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Artigo/Article

Effect of windbreaks on wind speed and canker incidence on grapefruit

James H. Graham[1], Monty E. Myers[1], Tim R. Gottwald[2] & Clive H. Bock[3]

SUMMARY

For fresh grapefruit, the goal is to maximize pack-out by minimizing canker lesions on fruit. The objective of these trials was to determine the relationship between wind speed and incidence and severity of citrus canker on 5 to 7 yr-old Ruby Red grapefruit trees located in two trial blocks (~4.5 ha) surrounded on all sides by a 6 to 10 m tall *Corymbia torelliana* windbreak. The experiment was conducted from 2013 to 2015. A series of weather stations were deployed in east-west and north-south directions across the orchards to measure the effect of proximity of citrus trees to the windbreak on wind speed expressed as the number of wind gusts ≥5 m s^{-1}, and to determine the relationship with incidence of fruit lesions on grapefruit. The number of wind gusts ≥5 m s^{-1} increased with distance from the windbreak. The highest fruit canker incidence occurred in approximately the central zone of the block and the lowest incidence was found nearest windbreaks. Number of wind gusts and canker were linearly related, i.e., the greater the number of gusts, the higher the fruit disease. As the number of wind gusts increased with distance from the windbreak, incidence of unsightly wind scar also increased. These results confirm that windbreaks are a highly effective method for protection of fruit from infection by *Xanthomonas citri* subsp. *citri*, as well as physical damage from wind buffeting.

Index terms: *Corymbia torelliana*, wind gusts, proximity to windbreak.

Efeito de quebra-ventos na velocidade do vento e incidência de cancro cítrico em pomelo

RESUMO

Para o mercado de pomelos frescos, o objetivo é maximizar a porcentagem de frutos com padrão de mercado, minimizando as lesões de cancro cítrico nas frutas. O objetivo desse ensaio foi determinar a relação entre velocidade do vento, incidência e severidade do cancro cítrico em plantas de pomelo Ruby Red de 5 a 7 anos, localizadas em dois blocos de ensaio (~4,5 ha), cercados por todos os lados por plantas de 6 a 10 m de altura do quebra-vento *Corymbia torelliana*. O experimento foi realizado de 2013 a 2015. Uma série de estações meteorológicas foram implantadas nas direções leste-oeste e norte-sul através dos pomares para medir o efeito da proximidade das plantas de citros com os quebra-ventos, sendo que a velocidade do vento foi expressa como o número de rajadas de vento ≥ 5 m s^{-1}, para determinar a relação com a incidência de lesões nas frutas de pomelo. O número

[1] Citrus Research and Education Center, University of Florida, Lake Alfred, FL, USA
[2] Horticultural Research Laboratory, Agricultural Research Service – ARS, United States Department of Agriculture – USDA, Ft. Pierce, FL, USA
[3] Southeastern Fruit & Tree Nut Research Laboratory, Agricultural Research Service – ARS, United States Department of Agriculture – USDA, Byron, GA, USA

Corresponding author: James H. Graham, Citrus Research and Education Center, University of Florida, Lake Alfred, FL, USA. E-mail: jhgraham@ufl.edu

de rajadas de vento ≥ 5 m s^{-1} aumentou com a distância do quabra-vento. A maior incidência de cancro nas frutas ocorreu aproximadamente na zona central do bloco e a incidência mais baixa foi encontrada quanto mais próximo do quebra-vento. O número de rajadas de vento com os valores de incidência e severidade do cancro foram relacionados linearmente, ou seja, quanto maior o número de rajadas, maior a doença da fruta. À medida que o número de rajadas de vento aumentou com a distância do quebra-vento, a incidência de cicatrizes ocasionadas pelo vento também aumentou. Esses resultados confirmam que os quebra-ventos são um método altamente eficaz para a proteção de frutos da infecção por *Xanthomonas citri* subsp. c*itri*, bem como danos físicos causados por rajadas de vento.

Termos de indexação: *Corymbia torelliana*, rajadas de vento, proximidade com quebra-vento.

