

# Absence of windbreaks and replanting citrus in solid sets increase density of Asian citrus psyllid populations



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## ABSTRACT

Densities of an herbivorous pest may be impacted by landscape and orchard architecture. We present two orchard experiments where the densities of the Asian citrus psyllid (*Diaphorina citri*) were compared depending on: (1) the presence or absence of a windbreak and (2) if the orchards consisted of a solid set re-planting or an orchard with a mixture of mature and reset-replacement trees. Psyllid abundance was measured on the edges of five orchards. The factor investigated was the presence or absence of a windbreak. We observed significantly fewer psyllids on the edges of orchards with windbreaks as compared to those without windbreaks. We found no significant difference in the number of natural enemies between the edges with or without windbreaks, suggesting that windbreaks do not affect densities of psyllid natural enemies. Also, during two consecutive years, we compared the densities of psyllids on young trees less than 3 years of age in a solid set re-planting versus on resets (trees planted in replacement of dead or huanglongbing-infected trees) present randomly within mature orchards. This was conducted in four orchards and among three citrus varieties. More psyllids were found in the solid set re-plantings as compared with on the resets within mature orchards. To our knowledge, this is the first report to demonstrate that the planting strategy of new trees in orchards may impact the populations of a horticultural pest. Overall our data suggest that establishment and conservation of windbreaks might be beneficial to protect orchards from *D. citri*. The data also suggest that *D. citri* populations increase more within uniform landscapes of seedling trees as compared with mature orchards with randomly interspersed young seedlings.

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## 1. Introduction

Densities of an agricultural pest might be impacted by landscape and orchard architecture (Ricci et al., 2008). This includes the presence of non-crop habitats such as windbreaks, orchard margins, and remnant native vegetation. Current trends and economic constraints in agriculture lead to the simplification of landscapes, with the merging of small exploitations and consequently disappearance of boundaries such as field hedges between small properties (Baudry et al., 2000). Reduction of non-crop areas and the associated loss of complexity and biodiversity reduce resilience capacity of agrosystems to cope with disturbance and pest outbreaks (Altieri et al., 2011). In the present study, we examined the effect of two major Florida citrus orchard landscape

features: (1) windbreaks and (2) solid set re-plantings of young citrus trees on the density of the current major citrus pest, the Asian citrus psyllid, *Diaphorina citri* Kuwayama (Hemiptera: Psyllidae).

*D. citri* transmits the bacterial pathogen, *Candidatus Liberibacter asiaticus* (CLAs), which is the presumed causal agent of the citrus disease, huanglongbing (HLB) (Grafton-Cardwell et al., 2013; Hall et al., 2013). HLB is considered the most destructive disease of citrus crops worldwide. All known citrus cultivars are susceptible to HLB (Folimonova et al., 2009) and prevention of disease transmission has proven difficult (Grafton-Cardwell et al., 2013). Infected mature trees decline and may die within 5–10 years of infection, due to symptoms of HLB or because of secondary infections to the weakened trees (Bové, 2006). Before their demise, a portion of the fruit produced by infected trees is unmarketable, because these fruit are small, misshapen, with uneven color development (Bassanezi et al., 2009). Juice from infected fruit tastes bitter and unbalanced due to low soluble solids and high acid contents (Gottwald, 2010). Fruit and foliage drop are additional costly symptoms of infection (Gottwald, 2010). First discovered in

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Florida in 1998 (Halbert, 1998), *D. citri* quickly became established throughout the state, making eradication impossible.

Measures for HLB management have consisted of: (1) reduction of *D. citri* populations by intensive insecticide treatments (Qureshi et al., 2014; Boina and Bloomquist, 2015), (2) removal of infected trees to reduce Clas inoculum (Bassanezi et al., 2013), and (3) re-planting healthy citrus plants produced in insect-proof nurseries. Among these recommended measures for HLB management, the removal of symptomatic trees is the most controversial and difficult to accomplish by citrus growers. First, it increases per-acre orchard maintenance costs by ≈\$400 annually (Spren et al., 2014); second HLB is already widespread throughout Florida with 40% of citrus trees in Florida infected with Clas in 2012 (Spann and Schumann, 2012), and between 37.5 to 100% of *D. citri* infected with CLas (Coy and Stelinski, 2015); and third newly planted young trees designated to replace removed trees are more susceptible to Clas infection than mature trees (Brlansky et al., 2014). This is likely because young trees produce more newly emerging leaves termed “flush”, which is the only site of *D. citri* egg laying and nymphal development (Hall and Albrigo, 2007). Consequently, young citrus trees can be infested and infected soon after planting and die faster than mature trees (Gottwald et al., 2007) and before reaching the fruit bearing stage (Brlansky et al., 2014; Grafton-Cardwell et al., 2013). Therefore, many growers have abandoned infected tree removal and instead are attempting to prolong life and productivity of diseased trees with intense supplemental applications of micronutrients (Gottwald et al., 2012; Spren et al., 2014; Stansly et al., 2014). This has led to widespread abandonment of systematic removal of infected trees and many growers prefer to wait until the entire orchard becomes unproductive to abandon it and replant solid set re-plantings (SSRPs). A SSRP is an orchard where all the trees have been simultaneously replanted (example of 3 year old replanting, Fig. 1A). This is in contrast with the situation where young citrus trees are intermittently re-planted to replace HLB-infected trees within an orchard of mature trees (in this situation, young citrus trees are referred as ‘resets’, Fig. 1B). Economical models demonstrated that the reset strategy is usually more profitable than SSRP (Muraro et al., 1999). However these models were developed before the establishment of HLB in Florida and need to be revised to be more representative of the current situation. Evaluating the susceptibility of young resets to HLB in a grove with mature trees versus solid set young trees is an important step in the development of these future economic models.

