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Evidence that mass trapping suppresses pink bollworm populations in cotton fields

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Abstract

Mass trapping was used to control pink bollworm (PBW), *Pectinophora gossypiella* (Saunders) (Lepidoptera: Gelechiidae), populations in cotton fields in Brazil. Oil traps containing lures with a high dose of pheromone, installed at a density of 20 traps per ha soon after the occurrence of the first cotton fruits (or bolls), suppressed PBW populations below detection levels using Delta traps and manual examination of 100 green cotton bolls per ha. Pheromone sources of 0.2 g (approximately 150 NoMate® fibers) were effective in attracting PBW male moths to oil traps for at least three weeks. Trap captures showed that PBW males located the *high concentration* pheromone plumes, oriented upwind, and landed on or inside the traps. The long life of the pheromone sources and the long lasting viscosity of the oil surface ensured low trap maintenance, thus rendering mass trapping viable as an alternative technique for the control of *P. gossypiella* populations in commercial cotton fields. We discuss probable mechanisms promoting suppression of PBW populations in fields with mass trapping control.

Introduction

The pink bollworm (PBW), *Pectinophora gossypiella* (Saunders) (Lepidoptera: Gelechiidae), sex pheromone gossyplure is a 1:1 mixture of (*Z,Z*)- and (*Z,E*)-7,11-hexadecadienyl acetates (Hummel et al., 1973). Gossyplure has been used successfully to suppress PBW populations in commercial cotton fields by disrupting chemical communication among the adult moths (Gaston et al., 1977; Brooks et al., 1979; Henneberry et al., 1981; Baker et al., 1990) and in part by attracting males to surfaces containing contact insecticide (Conlee & Staten, 1981). Several formulations of gossyplure are commercially available: hollow fibers (e.g., Doane & Brooks, 1981), flakes (e.g., Henneberry et al., 1981), microencapsulated formulations (e.g., Critchley et al., 1983; Flint & Merkle, 1984), and twist-on ropes (e.g., Flint et al., 1985; Staten et al., 1987).

Although disruption of sex chemical communication is frequently used to control PBW in the Southwestern USA (Baker et al., 1990), it is seldom used in other cotton growing areas of the world (Campion et al., 1989). Among the many reasons for the apparent reluctance to use pheromone in the control of PBW are that mating disruption requires intensive monitoring of the moth population and that the area to be controlled must be semi-isolated. In addition, field applications of gossyplure are relatively expensive, and with the exception of the rope formulation, depend on proprietary equipment which may not be readily available. Furthermore, to achieve population control levels, several applications of pheromone are usually necessary during a growing season.

Although mass trapping was among the first techniques conceived to suppress populations of lepidopteran pests using pheromone (e.g., Roelofs et al., 1970), it has been only marginally pursued, and practically dismissed as a reliable form of pest control. Mass trapping is not used in the USA to control PBW because of the high cost and dependence on manual labor to install and maintain traps, and because it ineffectively controlled PBW populations during initial trials.

Much of the world's cotton is cultivated in regions where manual labor is readily available, and relatively inexpensive. Since integrated pest management (IPM) in cotton has become more universal (Campion et al., 1989), effective, selective pest control techniques that have low impact on beneficial insect populations are in increasing demand. Mass trapping using sex pheromones as baits has the potential to become an ideal IPM tool to control PBW, one of the most important direct pests of cotton. Here we report the results of a mass trapping program that successfully reduced PBW populations in semi-isolated cotton fields in São Paulo, Brazil.

