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Research On Controlling Insects Without Conventional Insecticides

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ABOUT THIS REPORT . . .

For over half a century entomologists and others with Federal, State, industrial, and other institutions have been searching for safe and effective methods of controlling insect pests, particularly through the use of natural enemies of those pests.

Spectacular success has been achieved in some cases, but the usefulness of natural control agents has so far had its limitations. However, in recent years research has taken a more hopeful turn. Scientists have concentrated on ingenious new techniques for exploiting the natural characteristics of insects--luring them with certain chemicals to which they are attracted, sterilizing them sexually, developing new crop varieties less suited to the pests, and mass producing and utilizing natural insect disease organisms for direct control.

This report describes some of the research on insect controls that do not involve conventional insecticides, gives a preliminary evaluation of the new techniques which are still largely experimental, and tries to help agricultural leaders judge the practical possibilities for controlling agricultural insect pests in new and better ways.

One promising nonchemical control method, the use of diseases against insects, is excluded from this discussion, as it is covered in the Special Report 22-74, "Use of Diseases to Kill Plant Insect Pests--A Research Progress Report."

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RESEARCH ON CONTROLLING INSECTS WITHOUT CONVENTIONAL INSECTICIDES

In the early days of agriculture, nature's own checks and balances were the only curbs on noxious insects. But as farming expanded and farmers aspired to a more efficient and dependable agriculture, and as new foreign insect pests inadvertently became established in the United States, insect control became increasingly necessary.

Most of the estimated 700,000 described species of insects in the world are harmless. Some 10,000 species in the United States have been classed as public enemies, capable of causing trouble for man under certain conditions. Entomologists consider that several hundred of these species are particularly destructive and generally require some measure of control in order that we may feed and clothe the nation economically and conserve its agricultural manpower and resources. One hundred and twenty-three of these noxious species are immigrants, many of which are among our most destructive insects.

Men and women were concerned with insects in this country over 200 years ago. Insect pest problems arose before the nation was born. As the population grew agricultural production also increased and some of our insects thrived under conditions ideal for their survival. From time to time new crops were introduced from abroad, some of which proved to be attractive to our native insects. Of even more significance, world commerce brought many new pest species to our shores, unaccompanied by their natural enemies. Some of the arrivals were not pests in their native lands but rapidly acquired this status under conditions in the United States.

The growth of commerce called for better agricultural commodities for shipment and storage. Consumers also demanded better quality products and discriminated against those stunted or damaged by insects. This forced farmers to use more effective measures against insect pests.

Improved tillage and crop rotation helped control some insects and cut down on insect damage to farm commodities. Special cultural practices and the observance of safe planting dates (a practical aid in control of the hessian fly) have been of value in the protection of certain crops from injurious insects.

The development and use of insecticides is a significant chapter in the history of our expanding agriculture. Insect control was at first a secondary use for some industrial chemicals such as paris green and london purple, but for the past half century chemicals have been developed specifically for insect control. During the 1940's, DDT, developed to protect our armed forces from insect pests, proved useful in agriculture. More recently, some highly successful broad-spectrum organic insecticides were also developed and greatly improved the efficiency of our agriculture.

However, great interest both historically and currently lies in other directions. For example, nature's own control agents, the parasitic and predatory insects and insect diseases, have received and continue to receive much research attention.

As early as the 12th century, Chinese and Javanese gardeners piled brush between their citrus trees to form bridges for predatory ants to attack caterpillars in the trees. A century and a half ago Erasmus Darwin recommended using syrphid flies against aphids, and English entomologists found the lady beetle ideal for this purpose. Three-quarters of a century ago a tiny wasp, Apanteles glomeratus, was brought into the United States to combat the imported cabbageworm.

At about that time our entomologists began searching foreign lands, where many of our most troublesome pests originated, for effective biotic agents. American entomologist Alfred Koebelé's introduction of the vedalia, a lady beetle from Australia, into California in 1888 quickly brought the cottony-cushion scale under control.

Since then many parts of the world have been searched for parasites and predators, and a wide range of insects has been screened for parasitic and predatory species. Many insect families, genera, and species have been systematically tested against certain pests.

Over 650 species of insect parasites and predators have been collected and brought into the United States, and at least 100 of them have become established. Although the control of the cottony-cushion scale by a lady beetle has been perhaps the most sensational, parasites and predators imported into this country are giving outstanding control of 20 of our serious insect pests.

The search for biological control agents is continuing.

Growing resistant varieties is an ideal way to protect crops from damage by insects. For the past 50 years entomologists and agronomists have been cooperating in a search for insect resistance in various crops and in the development of varieties that can withstand insect attack. As a result, insect resistance has been found in more than 100 species of plants. The practical importance of this type of insect control is demonstrated in strains of corn resistant to the European corn borer, corn earworm, and rice weevil; in varieties of alfalfa resistant to the pea aphid, leafhoppers, and spotted alfalfa aphid; and in varieties of wheat resistant to the hessian fly and wheat stem sawfly.

Some recent scientific innovations offer additional ways to achieve insect control. These are chemicals which can be used to lure certain species to their doom and sexual-sterilization techniques to destroy the reproductive potential of a species.

CHEMICALS AND INSECTS

Insecticides are tremendously important in improving the efficiency of agricultural production and in protecting the health and comfort of man, but their use has created special problems. One of the problems is that some 70 species of insects in the United States have displayed resistance to certain of the chemicals used against them.

Another problem is that some chemicals may destroy beneficial insects, birds, and other wildlife, and if applied directly or carried into lakes, ponds, and streams in sufficient amounts certain insecticides will kill fish. The use of chemicals is responsible for the buildup of certain insect pests through the destruction of their parasites and predators.

DDT, for example, is used against the codling moth in apple orchards but does not control leafrollers, aphids, mites, and scale insects on the same trees. Instead, DDT kills some of the natural enemies of these pests. Oddly enough, DDT destroys the predatory mites which prey on the plant-eating mites but does little harm to the latter. And when California orange groves were sprayed with DDT in 1945 to control the citricola scale, the DDT killed vedalia lady beetles, which had kept the cottony-cushion scale under control since about 1890. This permitted a resurgence of cottony-cushion scale until the use of DDT against the citricola scale was abandoned and the lady beetle recolonized.

In spite of these examples, it should not be inferred that all of the friendly insects are being killed by chemicals. Claims of wide scale destruction of parasites and predators by insecticides have not been substantial. Some of these beneficial insects may be protected at the time of spraying, even inside the treated host, and survive to destroy the weakened host. Parasites with alternate hosts are even less susceptible since they can survive on one host in an untreated area and then spread to destroy individuals of other host species still present in the treated area.

THE BALANCE OF NATURE

Scientists do not agree on the interpretation of the term, "balance of nature." At best, the term has inexact and faulty implications.

Opponents of chemicals for insect control frequently assume that all nature was once in "harmonious equilibrium" before modern man disturbed this plant-animal utopia. However, in ancient times when man did little to disturb the insect world nature permitted the plagues of the locusts, with the fat and the lean years. Food supplies shrank, man became hungry, but the locust populations eventually receded. That balancing left a deep imprint on mankind. Animal and plant populations have fluctuated continuously, and some species have disappeared.

A curve drawn to represent the population of an insect species over a period of time generally is a wavy line reflecting the oscillations in numbers--up when conditions are favorable, down when adverse. So balance in such cases is an average of conditions over the years.

The insect world has its own balance as between beneficial and destructive species, but this balance is not always favorable to man. When the food supply of one species is reduced or the food of another is increased, the equilibrium of nature is disturbed and adjustments must again be made. In a sense, therefore, man has upset the balance of nature by replacing great expanses of forests and native grass with crops, cities, and towns. Thus he has favored certain pests.