It also has been pointed out that the reduction of the local inoculum by HLB-infected tree removal in an orchard is not effective in cases where infected psyllids are able to migrate from nearby non-managed areas (Bassanezi et al., 2013). This issue is referred to as the “bad neighbor effect” (Spren et al., 2014) and is caused by growers who fail to remove HLB-infected trees or to

manage their *D. citri* populations. This likely contributes to infection of neighboring orchards with Clas-infected psyllids. However, the major problem in Florida spans beyond the “bad neighbor” effect given that there were approximately 51,386 ha of abandoned citrus in Florida in 2013 (US Department of Agriculture, 2013) that receive no insecticidal treatment and are an important source of CLas-infected psyllids (Tiwari et al., 2010). It is known that *D. citri* move frequently from abandoned to managed orchards (Boina et al., 2009; Lewis-Rosenblum et al., 2015). *D. citri* are also able to disperse several kilometers without wind assistance and over fallow fields, lakes, and roads (Martini et al., 2013, 2014; Lewis-Rosenblum et al., 2015). Therefore protecting an orchard from *D. citri* immigration is essential, especially for protection of young trees.

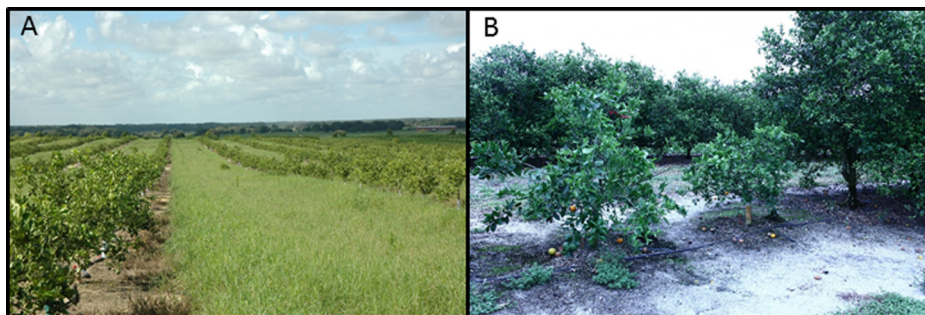
A possible tactic to protect citrus orchards from infestation by *D. citri* is the use of windbreaks. Windbreaks consist of either living trees or artificial structures and are erected to protect orchards from prevailing winds and storms, reducing abrasion and wind scars on fruit. They have been also very important tools in managing citrus canker (causal agent: *Xanthomonas axonopodis* Hesse), which is spread by wind-blown rain. This is a fungal disease that causes yield loss in commercially cultivated citrus (Gottwald and Timmer, 1995; Moschini et al., 2014).

Living windbreaks surrounding citrus orchards are known to be habitat for predators such as lady beetles and spiders (Inoue et al., 1991) and have proven to efficiently reduce some citrus pests, such as the brown soft scale, *Coccus hesperidum* L., or the Texas citrus mite, *Eutetranychus banksi* McGregor (Reed et al., 1970). In contrast, in South Africa, the thrips, *Scirtothrips aurantii* Faure, has been found in higher densities in citrus surrounded by silky oak (*Grevillea robusta*, Proteaceae) windbreaks than in the center of orchards, because silky oaks offer alternative habitats for thrips (Grout and Richards, 1990). To date, the effect of windbreaks on populations of *D. citri* has not been described. This is despite the fact that *D. citri* tend to aggregate on the edges of orchards (Gottwald, 2010) and that Shen et al. (2013) suggested that windbreaks may delay Clas infection. The objectives of this investigation were to assess the effect of: (1) windbreaks on *D. citri* population densities and (2) reset planting versus SSRPs on *D. citri* populations infesting young citrus trees.