Materials and methods

Cotton fields. The experimental area of 2 ha, located at Fazenda Hoechst, Cosmópolis, São Paulo, Brazil, was subdivided into four fields (Figure 2). Field I (1 ha) was submitted to an IPM program (Table 1). Field IIa (0.3 ha) and Field IIb (0.3 ha) were separated from each other by 0.3 ha peanut field. Field IIa was treated with pesticides during the early part of the season (Table 1). Field IIb did not receive any pesticide application (Table 1). Field III (0.4 ha), separated from the other cotton fields by a small dirt road and a 1 ha soybean field, was treated with pesticides throughout the cotton growing season (Table 1). Cotton seeds (*Gossypium hirsutum* – var. IAC 20) were planted on October 13 in Fields I, IIa and IIb, and on October 27 in Field III. Phenology of cotton plants (height, number of leaves, reproductive organs, damage, and fauna associated) was monitored weekly by examination of 200 randomly chosen plants per ha.

The study area was isolated from other cotton fields by at least 10 km. However, gardens and small fields with okra, *Hibiscus esculentum*, a secondary host of PBW, were scattered throughout the region. One such field, sustaining PBW populations, was located ca. 500 m north of the experimental area.

Oil traps. The sturdy, weather-resistant traps used in this mass trapping program (Figure 1) were built from empty motor oil cans (one liter volume, 20 cm height, 12 cm diam) in which three triangular holes (5 × 5 × 5 cm) located at the midline of the cylinder height provided the entrance for moths. Moths that entered the can could become trapped on the viscous oil surface (100 to 200 ml used car oil) at the bottom of the can. Used car oil proved to be a long lasting and efficient adhesive for moths, requiring little maintenance throughout the cotton growing season, when compared with other sticky surfaces (Mafra-Neto, 1988). Oil traps were installed on bamboo stakes, 20 cm above the canopy of the plants, at a density of 20 traps per ha.

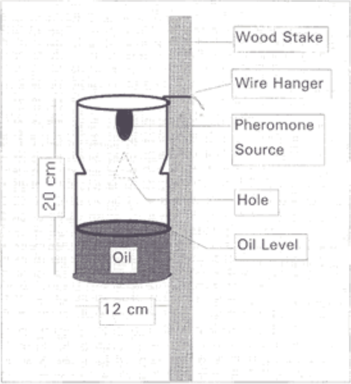

Figure 1. Non-saturating oil trap with pheromone lure for mass trapping programs. Oil traps were manufactured using empty oil cans, which received 0.1 to 0.2 l of car oil. A source of pheromone, inserted through one of the two punctures used to pour the car oil, was held in place by a wire tied to the wood stake supporting the trap. Three holes were cut on the side of the oil can, 10 cm from the top in order to allow moths to enter the trap. Oil traps were placed in the field, tied to a wood stake 20 cm above the plant canopy. Male moths attracted to the pheromone source enter the oil can, eventually getting trapped on the viscous surface of the oil.

Each oil trap had a pheromone source consisting of 0.2 g NoMate® fibers (ca. 150 fibers) wrapped in two layers of cotton gauze. The pheromone source was easily slid into the can through one of the holes on the top of the oil can (one of the two holes punctured to pour the oil). The pheromone source was held in place by a piece of wire tied to the bamboo stake. A NoMate® hollow fiber has approximately 260 μg gossyplure, therefore, each oil trap had ca. 39 mg active ingredient (A.I.) of pheromone. Thus oil traps had a unusually high dose of pheromone for a point source intended to elicit oriented attraction (Linn & Roelofs, 1985; Baker et al., 1989). PBW-rope®, a formulation designed to promote disruption of the male orientation to pheromone sources (Flint et al., 1985;

Table 1. Insecticide treatment in cotton Fields I, IIa, and III (liters/hectare). Field IIb did not recieve insecticide treatment

Date	Field I Product	L/HA	Field IIa Product	L/HA	Field III Product	L/HA
12/12					Endossulfan	1.20
12/18	Endossulfan	1.50	Endossulfan	1.50		
12/19	Endossulfan	1.50	Endossulfan	1.50	Azinphos-methyl	1.00
12/22	Endossulfan	1.50	Endossulfan	1.50	Endossulfan	1.20
12/30	Endossulfan	1.50	Endossulfan	1.50		
01/05	Endossulfan	1.50	Endossulfan	1.50		
01/07	Endossulfan	1.50	Endossulfan	1.50		
01/15	Endossulfan	1.50				
01/17			Endossulfan	1.50		
01/20	Endossulfan	1.50	Endossulfan	1.50		
01/30	Endossulfan	1.50			Malathion	0.75
					Deltamethrin	0.45
02/03	Endossulfan	1.50				
02/04					Parathion	1.00
					Deltamethri	0.40
02/11	Endossulfan	1.50			Malathion	0.75

