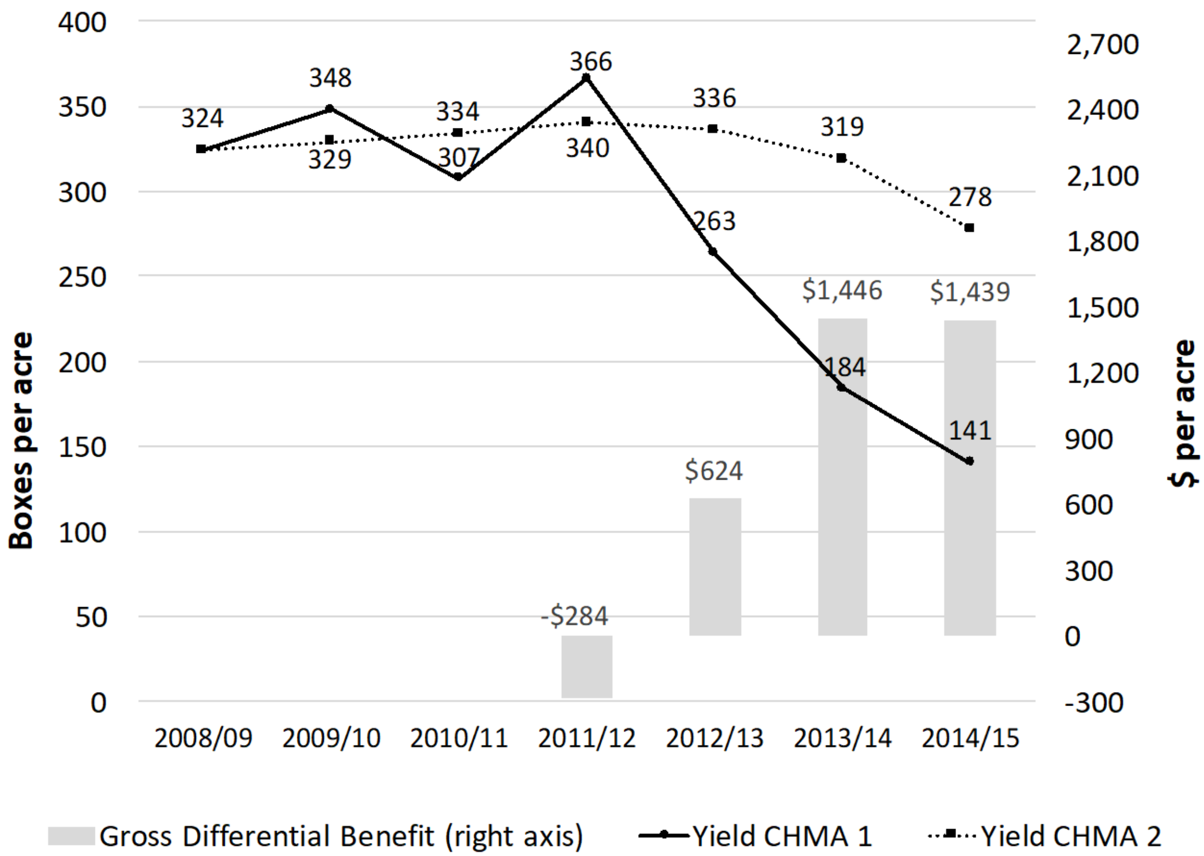
6. Unfortunately, there are no data on patterns of CHMA participation that we could compare our sample to.