INTRODUCTION

Citrus canker is caused by the plant pathogenic bacterium *Xanthomonas citri* subsp. *citri* (*Xcc*), and is a major disease of several citrus species in many tropical and sub-tropical citrus producing regions (Schubert et al., 2001). The disease can reduce yield directly (Behlau et al., 2010), but the unsightly canker lesions on fruit reduce pack-out for the domestic and export markets (Gottwald et al., 2009). The pathogen is spread in rain splash (Pruvost et al., 2002), and higher wind speeds may enhance the potential spread (Bock et al., 2005, 2010a), and infection (Bock et al., 2010b; Gottwald & Irey, 2007). Rainstorms at local scales contribute to spread of the pathogen – dispersal up to 579 m is well established (Gottwald et al. 2002), and studies on the effect of wind speed dispersing inoculum from diseased trees confirmed a many-fold increase in the quantity of *Xcc* in rain splash downwind of infected trees at higher wind speeds (Serizawa et al., 1969; Serizawa, 1982; Bock et al., 2005, 2010a).

Canker suppression on susceptible citrus cultivars is challenging with copper bactericides (Behlau et al., 2010; Leite & Mohan, 1990; Stein et al., 2007) because wind-blown rain introduces *Xcc* directly into stomata, by-passing the protective copper film on the plant surface (Graham et al., 2004). Windbreaks are known to reduce wind speed for up to 50× the height of the windbreak downwind from the windbreak (Heisler & Dewalle, 1988), although the reduction in wind speed declines with distance. Reduction in rate of progress of citrus canker epidemics has been reported in at least one study using artificial windbreaks (Gottwald & Timmer, 1995), but in a more recent study little effect of artificial windbreaks in reducing disease was reported (Behlau et al., 2008). Nonetheless, recently in Florida living windbreaks have been deployed around the perimeter of 5 to 10 ha blocks of grapefruit (*Citrus paradisi* Macf.), which is particularly susceptible to canker (Gottwald et al., 1993), and is the most important fresh fruit citrus grown in Florida (Graham et al., 2011). These windbreaks are assumed to reduce wind gusts that promote dispersal of *Xcc* and subsequent infection that can promote increased incidence and severity of citrus canker especially during tropical storms and hurricanes (Graham et al., 2008; Gottwald & Timmer, 1995; Bock et al., 2010a, b). Windbreaks are also important in preventing wounds for bacterial entry into tissues and consequently infection (Bock et al., 2010a) and reducing wind scar that may down grade appearance of the rind for fresh fruit packing (Graham et al., 2011).

Although windbreaks might help reduce canker (Gottwald & Timmer, 1995), frequent applications of copper are still required to protect fruit that are continuously expanding over a 90-120 day period after flowering, depending on the citrus cultivar (Behlau et al., 2010; Graham et al., 2016; Stall et al., 1982; Stein et al., 2007). Thus, an integrated approach combining windbreaks and copper sprays minimizes loss of fresh market grapefruit due to infection by *Xcc*. Although windbreak attributes for reducing wind speed have been evaluated in citrus orchards (Tamang et al., 2010), no in-depth investigation of the relationship of prevalence of canker and recorded wind speeds in conjunction with distance from a windbreak has been reported, and it is not established to what distance from a windbreak protection against canker is afforded.

The objectives of this study were to i) characterize wind speeds at different distances from windbreaks at the canopy level in orchards, ii) assess the incidence of canker on trees at different distances from windbreaks, and iii) ascertain whether there is a relationship between distance from a windbreak, wind speed and prevalence of citrus canker on fruit, and characterize that relationship.

MATERIAL AND METHODS

Locations

Two commercial orchards of red grapefruit in east-central Florida were selected for the evaluations in 2013 and 2014, one in Indian River County (IRC) and one in St. Lucie County (SLC). Trees in the IRC orchard were 7 y old, and in the SLC orchard were 6 y old. The orchard in the IRC

was smaller (34 rows × 40 trees per row) than the orchard in the SLC (50 rows × 46 trees per row). Both orchards were surrounded by living windbreaks of *Corymbia torelliana*. At the IRC location, the mean windbreak height was 8.7 m, and at the IRC location, the mean windbreak height was 7.8 m. Windbreak tree height was calculated by triangulation using a laser range finder to measure distance from the top to the base of the tree. To estimate porosity of the windbreak, multiple photos of the windbreak from each location were subjected to image analysis using APS Assess (Lamari, 2002). The windbreaks at the IRC and SLC locations were estimated to have a porosity of 21.9% (sd = 6.74) and 20.0% (sd = 3.68), respectively.

