PESTICIDES IN TROPICAL AGRICULTURE

A collection of papers comprising the Symposium on Pesticides in Tropical Agriculture, presented before the Division of Agricultural and Food Chemistry at the 126th meeting of the American Chemical Society, New York, N. Y., September 1954

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Introduction

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The growing world population requires an ever-increasing dependable supply of essentials for living. Agricultural development of tropical lands has been on the increase for decades. However, only in relatively recent years has intensive agricultural development of these lands become so important.

Pest control of small agricultural developments has not been economically feasible, because of a milpa or roving agriculture carried on by individuals. All of this is changing with greater demand for food, higher costs of production, and transportation developments within tropical countries. Intensive agriculture is developing, and with this crop pests are becoming a growing problem because of concentrated acreages and the need for more economical production.

Pest control is an old problem in the tropics as well as in other parts of the world. However, many well recognized factors such as supply, demand, distribution, and finances have limited the use of pesticides. Recently this has changed. The assistance programs, recognition of need for agricultural development by tropical nations, pioneering instinct on the part of many individuals, further development by foreign capital, and desire of chemical industry to develop foreign markets has contributed to the changes.

The need for pest control in tropical crops is definitely on the increase, and this is brought out in the papers of this symposium. These by no means cover this important subject. Omission of discussion of many crops from this program does not depreciate their importance, but time does not allow their inclusion. Literature on pesticide control of tropical crops is accumulating in many scattered publications—for example, tea culture has been adequately covered by Lamb and others in *World Crops* for May 1954. It is hoped that this symposium will pave the way for future discussions of this important subject. Pest control in tropical agriculture is a challenge to both the scientist and the manufacturing chemist.

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Use of Pesticides on Basic Food Crops in the Tropics

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Any significant rise in living standards in tropical countries depends upon improved yields of basic food crops. While the wider use of pesticides and fungicides would improve yields of these crops, this increased use of these materials must develop along with a general improvement in other agricultural techniques. Pesticide materials now available meet most of the requirements for good control of the prevalent diseases and pests. It is essential, however, that the companies producing them have more accurate data on tropical conditions and that they give more attention to educating the farmers in the correct use of the materials.

During the past three or four decades the precise use of insecticides and fungicides has become a standard procedure in the production of maximum yields of food crops. In regions where the highest average yields are obtained, effective insect- and disease-control programs are not only widely practiced; they are regarded as basic to a sound agriculture. It is more than coincidence that high average yields of food crops often are associated with a high standard of living. Yet only recently has it been recognized that any significant rise in living conditions in tropical countries depends upon an improvement in the yields of the basic food crops, such as corn, wheat, beans, and potatoes.

The use of insecticides and fungicides in the tropics has been confined largely to the plantation crops, such as bananas, cacao, sugar cane, and coffee. These export crops are grown on a large scale; the owners and operators are interested in cash returns, and have the capital to invest in pest control. Unfortunately, the basic food crops in the tropics are generally left to fend for themselves, and little or no effort has been made to control the injurious diseases and insects that attack them. The fields are small, the average farmer has no information available on pest control, and even if it were on hand, very few would be able to act upon this information because of limited capital and inadequate credit facilities. As a result, the yields of basic food crops are extremely low, and the population is correspondingly ill-fed, with a large percentage of the people tied to an unproductive agricultural existence.

Tropical farmers have often resorted to ingenious schemes to escape the local pests and diseases. Certain dates of planting are religiously observed, and more often than not there are good reasons for planting at such particular times. Blights are avoided and peak populations of insect pests appear too early or too late to do serious damage. Low-yielding native varieties are planted widely because they are drought-tolerant or have some resistance to locally prevalent insects and plant pathogens.

There can be little doubt that wider use of the proper fungicides and pesticides on tropical food crops could do much to alleviate the hunger and poverty of many people. But there are several reasons why this development will probably be slow. First of all, accurate information on the nature and control of local pests is lacking for much of the tropics. Recommendations too often are based on experience in the

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temperate zones. Second, the inability of impoverished farmers to invest even in such elementary agricultural needs as fertilizer rules out their using insecticides. Third, a large proportion of the population is on the land, producing their own food at a very low cost. It is difficult to show, in these cases, that it is economically feasible to control insects and diseases unless all other factors contributing to higher yields (fertilizers, good land preparation, use of higher yielding varieties, etc.) are likewise given some attention. Thus the wider use of pesticides on low-cost basic foods must develop along with a general improvement in agricultural techniques. Fourth, the great potential market for fungicides and insecticides in the tropics has not yet been developed by the companies that manufacture them. Inadequate stocks and uninformed or apathetic dealers and representatives are the basis for many complaints. These faults are being corrected, but too often these conditions are characteristic.

Corn

Corn is a basic food throughout the American tropics. The kinds of corn planted usually are local varieties that have survived centuries of selection and will give consistent but low yields year after year. During this long period of selection, corn varieties with some tolerance or resistance to the prevalent pests and diseases have tended to survive. It is doubtful that extensive use of pesticides on these native varieties is practical. However, as new higher-yielding varieties and hybrids are introduced, the plant pathologist and entomologist must be on the alert to protect the potentially greater yields from the depredations of insect pests and diseases that previously might have been unimportant. However, for the control of the common endemic diseases of corn we rely upon the plant breeder and plant pathologist to develop resistant varieties cooperatively.

The two most important leaf diseases of corn in the tropics are rust *Puccinia sorghi* Schw., and leaf blight, *Helminthosporium* spp. Experiments in Mexico have shown that rust can be controlled by applications of ordinary sulfur dust or certain fungicides based on carbamic acid, such as ferbam (iron salt of dimethyl dithiocarbamic acid). However, the cost and difficulty of application have restricted the use of any fungicide for rust control to the protection of special lines of interest to the plant breeder despite their susceptibility to rust. For the control of *Helminthosporium* blight, the plant breeder has at his disposal a number of sources of resistance, and with epiphytotics sufficiently frequent to provide good screening, he usually has no difficulty selecting desirable resistant types.

Corn seed treatment has not usually resulted in improvement in stand where it has been tried in Mexico. High soil temperatures, favoring rapid emergence, tend to reduce any possible benefit. One important need is a good repellent that can be safely applied to corn seed. Rodents and crows are common thieves in recently planted fields, and are responsible for much of the replanting that has become customary in tropical lands.

In Mexico there exist two major insect pests of corn, an armyworm *Laphygma frugiperda* (A. & S.), which breeds and feeds in the leaf whorls of young corn, and the larvae of certain coleoptera which inhabit the soil and feed upon the roots of the corn plants. Of these two the armyworm is the most important. Its attack is particularly severe on corn grown during the summer but, as it is able to breed continuously, it is a problem in corn grown throughout the year in the tropics.

In Mexico it has been found that DDT used as a dust applied into the leaf whorls of the corn plants, while the larvae are still in the early stages of development, has given excellent control of the pest. Work conducted in Colombia *(1)* has shown that a complex of species including *Laphygma frugiperda* commonly attacks corn. There it has been found that toxaphene is the most effective means of controlling this pest.

The principal soil inhabiting pests of corn are the larvae of *Diabrotica* and white grubs. While more research needs to be done on the dosage requirements and residual effects of the chemicals used to control these important pests under tropical conditions, results to date indicate that the soil insecticides commonly used in the United States, such as chlordan, aldrin, and dieldrin, are promising.

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In addition to these two groups of insects, spider mites of the genus *Paratetranychus* are a third but less important pest of corn grown in the tropics. Work completed to date has shown that Aramite [2-(*p-tert*-butylphenoxy)-1-methylethyl 2-chloroethyl ester of sulfurous acid], Neotran [bis(*p*-chlorophenoxy) methane], and Ovotran (*p*-chlorophenyl ester of *p*-chlorobenzenesulfonic acid) as well as some of the highly toxic phosphate insecticides have given excellent control of this mite.

Wheat

Stem rust (*Puccinia graminis tritici* Eriks. & Henn.), leaf rust [*Puccinia rubigo-vera tritici* (Eriks. & Henn.) Carl.], and stripe rust [*P. glumarum* (Schmidt) Eriks. & Henn.] are the principal foliage diseases of wheat in Latin America. The wheat breeders and pathologists look for resistance to these rusts as a basic character in any improved variety. The constant struggle to produce varieties resistant to a changing group of rust races is a well-known story. The use of protective fungicides to control the rusts is not considered practical. Interest has been renewed recently, however, in this method of control as a means of halting outbreaks in critical areas which are potential centers of inoculum for more widespread areas.

There is a real need for a systemic fungicide that will reduce or prevent damage from rust. The search for a practical, effective material offering possibilities for rust control is still in the experimental stage.

The control of stinking smut or bunt can be accomplished easily and cheaply with materials now available. Where this disease is still responsible for important losses, an education and extension program is needed rather than new fungicides.

Insects do not represent a major problem in wheat production in Mexico. Sporadic damaging outbreaks of cutworms, including *Agrostis ypsilon* Rotenburg and other species, occur in the state of Sonora, the major wheat-producing state of the republic of Mexico. Little or no research work has been done on this entomological problem as yet. The farmers find that flood irrigation, when it is possible, gives good control of the cutworm.

The presence of aphids, *Toxoptera graminum* (Rondani) and *Macrosiphum granarium* (Kirby), on wheat during March and April has caused considerable alarm to wheat farmers in central Mexico. It has been found, however, that in the majority of cases the aphids do not represent a serious economic problem. Naturally occurring predators are able to reduce the aphid populations rapidly. For cases in which this natural biological control is not effective it has been found that benzene hexachloride (BHC) applied as a dust gives good control of these pests.

Beans

Beans are grown widely throughout Latin America and are one of the staple foods. As they are often interplanted with corn or other crops, disease and insect control with pesticides is seldom practiced. At present levels of production it is doubtful whether such control would pay. Investment in pest control is economically sound only when it is practiced in conjunction with improved cultural methods and higher yielding varieties.

While insect control is more often a limiting factor in tropical bean production, there are several diseases that are serious in certain seasons and locations. Bean rust is one of the most widespread diseases, and it can be controlled effectively with protective fungicides, such as elemental sulfur and certain of the carbamic acid derivatives. The economics of bean production usually preclude any costly applications, however, and the problem has generally been turned over to the plant breeder to solve with resistant varieties. At present, the most practical control of bean anthracnose and the bean blights is through the use of clean seed and resistant varieties. Control with fungicides has always proved difficult and of doubtful value.

Insects are among the limiting factors in bean production in Mexico. The most common and widespread insects occurring on beans are the leafhoppers of the genus *Empoasca*. It has been found that DDT gives excellent control of these pests. The Mexican bean beetle, *Epilachna varivestis* Mulsant, does not occur as generally as the leafhopper, but when it becomes established it will completely destroy a bean crop if the proper control measures are not practiced. It has been found that cryolite and methoxychlor [1,1,1-trichloro-2,2-bis(*p*-methoxyphenyl) ethane] give very

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inconsistent results in the control of this beetle in Mexico. Dilan and some of the phosphate compounds have given good results in experimental tests.

In addition to the leafhoppers and Mexican bean beetle there are other insects which, when their damage is taken collectively, constitute an important loss in bean production. These insects are the apion pod weevils, *Apion* spp., *Diabrotica* spp., white flies, *Trioleurodes* spp., and leaf miners, *Chalepus signaticollis* Baly. It has been found that when the proper insecticides are applied correctly to a good stand of beans the use of insecticides is profitable to the grower.

Potatoes

The potato is a basic food crop in the Andean region of South America, and is an important cash crop in many other sections of Latin America. The investment necessary to produce a crop is considerably higher than in the case of corn, wheat, or beans, and the potato grower is correspondingly more interested in protecting this investment wherever diseases or insects are likely to be a problem.

By far the most important disease is late blight, *Phytophthora infestans* (Mont.) DBy., which is a serious problem throughout the world wherever potatoes are grown. Potato growers from Mexico to Chile apply some sort of protective fungicide to prevent the ravages of this fungus. The materials used may vary from country to country, but in general can be classified in two groups: copper compounds and organic compounds, primarily certain carbamic acid derivatives.

The copper compounds include Bordeaux mixture and the so-called "fixed coppers" including the copper oxides, copper oxychloride, copper oxychloride sulfate, and related materials. Bordeaux mixture, since its discovery about 70 years ago, has been the classic fungicide for the control of late blight and still is more widely used than any other single material. Certain of its qualities, particularly adhesiveness, remain unequaled by its commercial competitors, and it is cheap and effective. However, the inconvenience of preparing Bordeaux mixture, and the unreliable quality of hydrated lime available in most places, have tempted many growers to switch to other copper compounds or organics.

In a series of thorough trials over a period of 6 years in Mexico, a number of the fixed copper compounds have been compared under severe blight conditions. No important difference in effectiveness has been demonstrated among them. Experiments elsewhere have likewise failed to show any marked superiority of one material over the others. They are easy to apply, though more expensive than Bordeaux mixture and perhaps less effective under severe blight conditions.

The organic compounds developed by commercial companies for late blight control have proved to be excellent fungicides, and they have usually given better yields than the copper compounds. The best organics tested in Mexico have been based on the zinc and manganese salts of ethylene bisdithiocarbamate. The main disadvantage of the available organics is their comparatively high cost. Furthermore, there is some doubt as to their effectiveness when the interval between applications is long. Because large acreages in the mountainous regions of South America are treated with small hand equipment, the interval between applications often is 3 weeks or more. Under such conditions the or anics have failed to produce as good results as more adhesive and more stable compounds.

Early blight, *Alternaria solani* Kuhn., is a problem in some areas, particularly in warmer climates where potato growth is not optimum. Control can be obtained by protective sprays, particularly with the organics that have been recommended for late blight control.

In a very local area in Mexico, the larvae of *Phyrdenus muriceus* have been found to be an important pest of potatoes. The application of soil insecticides, including aldrin, dieldrin, and chlordan, have given good control in experimental tests. Further work, however, needs to be done with this pest before definite conclusions may be made. As in other countries, the use of DDT applied to the foliage results in healthier plants and greater yields.

Tomatoes

The most important foliage diseases of tomatoes are the early and late blights that also attack potatoes. Because tomatoes are a warm country crop, early blight

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is more important on them than on potatoes, while late blight tends to be less of a problem. The organic fungicides have given excellent results in the control of these two diseases, and in general are the same materials that are effective controls for potato late blight. The copper compounds have not been as good on tomatoes.

The limiting factor in tomato production in the tropics is more apt to be a virus disease than a fungus disease of the foliage. The control of virus disease by control of the insect vector has been investigated in Mexico on potatoes (leaf roll, purple top), tomatoes (several unidentified viruses, one of which perhaps is curly top), and corn (corn stunt). Virus control in this way has been variable but usually negligible. This lack of control perhaps is due to slow kill of the insect vector, or to the continuous entry of the vector into the field.

The tomato suck-fly, *Dicyphus minimus* (Uhl.), has been found to be a problem in tomato production in the state of Morelos. The use of DDT has given good results in the control of this pest.

Discussion

At present fungicides are used sparingly on the basic food crops in tropical America. Their wider use on these crops must develop along with the evolution from a small scale subsistence type of agriculture practiced by the majority of the population, to a cash-crop type of agriculture, where larger individual holdings on the better lands can support the rest of the population.

The pesticide materials now available meet most of the requirements for good control of the prevalent diseases and pests in the tropics. Most urgently needed are accurate data to provide reliable guidance to commercial firms having pesticides for the market in tropical countries. In the tropics, as elsewhere, the more progressive farmers are always interested in improvements and better methods. Too often, unfortunately, they are disillusioned by control failures which are due to lack of information or to ineffective or inappropriate materials.

The pesticide companies must gain the confidence of the farmer not only by selling high quality materials but also through a program of education implemented by competent representatives who are willing to tell their clients, the farmers, what pesticide to use and to show them by demonstration how, where, and when to use it. Further, as many of the newer insecticides—for example, the organic phosphate insecticides—are extremely toxic to mammals, it is the responsibility of the pesticide companies to make sure that they are clearly and properly labeled in the language of the country in which they are to be used. The situation in which these things may not have been done is slowly being corrected, and the responsibility for correcting it rests with the sales and development divisions of reputable companies. Basic to the extended use of pesticides, of course, is research work establishing the facts necessary to intelligent use of the proper materials under local conditions.

The use of fungicides and insecticides in some areas will give much greater flexibility in planting dates of important crops. Farmers have established certain dates as most appropriate for planting because they favor the escape of insect pests or diseases that may be ruinous. In certain parts of Central America farmers try to plant their corn before a certain day in May, because corn planted later never does well. It has been shown, however, that the planting date can be delayed a month or more and a good crop still result, if the soil near the hill of corn is treated with benzene hexachloride. This treatment controls a corn root worm that makes a seasonal appearance and ruins late plantings of untreated corn.

The principal potato-growing areas of Mexico are in the high forested mountains of Central Mexico. Here potatoes are planted in the latter part of the dry winter season, with the hope that enough rain will fall to get a crop but not enough to bring the deadly late blight. When the rainy season comes, the plants die and are called mature. Throughout the colder dry season the farmers are in constant danger of losing everything from frost.

Yields average around 60 bushels per acre. By growing the crop in the valleys during the rainy season and protecting the plants against late blight, it has been demonstrated repeatedly that yields of 600 bushels per acre can be obtained.

As knowledge of the control of insect pests and diseases in the tropics is increased, the growing season of basic food crops can be lengthened and almost cer-

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tainly the kinds of crops can be diversified. This would do much to create a more stable agricultural economy and give stimulus to the agricultural progress that must accompany the further profitable use of pesticides.

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Factors Influencing the Demand for Pesticides in Tropical Agriculture

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Many new and effective pesticides developed since World War II have stimulated interest in safer and better application methods. Factors affecting this interest in the highly populated areas of the tropics and elsewhere include the farmer's ability to purchase the modern pesticides, his opportunity to learn application methods, his standard of living and farm practices, and his customs, religion, and superstitions. International organizations, the pesticide industry, and technical-assistance programs cooperating with local governments are doing much to stimulate this interest. This will result in wider use of pesticides abroad, which, in turn, will contribute to more economic stability and a better food supply.

Of the many intricate factors affecting the use of pesticides in tropical agriculture, the one probably foremost in the minds of manufacturers, industrial chemists, and dealers in chemical products has to do with foreign markets. If there is to be an expansion in the use of their products abroad, there must be a demand and market for them, as well as suitable foreign exchange and the technical knowledge and equipment indispensable for applying them. Too often, however, in our eagerness to develop new markets, we lose sight of the problems confronting the peoples of other nations. Our analysis of the situation may be misleading in that we fail to interpret the effects of custom, tradition, educational facilities, and religious superstitions on the advancement or retardation of agricultural technology and production.

