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MANIPULATION OF COTTON AGRO-ECOSYSTEMS FOR BETTER INSECT PEST MANAGEMENT

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An attempt is made here to analyze the components of cotton agro-ecosystems and to illustrate how changes in these systems can aggravate pest problems on the one hand and on the other can be used for more effective management of pest populations.

The term agro-ecosystem is derived from the well-known ecological term "ecosystem" and emphasizes the special characteristics of agricultural ecosystems. These agro-ecosystems are a part of what Marston Bates has called the "man-altered landscape." The agro-ecosystem is a unit composed of the total complex of organisms in a crop-producing area together with the over-all conditioning environment and as further modified by the various agricultural, industrial, recreational, and social activities of man. In any case, the cotton agro-ecosystem should be considered more as a man-manipulated system than as a natural area.

In the practical analysis of an agro-ecosystem for pest management, emphasis is placed on the populations of the pest species, their competitors, the organisms that prey on the pests, the main and alternative food supplies of the pests, and the manner in which the other elements of the environment modify all of these. The determination of insect pest population levels is broadly under the influence of the agro-ecosystem and a knowledge of how this influence operates is essential to integrated pest control. A thorough understanding of the agro-ecosystem is also necessary to harmonize the control practices for different pests in such a manner as to prevent unacceptable disruptive effects. In the same way, a knowledge of the agro-ecosystem permits assessment of the mortality factors operating on a pest or potential pest population and will suggest subsequent manipulations to reinforce and enhance their action.

There are approximately 35 million hectares of cotton grown in the world each year. This is about 2.5% of the cultivated land. It is the most important cultivated crop in large agricultural states such as California and Texas. In some countries, e.g. Nicaragua, Egypt, Syria, it makes up 40% or more of the value of all export earnings. In nearly all cotton growing areas, insects are a serious hazard to the production of cotton and large amounts of insecticides are widely used for insect control.

COMPONENTS OF THE COTTON AGRO-ECOSYSTEM

In spite of its superficial simplicity, the cotton agro-ecosystem is a biological system. This system is dominated by a rather uniform, dense population of a highly-selected strain of plants. The major components of a cotton agro-ecosystem include the population of cotton plants, the soil substrate and its essential biota, the enveloping chemical and physical environment, an energy input from the sun, and the varied additional inputs of man. In certain cotton agro-ecosystems at particular times, additional elements, such as weedy plant species, plant pathogens, or phytophagous arthropods, may become critical or dominant components in the system. The cotton agro-ecosystem is a very ancient one. Cotton fabrics dating back to 3000 B.C. have been found in the Indus River Valley and cotton specimens dating to 2500 B.C. were found in Perú. Recently, a boll weevil has been found in Mexico associated with a cotton boll at least 1000 years old.

The Cotton Plants

There are something over 30 species of cotton but only four are cultivated commercially. The cultivated species native to the Old World are *Gossypium arboreum* and *G. herbaceum*. The New World cultivated species are *G. hirsutum* and *G. barbadense*. The famous long staple cottons of Egypt, Tanguis cotton of Peru, the Sea Island cotton of the West Indies, and the Pima cottons of southwestern United States are derived in large part from *G. barbadense*. The bulk of the other commercial cottons of the world are highly-selected strains of *G. hirsutum*. In many areas, the commercial cultivated cottons grow as escaped plants the year around. Most of the modern cottons are grown as annual shrubs although many retain the perennial characteristics of their ancestors. In some cotton agro-ecosystems, this perennial characteristic is utilized when the cut-off cotton plants are permitted to send out new shoots in the second or third growing season (ratoon cotton or socas). Special strains of cotton have been developed to provide special fiber quality, timing of fruiting, high fiber yield, and other characteristics. Most of these agronomic developments have occurred with little consideration of their relationship to pest problems. This was dramatically demonstrated by the devastating impact of the boll weevil on susceptible cotton plantings as it spread across the U.S. Cotton Belt in the early part of this century.

"As the boll weevil moved in its relentless march across the Cotton Belt, the damage it caused threatened to ruin the cotton industry. To appreciate the chaos caused by the weevil, it must be remembered that southern agriculture and industry depended almost entirely on the one crop--cotton--and that loss of from one-third to one-half of the yield occurred for the first few years in each newly invaded area. Farmers, merchants, and bankers were bankrupted; farms and homes in whole communities were deserted; labourers and tenants were demoralized and moved to other sections; and a general feeling of panic and fear followed the boll weevil, as it moved into locality after locality. . ." (Loftin, 1946)

In some cotton producing areas, considerable attention has been given to incorporating some insect resistance into commercial cotton varieties. The success with plant resistance for Empoasca in Africa is discussed in another paper by F.E.M. Gillham. With this exception of Empoasca, the great potential of plant resistance has been largely ignored as a possible means of controlling cotton pests until recently.

The pigment gossypol is present in small lysigenous glands in all parts of the plant (except the roots) of nearly all cottons. Because gossypol is toxic to non-ruminant animals and it has other disadvantages in processing cottonseed, considerable effort has been devoted to developing commercial cotton varieties with low gossypol content. Although desirable in some views these low gossypol cottons have proved to be highly attractive and susceptible to several cotton insects. In fact, such cottons are attacked by insects with no previous history of having been pests of cotton (Jenkins, Maxwell, and Lafever, 1966). This example stresses the necessity for a cooperative approach in developing varieties of cotton.