## 2. Material and methods

### 2.1. Insect vacuum sampling device

All samples were collected with an insect vacuum. Sanders and Entling (2011) showed that suction sampling is particularly efficient for aboveground vegetation characterized by high canopy density and Thomas (2012) proved that this method is particularly effective for *D. citri*. The vacuum insect sampler used was a D-Vac



**Fig. 1.** Example images of: (A) solid set re-planting where all the young citrus trees have been re-planted <3 years ago following removal of dying trees, or (B) reset trees where young trees were intermittently re-planted to replace diseased trees within a mature orchard.

Vacuum Insect Net—Model 24 (Rincon-Vitova Insectaries, Ventura CA). This sampling device has an air flow capacity of  $21.23 \text{ m}^3 \text{ min}^{-1}$  at the collection head with a 3.75HP engine. The original collection cone was replaced by a custom made  $0.23 \text{ m}^2$  opening metallic collection cone. For each sample, the metallic collecting cone was applied for 10 s onto  $\approx 2 \text{ m}^2$  of the citrus canopy. The insects were collected into mesh bags that were replaced for each sample. Mesh bags were brought back to the laboratory and placed into a freezer ( $-4^\circ\text{C}$ ) for 24 h. The number of *D. citri* collected within each bag was determined using a stereomicroscope.

## 2.2. Does presence of windbreaks impact *D. citri* densities on the edges of citrus orchards?

To assess the effect of windbreaks on *D. citri* population densities, we selected one 'Hamlin' organic citrus orchard (Uncle Matt's Organic Citrus Grove and Peach Orchard, Clermont FL), as well as, three 'Hamlin' and one 'Navel' citrus orchard (Water Conserv II, Winter Garden, FL) (Table 1). None of these orchards received insecticidal treatments during the course of the investigation. Each orchard had one edge associated with a windbreak and the opposite edge without a windbreak. Citrus trees were between 2 and 4.1 m in height, whereas windbreaks were between 8 and 25 m in height. Four windbreaks consisted of Cadaghi trees (*Eucalyptus torrelliana*) and one consisted of longleaf pine (*Pinus palustris*) trees. Windbreaks were positioned 3 to 6 m away from citrus tree border rows (Table 1). Density of canopy within a subsample of four trees was assessed by counting the number of leaves present within a  $4.1 \text{ dm}^3$  cube at three different locations. From the 14th of April 2014 to the 1st of August 2014, each orchard was sampled three to four times on the two opposite edges (with or without windbreak). On each edge, 10 trees (20 trees total per orchard) were sampled with the vacuum sampler. Each tree was randomly selected for sampling within the first row and all sampled trees were separated by at least one buffer tree. Depending on the size of the orchard, 10 trees represented between 22% and 43% of the total edge. Additionally, beginning on the 29th of May 2015, the numbers of ladybeetles (Coleoptera: Coccinellidae), lacewings (Neuroptera: Chrysopidae), spiders (Araneae), which are predators of *D. citri* in Florida (Khan et al., 2014; Monzo et al., 2014), were collected and noted.

## 2.3. Do solid set new plantings increase *D. citri* density?

To assess the effect of planting young trees as resets or within SSRP on *D. citri* populations, we performed an investigation in three commercial citrus orchards situated in Lake Alfred, FL. One 'Hamlin' citrus orchard was sampled in 2013 and 2014; 'Grapefruit' and 'Valencia' citrus orchards were sampled only in 2014. Each orchard was divided into two parts: one was a SSRP, and the other was comprised of a mixture of mature and reset trees. None of the young planting trees in SSRP were nearby a mature tree; whereas, young trees planted as resets in a mature orchard were surrounded by at least five mature trees. In each orchard, seven trees in the

reset portion of the orchard and seven trees in the SSRP portion were randomly selected (14 trees per orchard) for sampling. To avoid edge effects, all trees were at least three rows within the interior of the citrus orchard, and each sampled tree was separated by at least three rows of buffer trees. All trees sampled were planted between 1 and 3 years prior to the investigation. Orchards were sampled with the insect vacuum 6 and 8 times between the 26th August 2013 through 13th of September 2013 and 25th of June through 3rd of October 2014, respectively. Additionally, during the final sampling date, leaf samples were collected from each tree for detection of CLas by quantitative polymerase chain reaction (qPCR), as described below. Finally, in order to measure temperature and humidity within the canopy of young trees planted as an SSRP or around resets within mature groves, Hobo® data loggers (Onset, Cape Cod, MA) were attached onto six randomly selected young trees (three in the SSRP side, three in the mature and reset side) within the Hamlin orchard in 2013.

