Design and Evaluation of Traps for *Idiarthron subquadratum* (Orthoptera: Tettigoniidae) with Farmer Participation in Coffee Plantations in Chiapas, Mexico

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ABSTRACT Three new types of traps designed and made by farmers were evaluated for capture of *Idiarthron subquadratum* Saussure & Pictet. Bag, sack, and fabric traps were compared with previously used bamboo internode traps. A participatory methodology was used involving farmer interviews and workshops to design and make the traps. Farmer participation was useful for obtaining information on perceptions, knowledge, and control activities of *I. subquadratum*. The bag trap captured a greater number of individuals than the bamboo and fabric traps, but its captures were similar to those of sack trap; captures were similar in bamboo, sack, and fabric traps. When captured individuals were analyzed by stage of development, no significant differences between types of traps were detected for captured adults. The number of individuals captured in the traps showed a similar trend to that counted in nocturnal sampling. A significant positive relationship was detected between numbers of adults captured and the damage of leaves and fruits. Taylor's Power Law indicates that *I. subquadratum* individuals were more abundant in some traps than in others. With densities greater than five individuals per trap, a smaller number of bag traps was required to estimate the same population compared with the other types of traps. Sampling procedure that used the bag traps had the lowest cost. This study shows that resource-poor coffee, *Coffea arabica* L., farmers had accumulated knowledge of *I. subquadratum* based on unpublished data and experience and that they were capable of applying this knowledge to develop an economical and more suitable technology for their conditions.

KEY WORDS coffee pest, sampling, Taylor's Power Law, farmer participatory research

Idiarthron subquadratum Saussure & Pictet (Orthoptera: Tettigoniidae) is widely distributed in coffee, *Coffea arabica* L., plantations of Mexico (Villaseñor 1987, Barrera 2002), Guatemala (Hernández 1988), Honduras (Muñoz 1990), El Salvador (ISIC 1989, 1990), Costa Rica (ICAFE 1989), and Colombia (Cárdenas and Benavides 1988). This insect is univoltine, arboreal, polyphagous, and nocturnally active. Both nymphs and adults leave their daytime shelters at night and disperse by jumping between tree and bush canopies. This species feeds on leaves and fruits of several plants, including coffee (*C. arabica*), banana (*Musa* spp.), orange (*Citrus* spp.), chayote (*Sechium edule* Sw.), and pacaya (*Chamaedorea* sp.). Mating occurs in plant canopies at night or in daytime shelters. In Siltepec, Chiapas, Mexico, mating usually occurs in October, and oviposition occurs in November and December. Adults are killed by low temperatures in January and February, and eggs undergo diapause. At the beginning of the rainy season, between May and June, nymphs emerge and start to feed on coffee plants. Six instars have been observed under laboratory conditions. The life cycle from egg to adult is ≈80 d at 28°C (Barrera et al. 2002, 2003a; Zúñiga et al. 2002).

Historically, *I. subquadratum* has not been a pest, but it has become one in coffee plantations of Siltepec for the past 15 yr. Climatic factors and/or habitat modification and chemical insecticide effects on natural enemy populations have been suspected as possible causes for *I. subquadratum* outbreaks (Barrera et al. 2002). This insect was reported initially as a pest in plantations close to the village of Vicente Guerrero and thereafter spread to plantations near the village of Vega de Guerrero, two neighboring localities of Siltepec, where coffee is cultivated by resource-poor farmers. Low densities of potential natural enemies such as birds, rodents, bats, and insect parasites and diseases have been reported in both localities (Barrera et al. 2002, 2003b).

Attempts at controlling populations of *I. subquadratum* have focused on cultural practices such as decreasing the number of shade trees, weed control, and elimination of daytime shelters (e.g., fallen banana leaves) as well as the use of chemical insecticides and traps (Barrera 2002). Traps without lures or baits are

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of particular interest because they do not injure nontarget organisms, and they take advantage of the behavior of *I. subquadratum* to hide gregariously in shelters during the day. A trap of this type consisting in a 10 by 30-cm bamboo, *Bambusa vulgaris* Schrad., internode has been used in El Salvador (ISIC 1989, 1990) and Mexico (Barrera et al. 2002, Zúñiga et al. 2002). The "shelter trap" is checked during daytime and captured individual are eliminated by hand or used as food for domestic animals (Barrera et al. 2002).

Some farmers from Siltepec have begun to use bamboo traps to control *I. subquadratum* after seeing researchers from El Colegio de la Frontera Sur, a Mexican research center, performing studies in the area with this trap. However, some other farmers have used different materials, including sacks, plastic bags, or old clothes to capture *I. subquadratum* in their coffee plantations (Barrera et al. 2002). The use of these objects to control this insect is a clear example of the use of local knowledge by farmers to solve the problems that afflict them and demonstrates that farmers know the behavior of this insect and use that information to control it. The importance of local knowledge to generate and validate technological processes and products has been recognized by several researchers working with resource-poor farmers in developing countries (Bentley 1992, Ochou et al. 1998, Morales and Perfecto 2000, Price 2001, van Mele and Cuc 2001, Wiegel and Guharay 2001, Songa et al. 2002).

To improve trap-based sampling procedures for *I. subquadratum* in Siltepec, a study was performed with two objectives: 1) to determine farmer knowledge and pest control activities against *I. subquadratum* by coffee growers, and 2) design new traps for *I. subquadratum* with farmer participation and compare their insect captures and costs with that of a standard bamboo trap.

Materials and Methods

Study Area. This study was conducted in the coffee-growing region of Siltepec, Chiapas, Mexico, which is located at 15° 33′ N and 92° 19′ W and has a semi-warm, wet climate with abundant rain in summer, annual mean rainfall of 2,637 mm, and annual mean temperature of 21.8°C (INEGI 2002). The work was performed in the plantations of coffee farmers of Vicente Guerrero and Vega de Guerrero, two localities between 1000 and 1,100 m above sea level, in which *I. subquadratum* is the most important pest of coffee. Both localities were compared to determine whether contact time with this insect pest would influence perceptions, knowledge, and activities of control practiced by the farmers, because *I. subquadratum* was reported in Vicente Guerrero 3 yr earlier in Barrera et al. 2002.

Phases of Study. The study was performed in three phases: 1) a survey was conducted to obtain information on coffee-farming practices and information on farmer perceptions and pest control activities against *I. subquadratum;* this survey also facilitated the selection of farmers willing to collaborate in the study; 2) several workshops were conducted to design and make trap models for *I. subquadratum* with participation of farmers; and 3) an experiment was conducted in plantations to compare captures of *I. subquadratum* in traps designed by farmers with captures obtained in the bamboo trap used by researchers. Nocturnal counts of *I. subquadratum* individuals and damage to coffee leaves and berries also were assessed. Finally, we analyzed the costs associated with sampling this insect by using these traps and the number of traps required to estimate a given population.

Survey. Information for the survey was obtained through interviews with individual farmers and workshops with groups of farmers. A structured questionnaire of 37 closed and open questions was used for interviews, to obtain information on 1) farmers, 2) coffee plantations, and 3) farmer's knowledge, perceptions, and activities against *I. subquadratum.* The period of questioning lasted 20–30 min and was conducted in January and February 2003. A sample of 15 coffee growers in each locality was interviewed, which represented 6 and 15% of the population >15 yr old in Vega de Guerrero (258 inhabitants) and Vicente Guerrero (98 inhabitants), respectively (INEGI 1996). Two workshops also were conducted in each locality in February and March 2003. It took ≈2.5 h to carry out each workshop with participation of 20–25 farmers in Vicente Guerrero and 15–35 in Vega de Guerrero. Photographs and alcohol-preserved specimens of *I. subquadratum* were shown to farmers who were then asked questions about their recognition and names used for the insect; their knowledge of its feeding habits, activity patterns, pest status, and seasonal abundance; and control practices used locally. Notes were taken during the discussion of topics, commentaries, and ideas. Results were analyzed by frequency tables and descriptive analysis for each locality by using the SPSS Package (SPSS Inc. 1995). Means for each variable by locality were compared by *t*-test. The standard error was calculated using a correction for finite populations, because the human population size in each locality was different, whereas the number of sampled farmers was the same size for each community (Scheaffer et al. 1987).

