Control of the Pink Bollworm, *Pectinophora gossypiella, (Lepidoptera ; Gelechiidae)* with Gossyplure: Problems and Progress*

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INTRODUCTION

Control of pest insects is traditionally accomplished with insecticides. The reasons are persuasive : insecticides are generally effective, inexpensive, and available. While we now realize that there are disadvantages to the continuous use of insecticides, insecticides will remain the major tool for control of insects in the foreseeable future. However, agricultural researchers have developed many new non-insecticidal methods of insect control during the last few decades that are often applicable to specific problems These new methods are adjuncts to insecticidal control and thus the integrated pest management concept was born. We have, for example, seen the successful application of sterile insect releases and other autocidal methods, biological control, and pheromones for control of specific pests. The successful use of methods requires a higher level of understanding of the basic biology of the insect pest and close cooperation between the farmer, fieldman, and professional entomologist.

Karlson and Luscher (1959) proposed the name "pheromones" for chemicals produced by an organism that induce a response in another organism of the same species. While the correct chemical determination of the pheromone of the pink bollworm was made in 1973 (Hummel *et al.* 1973), hexalure (Keller *et al.* 1969), an attractant for pink bollworm males, was already in wide use for monitoring populations. Hexalure and, to a greater extent, gossyplure have significant applications for management of pink bollworm. The most important uses of gossyplure for control are 1) detection and estimation of population density of males, 2) male annihilation through destructive trapping and 3) confusion (disruption of communication between sexes) that leaves female moths unmated.

It is the objective of this paper to relate and disuss the latest information on these 3 uses and to suggest some areas of research where more information is needed.

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Control of Pink Bollworm with Gossyplure

The first demonstration of communication disruption of pink bollworm was made in soutnern California cotton fields using the sex attractant hexalure (McLaughlin *et al.* 1972). Subsequently, the structure of the true pheromone was determined by Hummel *et al.* (1973) who introduced the name gossyplure. Gossyplure became commercially available in 1974 (Farchan, 4702 E. 355th St , Willoughby, OH 44094) and was immediately tested in the field. Shorey and his colleagues at the Univ. of California, Reverside, conducted numerous tests with gossyplure for communication distruption during the 1973-76 period and after some difficulties their efforts yielded encouraging results (Shorey *et al.* 1977). The first commercial application of the gossyplure communication disruption system was made to cotton in Arizona and California in 1976 (Brooks *et al.* 1979). The dispensers were hollow fibers containing a mixture of hexane and gossyplure (Conrel, 110 "A" Street, Needham Heights, MA 02194) and were dispensed at a rate of 2.4-7.4 g Al/ha. In 1979, a laminated plastic dispenser (Hercon Inc., 1107 Broadway, Manhattan, New York, NY 10010) was used to dispense gossyplure at a rate of 3.7-4.9 Al/ha to cotton fields in Arizona (Henneberry *et al.* 1980). These 2 dispensers are currently the only commercial products available for communication disruption of the pink bollworm.

Commercial applications of gossyplure have been considerably refined during the last few years. Early problems with dipensing equipment have been largely overcome although special machinery is still required. Timing of application and analysis of results have improved (Lingren *et al.* 1980). The inconsistent results that marked early commercial applications of gossyplure are less frequent and the degree of confidence farmers and fieldmen have in the method has risen. The improved performance of commercial products has occurred largely because of an improved understanding of the basic biology of the pink bollworm.

The hollow fibre gossyplure formation has been tested in several cotton growing areas of the world including the Punjab in India (Doane and Brooks, 1980) where present insecticides are often inadequate against the pink bollworm (Agarwal and Katiyar, 1975). Due primarily to climate, cotton production methods and seasonal distribution of pink bollworms in India are different from those encountered in North America. Doane and Brooks (1980) report that boll infestations in gossyplure treated fields throughout the season with a concomittent 34% increase in yield of cotton seed. The apparent problems were dispersal of mated females into the treated fields, the continuous emergence of moths from piles of cotton stalks adjacent to the fields, and the timing of heavy pink bollworm emergence to the first rains in July. These authors indicate that destruction of piles of cotton stalks before monsoon rains will be a prerequisite for effective control by applications of gossyplure.