During the past 10 years, the pesticide industry and those who have been engaged in foreign programs have witnessed an unprecedented increase in the use of insecticides and other chemicals throughout many countries all over the world. Some of the problems that had deterred progress in the use of pesticides are better understood today. Ways and means are being found to overcome them to the advantage of both producer and consumer.

Interest in the use of modern pesticides and methods of applying them elsewhere in the world follows closely the research and practices that have been developed in the United States. This is especially true throughout Latin America, where agricultural officials and growers alike are rapidly becoming conscious of the need for pest control to improve crop and animal production. If we are to expect a normal and continued increase in the demand for American pesticides abroad, there are many complex problems that must be overcome.

Unfavorable Factors

Prior to World War II, which ushered in a new era of pesticidal chemistry and more new products than we can satisfactorily evaluate, the Latin American grower fought his pests singlehandedly for the most part, utilizing the few products that were available with little or no technical assistance. Only the more prosperous grower could afford to purchase chemicals and the equipment to apply them. The underprivileged, because of inadequate knowledge as well as lack of material means, constantly faced the threat of one crop loss after another. A situation of this kind

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cannot long be tolerated. Neither can a grower's incentive to sow his seed and reap a harvest hold up indefinitely without technical assistance if he is unable to obtain compensation otherwise. Conditions of this kind are common. The factors responsible for them are deep-rooted and varied. Until the scientist and government official can work out a solution to these problems, one cannot expect new markets for pesticides to develop rapidly.

Agricultural practices in foreign countries are varied, whether they be in methods of tilling the soil or in pest control. Some of the same practices have been repeated for hundreds of years. Pest control has been accomplished largely by trial and error through cultural methods, or not practiced at all. Even in countries where agriculture is striving to become modernized, the low purchasing power of large populations is not conducive to the acquisition of mechanical means to conduct the type of agriculture we are accustomed to in the United States. A lower standard of living exists. People manage on less and they forsake the better. Most of them live in areas where transportation is a problem. They do everything the hard, slow way. Their health is impaired. They become disinterested unless assistance of some kind is provided.

This situation will require time, patience, material aid, and assistance to overcome. We cannot count strongly on the people of these countries to demand our insecticides, fungicides, and other chemical products on their own initiative. This is perhaps one of the biggest problems facing the exporter of American pesticides.

Sales of pesticides to many parts of the world have increased considerably during the past 10 years, but most of these shipments abroad have been utilized on such exportable crops as cotton and bananas in the American republics, or on crops that provide means of obtaining dollar exchange so that American goods can be purchased. Insecticides are also used to control household insects and against vectors of human diseases, on citrus fruits, on migratory locusts and ants, or against pests of national concern where governments have assumed responsibility for control or made it possible for growers to purchase insecticides at cost. Large quantities of insecticides such as DDT have gone into health programs abroad. But it will require more than the demonstration of our firm belief in pesticides before peoples and governments are able and willing to tackle their own problems through know-how and suitable economic backing.

Another factor having an important bearing on the unfavorable demand for pesticides in most of the so-called underdeveloped countries is the scant attention given market grading of vegetables, fruits, and meats for home consumption. Because there is no food surplus, everything that is grown finds its way to hungry stomachs if it is at all worth eating. Why, therefore, should a grower spray his citrus trees with expensive insecticides if he can sell all he produces at a price that satisfies him, even though his product is far below American standards? The same holds true for the vegetable grower. Acres of crop land riddled by insects and disease are plowed under because that appears to be the only practical thing to do. In cases of this kind, the farmer will often plant a different crop, and if nature is on his side, he still feels that his efforts have not been in vain.

Need for Education

Lack of facilities for education and service to rural communities deprives hundreds of thousands of small scale growers of a means of learning the essentials in the protection of their crops and livestock against destructive enemies. Most of these people, regardless of where they live, would gladly join the ranks of those who know better, if given the opportunity.

There are many places in Latin American agriculture where a little organized assistance to the small farmer would pay dividends in crop and livestock production. Species of leaf-cutting ants, for example, occur all the way from Mexico to Argentina. They are especially abundant in the tropical and semitropical areas. Brazil has long recognized the destructiveness of these ants and has done more to study and combat them than any other nation. Many campaigns have been waged against these pests, which attack many crops; yet for some reason the small grower is often neglected, and he loses interest because he is unsuccessful in his control efforts or he cannot

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afford chemicals to do the job at the proper time. For a long time sulfur and white arsenic were the cheapest and most reliable chemicals used in ant control. Then came carbon bisulfide and more recently methyl bromide, chlordan, aldrin, and dieldrin—all effective ant killers. Although the most economical materials and means for fighting ants appeal to a farmer, he often loses out simply because he has no chance to learn how best to apply those materials that are available.

An uninformed farm population cannot be expected to purchase agricultural chemicals without the assistance of appropriate farm organizations. Neither can these farmers be expected to become interested in obtaining the best weapons for fighting insect and disease plagues unless these weapons can be properly demonstrated. DDT, for example, became a household expression the world over not necessarily because of its merits, but because of the way it was used and demonstrated in the most remote parts of the earth. The merits alone of a given product cannot be relied on to build a market for it abroad. This is especially true today with the many new insecticides that cause confusion even to the growers of the United States.

Some of the countries the technical organizations abroad are concerned with have not even had trained entomologists or plant pathologists on their staffs. Where specialists do exist and are performing excellent work, their efforts are too often confined to the laboratory. Applied science in pest control, as it is understood in the United States, is still in its infancy in most countries. There is still a lack of trained men with initiative and interest who can be counted upon and be provided the means of conducting first-class field work with pesticides.

One more factor that could retard pesticide usage abroad is the matter of safety. Contamination of food due to harmful residues, their toxicity to man and animals, and similar problems that industry has faced in this country have not been taken very seriously in many countries now importing our new pesticides. Both men and animals have been poisoned through carelessness. We must establish confidence among those with whom we do business or with whom we cooperate, by exercising greater precautions in demonstrating and selling our chemicals to all foreign customers. We can easily lose the ground that we have gained if we misrepresent the facts or sell inferior products at reduced prices. A grower usually attributes poor results from a given product to the material itself, even though he may be mistaken. His inability to have the product analyzed locally places him in a position of great disadvantage, particularly if the product is below standard to begin with.

Factors Creating a Demand

Perhaps the major factor in the present demand for pesticides is the need for greater production of food, fiber, and livestock the world over. Since most nations have been brought closer together by political and military agreements for the purpose of survival, we have learned that in order to command confidence and respect, above and beyond what the power and position of the United States may mean, we must also be able to render many kinds of assistance—military and economic aid and technical assistance as well. The attention given by various international and government organizations to the many problems relating to agriculture, health, and education has already been of tremendous benefit to millions of people. The Food and Agriculture Organization and World Health Organization of the United Nations, the old Mutual Security Agency, and the Technical Cooperation Administration of the Department of State, the Foreign Agricultural Service of the Department of Agriculture, the Institute of Inter-American Affairs, and more recently the Foreign Operations Administration have all played a part in technical assistance. The combined efforts of these organizations have done much to increase the general acceptance of our pesticides abroad. There is little use, however, for our technical aid in improving crop and livestock production anywhere in the world if we neglect to impress and train native technicians in the proper methods of defending their animals, plants, foodstuffs, and their own health against their common enemies.

One outstanding example of the role of pesticides in technical assistance is in the control of the desert locust in the Near East, South Asia, and Africa. Since April 1951, when the United States Government received a request to assist the Government of Iran in one of its worst locust invasions in 80 years, a locust-control

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team has been operating in six or more countries. Direct aid given to Iran stimulated interest and threw a new light on the locust problem. It was not long before a regional project was developed with the Department of Agriculture serving as the operational agency, so that assistance and control demonstrations could be conducted under bilateral agreements with all countries in which there are FOA missions, from Ethiopia through the Near East to and including India.

The regional program has consisted largely of aerial spray demonstrations for locust control in the most heavily infested areas, the training of pilots and mechanics, and some assistance in the control of other insect pests. During the last three seasons a total of 202,750 acres in six countries have been sprayed for the control of locusts, protecting food crops and pastures in more than 2,000,000 acres. This cooperative service has brought to the countries of Iran, Iraq, Pakistan, India, Jordan, and Ethiopia a new method of combating locusts together with the introduction and demonstration of new and more effective insecticides. It has trained several dozen pilots to operate spray planes and encouraged countries to purchase their own planes for controlling locusts and other insects. Plant-protection organizations have developed greater interest in insect control, which has made possible larger appropriations from local governments for control work. Its results have brought hope and encouragement for increased plantings without fear of heavy losses caused by locusts. This coordination of efforts of the various nations has contributed to progress in international cooperation through the FAO and other groups interested in the welfare and food production in the countries involved.

These combined efforts in locust control have made possible the planning of demonstrations on the control of many other destructive insects by U. S. technicians. Part of their work will be to demonstrate the use of new insecticides on sugar cane, rice, wheat, cotton, and olives. Some countries of the Near East and South Asia have already begun placing orders for new pesticides, and large scale aerial spraying operations are expected soon to be a common sight in some areas. Among the objectives of this new program will be the encouragement of insect control through demonstrations of improved cultural practices, the use of cheaper and more effective insecticides, and the proper use of appropriate spray and dust equipment. It will also develop organized crop pest-control programs, demonstrate and establish efficient field organization, and institute survey and reporting services for appraising major insect problems, including locusts.

Entomologists in technical-cooperation missions in Latin America and several other countries in the Eastern Hemisphere are also contributing to the more general use of pesticides. For the first time in some countries insect control is being organized on a scientific, practical basis. An important phase of their work is the training of nationals. Young assistants with necessary background are given on-the-job training both in the laboratory and in the field. The better qualified and experienced individuals are given opportunity to seek advanced training in the United States, where they may spend from several months to a year or more in colleges and experiment stations, as well as visiting manufacturers of pesticides and farm equipment.

The work of the mission entomologists abroad should be of vital interest to the pesticide industry. These men are conducting a real two-way program. They are interested not only in controlling the pests but in demonstrating our many effective pesticides. They have already obtained some striking results in controlling pests of potatoes, citrus, cotton, coffee, sugar cane, and livestock. They are developing interest abroad and proving to the small grower, as well as to the large, that insects can be controlled economically. Working together with extension specialists more than 9000 persons attended 88 insect-control demonstrations in three provinces in Bolivia during April 1954. Work of this nature will produce long-lasting results in terms of good will, self-sufficiency, and the ability of a country to import pesticides. It can then grow crops and livestock and not be forced to import foodstuffs that it can produce in surplus, if its agricultural problems are analyzed and properly dealt with.

Technical assistance that aims toward teaching both technician and farmer how to protect what is grown is only a small part of the assistance provided in the field

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of agriculture. Health and education must also be considered. All are interdependent. Whatever is done must be organized and carried out in a way that will guarantee a balanced program. Where health problems are vital in any agricultural community, they must be dealt with if a goal has been set to increase food production. Pesticides required to fight malaria and other insect-borne diseases have played an important part in helping to build better international relations, which in turn affect international trade negotiations.

With the improvement in agricultural practices and health and living conditions, farmers the world over will be demanding more of everything. Increased purchasing power will enable them to obtain their pesticides abroad if local industry cannot fill the demand.

Developing Foreign Markets

For many years the pesticide industry seemed slow in taking the initiative to promote a stronger export market. Ten or fifteen years ago it did not have the wide variety of products to offer that are now available. Little effort was made to expand or strengthen its position. The contacts between the exporter of pesticides and the importers and officials of foreign governments were not conducive to the gaining of new markets. Business in the foreign markets did not flourish.

In contrast to the situation of a decade ago, the pesticide industry today has assumed a much greater responsibility in supplying its products both in this country and abroad. Manufacturers have sent picked men abroad—not mere salesmen, but men trained in the sciences who are helpful in many ways. In fostering better public relations, these men build good will. The foreigner confides in them more easily and is less likely to doubt them or the products they sell.

Private chemical companies in their support of research are promoting grants to students working on tropical problems abroad. They have been very generous in offering sample chemicals to various programs. Through the medium of international meetings, tropical pesticide problems become much better understood. Those in government appreciate the cooperation of the chemist, the manufacturer, and the exporter in meeting specifications and supplying the chemical products used in its overseas programs. Some of these programs would not have been successful without this cooperation. Good working relationships between industry and government are just as important abroad as they are at home in arriving at the goals both are striving for.

Pest control will continue to be one of the most important weapons in the great fight against poverty and hunger. Agricultural improvement will require it every bit as much in the tropics as elsewhere. We can be hopeful in looking forward to interesting changes as people become more able and willing to fight a winning struggle. Pesticides and the equipment to apply them will become as valuable to the small farmer as his machete and his hoe. Let us all hope that the pesticide industry will not fail to meet his demands.

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Pesticides in Sugar Cane

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Fairly extensive pesticide programs could be put into practice on approximately 8,000,000 of the estimated 15,000,000 acres that are in sugar production throughout the world. Weeds, diseases, insects, rats, and the bacteria that cause inversion in freshly expressed juice and the pesticides now in use for their control are discussed. Estimates are given of the amounts now in use, that probable in future use, and the possible maximum use.

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An estimated 15,000,000 acres of land throughout the world are devoted to growing sugar cane. Individual holdings may vary from fractional acreage to more than 100,000 acres. It is the principal crop in many tropical countries as well as in both temperate zones in certain favorable areas.

The chief end product is sugar, a surprisingly large amount of which consists of crude forms processed by many widely variable, primitive types of mills or small power mills. Much of the sugar cane grown in primitive tropical gardens is consumed directly, the only processing being dental in nature. Chewing the soft cane stalks yields copious amounts of nutritious juice and sucrose is an important supplement to meager diets.

Other products of sugar cane are edible sirup, blackstrap molasses, and invert molasses. Promising by-products, largely undeveloped as yet, include wax and aconitic acid from the filter press mud, and paper or building board from the expended, processed fiber, bagasse.

Sugar cane is grown under a wide diversity of agricultural conditions, from the hand-cultivated tropical gardens of Pacific Islands and room-size fields of the Ryukyus to the almost completely mechanized agriculture practiced in the Hawaiian Islands. Many of the agricultural systems would be uneconomic on a competitive market; however, there are vast acreages of undeveloped or unutilized land available for production if there were a market for the sugar. Cuba, for example, is producing at approximately half of its developed capacity and, with sufficient incentive, could readily supply any demand that can now be foreseen. Sugar is by far our cheapest food source of energy and much greater utilization would seem desirable.

Any extensive, economic increase in sugar production would necessitate many changes in agricultural practices, including: varietal improvement, mechanization, soil and water conservation, and the use of various pesticides. All of these practices are well advanced in some cane-producing areas, and extensive research projects on every phase of sugar cane agriculture and processing are under way at research centers in every longitudinal area. This research information is freely exchanged at triennial meetings of the largest, if not the only, international scientific group devoted to a single crop, the International Society of Sugar Cane Technologists. Its latest meeting was held in the British West Indies in 1953 and was attended by more than 300 workers from 35 countries or islands. These research workers have many problems for which pesticides may be the solution.

A type of agriculture sufficiently advanced to warrant serious consideration of fairly extensive pesticide programs is practised on 8,000,000 acres of the total world acreage devoted to sugar cane. All of this vast area has serious problems that

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should yield to one or more of the following pesticides: weed killers, fungicides, insecticides, rodenticides, or bactericides.

Specific products mentioned are those widely acknowledged in use; however, similar or superior products may replace any product now in use.

Weed Killers

The use of 2,4-D as a pre- or postemergence weed killer has become standard practice in many sugar cane areas and even more general adoption of this or some other herbicides for these purposes seems a foregone conclusion. One large unit in Cuba in 1953 used 0.29 gallon of concentrate of 2,4-D per acre of cane on over 50,000 acres. A second unit reported use of 1.23 pounds per acre on a 40,000-acre unit. Another similar unit used none, claiming hand weeding to be cheaper. If a quarter of Cuba's 3,000,000 acres in cane were sprayed with 2,4-D, the operation would use 1,000,000 pounds.

It is estimated that over 100,000 acres in Hawaii and some 250,000 acres in Louisiana each year are treated with herbicides, mostly 2,4-D and TCA (sodium salt of trichloroacetic acid), for pre- and postemergence weed control. Johnson grass on ditch banks on some 50,000 to 75,000 superficial acres in Louisiana is controlled with sodium chlorate or TCA. Some trials with CMU [3-(*p*-chlorophenyl)-1,1-dimethylurea] are in process. Florida cane growers use 150,000 pounds of 2,4-D amine salt of Karmex W on 43,000 acres of cane and anticipate using up to 100,000 pounds per year. Of the growers in Puerto Rico, 60% are said to use herbicides as either pre- or post-emergence sprays.

In Jamaica, it is estimated that 20 tons of 2,4-D acid equivalent are used per year now and a rapid increase is anticipated to the point that all plant cane in the first year of a 5- to 6-year cycle will be treated. In Barbados no herbicides are used. In British Guiana, where cane is grown below sea level, approximately 50 tons of 2,4-D acid equivalent are used annually for pre-emergence spraying. This amount is expected to increase to 60 to 65 tons in the near future. Their contact spraying program is now awaiting development of a satisfactory mixture, probably similar to CADE. Some 3000 gallons of pentachlorophenol (25% emulsion concentrate) is used for aquatic weeds and chemical rogueing of diseased cane stools. No herbicides are now used on Taiwan (Formosa) but may be used if proved practical. Large quantities of other pesticides are used. Definite figures on usage in other areas are not available.

Control of broadleaf weeds with 2,4-D has posed a new problem, the invasion of fields by true grasses, which will need specific herbicides.

Pasture land and railroad rights of ways in connection with sugar cane operations offer additional opportunities for the use of herbicides. On one property of 100,000 acres, over 300 miles of permanent railway are maintained. Roughly half of this right of way receives one or more applications of a 2,4-D and TCA mixture each year; the rest is burned. A cheap, nonpoisonous soil sterilant is indicated. All Cuban plantations have their own rail systems with similar problems, but permanent rail transportation is less common in other areas.

Potential use of herbicides in sugar cane might be placed at 8,000,000 to 10,000,000 pounds a year, while actual use currently is probably 15 to 20% of this amount. Doubling the use of herbicides in the near future would appear possible, making the probable consumption approach 3,000,000 pounds a year.

