Population Abundance, Phenology, Spatial Distribution and a Binominal Sampling Plan for Heliothrips haemorrhoidalis (Thysanoptera: Thripidae) in Avocado

Authors: Larral, Pilar, Ripa, Renato, Funderburk, Joe, and Lopez, Eugenio

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Population abundance, phenology, spatial distribution and a binominal sampling plan for *Heliothrips haemorrhoidalis* (Thysanoptera: Thripidae) in avocado

Pilar Larral[1,], Renato Ripa[1], Joe Funderburk[3], and Eugenio Lopez[4]*

Abstract

The economic impact of the greenhouse thrips, *Heliothrips haemorrhoidalis* (Bouché) (Thysanoptera: Thripidae), has increased on Chilean avocados as a consequence of the high value of the crop and the increased injury to the fruit surface. The population dynamics, phenology, and patterns of aggregation of *H. haemorrhoidalis* was determined with the objective of rationalizing the use of pesticides using a therapeutic control approach. The study was conducted in 2 avocado fields during 2005 to 2007 in the Valparaiso Region of Chile. New colonies developed on the leaves and small fruits, reaching greatest numbers at the beginning of the winter months. Immature stages were greater in number than the adults during most of the production season. The spatial distribution was calculated using Taylor's power law, showing an aggregated pattern with indices of 1.46 and 1.53 on leaves and fruits, respectively. Pooled data were used to describe the relationship between population density and the proportion of infested leaves and fruit. In the case of a density of about 2 thrips per leaf or fruit, the proportion of infested samples was 0.8. Sample size curves were generated as a function of mean density of thrips with about 20 presence/absence samples needed to estimate densities of 0.5 thrips or more at a precision level of 25%.

Key Words: greenhouse thrips*,* sampling, spatial distribution, sample size

Resumen

El trips de los invernaderos, *Heliothrips haemorrhoidalis* (Bouché) (Thysanoptera: Thripidae), ha incrementado su impacto económico en los paltos en Chile, debido al incremento del daño que provoca en la superficie del fruto y al mayor valor de la producción. Con el objetivo de racionalizar el uso de plaguicidas mediante un enfoque de control terapéutico, se determinó la dinámica poblacional, la fenología y los patrones de agregación de H. haemorrhoidalis. El estudio se realizó en 2 huertos de palto, durante 2005 a 2007 en la Región de Valparaíso, Chile. Las colonias de trips se desarrollaron en las hojas y frutos pequeños, alcanzando su máximo a comienzo de los meses de invierno. Los estadios inmaduros superaron a los adultos durante la mayor parte de la temporada de producción. La distribución espacial se calculó utilizando la Ley de Potencia de Taylor, mostrando un patrón agregado con índices de 1,46 y 1,53 en hojas y frutos, respectivamente. Los datos de ambos predios fueron utilizados para describir la relación entre la densidad de población y la proporción de hojas y frutos infestados. En el caso de una densidad aproximada de 2 trips por hoja o fruto, la proporción de muestras infestadas fue de 0,8. Se generaron curvas de tamaño de muestra en función de la densidad media de trips, resultando necesario 20 muestras de presencia/ausencia para estimar una densidad de 0,5 trips o más, con un nivel de precisión del 25%

Palabras Claves: trips de los invernaderos, trips del palto, monitoreo*,* distribución espacial, tamaño de muestra

Historically, the avocado crop in Chile had few pests, which were typically managed without insecticides. The value of the crop and insect pest impacts have increased recently. The area currently planted with avocado in Chile is about 36,355 hectares (Odepa 2013). Greenhouse thrips, *Heliothrips haemorrhoidalis* (Bouché) (Thysanoptera: Thripidae), have emerged as an economically important pest in the Valparaíso Region (Larral et al. 2008), where 60% of the Chilean avocado crop is cultivated (Odepa 2013). Feeding results in decreased plant vigor and cosmetic injury to fruit that results in rejection of fruit destined for export (Ripa et al. 2007). Goodall et al. (1987) suggested that higher plant densities favored populations of *H. haemorrhoidalis*. The relationship between *H. haemorrhoidalis* populations and damage to avocado has yet to be quantified and is not understood.

