Use of Pheromones in Pest Management[1]

Helmut Riedl
Mid-Columbia Agricultural Research and Extension Center, Oregon State University, 3005 Experiment Station Drive, Hood River, Oregon 97031

Insects have a highly developed chemical communication system. They use chemical signals more than any other animal group to communicate among themselves and with the outside world All messenger substances which regulate behavior between individuals of the same species are called *pheromones* The pheromone communication system is most advanced in social insects Pheromones can have many different functions. For example, sex pheromones help bring males and females together for mating and reproduction. Alarm pheromones are commonly found in ants, bees, and wasps to alert the colony about imminent danger from an intruder Ants can also produce a trail pheromone which guides members of the colony to a recently discovered food source. Aggregation pheromones are used by bark beetles (Scolytidae) during mass attacks to attract mates and increase the number of beetles attacking a tree. Of all the behavioral chemicals which are involved in within-species communication, sex pheromones have found the widest application in pest management. They are the focus of this review. Readers who seek additional information about pheromones and their application are referred to the recently published book, *Behavior—Modifying Chemicals in Insect Management* (Ridgway et al., 1990).

SEX PHEROMONES

The idea that insects use odors to attract the opposite sex for mating was proposed more than 150 years ago. Since then the presence of sexual attractants for the purpose of mate finding was demonstrated in many insect species, particularly in Lepidoptera The first chemical identification of a sex pheromone was that of the famous silk worm, *Bombyx mori*, in 1959. A German biochemist, Adolf Butenandt, extracted the abdomens of 250,000 female silkworm moths to obtain 12 mg of the sex attractant which he called Bombycol He identified the compound as a straight chain alcohol with 16 carbon atoms. Identifications of many other sex pheromones followed, primarily of species of economic importance. Rapid advances in analytical techniques, particularly in gas chromatography and mass spectrography, made these identifications possible and less cumbersome. Analytical methods have become so sensitive that the chemical composition of pheromone components can now be determined from single insects.

Pheromone Production, Release, and Perception. In Lepidoptera (moths and butterflies) the sex pheromone is produced in glands located in the tip of the abdomen During "calling" the pheromone is released. The female raises the tip of the abdomen and exposes the pheromone glands to release the sex scent to the atmosphere. The pheromone diffuses and is then carried downwind. The male moth detects the female scent with his antennae at extremely low concentrations. The antennae are equipped with thousands of sensory hairs. These olfactory hairs

[1] Technical Publication 9710 of the Oregon State University Agricultural Experiment Station, Corvallis, Oregon

are tuned to the sex pheromone and tell the male to move upwind towards the "calling" female. In some large moths, males can detect "calling" females over long distances.

Sex Pheromone Chemistry. The chemical structure of sex pheromones of many lepidopterous and other insect species are now known. Generally, they are straight carbon chain molecules which contain between 12 and 17 carbon atoms. Some consist of mixtures of alcohols, acetates, and aldehydes; others are mixtures of various isomers. The sex pheromones of many species consist of blends of several components. Related species often use the same components but in different ratios.

Controlled-Release Technology. To make use of pheromones in the field they must be released slowly into the atmosphere. The objective is to achieve constant release over a long period of time. Rubber and polyethylene plastic were some of the earliest slow-release substrates and they are still used today as baits in traps. The synthetic pheromone is dissolved in an organic solvent and applied to the substrate. It becomes embedded in the matrix of the substrate and is slowly released. Another release method is hollow fibers (small plastic tubes) which are filled with the attractant. The fibers are welded shut on one end and the pheromone evaporates through the open lumen of each fiber The rate of release is controlled by the size of the opening and the number of fibers. Another dispenser system releases the pheromone through a plastic membrane. The diameter and thickness of the membrane control the rate of pheromone release. For monitoring, it is desirable to adjust the rate of pheromone release in order to maximize the response of males to the bait.

For mating disruption, dispensers are often constructed in such a way as to release large amounts of pheromone at a constant rate. Slow-release systems which are being developed for mating disruption include hollow fibers, plastic membranes, plastic laminates, polyethylene tubes and silicon polymers. Some of these mating disruption dispensers are applied manually within the crop canopy (e.g. polyethylene tubes), others require specialized application equipment (e.g. hollow-fibers). There is also considerable interest in sprayable slow-release pheromone formulations which can be applied with conventional spray equipment.

APPLICATION OF PHEROMONES

Use of Pheromone Traps for Detection and Monitoring. Disposable adhesive-coated cardboard traps are available from several commercial suppliers for use with pheromone baits. The number of individuals caught depends not only on the effectiveness of the pheromone bait, but also on the design features of a trap such as shape, size, and opening. Pheromone traps have several advantages over previous trapping methods. They are species-specific (trap only one species), sensitive at low population density, easy to maintain, and inexpensive. There are also disadvantages Pheromone traps do not perform well under poor weather conditions. Their drawing range is not well defined. Also, they catch only males. This can be a disadvantage since control decisions are often based on female activity (egg laying) rather than male flight. In spite of these shortcomings, pheromone traps have become valuable tools for detection and monitoring of pest species.