## 2.4. Quantification of CLas in plant samples

DNA from six leaves per tree was isolated using a modified CTAB method. Briefly, 200 mg of petiole tissue were ground with Tissue Lyser (Fischer Sonic dismembrator 550, Fisher Scientific Waltham, MA) in 2 ml Eppendorf tubes and 500  $\mu\text{L}$  of CTAB buffer (100 ml/l 1 M tris-HCl; 280 ml/l 5 M NaCl; 40 ml/l 0.5 M EDTA; 20 g/l CTAB; 5 ml/l  $\beta$  mercaptoethanol; 575 ml/l DNase free water, pH 5) were added to the sample. The samples were incubated for 15 min at  $55^\circ\text{C}$  in a circulating water bath. The samples were centrifuged at 12,000 rpm for 5 min and the supernatant was transferred into a new Eppendorf tube. Chloroform-isoamyl alcohol (250  $\mu\text{L}$ ) was added to the sample and subsequently centrifuged at 13,000 rpm for 1 min. The aqueous phase was transferred into a new Eppendorf and 50  $\mu\text{L}$  of 7.5 M Na Acetate followed by 500  $\mu\text{L}$  of ice-cold absolute ethanol were added. The DNA was allowed to precipitate for 1 hour at  $-20^\circ\text{C}$  and the sample was centrifuged at 13,000 rpm for 1 min. The supernatant was removed and the DNA was washed three times by adding 70% of ice-cold ethanol followed by centrifugation at 13,000 rpm for 1 min. At the end of the third wash, the supernatant was removed and the pellet was allowed to dry for approximately 15 min. The pellets were re-suspended in 250  $\mu\text{L}$  DNase free water and incubated at  $65^\circ\text{C}$  for 20 min and then stored at  $-4^\circ\text{C}$ . The concentration and purity of the extracted DNA was measured with a spectrophotometer (Nano Drop 2000, Thermo Fisher Scientific, Waltham, MA).

The presence of CLas was assessed by the detection of the 16S rRNA gene by qPCR according to Coy et al. (2014). In brief, a multiplex TaqMan (Applied Biosystems, Foster City, CA) assay targeting the 16S rDNA of CLas and the *D. citri* wingless gene (*Wg*) was applied to detect CLas in *D. citri* samples. Duplicate amplifications of each sample were conducted, using *Wg* primers (*Wg*F: 5'-GCTCTCAAAGATCGGTTTGACGG-3'; *Wg*R: 5'-GCTGCCACGAACGTTACCTTC-3'), *Wg* probe (5'-JOE-TTACT-GACCATCACTCTGGACGC-3BHQ2-3'), CLas 16S primers (LasR: 5'-GCGTTATCCCGTAGAAAAAGGTAG-3'; LasFc: 5'-

**Table 1**  
details of the orchards and associated windbreaks used to assess the effect of windbreaks on *Diaphorina citri* populations.

Orchard	Variety	Location	Windbreak variety	Windbreak height	Distance <sup>a</sup>	Edge with windbreak	Citrus tree height	Canopy density <sup>b</sup>
Uncle Matt	Hamlin	Winter park, FL	Longleaf pine	12 m	6 m/130 m	North	3.47 m	$8.31 \pm 0.76/12.74 \pm 0.59$
Water Conserv II-1	Hamlin	Clermont, FL	Cadaghi trees	8 m	4 m/210 m	East	2.78 m	$5.58 \pm 0.32/9.16 \pm 1.15$
Water Conserv II-2	Hamlin	Clermont, FL	Cadaghi trees	25 m	6 m/165 m	South	4.1 m	$12.93 \pm 1.28/11.78 \pm 1.89$
Water Conserv II-3	Hamlin	Clermont, FL	Cadaghi trees	8 m	3 m/138 m	East	2 m	$10.45 \pm 1.02/11.95 \pm 1.16$
Water Conserv II-4	Navel	Clermont, FL	Cadaghi trees	8 m	5.7 m/209 m	West	2 m	$11.72 \pm 0.34/10.51 \pm 0.40$

<sup>a</sup> Distance from windbreak to the first citrus row/distance from windbreak to the last citrus row.

<sup>b</sup> Mean number ( $\pm\text{SE}$ ) of leaves per  $\text{dm}^3$  within the tree facing the windbreak/on the trees facing the control edge.