BIOLOGICAL CONTROL

Biological control of insects is the suppression of pest species through the action of other living organisms--the predaceous and parasitic insects and other animals and such insect disease organisms as viruses, bacteria, and fungi.

These biotic agents help control injurious insect species by greatly limiting the potential increase of the pest. The biologically curtailed pest may be much reduced in numbers, or in other cases be left relatively abundant. The resultant population may be so decreased that it is ineffectual. But often the surviving pest population is large enough to cause considerable economic damage.

Agents of Biological Control

Parasites and predators are the two kinds of agents most frequently referred to in biological control.

The parasites[1] discussed in this report are insects that live at the expense of insect pests and their relatives. The insect parasite usually makes its initial attack as an adult laying eggs in or on the body of the victim. Larvae from these eggs then develop inside or outside the host and feed on it. In either event the host ultimately dies from the attack, although it may live and feed for some time after being parasitized.

A predator kills the host rather quickly by direct attack and usually devours several or many individuals. The predator is often larger than the prey and frequently both adults and immature stages of a predator feed on the same insect pest.

Parasites have a restricted host range, often being specific for one insect. This characteristic may add to their effectiveness in the control of a particular pest. Predators, on the other hand, are generally less discriminating and may therefore be less effective against a specific pest insect. There are, of course, exceptions.

The insectivorous habit is found in all the major orders of insects although it is more common in some than in others.

The Hymenoptera (bees, wasps, and ants) is chief among the insectivorous orders. This order predominates not only in the number of species which feed on insects but also in the frequency and effectiveness of the members' attacks on noxious insects. Four families of parasitic wasps--Ichneumonidae, Braconidae, Chalcididae, and Scelionidae--are particularly significant in biological control. The tachinid flies of the order Diptera are important parasites of caterpillars.

Other orders with prominent insectivorous species are Coleoptera (the beetles), Hemiptera (the true bugs), and Lepidoptera (the moths and butterflies).

Certain species of predaceous mites are instrumental in checking injurious populations of other mites. For example, the typhlodromid mites suppress the two-spotted spider mite and other tetranychid mites.

Certain larger animals also are important in controlling insect pests although their value is difficult to measure. Birds are traditionally considered heavy consumers of insects under certain situations. Skunks, snakes,

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[1] Many microbes--bacteria, viruses, nematodes, protozoa, and fungi--also are true parasites. However, they are discussed only briefly in this report because the subject has been covered in Special Report 22-74, "The Use of Diseases to Kill Plant Insect Pests--A Research Progress Report."

moles, and mice also devour many insects. A shrew, one of the rodents, was distributed by the Canadians in Newfoundland forests in 1958 to help control the larch sawfly. But these larger species are rarely used deliberately to control insects.

Advantages of Biological Control

Use of parasites and predators for insect control presents some advantages not possible with chemicals. Because they are living forms, parasites and predators can be self-perpetuating if successfully established. The difficulty is in getting them established.

In those instances where parasites and predators have been established they become a part of the fauna to survive adverse weather, reduced food supply, secondary parasites and insecticides.

Biological control agents are virtually harmless to all but their particular hosts. Even if they parasitize or prey upon several different species, their diet is so restricted they feed only upon other insects. They, therefore, present no hazard to the health of man, animals, or plants.

Biological control agents may be effective when used in combination with other control measures. It is even possible to employ insecticidal sprays without harming many of the beneficial parasites and predators if the sprays are carefully selected and applied at just the right time. The use of insect pathogens in combination with other biological control agents or even insecticides is also an especially promising field.

The initial outlay necessary to discover, import and breed large numbers of a parasite for colonization is quite high, but the savings resulting from the self perpetuation of an efficient biological control agent can be substantial.

Limitations of Biological Control

Biological control is no panacea for meeting the insect problems of agriculture despite its merits. One of the chief problems in biological control through the introduction of parasites and predators is the difficulty of getting them established, and in sufficient numbers to be effective.

Another important shortcoming of biological control is that practically total control of some pests is necessary in order for the producer to meet current market standards and to safeguard the value of the crop. Biological control agents by themselves, however, seldom destroy all of a pest species even in restricted areas.

A moderate infestation of an insect pest on a forest, grain or fiber crop can often be tolerated even though substantial loss may result, but the fruit grower of today cannot tolerate even 5 percent damage by codling moth in apples or just a few fruit fly larvae in a basket of cherries, because of the consumer demand for clean fruit and because of pure food regulations which are in operation in most States. Also a 25-percent survival of the citrus black scale, for instance, may start a serious outbreak the following year.

At this stage of development natural control agents cannot approach the effectiveness of chemical sprays against many fruit and vegetable pests.

To suppress an insect pest without the use of chemicals, it generally takes a combination of natural and biotic factors, that may include adverse climate and other detrimental influences in the environment, and the insect parasites, predators, and diseases. The failure of any one of these may prevent control, and often the biotic agent kills a pest too late to prevent serious crop damage. A parasite of the squash bug, for example, destroys a very high proportion of its host, but only after the bug has caused heavy damage to the crop.

A succession of parasites and predators that attack the host insect in different developmental stages is usually needed to adequately suppress the host. Several parasitic insects and a disease pathogen, for example, attack the several larval stages of the gypsy moth, and predatory beetles devour the eggs, larvae, and pupae. But such a biotic complex is not available for many pests.

Another exacting and often unattainable requirement is that many parasites must have an alternate host on which to live until the primary host is again available. For example, Dexilla ventralis, a parasite of several species of the genus Popillia in Korea, was introduced into the eastern United States in the 1920's to control the Japanese beetle (P. japonica). However, this parasite did not become established in this country, mainly due to the lack of suitable alternate hosts to bridge the summer period when grubs of the Japanese beetle are not available in the field in a suitable stage for parasitization.

Some parasites and predators may be reduced to such low levels during light infestations that they cannot increase rapidly enough to be effective in a sudden outbreak of the pest. And when the pest population becomes very low, the parasites and predators may die out.

Some parasites and predators attack a pest on one plant quite readily but not on another. For example, a parasite that controls the greenhouse whitefly effectively on tomatoes is much less effective against the same pest on tobacco. The vedalia lady beetle attacks cottony cushion scale on citrus but ignores it on Spanish broom.

Thus, natural biological control agents have important limitations as the sole means of insect control. Nevertheless, they are of vital importance from an overall standpoint. They keep the numbers of many potentially destructive pests to such low levels that they are generally of minor importance and they prevent population explosions among many of the more destructive species, thereby making it possible to deal with them by applying other control measures.

The Appendix (pages 20 to 22) contains a list of insect parasites and predators successfully colonized in the Continental United States.

INTEGRATED CONTROL

Just as biological control involves the interaction of the whole environmental complex with the biotic agents and their hosts, so do many of the best control programs achieve their highest efficiency when various measures are employed concurrently or successively. For example, various cultural and mechanical measures can be used to get adequate control with limited chemical treatments; or various measures, including chemical treatment, can be used together with parasites and predators in a single control pattern. This approach is called integrated control.

Some entomologists believe that the integrated-control approach is a necessity in modern agriculture.

The integrated control concept has been put into practice in a number of instances, especially in California for the control of the alfalfa caterpillar and the spotted alfalfa aphid attacking alfalfa, and the cyclamen mite on strawberries.

Beneficial insects can sometimes survive treatments with an insecticide of short residual action if it is properly chosen and used. For example, it may be applied when the beneficial insects are in a resistant stage. Or it may be used so the beneficial insect is not readily exposed to the insecticide. Or areas can be left untreated so a reservoir of beneficial insects will be spared.

In one California experiment involving the rotational treatment of a citrus grove with chemicals to control the purple scale, only one-third of the trees were treated each year. The remaining two-thirds sustained a reservoir of beneficial insects. In 5 years this practice achieved exceptional control of the scale at a reduced spray cost.

