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Inexpensive artisanal traps for mass trapping fruit flies (Diptera: Tephritidae) in Haiti

Fractyl Mertilus[1], Jorge Peña[2], Dennis Ring[1], and Timothy Schowalter[1,]*

Abstract

Field experiments were conducted in a mango orchard in Croix-des-Bouquets, Haiti, to compare the effectiveness of 2 inexpensive artisanal trap types and the standard McPhail trap (Great Lakes IPM, Inc., Vestaburg, Michigan) for capturing fruit flies *Anastrepha obliqua* (Macquart) and *Anastrepha suspensa* (Loew) (Diptera: Tephitidae) and to ascertain the optimal trap density for mass trapping these flies. Two artisanal trap designs were constructed from inexpensive plastic soda bottles. In 1 design the plastic bottle was clear, and in the other design the plastic bottle had the bottom 20% painted yellow. These 2 traps and 1 McPhail trap were placed in replicated groups in the mango orchard. The mean number of flies captured in clear artisanal traps (13 flies) was similar to that captured in the McPhail trap (16 flies), but the cost of 20 artisanal traps (US $70) was less than 1 third of the cost of 20 McPhail traps (US $220). A 2nd field trial was implemented to compare the number of flies captured in 24 McPhail traps per ha (236 flies) to the number of flies captured in 36 clear artisanal traps per ha (239 flies). The number of flies captured did not differ significantly between the 2 trap type densities. A 3rd experiment evaluated the optimal trap density for mass trapping fruit flies. Our data indicated that a density of 25 traps per ha is adequate to protect a mango orchard through the maturation phase of the mango season. These results indicated that cost-effective artisanal traps can replace the McPhail trap for mass trapping fruit flies in Haiti.

Key Words: pest management; mango production; *Anastrepha obliqua*; *Anastrepha suspensa*

Resumen

Se realizaron experimentos de campo en un huerto de mango en Croix-des-Bouquets, Haití, para comparar la eficacia de 2 clases de trampas artesanales de bajo costo y la trampa McPhail (Great Lakes IPM, Inc., Vestaburg, Michigan) estándar para capturar moscas de la fruta *Anastrepha obliqua* (Macquart) y *Anastrepha suspensa* (Loew) (Diptera: Tephritidae) y para determinar la densidad de trampas óptima para la captura masiva de estas moscas. Dos diseños de trampas artesanales fueron construidos de botellas de soda de plástico de bajo costo. En un diseño la botella plástica fue transparente, y en el otro diseño la botella plástica tenía el 20% del fondo pintado de amarillo. Se colocaron estas 2 trampas y 1 trampa McPhail en grupos replicados en el huerto de mango. El promedio del número de moscas capturadas en las trampas artesanales transparentes (13) fue similar a la captura con la trampa McPhail (16), pero el costo de 20 trampas artesanales (70 dólares) fue inferior a 1/3 del costo de 20 trampas McPhail). Un segundo ensayo de campo comparó el número de moscas capturadas en 24 trampas McPhail por hectárea (236) con el número de moscas capturadas en 36 trampas artesanales claras por hectárea (239). El número de moscas capturadas no difirió significativamente entre las 2 densidades de tipo trampa. Un tercer experimento evaluó la densidad óptima de la trampa para atrapar en masa las moscas de la fruta. Nuestros datos indicaron que una densidad de 25 trampas por ha es adecuada para proteger un huerto de mango a través de la fase de maduración de la temporada de mango. Estos resultados indicaron que las trampas artesanales son de costo efectico y pueden reemplazar la trampa de McPhail para atrapar en masa las moscas de la fruta en Haití.

