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Is mass-trapping a feasible management tactic of the citrus mealybug in citrus orchards?

JOSÉ CARLOS FRANCO ⁽¹⁾

SMUEL GROSS ⁽²⁾

ELSA BORGES DA SILVA ⁽¹⁾

POMPEO SUMA ⁽³⁾

AGATINO RUSSO ⁽³⁾

ZVI MENDEL ⁽²⁾

ABSTRACT

The present study assessed the efficacy of mass-trapping of males against citrus mealybug, *Planococcus citri* (Hemiptera: Pseudococcidae), in sweet orange in Portugal and Italy and grapefruit in Israel. It was thought that a "male vacuum" in the citrus mealybug population in the spring, when it is still at low density, would result in delaying the population build-up until the recovery of natural enemies in mid-summer. In order to test this hypothesis, we have examined the effect of mass-trapping, comparing treated with control plots. We used 30x30cm-plate traps covered with non-drying glue on both surfaces, baited with rubber dispenser impregnated with 200 µg of pheromone. The results suggest that a significant reduction of males in the mass-trapping plots can be achieved. However, the extent of male reduction was not enough to decrease significantly the infestation on fruits. We can postulate that another kink of "male vacuum" may be obtained inside an orchard by creating a strong attraction effect from the edges of the plot and this may eventually be explored for management purposes by using attract-annihilate tactics combined or chemical interventions selectively applied at the edge of the orchard. Further improvements are necessary mainly by: 1) application of the method in much larger plots; 2) starting mass-trapping early in the season before the beginning of male flight; 3) attraction of males to the edges of the orchard, early in the season when male population is usually low, which may bring about a "male vacuum" inside the plot that may result in significant reduction of matting.

Keywords: Mass-trapping; Pheromones; *Planococcus citri*.

⁽¹⁾ Departamento de Protecção das Plantas e de Fitoecologia, Instituto Superior de Agronomia, 1349-017 Lisboa, Portugal.

⁽²⁾ Department of Entomology, ARO, The Volcani Center, Bet Dagan, 50250, Israel.

⁽³⁾ Dipartimento di Scienze e Tecnologie Fitosanitarie, sez. Entomologia Agraria, Via Valdisavoia 5, 95123 Catania, Italy.

RESUMO

O presente trabalho teve como objectivo avaliar a eficácia do método da captura em massa como tática de protecção relativamente à cochonilha-algodão dos citrinos, *Planococcus citri* (Risso) (Hemiptera: Pseudococcidae), em pomares de laranjeira-doce, em Portugal e Itália, e de toranjeira, em Israel. Considerou-se que a criação de um “vazio de machos” na população de cochonilha-algodão dos citrinos, na Primavera, altura em que a sua densidade se encontra, ainda, em níveis baixos, resultaria num atraso do crescimento populacional, de modo a permitir a recuperação das populações de inimigos naturais, durante a primeira metade do Verão. Tendo em vista testar esta hipótese, analisou-se o efeito da captura em massa, comparando os resultados de parcelas tratadas com os obtidos em parcelas testemunha. Na captura em massa, utilizaram-se armadilhas de 30 x 30 cm, com dupla superfície adesiva, activadas com 200 µg de feromona. Os resultados sugerem que a captura em massa é capaz de reduzir significativamente a densidade de machos da cochonilha nas parcelas tratadas. Contudo, o nível de redução obtido na população de machos não foi suficiente para diminuir, de modo significativo, a intensidade de ataque nos frutos. Propõe-se como tática alternativa, a criação de outro tipo de “vazio de machos” no interior do pomar, através da instalação de uma barreira de armadilhas, na margem do pomar, com o objectivo de originar um forte efeito atractivo nos machos, do interior para o exterior do pomar. Este efeito de atracção poderá ser explorado em termos de estratégia de protecção relativamente à cochonilha-algodão aplicando o método de “atração e morte” ou efectuando um tratamento insecticida selectivamente na margem do pomar. Em termos de perspectivas futuras, considera-se importante explorar os seguintes aspectos: 1) aplicação do método em parcelas de maior dimensão; 2) iniciar mais cedo a captura em massa, antes do início do voo dos machos; 3) atracção de machos para as margens do pomar, no início da estação, quando a respectiva densidade ainda é muito baixa, originando um efeito de “vazio de machos” no interior do pomar e, conseqüentemente, reduzindo a taxa de acasalamento.