Staten et al., 1987), is the only commercial point source with higher gossyplure dose than the sources in the oil traps. NoMate® fiber applications to promote mating disruption are effective for 14 to 20 days (Flint et al., 1985), so the pheromone sources of the oil traps were replaced every third week.

Monitoring PBW. Delta monitoring traps with the standard trap-bait of 10 fibers (Scentry Inc.) were placed out for one night weekly from the beginning of the season. Oil traps used for mass trapping were installed in all fields once the Delta-trap catches averaged 5 or more moths per night. The oil traps remained in the fields until the end of the season, with the exception of a 10 day period (March 5–14) when they were inactivated to allow recolonization of the experimental fields by PBW moths immigrating from the surrounding areas. To assess the effects of the treatment, one day each week the pheromone sources were removed from the oil traps, and moth density was estimated by placing out four Delta traps per ha for a period of 15 to 24 h: Field I received four Delta traps, Fields IIa and IIb received one Delta trap, and Field III received two Delta traps. In addition the PBW population in a neighboring okra field was monitored bimonthly during January and February with two Delta traps. Preliminary trials indicated that oil traps that had the pheromone source removed trapped the same number of males as control oil traps that had never received pheromone.

Larval and pupal PBW populations were monitored by weekly examination of cotton fruits. The susceptible green cotton fruits (100 per ha) examined were randomly collected while inspecting the cotton plants for phenological data. All fruits were dissected, so that healthy and parasitized PBW immatures could be determined (Fernandes, 1986; Mafra-Neto, 1988; Pierozzi, 1985).

Effectiveness of suppression. We started the mass trapping program with oil traps only after the adult population was established in the field. A population was considered established after it reached density levels of 5 males caught per trap per night (MTN). The density of PBW populations increases with the fruit load of the cotton plants: Delta traps monitoring PBW populations in cotton fields of the Campinas region in January, when the first fruits are being formed, captured between 1 and 38 MTN. By March these traps captured between 148 and 272 MTN, a high population density level maintained until the end of the cotton season (Fernandes, 1986). In the present experimental area, if after the installation of the oil traps the established PBW populations increased as predicted by Fernandes (1986), reaching a plateau by March, then the mass trapping programs would be considered a failure in controlling populational growth. However, if the PBW population densities in the fields under the mass trapping program were maintained at low levels throughout the cotton growing season, then

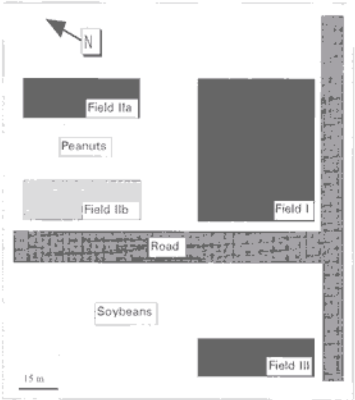

Figure 2. Diagram of the location of cotton fields in the experimental area: Filed I, under IPM control, and Field III, under chemical control, received insecticide applications from mid December until mid February; Field IIa received insecticide treatments until the 20th of January; Field IIb did not receive applications of insecticide. The arrow points north.

mass trapping would be considered successful in controlling population growth. In addition, PBW adults were allowed to invade the experimental area due to inactivation of the oil traps, by removal of the pheromone sources, for 10 days in March. Adult and larval population densities were monitored as before. At the end of 10 days the oil traps were re-activated, by addition of a pheromone source to the oil trap. The mass trapping program was considered effective only if it reduced the PBW adult population density during the weeks following oil trap re-activation.