Colonies of *H. haemorrhoidalis* are formed on the leaves and fruits of avocado. Adults and larvae feed by piercing the epidermal tissue and sucking the cellular contents. Feeding produces russeting on leaves and fruit (Stevens et al. 1999). Russeting does not compromise the quality of the fruit pulp, but avocados are rejected for export if the total injury exceeds 1 cm^2 per fruit in Chile (Larral & Ripa 2007). It is unacceptable for premium export grade in New Zealand with injury covering more than 2 cm^2 (Stevens et al. 1999). Growers have responded by increasing pesticide use. The absence of monitoring methods, coupled with limited knowledge about pest phenology and population dynamics, has resulted in inadequate pest control with the available pesticides.

A cornerstone in developing a therapeutic control approach in an integrated pest management strategy is an understanding of pest phenology and behavior and the development of a statistically accurate sampling plan (Nyrop et al. 1999). A therapeutic management approach for greenhouse thrips in avocado can be developed and implemented with the above knowledge. Insecticide applications can be targeted to

[1]Centro de Entomología Aplicada Ltda., Quillota, Chile, E-mail: plarral@biocea.cl (P. L.); rripa@biocea.cl (R. R.)
[3]University of Florida, North Florida Research and Education Center, Quincy, Florida 32351, USA, E-mail: jef@ufl.edu (J. F.)
[4]Facultad de Ciencias Agronómicas y de los Alimentos. Pontificia Universidad Católica de Valparaiso, Quillota, Chile, E-mail: eugenio.lopez@pucv.cl (E. L.)
*Corresponding author; E-mail: plarral@biocea.cl

prevent damage while reducing unnecessary use with greater potential for integrating chemical, cultural, and biological control methods. The objectives of the current study were to determine the population abundance and phenology of *H. haemorroidalis* in avocados, to estimate the dispersion characteristics of greenhouse thrips in avocado trees and orchards, and to establish the relationships between density of *H. haemorrhoidalis* and percentage of leaves and fruit infested in order to develop a presence or absence (binomial) sampling plan.

Materials and Methods

Data were taken from 2 commercial, non-sprayed orchards in Quillota Province, Valparaíso Region, Chile. Each orchard was approximately 3 ha in size with mature 'Hass' avocado trees that were about 8 years old. Ten trees were randomly selected from each orchard. These were sampled about every 21 days for 2 years, from Jul 2005 to Dec 2007. Twenty fruits from below 2 m were chosen randomly on each tree and labeled using small colorful yarn tied to the base of each leaf and fruit. Marked fruits that fell during the course of the study were replaced with another that was randomly chosen. Ten mature leaves were also randomly chosen. On each marked fruit and extracted leaf, the number of *H. haemorrhoidalis* adults, first instars, second instars, propupae, and pupae were counted, using in the field a 3X magnification headband and in the laboratory a 50X stereoscope. The size of the fruit was measured on all sampling dates.

STATISTICAL ANALYSIS

Means (± SEM) on leaves and fruits were determined for larvae I, larvae II, propupae, pupae, and adults on each sample date in each field in order to determine population abundance of thrips. Taylor's power law relationships (Taylor 1984) were conducted for each *H. haemorrhoidalis* life stage and for life stages combined. Separate analyses were conducted for leaves and fruits in each field. Taylor's power law relates variance (s^2) to mean (x) by the equation $s^2 = ax^b$, which is expressed as a linear relationship $\log s^2 = a + b(\log x)$. The slopes (b) were compared to 1 using a t-test. Values of $b < 1$, $b = 1$, and $b > 1$ were considered representative of uniform, random, and aggregated distributions. Slopes of individual life stages were compared using the 95% confidence interval (CI). The goodness-of-fit of each relationship was evaluated by determining the coefficient of regression (R^2).

A binominal sampling plan was developed by establishing a relationship between the total population (m) and the proportion of infested structures (leaves and fruits). This was done using variables a and b from the Taylor's power law variables in the equations of Wilson & Room (1983), where $p = 1 - \exp[-m(\ln (a \bullet m^{(b-1)})/ (a \bullet m^{(b-1)} - 1))]$. Calculation of the sample size was made for the population with a constant coefficient of variation (CV) of 25% (CV = (S/√n)/m), which is considered acceptable in scouting programs (Southwood & Henderson 2000). The formula $n = am^{b-2}/D^2$ was used based on the parameters from Taylor's power law where n is the required sample size and D is the desired level of precision of 25%.

