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Optimal pheromone trap density for mass trapping cacao mirids

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Short Title: Pheromone trapping of cacao mirids

Key words: Theobroma cacao, Sahlbergella singularis, Distantiella theobroma, Heteroptera: Miridae, pheromone trap

Abstract

The mirids *Sahlbergella singularis* and *Distantiella theobroma* are the key insect pests of cacao in Ghana and elsewhere in West Africa. Since 1954, spraying with synthetic insecticides has been the principal means of controlling these pests. In West Africa, environmental concerns, economic stimuli and unreliable access to insecticides have stimulated interest in ecologically more benign mirid control strategies as an alternative to a total reliance on insecticides. Males of both mirid species, and those of the less damaging *Bryocoropsis laticollis*, respond to the same synthetic sex pheromone blend, so pheromone-based strategies may provide control as well as monitoring opportunities. Pheromone traps were deployed for three months at nine densities between two and 30 traps 0.1 ha^{-1}plot (20-300 traps ha^{-1}) plus an untreated control treatment in a replicated large-scale field experiment on mature mixed Upper Amazon hybrid cacao in Ghana, in order to determine the optimal dispenser density for mass-trapping, lure and kill and/or lure and infect. At the end of the trapping period, mirid populations in the various treatments were assessed by insecticide knockdown on 400 trees and by searches to hand height on 1,200 trees, together with an assessment of mirid damage. In total 781 *S. singularis* and 235 *D. theobroma* were captured in the pheromone traps. The optimal dispenser density for *S. singularis* was 150 traps ha^{-1}. Over 300 traps ha^{-1} was probably optimal for *D. theobroma* as a smaller proportion of the population was captured, and numbers caught $trap^{-1}$ showed no decline with increasing trap density. From insecticide knockdowns, mirid population density was estimated at 4,700-6,080 ha^{-1}, 63% of which were *D. theobroma.* Too few pods and orthotropic shoots were damaged by mirids to establish the efficacy of pheromone trapping for mirid control.

Introduction

Cocoa is a valuable export crop for several West African countries including Ghana where it is the largest agricultural commodity accounting for 20% of the nation's export receipts in 2014 (SGER, 2014). *Sahlbergella singularis* Haglund and *Distantiella theobroma* (Distant) (Heteroptera: Miridae) are the most damaging pests of cacao in West Africa (Entwistle, 1972; Collingwood, 1977), causing losses estimated at 25 — 30% per annum (Stapley & Hammond, 1959; Johnson, 1962; Babin et al., 2004; Anikwe & Makanjuola, 2013. *Sahlbergella singularis* attacks cacao from Sierra Leone to the Central African Republic, while the geographical range of *D. theobroma* is narrower (Entwistle, 1972). In Ghana, *D. theobroma* is often the more damaging of the two species (Collingwood, 1977). The lifecycle duration of both species is similar at about two months (Johnson, 1962), but females of *S. singularis* are twice as fecund as those of *D. theobroma* laying about 200 eggs over 30-40 days, resulting in multiple overlapping generations each year (Williams, 1953).

All mirid active stages feed on cacao stems and pods causing little direct damage. However, their phytotoxic saliva results in sunken lesions that become infected secondarily by parasitic fungi that cause shoot die back (Johnson, 1962; Adu-Acheampong et al., 2012). Damage varies from mild 'blast' where leaves on fan branches die but remain hanging, through 'staghead' where the whole canopy of individual trees is defoliated and shoots die back, to the most severe 'pockets' where up to 100 trees become stagheaded with corresponding breaks in the cacao canopy (Williams, 1954; Johnson, 1962).

Mirid aggregations are almost invariably associated with breaks in the cacao canopy (Williams, 1953, 1954; Collingwood, 1977). Immature cacao is particularly vulnerable until the canopy closes (Johnson, 1962), whereas canopy breaks in mature stands may be caused by the

fall of a branch or all of a shade tree (Collingwood, 1977), by outbreaks of cacao swollen shoot virus (Williams, 1953) and by edge effects inherent with the small size of smallholders' mixed-crop farms, 70% of which are less than 1.5 ha (Awudzi et al., 2016). Unless treated, an aggregation may create a pocket which can persist for several years until the canopy is regenerated (Johnson, 1962). Owusu-Manu (2002) concluded that insecticide is essential to restore a broken canopy, but is not economical thereafter. Collingwood & Marchart (1972) recommended that a continuous canopy was the best insurance against mirid damage and noted that well canopied cacao is largely self-protective.