Cotton plant is characteristic in having dimorphic branches, indeterminate growth and by its shedding of small floral buds (squares) and young bolls (Faton, 1955). The last two of these characteristics are of great importance to insect pest management. Flowering is progressive and for a time it becomes more rapid as the plant grows. Normal shedding is slight early in the growing season but gradually increases as the season progresses. For a time, flowering is considerably greater than shedding, but later in the season boll shed may equal or even out-number the flowers produced. Even when there are no insects to bother fruiting forms, more than half the flowers that open fail to make mature bolls. In a sense, the cotton plant has a limited capacity to set bolls depending upon its growing conditions and health. Those cotton squares and small bolls in excess of this level will drop from the plant even if no insects are present. It matters not at all whether the squares drop because of insect feeding or because of limited fruit-carrying capacity of the plant. Insect-caused injury affecting fruiting forms in excess of the carrying capacity does not result in crop loss.

The seasonal distribution of flowering and boll-set in relation to insect infestations are also important. Some varieties of cotton, at least under some growing conditions will set most of the cotton crop within a period of a few weeks. Hence, protection of the plant from the ravages of insects need not be extended throughout the entire growing season.

The Insect Pests

Insects and related arthropods are a problem nearly everywhere cotton is grown. In the United States, over 100 species of insects and spider mites are known to attack cotton. In most cotton agro-ecosystems, there is a variable group of lepidopterous larvae attacking the roots, leaves, squares, and bolls. The complex varies from area to area and often is an apparent limitation to economically-sound production of cotton lint. In certain parts of the Western Hemisphere, weevils are the most important pests. From a world viewpoint, the widespread pink bollworm (Pectinophora gossypiella) is considered to be the most destructive cotton insect, but locally other insects often cause more damage. A large array of other pests, including stem weevils, plant bugs, aphids, thrips, and spider mites, attack in varying degrees all parts of the plant at all times in the growing season. For details see Pearson (1958). There were 1,326 species of insects listed from cotton in 1958. Only about 15% of them can be considered to be significant pests, and less than 50% are of major importance. With the exception of the pink bollworm, the major cotton pests are indigenous to the continents where they cause damage.

Appropriate manipulation of the agro-ecosystem by man can aid in preventing economic damage from these insect pests. Associated with the insect pest of cotton there is also a complex of beneficial organisms (parasites, predators, pathogens, and pollinators) and a group attracted to the cotton plants for nectar and to weed hosts.

Key Pests. There are usually only one or two key pests in any cotton agro-ecosystem. Key pests are serious, perennially occurring, persistent species that dominate control practices because in the absence of deliberate control by man, the pest population usually remains above economic-injury levels. In the cotton agro-ecosystems of the San Joaquin Valley of California, the key pests are bollworms and lygus bugs. In the Cotton

South, the boll weevil is the sole key pest over much of the area.

Evolutionary changes in cotton pests. The cotton pests are subject to many evolutionary pressures in addition to that resulting from the application of pesticides. Changes in the agro-ecosystem can eliminate a pest population or reduce it to insignificance. Or the surviving population of insects may be well-adapted to the new conditions and assume greater importance as pests. In a similar way, pest populations may evidence new characteristics so they can expand their geographical distribution.

For many years, the cotton boll weevil (*Anthonomus grandis*) in the United States was confined to the more humid regions of the South. It was assumed that it could not survive in the hot, dry regions of the Southwest. Then suddenly in the early fifties it moved westward into these formerly unoccupied areas.

In the Near East, the Egyptian cotton leafworm (*Spodoptera littoralis*) seems to have changed its habits. Formerly, the larvae fed almost entirely on the leaves, but now the middle and late instar larvae often enter the bolls. Also, this insect has now become the worst pest of apples in Israel, while prior to 1950 it had never been recorded on that crop.

Natural Mortality. The actions of parasites, predators and pathogens are important causes of pest mortality in many cotton agro-ecosystems. In others, and especially where heavy use of pesticides has eliminated the natural controls such actions may be minimal. The importance of parasites and predators in cotton agro-ecosystems has been most clearly demonstrated by the release of secondary facts through the use of organic insecticides. Also in many instances, there have been tremendous resurgences of pest species following the use of pesticides. These pest resurgences and secondary outbreaks are largely the result of the elimination of parasites and predators. There are many examples of such pesticide-induced outbreaks of bollworms, tobacco budworms, cotton aphids, and spider mites in the Cotton South. Examples from other countries are given in later sections of this paper.

The direct effect on the natural enemies is only one of the ways insecticides can disrupt natural control. Disruption of the food chains can also be important. For example, if aphid, spider mite, and thrips, hosts of omniverous predators such as Chrysopa, Nabis, Geocoris and Orius, are eliminated from the cotton agro-ecosystem early in the season by chemical treatments, which in themselves are not significantly harmful to the predators, the latter will starve, emigrate, or cease reproducing. Later, in the season when such strong-flying species as Lygus and Heliothis invade the fields, they are essentially free of predator attack and an explosive outbreak of the pest occurs. These alternative food sources for the predators thus can maintain the continuity of critical mortality factors. The value of partial control (e.g., 80% kill with an insecticide) in preference to full control (i.e., 98-100%) in some circumstances can also be most valuable. Each alternative situation must be carefully evaluated with full consideration of all implications to the population dynamics of the pest species.

Soils, Fertilizers, and Water

"How much water cotton needs depends on many factors, such as weather, climate, length of growing season, variety, depth and texture of soil, fertility, leaching requirements, quality of water, and the efficiency of scheduling and applying irrigation water." (Longenecker and Erie, 1965) Optimum use of water is rarely achieved and in most cotton agroecosystems the timing, quantity and quality of water is less than ideal.

Only 12% of the cotton in India is under irrigation. Where irrigation can be provided, the yields are 200 to 400 lbs/acre. Where there are no irrigation facilities, the production is only 90 to 110 lbs per acre, and in unfavorable weather the results are even worse. The average yield last year in Inida was only 126 lbs/acre (the highest on record for that country). The highest yields of cotton are grown in agricultural areas with bright sunshine and adequate supplies of irrigation water (Australia, Arizona, California, Israel).