Palavras-chave: Captura em massa; Feromonas; *Planococcus citri*.

1. Introduction

The citrus mealybug (CM), *Planococcus citri* (Risso) (Hemiptera: Pseudococcidae), is a major pest of citrus in many citrus growing areas. Growers rely upon several pest management tactics to ensure marketable crops in the areas where CM occurs in high densities. By far, the most common tactic to manage CM, when local or acclimatized natural enemies fail to prevent an outbreak, has been the use of organophosphates (OP's). Augmentative releases of mass reared natural enemies (Bartlett, 1978; Kennett *et al.*, 1999) are also practiced to a lesser extent. Biological control of the mealybug is not effective enough to prevent CM outbreaks in the Mediterranean climate (e.g. Mendel *et al.*, 1999).

The reduction of CM population by means of chemical control is problematic. The inefficacy of insecticide treatments, due to the cryptic nature of mealybugs, and the use of non-selective insecticides (e.g., methidathion, cypermethrin) or of certain IGR (e.g., pyriproxyphen) are said to spark off outbreaks of CM (Meyerdirk *et al.*, 1979; Viggiani, 1980; Smith *et al.*, 1988; Bedford, 1997; Hatting & Tate,

1997a, b). Resistance of CM populations to OP's has also been reported in several areas (Panis 1977; Krishnamoorthy, 1990; Peleg & Bar-Zakay, 1995).

The identification and synthesis of the sex pheromone of CM (Bierl-Leonhardt *et al.*, 1981) has opened new management opportunities, exemplified by interference with the mating process. Mass-trapping, mating disruption and lure & kill are tactics envisaged. So far, little research has been done in the matter (see Rotundo *et al.*, 1979).

Mass-trapping has been included among the pest management methods of behavioral manipulation (Foster & Harris, 1997). It is an attract-annihilate tactic. The behavioral manipulation combines a long-distance attractant with a device designed to capture as many individuals of target species as possible and baited with a pheromone or a kairomone. Mass-trapping of insect pests has become a routine management practice in commercial orchards or forests in a rather limited number of cases (Howse *et al.*, 1998). Mating disruption has proved to be the most efficacious management of lepidopteran pests using pheromones. Experience has revealed that mating disruption is not effective when male density is high. Since male density of scale insect is much higher by far than that of fruit moths, we suggest that mass-trapping of males may prove to be a suitable approach for coping with the citrus mealybugs.

The purpose of the present study is to evaluate the efficacy of the mass-trapping of males for the control of CM. We assumed that a "male vacuum" of the CM population in the orchard, during springtime (between March and mid May), when the mealybug population is still at low density (Franco *et al.*, 2000), could be obtained by mass-trapping in order to delay the population build-up and fruit infestation until the recovery of CM natural enemies gets going in mid May (e.g., Mendel *et al.*, 1999).

In recent studies, we have determined the optimal dose of the pheromone baits, have developed lures effective for at least four months and have selected the suitable trap design for mass-trapping of CM (Gross *et al.*, 2001; Suma *et al.*, 2001).

The objectives of the present study were the evaluation of the effect of a preliminary layout of traps for mass-trapping on fruit infestation, and the determination of the effect of male suppression, using these traps, by examining the amount of male capture and mating reduction. Considering the possible contribution of males from the plots adjacent to the treated orchards to the results, we also studied the flight distance of the males.