Theory of Communication Disruption

Shorey (1976) suggested that pheromone communication disruption could be attributed to one or more of 3 factors: 1. sensory adaptation or failure of the antennal receptors after continuous exposure, 2. central nervous system habituation or failure of the CNS to react after continuos exposure, and 3. confusion - males chasing sources of pheromone that are predominantly not female moths. Which of these factors is operating in the case of the pink bollworm is the subject of continuing discussion. Doane and Brooks (1980) found that pink bollworm males "appear to continue searching behaviour in fields permeated with normal background concentrations of pheromone capable of producing effective mating disruption". Furthermore, they found that males in gossyplure baited fields will respond to traps emitting gossyplure at significantly higher than background levels. Dr. Jan Gillespie of Hercon has observed apparently normal male searching behaviour in gossyplure treated fields (personal communication). In our own unpublished studies, we have found that virgin males subjected to 3 days of continous high concentrations of gossyplure in the laboratory are captured in a a gossylure baited trap in the wind tunnel during a 12 hours post exposure test period. Cook and Shelton (1978) in their laboratory studies of antennal responses of the pink bollworm found that sensory adaptation was evident with extended exposure to gossyplure but a normal level of sensitivity returned after 3 minutes in a gopsyplure free environment. These findings, some undocumented at present, suggest that males are not habituated and unresponsive as suggested by Shorey *et al.* (1976) even through some sensory adaptation of antennal receptors occurs. Therefore, the predominant effect of gossyplure in the field must be to confuse the males— this is consistent with the current commercial practice of putting out several thousand sources of gossyplure per hectare; A definitive study should be conducted and documented.

Dispensing Gossyplure for Confusion

Stainless steel planchets, loops of plastic or string, foil and nylon wrapped cylinders, microcapsules, foil evaporators, polyethylene capsules, and even foliar sprays of active ingredient have been tested as dispensers of gossyplure for confusion (see Henneberry *et al* 1980). The 2 current commercial dispensers, multilayered flakes and hollow fibers, are the culmination of long experimentation The United States Environ mental Protection Agency (EPA) has approved gossyplure for disruption in the hollow fiber formulation and approval is expected for the flake. This is not to say that other formulations are not effective. Boness *et al.* (1977) obtained 62 per cent reduction in pink bollworm infestations with an application of gossyplure in polyethylene capsules. However, on a worldwide basis, the hollow fiber substrate has accumulated the greatest use, due largely to aggressive marketing by its manufacturer and a reasonably successful record.

If one were to list the desirable qualities of a gossyplure dispensing system, they might include ready availability, economical cost, the ability to be applied by conventional equipment, positive adherence to the plant, long storage life, consistent and predictable emission rates under various conditions and, of course, biological effectiveness. Many of these qualities are extremely difficult to achieve (see Plimmer and Inscoe 1979, for a discussion of these problems from the chemist's point of view). While the commercial development of new products is very expensive and by no means certain, it is safe that we will see improved formulations of gossyplure in the future.

The quality of commercial gossyplure (Chemsampco, P. O. Box 20305, Columbus, OH 43220) has improved recently as determined in our unpublished tests of its attractiveness in traps. However, the effect of the lure's attractant quality on its confusant quality is unknown. We assume that the purest lure is the best confusant but minor amounts of related compounds may have important effects. We have attempted to determine why certain lots of gossyplure catch significantly fewer moths in traps than other lots. we suspected that the *E,E*-and *E,Z* isomers of gosspplure were detrimental contaminants (Bierl *et al*, 1973), even when present in amounts less than 1 per cent. However, our field tests showed no reductions in catch at upto 5 per cent of these isomers (unpublished data), amounts far greater than found in commercial gossyplure. The detrimental (inhibitory) components of some lots of gossyplure remain undermined.

At least one commercial company is experimenting with combinations of insecticide and gossyplure substrate. Incomplete laboratory and field tests indicate additional control capability based on the killing by contact of males attracted to the insecticide substrate source (personal communication, Dr. R. T. Staten, USDA 4125 E. Broadway, Phoenix, AZ, 85040). Such combinations may have application, especially where the confusion component is considered marginally effective for one reason or another, but documentation and registration will be required.

Monitoring or Annihilating Pink Bollworm Males with Gossyplure Baited Traps

There is a natural inclination among people working with the pink bollworm to use trap catches to estimate populations of moths (and thus economic thresholds). This is almost universally an error. Gossylure baited traps do not catch female moths and probably do not accurately indicate peaks of male moths particularly in areas of continuous generations. Minks (1979) discussed the problems of interpreting pheromone trap catches and concluded that pheromone trays cannot reliably determine thereshold populations of pest insects. We have observed this is true for the pink bollworm (Flint *et al*. 1980). The only accurate method of determing if economic damage is occurring is to measure infestations in bolls and apply the desired economic therehold (usually 10-15 per cent boll infestation in Arizona) before applying insecticides. However, there are some uses for which gossyplure baited traps are useful: surveying for the presence of pink bollworm, monitoring ratios of released and native males in sterile moth release programs, and possibly to determine when an application of gossyplure confusant is no longer present in sufficient quantity to inhibit captures of males in traps.

