

Optimum spacing of pheromone traps for monitoring the coffee leaf miner *Leucoptera coffeella*

T. Bacca^{1,2}, E.R. Lima¹, M.C. Picanço¹, R.N.C. Guedes^{1,*} & J.H.M. Viana³

¹Departamento de Biologia Animal, Universidade Federal de Viçosa, Viçosa MG 36571-000, Brazil; ²Universidad de Nariño, Facultad de Ciencias Agrícolas, Torobajo, Pasto, Nariño, Colombia; ³Departamento de Solos, Universidade Federal de Viçosa, Viçosa MG 36571-000, Brazil

Accepted: 21 November 2005

Key words: population monitoring, sex pheromone, trap density, trap interaction, sampling range, geostatistics, spatial analysis, coffee pest, Brazil, Lyonetiidae, Lepidoptera

Abstract

Pest monitoring with pheromone traps is affected mainly by factors such as trap placement and pest biology. The intertrap distance can affect the capture due to competition among traps that are placed at short distances. We studied the interference among pheromone traps used to monitor males of the coffee leaf miner, *Leucoptera coffeella* (Guérin-Ménéville) (Lepidoptera: Lyonetiidae), with traps placed at various distances. Using geostatistical analysis, we determined at what distance captures were independent from other traps. Traps were placed in groups of 12 with distances among traps per group either 2, 5, 10, 15, or 30 m. Traps were checked for males every 4 days during 16 days. We found interference between traps when intertrap distances were shorter than 10 m. The range and magnitude of spatial dependence varied considerably among each sampling date and wind direction. For directions of 45° and 135°, the traps should be placed 110 and 177 m apart, respectively, to obtain spatially independent counts and therefore representative samplings for assessing the insect population in the area. These results have implications for developing sampling plans for managing *L. coffeella* with pheromone traps; the spatial analysis indicated that a trap density of one pheromone trap for every 3.5–4 ha would be adequate for the monitoring of the coffee leaf miner.

Introduction

The coffee leaf miner, *Leucoptera coffeella* (Guérin-Ménéville) (Lepidoptera: Lyonetiidae), is one of the major pests of coffee in almost all coffee-growing areas of the Americas, causing significant yield losses (Le Pelley, 1968; Souza et al., 1998). In many areas, including Brazil, insecticides are generally used to control this pest, but the development of resistance to the commonly used organophosphate insecticides has compromised this control method (Fragoso et al., 2002, 2003). Because insecticide applications are most efficient when control decisions are based on population levels within individual fields (Pedigo, 1999), one method to reduce the use of insecticides in coffee fields is through the efficient monitoring of pest populations in order to determine the correct timing of pesticide applications. Estimating the percentage of leaves mined is

often labour intensive, because it requires examination of a high number of leaves (Vieira et al., 1999). A good alternative for such sampling is the use of pheromone traps (Howse et al., 1998). By monitoring *L. coffeella* males using pheromone traps, it may be possible to determine the correct timing for insecticide applications, leading to a reduced and more rational use of insecticides.

Francke et al. (1988) identified the sex pheromone of *L. coffeella* and, starting from this research, Lima (2001) carried out field studies aimed assessing the best method for monitoring numbers of *L. coffeella* males (i.e., trap design, trap height, pheromone persistence, and effectiveness of doses). Several factors affect the efficiency of pheromone traps (Howse et al., 1998; McNeil, 1991). One of these factors is the density of traps; intertrap distances may affect the number of males captured because of interference between traps. When traps are placed close to each other, their radius of attraction may overlap, thus reducing the number of males caught per individual trap. In fact, trap interference may occur even without such overlap due to insect flight between different trapping zones (Wall &

*Correspondence: R.N.C. Guedes, Departamento de Biologia Animal, Universidade Federal de Viçosa, Viçosa MG 36571-000, Brazil. E-mail: guedes@ufv.br

Perry, 1978, 1980, 1987). Furthermore, the interaction of traps is not constant with distance, but varies with lure concentration and wind conditions. By reducing the pheromone release, the active space of a trap decreases because the average concentration of pheromone downwind from the traps decreases (Bradshaw et al., 1989; Judd & Borden, 1989).