2. Material and methods

Two mass-trapping experiments were carried out, the first in 2000 and the second in 2001. Each experiment was performed simultaneously in Israel, Italy and

Portugal. A complementary study was conducted in Israel to estimate the flight range of CM males, in order to evaluate the effective attraction distance of the trap.

2.1. Experiment 1

Three treatments, (i) mass-trapping; (ii) insecticide application and (iii) control (untreated), each replicated three times, were conducted in three to four 1-3 ha citrus plots, including sweet orange (Italy and Portugal) and grapefruit (Israel). In each plot, nine subplots (three per treatment) were chosen at random, comprising 12 trees, i.e., four trees in each of three parallel rows. The subplots were situated at a distance of at least 50 m from each other. In order to eliminate the effect of males coming from the surrounding trees on the subplots, all the trees of each plot were treated with chlorpyrifos (0.4%, 48% active ingredient) except those used for mass-trapping as well as of untreated subplots. The insecticide was applied to the canopy in the second half of March, in Israel and Italy, and in the second half of April in Portugal.

For the purpose of mass-trapping, we used 30 cm x 30 cm sticky plates (double face) baited with rubber dispensers (West Co. Pennsylvania, USA) that had been impregnated with 200 µg of the racemic mixture of the CM sex pheromone. A trap was suspended inside the crown of each tree. The traps were activated from late March to May, in Italy and Israel, and from early June to mid July in Portugal, and were replaced by new traps of the same type in the middle of the activation period.

The effect of each treatment was assessed by estimating CM density on fruits. Fruit sampling was carried out in the second half of July. The infestation level of CM on fruits was estimated by checking the number of mealybugs per fruit in five fruits in Italy and Portugal, and six fruits in Israel, all randomly selected in each of four trees in Portugal and Israel and five in Italy, for each subplot.

2.2. Experiment 2

The mass-trapping subplots were compared with controls with four (Portugal) or five (Israel) replicates using the same type of subplots described in experiment 1 and a similar spatial design. Two citrus orchards were selected for the experiment in each country, Israel and Portugal, from those used in experiment 1 (Table 1).

Traps for mass-trapping were exposed from April to July in Portugal and from mid June to July in Israel.

The effect of mass-trapping on the reduction of mating was assessed during two periods of two weeks each by exposing sprouted potatoes infested with virgin females of CM inside the canopy of the central tree of each subplot. The potatoes were introduced in small cages made of cylindrical plastic containers with several circular holes to allow for the male entry. After each exposure period, potato traps

were brought to the lab and the number of the fecundated and unfecundated mealybug females was determined.

The effect of mass-trapping was further evaluated by activating small delta traps (15 cm x 15 cm) baited with 50 µg of pheromone, both inside and outside mass-trapping subplots, in order to compare the amount of male capture.

Finally, the effect of mass-trapping on the infestation level of fruits by CM was assessed at the end of July by fruit sampling. The number of mealybugs per fruit was counted in eight fruits randomly selected in each of six trees per subplot.

Table 1

Location of experimental plots and citrus varieties used

Country	Location	Citrus variety
Italy (Sicily)	Motta S. Anastasia (17 km from Catania)	Moro (Italy 1)
	Scordia (37 Km from Catania)	Tarocco (a red sweet orange variety of local economic relevance) (Italy 2)
	Gelso Bianco (15 Km from Catania)	Moro (Italy 2)
Portugal	Tavira (eastern Algarve)	Navelina (a navel sweet orange variety) (Portugal 1) Navelina (Portugal 2)
	Faro (central Algarve)	Newhall (a navel sweet orange variety) (Portugal 3)
Israel	Matzuba	Star-Ruby (a red grapefruit variety of <i>Citrus paradisi</i>) (Israel 1) Sweetie (<i>Citrus paradisi</i> x <i>Citrus grandis</i>) (Israel 2)
	Mizra (eastern Yzre'el Valley)	Star-Ruby (Israel 3) Sweetie (Israel 4)