California entomologists also applied the principles of integrated control against the spotted alfalfa aphid. They applied a systemic insecticide, which is absorbed into the plants. The chemical in the plant juices killed the plant-sucking aphid, but its parasites and predators, not plant feeders, were spared.

ARS entomologists found that when the tobacco budworm and tobacco hornworm were both infesting tobacco at the same time, top treatment of the plants with an insecticide gave good control of these pests in the upper leaves where they were most abundant. This restricted treatment spared the lower leaves from heavy insecticidal residues and gave Polistes wasps an opportunity to prey on the lighter hornworm populations on those parts of the plant.

In some cases the environment of a parasite or predator may be modified in such a way that the beneficial insect can operate to better advantage and thus reduce the amount of chemical control needed. The parasites might be provided with better food--certain nectar-bearing plants, for example--and they might be protected from secondary parasites or predators. Some parasites cannot tolerate the presence of ants that gather to feed on the honeydew of scale insects on citrus; control of the ants in such instances enhances the value of the parasites.

California workers showed that airborne dust on citrus foliage adversely affected the activity of parasites of the California red scale. Reduced soil tillage, growing of permanent cover crops in the groves, and irrigation by overhead sprinklers are being tried to reduce the amount of dust in the grove, and at the same time improve temperature, humidity, and light conditions for the parasites.

Proper timing of treatments has been used repeatedly to gain a degree of selective action with insecticides. Obviously, unnecessary treatments should be avoided and minimum dosages of insecticides used to gain the necessary amount of control. Elimination of all individuals of the pest species in a field may not always be desirable. The insecticide application ideally could lower the pest population below the economic level, and at the same time leave a food supply for an adequate number of beneficial insects to reduce any upsurge in populations of the pest.

Integrated control is one of our best approaches to safe, effective insect control. But development of the complex programs involved in this approach depends on our acquiring a much better knowledge than we have of the fundamentals of the ecology of insect pests as interrelated to their parasites and predators, insecticide use and its effects, and related crop-production practices.

One of the major obstacles to the development of properly integrated biological and chemical control procedures for some insects lies in the necessity of employing insecticides for the routine control of certain key insects for which natural enemies are a minor control factor. For example, in areas infested with the boll weevil it is difficult to consider integrated biological and chemical control for the bollworm. Biological agents are not effective in controlling the boll weevil and insecticides are necessary for this insect. The use of insecticides for boll weevil control destroys the natural enemies of the bollworm, which often control this insect effectively in the absence of insecticides. As a result insecticides may be required to control the bollworm.

The same situation exists with other major insect pests and major crops. Also, fluctuation in abundance of different kinds of insects from year to year may necessitate the use of an insecticide for a normally minor pest and thus complicate the development of a properly integrated biological-chemical control program for other insect pests.

OTHER CONTROLS WITHOUT CONVENTIONAL INSECTICIDES

Scientists have long tried to find effective natural controls for insect pests. Achievements of biological control could not keep pace with the expanding pest problem. Chemical insecticides were adopted. Yet there have always been farsighted scientists and many progressive farmers who felt that a better alternative can and must be found.

In recent years other alternate methods of insect control have been receiving increased research attention. A variety of biological principles are being applied. Some of these principles are population attrition through induced sexual sterility, the selective attraction, trapping, and destruction of certain species, and the development of crop varieties which will resist or tolerate specific insects.

The Sterility Methods of Insect Control

One of the encouraging developments in the conquest of man over insects is the concept of sexually sterilizing insects by various techniques so they may help destroy their own kind by preventing reproduction. This is the newest of the insect control methods. There are two ways in which the sterility principle might be used to help control or eradicate insects.

One method involves rearing, sterilization, and release of insects into the natural population so the sterile insects will compete in mating with normal ones and thus lower the reproduction rate. The other method, still in early stages of investigation, is to treat and sterilize insects in the natural population to reduce reproduction, rather than treat to kill. The latter plan saves the expense of rearing the pests to be sterilized. In either case, the sterile insects mate with fertile ones and the eggs that result are sterile.

By the former plan, enough sterile insects are released to outnumber the natural insect population and lower its reproductive capacity sufficiently to cause a downward population trend. If such releases of sterile insects are continued at the same level for several generations, the natural population will decline more rapidly with each subsequent generation since the ratio of sterile to fertile insects will become progressively higher each generation. This feature of progressive increase in efficiency as the natural population declines is unique. All other systems of population control achieve about the same degree, or perhaps a lesser degree, of effect as the population declines.

A satisfactory way of producing sterility in the insect is a basic requirement in this type of insect control or eradication. Three ways of producing sexual sterility in insects have been used or proposed: (1) Exposure to gamma radiation, as employed for sterilizing screwworm flies, (2) use of chemicals which sterilize insects, and (3) application of certain hybridization techniques. Research on hybridization as a means of producing sterile insects for release has thus far been greatly limited. The method could be of great value in meeting a number of our key insect problems.

Release of Sterile Insects for Mating

Early experiments in sterilizing insects employed X-rays, but the first attempts at sterilizing insects as a control measure employed radiation with gamma rays from cobalt-60. The eradication of the screwworm from the island of Curacao off the Venezuelan coast used the radiation-sterility technique developed by USDA entomologists. Later screwworms were eradicated in southeastern U.S. through mass releases of irradiated screwworm flies. A similar program is now under way to control the pest in the Southwest. Information on the use of the sterile insect release method against the screwworm is given in ARS 22-79, "Status of the Screwworm in the United States."

The success of the male-sterility technique in the eradication of the screwworm in the Southeast created much interest and speculation among scientists as to the potential usefulness of the method against other insects. It should be emphasized that the screwworm is among the most favorable species for the practical application of the sterile insect release method alone because of two features: (1) The natural population of the insect is relatively low, even during periods of high destructiveness and (2) a good economical method of mass rearing the insect was available.

The sterility method alone will not be an economically feasible control method for many insects that have reached their normal population densities. In all probability the method will have its greatest value as a much-needed adjunct to other methods of control for well-established insect populations, and for eliminating incipient infestations before the natural population has reached a high level.

A great deal of research has been initiated by USDA scientists to explore the potentialities of the method for certain select species. Research on the release of sterile insects as a means of insect control is under way on the Mediterranean fruit fly, melon fly, Mexican fruit fly, oriental fruit fly, boll weevil, pink bollworm, codling moth, European corn borer, sugarcane borer, tobacco budworm, tobacco hornworm, fall armyworm, Drosophila fruit flies, gypsy moth, and on several other insect pests and disease carriers.

Success with this technique depends on the following conditions:

(1) Sexual sterility of the insects must be obtained without serious adverse effects on mating behavior. The gamma radiation procedure is satisfactory for some insects but it has serious adverse effects on many species, such as boll weevils, mosquitoes, gypsy moths, sugarcane borers, and other insects. Chemosterilants appear to produce sterility with much less adverse effects in most insects, although in some species the competitiveness of the males after treatment is still greatly reduced. However, in general, it appears feasible to produce sterility in most insects either by radiation or with chemicals without serious adverse effects on the competitiveness of the males.

(2) The insects must be reared in substantial numbers. The numbers needed and the cost of rearing them that will permit practical use of the sterile insect release method will depend on the circumstances. For the elimination of very low level populations which are often difficult to detect and destroy, sterile insects may be of great value even though the cost of rearing the insects is high per unit number. It is possible, however, to rear many insect species on special media by the hundreds of millions or even billions at relatively low cost. Screwworms, for example, are raised successfully on a mixture of ground meat, blood, and water. Progress is being made in the development of mass rearing methods for a number of other insects.