Trap Design and Construction. Three workshops to design and make the traps were conducted in each locality. Workshops lasted ≈2.5 h and were carried out from March to June 2003. The number of participants in each workshop varied from 15 to 39 in Vicente Guerrero and from 15 to 33 in Vega de Guerrero. Workshops were facilitated by a coordinator who asked farmers whether they knew of or had used traps for *I. subquadratum.* Farmers were asked to propose materials and objects to make traps. After several ideas for traps had been proposed, working groups of seven to 10 farmers were formed to design trap models. Paper and pencils were provided to draw trap models, and various materials and objects, such as wood strips, banana leaves, plastic, and polyethylene tubes, bags and sacks, pieces of textiles and cardboard, cardboard boxes, and bottles were made available to construct prototype traps. Between nine and 11 trap models were produced in each workshop, but eventually the farmers and the workshop coordinator selected three models based on ease of construction and availability of materials. In the last workshop, a group of voluntary farmers (10 in Vicente Guerrero and 11 in Vega de Guerrero) was identified in each community to participate in a field experiment aimed at evaluating the new traps in their coffee plantations.

Trap Evaluation. Of the volunteer farmers, two were selected at each locality, based on the following characteristics of their coffee plantations: 1) easy access; 2) proximity to farmer's house to assure that traps were not stolen; 3) minimum area of 3,000 m^2; and 4) comparable agronomic management, altitude, and shade conditions. The three new types of traps designed by farmers were compared with the standard bamboo trap. For this, four plots were established in each of four coffee plantations (two in Vicente Guerrero and two in Vega de Guerrero). Each plot consisted of one of each type of trap placed on coffee bushes at one of the ordinal points, 3–5 m apart, thus forming an approximate square. After each sample was taken, trap position was rotated clockwise to the next corner of the plot, to avoid possible effects of position. Experimental plots had irregular forms, but the approximate total area of each one was 2,500 m^2. Each trap was sampled at 3-wk intervals (total of six sample dates) from 10 July to 23 October 2003, when the *I. subquadratum* population was at its annual peak.

The following variables were recorded in each experimental plot: 1) number of individuals of *I. subquadratum* found in each type of trap, 2) damage to leaves and fruits by *I. subquadratum,* and 3) number of individuals of *I. subquadratum* observed by nocturnal direct counting. Captured individuals were classified by stage (nymph or adult) and sex (female or male). All captured *I. subquadratum* were placed in transparent plastic containers with different colored lids, according to trap type in which they were captured, to allow farmers to compare visually the prevalence of captured insects from each type of trap. Trap captures and feeding damage were recorded in daytime, whereas observations of insect activity on coffee plants were recorded at night. Damaged and nondamaged leaves and fruits by *I. subquadratum* in each experimental plot were quantified on 10 randomly selected coffee plants around each group of four traps, resulting in samples of 50 plants per experimental plot. A central branch was selected at random on each plant and the number of fruits and leaves were counted with and without characteristic *I. subquadratum* feeding damage. Nocturnal sampling consisted of counting all observed individuals of *I. subquadratum* in 150 coffee plants selected at random per experimental plot, between 1930 and 0600 hours, by using flashlights to illuminate insects on plants. Some farmers participated in counting insects in four of the six nocturnal samplings.

Trap Data Analysis. Numbers of *I. subquadratum* individuals per trap were transformed to $\ln(x + 1)$ and were analyzed by analysis of variance (ANOVA) for a split-split-plot design; whole plots were localities (Vicente Guerrero and Vega de Guerrero), subplots were coffee experimental plots (two per locality), pseudoreplicates were the blocks or groups of four traps ($n = 5$), and treatments were each of the four types of traps. Statistical tests were performed using the GLM module of Statistica software (StatSoft 2003). Differences in means were determined ($P < 0.05$) by Tukey's honestly significant difference (HSD) test when the ANOVA F value was significant ($P < 0.05$). The relationship between number of *I. subquadratum* individuals in each block (total in the four traps) and damage of *I. subquadratum,* expressed as median of percentage of damaged leaves and fruits per block, was subjected to linear regression.

The mean (m) and variance (V) of captures in each type of trap and the observed number of *I. subquadratum* individuals per coffee plant by nocturnal counting were calculated. These data were adjusted to Taylor's Power Law by using the equation

$$log\ V = b \log m + \log a \quad [1]$$

where a and b are coefficients. The parameter b is a measure of population aggregation, with $b > 1$ indicating an aggregated distribution, $b = 1$ randomness, and $b < 1$ regular distribution, whereas a is a scaling factor related to the sampling procedure (Taylor 1961, Southwood 1978).

Optimal number of traps (n) to estimate different simulated densities (m) of *I. subquadratum* (ranging from one to 25 individuals per trap) with two reliability levels (10 and 20% SEM) was calculated for each type of trap using the equation (Nordenfors and Chirico 2001)

$$n = (1/A^2)(V/m^2) \quad [2]$$

where the coefficient of variability A was calculated by

$$A = SEM/m \quad [3]$$

where m is the mean and V is the variance estimated using equation 1.

Sampling procedures for each type of trap were compared using the equation of Wilson et al. (1989) that calculates the ratio of the costs of two (or more) sampling methods:

$$C_1/C_2 = [(n_1{*}(d_1 + e_1)]/[(n_2{*}(d_2 + e_2)] \quad [4]$$

where C_i is cost per sample for a given level of reliability for the ith sampling method (each method uses a different type of trap); n_i is optimal number of traps required for an estimate with a given level of reliability obtained with equation 2, by using the ith sampling method; d_i is time (cost) required to examine a trap by using the ith sampling method; and e_i is time (cost) required to move from trap to trap for the ith procedure. When ratio C_1/C_2 is greater than unity, procedure 1 costs more for a given reliability level than does procedure 2. Equation 4 was modified in equation 5 to include the cost of the trap (f_i), that was estimated with cost of materials and labor used to make each designed trap model:

$$C_1/C_2 = [(n_1 * (d_1 + e_1 + f_1)]/[(n_2 * (d_2 + e_2 + f_2)] \quad [5]$$

Results

Survey. *Farmer and Coffee Plantation Profile.* The profile of interviewed farmers and their coffee plantations were very similar in both localities. Interviewed farmers were nearly all adult males of 52.1 ± 4.2 yr (mean ± SE) in Vicente Guerrero and 48.1 ± 3.7 yr in Vega Guerrero; only one woman was interviewed in each locality. These farmers reported cultivation of three coffee varieties, *Coffea arabica* variety Bourbon, *C. arabica* variety Caturra and *C. arabica* variety Typica. Bourbon was cultivated in a greater proportion in both localities (73% in Vicente Guerrero; 60% in Vega Guerrero). All coffee plantations of interviewed farmers had shade trees, commonly chalum (*Inga* spp.), cedar (*Cedrela* sp.), and banana.

Farmer Knowledge and Perceptions of I. subquadratum. As a rule, interviewed farmers of both localities had similar knowledge and perceptions of *I. subquadratum.* All farmers recognized this insect and gave it the name of "chacuatete" and some also called it a "cricket." *I. subquadratum* was reported in all plantations of interviewed farmers of Vicente Guerrero (100%) and in nearly all plantations of Vega de Guerrero (93%). This insect was reported to have become a pest over the past 6.9 ± 0.9 yr in Vicente Guerrero and over the past 3.9 ± 0.6 yr in Vega de Guerrero (t = 3.67, df = 28, P < 0.001). Farmers mentioned having seen *I. subquadratum* consuming and hiding in coffee plants; the majority had seen it feeding at night (93% in Vicente Guerrero; 80% in Vega de Guerrero), and more than one-half indicated that *I. subquadratum* hid during the daytime (87% in Vicente Guerrero; 67% in Vega de Guerrero). Farmers mentioned that this insect fed on coffee, banana, and chayote. Furthermore, they indicated that feeding damage was first observed in banana, and they also reported that it was found in greater abundance in coffee plantations that had banana as shade. All interviewed farmers, and those that participated in workshops, said that *I. subquadratum* caused damage to their coffee plantations.