Palabras Clave: manejo de plagas; producción de mango; *Anastrepha obliqua*; *Anastrepha suspensa*

Fruit flies (Diptera: Tephritidae) represent 1 of the most economically important insects in the tropical and sub-tropical regions of the world. Fruit fly larvae feed in the pulp of ripening host fruit, causing fruit spoilage (Aluja 1994). This damage has a serious impact on international marketing of fresh fruits and vegetables (Pierreval 2012). As a consequence, infestations of these insects require implementation of area-wide or national control programs in order to comply with sanitary and phytosanitary standard measures (Aluja 1994; IAEA 2003). Haiti is among the twenty greatest mango, *Mangifera foetida* Lour. (Anacardiaceae), producers in the world and the 6th largest mango exporter to the US market after Mexico, Peru, Ecuador, Brazil, and Guatemala (Bonicet 2013). Moreover, the Central Bank of Haiti estimates mango export at about US $10 million (Pierreval 2012). In addition to its economic importance, mango is an important source of vitamin A for undernourished nations (Muoki et al. 2009). The Caribbean fruit fly, *Anastrepha suspensa* (Loew), and the Indian fruit fly, *Anastrepha obliqua* (Macquart) (Diptera: Tephitidae), are the primary pests of mango in Haiti (MARNDR 2009). In 2007, losses in mango production were estimated at more than US $4 million, equivalent to 40% of the value of mango exports (Pierreval 2012). In 2007, Haitian mango exports to the US were banned due to infestation with fruit fly larvae. Since 2008, a nation-wide program has been implemented to detect and control fruit flies, in order to protect the mango export economy in Haiti (MARNDR 2009).

In 2010 the National Mango Forum organized by 2 United States Agency for International Development-funded programs set a goal to

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help Haiti increase its export from 2.5 to 5.0 million cases of United States Department of Agriculture-certified mangoes by 2015 (USAID 2010). As a result, maintaining pesticide-free mango production is a crucial goal for the mango industry. However, a weakness of the mango industry in Haiti is the scarcity of commercial orchards. Instead, Haitian mango production relies primarily on individual mango trees dispersed throughout smallholder farms. Thus, mango production is not an important and permanent source of income to smallholders (Castañeda et al. 2011). Therefore, despite the fact that farmers with small or average orchards could improve production by applying sanitation and fruit fly control methods, only a few smallholders have shown interest in investing money for this purpose (Castañeda et al. 2011). This situation makes it difficult for the Division of Plant Protection to manage the National Program for Detection and Control of Fruit Flies. Given the distributed nature of mango production in Haiti, mass trapping and other non-insecticidal techniques may be better options for management of fruit flies in Haiti than broadcast insecticide applications (MARNDR 2014).

A mass trapping network established in Haiti has contributed to a significant reduction in *Anastrepha* species density (MARNDR 2014). These data demonstrated mass trapping to be an appropriate management method (Kogan & Jepson 2007). However, the density of McPhail traps (Great Lakes IPM, Inc., Vestaburg, Michigan) recommended for mass trapping methods to control fruit flies (25–50 traps per ha; Martinez-Ferrer et al. 2012) represents a financial cost that cannot be supported by smallholders (Burrack et al. 2008; Lasa et al. 2013; Malo & Zapien 1994). Thus, in order to be sustainable and to reduce food safety risks, new trapping methods and trap devices must be designed to control fruit flies in a more cost-effective manner.

In addition to attractive trap design and bait (Lasa et al. 2014a), the efficacy of mass trapping as a pest control method depends on trap density and distribution (El-Sayed et al. 2006). An adequate number of baited traps must be distributed in infested areas in order to minimize the adult fruit flies in the area (Martinez-Ferrer et al. 2012). Calkins et al. (1984) demonstrated that 20 to 25 traps provided a high probability of detecting *A. suspensa* in citrus groves in Florida. Standardized trapping guidelines for area-wide management of fruit flies recommend 20 to 25 traps per ha for detection surveys (IAEA 2003). However, Martinez-Ferrer et al. (2012) reported that a density of 25 traps per ha was sufficient as a stand-alone method to control the Mediterranean fruit fly (*Ceratitis capitata* Wiedemann; Diptera: Tephritidae) in Spain.