Weather data

Nine weather stations (HOBO, Onset Inc., Bourne, MA) at each orchard were used to record wind speed, leaf wetness, rainfall at different distances from windbreaks and at citrus canopy height (approximately 1.6 m). Each variable was measured at 30 s intervals. The weather stations were positioned perpendicular to each other in a N-S and E-W orientation crossing at the orchard centers (Figure 1). Each weather station was placed within-row between two trees. Infection of fruit by *Xcc* occurs mostly during the early stage of fruit development and expansion (Verniere et al., 2002; Graham et al., 2016), which in Florida is during the spring and early to mid-summer period. Thus, the periods of weather monitoring were 1 March to 25 June 2013, and 11 March to 31 August 2014. In 2013, weather station malfunctions precluded wind speed comparisons beyond June 2013. A wind speed of 5 m s^{-1} (18 km h^{-1}) was selected as the lower threshold of wind gust speed at canopy height between trees within rows deemed to promote incidence or severity of citrus canker (Bock et al., 2010b). Wind speed was measured every 30 sec. Thus the proportion of wind speed gusts >5 m s^{-1} were = wind speed gusts >5 m s^{-1} ÷ the total number of wind gusts recorded.

Assessments

The incidence of fruit infected with citrus canker was assessed on 7-10 trees adjacent to each weather station and in the orchard corners (Figure 1). A sample of 10 fruit was arbitrarily selected from each tree, and assessed for presence of canker lesions. At both locations the assessment was made on 14 November in 2013 and 27 October in 2014. Wind scar on the same fruit assessed