Farmer Activities against I. subquadratum. Farmers reported very similar control activities for *I. subquadratum* in both localities. A high proportion mentioned carrying out some control actions against *I. subquadratum* (93% in Vicente Guerrero; 80% in Vega de Guerrero). A few farmers had eliminated banana plants from their plantations as a measure to reduce infestation, whereas the majority had used chemical insecticides and traps. The most used method to control *I. subquadratum* was chemical control, and the most used insecticides were parathion (67% in Vicente Guerrero; 33% in Vega de Guerrero) and malathion (7% in Vicente Guerrero; 27% in Vega de Guerrero). Farmers reported using these insecticides during 2.0 ± 0.7 yr in Vicente Guerrero and 1.3 ± 0.3 yr in Vega de Guerrero. Some farmers had used some type of trap to capture *I. subquadratum,* particularly those in Vicente Guerrero (40%) compared with Vega de Guerrero (7%; t = 2.467, df = 28, P =

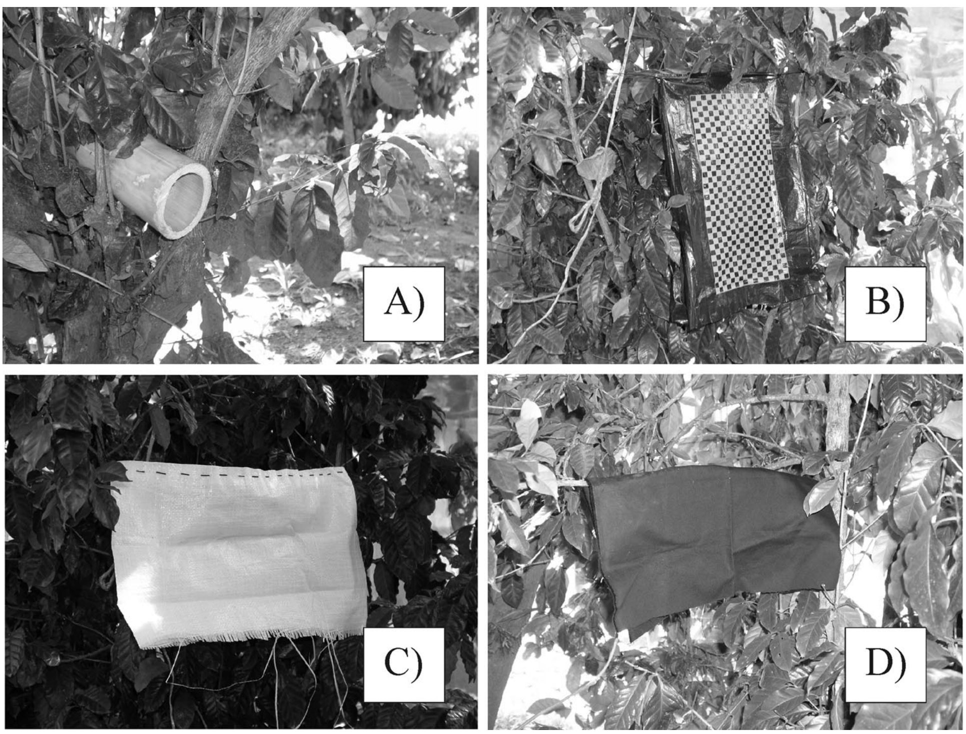

Fig. 1. Types of traps for *I. subquadratum.* Conventional trap (A) is bamboo internode. Traps designed and made by farmers: (B) black plastic bag, (C) white plastic sack, and (D) black polyester fabric.

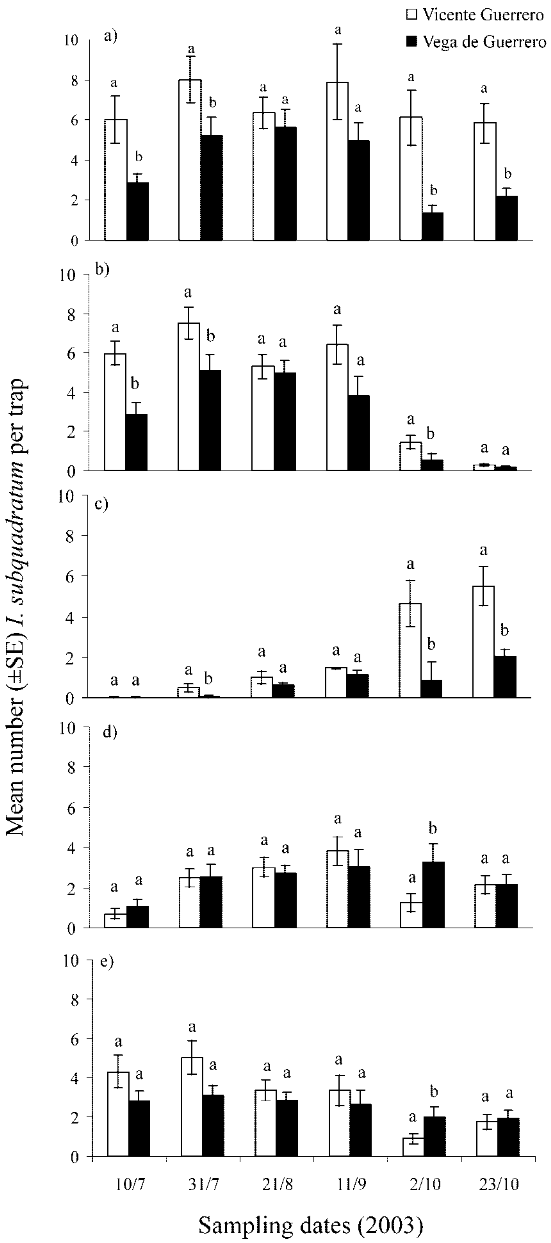

Fig. 2. Mean number of *I. subquadratum* individuals captured in two localities in Siltepec, Chiapas, Mexico, in 2003. (a) Total population. (b) Nymphs. (c) Adults. (d) Females. (e) Males. Columns followed by different letters are significantly different [ANOVA for transformed data ln $(x + 1)$ followed by Tukey's HSD test, df = 471, $P < 0.05$].

0.021). In Vicente Guerrero, farmers had used traps made with sacks, old clothes, nylon bags, and maize ear husk leaves, whereas in Vega de Guerrero farmers had only used the bamboo trap. Farmers mentioned that traps were used from July to November.

Trap Design and Selection. During workshops, farmers in both localities proposed various materials as traps for *I. subquadratum.* These included sacks, plastic bags, fabric, cardboard and wood boxes, car tires, sheets, banana leaves, plastic buckets, mosquito nets, and umbrellas. Farmers proposed various designs to make traps with locally available materials, and after five workshops carried out in each locality, three types of traps were selected called "bag," "sack," and "fabric," which were compared with the bamboo trap (Fig. 1).

The bamboo trap (conventional trap) was made using a 10-cm-diameter by 30-cm-long bamboo internode, closed at one end as described by Zúñiga et al. 2002 (Fig. 1A). The bag trap was made using a 30 by 50-cm black plastic bag, without handles, and held in position from a coffee branch with the opening pointing downward, with nylon threads sewn to its corners (Fig. 1B). The sack trap was made using a 53 by 90-cm white plastic sack that was cut in three parts (53 by 30 cm); each part was used to make a trap. One of the open sides was sewn and the other was left open, and the trap was suspended from a coffee branch in the same way as the bag trap (Fig. 1C). The fabric trap was made using a 40 by 40-cm black polyester fabric that was laid over a coffee branch and was tied with a nylon thread (Fig. 1D). The estimated costs for each type of traps were 8.8, 10.0, 11.9, and 26.3¢ (assuming 1US$ = 11.5 Mexican pesos) for the bag, sack, bamboo, and fabric traps, respectively.

