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Efficiency of optimal pheromone trap density in management of red palm weevil, *Rhynchophorus ferrugineus* Olivier

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The red palm weevil (RPW), *Rhynchophorus ferrugineus* Olivier is an invasive, hidden pest of date palms causing significant economic losses in Middle East. Mass trapping of weevils with synthetic male aggregation pheromone and food baited traps has been an important component of Integrated Pest Management (IPM) program against RPW. As the viability of pheromone trapping system depends on the optimum trapping density, field experiments were conducted in two locations of Eastern Province of Saudi Arabia. The efficiency of four pheromone trap densities viz., 1, 2, 4 and 8 traps/4 ha, were evaluated using the Standard Saudi Trap. In Al Hassa experiment, the treatment with 1 trap / 4ha captured an average 10.0 weevils as compared to 61.5 weevils in 8 traps / 4 ha, while at Al Qatif experiment an average of 5.0 and 49.8 weevils were captured in 1 trap and 8 traps / 4 ha respectively in 10 weeks indicating the superiority of high density trapping. Although RPW adults are strong fliers, these experiments showed that more traps per unit are necessary to capture the resident adults in a shorter period of time. Hence, our studies provide information for optimizing trap density for mass trapping program.

Key words: Red palm weevil, *Rhynchophorus ferrugineus,* pheromone, trap density, date palm.

INTRODUCTION

The red palm weevil (RPW), *Rhynchophorus ferrugineus* Olivier, is the most dangerous pest of date palm (*Phoenix dactylifera*) in Middle East region responsible for the death of a large number of palms and consequent yield losses (Abozuhairah et al., 1996; Abraham et al., 1998). It was reported as a serious invasive pest of Canary Island date palm in Europe from the year 1996 and continues to remain a serious threat even today

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(Barranco et al., 1996; Esteban-Durán et al., 1998; Ferry and Gómez, 2002; Haddad, 2009). More recently *R. ferrugineus* has been reported for the first time in the year 2010 from a location in Orange County, California, USA (CDFA, 2011). The larvae of RPW bore in to the stem tissues of a palm to complete the life cycle. Upon emergence the adults fly out and infest new palms or remain in the same palm and cause re-infestations at a new site on the same palm (Nirula, 1956; Esteban-Durán et al., 1998). Since the destructive stage is hidden inside the palm stem tissue, it is difficult to administer an appropriate control method (Abraham et al., 1998; Murphy and Briscoe, 1999). Among recent works an improved instrumentation and signal analysis software were described for early detection of RPW larval stages in groves and greenhouses (Mankin, 2011).

For the most effective management of this pest, integrated pest management (IPM) developed earlier was applied in most of the Gulf countries. As an important module of IPM program, the Agriculture Ministry of Saudi Arabia has been organizing the mass trapping of RPW for over 15 years (Abraham et al., 1998; Faleiro, 2006). Recent researches have also been focusing on finding environment friendly natural products as alternatives for the management of *R. ferrugineus*.

The male aggregation pheromone of *R. ferrugineus* was identified as 4-methyl-5-nonanol and 4-methyl-5-nonanone by Hallett et al. (1993) and soon commercial formulations were available for monitoring or mass trapping. The pheromone components 4-methyl-5-nonanol and 4-methyl-5-nonanone in the ratio of 9:1 was found to be effective for attracting both male and female adults of RPW (Hallet et al., 1999; Abozuhairah et al., 1996). Pheromone trapping of adult palm weevils was used to capture and kill the insect to reduce the insect populations in the field (Oehlschlager et al., 1993; Abraham et al., 1998; Vidyasagar et al., 2000). The aggregation pheromones have high potential in the management of palm weevils especially the American palm weevil, *Rhynchophorus palmarum* and *R. ferrugineus* as it attracts both males and females (Rochat et al., 1991; Oehlschlager et al., 1993; Giblin-Davis et al., 1996; Hallett et al., 1999). The trapping methods are also advantageous as they are efficient in attracting a much higher percentage of females in comparison to males and this kind of pheromone based system helps in further reducing progenies (Vidyasagar et al., 2000;Faleiro et al., 2002; Soroker et al., 2005). However, the trap requires addition of food bait and pesticide to kill the attracted weevils. Most studies have not been transferred to the field. Moreover, for the success of IPM it is necessary to know the optimum number of traps for a specific unit area.