Figure 1. Average number of ACP per block by CHMA



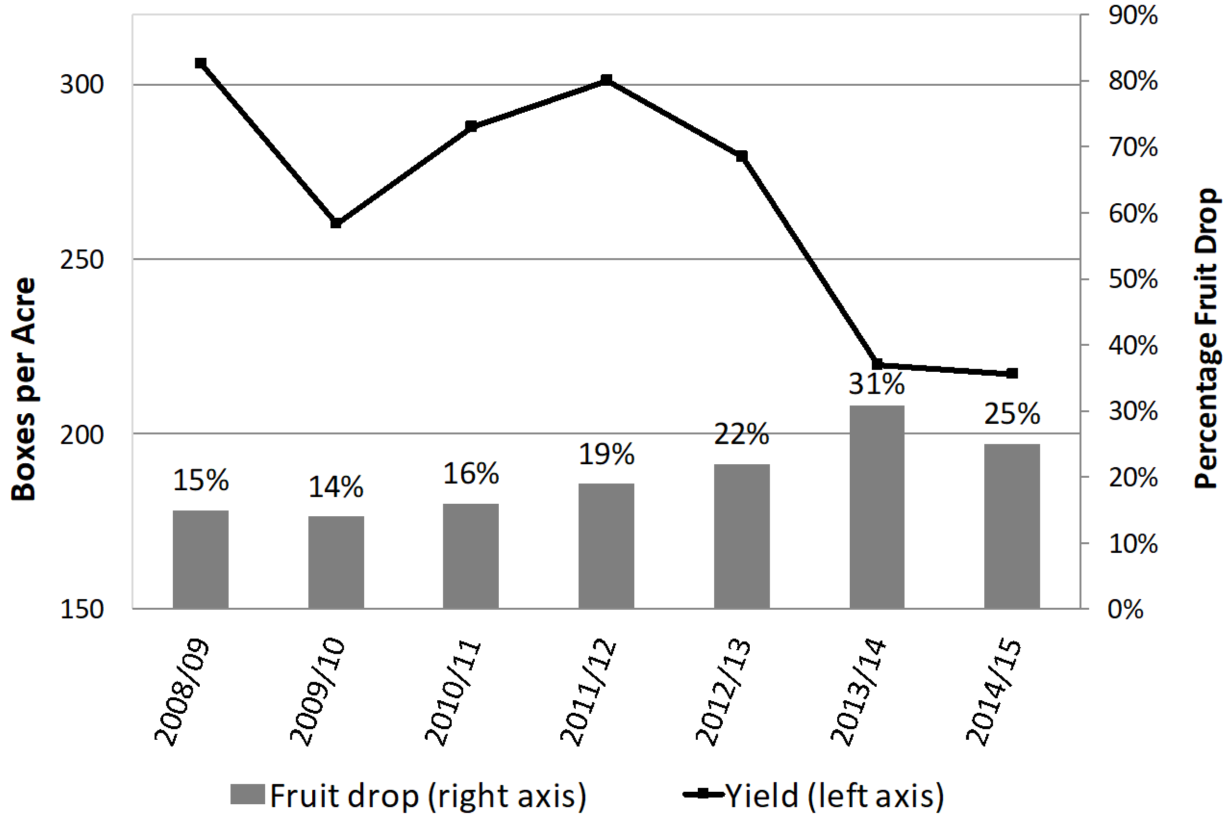
Source: USDA-APHIS-PPQ-CHRP.

Figure 2. Regression results: yield per acre by CHMA and gross differential benefit



