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POPULATION DYNAMICS OF *DIAPHORINA CITRI* KUWAYAMA (HEMIPTERA: LIVIIDAE) IN ORCHARDS OF 'VALENCIA' ORANGE, 'PONKAN' MANDARIN AND 'MURCOTT' TANGOR TREES

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Abstract

The purpose of this work was to study the population dynamics of *Diaphorina citri* Kuwayama (Hemiptera: Psyllidae) in orchards of 'Valencia' orange, 'Ponkan' mandarin, and 'Murcott' tangor trees located at the São José farm in the municipality of Taquaritinga, São Paulo (SP). Yellow sticky traps used to monitor this disease vector were evaluated monthly for 4 yr between Sep 2004 and Aug 2008. The largest number of *D. citri* was captured on the 'Ponkan' mandarin trees followed by the 'Murcott' tangor and 'Valencia' orange trees with significant differences. Chemical pest control and environmental factors likely are responsible for these results. Pearson's correlation analysis indicated that there is a weak correlation between the abundance of *D. citri* and the environmental factors of temperature and precipitation. An analysis of variance suggested that there was a significant difference in the abundance of *D. citri* among the 3 citrus tree varieties, and the autocorrelation was significant for the 'Valencia' orange orchard. Spectral analysis indicated that there were greater frequencies of peaks in the 'Ponkan' mandarin and 'Murcott' tangor trees, and the simulations performed using a stochastic logistic model suggested that the psyllid populations on orange trees are the most susceptible to local extinction; this result likely occurred because of the high levels of chemical control applied to orange trees. Therefore, in a *D. citri* management program, the different citrus varieties planted on a farm should be considered, thus varieties without the proper management of the vector does not become a source of psyllids for infestation of other varieties.

Key Words: citrus greening, huanglongbing, population ecology, vector

Resumo

O propósito deste trabalho foi estudar a dinâmica populacional de *Diaphorina citri* Kuwayama (Hemiptera: Liviidae) em pomar de laranjeira 'Valência', tangerineira 'Ponkan' e tangoreiro 'Murcott', localizados no Sítio São José, município de Taquaritinga, São Paulo (SP). Para o monitoramento do vetor foram utilizadas armadilhas adesivas amarelas, sendo avaliadas mensalmente, durante 4 anos, de setembro de 2004 à agosto de 2008. A maior captura de *D. citri* ocorreu, seguida do tangoreiro 'Murcott' e da laranjeira 'Valência'. Esse resultado deve-se, provavelmente, ao controle químico de pragas e fatores ambientais. A análise de correlação de Pearson indica fraca correlação entre a abundância de psilídeos e os fatores ambientais temperatura e precipitação. A análise de variância sugere diferença significativa entre a abundância de *D. citri* nas três variedades e a autocorrelação foi significativa para o pomar de laranjeira Valência. A análise espectral indica maior frequência de picos na tangerineira 'Ponkan' e no tangoreiro 'Murcott', e as simulações realizadas com o modelo logístico estocástico sugerem que as populações de psilídeos mais susceptíveis à extinção local são as da laranjeira, em razão provavelmente, dos altos níveis de controle químico. Portanto, em um programa de manejo de *D. citri*, as diferentes variedades cítricas plantadas em uma propriedade devem ser consideradas, desse modo uma das variedades não se torna fonte de psilídeo para as demais.

Palavras Chaves: greening, huanglongbing, ecologia populacional, vetor

Citriculture is of great economic importance in Brazil, particularly in the southeastern region. This agricultural activity has resulted in high levels of productivity and global competitiveness for Brazil, making it the world's largest producer of citrus fruit and the leading producer and exporter

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of concentrated orange juice (Guedes et al. 2005). The 2009/2010 Brazilian orange crop produced approximately 397 million 40.8-kg boxes of oranges, which corresponded to 30% of the total global orange production, from an area of approximately 840,000 ha (Neves et al. 2010). About 800,000 ha of the latter were dedicated to citrus cultivation and approximately 600,000 ha, or 75%, were located in Brazil's southeastern region; of this area 76,000 ha, or 12.5%, were irrigated (Cati 2004).