In the present investigations, large scale field studies to find solutions for optimization of trap density have been conducted. This study will help in revising the present trapping methods for area-wide trapping of red palm weevil not only in Saudi Arabia but also in the entire Middle East region. It attempts to find a more efficient way of augmenting weevil capture in a unit area within a shorter period of time by testing variable number of traps. For this purpose, a field experiment with variable number of trap densities was designed and conducted it in two locations. These studies are planned to provide answers regarding the optimum density of traps for mass pheromone trapping program of *R. ferrugineus*.

MATERIALS AND METHODS

The field experiments were conducted in Al Hassa (25° 23' 24" N latitude, 49° 35' 5" E longitude) and Al Qatif (26° 34' 36"N latitude, 49° 59' 9"E longitude) regions of Eastern Province of Saudi Arabia in the year 2010 during early summer months. In each location several date farms were selected for setting up traps based on the experimental design. A careful choice was made to ensure the weevil capture rates in all these farms were more or less uniform prior to the start of field trials. Before the start of each experiment, regular trapping was discontinued for about one week to avoid any population changes due to emerging adults. The trap density experiment was organized for 10 weeks.

Al Hassa

The first experiment was organized in Al Hassa in Eastern Province of Saudi Arabia. This region has more than three million date palms and produces the finest date fruits in Saudi Arabia. The experiment was conducted with a randomized block design (RBD) having 4 treatments and 10 replications (Figure 1). For each treatment a block of 4 ha of date farm was selected and all treatments in each replication were in one continuous area. The distance between replications was kept at more than 200 m to avoid interaction. Standard Saudi Trap described in detail below was used in this trial. At this location date fruits were used as food bait in traps. The four treatments imposed were one trap per 4 ha; two traps per 4 ha; four traps per 4 ha; and eight traps per 4 ha. Total area under this field experiment was about 160 ha with about 16,000 palm trees.

Al Qatif

The second trial was conducted in Al Qatif in the Eastern Province of Saudi Arabia. This region has about one million date palms and the infestations by RPW were first reported from this region. We followed RBD with four treatments and 8 replications as in Figure 1. The pheromone trap used was also of the same design and lure except that the food bait used at this center was freshly cut date stem pieces in place of date fruits. According to the spacing of palms and replications, the total area under the field experiment was about 120 ha accommodating approximately a palm population of 12,000.

Standard Saudi Trap

The Standard Saudi Trap was prepared by making four square holes in the top half of the 6 L plastic buckets. The buckets were wrapped with jute cloth keeping 4 holes open. The pheromone lures used in this study were the Ferrolure+ (with composition of 4-methyl-5-nonanol and 4-methyl-5-nonanone in 9:1 ratio and purity of 98%) manufactured by ChemTica International, Costa Rica. Each lure contained approximately 600 mg of the lure in a bubble