Fungicides

A formidable proportion of the sugar cane crop each year is used for planting new fields or renewing old fields. One acre of mature cane may be used for planting as little as 5 or 6 acres or may plant as much as 25 or 30 acres. A well planted field may produce only one crop or, more commonly, it may produce five to eight crops and, occasionally, many more. Occasionally the resulting stand is a complete failure and frequently a partial failure. This may be due to diseases, insects, adverse weather, or any combination of the three. A program of seed treatment that would give reasonable assurance of a satisfactory stand, particularly if the quantity of seed cuttings could be materially reduced, would be widely adopted.

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Pineapple disease, *Ceratostomella paradoxa*, is generally considered to be the most serious disease of planted cane. It is controlled in South Africa by the use of Aretan in solution, in which cut ends of seed pieces are dipped prior to planting. Australia has a similar pretreating program and also uses a mechanical planter which sprays the seed piece as it is planted. The latter is not yet a general practice. Hawaii uses PMA (phenylmercuric acetate), in 10% aqueous solution, as a cold dip (1 to 400) or as a hot dip (1 to 1600) at 50° C. for 20 to 30 minutes. In 1953, 1800 gallons of PMA were used. Taiwan uses 60,000 pounds of Granosan annually for sett (seed piece) treatment on 60,000 acres. One large unit in Cuba abandoned fungicide treatment of seed pieces after several years of inconclusive results.

Root rots occur widely, but no chemical control program is in practice. Water soaking and drying out of seed pieces are serious problems at times.

A small amount of fungicide is used by cane breeders to control damping off in flats of newly germinated seedlings.

General adoption of a fungicide program in the near future for cane is not probable, although the problem is serious. A combined insecticide-fungicide program offers possibilities.

Insecticides

Many insects are serious problems in sugar cane agriculture. They are largely local in nature, both as to damage caused and control measures used.

The sugar cane borer, *Diatraea saccharalis*, is the most serious sugar cane insect pest in Louisiana. Ryania and cryolite (sodium fluoaluminate) were dusted on 65,000 acres in 1953 at a total cost of $600,000. Borers in other areas are controlled to a certain extent by natural or introduced parasites. Puerto Rico estimates an annual loss of $2,500,000 from borers. Serious losses are incurred in other areas, but no chemical controls have been adopted.

Wireworms are controlled by cultural practices in Louisiana, or by the application of 2 or 3 pounds per acre of chlordan or toxaphene in limited areas. Florida uses 40,000 pounds of chlordan per year for wireworm control at planting time.

BHC (hexachlorocyclohexane) is used on 44,000 acres of plant cane and 15,000 acres of ratoon yearly in Australia to control the Greyback beetle. Taiwan reports use of 315,000 pounds of 1% and 930,000 pounds of 3% BHC on 13,000 acres at the rate of 150 pounds per acre for control of soil insects.

A froghopper has caused heavy damage in Trinidad and has aroused some concern in other areas. It is controlled by local—i.e., stool—application of 5% BHC.

Cane growers in Barbados are interested in chlorinated hydrocarbons for control of sugar cane root borer, sugar cane root mealy bug, and yellow ant. They are interested in data on persistence of such chemicals in the soil and methods of testing for them. Jamaica reports a probable annual use of 5 tons of DDT for control of sugar cane fly.

British Guiana reports a minimum use of 40 tons of 14% gamma isomer of BHC for control of froghopper and hardback beetles and states there is a need for a higher gamma isomer dust with a fine particle size, 325 mesh, and free-flowing characteristics. This, it is claimed, would reduce costs by permitting the breakdown of this insecticide with locally available fine-mesh limestone. The small moth borer, *Diatraea canella*, has not yielded to either chemical or biological control. Favorable reports on endrin (isomer of dieldrin) from other areas has prompted British Guiana trials.

Other insects are of local importance including various beetles, grubs, the lesser cornstalk borer, and several vectors of virus diseases. The latter might be controlled by systemic insecticides.

Termites are a serious problem in several known limited areas and are on the increase. White refined arsenic has been used in Cuba with some success but has not resulted in control. Treatment of 13,000 infested acres required 1800 pounds of arsenic in 1953. Dieldrin and similar compounds appear more promising at present. Aldrin (hexachloro-diendomethano-hexahydronaphthalene) has been used at the rate of 2 pounds per acre on 750 acres in the Dominican Republic with good results. Termites do not seem to be a general hazard at this time.

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Insecticide-Fungicide

Yield increases in small trials of 25 to 30% have been secured in Louisiana by soil treatment at planting time with a combined insecticide and fungicide. This combined treatment deserves further investigation and it may have promising results. Hot water treatment of seed pieces can eliminate two virus diseases. Germination is stimulated at the same time and the possibility of augmenting this with fungicides has shown promise. Hot insecticides have not been tried.

The potential market for insecticides is of the order of 30,000,000 to 40,000,000 pounds, the probable market possibly 10,000,000. The fungicide prospect is suggested as a quarter of that for insecticides.

Annual Use of Pesticides (Pounds)

	Present	*Maximum Possible*	*Probable*
Herbicides	2,000,000	10,000,000	3,000,000
Fungicides	500,000	10,000,000	2,000,000
Insecticides	3,000,000	40,000,000	10,000,000
Rodenticides	25,000	1,000,000	100,000
Bactericides	250,000	1,000,000	1,000,000

Rodenticides

Rats are a serious pest in cane fields in several countries, particularly in Australia, Taiwan, British Guiana, Puerto Rico, and Mexico. They are a factor in dissemination of leaf scald disease in British Guiana. Trapping and warfarin [3-(alpha-acetonylbenzyl)-4-hydroxycoumarin] baiting are practiced. Warfarin is used by an estimated 80% of the cane growers in Puerto Rico. Mexico uses 1000 pounds of warfarin annually. British Guiana uses 12,000 pounds of 1% warfarin annually and anticipates this demand will continue indefinitely. Taiwan reports use of 6565 pounds of 0.5% warfarin on 13,000 acres with good results and expects to continue its use.

Rat control is needed on an estimated million acres of cane in the countries mentioned and to a lesser degree on much of the remaining 7,000,000 acres under consideration. One pound of warfarin should treat 8 to 10 acres of sugar cane. Maximum demand would be under 1,000,000 pounds, and the probable demand would be about 100,000 pounds.

Bactericides

Loss of sucrose due to inversion by bacteria during the time between crushing the cane and processing the juice is considered serious. A very conservative estimate places the annual loss for Cuba, if uncontrolled, at 75,000 long tons of sugar. This loss can be drastically reduced by spraying Steri-Chlor 4X into the juice immediately after extraction at the rate of 10 pounds per 1000 tons of cane. The practice is now common and offers a potential market for approximately 450,000 pounds of such a product in Cuba and probably at least that much in other areas. Demands in the near future should approximate 250,000 pounds and eventually should approach a maximum of 1,000,000 pounds.

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Pesticides for Cotton in the Tropical Americas

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Cotton is grown on approximately 8,750,000 acres of land in the continental Americas south of the United States. Insects take a heavy toll over much of this area and are often the limiting factor in the economical production of cotton. Large amounts of chemicals are imported for cotton pest control, but they fall far short of the actual needs for adequate control. In addition, chemicals offer protection against certain cotton diseases caused by seed-borne and soil-borne organisms.

The total cotton acreage in continental North and South America outside of the United States is close to one third of that in the United States, approximately 8,750,000 acres. Total production, however, is not quite in this ratio. Brazil, Ecuador, Paraguay, Argentina, and Nicaragua produce less cotton per land unit than is produced in the United States, and they represent about 70% of this total acreage. Peru, Mexico, El Salvador, and Guatemala, on the other hand, produce more cotton per land unit than the United States. These figures are according to *Agricultural Statistics* 1953, issued by the Department of Agriculture, and are based on the 1952 crop.

Among the many factors that affect cotton production are insects and diseases. Probably no other cultivated crop is so attractive to such a wide variety of insects, and in tropical conditions they multiply rapidly and spread. Therefore, the economical production of cotton in these areas, as elsewhere, often depends on whether or not the insects are controlled.

Principal Insect Pests

Many of the insect pests of cotton in these countries are common to the United States, and certain others are closely related to species that occur here. A few of the most serious pests in certain South American countries, however, are native and do not occur in the United States. For example, the Colombian pink bollworm (*Sacadodes pyralis* Dyar) is a serious cotton pest in Colombia, Nicaragua, Venezuela, and Paraguay. It is also reported from Argentina, British Guiana, Panama, and El Salvador. The Peruvian weevil (*Anthonomus vestitis* Boh.) and the Ecuadorian pink bollworm (*Cataraca lepisma* Wlsm.) are also native to the respective countries, but do not occur in the United States.

Cotton pests that are common both to the United States and tropical America include the cotton aphid (*Aphis gossypii* Glov.), the cotton leafworm [*Alabama argillacea* (Hbn.)], and certain grasshoppers and spider mites. Certain species of stink bugs, mirids, and cutworms which are closely related to species that occur here at times cause serious injury to cotton throughout Mexico and Central and South America.

The number one cotton pest in the United States, the boll weevil (*Anthonomus grandis* Boh.), occurs in Mexico, Costa Rica, Nicaragua, Colombia, and Venezuela and is probably also the number one pest in these countries.

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The pink bollworm (*Pectinophora gossypiella* Saund.), considered to be potentially the worst pest of cotton in the United States, occurs throughout the major cotton-producing areas in Mexico, Venezuela, Colombia, Brazil, and Argentina. It probably causes more damage to cotton in the tropical Americas than any other insect.

Several species of lepidopterous larvae cause bollworm-type injury to bolls and squares throughout the tropics. They include the bollworm [*Heliothis armigera* (Hbn.)], the tobacco budworm [*Heliothis virescens* (F.)], the black bollworm (*Prodenia latisfascia* Wlk.), and in Peru *Mescinia peruella* Schaus.

The cotton leafworm [*Alabama argillacea* (Hbn.)] and several other leaf-feeding lepidopterous larvae, particularly *Anomis texana* Riley and the salt-marsh caterpillar [*Estigmene acrea* (Drury)], sometimes cause total destruction of the cotton crop in localized areas.

Other insects which sometimes cause serious damage to cotton in the countries to the South include stainers belonging to the genus *Dysdercus*, root and stalk borers of the genus *Gasterocercodes*, cutworms, stink bugs, whiteflies, and leaf-cutting ants.

While these are the principal cotton pests, there probably are instances where some species not mentioned cause more local damage. A complete list of all insects and spider mite pests which cause economic injury to cotton in Mexico and Central and South America would be impressive, but no such list is available and it would require considerable research to compile it.

Cultural Control of Insects

The control of cotton pests in the tropical Americas varies from virtually no attempt in certain areas to the strict application of the latest methods in others.

Many people think of cotton-pest control in terms of applying chemicals to the cotton plant. Actually, chemical control should always be considered as secondary to farming practices that reduce insect losses. Many years of experimentation have shown that most of the major cotton pests have a weak link in their life history which can be taken advantage of by cultural practices to suppress the amount of damage. Research on the pink bollworm and the boll weevil, for example, has shown that to maintain a host-free period—that is, several months of the year in which no cotton is allowed to grow—is the most effective method of control. This has been demonstrated particularly well in the Matamoros and Laguna areas of Mexico and in Venezuela. To be most effective, however, legislation is required and enforcement of specified planting and plow-up dates and maintenance of an absolute host-free condition between these dates.

No amount of cultural control, however, no matter how rigidly followed, has ever completely eliminated insect damage to cotton over a wide area. Chemical control is still the only means of reducing losses when the insects are actually damaging the plants. Fortunately there are chemicals available which, when properly applied at the right time, will give effective and economical control of most cotton pests. It is a mistake, however, to rely on them entirely. Good farming practices should be given first consideration, and they should be followed by the application of carefully selected insecticides where and when needed.

Chemical Control of Insects

Most insecticides kill good as well as bad insects. The good insects, the parasites and predators, often hold destructive insects in check. Sometimes the application of an insecticide, while giving satisfactory control of one pest, may destroy the natural enemies of another pest, causing it to increase to such a degree that it will do more damage than the one being controlled. For example, the use of arsenicals for leafworm or boll weevil control has often caused the cotton aphid to increase to such proportions as to offset any good from leafworm or boll weevil control.

Many of the lepidopterous larvae which cause bollworm-type injury to cotton are held in check during most of the growing season by other insects that feed on the eggs and young larvae. An insecticide applied during the main fruiting period kills off these predaceous insects and an enormous "bollworm" population often results. It is sometimes better to take a small loss during the main fruiting period than to apply insecticides, although, if severe damage is being done at any time, the

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only recourse is to use insecticides. Correct timing, however, is just as important as using the correct insecticide or applying it correctly.

Many insecticides are effective against cotton pests, but no one insecticide will control all of them. Sometimes a mixture of two or more is required to do an effective job. For control of the boll weevil alone aldrin, calcium arsenate, dieldrin, endrin, BHC (benzene hexachloride), heptachlor, and toxaphene are effective. For control of both the boll weevil and the bollworm DDT may be added to any of these except calcium arsenate, endrin, and sometimes toxaphene. When the complex of boll weevil–bollworm–spider mite is to be controlled, sulfur may be added to all of these except calcium arsenate. DDT, endrin, or toxaphene may be used for the control of other bollworms except the pink bollworm. For pink bollworm control, DDT is the only insecticide recommended. Aphids and spider mites together are controlled with parathion and demeton. BHC is effective against the cotton aphid under certain conditions. Aramite will also control certain spider mites. Other insecticides that have shown considerable promise against many cotton pests under experimental conditions are methyl parathion and chlorthion, although neither is effective against the bollworm or the pink bollworm.

The insecticides and miticides mentioned are not the only ones known to be effective against cotton pests, but they include most of those used for that purpose in the United States. Many of them are imported in considerable quantities into Latin American countries and have proved their effectiveness there. Approximately 44,000,000 pounds of technical organic insecticides (DDT, BHC, toxaphene, aldrin, dieldrin, parathion, etc.), 3,600,000 pounds of calcium arsenate, and 82,000 pounds of nicotine sulfate were exported from the United States to these countries during 1953. Some insecticides are exported from Europe, particularly Folidol (methyl parathion) from Germany. Even though these imports represent considerable quantities of insecticides, they are still far short of the minimum needs for adequate cotton-pest control.

Cotton Diseases and Control

In addition to the many insect pests of cotton, there are certain diseases which are also amenable to control through the use of chemicals. The diseases are caused by organisms that attack the seed or seedlings and in severe infections will destroy the stand. *Xanthomonas malvacearum*, *Glomerella gossypii*, and sometimes *Ascochyta gossypii* cause bacterial blight, anthracnose, and wet weather blight. The seedling infections may carry over to mature plants, causing leaf spots, cankers, and boll rots. Certain soil-borne organisms may also cause damage, particularly *Rhizoctonia*, *Pythium*, *Fusarium*, and *Diplodia*. In some areas *Sclerotium bataticola*, *Sclerotium rolfsii*, and *Thielaviopsis* also cause trouble. Seed treatment is the most practical method of controlling seed-borne diseases and it offers some protection against the soil-borne diseases. Although information on seed treatment in the tropical Americas is meager, such treatment is practiced. Several seed-treatment chemicals are known to be effective in the United States when used as recommended, and it is reasonable to suppose that they will also be effective in the tropics.

Conclusions

There are approximately 8,750,000 acres of cotton grown in the tropical Americas. This means that under average planting conditions about 127,000 tons of seed are required, which if adequately treated would require about 265.5 tons of protectant chemicals. As the cost of seed treatment is reasonable, the farmers could well afford the extra cost as an added insurance of a uniform stand from the first planting. In general, the highest yields are obtained in areas of the tropics where there has been an active research program.

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Chemical Control of Pests and Diseases of Cacao

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The average world production of cacao has increased from 130,000 long tons in 1901–05 to 702,000 long tons in 1945–53. If fungicidal control were applied to the estimated world cacao acreage of 5,241,600 acres, at the concentration of only 2 pounds per 100 gallons of water, six times a year, it would be necessary to use 188,697,600 pounds of material. Pesticides are very likely to be used for the control of diseases and pests for a long time, as control by means of better yielding and resistant strains is still in the very distant future.

The world production of cacao has increased from an annual average of 130,000 long tons for the period 1901 to 1905 to an average of 702,000 long tons per year in 1945 to 1954 *(20)*. If suitable land available in the Western Hemisphere and in Africa were developed for cacao, the annual world output of raw cacao would be increased by 1,500,000 tons *(5)*. Overproduction of cacao appears at present remote.

The average yield of cacao is roughly 300 pounds per acre *(8)*. The total acreage with cacao, based on the average of 702,000 long tons, would be about 5,241,600 acres with a total of approximately 1,572,480,000 trees at 300 trees per acre. For spraying one tree 1 gallon of fungicide is used. Assuming that a fungicide is used at the concentration of 2 pounds per 100 gallons of water, the total amount of fungicide to be used would be 31,449,600 pounds. The amount of fungicide needed for six applications per year would be 188,697,600 pounds. The total cacao acreage under fungicidal spray cannot be estimated at present with any reasonable degree of accuracy; however, the sprayed acreage must be small. The above figures are simply an indication of the large potential market for fungicides.

Annual losses of production due to disease and pest were estimated by Hale *(20)* in 1953 as follows: capsid insects 70,000 tons, swollen shoot 50,000 tons, *Phytophthora* rot (black pod) 50,000 tons, witches' broom and others 20,000 tons, and ants 10,000 tons. According to Wellman *(51)*, cacao diseases are a threat to world production.

The problems of diseases and pests will not be solved merely by a chemical formula that inhibits or destroys fungus spores in vitro. A pesticide ought to have the ability to remain on the plant surfaces long enough to prevent or destroy disease agents and to destroy disease vectors before they attack. This is difficult to achieve under the severe weather conditions of the tropical moist forest, the natural habitat of cacao, where the chemical deposited is in many cases washed away by heavy rain. The inherent tenacity of a fungicide could be improved by the addition of adhesives. An effective adhesive or an alternative for use in combination with fungicides or insecticides in the tropics has not yet been developed.

Chemical Pest Control by Insecticides

Swollen Shoot. Losses due to swollen shoot, a virus disease discovered in 1937 in the Gold Coast and still restricted to West Africa, are staggering.