Our research was designed to evaluate the effectiveness of 2 inexpensive artisanal trap designs as an alternative to the standard McPhail trap for mass trapping fruit flies in Haiti. Our objectives were 1) to compare rates of fruit fly capture by 2 artisanal trap models and the McPhail trap, 2) to compare effectiveness of the better artisanal model and the McPhail trap for mass trapping fruit flies, and 3) to assess the optimal trap density for mass trapping fruit flies in mango orchards in Haiti (MARNDR 2009).

Materials and Methods

STUDY SITE

This experiment was conducted in a mango orchard located in the municipality of Croix-des-Bouquets (18.9711870°, −72.2852150°) in Ouest Département, Haiti, during Dec 2014 to Mar 2015. Annual precipitation total is 137 cm, with 85% of total precipitation occurring during Jun to Oct and only 3% during Nov to Feb (Rinaldo et al. 2012). The site has an altitude of 90 to 95 m, and less than 8% slope. The orchard had about 240 trees per ha, spaced at 7 × 6 m. This orchard was a commercial orchard until 15 yr ago, but it is now abandoned. The mango trees were 10 to 15 m tall at the time of the study. Other host plants such as guava, *Psidium guajava* L. (Myrtaceae), yellow mombin, *Spondias mombin* Jacq. (Anacardiaceae), and red mombin, *S. purpurea* L. (Anacardiaceae), occur at low abundance around the orchard. Like all areas of mango production across the country where the fruit fly program has been implemented, this area has been surveyed since 2008, using a combination of Jackson (ISCA Technologies, Cooper City, Florida), McPhail (Great Lakes IPM, Inc., Vestaburg, Michigan), and Multilure (Better World Manufacturing, Inc., Miami, Florida) traps (Vargas et al. 1997), which have reduced the fruit fly density to 2.5 flies per trap per day before the period of this study (MARNDR 2014).

TRAP MODELS AND LURES

Two artisanal trap models (AT1 and AT2; Fig. 1) were constructed as follows. The yellow artisanal trap (AT1) was constructed from a 0.59 L clear recycled plastic soda bottle. To allow attractant diffusion and fly entry into the trap, 2 holes (1 cm diameter) were cut on either side of the plastic bottles at two-thirds the height of the bottle. The bottom 20% of the bottle was painted yellow (Fig. 1). The clear artisanal trap (AT2) was constructed like AT1 but without the yellow base (Fig. 1). The conventional McPhail trap (MP) (Fig. 1) was used for comparison.

Each trap was baited with 2 pellets (5 g) of Torula Yeast with borax (ERA Intl., Baldwin, New York) dissolved in 250 mL of water. Torula yeast is the standard bait used in current traps because it is a proteinaceous food that releases volatile compounds that are highly attractive to fruit flies (Aluja & Rull 2009). Protein sources are critical for maturation and reproduction by both sexes after adult emergence, but especially for oviposition by females (Aluja & Rull 2009; Bateman 1972; IAEA 2003).

EXPERIMENTAL DESIGN

For the first experiment, conducted 31 Dec 2014 to 14 Jan 2015, traps were placed in a 3 ha portion of the orchard in groups (blocks) of 3, with 1 trap of each model in each 3-trap group. Each group was hung in mango trees at 3 to 4 m height, in a triangular pattern at 15 m apart. Twenty replicates of each block were distributed randomly within the study area.

For the second experiment, a total of 6 plots (0.25 ha, 50 × 50 m) were established in a different portion of the orchard during 17 Jan to 7 Mar 2015; plots were located 25 to 30 m from each other. This study period coincides with the major season of mango production at low altitude in this region in Haiti. The 6 plots were randomly assigned to either McPhail or artisanal treatment. For the McPhail treatment, 6 McPhail traps were placed on mango trees in a regular 2 × 3 pattern, with traps spaced 10 to 15 m apart within each plot (24 traps per ha). For the artisanal treatment, traps were placed on mango trees in a regular 3 × 3 pattern, with traps spaced 10 m apart within each plot (36 traps per ha).