Results

SEASONAL ABUNDANCE OF THRIPS IN AVOCADO

Heliothrips haemorrhoidalis formed colonies on the leaves (Fig. 1a, c). Populations were present on nearly all sample dates. Populations were abundant in field 2 from Aug 2005 when sampling began until Feb 2007 with the number of immatures outnumbering the number of adults on nearly all sample dates. Densities were greatest in field 2 from Feb to Oct 2006 when estimates of total thrips exceeded 1 per leaf. Populations of *H. haemorrhoidalis* were greatest in field 1 on all sample dates from Jan to Jul 2006 when densities exceeded 1 per leaf. Populations were very low in field 1 on all sample dates prior to and after that period.

Immature *H. haemorrhoidalis* outnumbered the adults on the fruits in both fields during the winter months of Jul, Aug, and Sep of 2005 (Fig. 1b, d). Fruits were harvested, and new fruits were not available until Dec 2005 when adult thrips formed colonies as the new fruits developed. The abundance of the immature stages increased in both fields from the summer months of Jan, Feb, and Mar 2006 until the fall and winter months of Aug and Sep when the fruits were harvested. Colonies re-developed on the new fruits in field 2 in Nov 2006, but the numbers of immatures were less than the numbers of adults on nearly all samples dates until Nov 2007. Almost no colonies of *H. haemorrhoidalis* developed on the new fruits in field 1 from Nov 2006 until sampling was discontinued in Nov 2007.

DISTRIBUTION OF THRIPS ON AVOCADO

Regression statistics of Taylor's power law relationships for individual sample estimates of *H. haemorrhoidalis* adults, pupae, and larvae on avocado leaves and fruits are shown in Tables 1 and 2, respectively. Values of the intercept a for all thrips stages in both fields ranged between 0.83 and 1.17 on leaves and between 0.48 and 1.01 on fruits. Values of the slope b for all thrips stages in both fields ranged between 1.44 and 1.53 on leaves and fruits, and each was significantly greater than 1, thereby showing that all populations were aggregated. The 95% CL of estimates of b for all stages overlapped in both fields; consequently, the degree of aggregation on leaves and fruits was similar for each thrips stage in both fields.

PRESENCE/ABSENCE SAMPLING PROGRAM FOR THRIPS ON AVOCADO

Because the pattern of aggregation of *H. haemorrhoidalis* was very similar for each life stage, Taylor's power law relationships for total adult and immature thrips were used in the Wilson & Room (1983) equation to describe the relationship between total population and the proportion of infested leaves and fruits. Figure 2 shows the relationships between population density and proportion of infested leaves and fruits using values of a and b from the Taylor's power law relationships for leaves and fruits for data pooled over fields 1 and 2. Determination of this functional relationship allows for estimating density in scouting programs without counting all inhabitants on leaves or fruits, thereby reducing the time of sampling. The proportion of infested samples was less than 0.8 for densities of about 2 thrips per leaf or fruit.

The number of presence/absence leaf and fruit samples needed to estimate density at the 25% level of precision as a function of mean density using the equation in Southwood & Henderson (2000) is shown in Figure 3. At densities of 0.5 thrips per fruit or greater, fewer than 22 samples are necessary to estimate density at the 25% level of precision.

Discussion

The abundance of pests is directly associated with the phenology of the part of plant on which they feed. The abundance of thrips and their phenology has been widely studied, mainly in species in-