In the Sudan, much of the success of the cotton crop depends on early and adequate pre-sowing rains (Ripper & George). Sixty percent of the considerable differences in yield from season to season are correlated with the amount of pre-sowing rains and with insect pests. In years of light pre-sowing rains, more sprays are needed over a longer period than when there are adequate rains.

There are some fifty short mountain streams or rivers traversing the coastal desert of Perú. The amount and seasonal occurrence of water in these streams largely determines the extent of the local agricultural development. The valleys differ in size, climate, soils, water supply and quality, crops, and pests. Each of these valleys is thus a self-contained micro-agro-ecosystem isolated from the others by severe desert stretches. Some of the streams extend far up into the Andes and have a permanent flow throughout the year. The shorter rivers that have their source in the lower hills flow only during the rainy season (December through April). In some of the valleys, irrigation water from wells has been developed to supplement and extend the supply from the rivers. (Elsewhere in this conference Boza Barducci has detailed the history of cotton production in one of these Peruvian valleys - the Cañete Valley.)

In the Manabi area of Ecuador, the rainy period is normally from January to April and this is the planting time. The rainfall for this period ranges from 40 to 110 cm. During the 1967-68 growing season there was only one rain, and a severe drought and crop failure resulted. In the affected provinces of Manabi, Guayas, Los Rios, there were 19,650 hectares planted to cotton, but only 3,910 hectares was harvested and in these the yields were about half normal (127 lbs/acre).

In Texas, under dry, non-irrigated conditions, the pink bollworm tends to affect fiber quality more than yield. Damaged bolls, unless almost completely destroyed, are harvested. The stained lint resulting from feeding of the pink bollworm larvae is thus ginned. This stained lint contributes to lower cotton grades and hence, coverpieces. Under irrigated conditions or high moisture conditions, the plant microenvironment is conducive to boll rots. Bolls damaged by the pink bollworm often rot to the extent that they are not harvested. In one dry-land situation, up to 50% of the bolls had to be infested with one or two larva before significant losses occurred. Under irrigated conditions, a 40% infestation resulted in severe losses (Adkisson, Brazzel & Gaines, 1963).

Irrigation and fertilizer practice may have an effect on the qualities of the cotton plant and influence the insect through the plant. Little information on this point is available for cotton, but it is common observation that Heliothis and the other lepidopterous species oviposit more heavily on plants with succulent growth.

Irrigation may also have direct influences on the insect pest population by modification of the prevailing physical environment. For example, Andres calculated a net reproduction rate for the spider mite, Tetranycuh pacificus, under hot, dry conditions and only 63 under humid conditions.

Weather and Climate

Although we are limited in what can be done to manage the physical environment of a cotton agro-ecosystem, an understanding of its influence on the physiology of the cotton plant and the insect pests is helpful. The cotton plant originated as a desert shrub and although extremely variable it is basically adapted to xerophytic conditions.

Both low temperatures and excessively high temperatures cause the plant to shed squares. In some areas, e.g. Israel, the excessively high temperatures of mid-summer cause the cotton to "cut out" and there is little boll set. Hence, there are two periods of boll set (about July 1 and Sept. 1). This extends the growing season and aggravates pest problems.

Some pests, e.g., pink bollworm, are most serious in late season. In areas where the pink bollworm is serious, it is often necessary to curtail the growing season even though there is favorable weather for boll set.

Weather is, of course, very important in determining the geographic distribution and seasonal incidence of insect pests. For example, the severity of the 1967 outbreak of Spodoptera littoralis in Israel has been blamed on the below normal temperature in July and August of that year.

Weeds and Other Plants

The cotton agro-ecosystem contains a large variety of plants that find the special conditions suitable for their growth and survival. Not only do these undesirable plants compete with the cotton plants for water, nutrients, and light, but they harbor and maintain insects and diseases. Some, e.g. Sida, are hosts for cotton viruses. Others maintain insect pests. Weeds also interfere with cultural practices and harvesting and when abundant, lower the grade of the harvested fiber. In some situations, these plants may be of benefit in helping to maintain beneficial insects.

The cotton fleahopper (Psallus seriatus) is dependent upon a series of host plants. In the spring it is on horsemint and other weeds, and then it migrates to cotton. When cotton has matured, the fleahopper transfers to croton and other weeds.

Parasites, Predators, Pathogens, and Others

A great variety of pathogens, including viruses, bacteria and fungi occur wherever the crop is produced. From the time the seed is planted in the ground until harvest, the cotton plant is subject to serious diseases. Plants infected with disease are sometimes more attractive to other pests and the weakened plants frequently are more susceptible to attack by insects.

In addition to the natural enemies of the insect pests, there are many other insects in the cotton agro-ecosystem. Some of these are attracted to the flowers for nectar and pollen. Another large group feed at the abundant extra-floral nectaries on the cotton plant. Finally, there are many scavengers and decomposers. At present, we have only the vaguest concept of how these numerous species operate in the cotton agro-ecosystem and of their importance.

Vertebrate Wildlife

The cotton field and its margins are important habitat for quail, doves, pheasants, rabbits, fish, toads, frogs, and other vertebrates. By and large, they do not have any significant influence on the production of cotton in the area. Decisions in pest control made only from the standpoint of cotton production may have disasterous impact on other values. Although cotton agro-ecosystems have been designed and developed for cotton production, they do have other values. Just as in the case of forested lands, the multiple-use concept should be applied to cotton lands. In agricultural areas, often far more is at stake than the personal interests of the individual farming the land at a particular moment in time.