Population and Damage Fluctuation. *Captured Population with Traps.* The mean numbers of *I. subquadratum* captured in each locality from July to October 2003, regardless of the type of trap, is presented in Fig. 2. In both localities, total captures had the same trend (Fig. 2a), that is, numbers rose at the beginning of the study, then remained high without pronounced changes from July through September and then fell in October when the study finished. The number of captured individuals of *I. subquadratum* was greater in Vicente Guerrero on all sampling dates. Nymphs were more abundant than adults from July to September (Fig. 2b), but in October this situation changed quickly. Few adults were captured on 10 and 31 July, but in the last sample on 23 October, almost all captured individuals were adults (Fig. 2c). The population of captured females showed a similar trend as the total population (Fig. 2d), but captured males showed a gradual decrease from the third sample onwards (Fig. 2e). In total, 2,489 nymphs and adults were captured, with a sex ratio of 0.55 male.

Nocturnal Sampling. Mean numbers of *I. subquadratum* individuals per coffee plant observed in Vicente Guerrero and Vega de Guerrero during the nocturnal sampling are shown in Fig. 3. The developmental state and sex of part of the observed population were not identified in the first two sampling dates, because it was particularly difficult to identify individuals located on the top of some coffee plants. Total population counted in the nocturnal sampling (Fig. 3a) showed a trend similar to that captured in the traps (Fig. 2a). With the exception of the last sampling date, nocturnal sampling did not reveal significant differences between localities in total observed population.

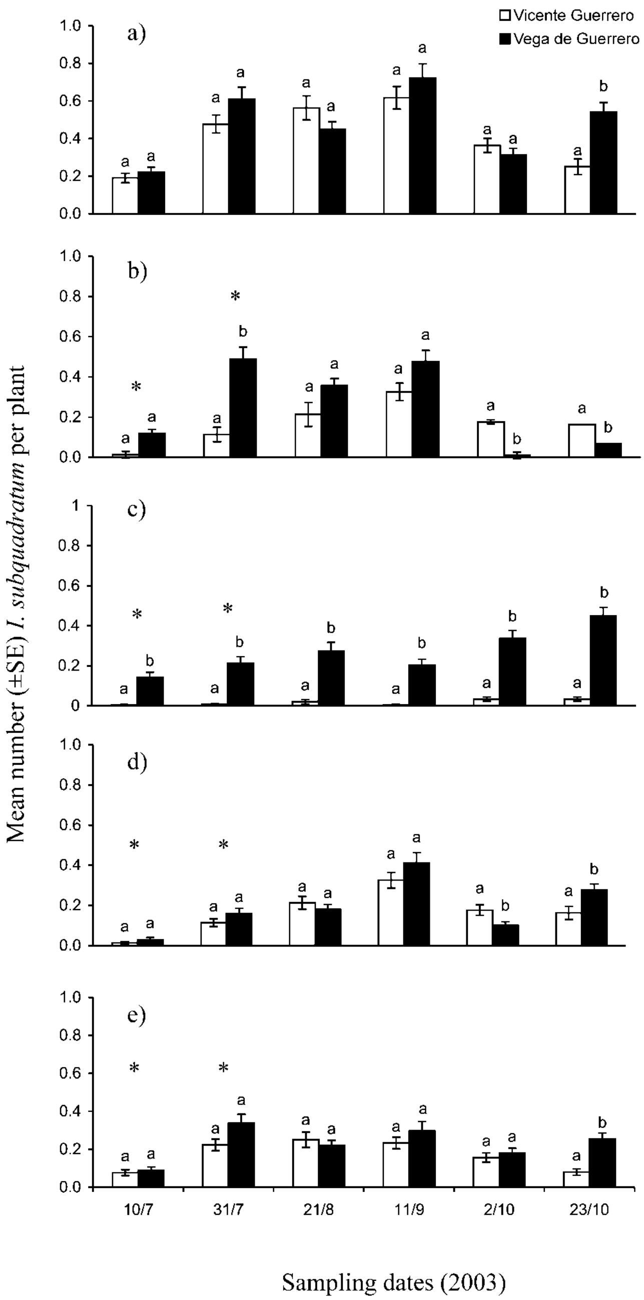

Fig. 3. Mean number of *I. subquadratum* observed per plant during nocturnal sampling in two localities of Siltepec, Chiapas, Mexico, in 2003. (a) Total population. (b) Nymphs. (c) Adults. (d) Females. (e) Males. * Numbers of no identified individuals were not included. Columns followed by different letters are significantly different [ANOVA for transformed data ln $(x + 1)$ followed by Tukey's HSD test, df = 596, $P < 0.05$].

Damaged and Nondamaged Leaves and Fruit. Total mean numbers of leaves and fruit per coffee branch and percentage of damage caused by *I. subquadratum* are presented in Fig. 4. Mean total numbers of leaves and fruit were similar in both localities; however, the total numbers of leaves were low in October in Vicente Guerrero (Fig. 4a), and total numbers of fruit were significantly lower in three of the six sampling dates in Vega de Guerrero (Fig. 4c). Damaged leaves and fruit increased in both localities (Fig. 4b and d); damaged fruit was significantly more prevalent in Vega de Guerrero (Fig. 4d).

Percentage of damage to coffee leaves was positively correlated with the total number of individuals

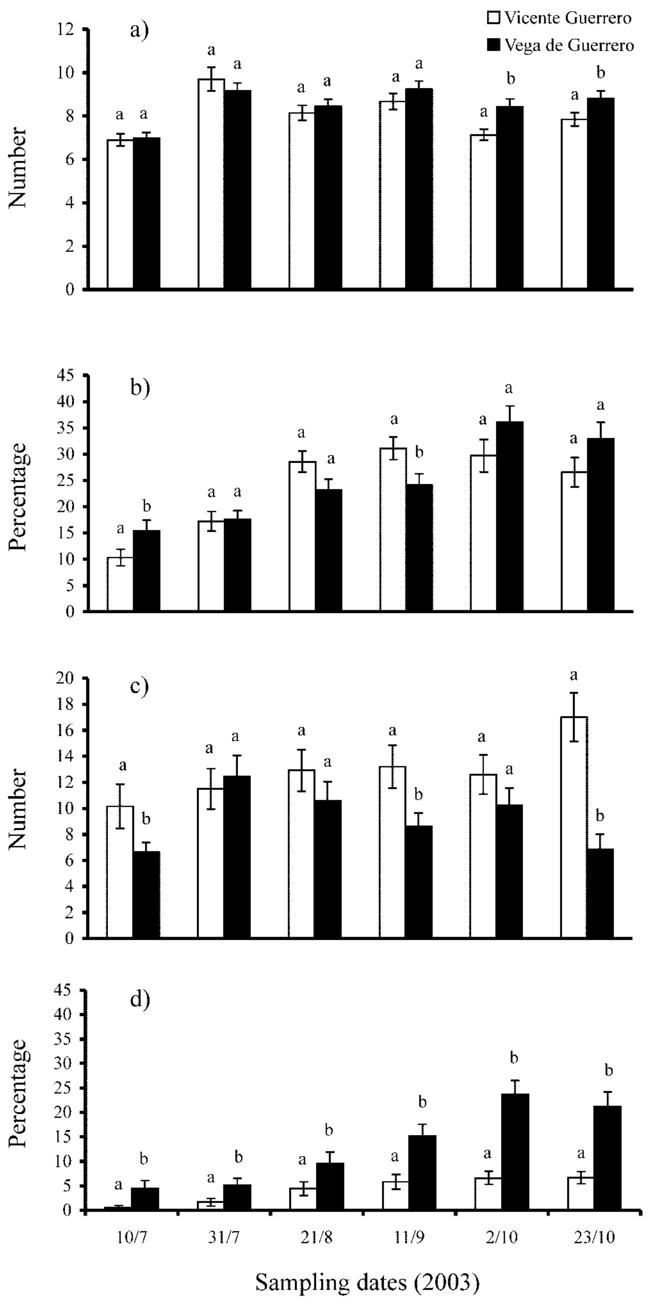

Fig. 4. Mean number of leaves and fruits per coffee branch and percentage of damage caused by *I. subquadratum* in two localities of Siltepec, Chiapas, Mexico, in 2003. (a) Total leaves. (b) Damaged leaves. (c) Total fruit. (d) Damaged fruits. Columns followed by different letters are significantly different [ANOVA for transformed data ln $(x + 1)$ followed by Tukey's HSD test, df = 144, $P < 0.05$].