2.3. Flight range

The experiment was conducted in the summers of 2001 and 2002 in a red pomelo orchard at Ein Harod Yihud in Izrael Valley. A wooden platform with 20 carton boxes containing about 1000 sprouted potatoes artificially infested with CM, "mealybug centre", was placed in the centre of the plot. The "mealybug centre" contained about 800,000 male pupae of CM. Small delta traps loaded with 50 µg pheromone were placed at increasing distances from the "mealybug centre", between 2 and 100 m, in 2001, and between 5 and 150 m, in 2002, in the four cardinal directions. The traps were placed inside the canopy of the tree nearest to

the point of its presumed location. Six trapping periods of one week each were conducted. The first period occurred before placing the “mealybug centre”, and the last after removal of the mealybugs from the plot. The flight distance and direction was determined by comparing male capture in traps distributed around the “mealybug centre”.

3. Results

3.1. Experiment 1

In Israel, no significant differences were found between the control and the mass-trapping subplots in each of the tested locations, in what concerns mealybug density on fruits (1.1 to 3.7 mealybug/fruit) or proportion of infested fruits (0.39 to 0.78) (Figures 1 and 2). In chlorpyrifos treated subplots, the mealybug density on fruits (0.3 to 0.7 mealybug/fruit) and the proportion of infested fruits (0.15 to 0.24) were significantly lower than those of the other treatments (Figures 1 and 2).

In Italy, two of the three studied orchards presented very low level of the CM infestation. In the infested orchard, both the mealybug density on fruits and the proportion of infested fruits estimated for the control subplots were significantly higher than those of the mass-trapping and the insecticide treated subplots (Figures 1 and 2). No significant differences were found between mass-trapping and insecticide treatments.

In Portugal, the three studied orchards presented considerable differences in the levels of CM infestation (Figures 1 and 2). The mealybug density on fruits ranged between 0 and 10.1 mealybug/fruit, and the proportion of infested fruits between 0 and 0.87. No significant differences were found between treatments in what concerns mealybug density on fruits. However, the proportion of infested fruits in insecticide treated subplots was significantly lower than that of mass-trapping treatment. No substantial differences were found between control and other treatments in respect of proportion of infested fruits (Figures 1 and 2).

3. 2. Experiment 2

Although the male density reduction due to mass-trapping accounts for the reduction in the percentage of CM mated females, a significant difference ($p < 0.05$) between mass-trapping and control subplots was found in Portugal, in late June (Figure 3). In this country, the effect of pheromone treatment was different between the two periods of the experiment. In both studied orchards, the mating success in mid April was slightly, but not significantly ($p > 0.05$), higher on

mass-trapping than on control subplots. The consistency of the results obtained in Israel in both experimental periods is probably due to the closeness of the two periods (late June and early July).

Figure 1

Mealybug density on fruits (mean \pm SE) according to treatment and study area, in the second half of July 2000