INFLUENCE OF AGRONOMIC PRACTICES IN COTTON AGRO-ECOSYSTEMS

Any modification of cotton agro-ecosystems has the potential to change the crop plant and the crop environment and, hence, the attractiveness and suitability of the plant or environment to pests. On the one hand, changes in agronomic practice have been introduced without regard to the influence on pest populations and often have aggravated the pest problems. These have involved cultivation practices, plant spacing, new varieties, or modified fertilizer rates. On the other hand, these same cultural practices can be utilized to man's advantage in the total effort to manage cotton pests. Over the decades there have developed a series of traditional cultural controls that have aided in cotton pest control. These include production of an early crop, uniform planting date, cotton free period, stalk destruction, early harvest, destruction of infested bolls, destruction of alternate hosts, and trap crops.

The time of planting of the cotton crop is a factor which can have profound effects on insect problems. In some areas, the planting is timed to have the harvest occur during a dry time of the year. In some cases the planting can be delayed to take advantage of a "suicidal" emerge of pink bollworm adults before fruiting forms are available on the cotton. The cotton planting is also timed to have optimum soil temperature for rapid germination of the seed and growth of the crop. Any factor that extends the growing season tends to expose the crop to a greater risk of damage from insect pests. It is also desirable to plant the crop in any one area as nearly as possible at the same time so that it all develops and matures at approximately the same time. Defoliation, rapid harvesting, and destruction of crop residue also offer great potential for reduction of crop pests.

Pink bollworm. In Central Texas, the pink bollworm is controlled successfully almost entirely by cultural controls. This program is dependent on the additive effects of the partial controls resulting from community-wide stalk destruction with a "flail-chopper," immediate plowing under of the shredded crop residues, suicidal emergence of the pink bollworm moths, pre-harvest defoliation, modern ginning operations, and sanitation around the gins.

Neiva District of Colombia. The Neiva district is a small cotton-growing district in the upper reaches of the Magdalena River in the state of Huila. Cotton is planted in mid-January in the river bottom and is harvested in May or June to avoid flooding by the river. There is lots of wild cotton in this area but, apparently because of the short growing season, it does not seem to aggravate the pest problems. In all the "inland" cotton-growing districts of Colombia, cotton is grown in the first half of the year. In 1961, it was decided that cotton production could be greatly increased by growing another crop in the second half of the year. This led to a catastrophe. In the first half of the year, 5,236 hectares of cotton were planted and they produced 956 kg./hectare. In the second half of the year, 3,100 hectares were planted and encountered severe insect outbreaks. In spite of a heavy regime of insecticides, the yield dropped to 773 kg./hectare. This was an economic disaster for the cotton farmers because of the very high costs of crop protection. The next year there were only 480 hectares of cotton in the Neiva district.

HETEROGENEITY IN COTTON AGRO-ECOSYSTEM

The fact that crop monocultures are often severly damaged by pests whereas the diverse climax vegetation of many natural environments is little harmed, has led to the assumption that maximum diversity is desirable in agricultural areas. It is thought that this will preserve the stability inherent in the natural environment. However, hedgerows and other "semi-natural" vegetation that adjoin crops are well known to be overwintering sites for pests and often contain alternate food plants of many crop pests. Such vegetation may also benefit natural enemies if it supports their alternative hosts or prey but this will not automatically favor biological control. Much depends on whether this counteracts benefits to the pest population. Once the delicate stability of the climax vegetation has been disturbed by man, if only slightly, the vegetation, although still complex, may nevertheless have been sufficiently altered to benefit a pest relative to the natural enemies that previously regulated it.

In the present state of knowledge, it is difficult to generalize. Sometimes any form of diversity of plant species and age structure decreases pest damage but other examples show that damage decreases with increasing simplification. The best examples of the latter are where essential alternate hosts for the pests are removed at least for critical times of the year.

Man has tended to organize and simplify the cotton agro-ecosystem to maximize the yield of cotton fiber. Control of weeds has eliminated or reduced competition with the cotton plant for water, light and nutrients.

Efficient utilization of these same resources has been achieved by spacing of the plants, proper timing of planting, fertilization, and irrigation. When the cotton farmer turned to the use of chemicals to eliminate pests, he unwittingly brought another type of simplification. This unilateral use of insecticides often destroyed beneficial forms such as parasites and predators. The simplified cotton agro-ecosystem is advantageous for efficient production and harvesting of cotton fiber, but it can create other problems. But complexity when useful can be maintained in some aspects of the cotton agro-ecosystem.

Diversity within the cotton-field environment should be considered separately from diversity in the "semi-natural" uncultivated environments which are often found adjacent to it. Within the cropped area, diversity can often be readily established and manipulated (in terms of numbers of plant and animal species, plant age and cultural practices). This is already important in integrated control systems in some cotton areas, (e.g., strip-cutting of alfalfa and of cotton). Nevertheless, the kind and amount of diversity must be considered. Furthermore, the same kind of diversity can be harmful in one place and beneficial in another, e.g., in parts of Tanzania and elsewhere growing maize with cotton increases Heliothis damage to cotton, whereas in Perú this same kind of diversity helps to manage Heliothis populations. In some circumstances, the maize is the source and cause of damaging Heliothis attacks but in others, conditions favor continuity of natural enemies and the establishment of a stable equilibrium between the pest and its enemies which keep the pest scarce.

Recent studies in the San Joaquin Valley of California have introduced an unusual type of heterogeneity which is useful in reducing problems with lygus bugs and other pests (V. M. Stern, unpublished data). For example, alfalfa is planted in 20-foot strips every 400 feet across a 160-acre cotton field. In the field, this total adds up to be 10 acres of alfalfa.