Various methods are used to determine the intertrap distance that may affect the captures or the active space of the pheromone plume. To find this distance, Elkinton & Cardé (1988) and Wedding et al. (1995) compared male captures in traps deployed in grids and hexagonal arrays with different distances. A mark–release–recapture technique has also been used to obtain the range over which the pheromone is attractive (Elkinton & Cardé, 1980; Bradshaw et al., 1989; Kondo & Tanaka, 1994; Turchin & Odendaal, 1996). A suitable intertrap distance is obtained when the insect capture stabilizes with increasing distance between traps.

Another method to determine intertrap distance was proposed by Rield (1980). Slightly different ranges of trap densities were tested in each of the Rield's experiments. The lowest trap density was 1 per hectare, the highest 2.2 per hectare. From these data, a quadratic regression was estimated, which relates the relative increase in trap catch to trap area, but this estimate is affected by characteristics of male dispersion. Another way of estimating optimum trap density or sample size is using a relationship between mean and variance (Jansson et al., 1989; Sallam & Garrad, 2001). These authors determined the number of pheromone traps to use per area, but this method to estimate the number of traps ignores the spatial location. Recent studies of insect populations have used a more explicit incorporation of space by specifying space as a function of distance through geostatistical tools (Liebhold et al., 1993; Blom & Fleischer, 2001). Geostatistical analyses use information on the value of a sample and its location to summarize the correlation among points at various distances and directions (Liebhold et al., 1993). Thus, geostatistical methods provide a more direct measure of spatial dependence by calculation of the minimal distance among traps that are statistically and spatially independent (Sciarretta et al., 2001; Gilbert et al., 2003; Ryan et al., 2004).

Our goals were to determine the interference distance of pheromone traps and estimate an intertrap distance at which independence between trap captures occurred, thus allowing an efficient trap distribution in the field, while preserving accuracy of population estimates. Geostatistical techniques were applied to determine the maximum distance at which dependence between trap captures exists.

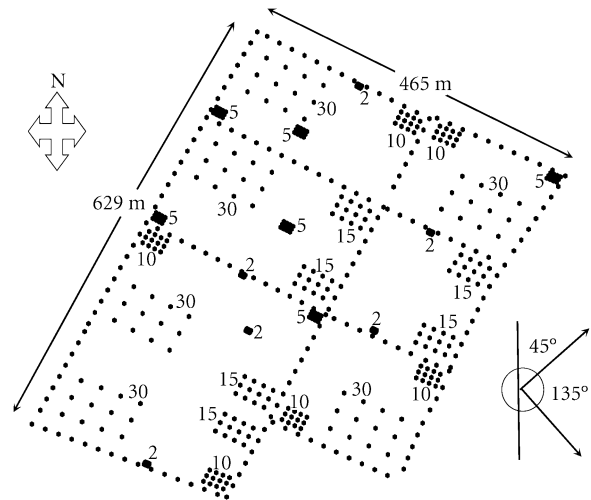


Figure 1 Location of the *Leucoptera coffeella* pheromone traps, showing regular grids of 2, 5, 10, 15, and 30 m distance between traps and the position relative to the north.

Materials and methods

Experimental plots and insect trapping

The study was conducted between July and August 2004, the main period of *L. coffeella* infestation in the region (Souza et al., 1998), at the farm of Daterra Atividades Rurais Ltda, in the county of Patrocínio, state of Minas Gerais, Brazil. The experiment was carried out in a 6-year-old plantation (30 ha) with 2.5 m between plants and 5 m between rows. White delta traps (Biocontrole®, São Paulo, Brazil) and pheromone lures of 300 µg (racemic mixture of the synthetic pheromone 5,9-dimethylpentadecane, synthesized by Fuji Flavour Co. Ltd, Tokyo, Japan) were used to capture the insects. The pheromone-baited lures were placed on white sticky pads with a black grid-lined surface (total sticky surface of 400 cm²). The traps were suspended from a coffee tree branch at a height of 0.2–0.5 m above the soil. All sampled data points were georeferenced using a global positioning system.