The third experiment was conducted from 21 Jan to 3 Mar 2015 in a third portion of the orchard. A total of 18 plots (0.25 ha, 50 × 50 m) were marked, with plots separated from each other by 25 to 30 m. Plots were randomly assigned to 1 of 6 treatment densities (4, 8, 12, 16, 24, and 36 traps per ha), with 3 replicates per treatment. Traps were hung in mango trees at 3 to 4 m height at regular spacing within the plot.

DATA COLLECTION AND ANALYSIS

For the first experiment, traps were sampled twice weekly, and the traps in each group were rotated clockwise to minimize any effect of trap location. The bait was replaced weekly, i.e., every second sample

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Fig. 1. Trap models developed and used for evaluation of mass trapping efficacy for fruit flies in a mango orchard in Haiti. AT1, yellow-bottomed artisanal trap; AT2, clear artisanal trap; and MP, commercial McPhail trap.

time. Fruit flies were collected from the traps, placed in labeled vials with 75% alcohol, and identified to species. Traps caught many insects from various orders, of which non-tephritid dipterans and wasps were predominant. Only 2 fruit fly species were identified: *A. obliqua* and *A. suspensa*. These fruit flies were identified to species and sorted by sex. Statistical analysis was performed using ANOVA (PROC General Linear Model), followed by Fisher LSD mean separation procedure ($\alpha = 0.05$) for significant results, in order to compare trap models on their average number of fruit flies captured (SAS 2009). A binomial test for equal proportions ($\alpha = 0.05$; Bonferroni correction for 3 comparisons, $\alpha = 0.017$) was performed to compare the trap models on the proportion of fruit flies captured.

For the second and third experiments, traps were sampled weekly, and the bait was replaced at the same time. Trapped insects were placed in labeled vials with 75% alcohol, and identified. Statistical analysis was performed using a binomial test for equal proportions ($\alpha = 0.05$) to compare the number of fruit flies trapped by the two methods (SAS 2009).

For the third experiment, statistical analysis was performed using SAS (SAS 2009). Because of differences in the variances of the treatments, data were transformed using the negative exponential function: y = asymptote $(1^{-(\text{curve}(x + \text{shift}))})$. The Gauss–Newton iterative method was used to estimate the asymptote, curve, and shift. Nonlinear regression analysis (Proc NLIN; nonlinear model − negative exponential) was performed to assess the relationship between the dependent variable (y = number of fruit flies caught) and the independent variable (x = trap density). This algorithm regresses residuals onto the partial derivatives of the model with respect to the parameters until the estimates converge (SAS 2009). Convergence criteria were met when the sum of squares was minimized. The initial parameter estimates for the nonlinear regression were asymptote = 50, curve = −0.40, and shift = −14.

Results

No significant differences were observed in the average number of fruit flies captured between the yellow-bottomed artisanal trap (AT1; 8.9 ± 2.6), the clear artisanal trap (AT2; 13 ± 2.9), and the commercial McPhail trap (MP; 16 ± 4.1) ($F = 1.2$, df = 2, 57, $P = 0.31$). However, significant differences were observed between the 3 trap models in total number of fruit flies caught ($P < 0.001$). The total number of fruit flies trapped was highest in McPhail traps (319 flies), followed by the clear artisanal traps (253 flies) and lowest in the yellow-bottomed artisanal traps (178 flies; Fig. 2).

The proportion of *A. obliqua* was significantly higher than that of *A. suspensa* in all 3 trap models. *Anastrepha obliqua* was represented by 99%, 100%, and 100% of specimens in the yellow-bottomed artisanal, clear artisanal, and McPhail traps, respectively; *A. suspensa* was represented by only 1%, <1%, and <1% in the 3 trap models, respectively.