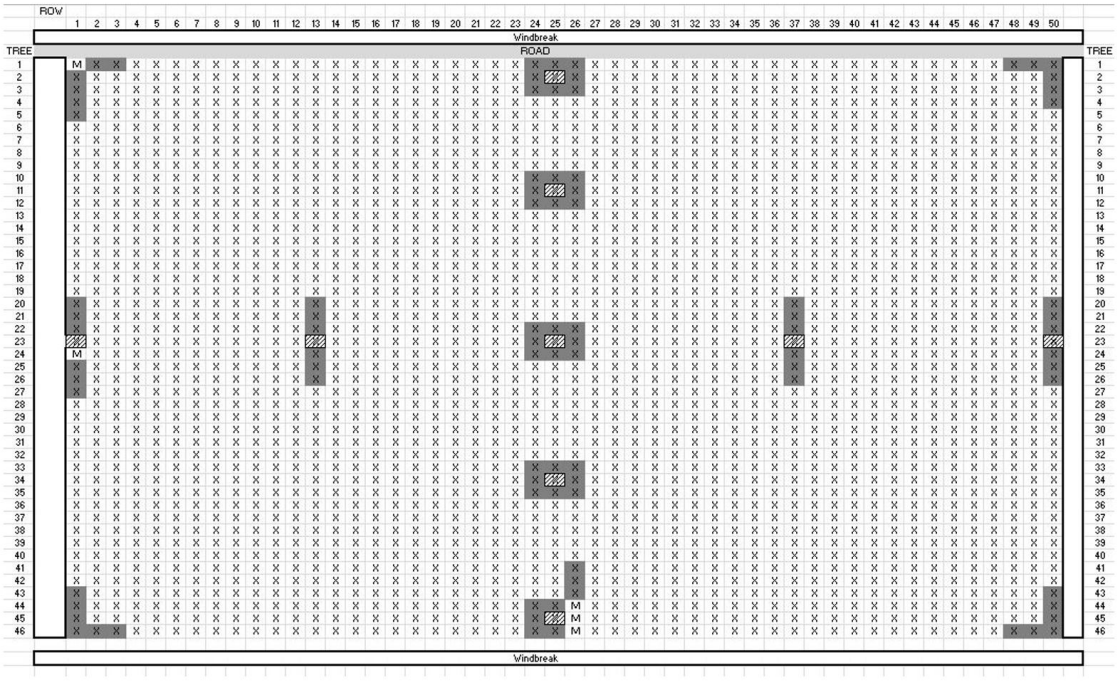

Figure 1. Representation of an orchard and distribution of the sample grapefruit trees (dark gray rectangles) and weather stations (rectangles with parallel lines). X = tree, M = missing tree. Sample layout was similar in both orchards although number of rows and number of trees within rows differed between orchards (see text).

for citrus canker was assessed on a 1 to 5 ordinal scale as follows: 0 = 0% area, 1 = 1-15% area, 2 = 16-30% area, 3 = 31-50% area, 4 = 51-75% area, and 5 = 76-100% area of the fruit showing signs of wind scar.

Orchard management

Both locations received regular sprays of copper bactericides to manage canker (Table 1). The orchard in SLC was more intensively managed with sprays every <10 to 30 days. Standard application practice was used, and other standard recommended orchard management was applied (leaf miner, weed control, fertilizer, etc.).

RESULTS

Wind speed and severity of citrus canker in relation to distance from windbreaks

Over the sampling period, gusts >5 m s^{-1} were infrequently recorded at the orchard edges near the windbreaks (Figure 2). Whereas high-speed wind gusts were most frequent towards the orchard centers. The exception was the SLC orchard in 2014, where wind speed was erratic across the orchard which may have been associated with other, undetermined factors. Overall, the frequency of wind gusts >5 m s^{-1} was low (<1.1% of records) at both locations, and these wind gusts were most often associated with rainstorms (data not shown). Similarly, the highest incidence of fruit with citrus canker was located on trees towards the middle of both orchards in both years (Figure 3). Thus, those trees furthest from the windbreaks had a higher incidence of citrus canker compared with those adjacent to the edges and corners of the orchards closest to windbreaks.

Table 1. Citrus canker bactericide sprays applied to windbreak experiments in St. Lucie County (SLC) and Indian River County (IRC) in FL. All sprays applied were formulated either as copper sulfate or copper hydroxide. Depending on experiment and time of year, sprays were applied approximately every 7 to 40 days

Experiment	Year and number of sprays applied	
	2013	2014
SLC	18	13
IRC	7	8

The incidence of citrus canker on fruit most often had a moderately strong positive relationship with distance from the windbreak (Figure 4, R^2 = 0.53 to 0.79). Thus, the closer the trees to the windbreak, the lower the incidence of citrus canker. Furthermore, the incidence of citrus canker on grapefruit most often had a weak to moderately strong relationship with the frequency of gusts >5 m s^{-1} (Figure 5, R^2 = 0.22 to 0.48). Only in 2014 in the SLC orchard was there no discernable relationship (R^2 = 0.11). Thus, the further away from a windbreak, the higher the incidence of citrus canker on fruit which relates to the frequency higher-wind speed gusts.

Severity of wind scar in relation to distance from windbreaks (assessed only in 2013)

Wind scar of fruit was more severe towards the center of the orchards (Figure 6A). This was true both across and down rows (Figure 6B). There was a strong relationship between severity of wind scar on fruit and distance from the windbreak (Figure 6C, R^2 = 0.74). Not surprisingly, there was a moderate relationship with proportion of gusts >5 m s^{-1} (Figure 6D, R^2 = 0.51).

DISCUSSION

Our evaluations of two orchards confirm that the incidence of citrus canker infected fruit tends to be least nearest windbreaks, and higher towards the center of the orchard. High wind speeds, i.e., gusts >5 m s^{-1} that result in increasing infection (Bock et al., 2010b), were reduced proximal to windbreaks. A moderate to moderately strong relationship was measured between distance from the windbreak and severity or incidence of canker on fruit. Furthermore, a moderate to weak relationship was found between wind speed >5 m s^{-1} and severity or incidence of canker on fruit. Thus, the quantity of wind gusts was correlated to the incidence of citrus canker.