Since the first report of the Asian citrus psyllid, *Diaphorina citri* Kuwayama (Hemiptera: Liviidae), in Brazil in 1940 (Costa Lima 1942), this species has been considered to be a secondary pest that caused minor damage, which only occurred sporadically in citrus orchards in several Brazilian states (Silva et al. 1968) including São Paulo (Gallo & Montenegro 1960). However, in 2004, bacteria associated to huanglongbing (HLB) or greening, which is a highly destructive disease (Teixeira et al. 2005), were found to be associated with *D. citri* in Brazil; therefore, the status of this insect quickly changed from that of a secondary pest to a key crop pest. In the state of São Paulo (SP), the disease is linked to 2 bacterial species: '*Candidatus* Liberibacter asiaticus', and '*C.* Liberibacter americanus', which are both transmitted by *D. citri* (Capoor et al. 1967; Yamamoto et al. 2006). The first species is predominant, whereas the second one has a lower incidence (Teixeira et al. 2010).

Diaphorina citri has a broad geographic distribution and can be found in several countries of Asia, the Middle East, the islands of Reunion and Mauritius, and the Americas (Halbert et al. 2010). Similar to HLB, which affects all citrus varieties that are planted (Halbert & Manjunah 2004; Bové 2006), the *D. citri* vector lives on all species of the genus *Citrus* and can be detected on other species of the family Rutaceae (Halbert & Manjunah 2004). Of the Rutaceae species, the main host is the orange jasmine (*Murraya exotica*) (Bergmann et al. 1994; Halbert & Manjunah 2004), which is an ornamental plant widely used as an amenity planting of streets, squares, and cemeteries and as a hedge. Therefore, in an HLB management program, any of these varieties that are planted on a property should be considered.

Knowledge of the disease vector is of the utmost importance for the management of HLB. One of the strategies used to reduce the incidence and spread of the disease is the control of *D. citri*, which must be based on monitoring and take into account the population dynamics of this species to inform decision making.

Surveys conducted by Boina et al. (2009) indicate that frequent movement of adult *D. citri* occurs between orchards and suggest that unmanaged orchards can act as refuges for *D. citri*, leading to the reinfestation of nearby orchards in which the disease is being managed. Similarly, orchards of citrus varieties such as lemon, mandarin, tangor, and others can serve as a breeding site and a source of psyllids for infestation of orange trees. Although these other varieties suffer fewer attacks by some insects and mites, in the case of psyllids, the stringency of control should be the same as for orange trees. The present work aimed to study the population dynamics of *D. citri* by comparing the occurrence of adults in managed orchards of 'Valencia' orange, 'Ponkan' mandarin, and 'Murcott' tangor trees.

Material and Methods

Study Area

The experiment was performed at the São José farm, which is located in the municipality of Taquaritinga, SP, in non-irrigated orchards of 10-yr-old 'Valencia' sweet orange with 3,223 plants and (S 21°23'40.07" W - 48°31'37.98"), 15-yr-old 'Ponkan' mandarin with 1,984 plants and (S 21°23'41.74" W - 48°31'28.51") and 15-yr-old 'Murcott' tangor with 2,064 plants and (S 21°23'47.99" W - 48°31'31.71"), located in the same area at an elevation of 580 m asl. The cultural and nutritional controls were the same for all 3 cultivars.

Survey and Sampling

Double-sided adhesive yellow sticky traps (BUG Agentes Biológicos®) measuring 18 × 9.5 cm were fixed with a wire in an external branch of the plant at a height of approximately 1.10 m from the soil level. It was used 1 trap per tree. The color yellow attracts psyllids, and the double-sided adhesive facilitates their capture (Purcell & Frazier 1985). Thirty traps were installed in 'Valencia' orange trees that had been grafted onto 'Rangpur' lime with a spacing of 6.5 × 3.5 m; 12 traps and 4 traps were installed in a border of 'Ponkan' mandarin and 'Murcott' tangor blocks, respectively. The number of traps was different because the goal was to evaluate, initially, the population of sharpshooter in the 'Valencia' sweet orange orchard and if the sharpshooter could develop in the others varieties and then colonize the 'Valencia' orange orchard. Monthly evaluations were performed for 4 yr from Sep 2004 to Aug 2008, and the psyllids caught by the yellow sticky traps were counted in the laboratory. The evaluations were not performed in the same time interval, so the number of captured psyllids/day was calculated.

Statistical Analysis

Pearson›s correlation analyses were applied to assess the association between the abundance of psyllids and the factors of rainfall and tempera-

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ture (Zar 2001). Autocorrelation functions were applied to analyze the correlation in a time series throughout the correlogram, and spectral analysis was used to assess the occurrence of peaks and highlight the cycles throughout the periodogram.