The percentage of females trapped in the yellow-bottomed artisanal trap (74%), the clear artisanal trap (63%), and the McPhail trap

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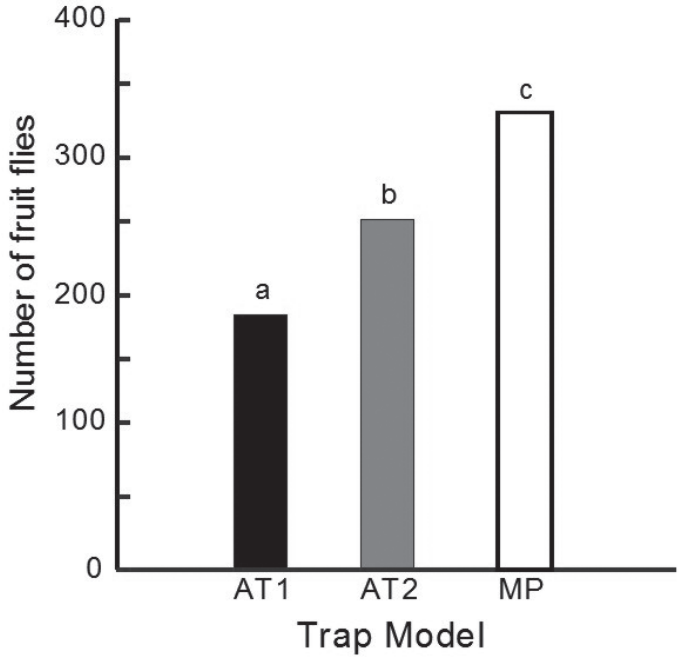


Fig. 2. Total number of fruit flies caught for each trap model in a mango orchard in Haiti. Bars labeled with the same letter were not significantly different (ANOVA, Fisher LSD α = 0.05).

(63%) was significantly greater than that of males captured (Fig. 3). Further analysis demonstrated that the proportion of females caught in the yellow-bottomed artisanal trap was significantly greater than that of the clear artisanal trap (Z = 2.5, P = 0.01), and that of the McPhail trap (Z = 2.7, P = 0.008). However, the proportions of females trapped in the clear artisanal trap and the McPhail trap were not different (Z = 0.099, P = 0.92) (Fig. 3).

Given the higher number of fruit flies captured by the McPhail traps compared with the clear artisanal traps in the first experiment, we used 36 AT2 traps per ha and 24 MP traps per ha for the second experiment. During the 7-week mass-trapping period, 236 and 239 fruit flies were captured using 36 AT2 per ha and 24 MP per ha, respectively. This difference in the total number of flies caught was not significant (Z = 0.13, P = 0.73) (Fig. 4).

The analysis of the number of fruit flies caught every week using both trap densities (24 MP per ha and 36 AT2 per ha) showed that the number fruit flies increased as mango fruits matured (Fig. 4). Fruit

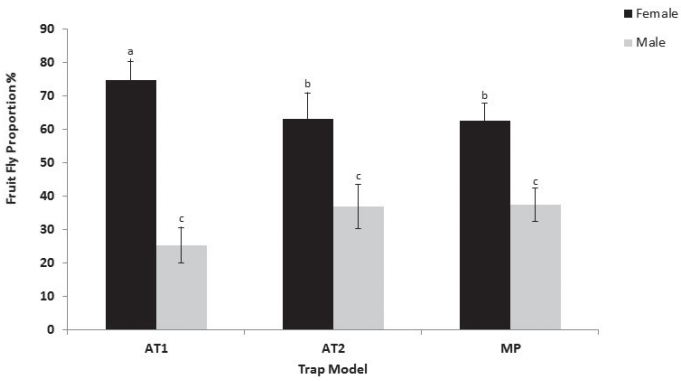


Fig. 3. Average proportion of female and male fruit flies caught per trap model in a mango orchard in Haiti. Bars labeled with identical letters were not significantly different after comparisons among trap models (ANOVA, Fisher LSD α = 0.05).