captured in traps only on 11 September ($r = 0.556$, df = 119, $P = 0.01$). When insects captured in traps were classified by developmental state, a significant negative association was detected between mean numbers of nymphs and damaged leaves ($r = -0.193$, df = 119, $P = 0.035$) and fruit ($r = -0.204$, df = 119, $P = 0.026$). In contrast, a significant positive relationship was detected between the numbers of adults captured and the prevalence of damaged leaves ($r = 0.239$, df = 119, $P = 0.010$) and damaged fruits ($r = 0.474$, df = 119, $P = 0.001$).

Captures per Type of Trap. Mean numbers of captured *I. subquadratum* individuals in four types of trap on six sampling dates, regardless of localities, are pre-

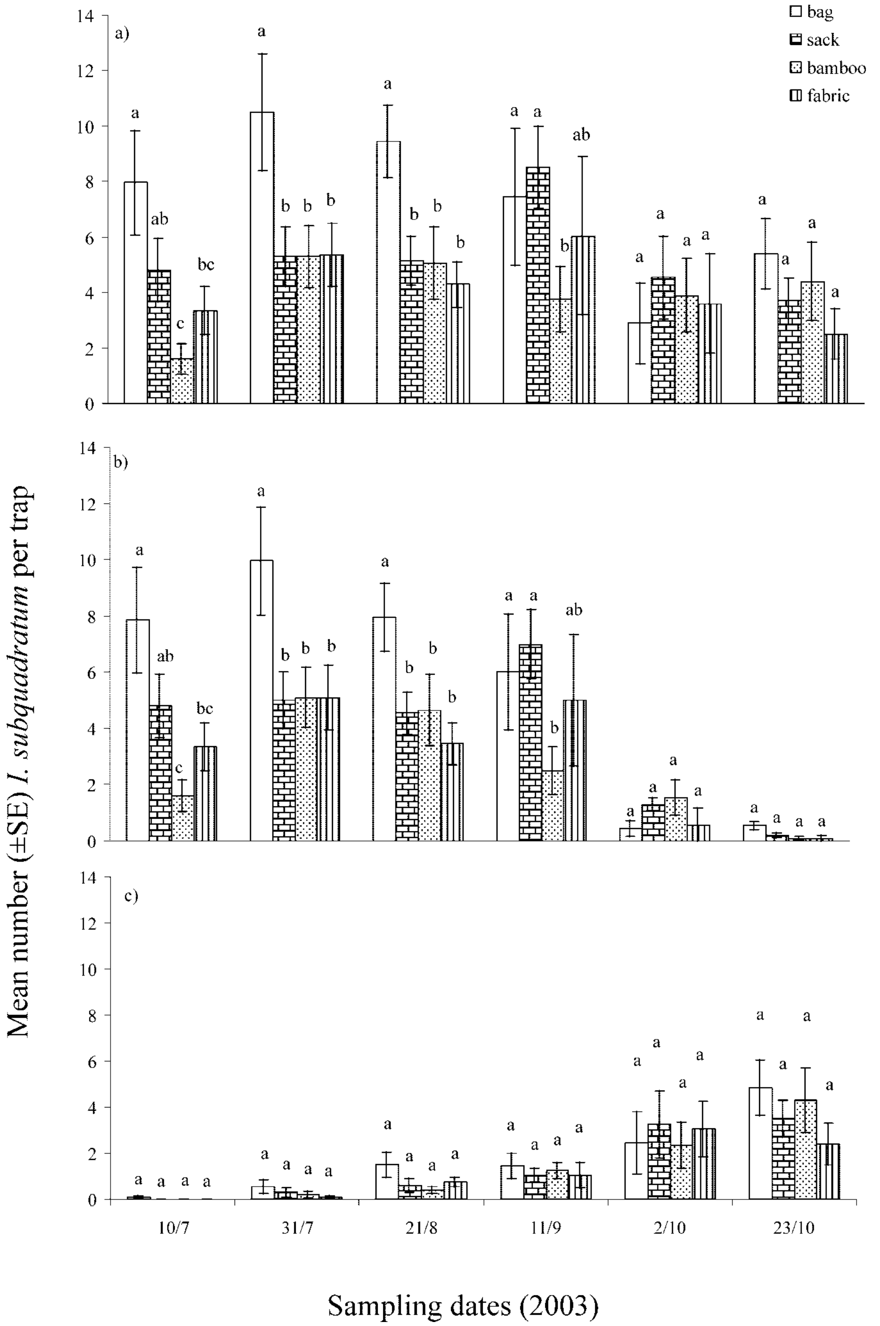

Fig. 5. Mean number of *I. subquadratum* by developmental stage of individuals captured per type of trap in Siltepec, Chiapas, Mexico, in 2003, arranged by date. (a) Total population. (b) Nymphs. (c) Adults. Columns followed by different letters are significantly different [ANOVA for transformed data ln $(x + 1)$ followed by Tukey's HSD test, df = 52, $P < 0.05$].

sented in Fig. 5. No significant differences in total number of captured individuals were observed only on October (Fig. 5a). Commonly, the bag trap captured a greater number of individuals than fabric or bamboo traps, but its captures were sometimes similar to those of the sack trap. When the captured population was classified by developmental stage, it was observed that this difference was due to the population of nymphs (Fig. 5b) but not of adults (Fig. 5c). Pooled data of all sampling dates (Fig. 6) confirmed the previous result, that is, the bag trap was statistically similar to the sack trap for captured nymphs, but