(3) The sterile insects must be readily dispersible in a manner that will bring them into effective competition with normal males. Airplane releases of the sterile insects has been an important means of obtaining quick and widespread dispersal.

(4) If the sterile insects to be released are in themselves destructive, the number required must not create serious economic losses to crops or livestock, or produce excessive annoyance or unjustifiable risks to the health of man.

Until recently the screwworm was the only insect that had been eradicated in practical operations by releasing sterile insects. However, in experiments in 1962 and 1963 on the island of Rota in the Pacific, the Department's Hawaii Fruit Fly Laboratory demonstrated that the melon fly can also be eradicated by the release of sterile males. The natural population was first reduced by about 75 percent with bait sprays. Then from 4 to 10 million sterile melon flies were released each week on the 33-square mile island.

The natural melon fly population on Rota began declining rapidly with each new generation, as evidenced by the increasing ratio of sterile to fertile flies. Within 3 months fruit infestations declined to zero. Thus the melon fly is the second important pest that has been eradicated by the release of sterile insects. The melon fly is a multiple-mating species and its eradication confirms the views of scientists that a monogamous mating habit in an insect species, as in the case of the screwworm, is not an essential requirement for the application of the sterility principle.

Research has been conducted on several other species of tropical fruit flies. Tests have shown that the reproductive potential of the Mediterranean fruit fly, the Mexican fruit fly, and Drosophila fruit flies also can be adversely affected by the sustained release of sterile insects. The boll weevil has been eliminated in a small isolated field by the release of large numbers of chemically sterilized males.

In laboratory investigations the reproductive potential of caged insect populations has been reduced by introducing sterile insects of a wide range of species, including certain mosquitoes, the house fly, face fly, pink bollworm, codling moth, European corn borer, and gypsy moth. Canadian entomologists have shown that the reproductive potential of the codling moth can be greatly reduced by the use of sterile males introduced into field cages containing populations of normal moths.

Much research must be conducted on each insect problem to determine if the release of sterile insects will be useful in practical control or eradication efforts. Field experiments are usually difficult and costly. However, sufficient progress has already been made to justify a continuation and intensification of research both in the laboratory and in the field on such species as the oriental, Mediterranean, melon, and Mexican fruit flies, the boll weevil, pink bollworm, codling moth, tobacco hornworm, and Drosophila fruit flies.

Sterilizing Insects in the Natural Population

The sterility principle has its greatest potential when used in ways that will induce continuing sterility within the natural insect pest population. Research in this area has not advanced to a stage that the method can be used in practical insect control. However, because of the great potential of the method, intensive exploratory research is under way by USDA entomologists and chemists.

It has been shown that when sterile insects are released and compete with the normal insects for reproduction, the biotic potential of the natural population can be greatly reduced. A scientist of the Department then reasoned that if it were possible to sterilize instead of killing a given percentage of the insects in the natural population, it should be possible to achieve a double effect on the reproductive potential of the total number of insects in that population. The insects sterilized could not reproduce. Thus the immediate effect on the population and its potential for reproduction would be the same as if an equal number of the insects had been killed by an insecticide. However, if the method of producing the sterility did not seriously interfere with the normal behavior and competitiveness of the insects that have been made sterile, the sterile insects in turn would be able to adversely affect the reproductive potential of the normal insects remaining in the population.

The great advantage and potential of producing sterility in a population of insects or other pests instead of killing portions of the population can be illustrated by the following theoretical situation: If the natural population of an insect within the area of competition consists of 1,000 individuals and 900 are killed with an insecticide, 100 insects will survive to reproduce. If, however, in a similar area 900 of the 1,000 insects are sterilized, those sterilized cannot reproduce. From the standpoint of reproduction, this result is equivalent to killing the 900 insects. In addition, however, the 900 sterile insects can now compete with the 100 normal fertile insects that remain in the population and theoretically prevent reproduction in 90 of the normal insects. Thus, only 10 of the normal insects would be expected to mate with fertile insects and be capable of reproducing. In addition, if some of the sterile insects survive to overlap the subsequent generation, further adverse effects on the reproductive potential of the population can be expected. No such "time" effect can result from the killing system.

An important problem in connection with this type of insect sterility control is the development of safe and effective means for initially sterilizing a part of the natural insect population. The use of chemosterilants in conjunction with attractants that will lure insects in large numbers may be the answer. Research in that direction is in progress.

USDA entomologists and chemists have screened 3,000 materials and have found that at least 50 of them produce sterility in insects. Of the materials that have the ability to sterilize insects, three are most promising. They are apholate, tepa, and metepa. The materials that have shown most promise against both sexes of insects belong to the same class of chemicals that possess activity against certain types of cancer. Our chemists and entomologists are therefore cooperating closely with scientists of the National Institutes of Health in the evaluation of materials that are of interest in research on cancer.

Little is known about the hazards that may be associated with the use of chemicals that sterilize insects. Since these chemicals produce sterility comparable to that produced by gamma rays or X-rays, researchers working with them are proceeding with extreme caution. Investigators must take extra care in handling the materials in the laboratory just as they do in handling radioisotopes. Field tests must also be carried out with great caution. It is anticipated that safe use of a chemosterilant of the type now known to be active may be possible only when the chemical is employed in such a way that the target species of insect only will be exposed to it. Consequently, research on chemosterilants has given greater impetus to investigations on specific insect attractants.

Even though practical ways of using chemosterilants have not yet been developed, much progress has been made in testing chemicals that will produce sterility when the materials are ingested or contacted by the insect. The insects that have been sterilized under laboratory conditions by the use of chemosterilants include the stable fly, house fly, horn fly, face fly, screwworm, green peach aphid, boll weevil, pink bollworm, plum curculio, Mexican bean beetle, codling moth, citrus red mite, two-spotted spider mite, yellow fever mosquito, common malaria mosquito, oriental fruit fly, melon fly, Mediterranean fruit fly, Mexican fruit fly, cabbage looper, fall armyworm, locust borer, German cockroach, and Drosophila fruit flies.

Limited field tests in semi-isolated areas have shown that house fly populations can be greatly reduced by using fly baits containing a chemosterilant.

Sex Lures and Other Attractants

Chemicals emitted from the body of the female of certain species of insects help the male in locating a mate. Some structurally related synthetic chemicals are also attractive. The response caused by such attractants may be useful in the control of harmful insects.

The major studies on sex attractants have been conducted with moths (order Lepidoptera). Sex attractants have also been found in members of other orders--the Coleoptera (beetles), Hymenoptera (wasps, bees, ants), Orthoptera (grasshoppers, crickets, cockroaches), and Hemiptera (bugs).

USDA and German researchers made some of the earliest studies of sex attractants, working on the gypsy moth and the silkworm, respectively. Adult virgin females of the tobacco hornworm, southern armyworm, saltmarsh caterpillar, European corn borer, pink bollworm, peach tree borer, lesser peach tree borer, banded cucumber beetle, cabbage looper, and hessian fly are known to possess some special substance that attracts the males. Chemists are in the process of isolating and identifying the attractants with the goal of synthesizing them in the laboratory.

Sex attractants may be used in several ways for controlling insects as well as for gathering fundamental information about pests which might lead to their control. Males may be lured by the chemical into traps and then killed. A toxic material may be mixed with the attractant to destroy the males. And the sex chemicals may be used to attract large numbers of insects which could be collected, sterilized, and released among females of the native population to reduce pest numbers.

Attractants are also being used in surveys to determine the presence of infestations and in capturing insects for the study of migration, ecology, and population density.

The lures under investigation are highly specific in attracting only the males of the target species. Accordingly, this approach offers the possibility of controlling insects without adversely affecting other insects or man and animals.