Windbreaks are widely considered to be useful for reducing incidence and severity of canker in citrus orchards and for limiting the quantity of inoculum produced and dispersed, and subsequent infection (Gottwald & Timmer, 1995; Bock et al., 2010a, b; Tamang et al., 2010). Smaller orchards are likely to benefit more from windbreaks than larger blocks as the distance to which a windbreak provides protection declines with distance from that windbreak (Heisler & Dewalle, 1988). Our results bear out this

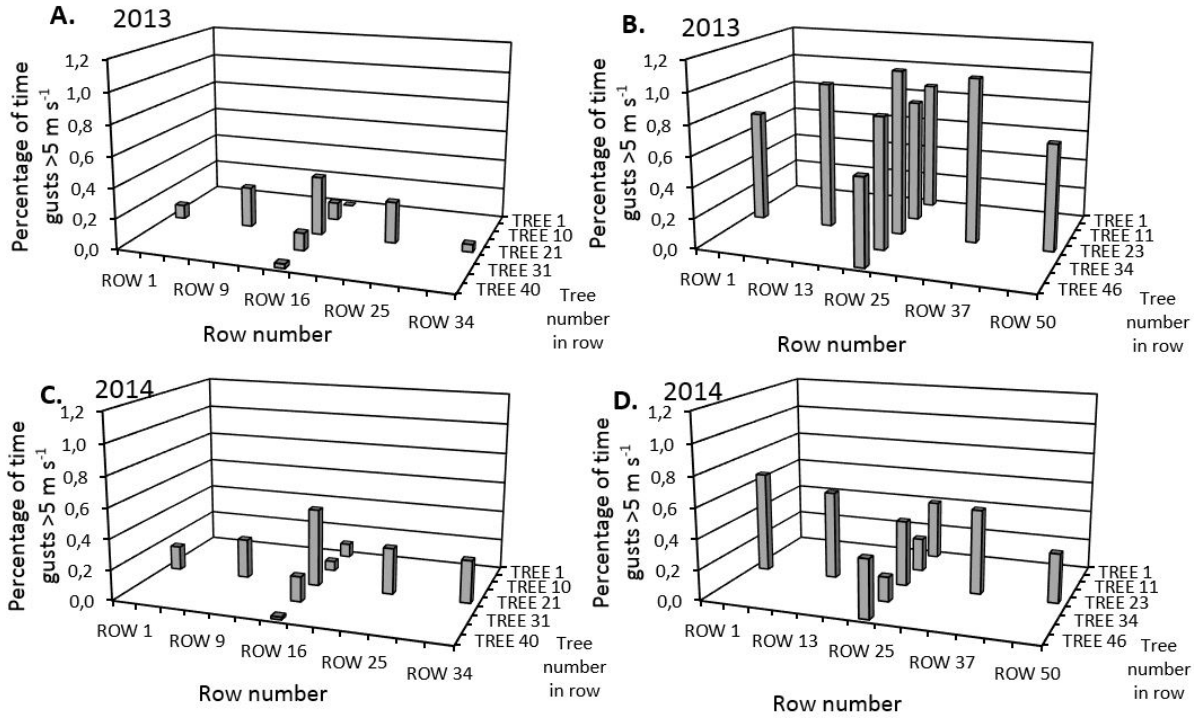

Figure 2. The proportion of wind speed gusts >5 m s^{-1} at different distances from windbreaks in two red grapefruit orchards in east-central Florida over two seasons. (A) and (C) are an orchard in Indian River County, and (B) and (D) are an orchard in St. Lucie County. The proportion of wind speed gusts >5 m s^{-1} = wind speed gusts >5 m s^{-1} ÷ the total number of wind gusts recorded. Wind speed was measured every 30 sec.