The status of the control of swollen shoot diseases has been summarized recently *(35)*. According to Posnette *(40)* the diseases grouped under swollen shoot are

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caused by a large number of viruses, some of which are related strains, while others probably are not. At present all West African cacao viruses are grouped under *Theobroma virus* I with letters to differentiate those better known and the name of the locality for the others. The swelling induced by some viruses has been found to be of little diagnostic value because not all of them induce this symptom.

The known vectors of swollen shoot belong to the *Pseudococcidae*, or mealy bugs. Mealy bugs are small, oval-shaped sucking bugs. They have a white, fluffy wax covering, the strands of which are secreted from glands on their dorsal surface. Thrusting a beak into the plant surface, they extract sap and, having found a suitable location, they are not likely to move from it. The young, however, are often carried from one place to another by attendant ants. As in the case of some other virus diseases, it is possible that some other sucking insects are also responsible for the transmission of the swollen shoot viruses. With the exclusion of the virus for which no vectors are known, all of the 15 viruses tested at the West African Cocoa Research Institute are transmissible by *P. njalensis* and *P. bukobensis*. *Ferrisia virgata* has transmitted all but two; *P. longispinus* T-T has transmitted only the two which *F. virgata* failed to transmit. An unidentified species of *Pseudococcus* has transmitted three out of four viruses tested so far. *P. brevipes* and *Paraputo ritchiei* have each transmitted the only virus with which they were tested. *Phenococcus maderiensis*, *P. concavoceraii*, *Geococcus coffeae*, and *Steacoccus* sp. failed as vectors of virus 1A *(40)*.

In some areas of West Africa, swollen shoot disease is under control by cutting out infected and suspected trees, the exclusion of areas of mass infection, and chemical control with systemic insecticides. In other areas of Africa, however, the disease continues to spread in spite of the control measures applied. Up to February 1954 *(19)* a total of 24,632,839 trees had been destroyed. The total number of trees in the Gold Coast alone is estimated at 400,000,000.

A limited degree of biolo ical control of the vectors of swollen shoot has been obtained by parasitizing the mealy bug vectors with *Aspergillus parasiticus*, according to a reference made by Chatt *(10)* to the work of Nicol, Owen, and Strickland.

The chemical found to be the most effective to date for the control of the mealy bugs is dimefox (bisdimethylaminofluorophosphine oxide). This is the active ingredient of the commercial product Hanane produced by Pest Control, Ltd., London, which holds a contract for investigation and control of swollen shoot viruses. Hanane is applied to the soil around the roots of the trees and a very significant reduction in the mealy bug population has been obtained by this method.

From results of the screening tests conducted at West African Cocoa Research Institute it was found that products containing dimefox were the most satisfactory for the control of *P. njalensis*. Samples containing the closely similar compound schradan (octamethylpyrophosphoramide) have been found of little or no value.

Pure dimefox was used as a standard in screening trials. Seedlings growing in sand and in soil were infested with mealy bugs and treated with concentrations of from 2 to 30 p.p.m. by weight of the soil and sand and seedling. In the sand the threshold for complete mortality of mealy bugs appears to be 3 p.p.m. and in soil 6 p.p.m. These dosages are equivalent to the addition of 0.1 and 0.2 ounce per ton of sand and soil *(32)*.

For the study of the transmission of swollen shoot virus by mealy bugs, cacao seedlings were treated with 25 cc. of a 0.5% solution of Hanane (0.125 gram of dimefox per plant). All the plants were placed in an insectary and 49 hours after treatment young nymphs of *P. njalensis* were allowed to feed on each plant. The bugs were obtained from cultures living on cacao plants known to be infected with the virulent strain 1A of the virus. It was found that infected bugs can transmit the virus to healthy plants treated with Hanane under the conditions of the experiment, before the bugs succumb to the toxic action of this chemical *(32)*.

Verona and Picci *(49)* have shown that the phosphorus contained in Hanane was used by the soil microbes for their nutrition in relation with studies conducted on the breakdown of systemic insecticides. Pianka, as cited by Nicol *(32)*, has reported that it is possible to enhance the activity of systemic insecticides by the addition of certain chemicals not necessarily systemic. Samples of dimefox activated by

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two different chemicals furnished by Murphy Chemicals, Ltd., were compared with pure dimefox at the West African Cocoa Research Institute on cacao seedlings. On the plants growing in sand, the activation in both cases was about double, but little activation resulted when grown in soil *(32)*.

An examination of treated cacao beans for toxic residues of Hanane showed that no Hanane was detectable chemically. Further analyses indicated that Hanane residue in no case exceeded 0.1 p.p.m., a limit tentatively set by the U. S. Food and Drug Administration *(32)*. However, until more complete evidence has been accumulated about the use of this type of insecticide, there will remain some doubt concerning its application to cacao.

The implantation method of application of Hanane to trees has shown that much smaller quantities of the compound are required than when soil applications are made *(32)*. In this method the Hanane containing 50% dimefox is placed in holes drilled around the base of the trees at ground level. Doses corresponding to 75, 150, 225, and 300 p.p.m. were used. These dosage levels are approximately 1/12, 1/6, 1/4, and 1/3 of those used for soil application. The results showed that 250 p.p.m. of the tree weight could reduce the mealy bugs to an average of one bug per tree. Six weeks after treatment, laboratory examination showed the presence of dead or morbid cells in the trunk tissue of a tree which was apparently healthy. Further experiments are in progress to determine the effect of Hanane on the health of the tree.

Virus on Cacao in Western Hemisphere. The strains of virus found on cacao in Trinidad and elsewhere are considered mild at present. The infected trees do not present the swelling typical of the African virus strains.

Capsid. Capsid damage is particularly severe in the Gold Coast, Nigeria, Ivory Coast, French Cameroons, and the Belgian Congo in Africa. In the British Cameroons, according to Urquart and Wood *(48)* there is not much capsid damage, although more capsids occur in cacao grown with no shade. The recurring attacks of this pest on young shoots retard growth of young trees, reduce the yielding capacity of mature trees, and induce premature senility. Injury by capsids to cacao shoots results in wilting of the leaves and the death of the stems affected. At time of feeding, the insects inject a toxic substance which accounts partially for this action. Some capsids—e.g., *Helopeltis theivora* and *H. antonii*—are known to attack cacao by damaging the pod only.

In West Africa two other species of capsids, *Sahlberghella singularis* and *Distantiella theobromae*, cause heavy losses to cacao in association with the fungus *Calonectria rigidiuscula (10)*. Capsids of the genus *Monalonium* also cause considerable damage to cacao in Peru, Ecuador, Colombia, and Central America. The wounds caused by these insects are infected with *Botryodiplodia theobromae* and result in dieback *(10)*.

According to Bellefroid *(7)*, in the Belgium Congo the control of *S. singularis* has been obtained by dusting the trees with a compound known as Nioka, a gammexane mixture containing γ-benzene hexachloride. The average amount of toxic agent that gave effective control was 1 pound per nearly 3 acres. The estimated increase in yield of cacao as a result of this treatment was 30%.

DDT emulsion has also been recommended for painting the trunks of small trees. According to Urquart and Wood *(48)*, Sutherland at Ibadan, Nigeria, obtained best capsid control with DDT 5% and with BHC (hexachlorocyclohexane) 0.45%.

Thrips. Important losses due to thrips injury to cacao trees have been recorded in areas of the West Indies, West Africa, Mexico, Brazil, and other areas of cacao cultivation. One of the species implicated is *Selenothrips rubrocinctus*, which is abundant largely in the nymphal stages and particularly in unshaded cacao plantings. Injury to fruits of cacao by thrips is confined only to the skin and is considered of little importance.

A severe thrips infestation occurred in 1953 in cacao plantations in the Comalcalco area of the state of Tabasco, Mexico. The trees suffered a nearly total defoliation. Control was reported to have been obtained by applications of aqueous solutions of Deenate 75W (DDT 75%) according to the formula: Deenate 150 gram, Spreader Sticker 15 cc., and water 100 liters. Bordeaux mixture and milk of lime have also been reported as giving good control in some localities.

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Ants and Other Pests. Losses caused by ants and other insects such as moths, beetles, and microlepidoptera have not been estimated with any degree of reliability. Studies on the entomology of cacao have been very limited.

Damage to cacao brought about by ants is chiefly caused by the "enxerto" ant, the name given in Brazil to *Azteca paraensis*. This ant and *A. chartifex* cut young cacao shoots to obtain sap in connection with nest building. Among the leaf-cutting ants *Acromyrmex subterraneous* and *Atta cephalotes* are the most important in areas of cacao production, and at times have caused extensive damage.

A certain amount of damage is done to cacao tree foliage by caterpillars of the moths *Earias biplaga*, *Mallodon downesii*, *Tragocephala gorilla*, *T. chloris*, and others.

Cacao beans in storage are spoiled by insects that oviposit on them and in the burlap bags. These insects attack in the larval stage.

In general, the control of insect pests of cacao has been neglected. Also, little is known regarding the effect of insecticides on cacao. Cardona *(9)* in Colombia has studied the influence of some insecticides on the pollination and fruit setting. He used various preparations of BHC Agrocide, chlordan, DDT, dieldrin, dieldrex, methoxychlor [1,1,1-trichloro-2,2-bis(*p*-methoxyphenyl)ethane], and toxaphene.

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Chemical Disease Control by Fungicides

Phytophthora Rot (Black Pod). *Phytophthora* rot is prevalent in most of the world's cacao-growing areas and causes losses comparable to those from swollen shoot. Since 1910 *(42)* Bordeaux mixture has been used extensively for the control of this disease in several countries of the Western Hemisphere as well as in Africa. Yield increases due to this chemical control of the disease have been put at 200 to 300% in Costa Rica by Fowler *(16)*. Results *(44)* from a fungicidal experiment conducted by the Inter-American Cacao Center in Costa Rica showed an increase in production of approximately 50% when Bordeaux mixture was used.

This fungicide has been used in Brazil, Ecuador, Puerto Rico, Fernando Pó, the West Indies, Philippine Islands, Central American countries, Cameroons, and Nigeria. From Brazil it was recently reported *(27)* that Bordeaux mixture had only a slight advantage over other compounds. Good results were, however, obtained with Cupro-san in combination with prophylactic measures. From studies conducted in Trinidad, Baker *(3)* concludes that control of black pod by sanitation and cultural methods is unlikely to be successful, whereas control might be practicable and profitable with spray and modern methods.

In Owena, Nigeria, the monthly application of 1% Carbide Bordeaux (copper sulfate, 1 pound, calcium carbide 6 ounces, water 10 gallons) mixture to developing fruits has proved highly effective against the disease. Perenox sprays were less effective than Carbide Bordeaux mixture when applied at monthly intervals. Preliminary large scale experiments also in this area confirmed that spraying rather than pod removal is the appropriate and economical control measure, when yields are relatively large in severe black-pod areas *(46, 47)*.

In 1953 it was reported *(34, 37, 39)* that *Phytophthora* rot of cacao is considered the limiting factor in cacao production in eastern Costa Rica. Losses due to this disease at La Lola farm in this area were about 47%.

Intensive investigations have been conducted at the Inter-American Cacao Center in Costa Rica since 1949 on the disease itself, on the screening of fungicides, and on the field testing of fungicides, alone and in combination with stickers. Siller and McLaughlin *(45)* suggested a rapid method of evaluating the newer fungicides for the control of *Phytophthora palmivora*, the fungus which causes this disease. The method consists of growing cacao seedlings in a nursery, and when the plants are 3 to 5 weeks old, they are sprayed with the test fungicides, alone and with stickers. A sporangial suspension of *P. palmivora* is then sprayed over the plants after the fungicide has dried. Records are taken on the number of infected plants during the succeeding 4 weeks.

Up to 1952, over 30 fungicides had been tested by this method at La Lola farm of the cacao center *(43)*. Bordeaux mixture properly prepared was found to be resistant to tropical weathering and the most effective. In some experiments Phygon-XL fungicidal powder, Bioquin I, Crag 531, and others were as effective as

Bordeaux mixture for the first week. After 4 weeks the effectiveness of Bordeaux mixture decreased somewhat, but for practical purposes the other compounds had almost completely lost the ability to protect plants against the disease. It appears then that there are fungicides as effective as Bordeaux mixture, but none have the residual capacity of this mixture. Perenox (copper oxide), zinc coposil, and cuprocide (cuprocisoxide), with and without stickers, have also been evaluated. Perenox alone at the concentration of 2 pounds per 100 gallons of water proved to be as effective as 1% Bordeaux mixture. The other two were ineffective.

Several field experiments were conducted in Costa Rica from 1949 to 1952 by McLaughlin and Bowman *(24)*, in which comparisons were made of Bordeaux mixture at 30- and 60-day intervals and Dithane Z-78 (zinc salt of ethylenebisdithiocarbamic acid) and SR-406 [captan, *n*-(trichloromethylthio)-4-cyclohexene-1,2-dicarboximide] at 30-day intervals. Bordeaux mixture was found the most effective in reducing infection, but no significant differences were found in yield due to the treatments. Results of 1952 to 1953 experiments *(37, 44)* showed that Bordeaux mixture and Dithane Z-78 applied every 30 days increased yield in comparison with the other treatments. The yield increase obtained with Dithane might have been due to the presence of zinc in this fungicide and not to a reduction in the incidence of the disease.

From a study conducted in Costa Rica in 1953 *(39)* on the mode of infection and tissue changes of cacao by *P. palmivora* it was found that infection of pods reaches its annual maximum during or immediately after leaf flushing of the trees. Based on this study, an attempt is being made to determine the spray cycles needed for economic control of the disease that would coincide with the periods of maximum infection throughout the year. Field tests with Phygon XL fungicidal powder, Crag 531, 1% Bordeaux, and Perenox are also in progress.

The control of *Phytophthora* rot of cacao is particularly difficult in view of the fact that the spores of *P. palmivora* reproduce inside the shell of living pods where they may escape the action of contact fungicides *(39)*.

In pure Criollo cacao and in hybrid containing the Criollo strain the incidence of *Phytophthora* trunk canker, another symptom produced by this pathogen, is high *(36)*. However, very few Criollo plantings are being made. Control is done mostly by cutting off the decayed area and covering it with Bordeaux paste.

Recent studies conducted in Colombia *(29)* appear to show, however, that copper fungicides have a certain deleterious effect on the fertilization of cacao flowers unless they are used in combination with urea and plant hormones. This does not, as yet, exclude the use of copper fungicides *(38)*. The increases *(38, 44)* brought about by copper fungicides in Costa Rica appear to counteract the detrimental effects.

Witches' Broom. Losses due to this disease are strikingly serious in Ecuador and it is also prevalent in Trinidad, Venezuela, Guianas, Peru, the Amazon basin, and parts of Colombia. Treatment by spraying for the control of witches' broom has never yet proved satisfactory, though some control of pod infection may result from copper sprays *(21)*. In 1944 Baker and Crowdy *(4)* concluded that spraying can be ruled out as ineffective and uneconomical. The fungus, *Marasmius perniciosus*, the cause of witches' broom, can infect only rapidly growing tissue. In Ecuador flushes of new growth appear on the cacao tree erratically, in which case it would be necessary to keep any new growth constantly protected. The brooms remain attached to the branch for some time and, once dead, give rise to sporophores which bear the spores of the fungus. Desrosiers and Bolaños *(13)* have initiated a study of control based on the sporophore production and aimed at inhibiting their development by means of eradicant fungicidal sprays to the infected tissue.

The chemicals thus far tested in Ecuador have been various phenol and cresol compounds commonly used as eradicant fungicides, herbicides, and wood and fabric preservatives, such as Santophen-20 (pentachlorophenol in Diesel oil), Santobrite (sodium pentachlorophenol), Elgetol (sodium-dinitro-*o*-cresolate), dinitro-*o*-cresol, Sinox-W (ammonium dinitro-*o*-seco-butylphenate), Sinox (sodium dinitro-*o*-cresolate), and Puratized agricultural spray (phenyl mercury triethanol ammonium lactate).

Applications of sodium pentachlorophenate at 0.20% and dinitro-*o*-cresol at 1.50% gave highly significant reduction in the development of sporophores of

Marasmius perniciosus, with an indicated preventive effectiveness of about 87%. Dinitro-*o*-cresol, although used in much stronger concentration than sodium pentachlorophenate, was much less toxic to the cacao tree. The applications were made only once late in the dry season, and the theory behind this work is that a significant control of witches' broom on the crop may be achieved by such a single application. This is because the heavy crop is formed with the beginning of the rainy season. The development of sporophores is also induced by the first rains and this results in heavy infection of the developing crop. Thus, a significant reduction in this first crop of sporophores might be expected to result also in a corresponding reduction in the amount of disease appearing on the crop *(13)*.

Monilia Pod Rot. This disease, still restricted to Ecuador, Colombia, and Venezuela, may well rank with witches' broom in the amount of losses produced. It is caused by *Monilia roreri* and is one of the most serious diseases of cacao. Little is known regarding the mechanism of infection of cacao pods by this fungus. Attempts to determine method of infection, suspected of occurring through the flowers, have been inconclusive. Bastidas *(6)* inoculated 3327 pods with cultures of *Monilia* by 11 different methods and could not induce infection.

For the control of this disease Bordeaux mixture in combination with better cultural practices has been recommended. Garces *(17)* recommended similar treatment, but when the pods are still young. Although only preliminary trials have been made on the chemical control of *Monilia* pod rot in Colombia, initial reports indicated that substantial control was being obtained with fungicidal sprays, but when the results were analyzed statistically they were not significant *(18)*.

Studies on the control of *Monilia* pod rot of cacao are now in progress in Ecuador. Desrosiers *(12)* reports that, although the data are not complete, there are indications that Parzate (zinc salt of ethylenebisdithiocarbamic acid) and sulfur may be successful. The results so far show about 13% *Monilia* on unsprayed trees as compared with almost zero on sulfur- and Parzate-sprayed trees.

Sphaeronema. This disease, mainly a trunk canker, was first described in Ecuador in 1918 by Rorer and was attributed by him to *Sphaeronema fimbriatum*, better known currently as *Ceratostomella fimbriata*. It has also been reported to cause a pod rot.

It is reported that in Venezuela *(26, 36)* this disease occurs in epidemic proportions in certain areas and causes serious trunk injury to 3 to 5% of the trees. It also occurs probably in other areas of tropical America. In Ecuador this disease is called "machete disease," because the fungus, a wound parasite, infects through cuts and produces severe cankering in the trunk. No chemical control has been attempted, and burning the infected trees is the only control used at present in Venezuela.