Ecological Modeling

A continuous-time logistic model was used to analyze the population dynamics with the stochastic dimension as the carrying capacity (K). The geometric population growth rate (r) was estimated from the successive abundances in each citrus variety. The minimum and maximum values of seasonal *D. citri* abundance were used to estimate the stochastic K value. In this case, values of K were randomly selected from an even distribution for each time point between the experimentally obtained maximum and minimum thresholds using the random number generator function "rand" in the algebraic manipulation software MATLAB 7.0. One hundred iterations were performed in the computational simulations.

Results and Discussion

The capture of *D. citri* was greatest in the 'Ponkan' mandarin trees, followed by the 'Murcott' tangor and 'Valencia' orange trees (Fig. 1). In late 2004, the capture of *D. citri* adults was less than 0.2 adults/trap (Fig. 1). In 2005, their capture in 'Ponkan' trees was greater than in 'Murcott' and 'Valencia' trees, and population peaks occurred in Apr, Sep, and Nov.

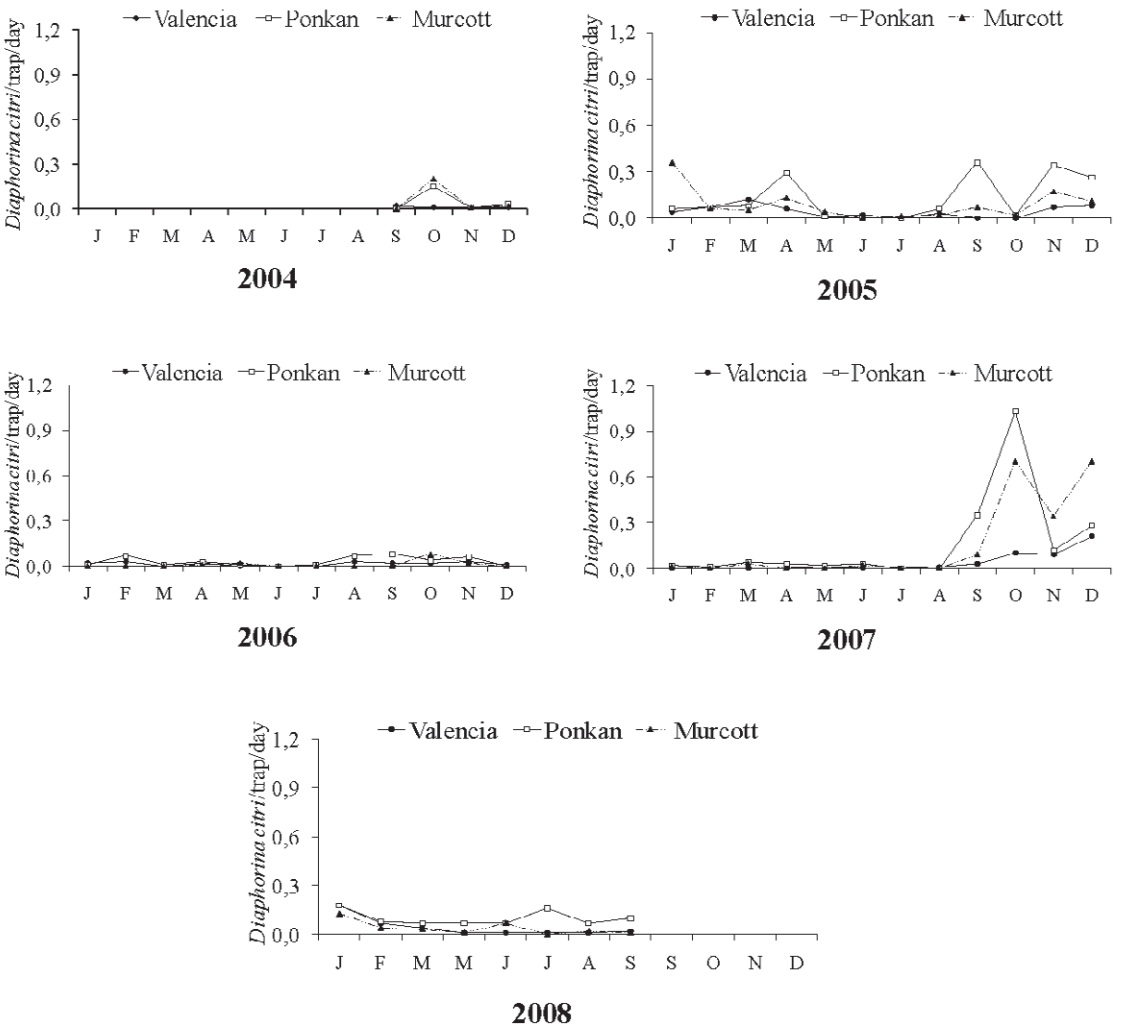


Fig. 1. The average number of *Diaphorina citri* Kuwayama captured on yellow sticky traps in orchards of 'Valencia' orange, 'Ponkan' mandarin, and 'Murcott' tangor trees in Taquaritinga, SP, Brazil.