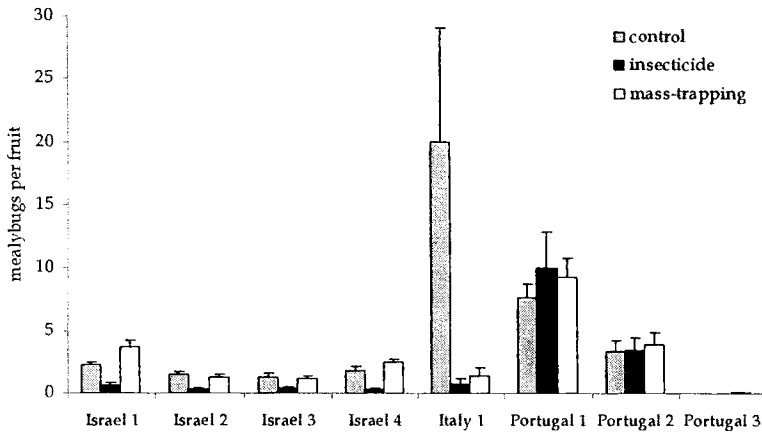
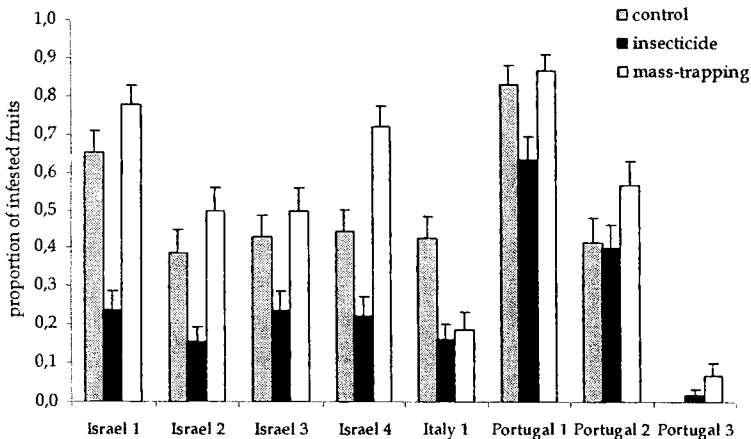


Figure 2

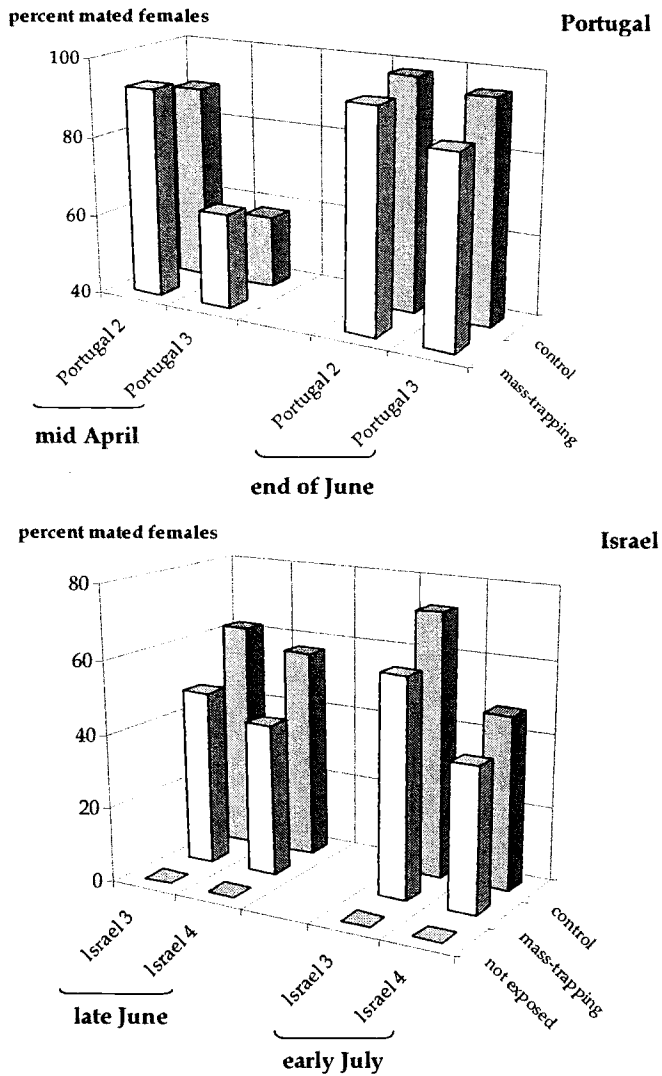
Proportion of mealybug infested fruits (mean \pm SE) according to treatment and study area, in the second half of July 2000



Mass-trapping showed a significant ($p < 0.05$) effect on the capture of CM males with pheromone delta traps. The male capture on traps suspended in the control subplots was three to four times higher than that on traps in mass-trapping treated subplots (Figure 4). The reduction in male capture observed in mass-trapping subplots was evident during whole experimental period (Figure 5).