The seasonal population cycle of mirids on cacao fluctuates in response to changes in tree physiology, particularly the fruiting pattern (Gibbs et al., 1968; Owusu-Manu, 2002; Adu-Acheampong et al., 2014). On Amelonado cacao, which presents a unimodal cropping pattern, peak numbers occur usually in October-December around peak harvest (Williams, 1954), whereas on Upper Amazon hybrid cacao, which fruits throughout the year, population peaks may occur at almost any time (Gibbs et al., 1968; Adu-Acheampong at al., 2014, 2015).

For over half a century, cacao mirids have been controlled by synthetic insecticides applied to the foliage (Collingwood & Marchart, 1971; Owusu-Manu, 2002). However, a rising market demand for organically produced cacao (Mahrizal et al., 2012), problems with pesticide-induced outbreaks of secondary pests (Entwistle, 1972), the cost and deleterious effects on the environment of pesticides (Afrane & Ntiamoah, 2011), and pressure to reduce unnecessary pesticide use have stimulated research for more ecologically benign methods of control (Babin et al., 2004; Anikwe & Makanjuola, 2013; Adu-Acheampong et al., 2015) including the use of sex pheromones (Padi et al., 2002; Ayenor et al., 2007; Mahob et al., 2011).

Several species of mirid have been shown to produce sex pheromones (collated by Fountain et al., 2014). Female *S. singularis* and *D. theobroma* produce the same two pheromone components in essentially the same ratio (Padi et al., 2002). Traps baited with synthetic pheromone lures captured males of both these species and the more minor pest *Bryocoropsis laticollis* Schumacher (Sarfo et al., 2018). The latter authors compared the efficacy of several pheromone trap designs and showed that those fabricated from locally available products were as effective as the best design from previous studies made entirely from imported materials.

Sarfo et al. (2007), compared three pheromone trap densities (50, 100, 150 traps ha^{1}) in 0.1 ha cacao plots and found that the total numbers of mirids caught increased with increasing trap density. However, this was a relatively small experiment with just three replicates, no untreated control, and captures were not identified to species. Despite these limitations, significant differences were found between treatments in the numbers of mirids captured per trap which demonstrated that a plot size of 0.1 ha was adequate for such studies. The aim of the present study was to establish the optimal trap/dispenser density for control of cacao mirids by mass-trapping or in combination with other biocides by lure and kill or lure and infect.

Materials and methods

Experimental site

Two adjacent 10.5 ha plantings, separated by a 10 m wide service road at Acherensua, Ghana (07° 00' 354" North, 002° 15' 261" West) were used. Following good farm practice (Opoku-Ameyaw et al., 2010), the plantation was fertilised, weeded and pruned to limit canopy height and to remove orthotropic shoots favoured by ovipositing mirids (Williams, 1953). The experimental site was surrounded on three sides by insecticide-treated cocoa plantings and by

secondary forest on the fourth. No insecticides were applied in the three months before and during the three-month experiment, although a programme of four insecticide treatments per annum had been applied previously on these plantings. Cacao trees were mixed Upper Amazon hybrids spaced 3 m x 3 m, about 25 years old. They formed a dense continuous interlocking canopy at a height of between six and 6.5 m maintained at that height by pruning.

Pheromone traps

Traps were 4.5 l polythene water bottles (26 cm high x 16 cm dia) with two 10 x 14 cm windows cut in opposite sides, as illustrated in Sarfo et al. (2018). The inverted bottles were filled to just below window level with a dilute solution of detergent in water, and were hung from cacao trees approximately 1.8 m above ground. Dispensers were polyethylene vials (0.5 ml, 22 x 8 x 1.5 mm wall thickness; Just Plastics, Norwich, UK) impregnated with 1.5 mg of a 2:1 blend of the diester, hexyl (*R*)-3-((*E*)-2- butenoy1)-butyrate, and the monoester, hexyl (*R*)-3-hydroxy butyrate and 1.5 mg 4-methyl-2,6-di-*tert*-butylphenol as antioxidant. The pheromone components were synthesised at NRI as described in Padi et al. (2002) and were at least 97% pure by by gas chromatographic analysis. Lures were suspended just above the liquid surface in the traps and renewed monthly. All traps were inspected, refilled, and the catch removed fortnightly.