Results

The first PBW males are caught by monitoring traps early in the season (October, November) when adults emerge from their overwintering cites (Fernandes, 1986; Mafra-Neto, 1988) and establish incipient populations on secondary hosts. Although there is a constant invasion of cotton fields by PBW adults, they can reproduce only when cotton starts producing flower buds (mid December) and fruits (mid January) (Figure 4) (Fernandes, 1986). PBW adults were present in all fields before the installation of oil traps in January. The first measurement of adult populations was made on January 14. Delta traps averaged 5 MTN in Field I, 2 MTN in Field IIa, 1 MTN in Field IIb, and no captures in Field III (Figure 3). Adult populations were considered established during the next week when survey Delta traps captured more than 5 MTN (Figure 3) in cotton fields with flower buds (Figure 4). Installation of oil traps eliminated the capture of males in survey Delta traps for the following 6 weeks, with exception for the capture of 1 MTN in Field IIa on February 18 (Figure 3). The inactivation of the oil traps to allow PBW populations to re-establish in the experimental fields was timed to coincide with the destruction of okra plants of a commercial field sustaining a PBW population (January 7 MTN, February 19.5 MTN), located ca. 500 m north of our experimental area. Destruction of the okra plants was achieved by first cutting the plants (March 1) and then, a few days later, by plowing the field and incorporating the plants to the soil. The destruction of the okra plants probably caused the resident PBW population to disperse to the adjacent areas (Flint & Merkle, 1981). Inactivation of all oil traps for 10 days (March 5 to 14) just after the destruction of the okra field allowed migrating PBW adults to establish populations in the experimental cotton fields. During the period of oil trap inactivation the levels of male capture in the monitoring Delta traps increased in all experimental fields (Figure 3). The increment of number of males captured, however, was greatest in the two fields located nearest the destroyed crop: Fields IIa (23 MTN) and IIb (15 MTN). Reactivation of oil traps on March 15 reduced adult populations in all fields to levels at which survey Delta traps captured less than 2 MTN (Figure 3).

PBW larval population was maintained at low levels in all fields during the entire cotton growing season (Figure 4). Larvae were detected for the first time in the middle of the season in Field IIa (4.3% infestation, Feb. 11), the field closest to the okra field. Infestations were restricted to Fields I and IIa, and were never higher than 5%, the injury level above which there is economic loss (Fernandes, 1986). Nearly all PBW larvae found were still penetrating the cotton fruit.

Discussion

Mass-trapping with oil traps suppressed *P. gossypiella* populations in cotton fields. Installation of traps early

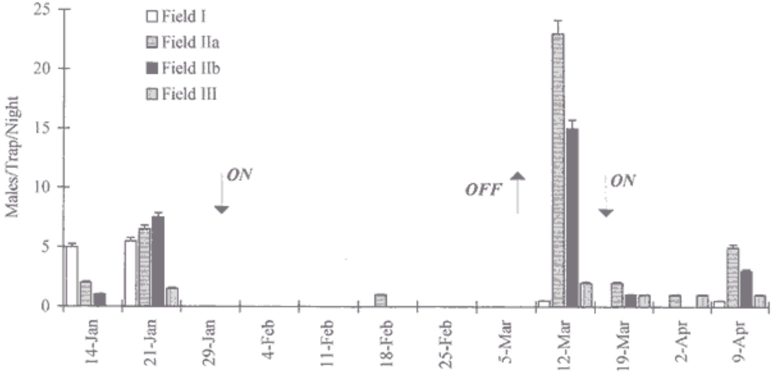

Figure 3. Histogram of the weekly surveys of monitoring Delta trap captures (males per trap per night). One night each week oil traps were deactivated by removing their pheromone source, and Delta traps were installed to monitor the density of the adult PBW population. In January PBW was allowed to invade and establish populations in the cotton fields. Mass trapping in all fields started on 21 January (ON), remaining until 5 March, a period when virtually no PBW males were captured by the monitoring Delta traps. Oil traps were deactivated (OFF) for 10 days (5 to 14 March) to allow PBW populations to once more invade the experimental cotton fields. Delta Traps registered the highest PBW population levels on 12 March. Reactivation (ON) of the oil traps 14 March resulted in suppression of the adult PBW population during the following weeks.