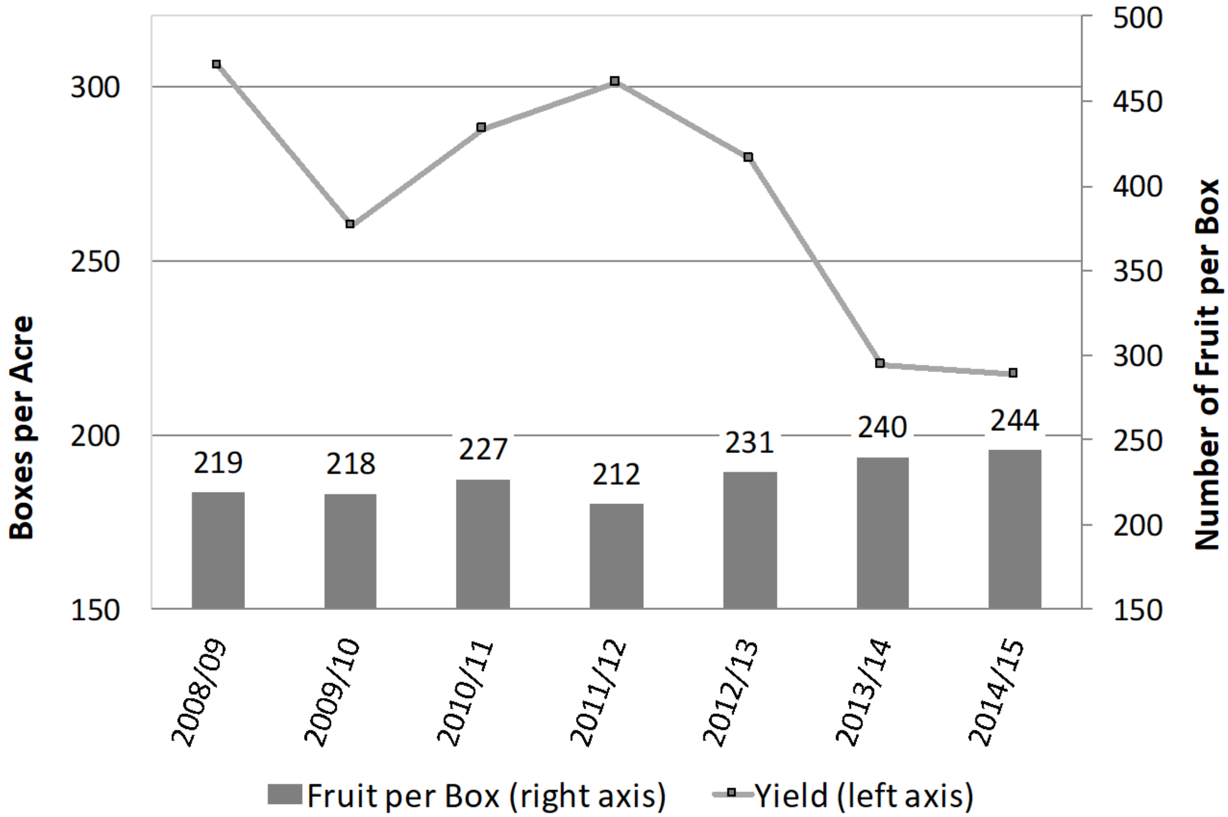
Source: Authors' calculations.

Figure 3. Yield and fruit drop of Valencia oranges in Florida



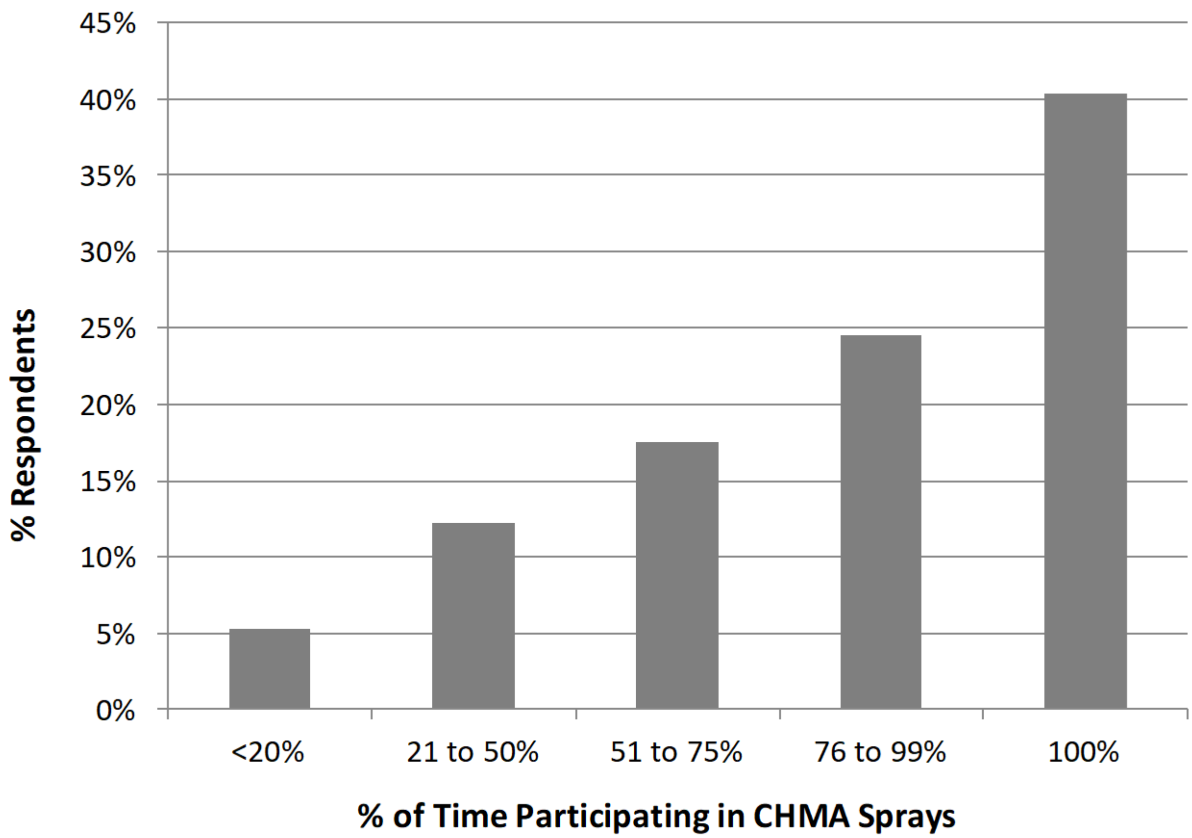
Source: USDA-NASS.