Anthracnose. This is a widespread fungus disease of cacao caused by *Colletotrichum* sp. which attacks young foliage, denuding young plants and trees of their leaves. It also attacks older trees and the attack is more severe in cacao grown in full sunlight. It may become a problem because cacao is now increasingly cultivated with no shade. Circumstantial evidence indicates that fungicidal sprays intended for the control of *Phytophthora* rot in Costa Rica appear to have had a beneficial effect in the reduction of this disease. Anthracnose also produced pod rot, but this symptom is not responsible for losses of importance.

Pellicularia (Koleroga). This fungus attacks cacao leaves, causing them to die and hang from their branches. It is not considered serious.

Diplodia. This disease has been reported from many areas of cacao production as caused by *Botryodiplodia theobromae*. It is associated with dieback of young branches and rotting of overripe pods. It is considered of little importance.

Thielaviopsis. A pod rot caused by a species of *Thielaviopsis*, probably *T. paradoxa*, was reported from Ecuador in 1953 *(15)*. It is only of occasional occurrence.

Rosellinia. Among cacao root rots, that caused by the *Rosellinia* fungus is a sporadic disease that occurs mainly in poorly drained soils.

Diseases in Propagators. Propagation of cacao by rooting branch cuttings is at present done extensively in many countries. Losses due to disease while the cuttings remain in the propagator are heavy. Desrosiers and von Buchwald *(14)*

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pointed out that there exist two problems in connection with propagator troubles—fungus infections and dying off of cuttings by an undetermined cause.

In the first case the cutting undergoes a rot on its base, resulting in its death. In Ecuador and in Costa Rica isolations made of infected material have given *Colletorichum*, *Fusarium*, and *Diplodia*, as well as bacteria.

In the second case, the dying off of cuttings begins with an intense chlorosis after the third day in the propagator. Within 10 days all the affected cuttings die out. Rotting of the base of the stem is believed to be due to nematodes and bacteria frequently associated with this condition.

For fungal infections treatment of the rooting medium with fungicides has offered a certain degree of control. In Ecuador *(14)* Fermate or Zerlate mixed with the water used for washing the cuttings have been used at concentrations of 0.125 to 0.50% (12.5 to 50.0 grams per 10 liters of water). The Shell compounds P-162 (experimental sample) and CBP-55 (brominated chlorinated C_3 hydrocarbons), formaldehyde, Bordeaux mixture, Fermate, and hot water treatment of the rooting medium (sawdust) have been tried in Costa Rica. Differences in percentage of rooted cuttings were, however, not significant.

Several combinations of phytohormones and fungicides have been also used for the control of propagator diseases. These attempts have been made both at the Tropical Experiment Station in Ecuador, and at the Inter-American Cacao Center in Costa Rica. From the latter studies *(2)* it has been found that 8000 p.p.m. of indolebutyric acid in the powder mixture of talc and Phygon XL (3 to 1) and of talc and SR-406 (3 to 1) gave highly significant increases in the percentage of rooted cuttings over hormone mixtures with no fungicide.

Root Rot in Nursery Beds. The growing of cacao seedlings is always difficult, owing to root diseases that result in very poor seedling stands, and a tip blight apparently caused by *Colletotrichum*. Formaldehyde sterilization of the soil of the seedbed has proved very beneficial. At La Lola Cacao Experimental Farm of the Inter-American Institute of Agricultural Sciences, Costa Rica, the technique of planting the seed in a layer of sawdust placed upon the seedbed has proved very effective, for control of both root rot and tip blight *(25)*. There is no information in the literature about chemical treatment of cacao seed, although it would apparently not be necessary when the seed is planted in the sawdust.

Root Rots in Transplanting. Transplanting losses are high, mainly due to root decaying organisms. There is need for studies of chemical root treatment before transplanting.

Other Minor and Undetermined Diseases. There are also many minor diseases, such as those caused by *Corticium salmonicolor*, *Marasmius sarmentosus*, *Trachysphaeria frutigena* (mealy pod), and others.

Among the determined diseases which might assume prominence at any time are the so-called "Buba" or cushion gall of Nicaragua *(52)*, several types of soft pod rot, a gray mold that attacks cacao leaves, a black rot of the interior of the pod, and undoubtedly other diseases. In general, it is possible that cacao crop losses due to diseases and pests are greater than those reported by Hale *(20)*.

Cherelle Wilt

Immature cacao fruits (cherelles) are subject to wilting and failure to develop. Losses due to this condition are in general very high and from some areas it has been reported that half of the developing fruits wilt. Humphries *(22)* followed the seasonal variation in the carbohydrate reserves of the bark and wood of the trees and concluded that the carbohydrate content of the trees bearing smaller crops did not limit the size of crop and that some other factors were concerned. He observed that fruits tend to wilt when the maximum demand for mineral nutrients is made on the tree by the developing crop, or in the case of young trees, by a heavy flush of new leaves. During the first 75 days after the setting of fruits they are dependent on nutrients transported in the xylem and are consequently sensitive to water strain or competition up to the time when mineral supplies are increased by the phloem. Until then the fruits are susceptible to physiological wilt. Humphries postulated that competition for potassium was the main cause of Cherelle wilt under the condition of his observations.

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Naundorf and Gardner *(30)*, claim that Cherelle wilt may be reduced by spraying young fruits with *p*-chlorophenoxyacetic acid and naphthaleneacetic acid at concentrations of 25 to 50 p.p.m.

Alvim *(1)* in Costa Rica confirmed in part the studies of Pound *(41)*, Voelcker *(50)*, and Humphries *(22)* and found that higher incidence of Cherelle wilt usually occurred after periods of intense growth of the leaf flushes and/or when the rate of growth in trunk diameter decreased or was checked. Spraying the fruits with *p*-chlorophenoxyacetic acid did not reduce the condition, as reported by Naundorf and Gardner *(30)*. Alvim concluded that Cherelle wilt in Costa Rica is apparently caused by food strain (carbohydrates) or by depression in the mechanism of food translocation, and not by hormonal or mineral deficiencies.

McLaughlin *(23)* stated that Cherelle wilt may be caused in Costa Rica by the fungus *P. palmivora* and an insect membracid. He admits, however, that it is not possible to separate the total effect of these two factors from physiological wilt, which also must be considered.

Chemical Weed Control

Chemical weed control in cacao plantations with volatile weed killers is generally considered detrimental to pollinating insects and to the flower and fruit set. Recently Naundorf *(28)* and Oliver *(33)* in Colombia conducted tests with compounds derived from 2,4-D and with an ammonium salt of dinitro-*o*-cresol to determine the effect of these materials on the flowers. They found that dinitro-*o*-cresol can be used at the dosages commercially recommended, and that only the volatile 2-4-D derivatives at concentrations of 500 to 750 grams per "plaza" (6400 square meters) can be used.

Adhesives

Most fungicides, especially the organic ones, have residual capacity markedly inferior to that of Bordeaux mixture. However, the tenacity could be improved by the addition of adhesives, especially when used in regions of heavy rain. Only preliminary trials in Costa Rica have been conducted in this important problem. Of 14 stickers tested on cacao seedlings in relation to the control of *Phytophthora* rot of cacao, none gave satisfactory results.

Because of the difficulty in evaluating adhesives, Chaves *(11)* devised a bioassay method for the comparative evaluation of these materials with the organic fungicide SR-406. This method is based on the relative comparison of the area of inhibition produced on cultures of *Helminthosporium oryzae* in Petri plates by leaf disks taken from plants treated with the fungicide alone and with adhesive, before and after the plants were exposed to natural conditions. Small cacao plants were sprayed with the fungicide alone (4 pounds per 100 gallons of water) and in mixture with three stickers: Armour sticker (50% Captan), RDA-156 (experimental sample of Standard Oil Development Co.), and P.E.P.S. (Goodrich Chemical Co.). Leaf disks were collected 3 hours, 5 days, and 13 days after fungicidal treatment. The relative amounts of fungicides retained on the surface of the leaves following these time intervals and varying rainfall effects were determined by the area of the zone of inhibited growth of *Helminthosporium oryzae.*

Armour sticker was used at the concentration of 1 pound per 100 gallons of water; RDA-156 and P.E.P.S. at the concentration of 1 pint per 100 gallons of water. The inhibition areas resulting 3 hours after treatment were not significant for any of the treatments. Inhibition resulting by treatments with SR-406 plus P.E.P.S. and SR-406 plus RDA-156 after 5 days when the plants received 2.11 inches of rainfall were better than that resulting from the fungicide alone or from fungicide in combination with Armour sticker. There was no significant difference between the fungicide plus Armour sticker and SR-406 alone, nor between the results of combinations of this fungicide plus P.E.P.S. and plus RDA-156. There was no inhibition of any of the treatments after 13 days following a rainfall of 2.45 inches.

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Spraying, Dusting, and Mist Spraying

Once an effective compound has been found for the control of a pest, it is necessary to consider the method of application to the cacao plantation. Up to the present time the usual method has been the so-called "dripping" method by which the pesticide is diluted with water to obtain a solution, suspension, or emulsion which is sprayed by pressure. Because of the large size of the drops formed, part of the fungicide drips and is lost. Although this method of spraying has given good control of *Phytophthora* rot of cacao in Costa Rica, it might prove profitable to use other methods such as dusting or mist spraying when water is not plentiful. Dusting, however, has many disadvantages.

The new method of mist spraying consists of using water only as a fungicide solvent and using air for atomization and transport. The very small size of the drops achieved in this method results in better coverage and saving of material. For mist spraying it is necessary to use highly concentrated fungicides. Sandoz, a copper oxychloride, has given excellent results in fruit orchards in Switzerland. Bordeaux mixture and some other fungicides commonly used are not adapted to this method.

Conclusion

Although progress has been made in the control of certain insects and diseases of cacao in some areas, the use of pesticides on cacao has barely begun, for all pests and diseases continue to cause staggering crop losses. When knowledge pertaining to the living habits of the plant and of the various pests which attack it, as well as the relationships between the plant and its pests, are better known, more effective control methods can be developed. Pesticides are very likely to be used to solve the problems of economic crop production for a long time, as the ideal method of achieving higher yields by better producers and the use of resistant strains is still in the very distant future.

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Control of Rubber Diseases by Chemicals

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The future of natural rubber is very bright, as it is more important than synthetic in European markets and supplies over half of world needs, in spite of subsidies to synthetics. However, it is susceptible to a number of diseases. Mildew is the most serious leaf disease in Africa and the Far East, but is being effectively treated with sulfur dusts. South American leaf blight is controlled by spraying with Dithane. Phytophthora foliage blight is increasing, but is being controlled by Dithane and Vancide. Tapping panel disease, also caused by Phytophthora, is increasing, although Orthocide and other treatments are proving effective.

Both war and peace are, in large measure, dependent upon transportation on wheels that are cushioned with rubber. Rubber is a unique agricultural product in its many capacities. It reduces shocks and vibrations, its elastic qualities are used to hold things together firmly but without rigidity, it insulates electric charges and conducts water and other liquids, it seals cracks. It has many other uses. Its multitudinous functions in industry are fabulous and, besides its money-making importance, its value in helping to bring pleasure and relaxation to civilized people cannot be readily estimated.

This use of rubber, a product of trees, is a development almost within the memory of living man. Only a little over 200 years ago *(2, 11)* the Frenchman, Charles Marie de la Condamine, took to Europe the first samples of a curious elastic product from juices of a tree growing in Peru. At first, it was of little common use. Some hundred years later (1839) Charles Goodyear discovered the vulcanizing process in rubber, and in 1888 pneumatic tires came in. The importance of the part rubber played in motor car development greatly stimulated search for sources of the raw product, which soon resulted in exploitation of jungle growths of Brazil. Most of the rubber of commerce was shipped from its port of Para (Belem) and was thus called "Para rubber." It came from wild trees of Hevea in the family *Euphorbiaceae*, the most important being *Hevea brasiliensis* Muell. Arg. The diseases of these trees are the subject of this paper.

Realization by tropical agriculturists of Europe of what might be gained by cultivating rubber trees in their tropical dependencies stirred their imaginations. Between 1873 and 1916, at least 11 exploration trips were sent from Europe to the Amazon Valley to secure seeds and to study the rubber tree and its possible adaptability to other parts of the world. Nine of these expeditions were successful in bringing seeds to Europe, and resulting seedlings were taken to the Far East. Among the explorers, the major credit for such transportation goes to Sir Henry Wickham, who brought out seeds in 1876. It was largely from his seeds that the trees came upon which were built the great rubber-growing industries of Malaya, Java, and Sumatra. The earliest experimental exportation of rubber from Java was in 1884, and that from Malaya in 1899. The first shipments were well accepted by the market and large rubber plantations were established in Java in 1906 and were soon followed by other large plantation developments in the Far East.

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World Growing and Plantation Rubber Future

Rubber prices were attractive, and by 1910 big companies had been formed for large scale rubber planting. The absolute necessity of research was clearly recognized and probably no agricultural enterprise has gained more from scientific attention *(11)* than the growing of hevea in plantations. The plantation processed latex rubber was increasingly standardized and purified, and it superseded the more difficultly won jungle material of uncouth and uncertain qualities. Other parts of the tropical world began to realize the potentialities of cultivating hevea rubber. It was taken to Liberia, Uganda, Nigeria, and the Congo; its exploitation as a plantation product was attempted *(3, 11, 38)* in the American tropics, first, early in the present century, in the Amazon region of Brazil, then in Colombia and Peru, and a little later in other American countries. Exact figures are not available but, at present, there are about 8,864,000 acres of rubber in the Far East, 150,000 in Africa, and 34,000 in the American tropics. New lands are also being planted to rubber in regions where it is now growing. Latex rubber became of very great importance in world commerce.

However, the hazards of shipping natural rubber from far corners of the earth to manufacturing centers in Europe, Asia, and North America were severely felt during the world wars. During these emergencies shipping was cut off, and feverish research succeeded in developing synthetic materials that partially replaced natural rubber. This has given growers considerable concern. On the other hand, recent writings *(5, 13, 25, 31, 32)* show that latex rubber continues its role and the synthetics will probably never be able to replace it wholly. With the new processing methods and more attention to the better plantation product, the future is even brighter; natural rubber seems able to do more than hold its place in commerce. Even with present governmental subsidies for synthetic plants, much more than half of world requirements are for natural rubber.

The requirements in 1951 *(31)* for the United States of America, Canada, the United Kingdom, France, and the Netherlands were 1,005,804 tons of natural rubber and 761,614 tons of synthetics. On the basis of consumption the United States required 41.7% natural, Canada 65.4, United Kingdom 98.6, France 93.3, and Netherlands 98.3; on the basis of importations, Belgium and Luxemburg needed 94.1% natural, Denmark 97.8, Greece 92.4, Italy 93.6, Norway 95.9, Portugal 98.2, and Turkey 100.0.

It seems probable that when governmental subsidies are relaxed in the United States and certain other countries where synthetics are produced on emergency funds, natural rubber will be in a fairer position relative to synthetics, and latex rubber may increase its popular lead. In 1952 the world consumed 1,860,000 long tons of latex rubber, and in 1953 about 80,000 more than this. The Far East still produces over 90% of the natural rubber of the world, and nearly half of that percentage comes from Malaya. Africa ships about 3%, and Latin America about 2%.

A recent analysis *(25)* of the natural rubber situation has been made by Lockwood, looking forward to what might be the necessities in the coming 25 years. His conclusions were that in the long run the future for natural rubber continues bright, and that world demand for rubber is sure to progress each year. The large requirements in the United States will continue at a greater pace, and in other countries the demands will probably grow much over what is now believed probable. Consumption in 25 years may be easily double that of today. He stated that "the total free world demand for new rubber about 1975 may possibly be around 2½ times 1950 consumption." The history of plantation rubber development indicates that research on natural rubber production problems needs to continue at least at the present high rate, and increased as insurance for the future.

Diseases of the Hevea Rubber Tree

When the hevea rubber tree was growing under the highly mixed tree stands of primeval jungle conditions, its disease problems were almost obscured. At least they were of minor importance when compared with the difficulties of securing the latex in the wilds, processing it, and getting it to market. When the tree came under man's gentle ministrations, this changed immediately. Pure stands were planted in

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countries with climates and soils good for the tree and, at the same time, good for its disease troubles. There were also plentiful sources of disease close by in jungle still standing, or sources left by jungles recently cleared away for cultivated trees. Disease organisms attacking other hosts found easy adaptability to large areas planted to a new tree. These circumstances made the pathological problems of supreme importance.

The diseases of hevea have been given a lot of attention. At many times in many places, diseases have been the main factors limiting profitable rubber growing. In India *(33)* a committee recently listed 14 commonly encountered serious rubber diseases in that country. Steinmann *(43)* long before that had listed 33 such diseases in the Netherlands Indies. There were 37 diseases fairly recently listed by Edgar in Malaya *(12)*, while Sharples in 1936 *(40)* listed 91 genera, making up 94 species of fungi attacking rubber in that country, although some of these were of comparatively minor effect. Stevenson *(44)* prepared a general list of 41 rubber diseases, published in 1926. Some 25 years before the work of Sharples, rubber had not become so severely involved by diseases, and Petch listed only 25 different fungus genera attacking the tree in Malaya. These figures give only an idea of diseases primarily in the Far East, that were attacking rubber in a new environment. As might be expected, rubber was found to be affected by many more diseases in the home environment where it originated.

When a survey was made in 1923 *(45)* by an expedition studying rubber diseases in the Amazon Valley, many diseases were found that were different from those listed for the Eastern Hemisphere. A total of 73 diseases were given as having been found on that expedition. In addition, a check list was prepared of all the fungi that were known to attack hevea. Of the large number of fungi named, 238 were from the Orient and Africa only, 106 were found in both the Eastern and Western Hemispheres, and 43 were exclusively of Western Hemisphere occurrence. Of the whole list, there were probably less than 40 of known considerable importance. A very recent publication *(22)* gives 16 parasitic fungi of special note on hevea at the present time in the American tropics, while 10 years previously only eight were considered specially important in the Amazon Valley. Research has shown that the challenge to rubber culture from disease attacks have been and continue to be met successfully. It was long recognized *(11, 26)* that planters owed a great debt to students of disease control. It has been said, especially in Malaya, which produces by far the largest quantity of rubber of any country in the world, that the rubber industry was saved, not once but several times, by the control measures devised by plant pathologists working on rubber. Chemicals, used to combat diseases, are a potent source of help in disease control.