TCGAGCGGTATGCGAATAC-3') and the CLas 16S probe (5'-56FAM-AGACGGGTGAGTAACGCG-3BHQ2-3'). qPCR settings were: (1) 2 min at 50°C, (2) 10 min at 95°C and (3) 40 cycles with 15 sec at 95°C and 60 sec at 60°C (data collection). The reactions were processed in a 7500 Fast Real-Time PCR System (Applied Biosystems) using Micro Amp Fast Optical 96-Well Reaction Plates (Applied Biosystems) and Micro Amp Optical Adhesive Film (Applied Biosystems). The concentrations of reagents and reaction protocol are described in Coy et al. (2014). A known Clas-infected citrus sample was serially diluted and used to calibrate the standard curve. Reactions were considered positive for either target sequence if the cycle quantification (Cq) value, determined by the ABI 7500 Real-Time software (version 1.4, Applied Biosystems), was  $\leq 36$ .

2.5. Statistical analysis

The analyses were performed with the statistical software R (v. 3.0.2; the R Foundation for statistical software R, Vienna, Austria). For the windbreak investigation, we first compared the density of *D. citri* collected on edges of orchards with a t-test between orchards and sampling dates. Density of *D. citri* predators were compared for each orchards with a Mann–Whitney non parametric test due to the non-normality of the data. To measure the overall effect of the presence of windbreaks on *D. citri* and their predator populations, we combined the data from the five experimental orchards. Then we performed a generalized linear mixed model with Poisson distribution (GLMM; function lmer from the package lme4) with the presence or absence of windbreak as the explanatory variable and the orchard and time as random variables. The effect of SSRP on the density of *D. citri* was also assessed with a GLMM with the planting architecture (reset or SSRP) as the explanatory variable and the orchard as the random variable. Finally, the proportion of infected trees in resets versus in solid set plantings was assessed with a chi-square test on the pooled data from the four experimental orchards.

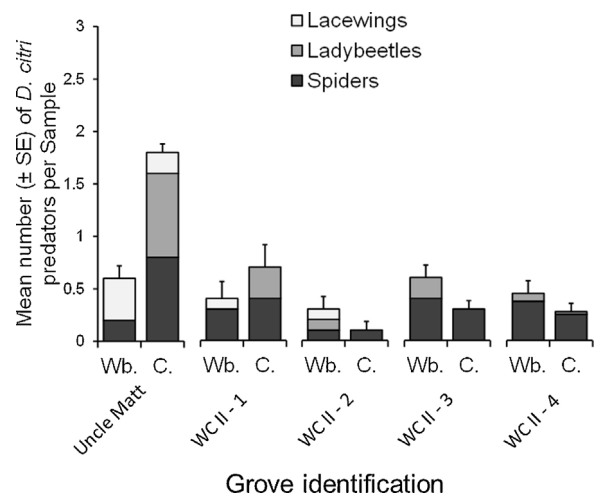


Fig. 3. Average number of *Diaphorina citri* predators ( $\pm$  SE) collected from citrus trees on the edge of five citrus orchards, depending on the presence or lack of a windbreak facing the border row. Predators collected included spiders, lacewings, and ladybeetles (adults and larvae). Wb.: presence of windbreak, C.: control.

3. Results

3.1. Does presence of windbreaks impact *D. citri* densities on the edges of citrus orchards?

Citrus canopy volume was similar between trees that faced a windbreak and those that did not (*t*-test:  $t = 1.349$ ,  $df = 4$ ,  $P = 0.249$ ). The *t*-tests performed for each sampling event revealed that of the 16 sampling dates in the 5 orchards, the density of *D. citri* was significantly lower (at  $\alpha < 0.05$ ) 12 times on citrus trees facing the windbreak as compared with those without a windbreak (Fig. 2). Overall presence of windbreaks significantly decreased the population of *D. citri* on the edges of orchards (GLMM:  $\chi = 1141.9$ ,  $P < 0.001$ ). The non-parametric tests for the presence