Pheromone traps are employed by Federal and State agencies in various survey programs to detect the presence of exotic pest species. These activities are carried out as part of a quarantine effort to prevent the establishment of new pests in the United States Pheromone traps are also used to monitor the spread of already established pest species. One example for such a program is the gypsy moth survey which is being conducted in many states.

Pheromone traps can provide valuable information on the seasonal activity of pest species. This information is used in pest management programs for the timing of control treatments. For instance, insecticide sprays against codling moth, *Cydia pomonella*, are timed using estimates of adult emergence (provided by the pheromone trap) and degree-day forecasts of egg and larval development (Riedl et al., 1986). Similar methods of spray timing are available for the European pine shoot moth, *Rhyacionia buoliana*, and other pests.

Pheromone traps are also used, but to a lesser extent, to evaluate whether a pest population is high enough to warrant control For instance, empirical treatment thresholds are available for the codling moth, a widely distributed pest of apples and other deciduous fruits. If codling moth catches exceed 1 or 2 moths for 2 consecutive weeks, a control treatment is necessary. Another example is the spruce budworm, *Choristoneura fumiferana*, a pest of eastern coniferous forests. Pheromone trap catches are correlated with infestation levels and traps can be used as an early-warning system to predict tree mortality.

A special and more recent application is the use of pheromone traps for resistance monitoring (Haynes et al., 1987; Riedl et al., 1986). Insecticide resistance has become a growing problem in recent years. It is important to detect resistance before it becomes widespread and leads to control failures and economic loss. Pheromone traps are used to collect and test insects for resistance. Insects captured on the adhesive-coated trap bottom are treated topically with a small droplet of insecticide in a solvent carrier or they are exposed to insecticide incorporated in the trap adhesive. By comparing the concentration-mortality response with a susceptible population it is possible to determine whether resistance has developed. Both pheromone trap assay methods have been used in recent resistance surveys for several tree fruit pests including codling moth, several leafroller species, and leafminers

Use of Pheromones for Control: Mass Trapping, Mating Disruption, and "Attract and Kill". The idea of using sex pheromones directly for control of insect pests is not new. Long before synthetic pheromones became available, it was proposed to use virgin female-baited traps and remove all male individuals in a population. The hope was that by removing all males, female insects would not be able to mate and reproduce. The practicality of this idea was not tested until synthetic pheromones became commercially available Mass trapping experiments with pheromone traps have been conducted with many pest species but results have generally been discouraging In mass trapping experiments pheromone traps are used in a similar manner as for monitoring except that trap densities are much higher.

Experiments conducted in California with codling moth indicated that even with very high trap densities such as 70 per acre it was not possible to remove enough males to prevent mating and achieve acceptable control Even if mass trapping was effective it may not be an economical control method because of the high material costs.

A more promising approach is the use of pheromones to disrupt the communication between sexes and thus prevent mating and reproduction. This control method has come to be known as the mating disruption or male confusion method Mating is disrupted by releasing large amounts of sex pheromone from many point sources into the atmosphere. Males are apparently unable to find "calling" females against this background of high concentrations of sex pheromone. It is not exactly clear how mating disruption works. Three hypotheses have been proposed. The "false trail" hypothesis suggests that males are more likely to follow the artificial sex pheromone signals which are emitted from many points in a field Another suggestion is that the pheromone trails of wild females become "camouflaged" by the large amounts of synthetic pheromone in the atmosphere A third hypothesis proposes that males become "habituated" in the presence of high concentrations of pheromone, decreasing their level of responsiveness to calling females

It was first demonstrated with the pink bollworm, *Pectinophera gossypiella*, that mating disruption might become a viable control tactic for some insect pests. Several slow-release formulations are now registered for pheromonal control of this cotton pest. Among tree fruit pests, the most successful example of control with the mating disruption method is the Oriental fruit moth on peaches. The pheromone is released from closed plastic tubes which are attached to tree branches at a density of 200 to 400 per acre This slow-release formulation is now registered for control of Oriental fruit moth and is used on 6,000 acres of peach orchards in California where populations have developed resistance to organophosphate insecticides.