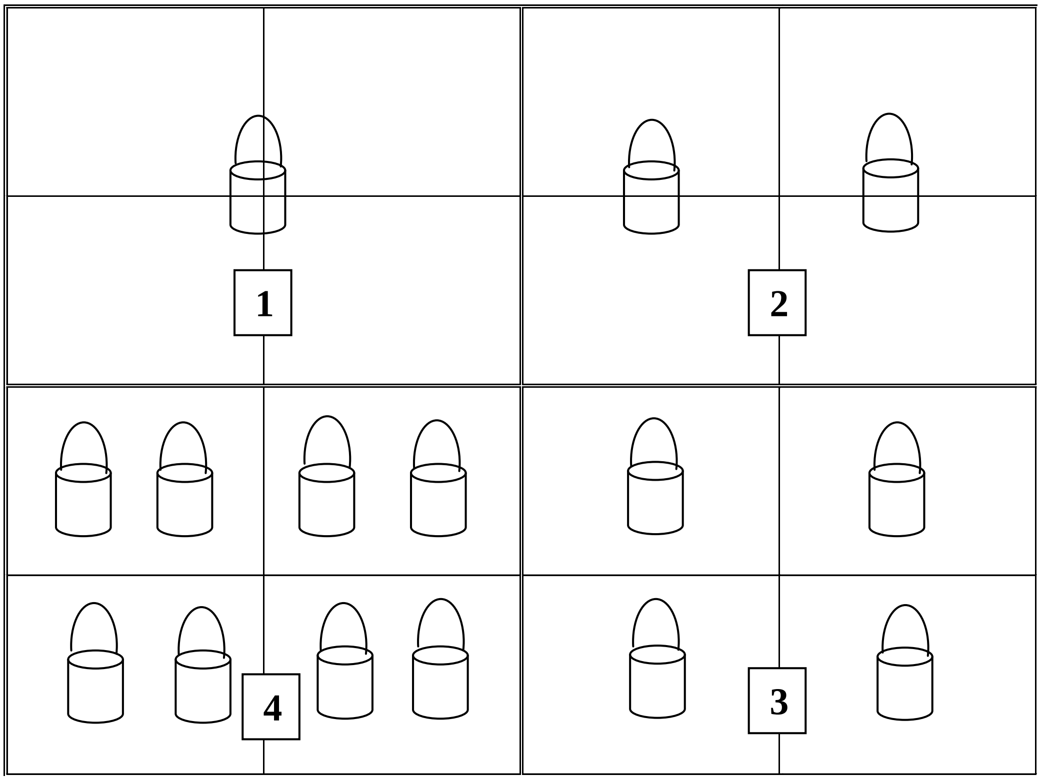


Figure 1. Diagram showing the schematic distribution of Standard Saudi Traps under trap density experiment. Each block of four squares represents four hectares. Treatments are 1. 1 trap/4 ha, 2.2 traps/4 ha, 3. 4 traps/4 ha and 4. 8 traps/4 ha.

formulation. One lure was attached to the lid of bucket from inside and bottom of the bucket was filled with 200 g of ripe date fruits and about 2 L of water. The food baited pheromone traps were mixed with pesticide carbaryl 10 WP 2g per trap to kill the attracted insects.

Weekly servicing and data collection

All the traps were examined every week and RPW adults captured in each trap were recorded in both the experiments. After removing dead insects all traps were replenished with fresh date fruits/stem pieces, water and pesticide. The Ferrolure+ sachets were replaced with new ones in all traps after six weeks to eliminate any differences in available pheromone.

Statistical analysis

The data collected every week at weekly interval for 10 weeks from two locations were subjected to statistical analysis of (one factor) One-Way ANOVA. Both experiments were statistically analyzed with Opstat software available online at CCS, Haryana Agricultural University, Hissar 125 004, India (website: www.hau.ernet.in). The values are presented in the form of table / figures and interpreted according to significance under results for each of the locations.

RESULTS

Generally the efficiency of pheromone trapping was correlated to the number of weevils captured in each trap for a specific period of time. However, in the case of trap density, it was very important to take in to account the total number of weevils trapped in a unit area with variable number of traps. The data were collected at weekly intervals for 10 weeks and statistically analyzed.

Figure 2A and B illustrates the results on the adult weevils captured in the trapping density experiment in Al Hassa region. Results indicated that the treatment comprising 8 traps / 4 ha captured higher number of adults than all other treatments. The treatments with 4 and 8 traps / 4 ha at weeks 1, 2, 3, 6, 8 and 9 were not significantly different in captured number of adults. Moreover, treatments with 1, 2 and 4 traps / 4 ha were not significantly different in adult catches through the study period.