Gyplure

The sex attractant extracted from the female gypsy moth was the first synthesized in the United States. A related substance called gyplure, which was also synthesized, also attracts the males. At present, the lure is used in special traps in surveys to determine the presence of the gypsy moth and the extent of infestations. Research is under way to determine if the attractant might be useful for the control or eradication of the gypsy moth.

Pink Bollworm Attractant

Improved detection of pink bollworm infestations may result from laboratory and field tests using a natural attractant obtained from female pink bollworm moths. This was reported last year by U.S. Department of Agriculture scientists. A means of early detection of this insect is needed because a damaging pink bollworm infestation cannot be determined until the damaged bolls fail to open properly.

The sex lure of the pink bollworm is located in the female's abdominal tip. Researchers have learned how to rear pink bollworm moths in large numbers on a synthetic diet. This is the first step in obtaining a supply of the attractant for chemical analysis and in developing a detection method and control for the cotton pest.

In field tests made at Torreon, Mexico, in cooperation with the Mexican Department of Agriculture, the extracted lure proved as effective in attracting male moths to baited traps as were light traps. Other insect species were not attracted to the substance.

Scientists are now working to identify chemically this natural attractant and hope it will lead to the production of a synthetic material that will be equally attractive. They believe a synthetic attractant for the pink bollworm offers as bright a prospect for future detection measures as gyplure does for the gypsy moth. Even if a synthetic is never available, they are confident enough material can be extracted from reared female pink bollworm moths for detecting the insect and defining the limits of any given infestation. Knowing the limits of an infested area would reduce the cost of control. The ultimate objective, however, is to utilize such powerful lures for direct control.

Other Sex Lures

Entomologists in the Agricultural Marketing Service have collected and tested a natural attractant produced by unmated female dermestid beetles. The substance attracted a high percentage of male beetles and may be useful in the development of a trap to lure the insects. The dermestids are serious pests of nonfat dry milk and other stored products.

Sex attractants have also been reported in other beetles, including the May beetle, banded cucumber beetle, mealworms, and several species of wireworms.

Among the Orthoptera, the cockroach produces a powerful sex attractant. Scientists working with the Department of Defense at Natick, Massachusetts, demonstrated the presence of a specific chemical substance in virgin females of the American cockroach which attracts the males. ARS scientists investigated ways of collecting the substance and have determined its chemical structure. Research is under way in efforts to synthesize the material. Such lure, if available in quantity, might be used in traps or in other ways as a means to control cockroaches.

The pine sawfly and the bumblebee among the Hymenoptera and the tropical water bug of the Hemiptera also possess sex attractants.

Other Chemical Attractants and Baits

A number of chemical compounds are very attractive to specific insects and can be used to lure the pests to traps or toxic baits. Extensive use has been made of traps painted yellow and baited with a mixture of 9 parts of anethole and 1 part of eugenol by volume to obtain information on the distribution of the Japanese beetle.

Methyl eugenol, a chemical compound, is a powerful attractant to males of the oriental fruit fly, a serious pest of tropical fruits. Flies attracted to the methyl eugenol, alight on surfaces treated with it, and avidly eat the material. In an experiment, a toxic chemical and methyl eugenol were mixed, smeared on fiberboard squares, and disseminated by plane over certain areas in Hawaii. The oriental fruit fly infestations in host plants were reduced by 60 to 82 percent, compared with untreated areas. Another test on the western Pacific island of Rota using a mixture of methyl eugenol and naled, a toxic chemical, as a bait has resulted in the eradication of the oriental fruit fly from those islands.

Acid corn or cottonseed protein hydrolysate liquid lures are used routinely in traps along our border with Mexico to detect invasion of the Mexican fruit fly.

Chemists in ARS have synthesized several attractants that are very effective in luring certain fruit flies. For example, siglure, medlure, and trimedlure are now available as strong attractants for the Mediterranean fruit fly, and cue-lure for the melon fly and several other species of fruit flies. These lures are of value in quarantine programs to locate fruit fly infestations. In Florida trimedlure is being used to detect the presence of any medflies that might have been introduced since eradication of the pest. There is great need to find new materials that will lure various species of destructive insects.

ARS scientists have found that one substance extracted from the cotton plant is especially attractive to the boll weevil and that another one is a strong feeding stimulant. These substances may be useful in trapping boll weevils or in the development of other means for controlling this pest.

For the control of house flies, effective baits have been developed that can be used without harm to man or animals or contamination of animal products. They may be used as dry baits, liquid baits, paint-on baits, or in bait stations. The baits contain a sweetening material, usually sugar, upon which the flies congregate to feed, plus a small amount of an insecticide.

The discovery by scientists in South Africa of compounds that strongly attract males of the Natal fruit fly started a series of investigations into such materials as an aid to control. As a result the use of a male attractant, terpinyl acetate, in citrus groves in South Africa was recommended as a control of this fruit fly. Within 6 months 120 glass traps baited with the attractant caught 58,000 males. Terpinyl acetate is also the best known attractant for the oriental fruit moth in the United States and has been used in surveys to determine the distribution of that insect.

The utilization of a protein hydrolysate-malathion bait spray, employing only about one-fourth as much malathion as would otherwise be required, was the major factor since 1956 in the eradication of the Mediterranean fruit fly from Florida.

A new bait for the imported fire ant developed by ARS scientists consists of corncob grits impregnated with soybean oil containing an insecticide known as Mirex. With this formulation, only 1/7 of an ounce of the toxicant is applied per acre in a single treatment, thus practically eliminating the hazards involved in previous treatments that called for much higher dosages of an insecticide.

Light As An Attractant

Light traps serve as an important and valuable method in collecting insects for taxonomic purposes, for the detection of the presence of insect pests, to determine insect population changes or trends, and in predicting potential infestations. They may eventually prove useful in the control of insect pests.

Light traps using ultraviolet or black light lamps are being used in experiments for attracting tobacco hornworm moths, by ARS entomologists and agricultural engineers. In a 113-square mile area in North Carolina 370 traps caught, in 1962, an estimated 50 to 60 percent of the adult moths in the area.

Other well-known insects which are attracted in the adult stage by artificial light include the codling moth, oriental fruit moth, corn earworm, various cutworms, fall armyworm, cabbage looper, cotton leafworm, European corn borer, European chafer, and pink bollworm.

In small-plot tests, Indiana and ARS scientists found that the yield of sweet corn undamaged by the corn earworm was significantly higher in plots where electric light traps were used than in check plots. Tomato hornworm infestation was reduced in plots with electric light traps.

Insect-Resistant Plants

The growing of crop varieties that are resistant to insects is a highly desirable means of pest control that has been used for many years. This method can be used without extra cost to the grower, without creating insecticide residues that might be harmful to man and domestic animals or wildlife, and without causing damage to parasites, predators or pollinating insects.

While breeding resistant crops seems an ideal approach to insect control, there are some difficulties in this method.

It usually takes several years to develop a variety resistant to one pest, and much longer to incorporate multiple resistances to a complex of insects and diseases which must be controlled on a single crop. Furthermore, our agriculture requires different varieties for the different geographic areas. Therefore, variety development must be done on not just one but several lines.

Add to this the necessity of having good agronomic and other characteristics as well as pest resistance. The resistant germplasm often is found in wild plant species or noncommercial breeding stocks, which introduce unacceptable characters as well as the resistance into the new lines. It sometimes takes many generations of breeding to eliminate the undesirable characters and reincorporate the best characters of existing commercial varieties, while retaining the new resistance. A resistant but otherwise poor strain, such as some of our earworm-resistant breeding lines of sweet corn, is worthless for commercial production.

Crop Varieties with Insect Resistance

There are insect-resistant varieties, strains, or hybrids of many crops, including alfalfa, apples, beans, cabbage, celery, clover, corn, cotton, cranberries, grapes, grapefruit, grass, oats, potatoes, rice, sorghum, sugarcane, turnips, vetch, and wheat. Some of these are suitable for use in breeding programs but do not possess enough desirable characters to be acceptable for commercial production.