Chemical Disinfection of Seeds and Seedbeds

A review of the literature shows little damage from seedling diseases of rubber. However, damping off was first seen in Malaya *(7, 41)* as early as 1914. It was also known in Java and Ceylon, and was seen in the Amazon Valley *(45)*. It was recognized as a condition usually arising as a secondary effect in young plants weakened from sun scorching, abnormally deep planting, or similar predisposing cause. Diseased seedlings, when studied by culturing methods, yielded such organisms as *Pestalozzia palmarum* Cke. and *Dioplodia spp.* These fungi are usually thought of as weakly parasitic in nature but able to attack physiologically subnormal hevea seedlings. When seedling trouble appears specially severe, it is considered best either to move operations or to clean up the seedbeds and disinfect with some such fungicide as formaldehyde. An old recommendation was 5% Izal. Arasan [bis(dimethylthiocarbamoyl)disulfide] solution can also be used, and a drench of 2% Fermate (iron salt of dimethyldithiocarbamic acid) can be applied. Spergon (choranil) and mercury- and copper-containing solutions produce toxic effects on seedlings. If the seeds are planted in well made seedbeds, with good drainage and with reasonable shading, there is usually very little or no damping off or other disease damage to the seedbed.

There has been some fear of transporting disease fungus spores on hevea seeds sent from one country to another. The seed does not remain viable long under usual conditions, but it is so composed that it can withstand strenuous treatment shortly

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after harvest. Several disinfectants may be employed, although those containing salts of heavy metals might be expected to be somewhat injurious. Imle *(16)* recommended a solution made from 1 part of commercial 37% formaldehyde in 120 parts of water. The seeds were submerged in this for 30 minutes, rinsed, dried, and shipped or planted immediately. He found dusting with Spergon was also a good treatment for ensuring that no unwanted fungus disease would be carried on hevea rubber seeds.

Dust Applications to Control Leaf Mildew in Orient

The hevea rubber leaf mildew does not occur at present in any country of the Western Hemisphere. It is, by all odds, the most serious leaf disease on hevea in Java, Ceylon, Uganda, Malaya, Indochina, and the Belgian Congo, and it develops *(4, 30, 36, 40, 43, 44, 48)* in most severe form at the lower elevations where rubber is grown. It has been the subject of a great deal of study since it first appeared in Java in 1918. The disease is caused by an inconspicuous fungus, *Oidium heveae* Stein. It attacks young foliage, and causes repeated defoliations. It is held over from season to season on the inflorescences. The damage it causes is great, as reported by Murray *(30)* and Young *(48)*. The very first year after the fungus was found and identified in Java, it reduced production 10%. When a method of control was devised and the trees were treated, planters obtained 16% increase of latex rubber from the good effects of the first treating season, and 75% increase the second season through cumulative effects of better health in their trees.

This disease is now successfully controlled *(1, 4, 12, 40)* by use of sulfur dusts. Early trials of many fungicides were disappointing, but later work was more successful. Bordeaux mixture was not good, but lime-sulfur solution and sulfur dusting both gave excellent results. Wet sprays had to be abandoned because of the commercial impracticability of spray coverage on such tall trees as hevea, and because of the difficulties of terrain. Airplane dusting was done in Java in 1929, using sulfur dusts, and effects were good. Eventually specially constructed light dusters were used. They were carried by laborers, and were fitted with minimum weight engines and blowers that shot the dust 50 or 75 feet into the air, thus getting it up into the tops of the tallest hevea trees.

By 1930 planters in Ceylon were using sulfur as a regular treatment during the mildew season, which comes after the rains start. The time to begin dusting is when first buds "break" following first rains after the long dry season. Dusting is continued until leaves are sufficiently mature to be immune from attack. Researchers found that the best sulfur was that which was fine enough to pass the U. S. 325-mesh or the British 300. Dusting is at the rate of 10 to 12 pounds per acre per application. The so-called "activated" sulfur has been used with good results at half the rate necessary with common sulfur. Dusting is repeated each 7 to 10 days until refoliation is complete, which usually requires five to seven dustings. Probably well over a million acres of rubber trees are attacked by the disease-producing mildew fungus. A lot of this acreage is being dusted, but large stretches are not thus treated.

Spraying for Control of South American Leaf Disease

The most dangerous disease of hevea rubber is the South American leaf disease, which is so far wholly confined to the Western Hemisphere. The classic description of the disease is that of Rands *(38)*. The causal organism is the fungus *Dothidella ulei* P. Henn. While it is cultivatable in culture with difficulty, it is to all intents and purposes an obligate parasite with three spore forms. The fungus is widely distributed by air, and scientists and planters still do not understand why this disease has not been found in the Far East before now. As the common name implies, it was first found in South America. Symptoms are the numerous scablike leaf spots causing leaf malformations and ragged appearance, occasional petiole lesions, and repeated defoliations. Effects are especially devastating under warm and humid conditions; it is spectacular in its severity, and has been given considerable study *(3, 8, 10, 15, 17, 20, 21, 23, 24, 27, 37, 38)*.

So long as rubber was recovered only from trees scattered in jungle growths of the Amazon Valley, this disease caused little concern. However, early in the present

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century it became the first and most serious problem when attempts were made to grow hevea rubber in large acreages of solid stands in plantations in South America. Rands stated that the blight occurred naturally throughout the whole native habitat of hevea, and that included the Amazonian parts of Brazil, Bolivia, Peru, Ecuador, Colombia, the Guianas, and Venezuela. Almost as soon as plantations were well established in Trinidad they were attacked, and Martin pointed out *(28)* that the South American leaf disease was taken to Mexico probably as early as 1910, although it was not definitely seen until 1948. It found its way to Panama and Costa Rica *(37)* quickly after hevea was planted, and it is still spreading, as is evidenced by reports of Wellman *(46, 47)*, who identified it for the first time as occurring in Nicaragua and El Salvador, in the later months of 1953.

To control this disease in the most practical manner in tropical America requires a considerable amount of technology. Rands stated *(38)* over 30 years ago that strains of hevea occurred that were resistant to this leaf disease, and Langford *(21)* later estimated that some 5% of Amazon jungle trees were of this category. After controlled testing, best progenies of such trees are used as clones and are the foliage source for commercial plantations in the Americas. Such tops are budded onto trunks that are from clones of leaf blight-susceptible type but high producers of latex, that are the result of breeding and selection by Far East rubber specialists *(11)*. Lastly, the root part of these trees comes from seeds of vigorous seedling trees. Such is the famous three-component tree. According to Gorenz *(14)*, it was first suggested in Java at least as far back as 1926, and it is used in the Orient in the control of rubber mildew as well as for purely horticultural advantages.

In the seedbeds and nurseries connected with the growing of these technologically developed trees, it is comparatively simple to produce good supplies of budwood in adequate amounts for resistant foliage. But it is another problem to grow great numbers of seedling root stocks from trees of variously susceptible nature. It is even more difficult to maintain large supplies of healthy budwood from high yielding but very susceptible clones. Obviously, this requires chemical control. Rands *(38)* recognized such necessity, looked forward to its use, and reported Bordeaux mixture as a successful spray over 30 years ago. He *(37)* and Brandes *(3)*, through the promise of the three-component tree developed by help of spray studies, materialized the cooperative effort of the rubber program work of numerous countries in developing a practical Western Hemisphere plantation culture of hevea.

Bordeaux mixture was the first fungicide widely applied in the rubber program but with varying degrees of success. Langford *(20, 24)* found so-called "insoluble" copper fungicides better than Bordeaux, and by using the more recently developed organic materials proved that, of many tried, the fungicides of organic compounds called Parzate [zinc salt of ethylenebis(dithiocarbamic) acid] and Dithane Z-78 [disodium salt of ethylenebis(dithiocarbamic) acid] gave much the best results. The best mixture was 1.5 pounds of either in 100 gallons of water. To this was added 4 ounces of Triton (benzyltrimethyl ammonium chloride) or 1 quart of rosin emulsion. This holds leaf disease very well in check when put on at 8-day intervals.

Refinements in nursery rubber spraying were, of course, inevitable. Grant *(15)* early observed that the cutting back of nursery seedlings and the resulting new growth needed very special attention. Resistant clones grew much faster than susceptibles, and their presence mixed in with the others added greatly to spray difficulties in nursery plantings. Manis and McMullan *(27)* obtained good control with heavy concentrations of Dithane, 4 pounds to 50 gallons of water, applied with a mist blower instead of the older medium pressure spray rigs with hoses. They also found that copper, even in heavy amounts, could not be relied upon for control of South American leaf disease under extreme conditions, whereas the organic spray produced excellent results. Imle *(17)*, in a summary of work on control of the disease in rubber nurseries, indicated the much greater advantage of using the mist blower, with its fixed nozzles and high pressure. He also described redesigning of nursery beds, with 4.5-foot spray ways for the machine. Seedlings as far as 40 feet from the nozzle were adequately sprayed. He likewise instituted and demonstrated (applications in operation in Turrialba, Costa Rica, work still unpublished) the use of the mist blower for *Dothidella* control in large trees being tapped for latex, by applications of Dithane.

This fungicide, as well as certain other organics, does not cause the "tacky" condition of latex said to be induced by copper contaminations. In Brazil and Costa Rica, rubber planters use much Dithane for nursery spraying. There are still some who prefer a certain amount of copper spray, but in Costa Rica, at least, the organic material is much more acceptable. It is also used for leaf disease on old trees in tap, being held for some special reason. Probably 10 tons of Dithane are used in the Western Hemisphere annually for control of South American leaf disease, and somewhat less than half as much of so-called insoluble copper sprays are still being applied.

The rubber growers in the Far East are fully alert to the possible (many feel it the probable) eventual introduction of *Dothidella* into the Orient, where all the hevea trees are highly susceptible to its infection. Quarantine restrictions have been very much tightened. Recently, descriptions and illustrations of the South American leaf disease have been given wide circulation in the eastern countries, especially in Malaya *(33)*. Moreover, the Far East rubber research men have developed a highly organized program of action, should the disease come in. Every effort has been made to educate all plantation owners and all their managers and chief assistants. Should a diseased tree ever be found in any place, the region would be immediately given special emergency designation. A defoliant *(18)*, the *n*-butyl ester of 2,4,5-T (2,4,5-trichlorophenoxyacetic acid) dissolved in Shell Diesoline, would be applied by air over the countryside for considerable stretches around the center of infection. The leaves that fall would then be destroyed. Large supplies of the defoliant are on hand, and airplanes can be called upon for immediate action.

Spray to Control Foliage Injury by Phytophthora

The fungus *Phytophthora palmivora* Butler attacks many tropical crop plants and is apparently almost ubiquitous where hevea rubber has been grown for a length of time. Generally it is of little consequence, and is not given a great deal of attention. This was the case in Costa Rica, until late in 1950. Manis has described *(26)* how this organism suddenly attacked with unusual severity on leaf petiole and leaf blades, and caused dieback. It had long been considered a devastating disease in Burma, South India, Ceylon, and Malaya. It occurs in Brazil *(10, 19)* and in Nicaragua *(46)*, but it is more severe in Costa Rica and is most serious there during the wet weather.

The methods of control include selection for resistance or field tolerance and Manis has announced excellent clones of this type that, remarkably enough, include resistance to both *Phytophthora* and *Dothidella*. The other control is by fungicides. Of several sprays tried, Dithane with sticker gave best results. Under usual moist weather conditions, applications are put on at 8-day intervals. During the more severe rainy season it is necessary to spray as often as twice a week. However, when continuous rainfall occurred for 10 days or more without cessation, and no spraying was possible, *Phytophthora* damage increased, and it was a struggle to get the disease under control when less difficult conditions returned.

If Dithane spraying was stopped for any reason, and a copper fungicide applied, the *Phytophthora* disease was once again severe. Dithane, again applied, brought the disease once more under control. Imle used a triple-strength Dithane mixture with a flour sticker in a mist blower, for *Phytophthora* control. Dithane was used at 6 pounds in 100 gallons of water, and was put on at the rate of approximately 2.35 pounds per acre. It required 30 to 33 gallons of the solution for 170 trees.

Dust and Spray Control of Target Leaf Spots

A spectacular disease of hevea leaves is found commonly in Peru and throughout the Amazon Valley. Symptoms are usually large leaf spots of brown color, becoming papery in texture. The trouble spreads rapidly and covers a large acreage of trees very quickly. It causes severe leaf fall, and is a major disease problem on hevea under certain environmental conditions. The organism that produces the trouble is the fungus *Pellicularia filamentosa* (Pat.) Rogers, and its spores are carried in the air.

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Carpenter *(9)* studied the disease in detail, and developed control measures with both sprays and dusts. Spraying with wettable Spergon gave the best control, although the fungicide was, at the same time, somewhat injurious to young hevea leaves. Fermate was nearly as good as Spergon, with no observable phytotoxicity. The copper fungicides, Copper King, basic copper arsenate, copper fungicide 34, and zinc (copper oxide) controlled the disease, but with less efficiency than the organic materials. Stickers added to effectiveness of spray treatments. The best stickers were Dresinate xxx, Casco glue, clay, Santomerse D, cassava flour, wheat flour, and calcium caseinate. Of a number of dusts, pure and in combinations, the best was composed of 15 parts of Fermate and 85 parts of Swan sulfur. No stickers were added, and this gave as good control as the best sprays. Recently Allard *(23)* has found spraying with Dithane with sticker a good control of target leaf spot.

Tapping Panel Diseases Controlled by Chemicals

The method of collecting the rubber-containing, milk-white sap or latex from hevea rubber trees is one of the most unique ways of harvesting from an agricultural crop. A shallow groove is cut in the bark in a special manner with a sharp, bent knife or gouge. The first cut is made at a convenient height and extended downward in a partial spiral of one third to one half of the circumference of the tree. Only the rather superficial latex tubes are opened by this cutting. These tubes occur just under the bark, but outside of the cambium, which is not injured any more than necessary. This operation is done daily, every other day, or at similar short intervals, and the latex is collected from removable cups attached to the lower end of the slanting cut down which the hevea sap flows. In a month's time the workman will have cut away a band of bark, sometimes almost an inch in width, through his successive visits to the tree. This cutting is called "tapping" and the part of the tree used for this purpose is often spoken of as the "tapping panel." The place where bark is removed starts healing as soon as possible, and in 6 to 9 months a new side of the tree is sometimes selected and the panel of the healing side is allowed to rejuvenate for future tapping.

This continual opening and reopening of bark tissues leave ideal places for the entrance of parasitic organisms. Two panel diseases are of great importance and have had considerable study *(4, 6, 28, 29, 34, 42, 43)*.

A very serious fungus parasite attacking tapping panels is *Phytophthora palmivora* Butler, ordinarily present only as a foliage inhabitant. The organism may give so little trouble on foliage that its presence may pass unnoticed. With the coming of warm and moist weather the fungus is enabled to attack with more success on tapping panels. It is a serious trouble in Malaya, Java, Ceylon, India, Brazil, Costa Rica, and other countries. The disease it causes, called black thread or black stripe, results in extreme reduction in latex flow, black streaks running through the bark, leaking of discolored juices out of the latex tubes, and rot of the infected panel.

Another moisture-loving fungus that attacks tapping panels is *Ceratostomella fimbriata* (Ell. and Halst.) Elliott, which is especially serious in Malaya and in Mexico. It is said to occur in less severe form in Sumatra and Costa Rica, and is of minor importance in several other rubber countries. *Ceratostomella* infection causes a moldlike growth on tapping panels and the disease is called moldy rot.

Infections by both of these organisms can become so serious that trees are forever spoiled for latex production. Unless the panel diseases can be kept to a minimum, there is no hope for economically profitable rubber growing. Both diseases are controlled by the same kind of treatment—fungicidal applications put onto the grooves cut in the latex-containing vessels of the bark. Work on control measures has been going on for the past 30 or 40 years, and is still in progress. Considerable testing has shown that certain chemicals are injurious to tapping panels—copper-containing materials, for example, may cause latex rubber to be tacky and unfit for commercial use.

In Malaya the Rubber Research Institute is continually studying new and old fungicidal treatments. These are gazetted and, if they have passed tests, they are included in an approved list, which gives the range of concentrations that will properly inhibit the disease and still not be too toxic for treating the newly cut bark tissues. The materials are applied by spraying a narrow band on the trunk, on each

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side of and including the tapping cut, or by painting with solutions and with pastes made from solutions. In some cases a fungicidal mixture is smeared into the tapping channel with the finger or with a bit of cloth. Carpenter cited *(6)* work in Malaya in which it was found that Fylomac 90 is a good treatment. This is an unusual fungicide, a preparation of tetradecyl pyridinium bromide. Panel disease has also been controlled by Spergon pastes. Where the disease is stubbornly present and treatments are poorly effective, it is often necessary to stop tapping for 15 days and treat the whole panel at least two or three times with a fungicide like Spergon or Fylomac.

When the trouble is black thread, planters use paints, coal-tar washes, asphalt, and other treatments with varying degrees of success. New tests have shown that Fylomac 90, applied in a 0.25% solution, effects a cure in eight successive applications. In one of the most recent studies on this, Carpenter *(8)* tested 22 fungicides on *Phytophthora* panel trouble in Costa Rica. His work was under ideal conditions for the disease and with a well tested invariably successful, artificial method of inoculation. He found only one fungicide sufficiently good for his purpose—Orthocide 50 [captan, *n*-(trichloromethylthio)-4-cyclohexene-1,2-dicarboximide], wettable, mixed with Filmfast sticker.

When either one of the panel diseases, or both together, are severe, it is often necessary to manipulate the tapping program. Tapping may be done early one day, and the fungicide applied that same day when flow is ended. In some cases the tapping may be done one day and latex collected, and the fungicide applied the following day. No tapping is done then until the day after that. The extra day between tapping and fungicidal treatment is not a bad practice, and does not seem to prejudice final control results.

Prevention of Budding Failure in Nurseries by Fungicidal Wiping Treatment

The production of three-component rubber trees is a recently perfected tour de force, combining strict attention to use of techniques dependent upon both horticultural and pathological research. The desired tree must have strong roots from a seedling, a trunk of highly productive bark for the tapping panel area that comes from budwood of a selected clone, and foliage of a proper type and disease resistance that comes from budwood from another clone. The practicability of the whole program is dependent upon the ease with which buds "take" to develop these three-part trees. Literally millions of buddings have been made, and the annual numbers are very large. However, budding is not always a successful operation. In Mexico, for example, Gorenz reported *(14)* that if top budding was 25% successful it was considered good, and results were very frequently less than 5%. Budding onto the roots usually gave somewhat better results, but often the number of those buds that took was unexplainably low. This was a serious handicap in establishing extensive rubber plantations in the Americas, where disease-resistant foliage is of such paramount importance.