Figure 4. Yield and fruit size of Valencia oranges in Florida



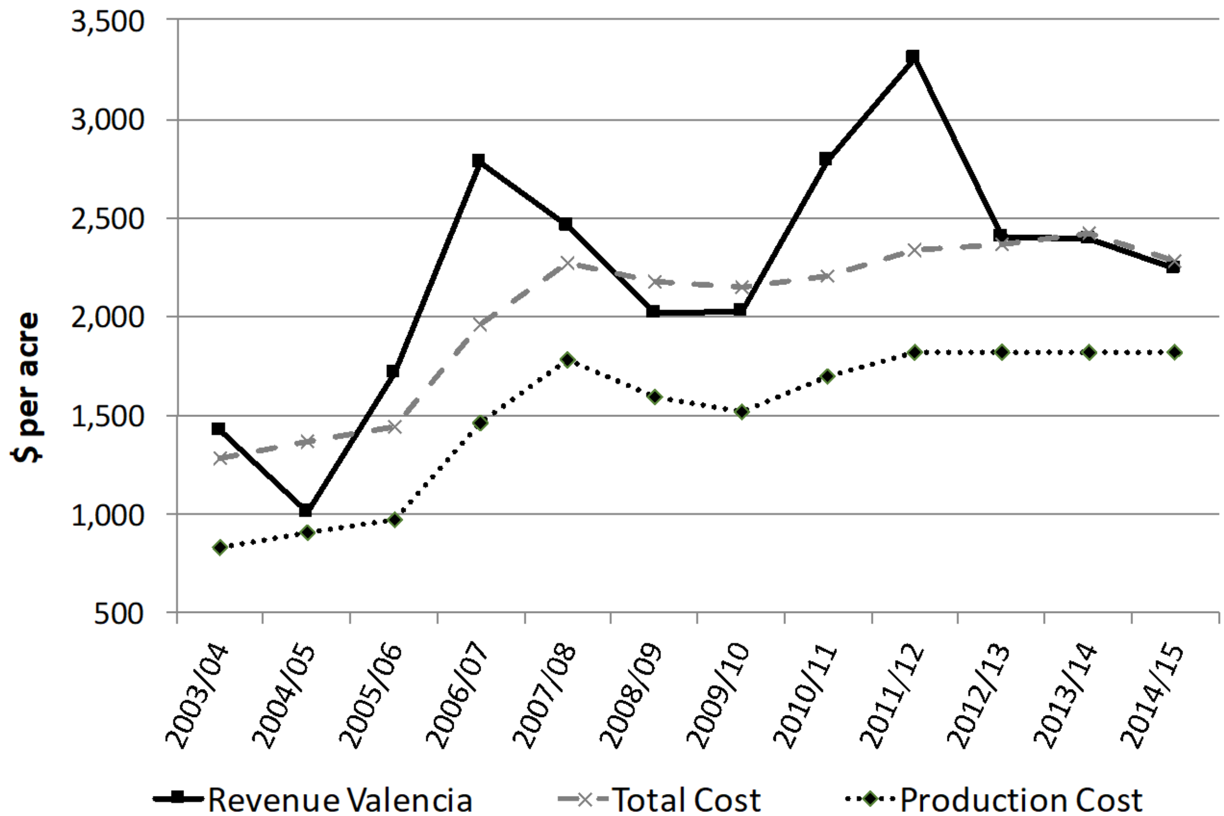
Source: USDA-NASS.