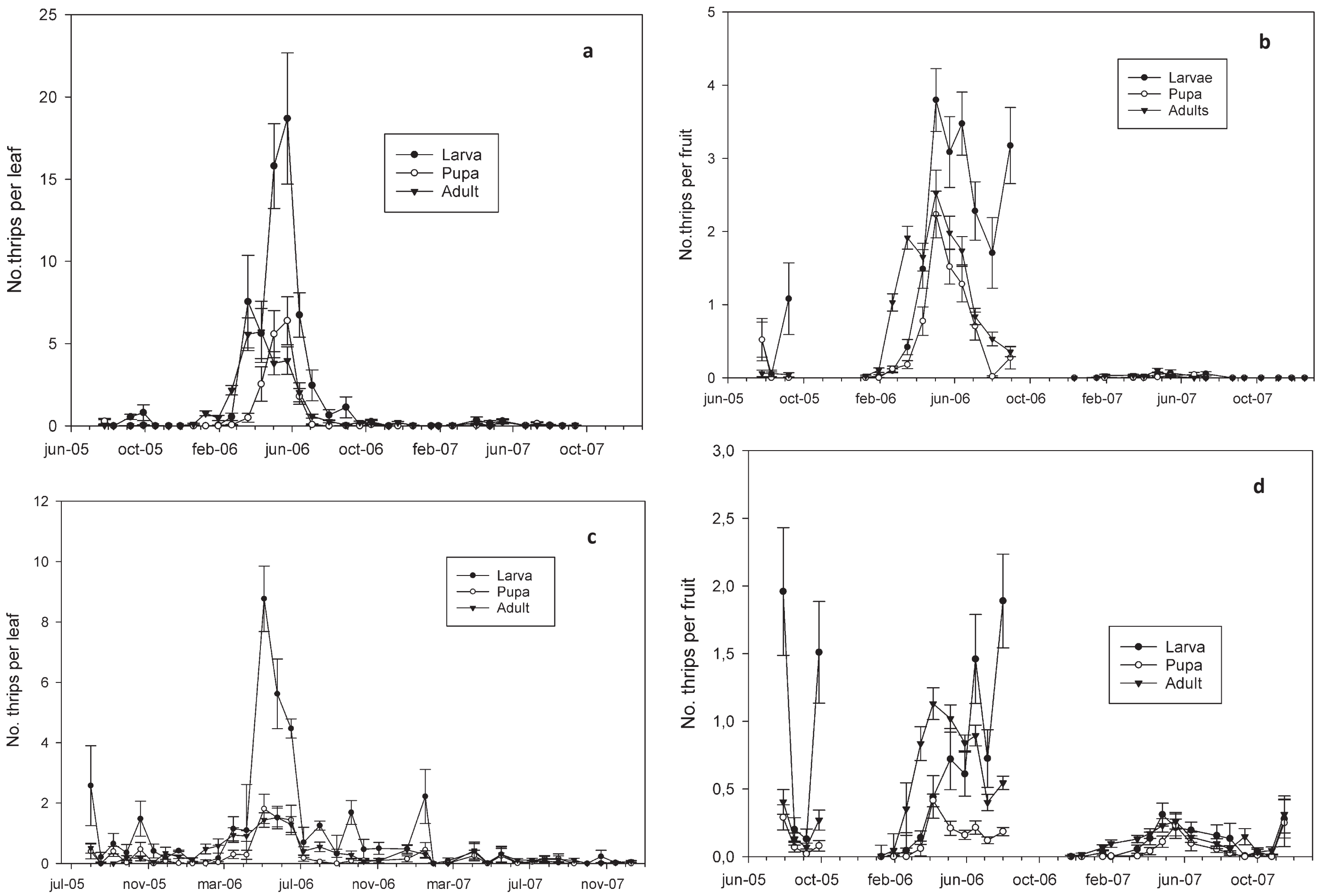

Fig. 1. Abundance (mean ± SE) of adult and immature stages of *H. haemorrhoidalis* per leaf and fruit (from sampling 10 leaves and 20 fruits of 10 sample trees) in Field 1 (a, b) and Field 2 (c, d).

festing and causing damage in crops during the flowering period, such as *Frankliniella* (Thysanoptera: Thripidae) species (Northfield et al. 2008; Osekre et al. 2009; Pearsall & Myers 2000). *Heliothrips haemorrhoidalis* formed colonies on the leaves and fruits of avocado. They were present on the leaves of avocado at all times of the year. The adults formed colonies when the fruits were small, and the colonies increased and caused injury until the fruits were harvested. The development and abundance of the pest is associated with environmental conditions. Chhagan & Stevens (2007) determined a minimum threshold temperature of 10.1 °C for *H. haemorrhoidalis*. This is greater than the minimum threshold of 6.9 °C reported for *Scirtothrips persea* (Thysanoptera: Thripidae), another avocado pest (Hoddle 2002).

Aggregation in thrips species has been established in several publications. Wang & Shipp (2001), Parajulee et al. (2006), Salguero Navas et al. (1994), and García-Marí et al. (1994) showed a significant regression in Taylor's power law for a population of *Frankliniellia occidentalis* (Pergande) (Thysanoptera: Thripidae) in cucumber, cotton, tomato, and strawberries with aggregation indices of about 1.5. Cho et al. (2000) described a very similar aggregation index in *Thrips palmi* Karny (Thysanoptera: Thripidae) in potato. These values are similar to the aggregation indices determined for *H. haemorrhoidalis* in this study. Worner & Chapman (2000) determined an even greater aggregation of thrips on *Viburnum tinus* L. (Dipsacales: Adoxaceae) with index 1.9.