Figure 3

Mating success of citrus mealybug, estimated by exposing sprouted potatoes infested with virgin females in mass-trapping treated subplots and control subplots, in Israel and Portugal, in 2001

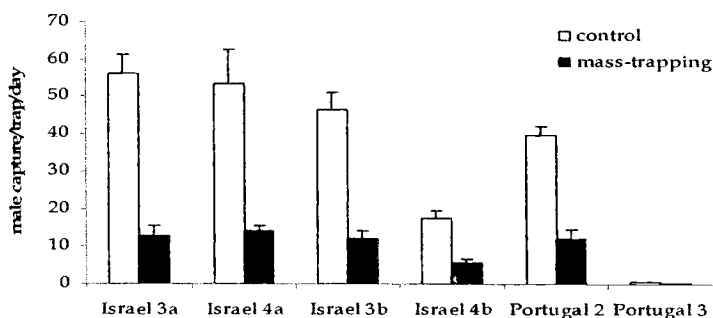


A positive relationship was noticed between the percentage of ovipositing females of CM (from the virgin females on the exposed potato sprouts) in mass-trapping subplots and the male capture on the traps used for mass-trapping (Figure 6). This suggests that a high reduction in mating success should be expected for very low male densities alone, when using a mass-trapping design similar to that adopted in this experiment. From this relationship, it is also clear that CM males may constitute a limiting factor of fertilization rate under certain levels of male activity.

The effect of mass-trapping was also assessed by estimating mealybug density on fruits. In Portugal, mass-trapping subplots presented, in late June, higher mealybug density on fruits than control subplots. However, the difference was not significant (Figure 8). No significant differences were found in late July (Figure 8).

Figure 4

Effect of mass-trapping on citrus mealybug male capture (mean \pm SE), estimated by suspension of pheromone traps in mass-trapping treated subplots and in control subplots. In Israel, the effect was evaluated during the two mass-trapping periods: a- late June; b- early July



3. 3. Flight range

Previous studies (Franco *et al.*, 2001; Gross *et al.*, 2001) suggest that most of the males that were trapped by sticky traps originated from other trees in the grove than that one and the neighbouring trees where the trap is placed. Information on the range of the trap attractiveness, and the flight distance of the male towards a pheromone source constitutes an essential element in the design of the mass-trapping. In the present study, male capture increased more than 50 times one week after the artificial infestation and decreased at least three times one week after the removal, from the orchard, of the infested sprouted potatoes. This means that almost all males trapped during the setting up of the “mealybug centre” originated from that source of mealybugs. From the distribution pattern of the

captures obtained in the first week after the artificial infestation, it becomes clear that some males were attracted from at least 100 m from the centre of the plot (Figure 7).

Figure 5

Comparative trend of male capture of citrus mealybug observed in mass-trapping and control subplots, in two citrus orchards under different mealybug infestation level in Portugal, in 2001 (Portugal 2- medium density; Portugal 3 – low density)

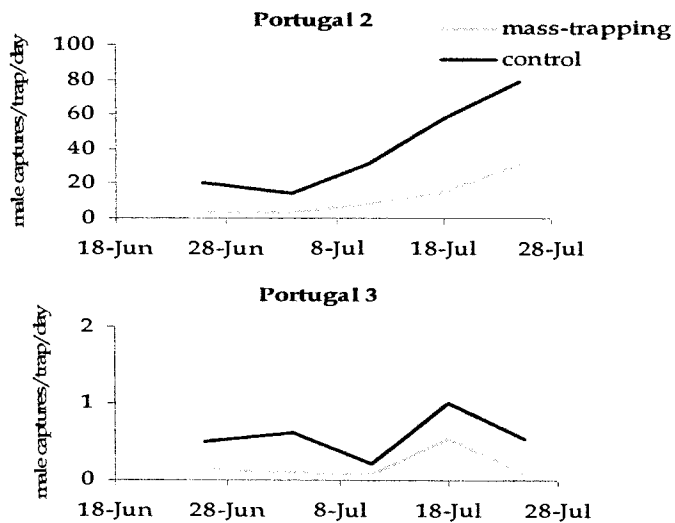


Figure 6

Relationship between the level of male density (average male capture) and mating success in citrus mealybug (percentage of ovipositing females) determined in Portugal, 2001