Figure 5. Level of CHMA participation



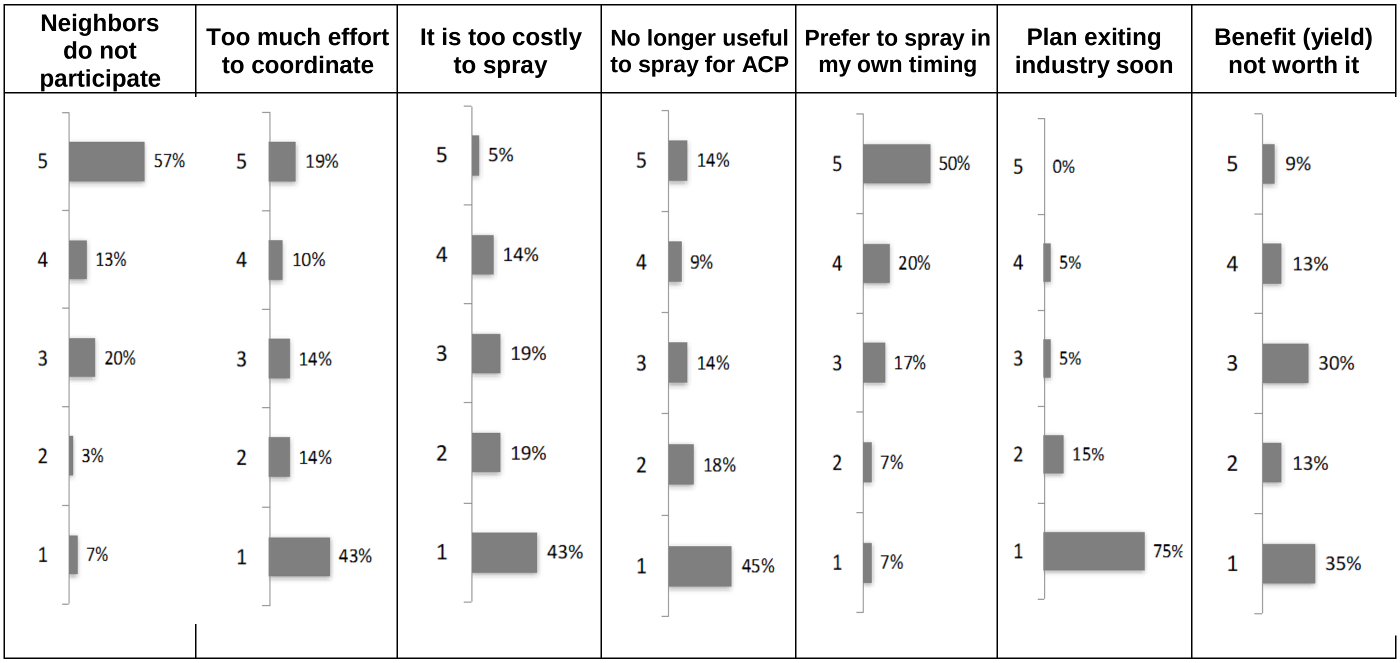
Source: Authors' survey results.

Figure 6. Revenue and cost of production per acre in Central Florida



Source: Authors' calculations.