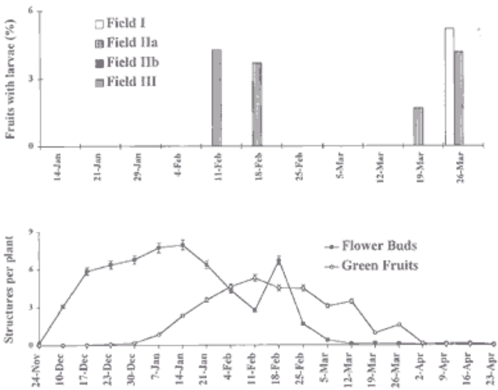

Figure 4. Histogram of the survey larval population (top): mass trapping protected all experimental cotton fields from PBW larval infestation. A low larval population, below economical threshold, was found infesting cotton fruits on Field I and Field IIa. The observed fruit infestation was below the expected percentage of infestation under low PBW densities in the Campinas region, which is 1 % in January, 9 % in February, and 26 % in March (Fernandes, 1986). The graph in the bottom depicts the mean number of reproductive structures per cotton plant.

in the season, at the first fruit stage (Flint & Merkle, 1984) presumably depleted the local PBW population of sexually 'competent' males, which in turn decreased the chances of newly emerged virgin females to mate. In addition, the semi-isolation of the experimental area reduced the effect of immigration of adults, particularly of gravid females, from adjacent fields. In a pilot study, a cotton field under mass trapping control surrounded by cotton fields under conventional insecticide control sustained low-density PBW populations of adults and larvae throughout the entire cotton growing season (Mafra-Neto, 1988). The majority of the PBW males were caught in traps on the edges of the mass trapping field near the insecticide controlled fields, suggesting that the trapped males were probably invading the mass trapping field (Mafra-Neto, 1988). The isolation of the fields in the present study allowed us to suppress the resident PBW population to a density below the detection levels of our monitoring tools, and to maintain a low population density levels throughout the cotton growing season.

Field PBW populations were effectively reduced by mass trapping when the cotton fruits were green, the most critical period of commercial cotton growing (Figures 3 and 4). The adult PBW population in the experimental fields before the installation of the mass trapping program was present at density levels comparable to those reported in previous years for conventional cotton fields of the Campinas region in which PBW caused economic losses (Fernandes, 1986). However, the mass trapping program suppressed and controlled the PBW population of the experimental fields. A three-year study using the same monitoring tools for PBW used in this mass trapping study (Delta traps with standard lure of ten fibers from Scentry Inc. for adult population, and dissection of green fruits for immature population) in fields under conventional control in the Campinas region reports that PBW populations invade and colonize the cotton fields in January. These populations grow with the increasing density of susceptible green fruits in the cotton field, reaching a peak in April, by the end of the growing season (Fernandes, 1986). For example, in a year of low population PBW density, the number of males captured per survey Delta trap per night predicted by Fernandes (1986) should range between 1.03 MTN and 5.71 MTN by January, between 65.04 MTN and 117.28 MTN by February, between 196.54 MTN and 228.86 MTN by March, and between 198.31 MTN and 313.23 MTN by April. The number of PBW moth captured in the experimental mass trapping fields and in the okra field in this study by January, before the beginning of the mass trapping program, were at the upper end of the predicted range of PBW population density. However, once installed and functional, the mass trapping program decreased the experimental fields' PBW population to zero, and maintained those low population levels until the program ended on March 5th. Further evidence of the suppressive effect of the mass trapping program is that while the experimental cotton fields, the primary host of PBW, sustained no Delta trap catches, the Delta traps in the neighboring okra field, a secondary host, were capturing close to 20 MTN.