Treatments

Traps were deployed in grid arrays to assess trap interference. Within each grid, 12 traps were deployed and spaced at either 2, 5, 10, 15, or 30 m apart. Each of these grid distance treatments was replicated six times. The minimum distance between neighbouring grids was 50 m (Figure 1). Additional traps (189) were installed on the borders of the subareas with a distance of 20 m between traps (Figure 1). A total of 549 traps were used in the experiment. The wind direction was determined by scoring displacement of smoke from a burning stick during the

morning and the afternoon of the experiment, which coincides with the beginning and the end of the period of the day in which males fly (Michereff, 2000).

Field counts

The number of males captured in the traps was recorded 4, 8, 12, and 16 days after placing the traps. The percentage of leaves mined was estimated by taking 10 leaves from each coffee plant containing a pheromone trap. The leaves (4th and 5th leaves, counting from the tip of a branch) were collected from the top third of the canopy of each coffee plant (Oliveira, 2003). Such sampling was carried out only once during the placement of the pheromone traps.

Statistical analysis

The number of males trapped on each date was log-transformed and subjected to ANOVA; the means of different grids were separated using Fisher's least significant difference (LSD) test ($\alpha = 0.05$). The male capture per square metre as a function of grid distances was estimated using the non-linear regression function $y = ax^b$, where y is the density of male *L. coffeella* captured per square metre, x is the grid distance, and a and b are constants obtained as fitted parameters. The number of males captured per square metre was determined by using the ratio between the number of males captured by the pheromone traps and each grid distance. The area of capture of each trap was estimated based on the radius of a circle centred at the trap, which varied according to the grid under consideration.

A semivariogram was used to calculate spatial dependence among pheromone traps and to determine a minimal distance at which interference for captures occurs. The semivariogram plots the sample semivariance (estimated as 0.5 of the average squared difference between sample pairs for the separation distances). The formula of the semivariogram is

$$\gamma(h) = \frac{1}{2N(h)} \sum_{(i,j):|h_{ij}=h} (c_i - c_j)^2$$

where $N(h)$ is the number of pairs of traps separated by distance h ; c_i is the number of males captured at the first trap of the pair; and c_j is the value for the number of males captured at the second trap of the pair for every two-by-two trap combination within a particular grid and between grids (Liebhold et al., 1993). The variances of capture at each distance were plotted against their respective h values. If spatial dependence is present, the semivariance is small for low values of h and increases with h . The semivariance will eventually become constant after some distance, which is indicative for spatial independence among samples. This constant semivariance is also referred to as the sill, whereas the distance at which spatial independence is reached is

Table 1 Effect of the distance among pheromone traps and mean number of *Leucoptera coffeella* captured at various times since the traps were put in the field. The results of analyses of variance (ANOVA) for each trapping interval are in the bottom rows of the table. Columns with different letters are significantly different (LSD test: $P < 0.05$; $n = 72$ traps)

Distance among traps (m)	Time since trap exposure (days)			
	4	8	12	16
30 m	24.44a	7.97a	10.63a	6.63a
15 m	16.98b	8.50a	10.73a	5.70a
10 m	17.52b	11.01a	10.45a	5.84a
5 m	11.45c	5.77b	5.47b	3.02b
2 m	8.41d	4.65c	4.19c	2.62c
ANOVA (d.f. = 355)				
F	28.23	12.11	26.89	25.46
P	<0.0001	<0.0001	<0.0001	<0.0001

referred to as the range, the lag (distance between sample pair), and nugget (semivariance value when $x = 0$) (Liebhold et al., 1993). Cross-validation (i.e., the correlation between estimated and observed values of male capture) was used to determine the quality of the model fitting. The semivariograms were calculated for all data sets at 45 and 135 degrees (azimuth). The direction of 45° corresponds to the direction of the rows of coffee plants, whereas 135° is perpendicular to this. The rows affect the wind direction, and thus the distance over which the pheromone is transported, reason why the semivariograms were calculated for these data sets after preliminary tests, seeking their best structure. This procedure was carried out to test if there is significant inequality between different directions in the distance grids used (anisotropy). Semivariograms were produced using the GEOVISUAL software (Yamamoto, 2002).