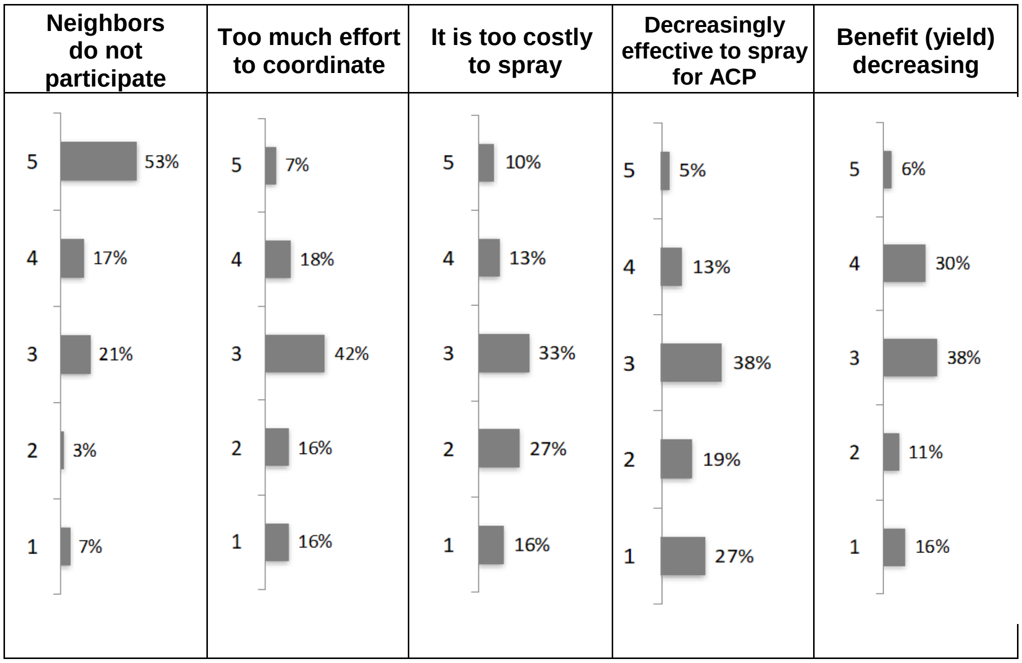
Figure 7. Reasons for not participating in CHMAs stated by non-CHMA participants



References:	Disagree		Somewhat Agree		Agree
	1	2	3	4	5

Source: Authors' survey results.

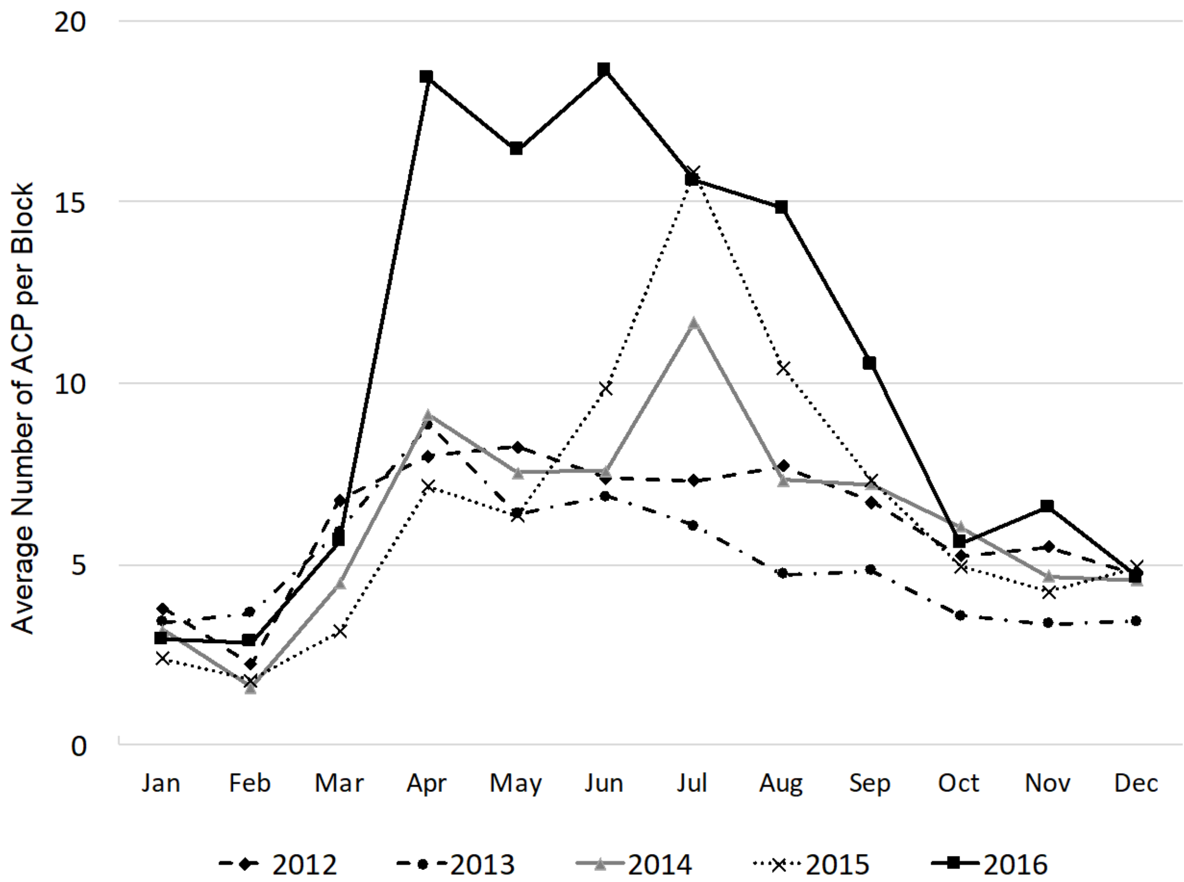
Figure 8. Obstacles to increase CHMA effectiveness stated by CHMA participants