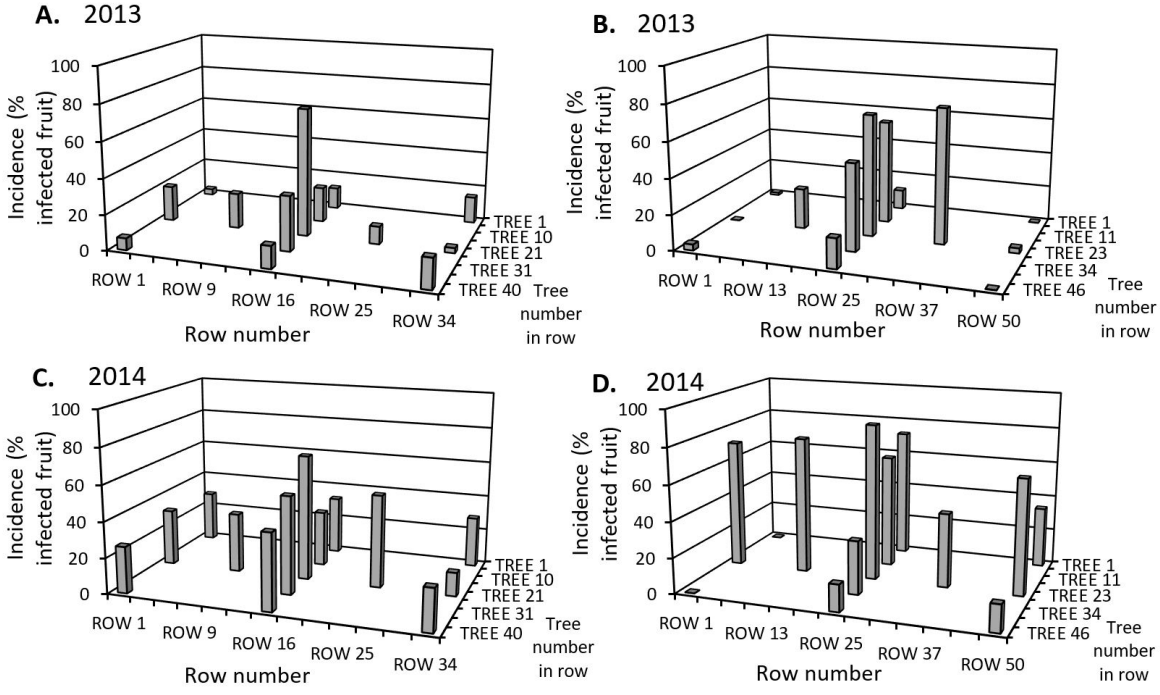

Figure 3. Incidence of canker on fruit at different distances from windbreaks in two red grapefruit orchards in east-central Florida over two seasons. (A) and (C) are an orchard in Indian River County, and (B) and (D) are an orchard in St. Lucie County.

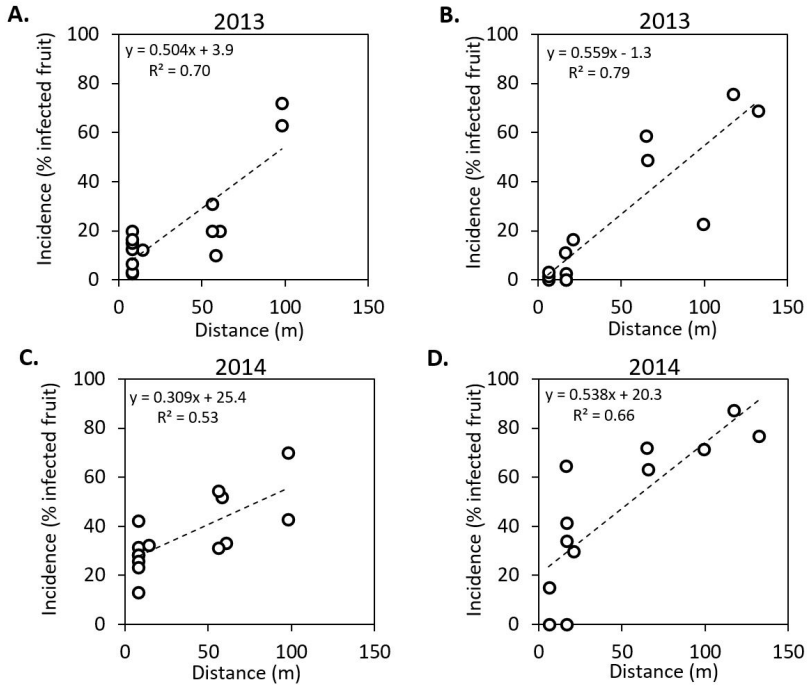

Figure 4. The relationship between the distance from a windbreak and incidence of fruit canker in two red grapefruit orchards in east-central Florida over two seasons. (A) and (C) are an orchard in Indian River County, and (B) and (D) are an orchard in St. Lucie County.