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Throughout 2006, from Jan to Aug 2007, and in 2008, the capture of *D. citri* adults was low, i.e., less than 0.2 adults/trap/day (Fig. 1). These results show that during this period, the weather conditions were not conducive to the population growth of *D. citri*, whose numbers were likely influenced by the rains; very high rainfall occurred in the summer (from end of Dec to end of Mar), whereas low rainfall occurred in the autumn (from end of Mar to end of Jun). Aubert (1985) notes that monthly rainfall above 150 mm is generally associated with a low population of *D. citri* because the eggs and young nymphs are washed off the plants. According to Regmi & Lama (1988), the adult psyllid population decreases during the rainy season because heavy rains can eliminate eggs and nymphs; however, adults can hide on the abaxial surfaces of leaves and on the twigs of the lower and inner portions of the trees. Raychaudhari et al. (1969) reported that the incidence of *D. citri* decreases with the onset of the rainy season, but the insect reappears in small numbers during the autumn when the amount of rainfall decreases.

In the second half of 2007, there was an increase in the psyllid population in all 3 citrus varieties; this increase was likely due to the rains that occurred in Jul 2007 (winter), which totaled more than the historical average rainfall for that month throughout the state of SP (Ciiagro 2008). This increased rainfall triggered the early growth of citrus plants and a consequent outbreak of *D. citri,* because the shoots (flushes) of the trees are the vector's preferred site for feeding and oviposition (Gallo et al. 2002). Hodkinson (1974) noted that under tropical conditions, several generations of psyllids can be observed throughout the yr, and their growth rates are influenced by weather and by the condition of the plants. In Brazil, it has been observed that psyllids are present throughout the yr but at low population levels in the autumn and winter (Yamamoto et al. 2001). However, *D. citri* reproduction and population growth may occur on all shoots, even when they appear during periods that are less favorable to the development of the insect (Yamamoto & Miranda 2009).

In Sep and Oct 2007, the population of *D. citri* was greater in 'Ponkan' trees, and in Nov and Dec, it was greater in 'Murcott' trees (Fig. 1). Due to their resistance or tolerance to citrus variegated chlorosis (CVC) (Li et al. 1996) and citrus leprosis (Bastianel et al. 2006), the application of insecticide is less frequent in 'Murcott' and 'Ponkan' orchards, allowing the development of *D. citri* to occur and its population to increase. However, in 'Valencia' orange tree orchards, the application of both insecticides and acaricides is more frequent, which reduces and/or limits psyllid population growth.

Sprouting is another factor that can affect the *D. citri* population. Hall et al. (2008) noted that the disease vector can occur at any time of the yr, depending on environmental conditions and the availability of shoots.

The analysis of the correlation between the number of *D. citri* adults captured in 'Valencia' orange trees and environmental factors revealed significant and positive correlations with both precipitation ($r = 0.34$, $P < 0.05$) and temperature ($r = 0.38$, $P < 0.05$) (Table 1). For *D. citri* adults caught on 'Murcott' trees, the result was similar, with significant and positive correlations between the number of individuals and precipitation ($r = 0.23, P < 0.05$) and temperature ($r = 0.28, P < 0.05$). The number of *D. citri* captured in 'Ponkan' trees was significant and positively correlated with temperature ($r = 0.23$, $P < 0.05$) but exhibited a low and negative, although not significant, correlation with precipitation ($r = -0.03$, $P > 0.05$). The results obtained in the 'Ponkan' variety suggest a nearly nonexistent association between precipitation and the number of *D. citri* adults. Temperature and rainfall can be either favorable or unfavorable to *D. citri*. The optimum temperature for the development of the psyllid is between 25 and 28 °C (Liu & Tsai 2000); however, high temperatures in summer (above 32-34 °C) and excessively low temperatures in winter (below 2.5 °C) hamper *D. citri* development (Aubert 1985). Precipitation can also positively or negatively influence the *D. citri* population. Intermittent and constant rains can cause frequent sprouting of citrus plants and thus encourage psyllid development. The weak influence of environmental factors on the abundance of *D. citri* has been reported elsewhere; for

Table 1. Correlations between the numbers of *Diaphorina citri* Kuwayama collected and temperature and precipitation.