Results

Field capture

The mean percentage of leaves mined was 7.61 (SE = 0.39), which is considered a moderate damage level (Oliveira, 2003). Regarding the male capture by pheromone traps, there were significant differences among distances at all of the sampling dates (d.f. = 355, $P < 0.0001$; Table 1). The largest numbers of *L. coffeella* were captured in the traps further apart than 5 m (Table 1), whereas the maximum numbers of males at the first sampling date (4 days) were captured in traps that were placed 30 m apart (Table 1). There was no significant difference in captures among traps placed further than 10 m apart, except for the first sampling date. Therefore, 10 m was the maximum distance at which interference among traps occurred (Table 1). A similar trend

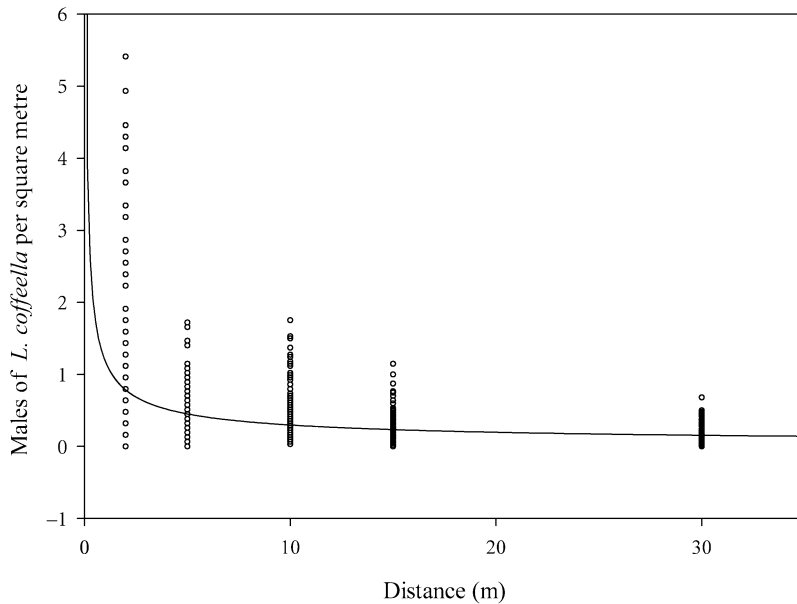


Figure 2 Relationship between male capture of *Leucoptera coffeella* per square metre and distance among pheromone traps ($y = 3.652x^{-1.65}$, $R^2 = 0.31$, $P = 0.001$; $n = 1440$).

in male captures was observed for all trap intervals. Thus, the data from 16-day trapping was used to establish the capture by distance relationship (Figure 2). The capture density (males captured per square metre) depended on the distance among traps; the greater the distance, the smaller capture density (Figure 2). The capture density also stabilized at 10 m, indicating that starting from this distance the traps did not compete with each other (Figure 2).

Table 2 Semivariogram parameters of capture of male of *Leucoptera coffeella* at various time intervals

Time of capture (days)	Direction ¹	Sill ²	Range ³ (m)	Nugget effect ⁴	Model types ⁵
4	45°	141	177	0	Exponential
	135°	141	37	0	Exponential
8	45°	29	110	14	Gaussian
	135°	–	–	–	None
12	45°	15	46	14	Spherical
	135°	15	70	14	Spherical
16	45°	8	24	4	Spherical
	135°	8	24	4	Spherical

¹Direction relative to the north.

²The upper limit of the semivariogram model which has such a limit.

³The distance beyond which there is little or no autocorrelation among variables. For the exponential and Gaussian models, it is the distance that approaches the sill asymptotically and for a spherical model, it is the distance at which the model reaches its maximum value.

⁴The value of semivariance by which the variance differs from zero.

⁵Models used to fit experimental variograms.