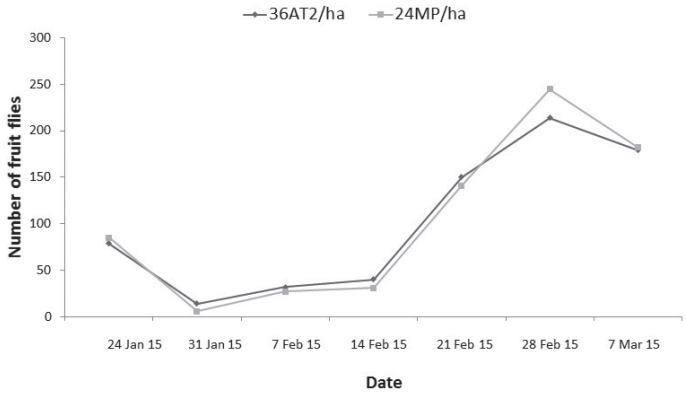


Fig. 4. Total number of fruit flies caught at 24 McPhail per ha (MP/ha) and 36 clear artisanal trap per ha (AT2/ha) in a mango orchard in Haiti. Bars labeled with the same letters were not significantly different (Binomial test for equal proportion, α = 0.05).

fly densities were low initially, because food and water sources in the orchard were limited during this driest season of the year and the beginning of the mango production season. The number of fruit flies captured related to trap density was borderline significant (F = 3.64, df = 2, 15, P = 0.051; Table 1; Fig. 5). Moreover, the parameter estimates (i.e., asymptote = 80 ± 27, curve = −0.11 ± 0.11, shift = −3.75 ± 2.7) (Table 2) showed a significant correlation that permitted development of a predictive equation to assess the relationship between the number of fruit flies caught and the trap density: $y = 80(1^{0.112(x-3.745)})$. The inflection point for the rate of fruit flies caught per additional traps occurred at 24 to 25 traps per ha (Fig. 6). Few additional fruit flies were captured at higher densities.

Discussion

Our data demonstrated that 36 clear artisanal traps per ha performed as well as 24 standard McPhail traps per ha but at a much lower cost. Furthermore, a density of 25 traps per ha was optimal for mass trapping, as found for previous studies in different orchard crops in different locations (e.g., IAEA 2003, Martinez-Ferrer et al. 2012). This density corresponds to the current recommendation for mass trapping fruit flies in Haiti.

Certain intrinsic characteristics of each trap model could have contributed to the observed difference in number of fruit flies caught between the 3 trap models. First, the entrance hole in the McPhail trap (6 cm diameter) is 6 times larger than the entrance hole in the artisanal trap models (AT1 and AT2 are 1 cm diameter), which might facilitate a better diffusion of the attractant and entrance of the flies (F. M, personal observation). Second, in addition to the chemical cues released from the food bait, the yellow bottom in the McPhail and the AT1 is considered a visual cue that attracts flies when they approach the traps (Aluja & Rull 2009, Cytrynowicz et al. 1982, Sivinski 1990). This coloration plays a key role in the McPhail traps effectiveness by

Table 1. Regression analysis (based on data transformation with the Gauss-Newton iteration method: negative exponential) for the effect of trap density on fruit fly capture in a mango orchard in Haiti.

Source	df	Sum of Squares	Mean Square	F value	Probability ($P > F$)
Model	2	11,868.2	5,934.1	3.64	0.051
Error	15	24,439.6	1,629.3		
Corrected Total	17	36,307.8			

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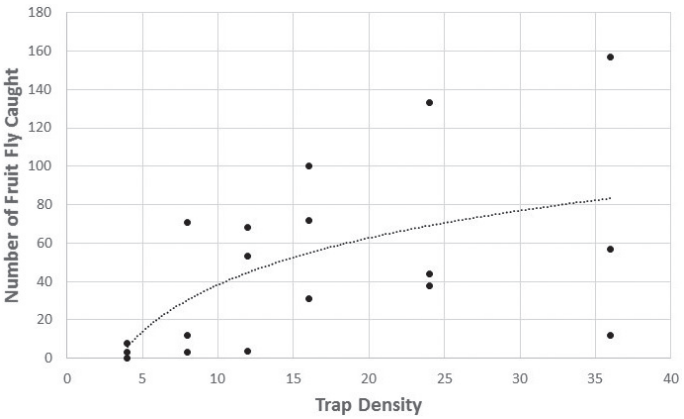


Fig. 5. Numbers of fruit flies caught by trap density in a mango orchard in Haiti.