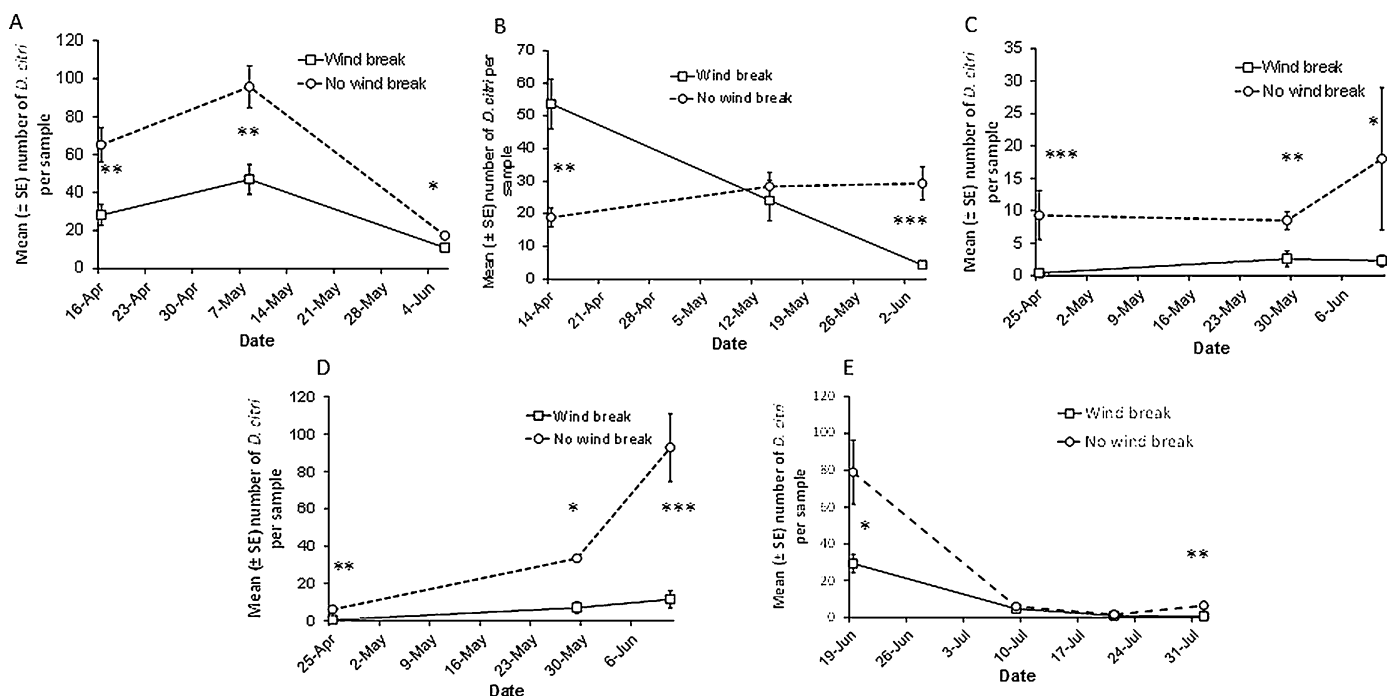


Fig. 2. Average density of *Diaphorina citri* ( $\pm$ SE) on citrus trees on the edge of five organic and experimental orchards, depending on the presence or lack of a windbreak facing the border row. Uncle Matt (A); Water Conserv II-1 (B); Water Conserv II-2 (C); Water Conserv II-3 (D); Water Conserv II-4 (E). \* $<0.05$ , \*\* $<0.01$ , \*\*\* $<0.001$ .

of natural enemies depending on the presence or absence of windbreak within each orchard were not significant at the  $\alpha < 0.05$  level. Overall, presence or absence of windbreaks did not significantly impact the number of *D. citri* predators collected (GLMM:  $\chi = 0.0444$ ,  $P = 0.833$ ) (Fig. 3). The predator community sampled was composed of lady beetles (24.07%), spiders (68.52%), and lacewings (7.41%).

3.2. Do solid set plantings increase *D. citri* density?

In three out of four orchards sampled, the density of *D. citri* within resets present randomly within mature orchards was lower than on young trees planted as an SSRP (Fig. 4). Overall, significantly fewer *D. citri* were found on resets within mature orchards than within young plantings in the SSRPs (GLMM:  $\chi = 19.446$ ,  $P < 0.001$ ). The Clas infection rate of the young plantings in SSRPs was higher than the infection rate of resets present within mature orchards (42.50% versus 28.57% respectively), but this difference was not statistically significant ( $\chi = 1.90$ ,  $df = 1$ ,  $P = 0.17$ ) (Table 2).

Temperature within SSRPs was  $0.78 \pm 0.09^\circ\text{C}$  higher than within mature orchards, on average, between 8:00 AM and 4:00 PM. There was a peak temperature difference between 8:00 and 10:00 AM. During this interval, temperature within SSRPs was  $1.30 \pm 0.10^\circ\text{C}$  higher than within mature orchards, on average, with a maximal difference of  $+4.02^\circ\text{C}$ . Humidity followed the opposite pattern. Relative humidity was  $3.26 \pm 0.41\%$  lower in the SSRPs than within mature orchards between 8:00 AM and 4:00 PM with a peak at 10:00 AM ( $-6.9 \pm 0.51\%$  on average and a maximal difference of  $-20.74\%$ ).

Table 2

Clas-infection rate of young citrus trees (less than 3 years old) in four different orchards, depending on whether they were planted as a reset or as solid set replantings (SSRP).