Semivariograms

Semivariograms generated for each sampling date indicated the presence of spatial dependence; the number of males captured was affected by the distance among traps (Table 2; Figure 3). The distance at which spatial independence among trap catches was reached varied among sampling dates from 24 to 177 m (Table 2). Cross-validation, a technique that compares the value of a point, estimated using the model and the neighbouring points, to the real value, was used to check the quality of the fitted models. Cross-validation was carried out comparing estimated with observed values of male capture and showed that models for captures at 4 and 8 days were robust ($r > 0.50$), but the reliability of the range for longer periods of capture was limited (i.e., 12 and 16 days; Figure 3). The experiment was carried out during a period of the year characterized by high pest populations, but only the first evaluation provided a good adjustment to the cross-validation (Figure 3). As the population of insects decreased through time, the cross-validation adjustments became worse (Figure 3). This may be due to a more random distribution of the insects at low densities, or to more complex models of distribution, improperly fitted by the mathematical models tested here.

Directional semivariograms were calculated for inter-trap distance at angles of 45° and 135°, showing significant inequality of the distance at which traps interfere with direction in the distance grids used (geometric and zonal anisotropy) (Table 2). Exponential, Gaussian, and spherical models are commonly used to fit semivariogram data (Liebhold et al., 1993). These models were used in the present study for the sampling dates that showed a