'Valencia' orange	
Correlation factor	Correlation coefficient (r)
Precipitation	0.34*
Temperature	0.38*
'Ponkan' mandarin	
Correlation factor	Correlation coefficient (r)
Precipitation	0.03^{ns}
Temperature	0.23*
'Murcott' tangor	
Correlation factor	Correlation coefficient (r)
Precipitation	0.23*
Temperature	0.28*

*Significant correlation ($P < 0.05$); ns - not significant.

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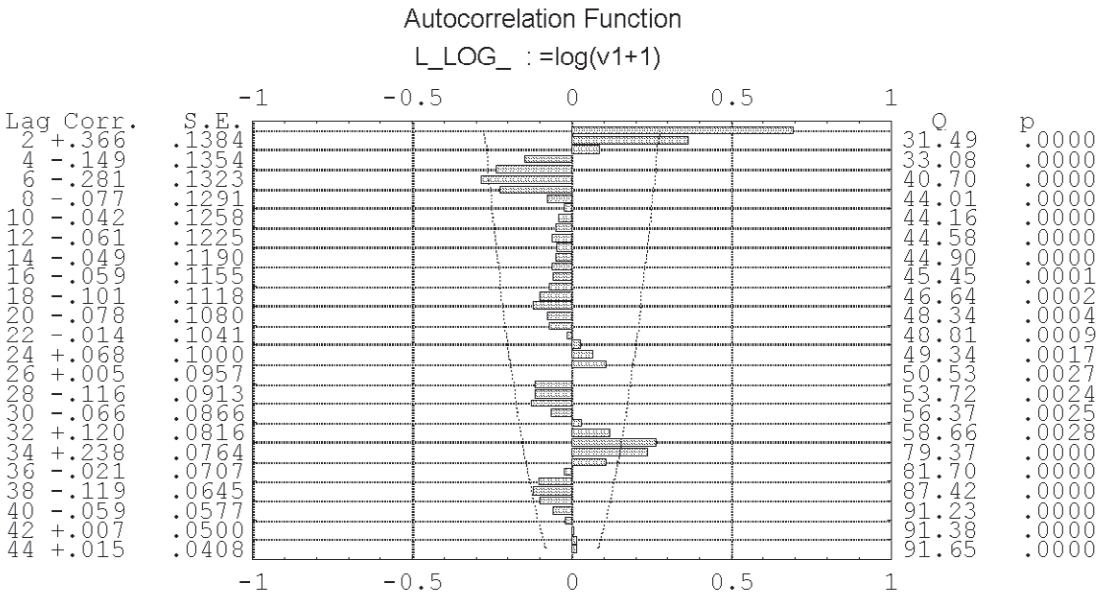


Fig. 2. A correlogram for *Diaphorina citri* Kuwayama captured in 'Valencia' orange trees in Taquaritinga, SP, Brazil.

example, in the study by Ahmed et al. (2004), environmental factors showed hardly any association with the abundance of this species.

The autocorrelation function was significant for the *D. citri* time series from 'Valencia' orange trees (Fig. 2) but not for the time series from 'Ponkan' or 'Murcott' trees (Fig. 2). This result suggests that there is a slight tendency for the occurrence of cycles but only for psyllids collected in 'Valencia' trees (Fig. 2); hence, it is possible that the fluctuation pattern will repeat at some point. The spectral analysis confirms this result because the greatest frequencies of peaks were observed in 'Ponkan' trees followed by 'Murcott' trees (Fig. 3 a-c), which does not suggest the occurrence of cycles.

The stochastic dynamics, which are described by the continuous-time logistic model, showed that the *D. citri* population from 'Valencia' orange trees was the most susceptible to local extinction as a function of the proximity of their values to zero (Fig. 4a). This result likely occurred because of the greater number of agrochemical applications for the control of pests, which contributed to the decline in the *D. citri* population. The psyllid population from 'Murcott' tangor trees is most likely to persist locally, followed by psyllids from 'Ponkan' mandarin trees (Fig. 4b and c). The levels of susceptibility to local extinction are different for all 3 citrus varieties, displaying clear differences in the time series for psyllid populations of the 3 crops (Fig. 4).