Conventional insecticides have been used to control other crop pests (Table 1), in particular the cotton boll weevil (BW), *Anthonomus grandis* var. *grandis* (Boheman) (Pierozzi, 1985). The insecticide applications, however, did not account for the sudden reduction of Delta trap catches following activation of the oil traps for mass trapping. Reduction of PBW populations from January 29 to March 5 could not be explained by the use of insecticides in two fields, Field IIb which never received insecticide, and Field IIa which did not receive insecticide applications after the 20th of January. Furthermore, the increase in Delta trap catches on March 12 following inactivation of the oil traps, and the reduction of Delta trap catches after March 19 following reactivation of the oil traps, indicate that indeed mass trapping, and not application of insecticide, was responsible for the suppression of PBW populations in the treated areas. Our mass trapping program resulted in reduction of the survey Deltà trap captures to values close to zero independent of the regime of insecticide application.

Trap captures are evidence that PBW males located the oil traps. Upwind flight of moths to pheromone sources is modulated by the chemical composition (Linn & Roelofs, 1985; Mafra-Neto, 1993) and the structure of the plume the source generates (Vickers & Baker, 1994; Mafra-Neto & Cardé, 1994, 1996). Sources generating large, turbulent plumes are located more frequently than sources generating narrow, homogeneous plumes (Mafra-Neto & Cardé, 1994; 1995a). If pheromone is presented as a large, homogeneous cloud, moths halt upwind progress (Kennedy et al., 1981; Baker et al., 1985), but resume upwind progress once the cloud is pulsed (Baker et al., 1985). PBW males also modulate their flight based on the pheromone plume structure (G. Hentzelt, A. Mafra-Neto and R.T. Cardé, unpubl.), thus the spatial distribution and the fine scale structure of the synthetic pheromone plumes broadcasted by the oil traps in the field should have had a strong effect on the pheromone-related behavior of PBW males. Our mass trapping technique differs from current commercial pheromone mating disruption techniques for PBW in that low density of high pheromone dose point sources were positioned above the plant canopy. Vertical position of the source, relative to canopy, shapes the structure of the odor plume, and horizontal position, relative to other sources, determines the area in which the plume will attract males (Lewis & McCauley, 1976). Commercial techniques usually rely on a high density of low-dose point sources dispensed on the soil or on top of the leaves of cotton plants (e.g., fibers and microcapsulates), or on an intermediate density (1000 per ha) of high-dose point sources placed under the canopy, 10 cm above the ground, as for the PBW-rope® formulation (Flint et al., 1985; Staten et al., 1987). Because commercial sources release pheromone on or under the canopy, where winds are typically slow and turbulent, the plumes from the numerous sources probably break apart and intermingle, creating a cloud of pheromone to which males cannot orient. The air currents above the canopy are usually faster and less turbulent than those below the canopy, thus the integrity of the structure of the individual plumes generated above the canopy, such as the ones generated by the oil traps, should be preserved for longer distances (A. Mafra-Neto, unpubl.). Nevertheless, plumes generated above the cotton field canopy will eventually break apart and intermingle, resulting in a network of isolated, highly concentrated pheromone plumes that interact at some distance downwind from the source (oil traps). The fact that PBW males were consistently captured in oil traps indicates that they were able to locate the high-dose pheromone plumes generated by oil traps in the field, to lock-on to the plume, to engage in oriented upwind flight, and to perform the necessary maneuvers in order to enter the oil trap and encounter its viscous surface. Our findings are in agreement with those of Doane & Brooks (1981), that PBW males are able to orient to traps emitting pheromone plumes of concentrations much higher than the background in field situations lacking constant unidirectional wind. Wind tunnel experiments in the field (Cardé et al., 1993) and in the laboratory (A. Mafra-Neto & R.T. Cardé, unpubl.) have demonstrated that, indeed, PBW males sustain upwind flight along highly concentrated pheromone plumes from, and subsequently land on, PBW-ropes®. The attract-and-kill effect of oil traps was, therefore, an important factor promoting the collapse of PBW populations using mass trapping.