Cho et al. (2000), Navarro-Campos et al. (2012), and Salguero Navas et al. (1994) observed greater aggregation of the larval thrips compared to the adult thrips. This was attributed to the reduced mobility and ability to disperse of the larvae. The pattern of aggregation was similar for all life stages of *H. hemorrhoidalis* on avocado. It is a colony-forming species with all life stages living in the same colony. The pattern of aggregation is expected to be similar for all life stages in colony-forming species (Southwood & Henderson 2000). This study was carried out in untreated avocado orchards. The aggregation index may differ in pesticide-treated trees (Trumble 1985).

The presence/absence census method developed by Wilson & Room (1983) to utilize Taylor's power law has been a convenient tool for integrated pest management (Kuno 1991). The relationship between the proportion of infested leaves and the mean density of the pest has been determined for different pests such as thrips, spider mites, psyllids, and white flies among others (Cho et al. 2000; Salguero Navas et al. 1994; Zalom et al. 1985; Naranjo & Flint 1995; Steiner 1990; Worner & Chapman 2000; Wang & Shipp 2001). The understanding of this relationship allows a less time-consuming monitoring and therefore less costly management of the pest (Binns & Nyrop 1992). Our results showed that *H. haemorrhoidalis* adults began infesting the small fruits of avocado. Injury to the fruits from feeding can be estimated to increase 0.22 cm^2 per adult per week (Stevens et al. 1999). The amount of injury of *H. haemorrhoidalis* that can be tolerated on exported avocado fruit is limited. Therefore, the pest must be detected at an early stage of the infestation providing the right pesticide treatment window by which a successful control is obtained avoiding ad-

Table 1. Regression statistics of Taylor's power law obtained for different *H. haemorrhoidalis* life stages from random samples of 10 individual avocado leaves collected from each of 10 trees in 2 fields located in Valparaiso Region, Chile, for all dates when the mean was not equal to zero.

	Taylor's power law regression statistics															
	Field 1 (35 samples from 26 Jul 2005 to 12 Sep 2007)								Field 2 (38 samples from 1 Aug 2005 to 10 Dec 2007)							
Instar	N dates	Intercept *a*	Slope *b*	CI 95%		R^2	*F*-value	*P*	N dates	Intercept *a*	Slope	CI 95%		R^2	*F*-value	*P*
Larva I	20	1.116	1.502***	1.376	1.629	0.972	624.5	0.0001	32	1.169	1.509***	1.386	1.632	0.954	625.5	0.0001
Larva II	19	1.007	1.470***	1.351	1.589	0.976	680.7	0.0001	33	1.096	1.510***	1.400	1.621	0.962	780.8	0.0001
Propupa	14	1.000	1.453***	1.316	1.59	0.978	535.4	0.0001	20	1.080	1.463***	1.295	1.631	0.949	334.7	0.0001
Pupa	15	1.020	1.502***	1.399	1.606	0.987	981.4	0.0001	27	1.116	1.527***	1.407	1.648	0.964	676.2	0.0001
Adult	29	0.830	1.455***	1.355	1.556	0.970	885.9	0.0001	35	0.89	1.436***	1.276	1.595	0.911	336.7	0.0001
All stages	29	1.091	1.624***	1.501	1.747	0.964	730.7	0.0001	37	1.242	1.595***	1.443	1.748	0.928	450.5	0.0001

***Indicates a slope significantly greater than 1.0 at $P < 0.0001$, *t*-test.

Table 2. Regression statistics of Taylor's power law analyses conducted for different *H. haemorrhoidalis* life stages from random samples of 20 individual avocado fruits collected from each of 10 trees in 2 fields located in Region V, Chile, for all dates when the mean was not equal to zero.