Experimental design

A split-plot randomized complete block design adapted from Stelinski et al. (2005) was used with eight replicates. A simpler randomized design was ruled out in order to minimize the risk of interference between treatments if untreated control plots were sited adjacent to those with high trap densities (McMahon et al., 2010). The two plantings were each divided into four 2.6 ha

blocks. Two 0.5 ha whole plots (50 x 100) m were demarcated centrally within each block. Whole plots were separated from neighbouring whole plots and from surrounding cacao plantings by 50 m wide guards of untreated trees. Whole plots were treated with either 75 pheromone-baited traps or 75 unbaited control traps (150 traps ha^{-1}) with the traps spaced 8 m apart on a square grid. Each whole plot was then subdivided into five 0.1 ha subplots with no internal guards. The existing 15 baited or unbaited water traps in each subplot were supplemented by (a) 0, (b) 2, (c) 4, (d) 8 or (e) 15 pheromone-baited traps (Figure 1). Thus the 0.1 ha subplots (a)-(e) in the pheromone-treated whole plots had totals of 15, 17, 19, 23 and 30 pheromone-baited traps (equivalent to 150, 170, 190, 230 and 300 traps ha^{-1} respectively), whereas the corresponding subplots in the whole plots with unbaited control traps had 0, 2, 4, 8 and 15 pheromone-baited traps (equivalent to 0, 20, 40, 80, and 150 pheromone-baited traps ha^{-1} respectively. All traps were spaced equidistantly apart.

Damage and population assessments

At the end of three months trapping, mirids and the numbers of pods with mirid feeding damage were counted to hand height (*ca*. 2 m) on 15 cocoa trees selected without bias in each subplot. Numbers of mirid-damaged branches and orthotropic shoots were counted up the entire height of the tree. Only shoots showing symptoms of dieback from persistent mirid feeding would be detectable in the canopy 6-6.5 m above ground level, and those with fresh or isolated feeding lesions were likely to have been overlooked.

Mirid numbers were also assessed by insecticide knockdown. Imidacloprid (as Confidor 200SL, 200 g l^{-1}, Bayer) was applied to run-off at the manufacturer's recommended dose of 6 g a.i. in 11 litres water with a motorized knapsack sprayer to the trunk and canopy of five

individual cocoa trees selected without bias in each subplot. White calico sheets were spread under the trees before the spray was applied to collect all insects killed an hour after spraying, as previous tests had shown that was an appropriate interval following imidacloprid treatment. Adult and nymphal mirids were identified to species and counted. The gender of adults from knockdown was not determined.

Statistical analyses

Total catches for the three-month trapping period (June – August 2008) in each plot of *S. singularis* (SS), *D. theobroma* (DT) and both species combined (SSDT) transformed to ($\sqrt{x}+ 0.5$) to stabilize error variances were compared by ANOVA in a polynomial (linear + quadratic) model using GenStat9 (Payne et al., 2006). After ANOVA's on all three data sets confirmed that the relationships between catch and increasing trap density were significantly curvilinear, GenStat9's FITCURVE directive was used to identify the most parsimonious best fit explanatory models that minimised residual variances. Contagiously distributed counts of mirid nymphs from searches to hand height were transformed to $Log_{10}(x +1)$ prior to ANOVA, whereas randomly distributed counts of mirid adults from hand-height and insecticide knockdown assessments were transformed to ($\sqrt{x}+ 0.5$). Chi-square analyses were used either when insects were too sparsely distributed for ANOVA, or in order to emphasise specific comparisons.