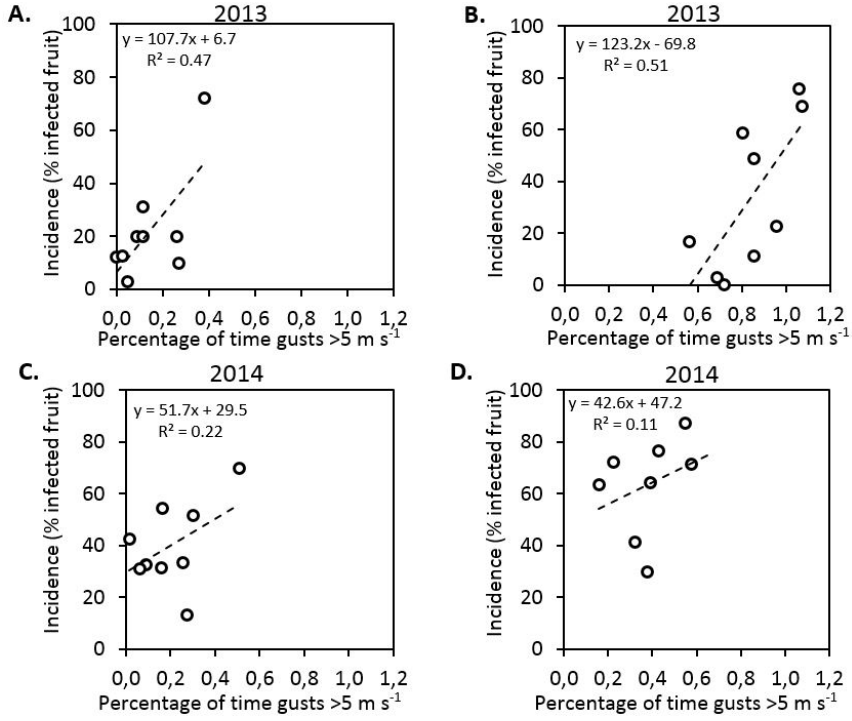

Figure 5. The relationship between the percentage of wind gusts >5 m s^{-1} and incidence of fruit canker at different distances from windbreaks in two red grapefruit orchards in east-central Florida over two seasons. (A) and (C) are an orchard in Indian River County, and (B) and (D) are an orchard in St. Lucie County. The proportion of wind speed gusts >5 m s^{-1} = wind speed gusts >5 m s^{-1} ÷ the total number of wind gusts recorded. Wind speed was measured every 30 sec.