	Taylor's power law regression statistics															
	Field 1 (29 samples from 26 Jul 2005 to 17 Dec 2007)								Field 2 (29 samples from 29 Jul 2005 to 15 Nov 2007)							
Instar	N dates	Intercept *a*	Slope *b*	CI 95%		R^2	*F*-value	*P*	N dates	Intercept *a*	slope	CI 95%		R^2	*F*-value	*P*
Larva I	17	0.907	1.374***	1.281	1.466	0.985	1001.1	0.0001	22	1.008	1.396***	1.232	1.559	0.938	317.2	0.0001
Larva II	17	0.620	1.220***	1.131	1.308	0.983	868.4	0.0001	24	0.843	1.367***	1.246	1.488	0.960	548.5	0.0001
Propupa+ pupa	14	0.895	1.390***	1.255	1.525	0.977	502.3	0.0001	21	0.936	1.404***	1.196	1.612	0.909	199.7	0.0001
Adult	20	0.480	1.259***	1.200	1.317	0.991	2041.2	0.0001	29	0.530	1.212***	1.095	1.329	0.941	451.5	0.0001
All stages	22	0.841	1.412***	1.306	1.517	0.975	785.3	0.0001	29	0.930	1.398***	1.290	1.506	0.962	707.7	0.0001

***Indicates significantly greater than a slope of 1 at $P < 0.0001$ according to a *t*- test.

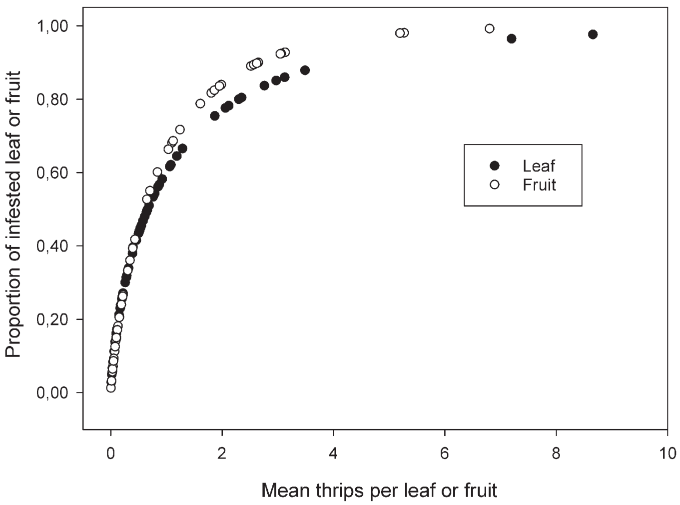

Fig. 2. Relationships between the proportion of infested leaves and fruits and *H. haemorrhoidalis* population density using Taylor's power law indices in the Wilson & Room (1983) equation for data pooled over avocado fields 1 and 2.

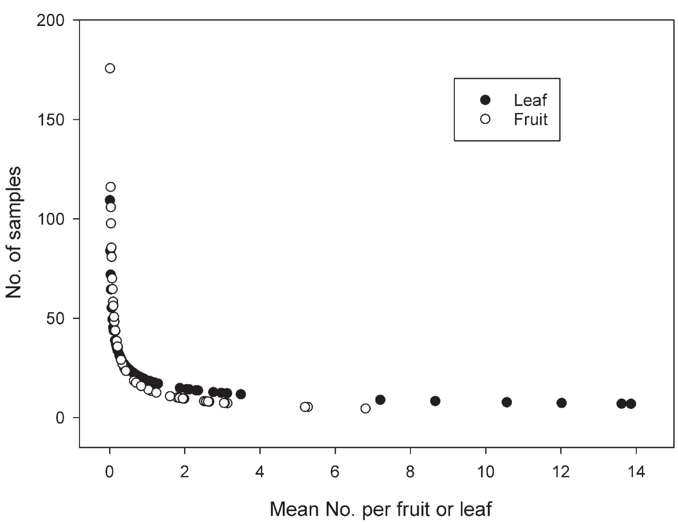

Fig. 3. Relationships between the number of leaf and fruit samples needed to estimate density at the 25% precision level and the number of thrips in each part of avocado tree as determined by using the equation in Southwood & Henderson (2000) for data pooled over avocado fields 1 and 2.

ditional treatments. The binomial sampling program reported here provides the monitoring parameters to estimate density with a 25% precision level before populations reach the economic threshold. This monitoring program was developed for orchards that were 2 ha in size. Observations suggested that population sizes are increased in certain areas of larger orchards perhaps due to influences such as proximity to bodies of water (P. L. and R. R., unpublished). Therefore, large orchards should be broken into smaller sections for monitoring purposes in order to further avoid treatment of the entire orchard unnecessarily.

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