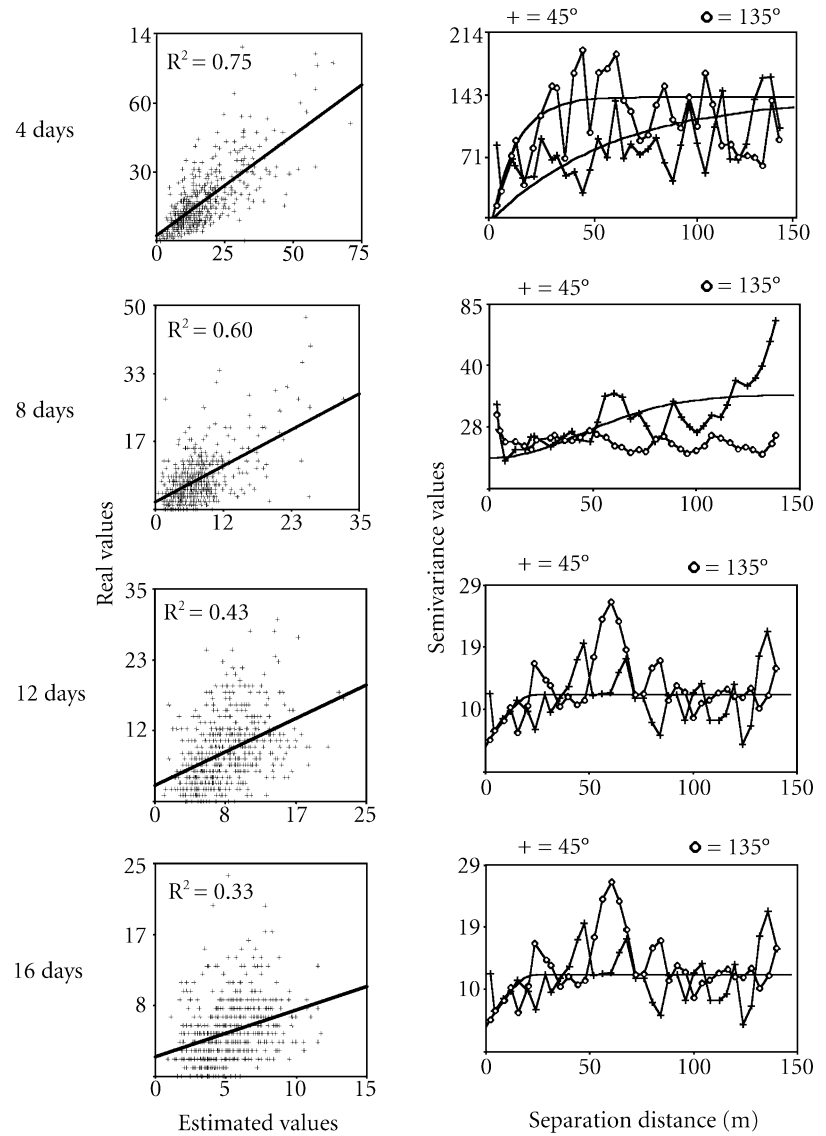


Figure 3 Anisotropic semivariograms and correlation coefficients ($P < 0.01$) of the cross-validation for pheromone trap capture of *Leucoptera coffeella*. Left-hand panels show the cross-validation that allows testing the interpolation system against sampled data. Right-hand panels show the semivariograms plotting the variance (one-half the mean squared difference) of paired sample measurements as a function of the distance (and optionally of the direction 45° and 135°) between samples.

non-random spatial dependence (Table 2). No significant model was obtained for 8-day capture in the direction of 135° , where there was a pure nugget effect, showing no spatial dependence (Table 2 and Figure 3).

Discussion

The low captures in the trap grids with 2 and 5 m distance were a consequence of the short distances among traps, resulting in maximum interference and competition among the pheromone plumes of neighbouring traps. Pheromone plumes from traps deployed upwind apparently prevented captures in traps deployed downwind (Wall & Perry, 1982). The larger numbers of *L. coffeella* captured in

traps of grids with distances larger than 5 m are the result of a greater active area of each trap, in contrast with trap captures within smaller grids. The same effect was observed by Wedding et al. (1995), and Elkinton & Cardé (1988), who found that the traps positioned closer to each other captured fewer insects than those further apart.

The evaluation of capture range of the traps at the different distances using only analysis of variance showed a lack of interference for traps at distances over 10 m. This means that 10 m would be the minimum distance at which to locate the traps when monitoring *L. coffeella*.

Geostatistical analysis went further and showed that the range of spatial independence of the pheromone traps was between 25 and 177 m. Several factors contribute to

this variation, such as the variation of wind velocity (not measured), rainfall (which is a known mortality factor for this species; Pereira, 2002), and an aggregated spatial distribution (which is predominant in *L. coffeella*; Vieira et al., 1999).

The geoanalysis was used to estimate the distance above which trap catching became statistically independent. The geostatistical method was used to interpolate the different distances among all traps in the study area (30 ha), hence was not restricted to the range of capture from 2 to 30 m, as was the case for the analysis of regression or variance that was done for the different subplots. A significant difference was found between the orthogonal directions of analysis, meaning that factors other than distance among traps affected the captures in the directions of the rows of coffee plants (45°) and perpendicular to them (135°). The rows could affect the microclimate and local wind flow and direction, hence affect the diffusion of the pheromone plumes. The direction of the prevailing wind was southwest coinciding with 135°. Independence among traps was observed for trap distances over 110 and 177 m for traps placed along coffee lines (45°), in contrast with traps placed perpendicular to the coffee lines. This larger dependence of catches of traps placed in the coffee rows may have been caused by the wind flowing in between the rows of coffee trees, thus carrying the pheromone plumes for longer distances along the rows of plants. The opposite effect occurred in the direction perpendicular to the rows of coffee trees. In this case, the coffee trees would break the wind resulting in the pheromone concentration dropping rapidly with distance from the traps, resulting in trap independence for distances in the range of 27–70 m. This effect is similar to that found by David et al. (1983).

The largest distances of trap dependence were 110 and 177 m. Therefore, the trap placement at distances greater than these will provide independent and representative samples. With this information, it is possible to determine the density of traps that should be used per hectare. If we assume that an adequate intertrap distance for our area would be 110 m, we would need approximately eight traps to cover the whole area of 30 ha.

It is possible to reduce the density of pheromone traps when increasing the pheromone dose per trap, thus increasing the distance among traps with interference and overlap of pheromone plumes, similar to what was done for traps for the sawfly *Neodiprion sertifer* (Wedding et al., 1995) and the pear moth *Cydia nigricana* (Wall & Perry, 1982). This would be a viable possibility if the increase of dose of pheromone per trap is cheaper than the increase of the density of traps utilized. However, experiments need to be done to assess the effects of increase pheromone concentrations on the range of pheromone traps.