Orchard	Reset		SSRP	
	Uninfected	Clas-infected	Uninfected	Clas-infected
Hamlin 2013	7	0	2	5
Grapefruit 2014	7	0	5	2
Hamlin 2014	0	7	5	2
Valencia 2014	6	1	3	4
Totals	20	8	15	13

4. Discussion

We demonstrated that the presence of windbreaks significantly decreased the density of *D. citri* on citrus orchard borders. The efficiency of windbreaks or hedgerows in reducing the population of orchard pests has been demonstrated for other species; for instance, codling moth (*Cydia pomonella*) populations are also reduced in the presence of hedgerows (Ricci et al., 2011).

The mechanism by which windbreaks significantly reduce *D. citri* populations requires more investigation. If windbreaks are known to offer an alternative habitat for natural enemies (Bianchi et al., 2006; Inoue et al., 1991; Macfadyen and Muller, 2013), we were unable to find such an effect among populations of predators adjacent to windbreaks in the current investigation with *D. citri*. Further work should be conducted to determine if *Tamarixia radiata* Waterston, a parasitic wasp that specializes on *D. citri*, benefits from the presence of windbreaks. Also, the presence of

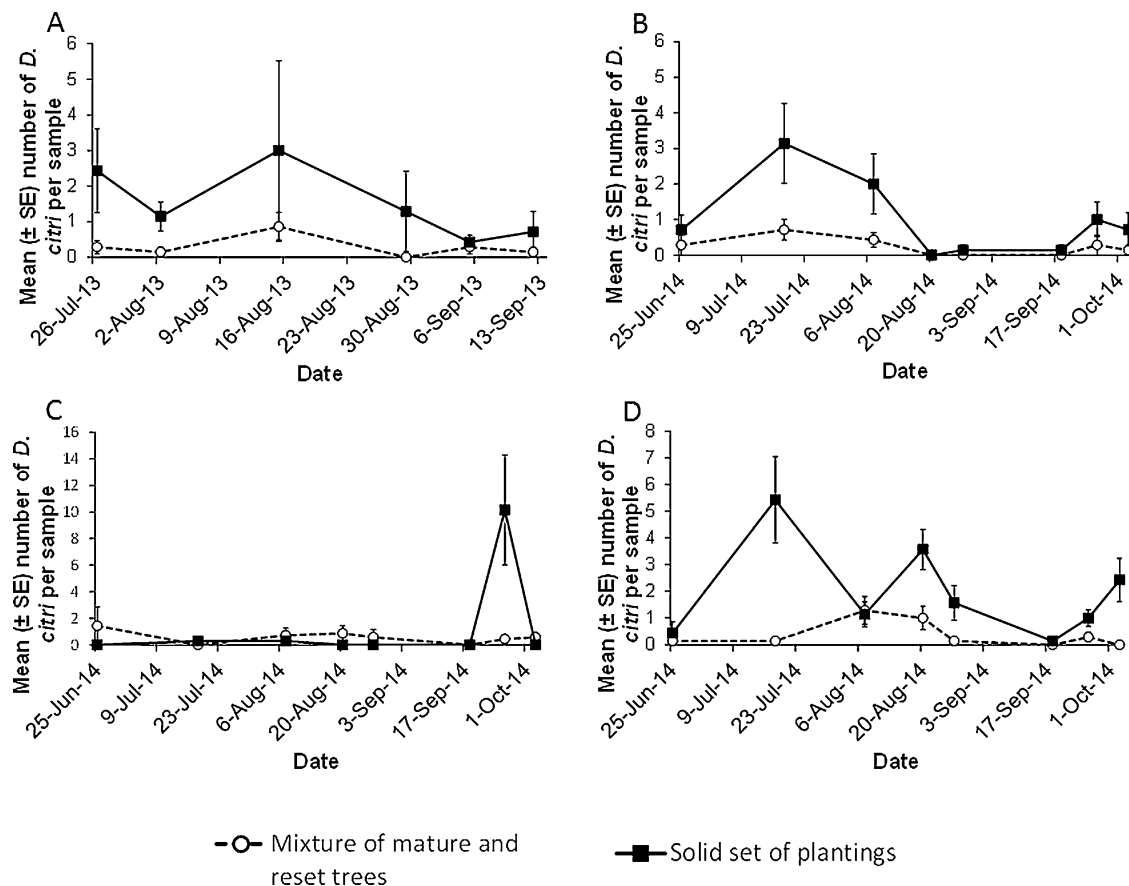


Fig. 4. Average density of *Diaphorina citri* ( $\pm SE$ ) on young (<3 years) citrus plantings depending on whether trees were within solid set plantings (all trees planted within the last three years) or if the citrus trees were present within mature orchards (reset trees planted within the last three years to replace mature trees). Hamlin citrus orchards in 2013 (A); Grapefruit citrus orchards in 2014 (B); Hamlin citrus orchards in 2014 (C); Valencia citrus orchards in 2014 (D).