Results

Pheromone trapping

In total 1,016 mirids, all male, were caught in the 1,072 pheromone baited traps, 781 of which were *S. singularis* (77%) and 235 *D. theobroma* (23%). No mirids were caught in any of the 360 unbaited traps. Significant differences were found between treatments at the whole plot level ($F_{1,7}$ = 6.39, 12.03, 13.05; P < 0.05, < 0.01, < 0.01, for SS, DT and SSDT, respectively) with fewer mirids trapped in low trap density whole plots (2 – 15 traps 0.1 ha^{-1}) than high (15-30 traps 0.1 ha^{-1}). At the subplot level there were significant interactions between numbers of traps and whole plot treatment ($F_{4,56}$ = 6.98, 2.61, 7.69; P < 0.001, < 0.05, < 0.001, for SS, DT and SSDT, respectively) showing that the curvilinear relationships between trap catches with increasing trap density differed between low (2 – 15 traps 0.1 ha^{-1}) and high (15-30 traps 0.1 ha^{-1}) trap densities. Exponential curves of the form $y = A + B * R^x$ provided the best fit models of the whole data for all three data sets (Table 1; Figure 2).

There were neither significant increases nor decreases in trap catch of mirids above 15 traps 0.1 ha^{-1} for any of the three data-sets (Figure 2). However, the flatter trajectory of the exponential curve towards its asymptote for *D. theobroma* (Fig. 2b) suggested that a higher trap density, perhaps > 30 traps 0.1 ha^{-1} may be optimal for this species, although that conclusion must be treated with caution owing to *D. theobroma*'s lower abundance in pheromone traps. That need for caution is reinforced from the results of a 2 x 2 contingency analysis of the total numbers of the two species caught in the high and low trap density whole plot treatments (χ^2 = 20.63; P < 0.001). *D. theobroma* represented 28% of the catch in high trap density whole plots and 14% in low which shows that males may be more responsive to the pheromone when presented at high than low concentrations.

As implied by the curvilinear increase in catch with increasing trap density (Figure 2), the mean numbers of mirids captured trap^{-1} decreased with increasing trap density for *S. singularis*, and for this species and *D. theobroma* combined (Table 2). However, for *D. theobroma* alone the numbers caught trap^{-1} remained virtually unchanged at all trap densities suggesting that the optimal trap density may be > 300 ha^{-1} for this species.

Population assessments

In total 119 mirids were collected from the 400 trees sampled by insecticide knockdown, 34 *S. singularis* (29%) and 85 *D. theobroma* (71%), and 322 from the 1,200 trees searched to hand-height, 13 *S. singularis* (4%; 4 adults + 9 nymphs) and 309 *D. theobroma* (96%; 25 adults + 284 nymphs). Too few mirids were collected by these two methods, and too few pods with feeding lesions were found for analyses of the full split-plot design, so ANOVA's were restricted to whole plots only. Therefore the two treatments being compared were the effects of 208 pheromone traps ha^{-1} and 60 traps ha^{-1} with eight replicates of each treatment. There were no significant differences in mean numbers of *S. singularis* adults and nymphs and *D. theobroma* adults between treatments by either method, but significantly higher ($P < 0.05$) mean numbers of *D. theobroma* nymphs were recorded to hand height on trees in plots with high density pheromone trapping relative to those in plots with the lower trap density (Table 3). As much higher numbers of *D. theobroma* were recorded in the high than low trap density plots by both sampling methods, a Chi-square analysis of total adults in low and high trap density plots showed that the overall difference was highly significant ($\chi^2 = 6.94$; $P<0.01$ with Yates' correction). A similar non-parametric analysis is not meaningful for nymphs because they were

distributed contagiously, with often high numbers on a few infested trees and none on the great majority, whereas adults were distributed near randomly.

After three months pheromone trapping, the estimated population densities from insecticide knockdown, assuming 1,100 trees ha^{-1}, were 55 *S. singularis* ha^{-1} in high-trap density whole plots and 110 ha^{-1} in low, and those for *D. theobroma* were 176 and 108 ha^{-1}, respectively (Table 3). Similarly, from searches to hand height the population estimates were 7 and 8 *S. singularis* ha^{-1} and 46 and 39 *D.theobroma* ha^{-1} in high and low trap density whole plot treatments, respectively

Damage assessments

A higher mean number of pods with mirid feeding lesions was recorded in the high trap density whole plots than the low (15.6 vs 10.9), but the difference was not significant (SEM = 3.14; $F_{1,7}$ = 1.4; P>0.05). As with pods, similar numbers of shoots and branches with visible feeding damage were recorded in all plots. There were no significant differences between treatments at the whole plot level (9.8 high vs 6.9 low; SEM = 10.45; $F_{1,7}$ = 1.51; P = 0.26), the sub-plot level ($F_{4,56}$ = 0.93;P = 0.45), or for the interaction between whole plots and sub-plots ($F_{4,56}$ = 0.51; P = 0.73). Therefore, at the end of three months continuous pheromone trapping, the difference in pheromone trap density in the two whole plot treatments affected neither the frequency of mirid feeding on pods, nor the numbers of *S. singularis* on trees, while the numbers of *D. theobroma* were significantly higher in the high pheromone trap density than in the low (Table 3).