Figure 3A and B show the results on the adult weevils caught in the trapping density field experiment at Al Qatif location. It showed that the treatment comprising of 8 traps / 4 ha trapped significantly higher number of adults in weeks 1, 3, 7 and 10 than all other treatments but were not significantly different than the treatment 4 traps / 4 ha in other weeks. Also the treatments with 1, 2, and 4 traps/ha were not significantly different in captured number of weevils in the weeks 1, 3, 7 and 10.

Table 1 indicates the mean number of captured weevils / trap / week for 10 weeks in different trap densities at

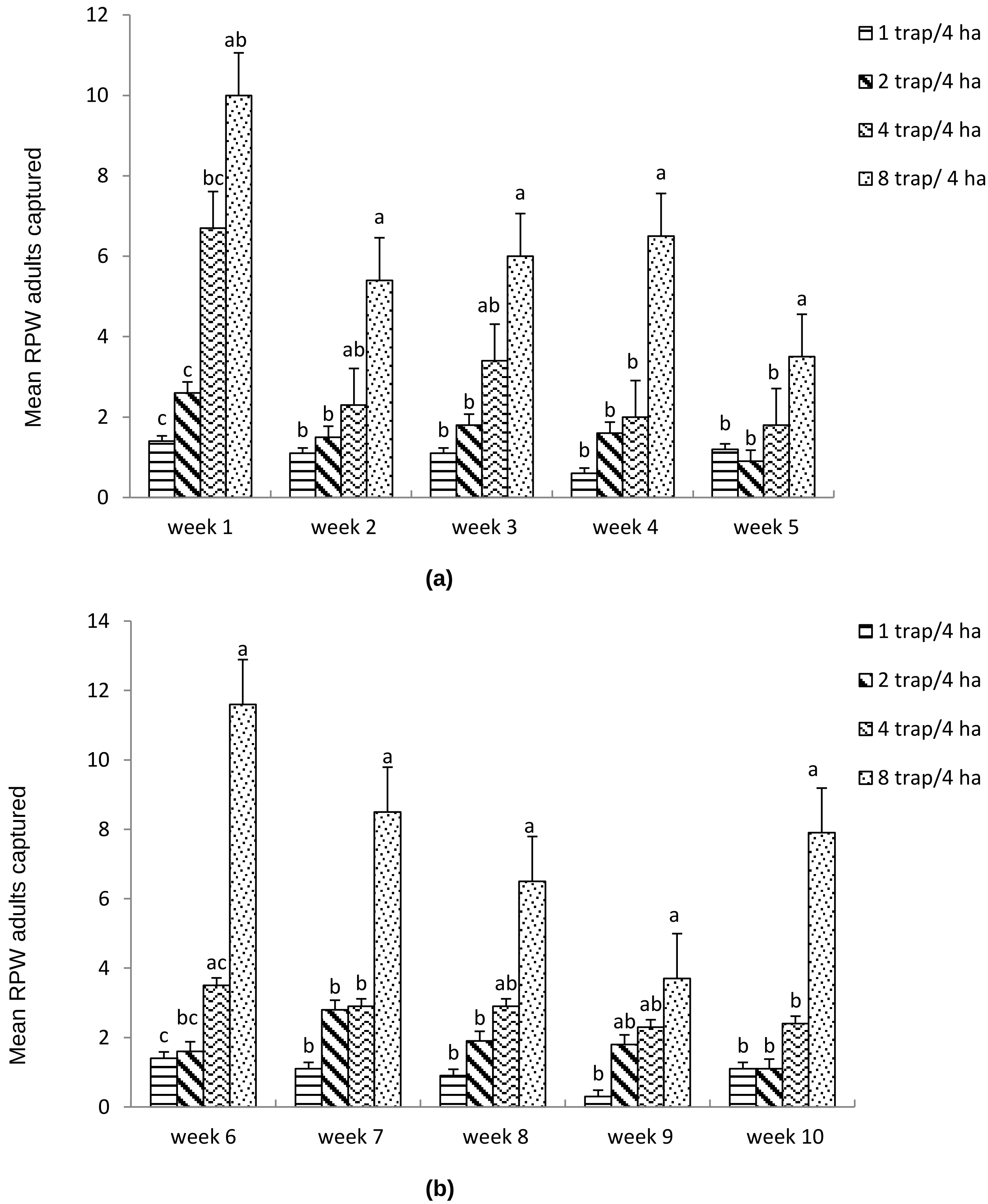
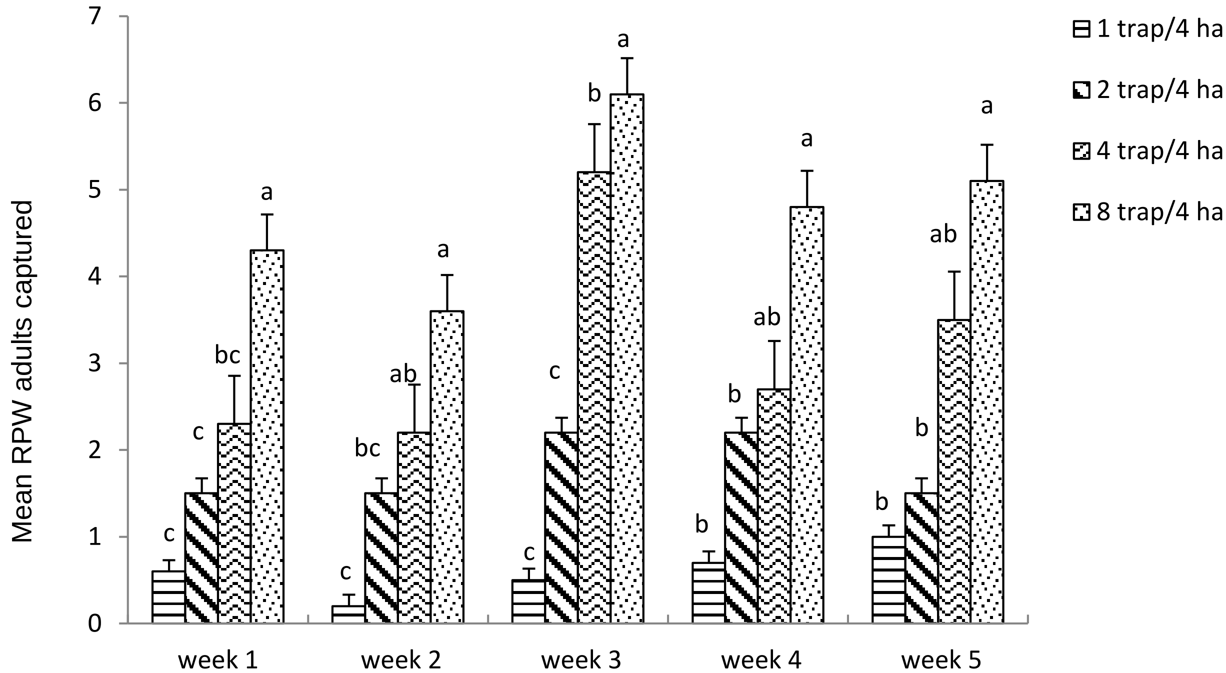
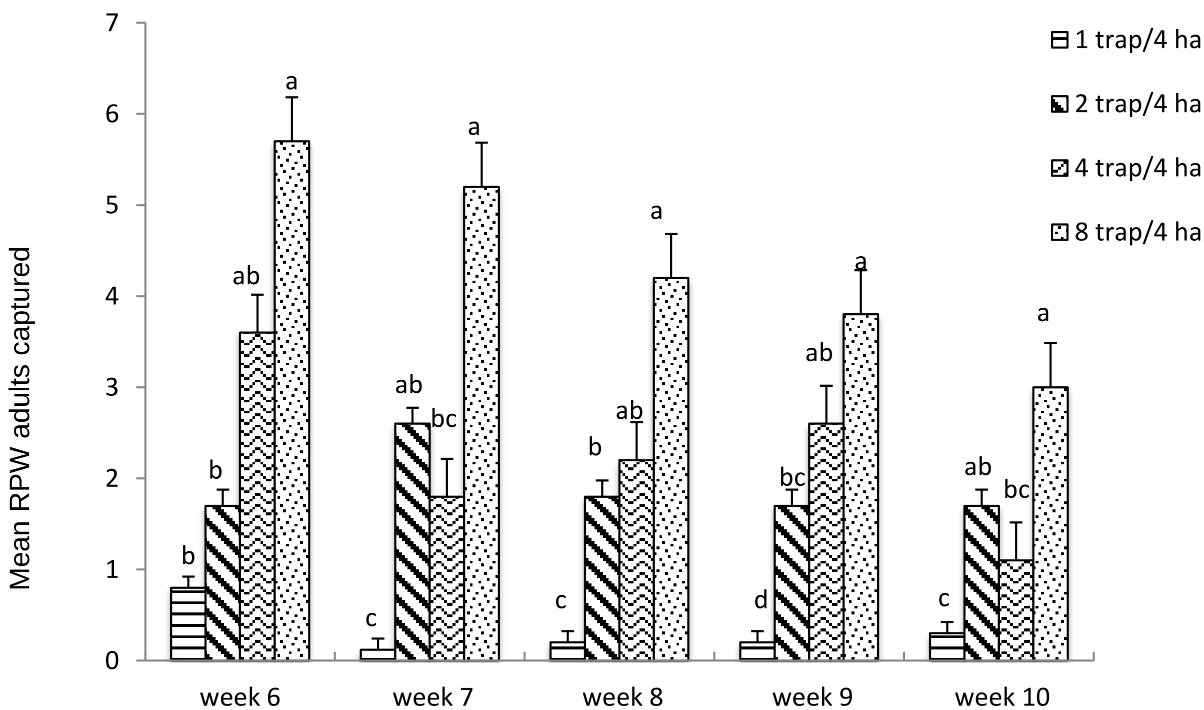