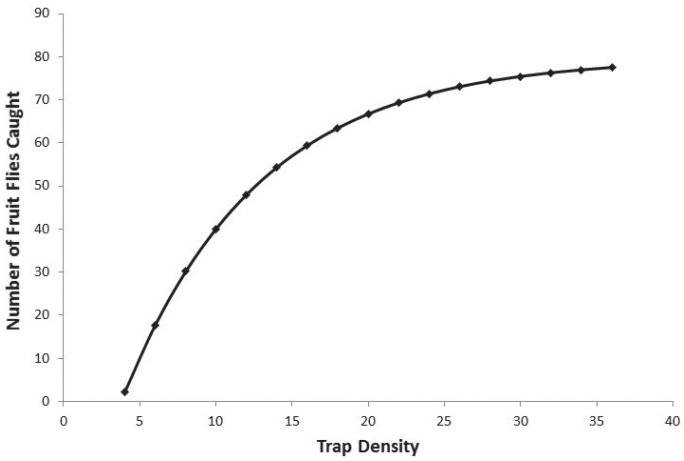


Fig. 6. Predicted number of fruit flies caught relative to trap density in a mango orchard in Haiti during Jan 21 to Mar 3, 2015.

guiding flies through the entrance hole in the underside of the trap whereas it may have had a negative effect on the performance of the yellow artisanal trap by distracting flies from entering the holes, which were not located in the yellow portion of this trap. Furthermore, the volume of the McPhail trap (3.4 L) is approximately 6 times larger than the artisanal trap models (0.59 L), which might prevent flies from escaping the former after entering (F. M., personal observation). These factors likely contributed to the larger number of flies in the McPhail trap compared with the clear artisanal trap and to the higher number of flies in the clear artisanal trap compared with the yellow-bottomed artisanal trap.

Our results indicated that the population of *A. obliqua* might be much higher in this mango growing area of Haiti than that of *A. suspensa*, based on the ≤1% representation of *A. suspensa* in samples. Previous studies have shown that the McPhail trap is effective against both fruit flies species (Burditt 1982). Furthermore, we confirmed that all 3 trap models are biased toward females, as shown in earlier studies (Lasa et al. 2014a). Female fruit flies need more protein than males, because of their requirements for oviposition (Aluja & Rull 2009, Bateman 1972). As a result, more females are typically attracted to sources of protein (e.g., Torula yeast) than males (Aluja & Rull 2009, Bateman 1972).

A comparison of the construction costs of these 3 trap models demonstrated that the artisanal models are much less expensive than the McPhail model. The cost of 20 McPhail traps used for the experiment (US $220) is 3 times the cost of 20 yellow-bottomed artisanal traps (US $75) and more than 3 times the total cost of 20 clear artisanal traps (US $70) (Table 1). These results demonstrated that the clear artisanal trap (AT2) was the most cost-effective model, followed by the yellow artisanal trap model (AT1). The importance of inexpensive traps was emphasized by Lasa et al. (2014b). Given the number of traps necessary for mass trapping, the cost per trap becomes a primary criterion for determining the economic injury level (Stern et al. 1959). If the cost of a management plan is too high, crop yield and market value may be insufficient to warrant its use. In Haiti, mass trapping with commercial McPhail traps requires a prohibitively-expensive number of traps per ha, making a fruit fly control program financially unfeasible for small growers. Fortunately, our data demonstrate that the clear artisanal trap model (AT2) is an efficient, but less expensive, alternative to the McPhail trap.

Table 2. Regression analysis of parameter estimates for a model of the effect of trap density on fruit fly capture in a mango orchard in Haiti.

Parameter	Estimate	Approximate standard error	Approximate 95% confidence limits	
			Lower	Upper
Asymptote	79.6108	26.2964	23.5614	135.7
Curve	−0.1119	0.1109	−0.3483	0.1244
Shift	−3.7450	2.6720	−9.4403	1.9503

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