Discussion

The exponential increase in total catch with increasing trap density (Figure 2) may have been due to increasing interference between the traps as they were positioned closer together, and/or to trapping out of the local population of mirids. If the former explanation was predominant, then it might have been expected that at densities above the optimum there would have been a reduction in the total catch. Yamanaka et al. (2001) observed this effect for the fall webworm moth, *Hyphantria cunea* (Drury) (Lepidoptera: Arctiidae), and attributed it to the males engaging in false trail following, repeatedly orienting upwind in different pheromone plumes, without usually being captured. No such reduction was observed in this study which suggests that trapping out of the local population of mirids was the predominant effect.

In the work described here, traps were hung at 1.8 m above ground level, based on the results of a previous small scale study (Sarfo et al., 2007). However, Sarfo et al. (2018) showed that traps at 1.8 m caught 8% of the numbers of male *S. singularis* caught in traps positioned just beneath the canopy. Similarly low trap heights had been used in earlier pheromone trapping studies in cacao (Padi et al., 2002; Ayenor et al., 2007; Mahob et al, 2011), although, in response to the results of Sarfo (2013), Awudzi et al. (2017) placed their traps at 2.7 m. Sarfo et al. (2018) also showed that only *ca.* 23% of mirid males that responded to the pheromone entered the trap, which suggests that traps at 1.8 m probably trapped out *ca.* 2% of responding males in the vicinity, a proportion unlikely to have a detectable effect on population development.

In terms of application of the pheromone for control of mirids there is no gain in using densities greater than 150 traps ha^{-1} for mass trapping or attract-and-kill of *S. singularis*, although a density above 300 ha^{-1} may be optimal for *D. theobroma*. Such high densities may be unrealistic for a practical wide-scale mass trapping programme, particularly when traps have to

be deployed in the upper canopy (Sarfo et al., 2018). El Sayed et al. (2006) suggested trap densities that have achieved successful mass trapping of low density pests have generally fallen in the range of 10-40 traps ha^{-1}, although densities similar to those we found optimal have been used successfully in fruit orchards (Teixeira et al. 2010) as have densities as high as 500 ha^{-1} (Reinke et al. 2012). In addition, mirids are highly aggregated (Collingwood, 1977), with the majority (*ca*. 90%) of trees uninfested even in a severe outbreak (Collingwood, 1971), so it may prove feasible to restrict pheromone trapping to known mirid pockets rather than regularly spaced over a whole farm.

In insecticide knockdown studies of untreated cacao in insecticide efficacy trials at sites possibly chosen because of high mirid infestations, the range of peak mirid populations has been estimated at typically between 2,500 and 7,000 ha^{-1}, with an exceptional estimate of 45,000 mirids ha^{-1} in one study (Collingwood, 1971)), although Williams (1954) concluded that numbers rarely exceed 1,000 $acre^{-1}$ (2,500 ha^{-1}). After three months pheromone trapping here, the estimated populations of adults and nymphs from insecticide knockdown were 55 ha^{-1} *S. singularis* in whole plots with high trap density and 110 ha^{-1} in plots with low trap density, and for *D. theobroma* the estimated populations were 176 and 108 ha^{-1}, respectively (Table 3). Although low, these population estimates are typical for well-managed cacao with an intact canopy (see Gibbs et al., 1968, Fig. 3) and agree with earlier estimates of population density for mirids in June-August (Williams, 1954; Gibbs et al. 1968). Furthermore cacao mirids may only slowly re-invade plots previously treated with insecticide (Owusu-Manu, 2002). In a five year study, Owusu-Manu (2002) found that mirid populations were highest every year in June-August on Amazon hybrid cacao, but other studies show that populations may increase locally at almost

any time of year on those genotypes (Gibbs et al., 1968; Adu-Acheampong et al., 2014; Awudzi et al., 2017).