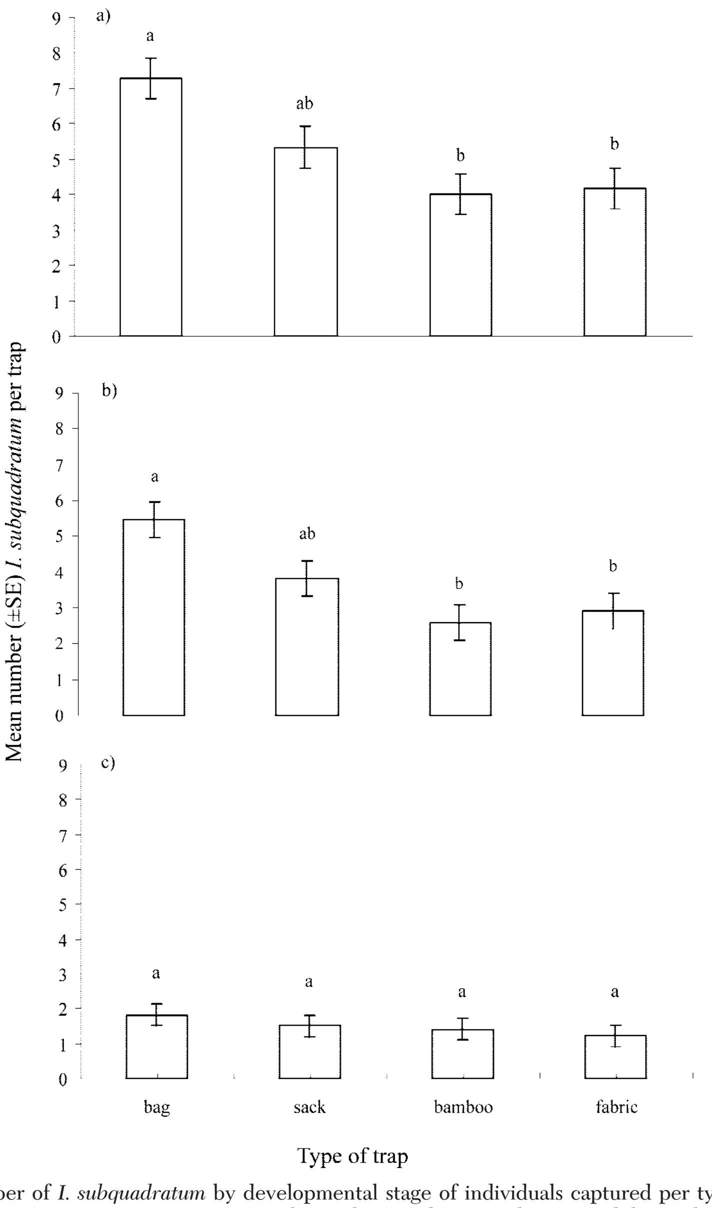

Fig. 6. Mean number of *I. subquadratum* by developmental stage of individuals captured per type of trap for pooled data in Siltepec, Chiapas, Mexico, in 2003. (a) Total population. (b) Nymphs. (c) Adults. Columns followed by different letters are significantly different [ANOVA for transformed data ln $(x + 1)$ followed by Tukey's HSD test, df = 471, $P < 0.05$].

different from the fabric or bamboo trap, whereas the sack, fabric, and bamboo traps were statistically similar ($P > 0.05$) (Fig. 6b). No significant differences between types of traps were detected on captured adults ($P > 0.05$) (Fig. 6c). No significant differences between types of traps independently of the sex of captured adults ($P > 0.05$) were detected over the six sampling dates (Fig. 7), although on some sampling dates significant differences were observed between traps in the numbers of females or males nymphs caught ($P < 0.05$). There were significant differences in captured female nymphs between traps on the third (21 August) and last (23 October) sampling dates (Fig. 7a). For captured male nymphs, significant differences were found on the first three sampling dates (10 and 31 July and 21 August) (Fig. 7b). Pooled data of all sampling dates by type of trap (Fig. 8), showed a greater number of captured female nymphs in the bag, sack, or bamboo traps, although only bag and fabric traps were significantly different. Captured male nymphs were found in significantly greater numbers in the bag trap ($P < 0.05$), followed by sack and

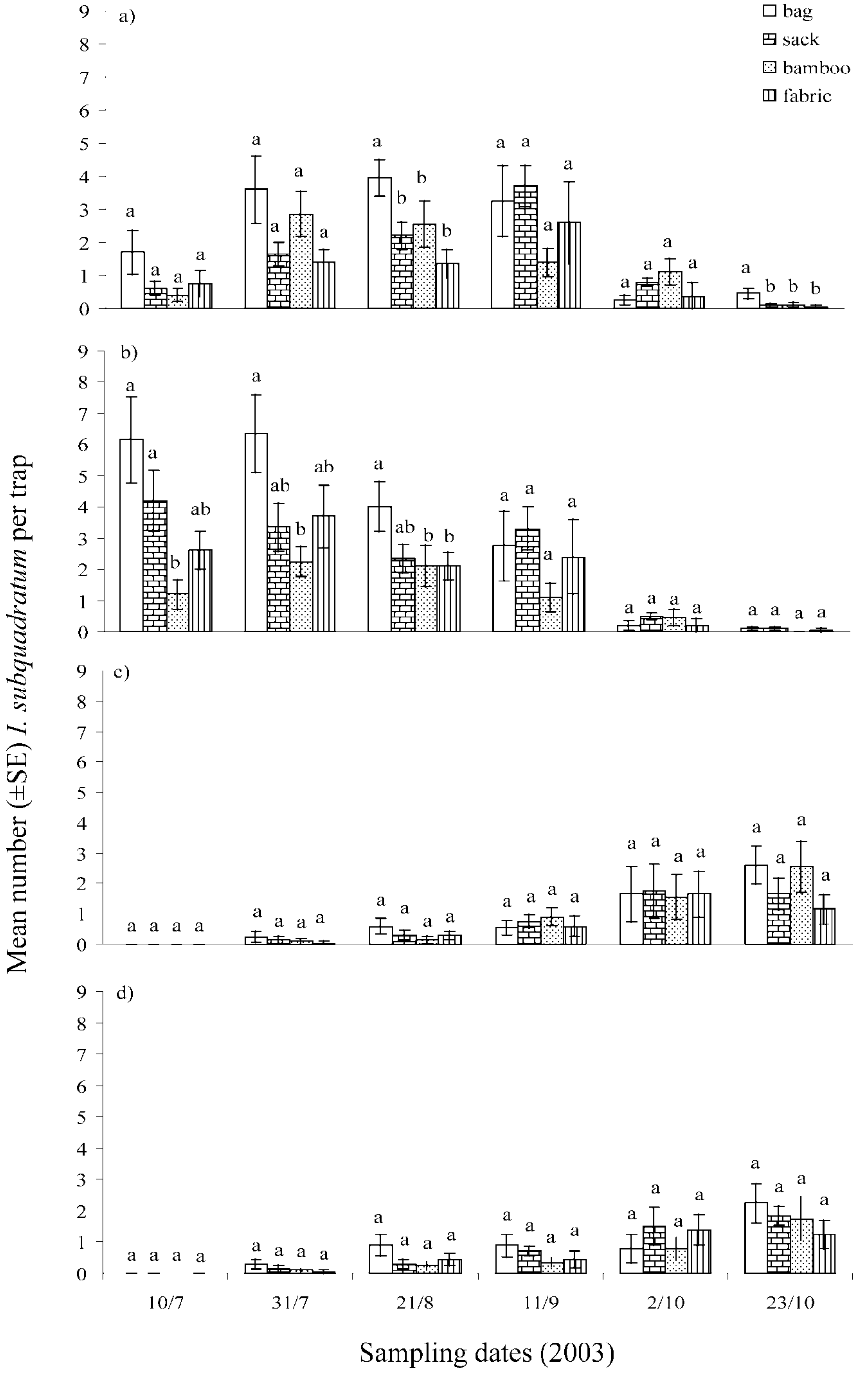

Fig. 7. Mean number of *I. subquadratum* by developmental stage and sex of individuals captured per type of trap in Siltepec, Chiapas, Mexico, in 2003, arranged by date. (a) Female nymphs. (b) Male nymphs. (c) Female adults. (d) Male adults. Columns followed by different letters are significantly different [ANOVA for transformed data ln $(x + 1)$ followed by Tukey's HSD test, df = 471, $P < 0.05$].

fabric traps and finally the bamboo trap, although the number found in this last trap was not significantly different from the fabric trap ($P > 0.05$).