Numerous tray designs for pheromone work with the pink bollworm are available. For general survey and testing where light populations are anticipated, the delta trap (Sandia Die and Cartridge, Rt. 5, Albuquerque, NM 87123) is excellent (Foster *et al.* 1979). Its features are simplicity, small size, and economy. Its disadvantage is that it loses its effectiveness after ca. 50 moths are captured and must be replaced. The various oil cup traps (Neumark and Teich 1973, Huber *et al.* 1979) have much greate capacity and are used in male annihilation programs. A recent trap that combines capacity with the ability to capture males alive is the Lingren trap (Lingren *et al.* 1980). Other designs are known (Foster *et al.* 1979) but do not provide additional features or perforr mance for the specific uses indicated. The delta trap was used in India in tests of ratios of the 2 components of gossyplure (Flint *et al.* 1980) and in communication disruption trials in the Punjab (Doane and Brooks, 1980).

Annihilation of males in sufficient quantities to prevent famales from mating is not easily accomplished in theory or in practice. Huber *et al.* (1979) presented several year's data for an area wide (ca. 5-7,000 ha) male pink bollworm annihilation program. They concluded that 10-12 oil cup traps/ha gave economical control of the light moth populations encountered in the test area. This type program must be inititated early in the season to prevent mating of overwintered and F_1 moths, much the same as with gossyplure confusants. The traps used in male annihilation programs are vulnerable to mechanized field work and should be adjusted to stay in near the tops of the plants. As in many sterile insect release Programs, we have not seen large scale tests with appropriate controls. The combination of confusant and Insecticide, previously mentioned, combines elements of both confusion and male annihilation. Data on this combination of methods is not yet available.

Timing Gossyplure Applications

Long range dispersal of native pink bollworm moths has been well documented (Stern, 1979). The short range intra and interfield movement is less understood because of the difficulties in testing. We know that pink bollworms are closely associated with cotton once the plants can provide cover and fruiting has begun, but prior to this the emerging overwintered moths are widely distributed throughout non-host habitats (Flint and Merkle, 1980).

Flint and Merkle (1980) studied the movement of native moths (captured alive, dye marked and released) early in the season in an area of mixed agriculture near Phoenix that included sugar beets, cotton, alfalfa, and desert. The results showed that males were almost equally distributed among the habitats and Ca. 25% were recaptured outside the habitats in which they were marked. About 80 per cent of the females captured in light traps were mated and about 50% of virgin females placed in mating stations in cotton and desert habitates were mated during a 1 night exposure. Flight (Malaise) traps operated outside cotton fields early in the season have shown similar percentages of mated females (Dr. Jan Gillespie, Hercon, personal communication). These results indicate that the moths are quite likely to be mated when they enter the first available fruiting cotton.

We might expect that applications of gossyplure at first square, as per current label directions, to be less effective if the target population is partially mated. Further studies are needed to determine if the first generation of field reared moths is a more suitable target. However, the timing of the first application just prior to emergence of the F_1 generation would require considerable expertise and has inherent risks if applied too late. The decision to terminate gossyplure treatments is almost as important as the decision to initiate treatments. The single most important factor must be the levels of infestation in the crop. The usual procedure is to revert to insecticidal control when economically important damage is occurring. Thus, monitoring crop infertation levels is a vital part of the gossyplure control program.

Behaviour of the Female

Very little is known about the behaviour of female pink bollworms (Leppla, 1972, Kaal and Shorey, 1973). The effects of gossyplure on female behaviour are known. The reason is that there is no way to monitor females other than direct observation at night. Lingren *et al*, (1980) have provided a summary of the latest monitoring technology including equipment for nocturnal observations. Lingren *et al*, (1980) found that a microencapsulated formulation of gossyplure caused a 94% reduction in trap catches of males and a 66% reduction in mating pairs found by direct observation. However, at 45 m from the treated area there was no reduction in mating while trap catches were still reduced 76%. These authors observed females calling, moving, and calling again, behaviour that cannot be duplicated by females in mating stations or gossyplure baited traps and which would increase the chances of mating for the free female activity is the use of flight (malaise) traps. Henneberry *et al*, (1980) found that among trapped females the numbers of mated females and the average number of spermatophores per mated female were reduced 45 and 64%, respectively, in gossyplure treated fields compared to control fields. Cook and Shelton (1978) found that female pink bollworms can detect. This raises the question of what effect gossyplure has on females in treated fields. Do females leave a treated area? At this time, we do not have the answer to this basic question.

Conclusions

Applications of gossyplure for control of the pink bollworm are being made in many of the cotton growing areas of the world (Doane and Brooks, 1980). Satisfactory methods have been developed, largely through trial and error and the confusion technique for pink bollworm can now be considered a part of the battery of methods for integrated control of this pest. However, improvements and refinements of the technique can still be made. The improvements will be made through better confusants and application methods but mainly through a better understanding of the basic biology and ecology of the pink bollworm moth.

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