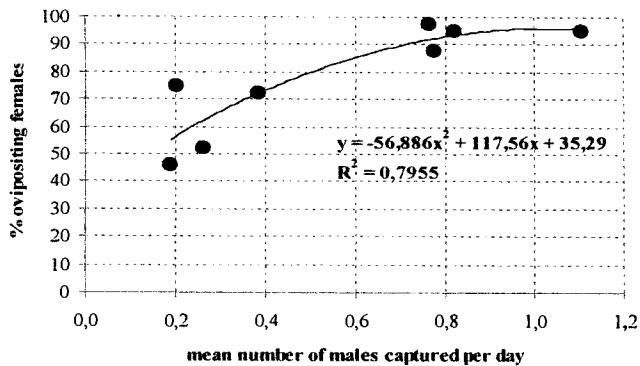


Figure 7

Pattern of male capture of citrus mealybug as related to time and distance from the artificial source of males ("mealybug center") in Israel in 2001 and 2002

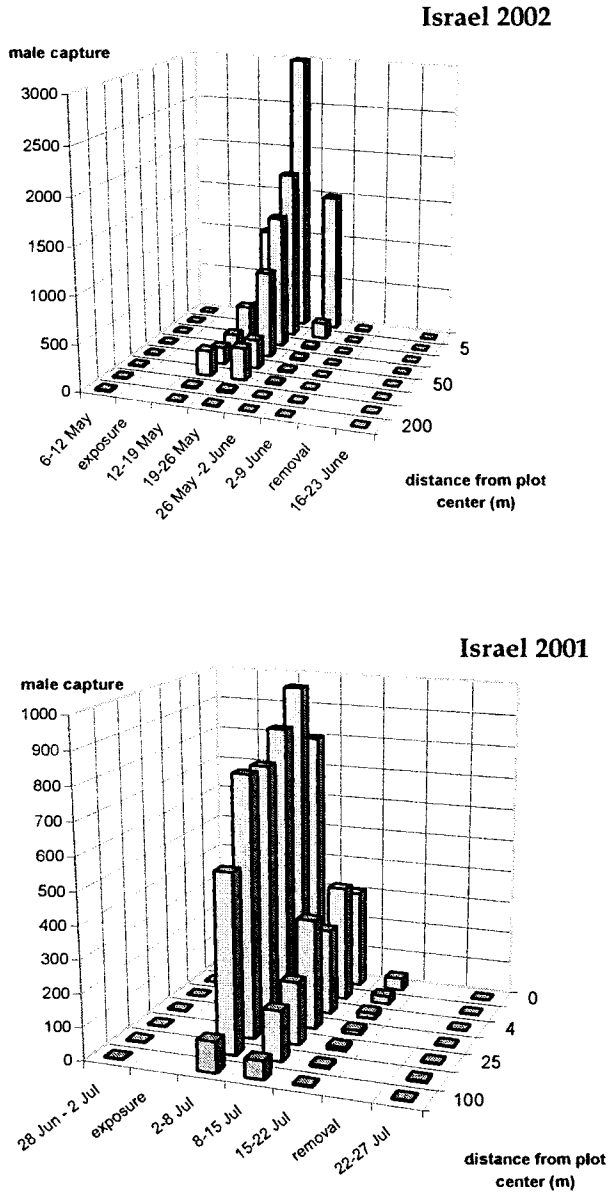
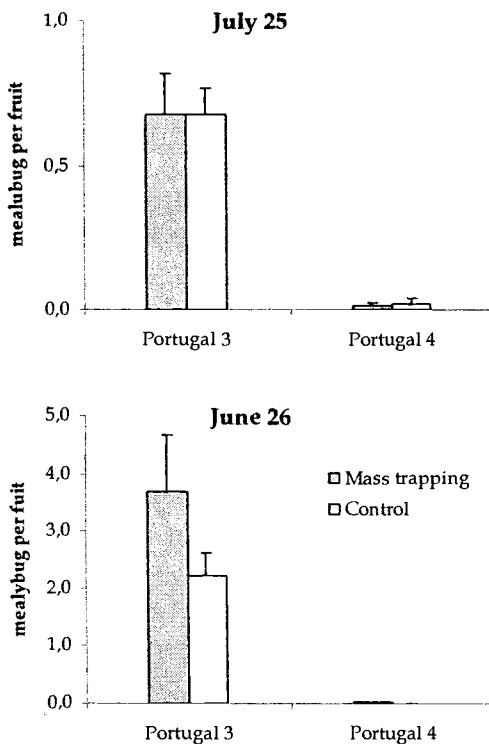