Only half of each alfalfa strip is mowed at one time, so some lush succulent alfalfa is always present. When lygus bugs move into the cotton form adjacent fields of alfalfa, safflower or other sources, they concentrate in the alfalfa strips. Hence, it is not necessary to treat the cotton for lygus bugs. The insect predators so important in natural control of bollworms are not destroyed by insecticides. In addition, the alfalfa strips produced significant numbers of other beneficial parasites and predators early in the season; these move back and forth between the alfalfa and the cotton. In some field experiments, no insecticide treatment of the cotton for either bollworm or lygus bugs was necessary.

The effects and value of the diversity in uncultivated areas adjacent to crops are very difficult to assess, especially in areas where it is complex. Very small changes in the complexity may be all that is needed to aid biological control agents. Often these alterations can provide food or shelter for parasite and predator adults or alternate hosts for their larvae during times in the seasonal history of the population. The stress should be on the right kind of diversity.

Another aspect of heterogeneity is related to importance of maintaining minimum population levels of the pest species. The local populations of natural enemies which depend on the abundance of the pest will invariably be more harmed than the pest if the pest is locally exterminated or if the pest becomes scarce at a critical time. This is a cause of many pest resurgences which, in these circumstances, will occur even if pesticides selective in favor of the parasite or predator are used. The preservation of minimum pest numbers necessary to maintain an effective local population of the natural enemies, is therefore important. Under some circumstances, it may be advisable to release populations of the pest at critical times of the year to maintain the continuity of the pest population regulation.

Crop Sequence. In Central Texas, where alfalfa and maize are grown in the same river valley, the bollworm is greatly favored. The overwintering population of bollworm attacks alfalfa in the early spring. This permits this pest to bridge the period between spring emergence and the appearance of the favored host, maize. The second generation of bollworms then may increase to large numbers on corn. During the summer, cotton is the main host for the bollworm with alfalfa becoming important again in the fall. In contrast, the tobacco budworm has no important hosts in this area other than cotton and is not able to maintain as large populations (Henry S. Adkisson, 1965).

In the Cauca Valley of Colombia, in recent years there has been an increasing diversity of the agricultural production. Sorghum, maize, and tomatoes (all hosts for the bollworm) have increased greatly in acreage and the bollworm problem has increased significantly.

The contrast in size of cotton plantings between Costa Rica and Guatemala may explain in part the magnitude of their respective pest problem. In Costa Rica, the fields are scattered and often surrounded by pasture land or uncultivated areas. In Guatemala, the cotton plantings are often grouped into nearly solid large blocks containing 30,000 manzanas or more.

Size of Planting per Grower (manzanas)	No. of Growers	Total Area (manzanas)
	Costa Rica	
less than 50	40	1063
50-99	29	2025
100-199	17	2081
over 200	11	2975
	97	8144
	Guatemala	
less than 500	36	9130
500-1000	30	20200
over 1000	34	74400
	100	103730

ECONOMICS OF PEST CONTROL

It is essential for the rational development of a pest control system in an agro-ecosystem to determine for the several pest populations a threshold level below which any inputs for control operations would be unwarranted economically or perhaps harmful. From the broad view of all human society, all crop losses (diminished supply of food and fiber) are to be considered real losses; however, the costs of achieving the full crop potential may exceed the potential benefit. Systems analysis can assist in reaching the decision as to how to maximize the return from both the viewpoint of society and the individual crop producer. The latter may consider only a portion of the reduction in yield or quality as a loss to him. His determination, made consciously, intuitively, on good or bad advice, or however, will be influenced by such elements as the available technology for crop protection, cost of avoiding the potential loss, marketing conditions, the ultimate use of the crop, and other benefit-related factors for the producer that can be achieved by avoiding the loss. Furthermore, the exogenous economic matrix must be understood by the crop protection specialist and fully meshed with an understanding of the ecology of the pest species and their natural enemies.

In developing procedures, to make decisions for crop protection actions it is essential to understand the relationship between pest infestation level and potential crop loss. Although the relationship between pest numbers and crop-loss is complex (Smith, 1967, 1968; Johnson, 1965), some guide-lines are needed to make crop protection operate efficiently. It is now a common goal in entomological research to determine "economic injury thresholds," that is, the maximum pest population that can be tolerated without producing an economic crop loss. With the economic injury levels defined, it is possible to design the management system to keep the pest population below these levels rather than attempting to eliminate them completely.

Initially, the determination of economic injury thresholds can be based tentatively on empirical evidence, i.e., by deducing from experience with the pest. Later, however, these levels should be reviewed constantly and readjusted in accordance with changes in farming practice and with additional information obtained from further observations and from experiments specially designed for the purpose.

IMPORTANCE OF CHEMICAL CONTROL

In 1964, 143,184,000 pounds of insecticides were used on crops in the United States. Over half of this amount (78 million pounds) was applied to cotton. That corresponds roughly to 6 pounds of active ingredient per acre (Eichers et al, 1968). In 1967, 3,295,835 acres of cotton were treated by commercial operators in California. (Cotton accounts for nearly 30% of the total acreage treated). Considering the additional treatments by farmers, the average number of treatments per acre for cotton was six. This was a cost of production amounting to about $35/acre, but some cotton farmers spent nearly $100/acre. In Nicaragua in 1966-67 season there were 15,381,389 liters of liquid insecticides and 2,897,579 kilograms of dusts applied on 155,000 hectares (i.e., 99.2 liters and 18.7 kg. per hectare). It is clear that large amounts of insecticides are applied to cotton.