Although the success of PBW population suppression using our mass trap technique could be explained simply by the constant capture of active males responding to pheromone, it is possible that a few other mechanisms enhancing mating disruption could be at play (Bartell, 1982; Cardé, 1990; Cardé & Minks, 1995). Some of the males that followed the pheromone plumes generated by the oil traps were captured, but others probably became arrested in-flight due to the high pheromone concentration (Baker et al., 1989) eventually abandoning the plume before entering and landing in the trap. Adaptation of the sensory input due to continuous stimulation with high concentration of pheromone has been correlated to inflight arrestment followed by termination of pheromone-related behavior (Baker et al., 1989). Furthermore, males of several species of moths when exposed to pheromone are able to respond to subsequent exposures of higher concentrations, but not to exposures of the same or lower concentrations (Shorey et al., 1967; Traynier, 1970; Bartell & Lawrence, 1973; Kuenen & Baker, 1982; Figueiredo & Baker, 1992). Thus interception of high concentration pheromone plumes from the oil traps may hinder subsequent responses of the male to less concentrated pheromone plumes, such as those emitted by calling females, due to central nervous system habituation and/or sensory adaptation. The depression of behavioral activity following pre-exposure to pheromone may last from a few hours to a few days (Shorey et al., 1967; Traynier, 1970; Bartell & Lawrence, 1973; Kuenen & Baker, 1981; Figueiredo & Baker, 1992). Thus, although the oil traps may not capture every PBW male in its field of action, the male's exposure to the high-dose pheromone plumes may hinder their ability to locate and court mates.

Usually female moths restrict pheromone emission to certain periods of the night, whereas males tend to have a broader period of response to pheromone (Cardé, 1986; Cardé et al., 1993). Since the oil traps constantly emit pheromone, a male 'in transit' in the beginning of his response period may encounter oil trap plumes and express the sequence of pheromone mediated behavioral responses, i.e., the male may lock-on to the plume and fly upwind to the trap, before females start their calling period. It is conceivable, therefore, that males could be removed from the mating pool either due to trapping or to a decrease in responsiveness caused by the high concentration of pheromone emitted by the oil traps before they are able to mate with females.

Our data show that a low number of traps with high dose sources of pheromone can disrupt mating of PBW in the cotton field. However, in order to increase the efficiency, and in order to reduce the cost of mass trapping programs, it would be worth knowing if traps with lower pheromone doses would be as effective in promoting population suppression of PBW as traps with high pheromone doses. It has been shown that the proportion of PBW males visiting low dose synthetic pheromone sources in the field increases with the density of sources (Miller et al., 1990). It is possible, therefore, that higher density of traps with lower doses of pheromone may be as effective as, or even more effective than, the dose and density examined here. Nonetheless, the fewer traps needed per area, the easier to implement, and the cheaper the mass trapping program becomes.

Even though the pheromone dose of each oil trap was high, the dose of pheromone used per area of mass trapping was much lower than the reported pheromone techniques of PBW control in commercial fields. Control with mass trapping was achieved with only 4 g of formulated gossyplure per ha (NoMate® Fibers), which contrasts with the average 19.8 to 29.6 g of NoMate® fibers in commercial fields in the United States (Baker et al., 1990), or the 78 g per ha for disruption using the twist-on PBW-rope® formulation (Staten et al., 1987). Our mass trapping technique has been successfully used by a few small cotton growers in the Paraná/São Paulo region in Brazil (Habib, unpubl.). However, replicated additional trials, possibly with other trap densities and pheromone loadings, should be conducted before this technique is widely recommended. Implementation of mass trapping on a large scale will depend on operational costs and feasibility, which will always be contingent on social and economic considerations (Campion et al., 1989). Nevertheless, mass trapping has the potential of becoming an effective form of PBW population suppression where cotton growing relies on manual labor.

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