Figure 2. Mean numbers of adult *R. ferrugineus* (RPW)captured in one unit area of 4 ha with different trap densities from **(a)** 1-5 weeks in Al Hassa. One-way ANOVA. (i) Week 1. , P = 0.000076; CD 3.490; SE(m) 1.196;(ii)week 2 P = 0.028782; CD 3.036; SE(m) 1.041; (iii) week 3 P = 0.000499; CD 2.220; SE(m) 0.761; (iv)week 4 P= 0.009723; CD 3.478; SE(m) 1.192; week 5 (v)P = 0.001772; CD 1.323; SE(m) 0.453, and **(b)** 6-10 weeks in Al Hassa. One-way ANOVA. (vi) week 6 P= 0.00287; CD 2.255; SE(m) 0.773; (vii) week 7P= 0.002693; CD 3.818; SE(m) 1.309; (viii)week 8 P = 0.001016; CD 2.644; SE(m) 0.906; (ix)week 9 P= 0.048798; CD 2.370; SE(m) 0.812; (x) week 10 P= 0.00957; CD 4.387; SE(m) 1.504. Higher trap numbers caught significantly more weevils. Bars labelled with same letters are not significantly different (P < 0.05). Standard errors are indicated.



(a)



(b)

Figure 3. Mean numbers of adult*R. ferrugineus* (RPW)captured in one unit area of 4ha with different trap densities in **(a)** 1-5 weeks in Al Qatif One-way ANOVA (i) Week 1P= 0.000022; CD 2.187; SE(m) 0.739. (ii)Week 2 P= 0.006449; CD 1.797; SE(m) 0.607; (iii) Week 3P= 0.000022; CD 2.187; SE(m) 0.739; (iv) Week 4 P= 0.003595; CD 2.036; SE(m) 0.688; (v) Week 5 P= 0.015488; CD 2.619; SE(m) 0.884 and **(b)** 6-10 weeks in Al Qatif One-way ANOVA (vi) Week 6 P= 0.037036; CD 3.478; SE(m) 1.175; (vii) Week 7P = 0.00076; CD 2.444; SE(m) 0.838; (viii) Week 8 P = 0.016226; CD 2.345; SE(m) 0.792; (ix) Week 9 P= 0.000203; CD 1.394;SE(m) 0.471; (x) Week 10 P= 0.005438; CD 1.387; SE(m) 0.469. Bars labelled with same letters are not significantly different (P < 0.05). Standard errors are indicated.