Collingwood (1971) reported that more than twice as many *S. singularis* than *D. theobroma* per unit area were recorded by pyrethrum knockdown than by visual inspections to hand height, which he attributed to a higher proportion of the former feeding in the canopy. His conclusion that *S. singularis* was more numerous in the canopy was confirmed here with an average 11 times more in knockdown samples than in searches to hand height,while for *D. theobroma* the ratio was about 3.3:1. Despite their bias in overestimating the abundance of *D. theobroma*, hand-height inspections are used regularly for mirid population studies on cacao in Ghana (Owusu-Manu, 2002; Antwi-Agyakwa, 2013; Awudzi et al., 2017) including for establishing the relative abundance of the two species (Antwi-Agyakwa, 2013; Adu-Acheampong et al., 2014). Here *D. theobroma* was the most abundant species in searches to hand height (96%) and by insecticide knockdown (71%) which suggests that its much lower representation than *S. singularis* in pheromone trap catches (23%) may reflect either a lower response to the sex pheromone as numbers caught $trap^{-1}$ showed no decline with increasing trap density (Table 2) and/or a higher proportion failing to enter the traps confirming Sarfo et al. (2018). Both insecticide knockdown and searches to hand height produced similarly low estimates of mirid population density. That indication of low mirid populations was reinforced by the damage assessments in which an average of only one pod from 5-7 trees searched to hand height showed any mirid feeding punctures and, similarly, an average of only one mirid-damaged shoot or branch was recorded from 8-11 trees surveyed, although that may also reflect a paucity of orthotropic shoots which are removed routinely during pruning operations (Opoku-

Ameyaw et al., 2010). As a result, it was not possible to differentiate between the success or otherwise of the various treatments on mitigating damage by mirid feeding.

Our results suggest that the optimal density for mass-trapping *S. singularis*, the dominant cacao mirid in most West Africa countries (Entwistle, 1972; Collingwood, 1977; Idowu, 1997; Babin et al., 2004; Mahob et al., 2011; Yede et al., 2012; Anikwe & Makanjuola, 2013), and often at sites in Ghana (Owusu-Manu, 2002; Antwi-Agyakwa, 2013; Adu-Acheampong et al., 2014; Sarfo et al., 2018), is 150 traps ha^{-1}, but in order to offer a viable alternative to insecticides (Baker, 2009) trap efficiency needs improvement. Coating the outside of traps with a killing agent and raising traps to canopy level are easily deployable measures that would potentially improve capturing efficiency by about 50 times (Sarfo et al., 2018). At a recent meeting, Guillon (2016) showed that a patented chemical synergist increased pheromone trap catches by 2.4-6.6 times and also captured an undisclosed number of female mirids. However, further work is needed to improve the capture rate for *D. theobroma*, and to establish whether whole farms should be treated or if it is feasible to restrict trapping to severely infested areas only.

Acknowledgments

We are grateful to Cocoa Research (UK) for funding this work. We thank Dr. Godfred Awudzi, Messrs Henry Ahiagaziga, Ebenezer Kwapong, Emmanuel Owusu, Colins Asumadu, Dickson Ampadu, Ebenezer Obeng-Mintah, Gordon Fiakegbe and Kofi Dadzie for technical assistance. This paper is published with the permission of the Executive Director, CRIG.

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Figure legends

Figure 1 Example layout of a block in the randomised block split-plot design experiment at Acherensua, Ghana. Whole plots were 0.5 ha with 75 pheromone-baited traps (A) or 75 unbaited traps (B). Whole plots were divided into five 0.1 ha subplots (a)-(e) which were supplemented by 0, 2, 4, 8 and 15 pheromone-baited traps respectively. Thickened lines separating whole plots and adjacent blocks represent 50 m of untreated cacao guard trees.

Figure 2 Effect of pheromone-trap density on total captures ($\sqrt{n} + 0.5$) of male (a) *Sahlbergella singularis*, (b) *Distantiella theobroma* and (c) *S. singularis* + *D. theobroma.* Vertical lines over 0 traps histogram are 5% LSD's aligned to the mean catch in 15 traps treatment. Horizontal lines in the 15 traps 0.1 ha^{-1} column are individual means from 15 blank traps + 15 supplementary pheromone traps (thick line) and 15 pheromone traps + 0 supplementary traps treatments (thin line); those means were identical for *D. theobroma* from both treatments. The best-fit exponential curves were derived from the equation $y = A + B * R^x$; for the respective parameters (Table 1).