Figure 8

Effect of mass-trapping on the density of citrus mealybug on fruits (Portugal, 2001)



4. Discussion

In experiment 1, the generalized chemical treatment was not sufficiently effective to reduce the mealybug density as expected. Male activity was relatively high in what was supposed to be a buffer zone between treatments. Nevertheless, a conclusion can be drawn that the pheromone trapping system was not sufficient in most cases to suppress the number of males. We assume that a large number of males came from trees surrounding the subplot. Despite the fact that no significant differences had been found, it is interesting to note that the proportion of infested fruits by the CM was consistently (seven out of eight experimental plots) higher in

mass-trapping than that in control subplots (Figure 2). Our findings suggest that mass-trapping may serve as a limiting factor of fertilisation during certain periods of the year (e.g., in the spring), when CM density is usually very low. The relationship observed in experiment 2 between the percentage of ovipositing females and the male capture (Figure 6), confirms this assumption. However, the mass-trapping effect was lessened by males attracted from outside the subplots, which may have contributed to increase the percentage of fecundated females, raising the infestation level. The results from the flight range experiment clearly showed that males of CM can be attracted from a distance of at least 100 m from the pheromone trap (Figure 7). It has been shown in other pest species that despite the high efficiency (at least 95%) of insect recruitment to the odour plumes emanating from traps, followed by an orientation up the plume to within 0.5 m of the source, many trapping systems are inherently inefficient concerning captures as low as 0.4% to 8.7% (Howse *et al.*, 1998).

The results of experiment 2 suggest that a significant reduction of males in the treated plots can be achieved by mass-trapping (Figure 4 and 5). However, the extent of male reduction was not enough to significantly decrease fruit infestation (Figure 8). The higher level of mating observed early in the spring (Figure 3), when the mealybug density is usually very low, suggests that mass-trapping subplots produced a strong attraction effect on males from outside the subplots. The positive relationship observed between the percentage of ovipositing females and the male capture (Figure 6) further confirms the existence of an attraction effect.

Based on the findings from experiment 1 and 2, we can postulate that another kind of "male vacuum" may be obtained inside an orchard by creating a strong attraction effect on the edge of the plot. This may eventually be explored for management purposes by using attract-annihilate tactics combined. Otherwise this can be done with chemical interventions selectively applied at the edge of the orchard, in order to control the expected build up of the CM population on the edges of the orchard. Further improvements are considered necessary with the emphasis on: 1) application of the method in much larger plots; 2) starting mass-trapping early in the season before the beginning of the male flight; 3) attraction of males to the edges of the orchard early in the season, when male population is usually low, bringing about a "male vacuum" inside the plot that may result in a significant reduction of matting.

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