Acknowledgements

We thank Rodrigo Saraiva and Lucimar Dias for assisting with the fieldwork and data collection. Daterra Atividades Rurais Ltda. provided excellent logistic assistance with technical support by Gustavo Guimarães. Arne Janssen (visiting fellow sponsored by CAPES Foundation, Ministry of Education, Brazil) corrected the English of earlier versions of this manuscript. Tito Bacca was supported by a scholarship from the Colombian Institute for Development of Science and Technology (COLCIENCIAS). This study was funded by the National Council of Scientific and Technological Development (CNPq) and Minas Gerais State Foundation for Research Aid (FAPEMIG).

References

- Blom PE & Fleischer SJ (2001) Dynamics in the spatial structure of *Leptinotarsa decemlineata* (Coleoptera: Chrysomelidae). *Environmental Entomology* 30: 350–364.
- Bradshaw JWS, Ellis NW, Hand SC & Stoakley JT (1989) Interactions between pheromone traps with different strength lures for the pine beauty moth, *Panolis flammea* (Lepidoptera: Noctuidae). *Journal of Chemical Ecology* 15: 2485–2494.
- David CT, Kennedy JS, Ludlow AR, Perry JN & Wall C (1983) Finding of a sex pheromone source by gypsy moths released in the field. *Nature* 303: 804–806.
- Elkinton JS & Cardé RT (1980) Distribution, dispersal and apparent survival of male gypsy moths as determined by capture in pheromone-baited traps. *Environmental Entomology* 9: 729–737.
- Elkinton JS & Cardé RT (1988) Effects of intertrap distance and wind direction on the interaction of gypsy moth (Lepidoptera: Lymantriidae) pheromone-baited traps. *Environmental Entomology* 17: 764–769.
- Fragoso DB, Guedes RNC & Ladeira JA (2003) Seleção na evolução da resistência a organofosforados em *Leucoptera coffeella* (Guérin-Ménéville) (Lepidoptera: Lyonetiidae). *Neotropical Entomology* 32: 329–339.
- Fragoso DB, Guedes RNC, Picanço MC & Zambolin L (2002) Insecticide use and organophosphate resistance in coffee leaf-miner *Leucoptera coffeella* (Lepidoptera: Lyonetiidae). *Bulletin of Entomological Research* 92: 203–212.
- Francke W, Tóth M, Szöcs G, Krieg W, Ernest H & Buschmann E (1988) Identifizierung und Synthese von Dimethylalkanen als Sexuallockstoffe weiblicher Miniermotten (Lyonetiidae). *Zeitschrift für Naturforschung* 43: 787–789.
- Gilbert M, Svatos A, Lehmann M & Bacher S (2003) Spatial patterns and infestation processes in the horse chestnut leaf-miner *Cameraria ohridella*: a tale of two cities. *Entomologia Experimentalis et Applicata* 107: 25–37.
- Howse P, Stevens I & Jones O (1998) *Insects and Their Use in Pest Management*. Chapman & Hall, London, UK.
- Jansson RK, Health RR & Coffelt JA (1989) Temporal and spatial patterns of sweetpotato weevil (Coleoptera: Curculionidae)