Most of the progress with insect resistance in economic plants has been made in field crops, principally alfalfa, corn, wheat, barley, sorghum, and sugarcane.

The control of the hessian fly by the use of resistant varieties has been especially successful. Seventeen hessian-fly resistant wheats are now being grown on $4\frac{1}{2}$ million acres in 26 States. Previous to the availability of these resistant varieties, the only method for controlling the fly in winter wheats was delayed seeding, a method that was effective only for control of the fall generation. Farmers can now plant fly-resistant wheat earlier, get fall and winter pasture for livestock, and avoid hessian fly damage the following spring.

Five varieties of alfalfa resistant to the spotted alfalfa aphid have been released to farmers in the infested area and the total acreage of these varieties is increasing each year. Control of the aphid with insecticides is seldom, if ever, required in fields where resistant varieties are grown. In Arizona, over a 3-year period, damage to alfalfa foliage by the spotted alfalfa aphid was 15 to 22 times greater on susceptible than on resistant varieties.

The development of corn-earworm-resistant corn has been encouraging. In the South the percentage of kernels damaged by corn earworm in Dixie 18, a hybrid dent corn, has been only about 1/6 that of susceptible hybrids. Due to the development of corn-earworm resistance in sweet corn, some of today's hybrids have only 10 to 15 injured kernels per ear as contrasted with 22 to 25 for susceptible hybrids grown a few years ago. These corn-earworm resistant hybrids require less insecticide application to obtain 100 percent worm-free ears than susceptible hybrids.

Potato varieties have been reported resistant to at least 14 species of insects, including leafhoppers, Colorado potato beetle, and the tuber flea beetle.

Effect of Resistant Crop Varieties on Insect Populations

Varieties on which insects feed may exert a profound influence on insect's fecundity. For example, the spotted alfalfa aphid produces about 30 offspring per week on a susceptible variety, whereas on resistant plants the aphid produces only 4 or 5.

The most striking examples of the effect of resistant varieties on insect populations over wide areas resulted from releases of hessian fly resistant wheats in California and Kansas. From 1942 to 1944 two soft white wheats, Big Club 43 and Poso 42, both resistant to hessian fly, were released in areas in California where plant injury by the fly was serious. As a result, infestation levels of 50 to 100 percent, which had occurred annually from 1920 to 1944, were reduced by 1946 so that the insect was no longer a problem. A similar situation occurred in central Kansas where the variety Pawnee, moderately resistant to the hessian fly, was released in 1943. This variety soon became the predominant wheat grown in central and eastern Kansas, and from 1948 to 1962 there was no serious infestation of the hessian fly in that area.

The effect of resistant hybrids in reducing the number of surviving European corn borers has been reported frequently. Federal and State workers in Iowa found that resistant hybrids commonly have 50 to 60 percent less borer survival than susceptible ones.

While some resistant varieties cause a reduction in the rate of reproduction of the insect, other varieties are resistant because they can withstand or tolerate a heavy insect infestation without serious permanent injury. The general vigor of the plant at the time of insect attack may affect the amount of injury. Strong healthy plants growing in fertile soil are frequently most subject to infestation by insects. The European corn borer, for example, usually chooses the most vigorous plants on which to deposit eggs. Some varieties are able to recover from injury more rapidly than others. For example, some corn hybrids are capable of producing new roots rapidly when the corn rootworm feeds on the older roots.

Because of widespread development of insect resistance to insecticides, entomologists and plant breeders have been concerned about the permanency of insect resistance in crop varieties. Scientists have found biological races of hessian fly which are able to develop on wheat varieties resistant to the predominant race found under field conditions. However, in spite of this situation, Pawnee, a variety resistant to the hessian fly, has maintained a satisfactory degree of resistance for more than 20 years. Atlas, a variety of sorghum resistant to the chinch bug, has remained resistant to this insect since release in 1928. Even though instances of biological races of insects capable of infesting formerly resistance crops have so far been rare, entomologists and plant breeders are attempting to develop crop varieties that are resistant to all races and to more than one species of insect.

LOOKING AHEAD

Until alternate methods of insect control are developed we must continue to use insecticides to produce the quantity and quality of foods and fibers we enjoy today. However, research is taking new directions which may progressively open up alternative methods of insect pest control and reduce our dependence on such insecticides.

The use of insect parasites and predators has in many instances been very much worthwhile. In most cases, however, the natural enemies of insect pests under natural conditions do not provide adequate control. Entomologists face these realities and attempt to create conditions more favorable for the parasites and predators or by mass producing and releasing them to prevent buildup of the host insect.

The use of insect diseases offers another promising way to obtain insect control. Like parasites and predators, the disease organisms often fail to achieve the desired degree of control under natural conditions.

ARS is currently constructing a laboratory at Columbia, Mo., that will be devoted to basic research on the use of insect parasites, predators, and diseases for the biological control of insects. The work will include genetic studies of parasites and predators, factors that affect host preferences, the nutritional requirements of parasites and predators, research on insect diseases, and ways to integrate biological and chemical insect control programs.

The sterility approach to insect control holds great promise as a new way to control insects, either by the rearing and release of sterile insects or by the developing of ways to sterilize insects in the natural population. Research in these areas is progressing at an encouraging rate.

A method related to the sterility concept--the creation of lethal genes in insect strains through natural selection or induced mutation--deserves investigation. Such strains might be mass produced and released to introduce the lethal genes in the natural population. At present there is more hope than assurance in this concept.

The attractant approach to insect control probably offers the greatest possibilities for the development of effective and highly specific ways to control key insect species. The use of insect attractants was considered for many years with only limited success. However, new methods are under consideration such as the sex lures. Moreover, as chemical assay techniques improve, scientists are in a better position to search for and identify the specific substances that attract--such as sex attractants and specific food elements.

Considerable success has already been achieved in the development of insect-resistant crop varieties to reduce insect damage, but little is known as to the nature of the resistance. Newer techniques in chemical analyses and a better understanding of the nutritional requirements of insects should help in identifying the chemical basis of resistance and perhaps lead to more rapid progress in this important approach to insect control.

Agricultural engineers and biophysicists are delving into light and other radiations that produce responses in insects. Entomologists are developing new concepts of how to utilize methods of control more effectively. They are giving more attention to the total insect population in an area rather than just segments of the population.

As we learn more and more about the behavior of insects, about their environment, their ecological requirements, their population dynamics and how their development can be interrupted most effectively by various approaches, it will be possible to use a particular method, or perhaps more often several methods, in an integrated system that will control specific pests. Insecticides will always be needed for the control of many insects, but alternate ways of controlling the major species will materially reduce the quantity of conventional insecticides needed.

APPENDIX

Insect Pests and their Parasites and Predators Successfully Colonized in Continental United States
(See text for overall value of these control agents.)