Table 1. Mean of captured weevils / trap / week for 10 weeks in different trap densities at Al Hassa and Al Qatif locations.

Location	Treatments	Weevils captured / Trap / Week									
		1	2	3	4	5	6	7	8	9	10
Al Hassa	1 Trap/4 ha	1.4	1.1	1.1	0.6	1.2	1.2	1.1	0.9	0.3	1.1
	2 Traps/4 ha	1.3	0.8	0.9	0.8	0.5	0.5	1.4	1.0	0.9	0.6
	4 Traps/4 ha	1.7	0.6	0.9	0.5	0.5	0.5	0.7	0.7	0.6	0.6
	8 Traps/4 ha	1.3	0.7	0.8	0.8	0.4	0.4	1.0	0.8	0.5	1.0
Al Qatif	1 Trap/4 ha	0.5	0.2	0.5	0.7	1	0.8	0.1	0.2	0.2	0.3
	2 Traps/4 ha	1.1	0.8	1.1	1.1	0.8	0.9	1.3	0.9	0.9	0.9
	4 Traps/4 ha	1.3	0.6	1.3	0.8	0.9	0.9	0.5	0.6	0.7	0.3
	8 Traps/4 ha	0.8	0.5	0.8	0.6	0.6	0.7	0.7	0.5	0.5	0.4

Al Hassa and Al Qatif locations. The mean number of captured weevils in Al Hassa with 8 traps / ha in 10 weeks was 61.6 weevils as compared to 10, 17.4 and 30.8 weevils in treatments 1, 2 and 4 traps / 4 ha respectively. Whereas the mean number of weevils caught in Al Qatif location with 8 traps / 4 ha was 48.8 weevils when compared with 4.5, 19.6 and 31.6 weevils in treatments with 1, 2 and 4 traps / 4 ha respectively.

In 10 weeks duration the 4 ha area with 8 traps on average captured 61.5 weevils whereas, treatments with 1, 2, and 4 traps / 4 ha trapped only 10, 16.9 and 28.5 weevils respectively. Overall best per unit area capture rates were recorded in high density trapping with 8 traps / 4 ha in all weeks and trap density of 4 traps / 4 ha was superior only to treatments with lower trap densities. The statistical values of each week are given in the legends of the corresponding graphs.

DISCUSSION

The studies carried out in Saudi Arabia during mid-nineties with mass pheromone trapping gave positive results in reducing the infestation levels in date farms (Abozuhairah et al., 1996). Abraham et al. (1998) described various methods under IPM for the management of this pest including surveillance and trapping of weevils with pheromone lures. Though mass trapping of RPW was an important component of IPM in Saudi Arabia, the trapping density was not followed systematically and was based on the ease of servicing regularly (Vidyasagar et al., 2000).

Our studies on trap density revealed that 8 traps / 4 ha of area were necessary to capture the maximum number of adults. For example in Al Hassa region the highest density of 8 traps attracted 61.5 weevils in 4 ha area in 10 weeks duration as compared to just 10.0 weevils captured in lowest density of 1 trap treatment during the same period. Similar results were obtained in Al Qatif region as well with 4 traps and 8 traps / 4 ha capturing an average of 28.75 and 49.88 weevils respectively in 10 weeks, suggesting the efficacy of higher density of traps. It was interesting to note that when comparison was made on the weevil capture rate per trap, lower density traps caught numerically more number of weevils than in higher density. But the overall performance of the higher density traps of 4 and 8 traps per 4 ha was much better than other treatments.