- counts in pheromone-baited traps in white-fleshed sweet potato fields in southern Florida. *Environmental Entomology* 18: 691–697.
- Judd GJR & Borden JH (1989) Distant olfactory response of the onion fly, *Delia antiqua*, to host-plant odour in the field. *Physiological Entomology* 14: 429–441.
- Kondo A & Tanaka F (1994) Action range to the sex pheromone of the rice stem borer moth *Chilo suppressalis* (Walker) (Lepidoptera: Pyralidae). *Applied Entomology and Zoology* 29: 55–62.
- Le Pelley RH (1968) *Pest of Coffee*. Longmans Co, London, UK.
- Liebholt AM, Rossi RE & Kemp WP (1993) Geostatistics and geographic information systems in applied insect ecology. *Annual Review of Entomology* 38: 303–327.
- Lima E (2001) Ferômonio sexual do bicho-mineiro do café, *Leucoptera coffeella*: Avaliação para uso em programas de manejo integrado. DS Dissertation, Universidade Federal de Viçosa, Viçosa, Brazil.
- McNeil JN (1991) Behavioral ecology of pheromone-mediated communication in moths and its importance in the use of pheromone traps. *Annual Review of Entomology* 36: 407–430.
- Michereff MFF (2000) Comportamento reprodutivo do bicho-mineiro-do-cafeeiro, *Leucoptera coffeella* (Guérin-Ménéville, 1842) (Lepidoptera: Lyonetiidae). MSc Thesis, Universidade Federal de Viçosa, Viçosa, Brazil.
- Oliveira IR (2003) Amostragem de *Leucoptera coffeella* e de suas vespas predadoras no cafeeiro. DS Dissertation, Universidade Federal de Viçosa, Viçosa, Brazil.
- Pedigo LP (1999) *Entomology and Pest Management*. Prentice Hall, Upper Saddle River, NJ, USA.
- Pereira EJG (2002) Variação sazonal dos fatores de mortalidade natural de *Leucoptera coffeella* em *Coffea arabica*. MS Thesis, Universidade Federal de Viçosa, Viçosa, Brazil.
- Rield H (1980) The importance of pheromone trap density and trap maintenance for development of standardized monitoring procedures for the codling moth (Lepidoptera: Tortricidae). *Canadian Entomologist* 112: 655–663.
- Ryan PA, Lyons SA, Alsemgeest D, Thomas P & Kay BH (2004) Spatial statistical analysis of adult mosquito (Diptera: Culicidae) counts: an example using light trap data in Redland Shire southeastern Queensland, Australia. *Journal of Medical Entomology* 41: 1143–1156.
- Sallam NM & Garrad SW (2001) Distribution and sampling of adults of *Rhabdoscelus obscurus* (Boisduval) (Coleoptera: Curculionidae) and their damage in sugarcane. *Australian Journal of Entomology* 40: 281–285.
- Sciarretta A, Trematerra P & Baumgärtner J (2001) Geostatistical analysis of *Cydia funebrana* (Lepidoptera: Tortricidae) pheromone trap catches at two spatial scales. *American Entomologist* 47: 174–185.
- Souza JC, Reis PR & Rigitano OLR (1998) Bicho mineiro: Biologia, danos e manejo integrado. Epamig, Belo Horizonte, Brazil.
- Turchin P & Odendaal FJ (1996) Measuring the effective sampling area of a pheromone trap for monitoring population density of southern pine beetle (Coleoptera: Scolytidae). *Environmental Entomology* 25: 582–588.
- Vieira JN, De Aquino LH, Bearzoti E & De Sousa JC (1999) Otimização da amostragem seqüencial para o monitoramento do bicho-mineiro do cafeeiro *Perileucoptera coffeella* (Lepidoptera: Lyonetiidae) em Lavras, Minas Gerais. *Ciência Agrotécnica* 23: 707–718.
- Wall C & Perry JN (1978) Interactions between pheromone traps for the pea moth, *Cydia nigricana* (F.). *Entomologia Experimentalis et Applicata* 28: 313–321.
- Wall C & Perry JN (1980) Effect of spacing and trap number on interactions between pea moth pheromone traps. *Entomologia Experimentalis et Applicata* 28: 313–321.
- Wall C & Perry JN (1982) The behaviour of moths responding to pheromone sources in the field: a basis for discussion. *Les Colloques de l'INRA* 7: 169–186.
- Wall C & Perry JN (1987) Range of action of moth sex-attractant sources. *Entomologia Experimentalis et Applicata* 44: 5–14.
- Wedding R, Anderbrant O & Jönsson P (1995) Influence of wind conditions and intertrap spacing on pheromone trap catches European pine sawfly, *Neodiprion sertifer*. *Entomologia Experimentalis et Applicata* 77: 223–232.
- Yamamoto JK (2002) Guia do Usuário Geovisual: Sistema Geovisual 2.0. Instituto de Geociências da USP, São Paulo, Brazil.