Taylor's Coefficients and Optimal Number of Traps. Coefficient b was significantly different from unity ($P < 0.05$) in 83% of calculated *I. subquadratum* cap-

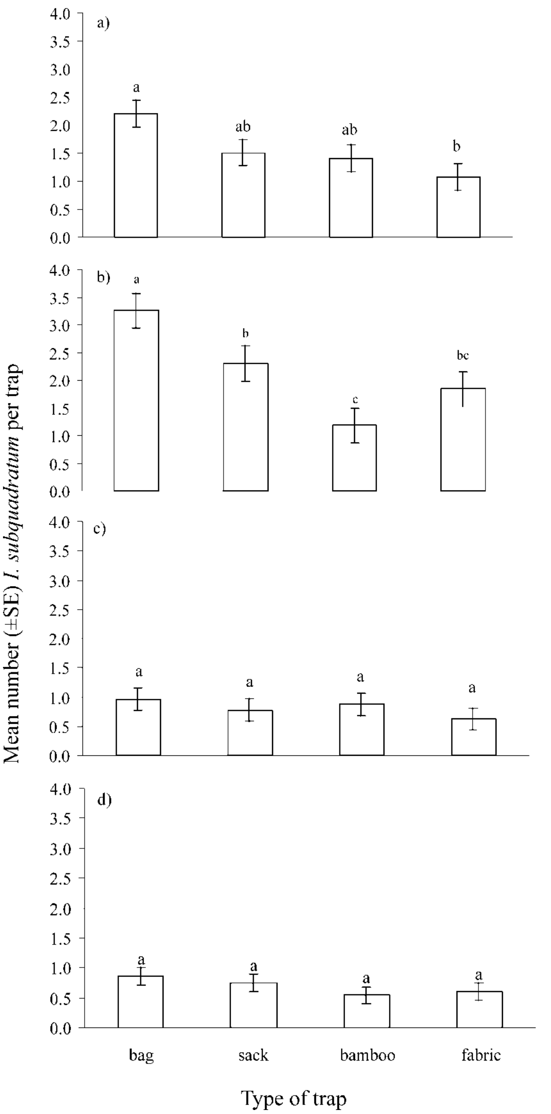

Fig. 8. Mean number of *I. subquadratum* by developmental stage and sex of individuals captured per type of trap for pooled data in Siltepec, Chiapas, Mexico, in 2003. (a) Female nymphs. (b) Male nymphs. (c) Female adults. (d) Male adults. Columns followed by different letters are significantly different [ANOVA for transformed data ln $(x + 1)$ followed by Tukey's HSD test, df = 471, $P < 0.05$].

tures (Table 1), indicating that *I. subquadratum* individuals were more abundant in some traps than others. The population was randomly distributed in the rest of the calculated cases $(b = 1)$ $(P > 0.05)$. The value of b was greater than unity in all captures with the sack trap, whereas the fabric trap had the greater quantity of calculated cases with $b = 1$. With respect to nocturnal counting of *I. subquadratum* on coffee plants, coefficient b was greater than unity in one-third of the calculated cases and indicated a random distribution $(b = 1)$ in the remainder of calculated cases (Table 2). When the observed population was <30% of adults

Table 1. Statistical results of an analysis of the distribution of *I. subquadratum* by developmental stage and sex of individuals captured in four types of traps using Taylor's Power Law

Developmental stage and sex of individuals	Bag trap					Sack trap					Bamboo trap					Fabric trap				
	a	*b*	*b*(±95% CI)	*r*	*n*	*a*	*b*	*b*(±95% CI)	*r*	*n*	*a*	*b*	*b*(±95% CI)	*r*	*n*	*a*	*b*	*b*(±95% CI)	*r*	*n*
Female nymphs	1.314	1.346	1.011–1.680	0.900	19	1.279	1.485	1.115–1.855	0.893	20	1.515	1.356	1.107–1.606	0.945	18	1.513	1.270	0.979–1.562	0.912	19
Male nymphs	1.241	1.554	1.092–2.017	0.880	17	1.688	1.484	1.202–1.765	0.930	21	1.534	1.421	0.939–1.903	0.861	16	1.714	1.317	0.980–1.653	0.889	20
Total nymphs	1.254	1.503	1.133–1.872	0.895	20	1.438	1.537	1.236–1.837	0.918	23	1.878	1.401	1.102–1.700	0.918	20	1.799	1.401	1.160–1.644	0.938	22
Female adults	2.037	1.484	1.229–1.739	0.955	17	2.017	1.500	1.277–1.722	0.968	16	1.673	1.724	1.214–2.234	0.905	14	2.255	1.841	1.413–2.268	0.938	14
Male adults	1.661	1.272	0.859–1.684	0.898	13	1.586	1.280	1.040–1.520	0.950	16	1.962	1.557	1.297–1.816	0.963	15	1.495	1.452	0.946–1.958	0.864	15
Total adults	2.240	1.469	1.223–1.715	0.957	17	2.184	1.491	1.267–1.714	0.965	17	1.397	1.911	1.493–2.328	0.939	15	1.720	1.598	1.181–2.015	0.904	17
Total females	1.387	1.454	1.107–1.801	0.890	22	1.342	1.636	1.215–2.055	0.870	23	1.605	1.476	1.135–1.818	0.901	21	1.871	1.506	1.195–1.816	0.911	23
Total males	1.688	1.373	1.031–1.714	0.882	22	1.475	1.603	1.251–1.956	0.895	24	1.745	1.424	1.135–1.818	0.911	23	1.510	1.467	0.995–1.939	0.809	24
Total pop	1.639	1.454	0.974–1.933	0.817	22	0.878	1.914	1.426–2.403	0.866	24	2.076	1.445	1.090–1.799	0.880	23	1.889	1.445	1.013–1.933	0.817	24

a and *b* are Taylor's coefficients. Coefficient *b* represents an index of population aggregation with 0 being uniform and >1 being highly clumped. *n* is the number of data pairs. *r* is the correlation coefficient.

Table 2. Statistical results of an analysis of the distribution of *I. subquadratum* by developmental stage and sex of individuals observed on coffee plants during nocturnal sampling using Taylor's Power Law, 2003

Developmental stage and sex of individuals	11 July–11 Sept. (30% adults)					2–23 Oct. (>30% adults)					All period (11 July–23 Oct.)				
	a	*b*	*b*(±95% CI)	*r*	*n*	*a*	*b*	*b*(±95% CI)	*r*	*n*	*a*	*b*	*b*(±95% CI	*r*	*n*
Female nymphs	1.517	1.121	1.007–1.235	0.988	13	1.057	1.021	0.893–1.149	0.994	7	1.408	1.104	1.020–1.187	0.988	20
Male nymphs	1.896	1.245	1.009–1.400	0.981	14	1.136	1.034	0.878–1.189	0.992	7	1.486	1.132	1.029–1.235	0.982	21
Total nymphs	1.950	1.259	1.016–1.502	0.970	11	1.000	0.999	0.948–1.049	0.999	6	1.594	1.142	1.016–1.267	0.981	17
Female adults	1.521	1.103	0.954–1.252	0.982	12	1.091	1.025	0.999–1.050	1.000	7	1.030	1.066	0.977–1.154	0.987	19
Male adults	0.863	0.879	0.617–1.141	0.938	10	1.227	1.044	0.949–1.139	0.996	8	1.131	0.993	0.875–1.112	0.976	18
Total adults	1.797	1.113	0.966–1.260	0.983	12	1.462	1.126	0.989–1.263	0.996	6	1.589	1.092	0.988–1.197	0.984	18
Total females	1.808	1.191	0.975–1.405	0.965	13	1.028	0.980	0.425–1.535	0.930	6	1.594	1.160	0.978–1.341	0.956	19
Total males	2.241	1.346	1.158–1.535	0.979	13	0.825	0.835	0.024–1.645	0.820	6	1.917	1.287	1.091–1.482	0.959	19
Total pop	2.310	1.517	1.236–1.797	0.952	16	1.222	1.051	0.334–1.768	0.826	8	1.958	1.431	1.179–1.684	0.929	24

a and *b* are Taylor's coefficients. Coefficient *b* represents an index of population aggregation with 0 being uniform and >1 being highly clumped. *n* is the number of data pairs. *r* is the correlation coefficient.

(10 July–11 September), the population was aggregated ($b > 1$) in five calculated cases and random ($b = 1$) in four cases. In contrast, when the observed population increased to >75% of adults (2–23 October), *b* was greater than unity in one case and statistically similar to unity in eight cases (Table 2). Taylor's coefficient of *a* ranged from 0.859 to 2.268 in traps (Table 1) and from 0.024 to 1.768 in nocturnal sampling (Table 2). The optimal number of traps to estimate different simulated densities of *I. subquadratum* with two reliability levels (10 and 20% SEM) by using Taylor's coefficients for total captured individuals with each of one of the four types of traps is showed in Table 3. With SEM = 20% and densities greater than five individuals per trap, a smaller number of bag traps was required to estimate the same population than the other types of traps. As was expected, optimal number of trap decreased as simulated densities increased (Table 3).