By using pheromone trapping in three date palm farms of UAE during 2000 and 2001, the populations of RPW was reduced by 29.7-51.7% (Abbas et al., 2002). Their studies also reported that insect populations peaked in March, April or May months and the marked weevils migrated 1-7 km from the release site and were recaptured within 3-5 days of release. A few trapping studies on RPW in date farms of India were conducted with ferrugineol as pheromone lure and different food baits for their preference (Muralidharan et al., 1999). For monitoring the presence and distribution of the pest the pheromone traps were used in the same study (Martorana, 2008).

The results from *R. palmarum* trapping experiments showed that peripheral traps were not effective in reducing adult weevil populations in oil palm plantations of Costa Rica (Oehlschlager et al., 1993). But, Jayanth et al. (2007) used indigenously synthesized pheromone for mass trapping studies in coconut plantations in South India for 10 months and reported that peripheral traps caught more adults especially in the south and south-eastern directions.

The studies conducted in Israel tested the density parameters up to 10 traps per hectare which was fairly high and required efficient management (Soroker et al., 2005). Their field trials were organized for monitoring with 1 trap per 3 ha in 2200 ha area and mass trapping with 5000 traps @ of 10 traps per ha in an area of 450 ha at 10 regions in Israel. A total of 600 weevils only were caught in five years and ~20% traps only captured weevils suggesting very low weevil populations. These studies had not thrown much light on the trap density for improved trapping of weevils but suggested the usefulness of mass trapping. Hence, one has to consider the practical application of such large number of traps per unit area in relation to the number of palms in a country and the area covered.

Studies on mass trapping of *R. palmarum* conducted in mid-nineties in Costa Rica gave good results with one trap per 5 ha in oil palm plantations (Oehlschlager et al., 1995). But the same density of trapping when followed in the Middle East region appears to have not given the same level of RPW population reduction. In a field study out of two trap densities of 1 and 2 pherolure traps per 5 acres tested, the pherolure traps @ 1 trap/5 acres gave better results (Jose et al., 2008).

A total of 2,252 pheromone traps were used in the mass trapping system in an area of more than 10,000 ha Al Qatif region in Eastern Province of Saudi Arabia (Vidyasagar et al., 2000). They reported that from an initial level of 4.12 weevils per trap per week in 1994, the adult population was reduced to 2.02 weevils per trap per week at the end of 1997.

In an endemic area of RPW infestation, the higher trap density is needed to reduce insect population in a much shorter time frame. It may be suggested to increase the trap numbers sufficiently to remove higher numbers of weevils rapidly to reduce the risk of new and re-infestations. Consideration should also be given about the pheromone dispersal, infestation levels, available resources and logistics before embarking on a plan to increase the number of traps in a given region. Therefore, in our studies presented in this paper we have tested up to 8 traps as the maximum per 4 ha area, because of the above mentioned reasons.

Faleiro et al. (2011) suggested the use of 4-7 traps / ha, where the infestation levels were >1%, and 1 trap / ha in farms with <1% infestation. However, their studies were based on data from one region and the experimental fields were also smaller. But our studies were conducted in very large experimental plots, representing two important regions namely Al Hassa and Al Qatif with high and low weevil populations respectively. Moreover, these two areas where we organized the study were the regions with earliest report of RPW infestations in Saudi Arabia, and despite regular area-wide trapping with Standard Saudi Trap for more than a decade, the insect populations still remain high. Hence, this investigation provides information for mass pheromone trapping of RPW in Saudi Arabia.

From our studies it was clear that by raising the number of pheromone traps per unit area, the number of trapped weevils could be drastically increased as compared to a sparsely distributed trapping system. The current practice of mass pheromone trapping appears to be inadequate in reducing the resident population of adult RPW in date palm farms.

Conclusion

This study revealed that trap density of 8 traps / 4 ha, or in other words 2 traps / ha is necessary to optimize the capture rate and drastically reduce weevil population and new infestations. There is a need to break the equilibrium between the emerging adult weevils that add to the resident population and the capture rates, so as to achieve satisfactory results in IPM program. The results from the study will help in revision of protocols for area-wide mass trapping and their integration in the management of RPW in Middle East.

Conflict of interests

The authors have not declared any conflict of interests.

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