References:	Disagree		Somewhat Agree		Agree
	1	2	3	4	5

Source: Authors' survey results.

Figure 9. Average ACP population in the state of Florida



Source: USDA-APHIS-PPQ-CHRP.

Table 1. T-test on equality of yield means for the year 2008/09

Group	Observations	Mean
CHMA 1	6	313.13
CHMA 2	5	337.39
Difference	11	-24.26

Probability of alternative hypothesis (Ha):

Ha: Difference < 0	Ha: Difference ≠ 0	Ha: Difference > 0
Probability(T < t) = 0.23	Probability(|T| > |t|) = 0.45	Probability(T > t) = 0.77

Table 2. Regression Results on Valencia Oranges Yields

Variable	Random Effects Model	Pooled OLS with Clustered Standard Errors
Year 2009/10	23.6	15.4
	(1.39)	(0.80)
Year 2010/11	-16.9	-25.1
	(-0.99)	(-1.30)
Year 2011/12	42.0**	33.8**
	(2.47)	(2.37)
Year 2012/13	-61.0***	-69.2***
	(-3.59)	(-3.17)
Year 2013/14	-140.1***	-148.3***
	(-8.24)	(-5.50)
Year 2014/15	-183.7***	-191.9***
	(-10.80)	(-7.33)
CHMA2 × Year 2009/10	-19.0	-0.9
	(-0.78)	(0.03)
CHMA2 × Year 2010/11	26.4	44.5
	(1.09)	(0.96)
CHMA2 × Year 2011/12	-25.8	-7.7
	(-1.06)	(-0.20)
CHMA2 × Year 2012/13	72.5***	90.6**
	(2.98)	(2.37)
CHMA2 × Year 2013/14	134.5***	152.6***
	(5.54)	(3.23)
CHMA2 × Year 2014/15	137.0***	155.1***
	(5.64)	(4.35)
Intercept	324.2***	324.2***
	(17.83)	(19.81)
Observations	77	77
Number of years	7	7
Wald χ^2_{12}	300.4	
Prob > χ^2_{12}	0.0	
R^2		0.60

t-statistics within parentheses.
*** $p<0.01$, ** $p<0.05$, * $p<0.1$.

Table 3. Differential yields and benefit for CHMA 2 over CHMA 1

	(1)	(2)	(3)	(4)	(5)	(6)		(7)	(8)	(9)
	Yield CHMA 1	Yield CHMA 2	Yield Difference CHMA 2 - CHMA 1	On-Tree Price*	Gross Differential Benefit	Application cost		Materials Cost	Net Differential Benefit if Aerial Application	Net Differential Benefit if Ground Application
						Aerial	Ground			
	(boxes/acre)			($/box)	($/acre)					
2010/11						64	200	144	-208	-344
2011/12	366	340	-25.8	11.00	-284	64	200	144	-492	-628
2012/13	263	336	72.5	8.60	624	64	200	144	416	280
2013/14	184	319	134.5	10.75	1446	64	200	144	1238	1102
2014/15	141	278	137.0	10.50	1439	64	200	144	1231	1095
				Cumulative	3224	320	1000	720	2184	1504

Source: Authors' calculations and USDA-NASS (2016a) where indicated with an asterisk.