Table 1 Parameters (± SEM) for fitting exponential curves of the form $y = A + B * R^x$ where y = expected catch and x = No of traps 0.1 ha^{-1} as in Figure 2

Mirid species	A	B	R
Sahlbergella singularis	3.498 ± 0.218	-1.724 ± 0.778	0.9806 ± 0.0172
Distantiella theobroma	2.182 ± 0.313	-1.653 ± 0.377	0.9811 ± 0.0088
S. singularis + D. theobroma	4.107 ± 0.300	-2.345 ± 0.686	0.9840 ± 0.0114

Table 2 Mean $(n + 0.5)^{0.5}$ ± SE number of males' $trap^{-1}$ of *Sahlbergella singularis* (SS) and *Distantiella theobroma* (DT) at eight trap densities on Upper-Amazon hybrid cacao at Acherensua, Ghana.

Mirid species	Number of traps 0.1 ha^{-1}							
	2	4	8	15	17	19	23	30
SS	1.801 ± 0.269	1.339 ± 0.086	1.309 ± 0.074	1.150 ± 0.070	1.090 ± 0.060	1.030 ± 0.062	0.970 ± 0.049	0.980 ± 0.048
DT	0.817 ± 0.054	0.855 ± 0.053	0.859 ± 0.047	0.851 ± 0.033	0.852 ± 0.037	0.911 ± 0.079	0.782 ± 0.020	0.812 ± 0.028
SS+DT	1.857 ± 0.265	1.423 ± 0.100	1.400 ± 0.080	1.246 ± 0.097	1.183 ± 0.078	1.181 ± 0.103	1.021 ± 0.057	1.058 ± 0.045

Table 3 Mean numbers of mirid adults and mean $Log_{10}(x+1)$ nymphs per 25 cacao trees by insecticide knockdown and per 75 cacao trees by search to hand height after three months of high density (208 traps ha^{-1}) and low density (60 traps ha^{-1}) pheromone trapping, variance ratios (F) and probability (P) of a difference. Estimated mean numbers of adults and geometric mean numbers of nymphs ha^{-1} in parentheses assuming 1,100 trees ha^{-1}.

		Sahlbergella singularis		*Distantiella theobroma*	
Method	Trap density	Adults	Nymphs	Adults	Nymphs
Knockdown	High	0.88 (42)	0.11 (13)	1.12 (49)	0.59 (127)
	Low	1.62 (78)	0.24 (32)	0.50 (22)	0.47 (86)
	$F_{1,7}$	2.33	0.84	0.92	0.34
	P	0.17	0.39	0.37	0.58
Search to	High	0.50 (7)	0.00 (0)	2.38 (35)	0.25 (11)
hand height	Low	0.12 (2)	0.10 (6)	0.85 (12)	0.45 (27)
	$F_{1,7}$	1.75	0.09	4.02	6.72
	P	0.23	0.78	0.09	0.04