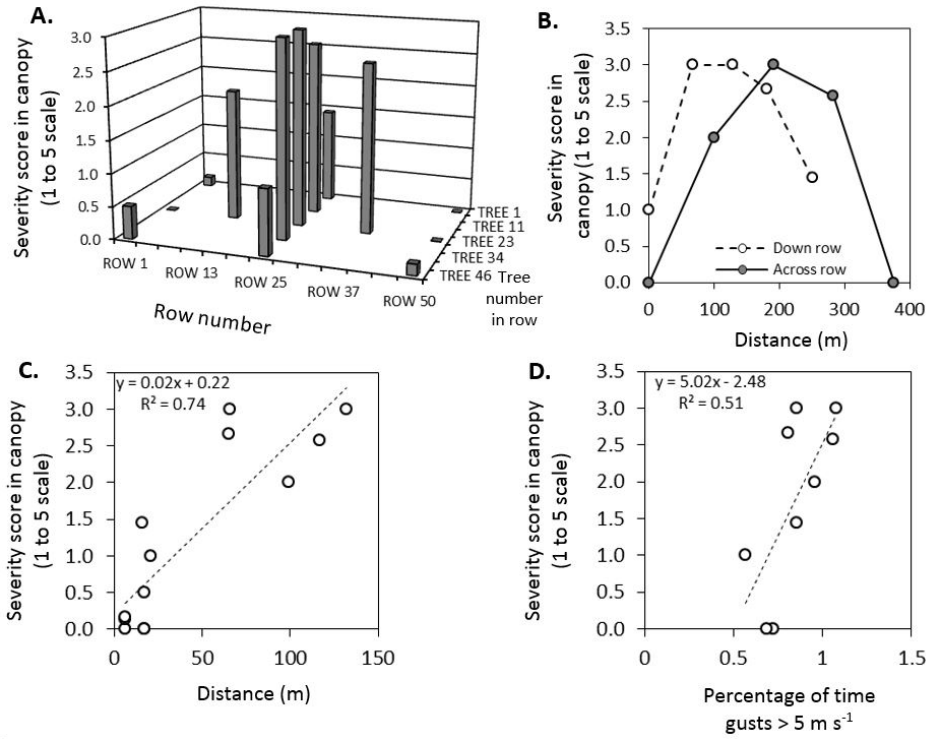

Figure 6. Wind scar on fruit in November 2013 in a red grapefruit orchard in St. Lucie County, Florida. (A) Distribution of severity in orchard; (B) Severity of scar symptoms down and across rows; (C) The relationship between severity of scar and distance from the windbreak, and (D). Severity of scar in relation to the percentage of time that gusts were >5 m s^{-1}. The proportion of wind speed gusts >5 m s^{-1} = wind speed gusts >5 m s^{-1} ÷ the total number of wind gusts recorded.. Wind speed was measured every 2 secs.

observation, and are in agreement with the observations of Tamang et al. (2010) on wind speed in wind-breaked citrus orchards. Although information for wind behavior in large and small orchards with perimeter windbreaks is lacking, these studies demonstrate effective reduction in wind speeds on the lee side of the windbreak and reduction in incidence and severity of citrus canker. Size of the orchard and windbreak characteristics may account for some of the variability reported in efficacy of windbreaks for reducing citrus canker that was previously reported (Gottwald & Timmer, 1995; Behlau et al., 2008).

To attain sustainable control of citrus canker for fresh grapefruit production, Florida growers must utilize all methods available and develop a fully integrated program to manage citrus canker. Windbreaks are considered essential for an integrated management program on highly susceptible grapefruit (Graham et al., 2011). Clearly, windbreaks for blocks as small as 5 ha are likely to be highly effective in reducing the incidence and severity of canker. Furthermore, our results indicate that windbreaks also reduce fruit scar caused by wind, another blemish on fresh fruit that can reduce marketability.

Windbreaks as part of an integrated program are valuable for another reason. Sole reliance on copper to control citrus canker on grapefruit presents several challenges. In Florida, up to 12 copper applications are recommended from the time of spring leaf flush to the point of full fruit expansion if sprayed at 21-day intervals throughout the summer months (Dewdney & Graham, 2016). Season-long application of copper to grapefruit, can lead to phytotoxicity to the fruit rind (Graham et al., 2008). Copper phytotoxicity results when a 'burn' causes rind tissues to develop corky lesions, a symptom sometimes resulting in a blemish called 'star melanose' or stippling. On grapefruit, these blemishes may make the fruit unacceptable for the fresh market, and the fruit must be diverted to the less profitable processed market (Graham et al., 2011). Furthermore, the acquisition of resistance genes to copper in *Xcc* has been reported (Behlau et al., 2012), and thus reducing copper usage will help manage this potential threat to control of the canker-causing bacterium. Finally, environmental

issues associated with excessive copper use can also be minimized by fully integrating various control measures.

The goal of growers who produce grapefruit for the fresh market is to maximize pack-out by minimizing canker lesions and other surface blemishes on the fruit. Our results confirm that windbreaks are a highly effective method for protecting fruit from infection by *Xcc*, as well as from physical damage from wind exposure which can result in wind scar. Windbreaks will enhance control of citrus canker when used as part of an integrated program.

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