FRUIT INSECTS

PEST	WHERE FOUND	PARASITE OR PREDATOR	SOURCE AND DATE INTRODUCED
Aphids, several species, Family Aphidae (see Field and Garden Insects)	Florida citrus and papaya areas	Leis dimidiata 15-spilota (Hope)	South China, 1924.
Apple mealybug, Phenacoccus aceris (Signoret)	Oregon, and Maine to Vermont	Allotropa utilis Mues.	Nova Scotia, 1960-61.
Black scale, Saissetia oleae (Bern.)	California	Aphycus helvolus Comp.	South Africa, 1924, 1937.
		Aphycus lounsburyi How.	South Africa, 1900, 1914; Australia, 1916.
		Aphycus stanleyi (Comp.)	South Africa, 1937.
		Coccophagus capensis Comp.	South Africa, 1914-15, 1921-23; Australia, 1918.
		Coccophagus cowperi Gir.	South Africa, 1937.
		Coccophagus pulvinariae Comp.	Do.
		Coccophagus rusti Comp.	Transvaal, 1937.
		Coccophagus trifasciatus Comp.	South Africa, 1924-25.
		Diversinervus elegans Silv.	East Africa, 1931, 1937, 1953.
		Lecaniobius utilis Comp.	Argentina, Brazil, 1934-35.
		Quaylea whittieri (Gir.)	Australia, 1900-01.
		Rhizobius debilis Blackb.	Australia, 1891-92.
		Rhizobius ventralis (Er.)	Australia, Tasmania, 1888-89, 1891-92.
		Scutellista cyanea Mots.	South Africa, 1900-01.
California red scale, Aonidiella aurantii (Mask.)	Chiefly California, Arizona, and Texas	Aphytis lingnanensis Comp.	South China, 1947.
		Aphytis melinus DeBach	India, Pakistan, 1956-61.
		Chilocorus kuwanae Silv.	China, 1901; Japan, 1916, 1923.
		Comperiella bifasciata How. (red scale strain)	South China, 1941.
		Cybocephalus sp.	South China, 1932-33.
		Habrolepis rouxi Comp.	South Africa, 1937.
		Lindorus lophantae (Blaisd.)	Australia, 1891-92.
		Orcus chalybeus (Boisd.)	Australia, 1892.
		Prospaltella perniciosi Tower (red scale strain)	Formosa, 1949.
Citrophilus mealybug, Pseudococcus gahani Green (see Tree and Shrub Insects)	California	Cleodiplosis koebelei (Felt)	Australia, 1928.
		Coccophagus gurneyi Comp.	Do.
		Scymnus binaevatus (Muls.)	South Africa, 1921.
		Tetracnemus pretiosus Timb.	Australia, 1928.
Citrus mealybug, Pseudococcus citri (Risso) (See Tree and Shrub Insects)	California and Florida	Allotropa citri Mues.	China, 1950.
		Cryptolaemus montrouzieri Muls.	Australia, 1891-92.
		Leptomastidea abnormis (Gir.)	Sicily, 1914.
		Pauridia peregrina Timb.	China, 1949, 1951.
Coconut scale, Aspidiotus destructor Sign.	Florida	Azya trinitatis Mshll.	Puerto Rico, 1938.
		Cryptognatha nodiceps Mshll.	Trinidad, 1936; Puerto Rico, 1938.
Comstock mealybug, Pseudococcus comstocki (Kuw.)	Eastern apple regions	Allotropa burrelli Mues.	Japan, 1939-41.
		Pseudaphycus malinus Gahan	Japan, 1941.
Cottony-cushion scale, Icerya purchasi Mask.	California, Arizona, and Southeastern seaboard	Cryptochaetum iceryae (Will.)	Australia, 1888-89.
		Rodolia cardinalis (Muls.)	Do.
Florida red scale, Chrysomphalus aonidum (L.)	Florida, Mississippi, Louisiana, California	Aphytis holoxanthus DeBach	Israel, 1959.
Gypsy moth, Porthetria dispar (L.) (see Tree and Shrub Insects)	New England, New York, New Jersey, and Pennsylvania	Anastatus disparis Ruschka	Central Europe, Japan, 1908-10.
		Apanteles melanoscelus (Ratz.)	Sicily, 1911-12.
		Blepharipa scutellata R.-D.	Europe, 1905-11, 1924-27.
		Calosoma sycophanta (L.)	Switzerland, Italy, 1905-10.
		Carabus auratus L.	Europe, 1907.
		Compsilura concinnata (Meig.)	Central Europe, 1906-11.
		Exorista larvarum (L.)	Italy, 1905; Europe, 1906-11, 1923-32.
		Monodontomerus aereus Wlkr.	Europe, 1905-10.
		Ooencyrtus kuwanai (How.)	Japan, 1907-9.
		Parasetigena agilis (R.-D.)	Central Europe, 1906-11, 1924-33.
		Phobocampe disparis (Vier.)	Central Europe, 1907-12, 1924-31.
Japanese beetle, Popillia japonica Newm. (see Field and Garden Insects and Tree and Shrub Insects)	The East	Dexilla ventralis (Ald.)	Korea, 1925-27, 1929-31.
		Hyperecteina aldrichi Mesnil	Japan, 1920-24, 1927-30, 1933.
		Prosena siberita (F.)	Japan, 1921-30.
		Tiphia popilliavora Roh.	Japan, 1920-22; Korea, South China, 1925-27, 1930-31, 1934-36.
		Tiphia vernalis Roh.	Korea, South China, 1924-33.

PEST	WHERE FOUND	PARASITE OR PREDATOR	SOURCE AND DATE INTRODUCED
		FRUIT INSECTS.--Continued.	
Long-tailed mealybug, Pseudococcus adonidum (L.) (see Tree and Shrub Insects)	California	Anagyrus fusciventris (Gir.) Anarhopus sydeyensis Timb. Tetracnemus peregrinus Comp.	Hawaii, 1936. Australia, 1933. South Africa, 1924, 1926; Brazil, 1934.
Olive scale, Parlatoria oleae (Colvée) (see Tree and Shrub Insects)	California and Maryland	Aphytis maculicornis (Masi) (Egyptian strain) (Indian strain) (Persian strain) (Spanish strain) Aspidiotiphagus sp. Chilocorus bipustulatus (L.)	 Egypt, 1948-49, 1951. India, 1951. Middle East, 1951. Spain, 1951. Iran, 1951. Israel, 1956-62.
Oriental fruit moth, Grapholitha molesta (Busck)	The East, California, and scattered elsewhere	Agathis diversa (Mues.) Agathis festiva Mues.	Japan, 1933-36. China, 1950.
Pineapple mealybug, Pseudococcus brevipes (Ckll.)	South Florida and Hawaii	Hambletonia pseudococcina Comp.	Brazil (via Puerto Rico), 1943-44.
Purple scale, Lepidosaphes beckii (Newm.)	California, Florida to Texas	Aphytis lepidosaphes Comp. Physcus fulvus C. & A.	Formosa and China, 1948-50; Formosa, 1949. China and Formosa, 1948-50.
Scales, several species, Family Coccidae (see Tree and Shrub Insects)	General in fruit areas	Chilocorus sp. near distigma (Klug) Exochomus quadripustulatus (L.)	Eritrea, 1953. France, 1905-06; Italy, 1915, 1927.
Walnut aphid, Chromaphis juglandicola (Kalt.) (see Tree and Shrub Insects)	Pacific Coast States, Utah and Idaho	Trioxys pallidus Hal.	France, 1959.
Western grape leaf skeletonizer, Harrisina brillians B. & McD.	Southwest, Utah, Colorado	Apanteles harrisinae Mues. Sturmia harrisinae Coq.	Arizona, 1951-53. Do.
Woolly apple aphid Eriosoma lanigerum (Hausm.)	General	Aphelinus mali (Hald.) Exochomus quadripustulatus (L.)	Northeastern U.S. Italy, 1928.
Yellow scale, Aonidiella citrina (Coq.)	California, Texas and Florida	Comperiella bifasciata How	Japan, 1916-17, 1922-24.
		FIELD AND GARDEN INSECTS	
Alfalfa weevil, Hypera postica (Gyll.)	General	Anaphes pratensis (Foerst.) Bathyplectes curculionis (Thoms.) Microtonus aethiops (Nees.) Tetrastichus incertus Ratz.	Italy, 1911-13, 1925-28. Italy, 1911-13 and California, 1960. Europe, 1957-61. Do.
Aphids, several species, Family Aphidae (see Fruit Insects)	General		
Asiatic garden beetle, Maladera castanea (Arrow)	The East	Tiphia asericae A. & J.	Korea, 1927-32.
Clover leaf weevil, Hypera punctata (F.)	General	Biolysia tristis (Grav.)	Italy, 1912.
European corn borer, Ostrinia nubilalis (Hbn.)	The East and the Midwest	Chelonus annulipes Wesm. Horogenes punctorius (Roman) Lydella thompsoni Herting Macrocentrus gifuensis Ashm. Phaeogenes nigridens Wesm. Sympiesis viridula (Thoms.)	Italy, 1929-37. France, Italy, 1921-23, 1925-37; Manchuria, 1930-32. France, Italy, 1920-35; Japan, Korea, 1929-36. France, 1926-33; Japan, Korea, 1929-32. Italy, 1924-32, 1937-38; Japan, 1931. Italy, 1930-34.
European wheat stem sawfly, Cephus pygmaeus (L.)	Eastern wheat areas and North Dakota	Collyria calcitrator (Grav.)	England, 1935-38.
Greenbug, Schizaphis graminum (Rondani)	General	Aphidus testaceipes (Cresson) Hippodamia convergens Guer.	U. S. native. Do.
Hessian fly, Phytophaga destructor (Say)	All small-grain areas	Pedobius metalicus (Nees)	England, 1890-94.
Imported cabbageworm, Pieris rapae (L.)	General	Apanteles glomeratus (L.)	England, 1875, 1883-84, 1891; Germany, 1881.
Japanese beetle, Popillia japonica Newm. (see Fruit Insects and Tree and Shrub Insects)	The East		