Figure 1

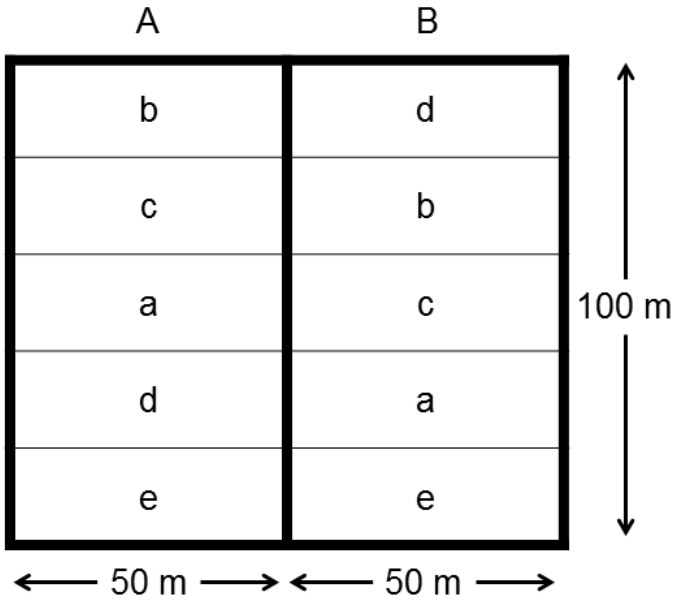
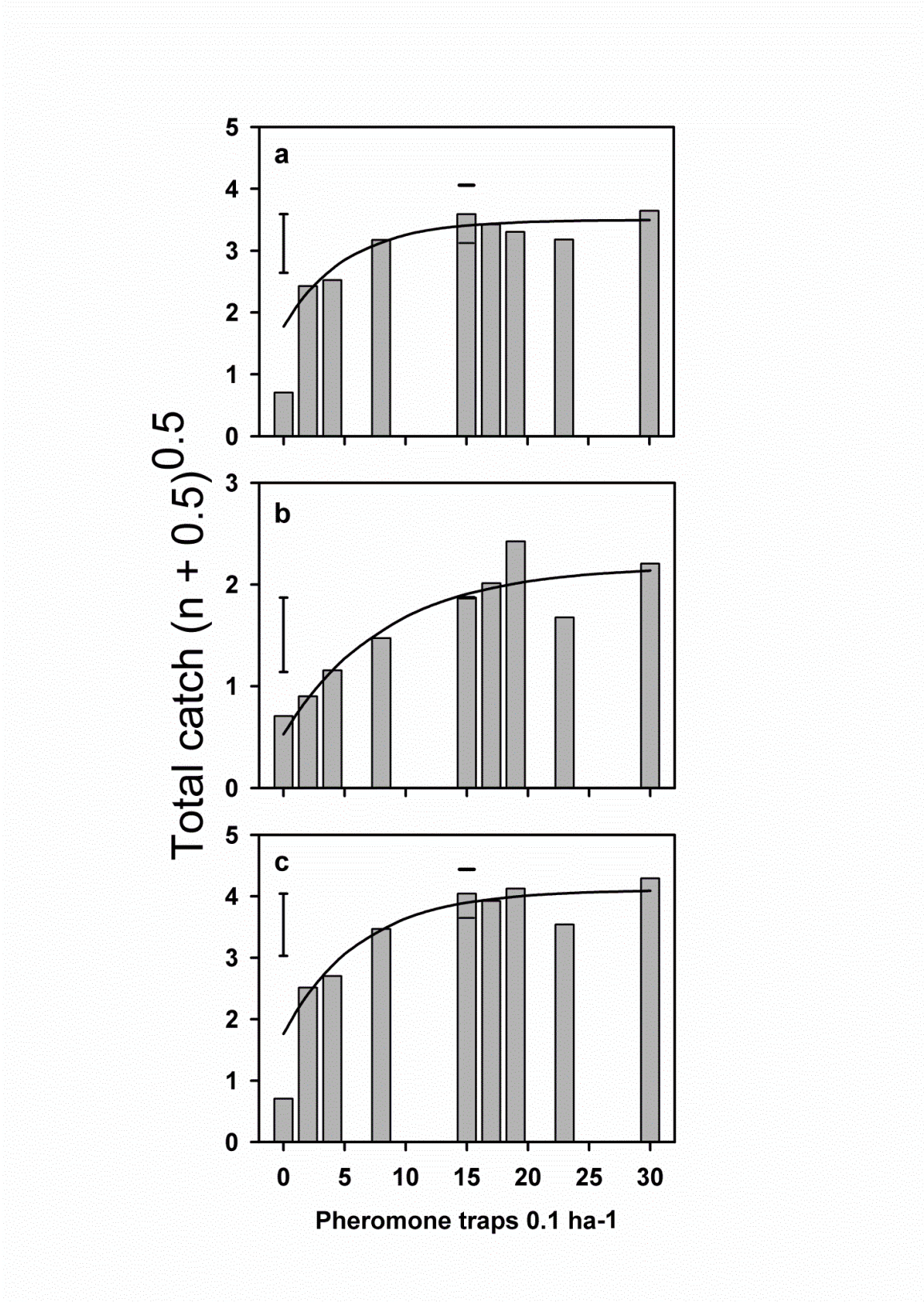
Figure 2