There is no characteristic pattern of *D. citri* population fluctuation among the 3 citrus variet-

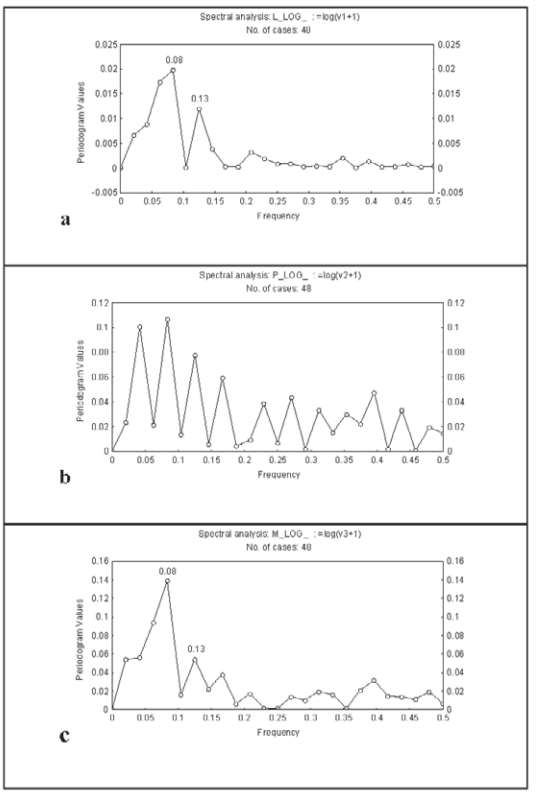


Fig. 3. Periodograms for *Diaphorina citri* Kuwayama collected in 'Valencia' orange (a), 'Ponkan' mandarin (b), and 'Murcott' tangor (c) trees in Taquaritinga, SP, Brazil.

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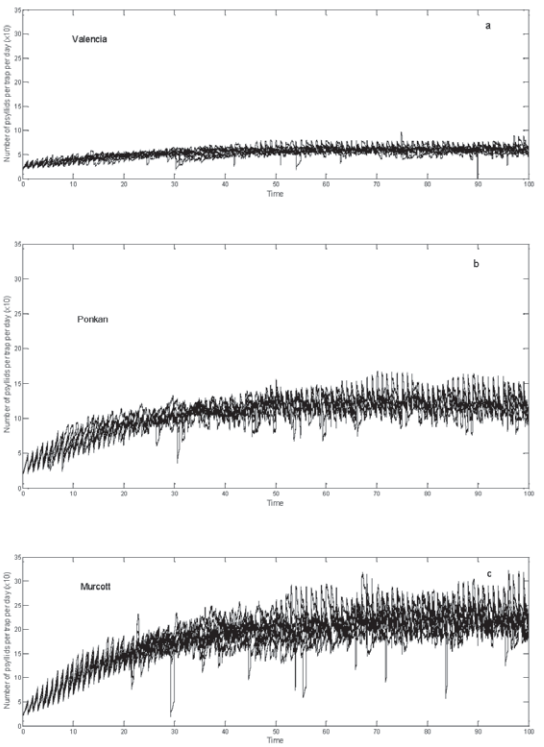


Fig. 4. Population dynamics with a stochastic carrying capacity for *Diaphorina citri* Kuwayama collected in 'Valencia' orange (a), 'Ponkan' mandarin (b), and 'Murcott' tangor (c) trees in Taquaritinga, SP, Brazil.

ies that were studied. The peaks and the quantity of psyllids captured varied from yr to yr depending on rainfall, temperature, and other factors. Depending on when it begins, rainfall can interfere with plant budding, which culminates in an early or late infestation by the vector (Yamamoto et al. 2001). The quantity of rain can also influence the vector population, which tends to decrease during periods of intense heavy rains (Regmi & Lama 1988).

Although resistant or tolerant to CVC and citrus leprosis, the 'Ponkan' and 'Murcott' tree varieties are as susceptible to HLB as orange trees (Garnier et al. 1984). Therefore, for efficient management of the disease, all of the citrus varieties planted on a property should be considered. Population monitoring is very important for the correct management of this vector because population density can vary from yr to yr and is heavily influenced by weather factors and the occurrence of new shoots.

Despite of the apparent influence of chemical control in the 'Valencia' sweet orange orchard, that possibly contributed to the differentiation of the dynamics of *D. citri* compared to other varieties, the cycles produced with the correlogram suggest the existence of density dependence in some extent, indicating that the ecological patterns found in the time series of D. citri are probably not only associated to the chemical control but mainly to intrinsic demographic factors of the species. In addition, the results observed in the simulations with the stochastic logistic model give significant evidences of also environmental stochasticity caused by random factors arising from the different agricultural systems (citrus varieties), which may influence ecological patterns of the insect species.

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