Although in some cases, there may be mis-use and over-kill with insecticides in cotton agro-ecosystems, it is also clear that the maintenance of these agro-ecosystems is dependent on pesticides. While the broad integrated control approach attempts to employ non-chemical control procedures and utilize environmental suppressive elements to their fullest, it should be understood clearly that chemicals are, and probably will remain, our main tool in the management of pest populations especially as they approach or exceed economic levels. It is vitally important to integrated control programs that an adequate array of pesticides be available and that they be used to reduce threatening situations with little or no disruption within the agro-ecosystem.

While discussing the importance of chemicals in integrated control programs, it is essential to give special consideration to selectivity. If chemicals are to be used in a harmonious manner in the agro-ecosystem then we must have materials that are inherently selective or which can be used selectively. All pesticides have some selectivity but the range in degree of selectivity is substantial. Much effort has been expended in seeking materials with relatively high toxicity to invertebrates and low toxicity to mammals. This is, of course, necessary but we must also seek differential toxicity within the Phylum Arthropoda. We do not need that ultimate in specificity which would permit us to prescribe a specific chemical for each pest species. However, we do need effective materials that are specific for groups of pests such as aphids, locusts, lepidopterous larvae, weevils and muscoid flies. There are now some indications that the chemical industry can produce such materials on an economically feasible basis.

Under integrated control systems, often the population dynamics of the situation or the pest abundance crop damage relationship is such that we do not need to have high percentage mortality. Instead of seeking 95% mortality or higher, we may be satisfied or even happier with a kill of 75% or even much lower. Under such circumstances, the dosage or pesticide needed for the low percent mortality permits the desired selective action.

The development of new highly specific pesticides will undoubtedly come very slowly. In the meantime, we shall have to make the best use of those chemicals now available. In this regard, we have not fully utilized the selectivity available through the modification of dosages, formulations, times of application, methods of application and other techniques. Over the years, economic entomologists have developed a wide array of procedures to increase the percent mortality to the target pest species. These same techniques should now be explored to provide a differential mortality between the target pest and the non-target organisms. We do not need "perfect selectivity" (an all or none situation) rather it is more desirable to have a differential kill that leaves the balance in favor of the beneficial forms.

INSECT RESISTANCE TO PESTICIDES

The development by insect pests of resistance to insecticides has played an important part in increasing difficulties encountered in pest control in cotton agro-ecosystems. The development of resistance to a pesticide in a particular pest population will depend on whether genes for resistance are present in the population, the degree and kind of selective pressure, the genetic mechanism controlling the resistance, the genetic plasticity of the species, the rate of gene flow in the population, characteristics of the species and population such as dispersal behavior, generation time and reproductive rates, and degree of isolation of the population. In an integrated control system, there is less risk of the development of resistance than where there is heavy selection pressure by the unilateral use of pesticides. This is the result of a lowered level of selection pressure because pesticides are no longer responsible for virtually all of the mortality. Furthermore, the selective action of the pesticide usage is directed against only relatively small portions of the population scattered in time and space. In the intervals between pesticide treatments, different selective pressures from other control procedures and from other elements of the environment will modify the large remaining population and may reduce any trend toward resistance. The use of selective materials enhances this pattern and avoids the development of resistance in other pest species associated with the target species.

U.S. Cotton Belt: (Newsom and Brazzel, 1968). The cotton leafworm, (*Alabama argillacea*) and the cotton aphid (*Aphis gossypii*) were the first cotton pests in the U.S. Cotton Belt to develop resistance to chlorinated hydrocarbons. As these were relatively unimportant pests crop protection practices for cotton were not affected seriously. However, by 1955, the boll weevil had become resistant to the chlorinated hydrocarbons. Resistance developed rapidly in all the other major cotton pests in some part or all of their areas of distribution. For the control of the boll weevil and the other resistant pests, a change was made to the organo-phosphorus insecticides. These have been fairly successful, but in 1965 a population of *Heliothis zea* was found to show appreciable resistance to organo-phosphorus insecticides. More recently, the same was shown for populations of *H. virescens* in Central Texas. Spider mites have also developed such resistance.

Perú: In the development of the cotton crisis in the Cañete Valley (see Boza-Barducci), the development of insecticide resistance was a critical factor. In late 1952, BHC was no longer affective against aphids. In the summer of 1957, toxaphene failed to control the leafworm Anomis. In the 1955-56 season, Anthonomus reached high levels in spite of treatments. Next Heliothis virescens developed a very heavy infestation and showed a high degree of resistance to DDT.

Egypt: Egypt produces annually about a million bales of extra long staple cotton (1 3/8" and over) and another million bales of long staple cotton (1 1/8 - 1 3/8"). This represents about one-half and one-third respectively of the world supply of these special cottons. Egyptian cottons are derived from Gossypium barbadense and have evolved in Egypt over a period of more than 150 years. The isolation of this closed cotton agro-ecosystem and the widespread and intensive use of insecticide for control of the Egyptian cotton leafworm (Spodoptera littoralis) have combined to facilitate the rapid development of resistance. A severe drop in total production and yield per acre occurred in 1961. In 1960-61, 2,205,000 bales were produced on 1,945,000 acres with an average yield of 542 lbs./acre. The following year it dropped to 1,548,000 bales from 2,062,000 acres with an average yield of 359 lbs./acre. This drop was attributed to the loss of control because of the development of resistance to toxaphene in the Spodoptera populations and the relaxation in hand collection of egg masses. In 1966, a similar loss occurred and control costs were very high. The Spodoptera population is now also resistant to endrin and parathion. More potent insecticides, such as Azodrin® and Cyolane® have been introduced, but their cost is considerably higher and the probability that resistance will develop to them looms over the outlook for the future.