Registrations of pheromones for mating disruption have been granted for about one dozen pest species in the United States. The majority of the registrations are for control of fruit insects, including Oriental fruit moth, codling moth, peach tree borers, and grape berry moth. Registrations for forest insects include Gypsy moth and western pine shoot borer Vegetable and field crop pests for which mating disruption is a registered control method are the pink bollworm, artichoke plume moth, and tomato pin worm. The growing concern about pesticide residues on food commodities has renewed the interest in alternative control methods such as mating disruption with pheromones However, there are also certain problems with this new control method First, success of mating disruption with pheromones has been limited to situations where pest density is low. Under high density conditions control with this method has not been satisfactory. Another problem is that it is often difficult to properly demonstrate the effectiveness of control by mating disruption since large test plots are required and a suitable untreated check area is often not available for comparison

Pheromone traps can be used to monitor the effectiveness of pheromone treatments. The lack of male response to traps is taken as an indication that pheromone concentrations are still high enough to disrupt male-female communication However, one should rely not only on pheromone traps but also on frequent field inspections to monitor the effectiveness of pheromone treatments since traps are not always reliable indicators. Development of damage in a pheromone-treated area means that some mating has occurred or that fertilized females have immigrated from untreated areas nearby.

A third control application of pheromones is their use in combination with insecticides. The pheromone acts as an attractant and improves the performance of a conventional insecticide Special formulations of insecticide-laced hollow fiber dispensers are available for control of several pest species.

COMMERCIALIZATION OF PHEROMONES

Before artificial pheromone lures became available some use was made of the natural pheromone released by virgin female insects to bait traps. As more and more pheromones of economically important pest species were identified and synthesized, commercial companies became involved who began to produce and supply pheromone dispensers and traps. There are now at least eight companies in the United States and more than 50 worldwide who are developing pheromone products for pest management applications. A partial list of pheromone companies in the United States and products they provide is given in Table 1. The involvement of private companies has benefitted the development of standard

Table 1. Commercial companies in the United States developing pheromone products

		Pheromone controlled-release systems for	
Company and location	Traps	Monitoring	Mating disruption
Trece Salinas, CA	X	rubber cap, polyethylene cap	
Scentry Buckeye, AZ	X	hollow-fiber, rubber cap	hollow-fiber
Hercon South Plainfield, NJ	X	plastic laminate	plastic laminate
BioControl Davis, CA			polyethylene tube
AgriSense Fresno, CA			silicone polymer
Consep Bend, OR	X	plastic membrane	plastic membrane

pheromone products. Registration of pheromones by the Environmental Protection Agency is required if they are used for mating disruption and in combination with insecticides but not if they are used as baits in traps

SUMMARY

Sex pheromones have found wide application in pest management programs in agriculture, forestry, and stored products Their principal use is as baits in traps. Pheromone traps are used in insect surveys for detection of exotic pest species and

for monitoring the spread of established pests. They also provide valuable information on the seasonal activity and on the need for control of many pest species of economic importance. Monitoring with pheromone traps has become an essential part of many pest management programs, has helped make insecticide applications more effective, and has contributed to a reduction in overall pesticide use Pheromone traps have also found application for monitoring the development and spread of insecticide resistance. The most promising control application of sex pheromones is the mating disruption technique. This selective control method is now registered against more than 12 pest species in the United States. Mating disruption with sex pheromones is a particularly useful control method in situations where resistance has developed and insecticide use is very high.

REFERENCES

Haynes, K.F., T.A. Miller, R.T. Staten, W.G. Li, and **T.C. Baker.** 1987 Pheromone trap for monitoring insecticide resistance in the pink boll worm moth (Lepidoptera Gelechiidae): new tool for resistance management Environ. Entomol 16 84-89.

Ridgway, R.L., R.M. Silverstein, and **M.N. Inscoe** (eds) 1990 *Behavior-modifying chemicals in insect management* Marcel Dekker, New York

Riedl, H., A.B. Seaman, and **F. Henry.** 1985 Monitoring susceptibility to azinphosmethyl in field populations of the codling moth (Lepidoptera Tortricidae) with pheromone traps J Econ Entomol 78 692-699

Riedl, H., J.F. Howell, P.S. McNally, and **P.H. Westigard.** 1986 Codling moth management use and standardization of pheromone trapping systems Univ Calif Agric Exp Sta Bull 1918·23 pp

VOICE: Question for Kirk Smith What manner of movement do you expect with the beneficial nematodes in the soil and how does their reproduction take place?

KIRK SMITH: Nematode movement in the soil is pretty complicated. It depends upon soil type, soil moisture, soil temperature, etc. They only move 3 or 4 in. in depth with a surface application. To get around this limitation, immediately following a nematode application we recommend a ¼ to ½ in. irrigation Nematodes will follow the water movement down through the soil strata. They do not tend to move much in the soil horizontally. In nursery situations with 1 to 3 or 5 gal pots one shot is enough to get the nematodes down into the root zone. Application techniques is one area we are studying now.

The nematodes reproduce in the insect hosts. We believe that the beneficial nematodes are best thought of as a biological insecticide. You make the application at the time the insect problem is present in the larval stage. The nematodes will persist for only about 3 or 4 weeks after application and will not kill the insects in the adult stage.