PEST	WHERE FOUND	PARASITE OR PREDATOR	SOURCE AND DATE INTRODUCED
		FIELD AND GARDEN INSECTS.--Continued.	
Pea aphid, Acyrthosiphon pisum (Harris)	General	Aphidus smithi S. & A. Hippodamia convergens Guer.	India, 1958-61. U.S. native.
Rhodes grass scale, Antonina graminis (Mask.)	Gulf States, New Mexico, Arizona and California	Anagyrus antoninae Timb. Dusmetia sangwani Rao	Hawaii, 1949. India, 1959-60.
Spotted alfalfa aphid, Therioaphis maculata (Buckton)	General	Aphelinus semiflavus How. Praon palitans Mues. Trioxys utilis Mues.	Near East, 1955-57. Do. Do. Do.
Sugarcane borer, Diatraea saccharalis (F.)	Gulf States	Agathis stigmatera (Cress.) Lixophaga diatraeae (Tns.) Paratheresia claripalpis (V.d.W.)	Argentina, 1929-30; Peru (assumed), 1932. Cuba, Puerto Rico, 1915, 1918-20, 1926-27, 1936-40. Argentina, 1929; Peru, 1929-31, 1932, 1936.
Yellow clover aphid, Therioaphis trifolii (Monell)	The East	Trioxys utilis Mues.	France, 1956-57.
		TREE AND SHRUB INSECTS	
Balsam woolly aphid, Chermes piceae Ratz.	East and West Coasts	Aphidoletes thompsoni Möhn. Cremifania nigrocellulata Cz. Laricobius erichsonii Rosen. Leucopis obscura Hal. Scymnus impexus Muls.	Europe, 1957-60. Europe, 1957-60. Europe, 1957-60. Europe, 1937-55. Europe, 1960-62.
Barnacle scale, Ceroplastes cirripediformis Comst.	Southern coastal areas, California, and Hawaii	Scutellista cyanea Mots.	Italy, 1895-98.
Birch leaf-mining sawfly, Heterarthrus nemoratus (Fall.)	Northern New England	Chrysocharis laricinellae (Ratz.) Phanomeris phyllotomae Mues.	Austria, 1930-34. Austria, 1930-35.
Browntail moth, Nygmia phaeorrhoea (Donov.)	New England	Apanteles lacteicolor Vier Carabus auratus L. Carcelia laxifrons Vill. Eupteromalus nidulans (Thoms.)	Austria, Italy, 1906-10. Europe, 1907. Europe, 1906-10. Central Europe, 1906-08.
Browntail moth,--Cont. Nygmia phaeorrhoea (Donov.)	New England	Exorista larvarum (L.) Meteorus versicolor (Wesm.) Monodontomerus aereus Wlkr. Townsendicellomyia nidicola (Tns.)	Italy, 1905; Europe, 1906-11, 1923-32. Central Europe, 1906-11. Europe, 1905-10. Europe, 1905-11.
Citrophilus mealybug, Pseudococcus gahani Green (see Fruit Insects)	California		
Citrus mealybug, Pseudococcus citri (Risso) (see Fruit Insects)	California		
Elm leaf beetle, Galerucella xanthomelaena (Schr.)	Pacific States and the East	Erynniopsis rondanii Tns. Tetrastichus brevistigma Gahan	Italy, 1909, 1911; France, 1924-25, 1932-35, Eastern U.S.
European earwig, Forficula auricularia L. (also general-nuisance pest)	Eastern Seaboard and the West	Bigonicheta spinipennis (Meigen)	France, England, Italy, 1924-29, 1931, 1938-39.
European elm scale, Gossyparia spuria (Mod.)	The East and California	Coccophagus insidiator (Dalm.)	France, 1953-56.
European pine sawfly, Neodiprion sertifer (Geoff.)	New England, New Jersey	Pleolophus basizonius (Grav.) Dahlbominus fuscipennis (Zett.) Exenterus abruptorius (Thnb.)	Hungary (via Canada), 1935, 1938, 1940. Europe (via Canada), 1935-36. Europe, 1941.
European pine shoot moth, Rhyacionia buoliana (Schiff.)	Northeast, North Central States, and Washington	Temelucha interruptor Grav. Orgilus obscurator (Nees) Tetrastichus turionum (Htg.)	Austria, 1931-35; England, 1936; Holland, 1937. Austria, 1931, 1933-35; England, 1936, Holland, 1937. Austria, 1931-35.
European spruce sawfly, Diprion hercyniae (Htg.)	Upper New England	Dahlbominus fuscipennis (Zett.)	Europe (via Canada), 1935-39.
Gypsy moth, Porthetria dispar (L.) (see Fruit Insects)	New England, New York, New Jersey, and Pennsylvania		

PEST	WHERE FOUND	PARASITE OR PREDATOR	SOURCE AND DATE INTRODUCED

TREE AND SHRUB INSECTS.--Continued.

PEST	WHERE FOUND	PARASITE OR PREDATOR	SOURCE AND DATE INTRODUCED
Japanese beetle, *Popillia japonica* Newm. (see Fruit Insects and Field and Garden Insects)	The East		
Larch casebearer, *Coleophora laricella* (Hbn.)	Eastern half of U.S.	*Agathis pumila* (Ratz.) *Chrysocharis laricinellae* (Ratz)	Austria, England, Holland, 1932-37. Austria, 1932-35; England, 1936.
Long-tailed mealybug, *Pseudococcus adonidum* (L.) (see Fruit Insects)	Citrus-growing areas		
Nigra scale, *Saissetia nigra* (Nietn.)	California	*Aphycus helvolus* Comp.	South Africa, 1938.
Olive scale, *Parlatoria oleae* (Colvée) (see Fruit Insects)	California		
Oriental moth, *Cnidocampa flavescens* (Wlkr.)	Massachusetts	*Chaetexorista javana* B. & B.	Japan, 1929-30.
Satin moth, *Stilpnotia salicis* (L.)	New England, Washington, and Oregon	*Apanteles solitarius* (Ratz.) *Meteorus versicolor* (Wesm.)	Hungary, 1927; Austria, 1932-33. Central Europe, 1932-34.
Walnut aphid, *Chromaphis juglandicola* (Kalt.) (see Fruit Insects)	Pacific Coast States, Utah, and Idaho		