Iraq and Syria: The situation in Iraq is quite similar to Egypt except the spring bollworm (Earias insulana) is the main pest. In some years the spring bollworm is reported to destroy 80% to 90% of the crops. In 1953, endrin was introduced for control. By 1964, it was useless because of resistance and spider mites had become a serious problem. In nearby Syria, no insecticides have been used for the past two years on cotton. A number of pests (aphids, leafhoppers, cutworms and thrips) are reported to cause minor damage. Heliothis occasions sporadic local damage. Spodoptera has not been reported in recent years. Earias and Pectinophora both appear regularly at the end of the season but the damage they cause is light.

EXTRA-LIMITAL ASPECTS OF THE COTTON AGRO-ECOSYSTEM

The cotton agro-ecosystem is more than the relationships among the cotton plants and their conditioning environment. The agro-ecosystem also includes the associated agricultural, industrial, recreational and social activities of man. Hence, crop pest control must now, more than ever, conform to the framework of society. The habits, customs and traditions ingrained into a culture must be accommodated. The structure of land tenure, religious beliefs, pricing and marketing systems, and educational institutions can all help or hinder a technological change or modify the magnitude of a pest problem. Furthermore, an action that brings about a new technology or a change in technology may have significant social and political consequences. These "extra-limital" aspects of the agro-ecosystem pose serious questions for the pest management specialist as well as for the ecologist.

In some situations, the new or modified techniques for pest control are developed and the advantages to be derived from their use are clear, but there is no motivation for the farmer to change his current practices.

This is particularly so in those areas where subsistence or peasant agriculture is the way of life. The modifications needed to introduce a more productive agriculture (with better pest control as a part of it) may require a shift in human values, ownership of the land, long established customs or other difficult changes. The importance of land ownership and social structures are exemplified by the self-sufficient hacienda or fazenda system of Latin America with its isolating and conservative influences (Tannenbaum, 1960).

Another consequence of pest control actions that has been given considerable attention lately, at least in certain quarters, is the broad social implications of control decisions. This is especially clear in pest control actions in forests where multiple-use of the land is a clearly established principle. An ill-considered action may control the target pest attacking the forest stand but at the same time recreational potential, fishery and hunting resources, or other values may be seriously eroded. The same may apply to control actions to agricultural areas where often far more is at stake than the interests of the individual farming the land at a particular moment in time.

The possibilities of a cotton crop failure in Central America are very great in the next year or two if current practices are not modified. The possible social and political implications are many, especially when one considers that over 30% of the export dollars for countries like Guatemala and Nicaragua come from the sale of cotton fiber. It is no exaggeration to say that pest control advice which leads to an economic calamity may topple a government. The further complications are many and foreboding.

A LESSON UNLEARNED

The story of cotton pest control in the Cañete Valley of Perú (see Boza-Barducci Chapter) stands as a classical example of the impact of unilateral use of pesticides in a cotton agro-ecosystem. The experiences in Peru in the early fifties strikingly illustrate that pest control cannot be analyzed or developed in isolation; rather, it must be considered and applied in the context of the ecosystem in which the pest populations exist and in which control actions are taken. But this important lesson has not been learned in spite of other relevant examples in cotton agro-ecosystems around the world.

Central America

The growth of the Central American cotton industry has been phenomenal. As late as 1950-51, there were less than 100,000 acres in Central America and a production of 55,000 bales. By the late fifties this had risen to about 300,000 acres and a production of 340,000 bales. The great increase in cotton acreage is the result of land reform, opening of new areas to agriculture through malaria control and new roads, and government supported prices. In the peak season of 1964-65, the acreage was 928,000 and the production 1,335,000 bales. At least 90 percent of this cotton is exported, and cotton is an important source of export earnings. The production has not remained so high in recent years because of low rainfall in some areas and increasing pest problems. For example, in Nicaragua the yield per acre dropped from 821 lbs. in 1964-65 to 621 lbs. in 1967-68.

With the exception of the cotton producing districts in Honduras, most of the cotton in Central America is grown in the fertile Pacific plain extending from Tapachula, México to the Guanacaste Province in Costa Rica. In general, the pest problems are very similar in all parts of the area. In El Salvador and in Guatemala, there seem to be more problems with rank cotton and boll rots. In Costa Rica, where the somewhat isolated fields are surrounded by pastures and undeveloped land, cotton production has fewer insect problems. The average number of insecticide treatments is only about 10 per season in Costa Rica as compared to the 30 or more in the other countries. In general, cotton is planted at the beginning of the rainy season and harvested in the dry season.

There has been a significant change in the composition of the insect pest complex on cotton during the past ten years and a major increase of magnitude of the problem. About ten years ago, the Colombian pink bollworm (Sacadodes pyralis) and the cotton boll weevil (Anthonomus grandis) were the most important pests of cotton. The cotton bollworm (Heliothis zea) was an occasional pest as were the cotton aphid (Aphis gossypii) and the cotton leafworm (Alabama argillacea). With the increasing cotton production, there has been a great increase in insecticide usage. In spite of increasing dosages and numbers of applications of pesticides, poorer control results have been obtained in recent years. The organic chloride insecticides have gone out of use probably because of the development of resistance but this is not well documented scientifically.

Currently, the cotton bollworm (together with Heliothis virescens and H. subflexa) is the most important pest. The Colombian pink bollworm is hardly noticed and the cotton boll weevil is of secondary status. An array of formerly minor pests has been raised to major status. In the last two years a complex of Spodoptera (=Prodenia) species have assumed major importance. There are at least five species involved (sunia, ornithogalli, eridania, dolichos, and latifascia). Their relative importance and habits are not known. The cabbage looper (Trichoplusia ni) has reached outbreak status in many fields. In all areas, the cotton whitefly (Bemisia tabaci) and its associated viruses appeared as a major pest and is very difficult to control. This happened in El Salvador in the late part of the 1961-62 season. The same occurred in Honduras in 1964 and in Nicaragua and Guatemala in 1965. Presumably, these secondary pests have been released from their natural control and have become difficult to control.