Several changes in horticultural treatments were tried, but made little difference in general success of buddings. Detailed studies showed that budding failure was apparently due to fungus infection of the bud patch itself. When isolations and cultures were made from dying and dead buds, the organism most commonly encountered was *Diplodia theobromae* (Pat.) Nowell, although Gorenz also found *Gloeosporium sp.*, *Phyllosticta*, and *Penicillium.* These ordinarily feeble and semiparasites are able to attack the bud patch after it has been weakened by the severe shock of being cut away from the branch, its leaf removed, and the patch then bound tightly into place in the bark panel cut in the tree standing in the nursery row. Some time before this work, Carpenter mentioned *(8)* that, in general, budding in nurseries increased in successful takes, when organic fungicides were used for spraying those nurseries. This may have been through a reduction in the number of spores from the semiparasitic fungi. Gorenz found that if he could eliminate fungus infection of buds, the relative amount of bud failure in nursery work could be greatly reduced.

He tested a number of fungicides and discovered that a solution of Fermate was the most successful of all, although solutions of Arasan and Zerlate were next in value. Ceresan, Semesan, sulfur, and copper fungicides were not so usable, and some were actually injurious.

The best control treatment was based on the use of a solution of Fermate with a concentration of 200 grams to 1 liter of water (about 7 ounces to 1 quart). Budwood was wiped with cloth moistened with the fungicidal solution, and then allowed to dry. This deposited a thin film of fungicide on the bud surface. The bark of the seedling was likewise cleaned off with the moistened cloth. A piece of bark was cut loose from the place on the seedling where the bud was to be inserted and let slip back into place, and the latex was allowed to exude on bark surfaces. The coagulum was, in turn, wiped away with the cloth moistened with Fermate solution. The prepared bud was then inserted and the budding was wrapped. The fungicide was not applied to exposed cambium of stock or bud. Such treated buddings had excellent—sometimes better than 90%—chances of growing. This method is now standard in several countries, and work has been started in its use in budding in other tree crops.

Use of Chemicals in Control of Root Diseases

In the Far East, on the whole, the most troublesome hevea rubber diseases are root decays. It is commonly realized *(4, 11, 35, 36, 40, 42, 43, 45)* that, left unchecked, rubber root rots would have very soon destroyed commercial production of plantation rubber in the Orient. There is no tree crop that has had its many root rot diseases given such thorough study as has rubber. E. W. Brandes, R. D. Rands, Theodore J. Grant, E. P. Imle, and John B. Carpenter agreed that these troubles have been of practically no concern in tropical America. Langford *(19)* found little root rot trouble in his considerable observations specifically on rubber in the Western Hemisphere.

In the Orient, rubber root rot is common, and when rubber is replanted in old plantations, root disease problems increase. Root decays are often troublesome in new but poorly prepared jungle areas, where stumps are allowed to rot in place. Sometimes root diseases are less dangerous if newly planted lands are quickly cultivated to a cover crop between the rows of young rubber trees. In intensive rubber-growing districts, replanting of old growths is occasionally necessary. Different methods are used to remove the trees. In some cases, poisoning is employed *(39)*, using 33 to 50% by weight solutions of sodium arsenate in water or in pastes. Growing trees are killed in place. Poisoned trees are liable to attack by white root rot, and this rot may increase in lands that were growing treated trees, if cleaning up is much delayed before planting.

Poisoning does not destroy root disease fungi infecting roots of treated trees. It does hasten death of stumps and somewhat reduces chances of killed root infection. However, if stumps are left in the field and new trees are planted around them, root diseases will usually be increased about 50% in the new plantings over what would be ordinarily expected. Where root disease incidence is likely to be high, it is better to fell the trees before or ofter trees are poisoned, and remove the stumps from the field with as much dispatch as practical considerations allow.

There are a number of root-infecting fungi but there are four very important root rots. Wet root rot caused by *Ganoderma pseudoferreum* (Wakef.) Van O. and S., and white root rot caused by *Fomes lignosus* Klotzsch, are both able to attack young vigorously growing trees and spread through new plantations, although they are sometimes dangerous in old plantations as well. Dry rot, called black line or zonate root rot, caused by *Ustulina zonata* (Lev.) Sacc., more often attacks older trees, as does the so-called stilbum or stinking rot caused by *Sphaerostilbe repens* Berk. and Br., that is more commonly found in low and poorly drained ground.

Gross aerial symptoms of advanced root infections are stunted growth of trees, leaf yellowing and sometimes wilting, and branch dieback and drop, and, in some cases, fungus fruiting bodies and gummy exudations appear from fungus injury at the base of trees. When excavated for examination, diseased roots may exhibit mold and threadlike growth over their surfaces. They show internal discolorations or hard and soft rotting, and they may display slender ropelike rhizomorphs of different colors twining over and closely attached to root bark. Sometimes roots are abnormally roughened and have excessively corky appearance, and, in some instances, soil particles seem glued to the roots.

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As the root infection transfer from one tree to another is often by root grafts between contiguous trees, or by the fungi growing along roots and in soil debris, the path of progress of the parasites may be artificially barred by digging trenches to isolate diseased areas. When otherwise vigorous trees are found attacked, main diseased roots are laid bare, the decayed parts cut away, the superficial fungus growths scraped off and destroyed, and the roots covered with tar paint or other fungicidal mixture. A wash of 10% copper sulfate is sometimes used on root surfaces for disinfection. If Bordeaux mixture or Bordeaux pastes are used, the subsequent effects are often bad because lime appears to encourage attack by the most important root rot organisms.

Discussion

Hevea rubber is undoubtedly one of the unique crops of history and of all agriculture, and one of the most interesting. It is not easy to produce rubber. Research is the tool by which it is possible to grow vast acreages of the tree as a profitable crop. This could never have been done without the past and present intensive investigations of careful scientists over more than 30 years. Repeated reference in the literature indicates that diseases are the limiting factors in natural rubber production, and that planters owe a debt to disease-control workers.

Hevea rubber probably holds the record for the great number of different necessary disease control methods applied to any single crop. The group of those that are successful and commonly used is impressive: seed disinfection to keep from transporting disease organisms from one country to another, seedbed soil disinfection, fungicidal dusting of foliage, liquid spray application of fungicide on foliage, disinfectant wash on repeatedly injured trunk, fungicidal smear in cut in trunk, spraying of fungicide in fresh grooves cut in the trunk and injured surfaces, painting with disinfectants on the trunk, wiping of bud and scion with fungicide, excavating and treating roots by scraping and disinfecting, poisoning to reduce root rot quantity, trenching to isolate local disease areas, application of a compound of resistant foliage onto a susceptible and heavy producing tree trunk, and, lastly, an organized program of possible defoliation and eradication held in readiness to meet invasion by a devastating disease.

Chemical means of controlling tropical plant diseases are becoming more common and increasing in importance. There are more such chemicals available year by year, and their values are proved by research. The amounts of fungicides used in hevea plantations, and in other tropical crops as well, are becoming greater each year. Genetic control of diseases holds a very high place in the future of tropical agriculture. However, no balanced tropical agricultural development is foreseeable that will not call for fungicidal treatments.

Parasitic fungi and other disease-producing organisms are probably more numerous and variable in the tropics than in other parts of the world. Conditions are favorable for their rapid and continuous multiplication and variation. By careful work problems of disease may be completely eliminated in certain cases and this may be continued for decades or even generations. Nevertheless, pathologists and fungicide makers should expect that the best disease control programs may break down. When they do, the planters and growers will again come for help to pesticide manufacturers and agricultural scientists. A new disease may come in, or another strain of an old organism may appear to overcome resistance upon which every confidence had been placed. Parasitic variants may even require fundamental changes in long-accepted dusting, spraying, or other fungicidal control. Throughout the centuries chemical control methods may be remembered as the first, as well as the last, resort in reducing disease losses in tropical agriculture.

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Bureau of Plant Industry, U. S. Department of Agriculture, and its successors. Special mention should be made of Theodore J. Grant and E. P. Imle, who, as directors of the regional rubber research station in Turrialba, have had much to do with the success of re-establishing rubber as a crop in the Western Hemisphere, and J. B. Carpenter, recently rubber pathologist at that station. Library facilities and reports of experimental work of the station were freely opened at all times.

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Coffee Diseases, Insects, and Weeds Controlled by Chemicals

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Commercial coffees come from indigenous African trees of Coffea dewevrei, C. canephora, and C. arabica; the last is the most important. Coffee ranks fifth in international trade in agricultural goods, and is the leading commodity imported into the United States. Over 13,000,000 acres in 53 or more tropical countries are planted to coffee. The crop has over 60 diseases. Sprays, first used in 1880, are now most common for rust (the most serious disease), koleroga, American leaf spot (second most serious), foliage deterioration (most widely spread), pink disease, and brown eyespot. Of the 10,000,000 acres that should be sprayed, only a small fraction are treated. Copper fungicide sprays are the most commonly used, although they are somewhat toxic. Stickers are of utmost importance in the tropics. Coffee insects most commonly treated are scales and aphids, stem borers, antestia and lygus, thrips, mealy bugs, and berry borer. Contact, stomach poison, and fumigant insecticides are used. Herbicides have been tested, may be used more in the future.

Food, water, and shelter are of paramount importance to man, but a harmless stimulant like coffee has such a good effect, and is so ingrained into civilization, that it may cost more than some of the absolute necessities of life. In world trade, coffee holds first place as one of the enjoyment goods *(13)*, surpassing alcoholic drinks, tea, and tobacco. In world international trade it ranks fifth in all agricultural products, exceeded only by cotton, wheat, sugar, and wool.

In the United States of America, it is the leading imported commodity *(52, 53, 103)*. In many of the producing lands, trade with the rest of the world depends on coffee. Horn *(27)* showed that the coffee market was recently dangerously understocked, and that coffee requirements will increase rather than decline. Prices have become high and are not likely to be low soon.

One of the main reasons for the recent scarcity of coffee is that technological control of pests has not kept pace with increasing commercial requirements.

The Coffee Tree

The coffee of commerce is from the nutlike seeds called "beans," that are borne by a tropical evergreen tree, with glistening and waxy surfaced, broad leaves. The seeds are two to a fruit, in pairs, and are covered with a thin, usually red flesh, that makes a cherrylike fruit. There are said to be 50 to 80 different species of coffee. It is still a profitable field of botanical study. At present three species of the tree produce coffee of commerce.

Coffea arabica L. produces coffee of the best quality and it is by far the most important species. It is composed of several varieties that have developed spontaneously in the past; a few new ones are being found at the present time. These varieties include Arabian, Mokka, Maragogipe, and such types, which produce the costly mild flavored coffees. This species is the most delicate, and is almost the only one

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grown in tropical America. Wherever possible it is grown in other regions of the world, but more rugged kinds have replaced it in some areas. The *Arabica* trees are comparatively low growing, some even dwarfed in habit; others, when unpruned, may develop to 15 feet in height, and they are planted on an average of 8 by 8 feet, which makes about 680 to the acre.

From *Coffea canephora* Pierre is obtained a coffee of lower quality, more commonly spoken of as Robusta, Uganda, or Quillou. It is a vigorous tree, second in importance to *C. arabica*, and has taken its place where diseases and pests prevent the more delicate species from growing. It is a much larger tree, has a wide spread, and when unpruned may reach 18 to 20 feet in height. The trees are planted about 10 by 10 feet and average about 435 to the acre.

Coffea dewevrei De Wild. is considered by some to produce coffee of even lower quality than Robusta. In some places it has replaced Robusta and can sometimes be grown by native populations where the other two species fail. It is of the least importance to world commerce. The trees are large leaved and often called Liberica and Excelsa. The trees grow to over 30 feet in height if not pruned and are planted about 12 by 12 feet, averaging close to 302 to the acre.

However, Arabian coffee is the great coffee of history and of commerce. It is the best liked and it is upon this species that the world largely depends. It is in large measure the coffee that has been given most careful scientific attention with respect to control of diseases, insects, and weeds. It is mostly from studies on this species that the information presented here comes.

History of Coffee

According to history, Arabian *(Arabica)* coffee was cultivated as far back as 575 A.D. *(52)*. It is indigenous to the high lands of Abyssinia *(103)*, from whence it was originally taken to Arabia. It was introduced from there into Java in 1696 and spread rapidly into other tropical areas of the East.

It was growing as an exotic exhibit in the government glass houses in Amsterdam in Holland. Dutch workers took it from there in 1710 and circled Africa with it, around the Cape of Good Hope, and it was soon growing in Surinam in the Western Hemisphere. Meanwhile it had traveled to the botanical garden hot houses in Paris, and from there it was also taken to French colonial sites in the West—French Guiana and Martinique. Direct introductions were likewise made from France to the Caribbean islands in 1721 and 1741. Coffee was found by these Dutch and French adventurers to be well adapted to the climates and soils of the western tropics.

Area and Production

Coffee is now cultivated in 50 to 60 countries of the world, within a wide belt around the equator, roughly between latitudes 28° N. to 38° S. It grows at a fairly wide range of ecological conditions with respect to climate and soil. According to DiFulvio *(13)*, 230,000,000 acres of tropical land are capable of growing coffee; only about 13,000,000 acres are cultivated at the present time. Somewhat less than half of the coffee-free available land is in Africa and the rest is largely in Brazil, although there is much unused in other lands of the Western Hemisphere, as well as in south India and other parts of southeast Asia.

World coffee production varies from year to year. In the 53 coffee-growing countries mentioned in the 1952 yearbook of the United Nations Food and Agriculture Organization *(16)*, 2,269,900 metric tons of coffee were produced in 1951. In the Western Hemisphere, North and Central America and the Caribbean Islands produced 366,600 and South America 1,500,600 tons. In the Eastern Hemisphere, Asia produced 82,300, Africa 315,400, and Oceania 5000 tons.

It is impossible to make a close estimate of how much coffee production could be increased if diseases, insects, and weeds were reasonably well controlled. Official data on these matters are almost nonexistent. The author's belief is that coffee production could be augmented, easily, at least one third the world over, if diseases and other pests were properly counteracted.

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Important Diseases Controlled by Chemicals

The coffee trees in the world are subject to a large number of diseases *(2–4, 8, 73, 92)*; lists range up to 60 and more, and yet the disease possibilities do not always disturb plantation owners. Occasionally, as where the leaf rust attacks, or where koleroga (black rot) is serious, growers are on the lookout for diseases and are anxious about their future. There are local places where diseases are apparently more benign than in others, and this tends to dull the worry about disease losses in a country.

Diseases are dependent on several factors. Some diseases are rare and some are almost always present but cause such minor effects that the blemishes are actually accepted as characteristic of normal trees. Often coffee diseases are not thought of until an especially acute and virulent attack brings them to popular attention. When coffee prices rise there is more interest in the growing of the crop.

Seed-Borne Diseases

Practically all the coffee planted commercially comes from seed, except in the rather limited Robusta-growing region of Java where grafted plants are used. Coffee seeds are planted in seedbeds and are treated in about the same way all over the tropics. The mature and apparently healthy fruits are selected and the seeds are pressed out, washed and dried in the shade, and planted rather soon, because coffee seed viability is lost within a comparatively short while. Handled in this manner, the chances are lessened that coffee diseases will be carried by seeds. However, it has been proved experimentally that infected plants can be produced from seeds contaminated with both the coffee *Colletotrichum* and the coffee *Cercospora* from either field material or artificial inoculation. This contamination is probably not uncommon in plantation practice and thus far it is not of extreme importance. The *Hemileia* rust is probably not carried on the seed *(93)*. The American leaf spot is not carried on seed *(97)*.

Coffee seed is covered with a tough parchmentlike shell and this may be washed and disinfected with strong chemicals. Solutions of formaldehyde, strong chlorides, salts of mercury, and salts of copper can all be used and after half an hour of soaking the treated seed rinsed in water. This frees the seeds from harmful fungus spores and residues of injurious chemicals *(98)*. Dry seeds may be dusted with Arasan [bis(dimethylthiocarbamoyl)disulfide] or Fermate (iron salt of dimethyldithiocarbamic acid) and planted without rinsing off the fungicides. Spergon (chloranil) can be dusted on and left for several hours, after which it should be washed off with water before the seeds are planted. The same is true of dusts of any of the mercurials used in seed treatment, whether compounds of organic or inorganic nature. Copper or mercury residues on seeds will injure the seedlings coming from such treated seeds.

Seedbed Treatment

Coffee seeds are planted close together and shallow in the soil. They are kept moist, the beds are often covered with sacking or light mulch to retain moisture, and the whole may be put under protective shade. Under usual plantation conditions, *Arabica* requires about 70 days for seeds to germinate and emerge above the soil. The seedlings may then stay in seedbeds for a few weeks. Meantime the soil is not allowed to dry out before the seedlings are transplanted to the nurseries. The long period under these conditions, at such a susceptible period in the life of the coffee tree, may be a distinct hazard to the seedlings.

Damping off, caused by *Pellicularia filamentosa* (Pat.) Rogers = *Rhizoctonia solani* Kuhn, can cause as much as 60% seedling losses annually in certain Central American and South American coffee regions, as well as in parts of the Eastern Hemisphere. As determined recently in Central America, satisfactory control *(11, 12, 20, 59)* is by seedbed drenching with one of several fungicides. The wettable Spergon solution is made of 2/3 ounce in 2 gallons of water, poured from a sprinkling can to cover 24 square feet. It is followed by a clear water rinse, as the cotyledons are injured by the fungicide if it is allowed to dry on them. Yellow Cuprocide (cuprous oxide) is used in the same manner; a solution of 1.5 ounces to 2 gallons of water is sprinkled onto 24 square feet of seedbed. This fungicide is usually not rinsed off, because it is less toxic than the other and it acts as partial control for certain seedling leaf spots. A Perenox (cuprous oxide) solution of about the same strength, perhaps a little stronger, could be substituted for the Yellow Cuprocide drench. A Fermate (ferric dimethyl dithiocarbamate) drench of 3 pounds to 100 gallons of water is also used with the same success. An Arasan drench is made of 2 pounds to 100 gallons of water. Neither Fermate nor Arasan needs to be followed by a water rinse.