Comparison of Sampling Procedures. Table 4 shows the comparison of costs of sampling procedures for *I. subquadratum* using the four types of evaluated trap for three simulated densities. Sampling procedures that used the bag trap had the lowest cost, with exception of sampling with the sack trap at the lowest density. Sampling with the sack trap had a smaller cost than sampling with the bamboo and fabric traps, except for sampling with the bamboo trap at the highest density. Sampling with the fabric trap was the most expensive procedure at all densities. The cost of sampling varied according to the values of Taylor's coefficients *a* and *b.*

Discussion

According to this study, traps designed, made, and evaluated with the participation of farmers captured greater or equal number of *I. subquadratum* individuals than a conventional trap (bamboo trap) used by researchers (Barrera et al. 2002, Zúñiga et al. 2002). This result and the dates of interviews and workshops show that farmers had accumulated knowledge of *I. subquadratum* based on unpublished data and experience and that they were capable of applying this knowledge to develop an economical and more suitable technology for their conditions.

Farmers interviewed in both studied localities were similar in age and in the way they cultivated coffee. Their perceptions, knowledge, and control activities for *I. subquadratum* also were similar, though farmers from Vicente Guerrero tended to know more about the behavior of this insect and to carry out more control actions, probably because they had suffered damage from this pest for a longer period. Through workshops and interviews, it was perceived that farmers needed technical support to understand some aspects of the biology and ecology of *I. subquadratum.* However, according to Bentley (1992), this support must be based on what farmers already know. Therefore, it is important to find out what they must learn so that teaching will be consistent with their knowledge. The importance of local knowledge on design of research has been indicated by various authors (Bent-

Table 3. Optimal number of traps for estimate different simulated densities of *I. subquadratum* individuals with four types of traps in 2,500 m², with two precision levels (SEM 10 and 20%)

Simulated density/trap	Bag trap (a = 1.639; b = 1.453)		Sack trap (a = 0.878; b = 1.914)		Bamboo trap (a = 2.076; b = 1.445)		Fabric trap (a = 1.889; b = 1.473)	
	10%	20%	10%	20%	10%	20%	10%	20%
1	164	41	88	22	208	52	189	47
5	68	17	77	19	85	21	81	20
10	47	12	72	18	58	14	56	14
15	37	9	70	17	46	12	45	11
20	32	8	68	17	39	10	39	10
25	28	7	67	17	35	9	35	9

a and b are Taylor's coefficients.

ley 1997, Morse and Buhler 1997, Ochou et al. 1998, Morales and Perfecto 2000, Price 2001). Nevertheless, this is not generally considered in formal research and development programs.

In this study, we stimulated farmers to propose designs and materials to make traps, because as Norton et al. (1999) suggest, researchers should not direct the research process, but facilitate it. In some of the workshops, farmers were not interested in investing time in trap design and construction, expressing apathy with nonattendance to workshops, sending women in their place, and sometimes they asked researchers for insecticides to control the pest. However, in other workshops farmer interest was evident and their ideas matured and took form when the advantages and disadvantages of proposed designs and materials were discussed by the group. As a rule, participatory workshops were an excellent methodological tool to take advantage of farmer knowledge on insect behavior to design and make traps and to use available low-cost materials in their communities.

New trap designs (bag, sack, and fabric traps) captured greater or equal numbers of *I. subquadratum* with respect to the conventional bamboo trap. These traps detected the same population trends observed in previous studies (Barrera et al. 2002). However, the bag trap attracted a greater number of nymphs than other traps. Nymphs may have been felt attracted to this trap because of the black color of the bag, which offered greater protection against light, and the plastic protected insects against heavy rainfall. This result suggests that nymphs and adults have different refuge needs and that this behavior difference must be taken into account to design and use traps for *I. subquadratum.*

According to Taylor's coefficient b, a population aggregation index (Taylor 1961), *I. subquadratum* generally showed aggregation behavior in all four types of traps, because its value was almost always statistically greater than unity. For the bamboo trap, this behavior had been reported in previous studies (Barrera et al. 2002, Zúñiga et al. 2002). Contrary to expectations, the calculated value of b for the total population indicated a random distribution for the bag trap ($b = 1.454$, CI = 0.974–1.933), a result that was associated with a greater capture variability observed in this trap. Differences in Taylor's coefficient a and b values between types of traps affected the number of traps required to estimate the *I. subquadratum* population with a given reliability level. A smaller number of bag traps compared with other trap types were generally required over a simulated range of densities. This fact, and the lower cost of the bag trap, resulted in a cheaper sampling system, with exception of sampling with the sack trap at low population densities. With respect to nocturnal sampling of *I. subquadratum*, b values were never statistically less than unity, a result that contradicts the findings of Zúñiga et al. (2002), in the sense that this insect is uniformly distributed ($b<1$) when it leaves shelters at night.

Table 4. Comparison of required costs of four sampling procedures by using different types of traps to obtain an estimate of three simulated densities of *I. subquadratum* with a reliability level of 20% SEM

Compared trap sampling procedures (procedure 1/procedure 2)	Procedure 1			Procedure 2			Simulated density								
							1 individual			5 individuals			15 individuals		
	d_1	e_1	f_1	d_2	e_2	f_2	n_1	n_2	C_1/C_2	n_1	n_2	C_1/C_2	n_1	n_2	C_1/C_2
Bag/sack	1.56	0.18	1.02	1.36	0.19	1.15	41	22	1.905	17	19	0.915	9	17	0.541
Bag/bamboo	1.56	0.18	1.02	1.13	0.21	1.37	41	52	0.803	17	21	0.824	9	11	0.833
Bag/fabric	1.56	0.18	1.02	0.8	0.19	3.02	41	48	0.588	17	20	0.585	9	11	0.563
Sack/bamboo	1.36	0.19	1.15	1.13	0.21	1.37	22	52	0.422	19	21	0.901	17	11	1.540
Sack/fabric	1.36	0.19	1.15	0.8	0.19	3.02	22	48	0.309	19	20	0.640	17	11	1.041
Bamboo/fabric	1.13	0.21	1.37	0.8	0.19	3.02	52	48	0.732	21	20	0.710	11	11	0.676

d_i is time (cost) required to examine a trap by using the ith sampling method; e_i is time (cost) required to move from trap to trap for the ith procedure; f_i is materials and labor (cost) used to make and examine each type of trap; n_i is optimal number of traps required for an estimate with a given level of reliability (equation 2), by using the ith sampling method; C_i is cost per sample for a given level of reliability for the ith sampling method; when ratio C_1/C_2 (equation 5) is greater than unity, procedure 1 costs more for a given reliability level than does procedure 2.

This study indicates the importance of farmer participation in the search for solutions to their problems. Also, it shows that farmers possess creativeness, experience, and knowledge that scientists hardly use to generate and validate technologies. This study also revealed that insecticide use is deeply rooted in farmers. Thus, although a proportion of farmers considered that traps could be useful to manage this insect, many of them continued to believe that synthetic insecticides represented the only solution to pest control problems. Recent studies in the coffee area of Siltepec, where we carried out this study, suggest that frequent use of insecticides by farmers to control *I. subquadratum* is causing high infestations of coffee leaf miner, *Leucoptera coffeella* (Guérin-Méneville) (Lepidoptera: Lyonetiidae) (Barrera et al. 2003b). This is normally a secondary insect pest in Mexican coffee plantations that rarely reaches economic threshold densities. Therefore, it is very important to inform farmers about risks associated with the exclusive use of insecticides against *I. subquadratum.* Our study demonstrated that traps designed by farmers were as useful as a conventional bamboo trap for monitoring *I. subquadratum* populations. Subsequent studies will focus on their use in mass-trapping for control of this tettigonid. These traps have some advantages because they do not contaminate, and presumably have little effect on, nontarget organisms. They also can be made with low-cost materials that are readily available in farmer communities.

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