natural enemies is likely to be associated with windbreak species and plant biodiversity. Therefore, further investigations are needed regarding preference and attraction of *D. citri* natural enemies toward windbreak species. Windbreaks are also known to alter microclimate (Baudry et al., 2000), which may affect herbivores and natural enemies differently. The main microclimatic changes induced by windbreaks within citrus orchards are reduction of leeward wind elevation, reduction of nighttime temperature, and an increase of daytime temperatures near the windbreak on the leeward side compared with temperatures further away from the windbreak (Tamang et al., 2010). Also, shade induced by windbreaks may reduce flush production and therefore reduce attractiveness of citrus toward *D. citri*. Finally, it is possible that windbreaks act as a barrier preventing *D. citri* from landing on borders of citrus orchards adjacent to windbreaks. However field data has demonstrated that *D. citri* adults are capable of migrating within such challenging environments (Martini et al., 2013).

We also found that young trees replanted as solid sets contain higher populations of *D. citri* than seedling trees replanted as resets within otherwise mature orchards. These data may indicate that replacing individual infected trees with uninfected seedlings in a mature orchard may be a more effective method to prevent infestation by *D. citri* (and associated *Clas* re-infection) than replacing entire blocks of orchards. Changes in microclimate may also reduce the population of *D. citri* on young citrus resets compared with young plantings in the SSRP configuration. We found that canopy temperature was greater, on average, in young trees present within SSRPs as compared with resets re-planted within mature orchards. This increase in temperature was particularly evident in the morning (up to 4° C) and is probably correlated to light exposure at this time of the day in Florida. Sun exposure is likely to have a strong impact on *D. citri* colonization of plants (Sétamou et al., 2012) and dramatically differs among trees depending on their size and the depth of the canopy. It is also possible that this microclimate changes the flushing pattern of the trees and therefore that flush production is higher in SSRP than in resets. Presence of mature trees surrounding young trees likely reduces wind and sun exposure on young citrus trees analogously to a windbreak. Additionally, the concentration of young trees in SSRPs, with high production of flush season-long (Hall and Albrigo, 2007), is likely to attract *D. citri* at a higher rate than within mature orchards containing randomly interspersed resets. It has been demonstrated that the proportion of *D. citri* immigrating into an orchard was correlated to the flush production of citrus trees (Lewis-Rosenblum et al., 2015). Overall, our two experiments tend to demonstrate that microclimate and orchard complexity are likely to influence *D. citri* population densities.

In the context of integrated pest management for *D. citri* and associated HLB, our results advocate for the conservation of windbreaks and hedgerows and support the implementation of new ones. We acknowledge that there are some constraints to implementing windbreaks, including cost, shading, competition for water and nutrients, obstruction for agricultural equipment, and loss of exploitable surface. However, windbreak protection against citrus canker and *D. citri*, in addition to other ecological benefits that includes increase of habitats for natural enemies, as well as, protection from wind and soil erosion (Baudry et al., 2000) may outweigh the disadvantages. Further investigations to evaluate potential changes in efficacy of windbreaks to decrease *D. citri* populations depending on windbreak structure (living versus artificial), species, size, cardinal orientation and distance from the orchard are needed. Our investigation also suggests that implementation of SSRPs as a method of re-planting citrus in highly HLB-infected regions will likely require much more intense management of the *D. citri* vector than for resets within mature citrus orchards.

Recently in reaction to the record low 2014 citrus production in Florida (US Department of Agriculture, 2015) the “USDA’s Tree Assistance Program” (US Department of Agriculture, 2014) has been launched to help growers to plant new citrus trees. Private companies have also undertaken similar initiatives. These planting programs designated to recover Florida citrus production impacted by HLB will probably include the implementation of large blocks of SSRPs. Therefore, particular attention should be taken to intensively manage the *D. citri* vector given that these blocks will be particularly susceptible to psyllid infestation. Our results suggest that these replanting initiatives should also favor reset plantings, as well as, the establishment of windbreaks on the edges of the new SSRPs. This cultural control method may reduce the need for the intense insecticide input that is currently required to manage populations of this phytopathogen vector (Qureshi et al., 2014). A potential bridge to allow for growth of natural windbreaks would be erecting temporary artificial windbreaks surrounding SSRPs to protect young citrus at planting. These artificial windbreaks could be removed as the natural windbreaks develop into mature trees that subsequently protect citrus at the fruit-bearing stage, when more protection from sun exposure will likely be needed to reduce populations of *D. citri*.

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