In several areas, the average number of applications is over 30 per year, and some individuals have made over 50 treatments to a field in a single season. There is heavy reliance on the use of a methyl and ethyl parathion to control these cotton pests. There is considerable evidence of insect resistance. If this resistance becomes greater then the possibilities of a complete crop failure are very great.

During the 1966-67 and 1967-68 growing seasons, serious residue problems developed in some districts particularly when the cotton insecticides drifted to beef and dairy cattle pasture areas. An increased hazard to man also resulted. There were hundreds of cases of insecticide poisoning in man reported with many deaths.

The situation in Central America is not a simple causal relationship between the misuse of pesticides and severe pest outbreaks. Other factors are involved; these include below normal rainfall, poor cultural practices, increasing cotton diseases and in some areas inadequate soil fertility. The 1966-67 and 1967-68 seasons were rainfall deficient periods in many growing areas and this hurt the cotton crop. But more importantly, there has been a general neglect of good cultural practices by many farmers. Abandoned cotton fields are often allowed to stand until the next growing season producing flowers, fruits, and insects. In fields where the cotton plants are cut off and burned, the plants "ratoon" and provide survival sites for insects and a source of virus diseases. Many fields are not plowed until time to prepare the land for the next growing season. In most Central American countries there are regulations to maintain a cotton free period, but these regulations are inadequately enforced. Nevertheless, the misuse of pesticides and the aggravated insect infestations have been the major element in the declining yields.

Turkey

At present Turkey is the sixth largest exporter of cotton and the ninth world producer of cotton fiber. The yield per hectare has more than doubled since 1950 (264 kg. to 551 kg.) as the result of better varieties, use of fertilizers, irrigation, insecticides, and better soil management. The Kaban Dam on the Upper Euphrates River will bring in about a half million hectares of new irrigated land and most of this will be planted to cotton. On the surface the outlook is bright but the danger signals are present. The pest problems have been gradually becoming more severe over the years. The cotton leafworm has become resistant to methyl parathion. The spiny bollworm is resistant to endrin. Spider mites were not an important problem prior to 1965; now treatments are required regularly at least in the Adama area. Mostly because of lack of rotation, verticillium wilt is serious in some areas. There has been a generally rising level in the cost of production mainly from the use of pesticides.

Colombia

Although cotton pest control is under a rigidly enforced supervised control program, some new problems are appearing and some of the old patterns of trouble are indicated for the future. Authorization to purchase and apply organic pesticides to cotton can only be made by a licensed "ingeniero agrónomo." A serious attempt is made to avoid unnecessary treatments with parathion as happened in 1964. In that year, early treatments with parathion for Alabama greatly aggravated problems with Heliothis later in the year. The growers now try to control Alabama and other early season lepidopterous pests with arsenicals. However, when Heliothis appears they treat with methyl parathion. The Heliothis problem has been increasing because of increased production of maize and other crops. The use of methyl parathion increases the problems with Tetranychus telarius, Eotetranychus planki, Liriomyza sp., Bemisia tabaci, and probably Spodoptera and Prorachia daria. These secondary pests and the impending resistance to parathion in Heliothis presents a grim outlook for the future of pest control in Colombia.

South Texas

The bollworm (Heliothis zea) has become an increasingly important pest of cotton over the past 20 years or more. The tobacco budworm (Heliothis virescens) has more recently become important as a pest of cotton. In recent years, its importance has paralleled that of the bollworm. Destruction of predators and parasites appears to be the major factor in the changing pest status of these Heliothis species. They have developed resistance to all of the chlorinated hydrocarbons and to the carbamate insecticides. In recent years, chemical control of these pests has depended on methyl parathion. During the 1968 growing season, populations of the tobacco budworm in the lower Rio Grande Valley were found to be moderately resistant to methyl parathion. The level of resistance is already sufficient in that valley to interfere with chemical control and to add to its cost. There is every reason to believe that very shortly methyl parathion will be ineffective against the tobacco budworm. The development of resistance in the cotton bollworm can be expected to follow the pattern of the tobacco budworm. No adequate substitute chemicals are available at this time. Opinion varies as to how much time is available before the current chemical control procedures fail completely. In any case, time is short.

CONCLUSION

Scientific pest control has always required a knowledge of ecological principles and especially of the natural factors regulating pest populations (FAO, 1968; Smith, 1968). With the introduction of new and more sophisticated technologies, it will be necessary more than ever to take into consideration the ecological aspects of pest control.

Modern holistic approaches in ecology have now reached the stage where they can be used effectively to understand and analyze insect pest problems. In many situations, there will be alternative control procedures to be selected, or we must choose between the positive and negative values of an action or group of actions. Modern computer systems analysis offers opportunities to obtain the best decision (Watt, 1968). It is, of course, critical in the use of these techniques that we pose good questions to the computer. However, the ability of computers to store and transmit information and to arrive at conclusions based upon the information by high-speed logical processes, offers us a powerful tool for pest population management and resource management.

It becomes clearer each day that resources of all categories are limited and decisions as to the allocation of the resources are extremely difficult. The difficulty lies in the complexity of our environment, the subtle, varied and multiple implications of specific actions, and the conflicts in interest and opinion as to what is important and desirable. In many situations, the short run view indicates that resources should be allocated to create higher productivity so that people may be fed; but in the long run other values such as the quality of human existence and the stability of production should be considered. Again, systems analysis offers a tool to help us optimize the allocation and utilization of resources (Watt, 1968).

LITERATURE CITED

[to be added later]