Rust, Oriental Rust, Leaf Disease, Leaf Rust

The rust of coffee *(Hemileia vastatrix* B. and Br.) is the most dangerous, most feared, and most troublesome disease of the crop in the world. It does not occur in the Western Hemisphere at present, but it is found in all of the most important Eastern Hemisphere coffee countries and is serious in about 20 of them. It has always been most severe on common commercial varieties of the Arabian coffee. It occurs on other species, such as the Canephora or Robusta, and has always been present on it although in less intensive amounts—for example, in Uganda *(70)* and in many other countries *(93, 99, 103)*. It also attacks the Dewevrei or Liberica coffee, but the injury is of comparatively minor degree.

The severity of its attack has been discussed by numerous writers—Ward *(90)*, Large *(31)*, Venkatarayan *(84)*, Wellman *(93, 99)*, Africa *(1)*, and Alvarado *(3)*. It has caused phenomenally serious devastation in certain countries where it first attacked. The classic example is Ceylon, where it reduced yields from 450 pounds per acre to 200 and less within 10 years. Planters sustained losses of £2,000,000 per annum for years until they finally abandoned coffee and started work with other crops. At one time Java produced 165,000,000 pounds annually of Arabian coffee; after *Hemileia* attacked, the plantations had to be abandoned. It was only after introducing low quality but more resistant Robusta, moving the *Arabica* plantations to very high regions, and spraying, that Java coffee again developed into an export crop.

In south India, losses have been about 70% of the crop annually, but spraying with Bordeaux mixture *(48, 75)* increases yields 50 or 70 up to 100% over attacked but unsprayed crops. In Uganda and in several other nearby countries *(70, 102)* losses are estimated at 30% of the crop each year. There is a total of nearly 3,000,000 acres of coffee in countries where the rust exists; in over a third of the acreage the crop should be sprayed for rust from two to three times each year.

The first spraying of any crop in the tropics was carried on in 1880 and 1881 by H. Marshall Ward, when he controlled rust of coffee with sulfur. That was 7 years before Millardet had announced the wonders of the new copper-containing spray, Bordeaux mixture. As the years passed, the most successful spraying for rust was done with Bordeaux mixture and the related Burgundy mixture, first used by Burck on coffee in Java in 1886, but not until many years later on coffee in India. It was not until results proved its practical worth that the treatment was accepted. According to Mayne and coworkers *(38)*, only about 300 acres were sprayed in India in 1929, but by 1933 planters were spraying 25,000 acres. In 1952 the sprayed acreage in this same area was reported *(48)* to be about 164,000. At present probably about 50,000 acres of coffee in India are relatively unsprayed.

Many different concentrations of Bordeaux mixture have been used for spraying. In early work in Kenya and Uganda *(14, 70)* the technicians used a mixture of 4 pounds of quicklime, 4 pounds of copper sulfate, and 40 or 50 gallons of water (formulas 4–4–40 and 4–4–50). Burgundy mixture was made of 4 pounds of copper sulfate, 4 pounds of washing soda, and 40 gallons of water. Variations in strengths were given much attention. Workers in India *(34, 35, 37–39, 48, 75, 79, 82)* made the largest contributions to *Hemileia* rust control by spray. Some of their first work showed that 4–4–50 Bordeaux was not so good as 2–2–50. A formula as low as 1–1–50 gave questionable results.

Probably the greatest worker with Bordeaux spraying to control leaf disease was Mayne. He proved in India that timing was of the essence and that many sprayings under south India conditions were wasted. Through work on seasonal disease

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occurrence and life history studies he outlined its epidemiology. He showed *(34, 36, 37)* that if spraying were properly timed it could give impressive results when applied only once a year in some seasons. It would nearly always give good control when applied twice at selected periods, although in some cases it needed three yearly applications. The most important spray is put on about a month after the first good blossom-producing showers, when vegetative growth or flush is well started, usually in April or May. In July and August come the heavy southwest monsoon rains, and these end with a short dry period, when some of the most successful planters spray again. The northeast monsoons come along then, after which the season becomes dry and cold until the first of February. During November another spray is often applied.

With slight adaptations, more or less the same type of timing has been found advisable in Uganda, Tanganyika, and Kenya. In these countries are some 335,000 acres of coffee; on about 80,000 acres in Kenya a large amount of the spraying is done on a custom basis by two competent private companies.

The advent of newer proprietary copper-containing fungicides stimulated attention to them to see if there might be a good substitute for Bordeaux. In the tropics this spray is not always dependable because of variability in lime supplies and effects due to transportation and storage and to mixing problems. When sprays like Perenox, Blightox, Cuprokilt (copper oxides), and others became available, there was much hope for their greater stability as standardized manufactured products, which would eliminate much of the occasional injury from poorly made batches of Bordeaux. This injury had been recognized, but the benefits from control of the leaf disease ordinarily far outweighed the toxic effects.

When several of the spray materials were tried side by side, it was found *(38, 74, 75, 79, 93)* that the good results from 2–2–40 or 2–2–50 Bordeaux compared favorably with Perenox mixed at 0.75 to 1 pound to 40 gallons of water. In some cases Perenox at that same concentration gave somewhat better results than the 2–2–40 Bordeaux. Addition of certain stickers gave significant increase in effectiveness of sprays. Blightox, Cuprokilt, and other similar fungicides gave about as good results as Perenox in the same concentrations. Copper Sandoz (copper oxide) had a good effect, but Dithane D-14 [disodium salt of ethylenebis(dithiocarbamic acid)] was of little value and caused severe leaf fall. The amounts of spray applied per acre ranged between 150 to 400 gallons, depending on spray equipment. The lesser amounts put on under high pressure were the most recommended.

Where countries do not have well defined wet and dry seasons, 6 to 12 applications of Bordeaux or other copper-containing fungicides are not only too expensive, but may cause serious toxic effects. In the Philippines, where rainfall is rather well distributed, work was carried on to learn the effective minimum application *(1)* of Bordeaux under those much more severe year-round conditions for leaf disease, starting with Bordeaux made up of 5 pounds of lime, 3 pounds of copper sulfate, and 50 gallons of water and varying the strengths and times of applications. The minimum coffee spray for good results proved to be 0.75 of the strength of the Bordeaux first used, put on at 2-week intervals. One of the more recent recommendations *(5)* for the Philippines has been to use 5–5–50 Bordeaux once a month. Such numbers of spray applications make coffee growing extremely expensive.

In India and British East Africa, where spraying is done most successfully, costs of an application vary considerably, but average \$5 to \$9 (U. S.) per acre per application. The quantities of proprietary copper compounds being used are increasing rapidly, and the coffee crop has become a stable year-after-year production.

American Leaf Spot, Ojo de Gallo, Gotera

Probably the second most dangerous and destructive disease of coffee is the American leaf spot [*Mycena citricolor* (Berk. and Curt.) Sacc. = *Omphalia flavida* Maubl. and Rangel)]. It is found in all the important coffee-growing countries of the Western Hemisphere *(95–97, 99)*, and is the most serious disease in that part of the world. Wallace has recently reported *(89)* a gemmiferous *Basidiomycete* attacking tea and coffee in the southern highlands of Tanganyika (East Africa). That parasite has a wide host range and the description sounds like the American leaf spot disease fungus.

Infections by the American leaf spot parasite cause excessive defoliation, and it is especially serious in cool, moist, highland coffee areas of the American tropics. The organism is a *Basidiomycete* with a large specialized gemmiferous infection body that can be seen with the unaided eye. It is apparently capable of attacking all varieties of coffee, and has a remarkably wide host range. It is distributed from tree to tree and from field to field by the action of raindrops. Man also takes disease material from one place to another. The devastations of the leaf spot have caused the complete abandonment of large areas of coffee in Guatemala, Mexico, Costa Rica, Colombia, and Brazil. It seems to be increasing in its distribution, and causing larger losses year after year in many countries. In Costa Rica coffee crops, in average years, sustain a 20% loss *(88, 95, 97)* from this disease alone. This loss may be considerably higher in years with unusually long wet seasons.

About 16 countries have the American leaf spot disease in serious amounts. As long as coffee was selling at low prices, pruning and shade management practices were used to reduce losses. The extra cost of spraying was out of the question, although old recommendations included the use of Bordeaux *(10)*. However, in recent years more studies have been in progress, and some important steps have been made towards the practical use of sprays. The Western Hemisphere countries in which the disease is indigenous have about 10,000,000 acres in coffee; at least 1,500,000 acres should be sprayed for the American leaf spot.

While Bordeaux mixture spray had been recommended *(3, 10, 92)* to control the disease in Costa Rica and Guatemala, it was on an experimental basis and applications were not accepted as practical. Years later, further spray studies were instigated in Costa Rica, the first of them *(101)* in 1947 and 1948 in the author's laboratory. Since then several technicians have been interested and many of the results have been gratifying *(56, 58, 59, 88)*. The availability of some of the newer patented copper compounds avoided some of the dangers and undependable action of Bordeaux, and yet controlled the disease. Several fungicides were tried on the American leaf spot at the rate of 2 and 4 pounds to 100 gallons of water. The copper-containing materials, Basicop (a basic copper sulfate), Crag (4-chloro-3,5-dimethylphenoxyethanol), and Perenox, were found to be good controlling materials; but fungicides with a zinc base such as Dithane and Zineb [zinc salt of ethylenebis (dithiocarbamic acid)] were ineffective. Some years before it had been found in the author's laboratory that an experimental organic spray material, SR-406 *(72)*, later called Orthocide, was a good controlling material if applied at frequent intervals, and that one of the most important factors in controlling this disease would be stickers for the fungicides. The organism spreads during wet weather, when it is most difficult for the spray to be applied to and remain on leaf surfaces.

In Costa Rica, spraying for the American leaf spot is done with such copper fungicides as Basicop, tribasic copper, Perenox, Crag, and Copper A (tetracopper calcium oxychloride) at 2 or 3 pounds to 100 gallons of water and at the rate of 150 to 175 gallons to the acre. It is begun when the rains start, is repeated monthly, and is continued until the rain stops. One man can spray an acre of coffee in 25 to 30 hours with a knapsack sprayer; the same area can be covered in 3 to 4 hours if motor-driven equipment is used with two men spraying from it. Each year more spraying is being done for leaf spot in Costa Rica, and a private company is now custom spraying in the country. It is calculated that it costs $7 to $9 (U. S.) per acre for each application. These fungicides are somewhat toxic to coffee, but even with chemical injury the advantages of leaf spot control far outweigh the ill effects from the fungicide on coffee leaf tissues.

Thread Blight, Koleroga, Black Rot

Thread blight *(Pellicularia koleroga* Cooke) attacks the crop in all the coffee areas of the world. It is serious in 36 of the 50-odd coffee countries, and is especially noticeable in moist places like parts of Nicaragua, Guatemala, Costa Rica, Belgian Congo, south India, and Colombia. It attacks all the coffees grown for commerce, but is especially destructive in varieties of *Arabica*.

The disease is caused by a fungus growing superficially on stems and undersides of coffee leaves. At the proper time multitudes of microscopic spores are released into the air and are carried to other coffee trees. The spores lodge on coffee

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tree surfaces, germinate, and grow along stems and side branches as thick dark threads. These travel, glued tight to shady sides of branches, and out by way of the petioles onto the under surfaces of leaves and even onto fruits. The threads form a thin sheet of fungus growth on new coffee tissues, in the meanwhile poisoning the tissues, causing them to turn black and rot and leaves and fruits to drop.

It causes varying amounts of damage. Plantations are seen where every tree is attacked and losses are high; more than 60% of the crop is lost annually in some unsprayed fields. In many cases there is a regular crop loss of 5 to 15% year after year. There are probably over 2,500,000 acres of coffee in the world that should be sprayed for koleroga.

Spraying to control koleroga has been carried on for a long time. Bordeaux mixture was first applied to control the trouble in south India, before it was used for *Hemileia* rust *(91)*. It has been claimed recently in India *(84)* that spraying with 2–2–40 Bordeaux has increased crops 65% where black rot is a serious malady. There it is applied *(38, 60, 84, 85)* once a year about the end of May or the first part of June. The epidemiology of black rot never has been adequately studied to determine the most effective time for spraying. Mostly a period is selected that is convenient for the grower, when no rain is falling *(15, 59, 77, 91)*. In some countries—e.g., Costa Rica and Nicaragua—koleroga spraying has been done on some farms more than once a year. With detailed studies this may be changed, but at present in certain places sprays are used several times a year. In some cases it is used once a month for a few times, then stopped until the disease starts again. Thomas pointed out *(76)* that in India 2–2–40 Bordeaux gave a little better control than some proprietary compounds tested with it. However, the difference has been considered of little special consequence since then, and several of the proprietary copper fungicides, including Copper King, Basicop, Perenox, Crag, and Copper A, have been used with good results. The proportions used for solutions are those recommended by the manufacturers. Costs of spray applications vary a great deal, largely between $5 and $9 (U. S.) per acre per application. Costs depend considerably upon the terrain, condition of the coffee plantation to be sprayed, water supply, and similar factors. In Costa Rica some of this spraying is done by a company on a custom basis.

Foliage Deterioration, Chronic Leaf Drop, Dieback

Foliage deterioration, chronic leaf drop, and dieback are caused by numerous fungi, acting in semiparasitic fashion: *Gloeosporium cingulatum* S. and V.S. = *Colletotrichum coffeanum* Noack, *Phoma sp.*, and others.

A chronically weak condition of coffee foliage is seen in all coffee countries. This comes from a complex of causes. In some cases, debility effects blend into those resulting after acute attacks by vigorous leaf-defoliating diseases such as koleroga, rust, leaf spot, and *Cercospora*. However, they are clearly different. The Nilgiri disease of India, top death of Java, and *muerta descendente* of Latin America, all seem to belong in this chronic complex. Many times this condition is blamed upon production of a good fruit crop. The chronic debility that develops has a combination of physiological and pathological relations. The first commonly noted symptom of the chronic effect is weak leaves and early leaf drop, followed by death of branch tips.

Physiologists consider that first a slow acting physiological debility results in weakening of foliage, which then becomes susceptible to advanced deterioration. Pathologists are inclined to view it as more a matter of parasitism. Both may be partly right. In any case, organisms that are ordinarily considered benign may attack and cause unwanted defoliation. In some cases, defoliation following old age of bearing wood is also prevalent, and lack of pruning may result in bad appearance of trees, due to a very different reason than the complex chronic deterioration discussed here.

Mayne, Thomas, and others *(38, 60, 81)* have observed in the Orient that active defoliation from coffee leaf rust will leave unhealed places at the points where unseasonably dropped leaves were attached to stems. Into the leaf traces left exposed *Colletotrichum* and similar weakly parasitic organisms will enter and cause dieback. Many gross observations in the western tropics on chronic deterioration, paralleling microscopic and cultural studies, have corroborated the conclusions drawn by scientists working in Africa, India, and Java. Dieback appears to follow a general debilitation that cannot be blamed on any single parasite, but is apparently cured in some cases, and in others greatly reduced, by spraying with such a fungicide as Fermate or a proprietary copper-based spray.

The chronically weakened condition, leaf loss, and dieback, that result inevitably from bearing a good crop of fruit, are very serious in some plantings. In Brazil, year after year, they probably cause as much as 60% of loss in some extensive areas. Certainly this is true in Central American countries and it is of concern in British East Africa as well as India. It seems, in addition, that it is in some way connected with the so-called "weak spot" of coffee leaves that has been given detailed experimental study and attention in Kenya and Tanganyika, and some study in the Kivu region of the Congo and in Mysore, India. The lack of foliage tone and weak spot seem to be closely connected.

It is believed that every country that grows coffee has areas of chronic foliage trouble and resulting dieback effects. Probably more than 25% of the more than 13,000,000 acres of coffee being grown in the world are affected by chronic foliage deterioration and dieback. In Africa, pathologists and physiologists have been working for several years *(28, 55, 61–64)* on control of this condition, and it needs as much study in the American tropics. Some of the deterioration can be avoided by heroic cultural measures, such as severe annual thinning of fruit, vigorous pruning each year, cutting trees back to stumps and allowing for rejuvenation of the plantation, and pulling out old trees and replanting with vigorous seedlings. Some of it can probably be relieved by fertilization.

In Kenya and other rust-infested countries, an occasional spray with a copper fungicide, even when leaf rust was not present, often resulted in a significantly high retention of leaves that were "normally lost." This retention effect was at first believed to be for some physiological reason, and was therefore called a "tonic" spray. Deeper examination of this tonic effect was then instituted, for it seemed possible that the trees might have lacked copper in trace quantities. Lime was known not to be a necessity in soils of those regions. Copper salt solutions were then injected into coffee trees, crystals of the salts were put under tree bark, and solutions were poured onto the soil around trees where roots could absorb. No such treatments gave the tonic effect that resulted from spraying. On the other hand, liquid spraying has reduced both leaf fall and weak spot occurrence on what would seem to be purely pathological bases.

Historical and isolation studies of weak spot have given varying results. In some cases those spots were found to be sterile, and in others superficial occurrence of both *Colletotrichum* and *Phoma* was demonstrated. In many cases unidentified fungus mycelium could be found in petiole tissue and in leaf tissue clear down into the palisade cells. These may have been, therefore, demonstrations of one of the reasons why leaves dropped prematurely. The problem is still not completely settled, but many workers now consider the good effect from tonic sprays due to control of weak pathogens.

Much has been done about materials, amounts, and manners of spraying to give tonic effects and control weak spot. It was found *(29)* that there was little to choose from between types of sprays, but the rates and strengths were important. The best rate was 1.33 pints applied per tree at a strength of 2.5 to 4% of whatever copper spray was used. Rayner found later that one year when noncopper sprays such as Tulisan and lime sulfur were tested with Bordeaux and Burgundy mixtures *(61)*, all four reduced leaf fall about 36%. But this was not always the case. In subsequent studies, the copper sprays caused leaf fall to be considerably increased during the first month after spraying. Later on, the untreated trees lost leaves badly and leaf retention was much greater in the sprayed trees. This immediate leaf fall did not occur on application of noncopper fungicides.

The timing of spraying for chronic leaf fall was studied further *(65)* and some most interesting results were obtained. Leaves could usually be retained on the trees by spraying. Tests with sprays on different aged leaves showed that those treated at under 4 months of age or over 9 or 10 months did not have a greatly increased length of life. The applications on leaves of the intermediate ages, toward the younger but not too tender condition, were best. In repeated tests it was proved that the use of certain noncopper sprays was superior to spraying with copper materials. The author has had the same general experience *(94)* in Costa Rica. From these and further studies it became clear *(66)* that certain specific times were best for applying so-called tonic sprays. These were associated with seasonal development of coffee.

In Kenya coffee goes through a long dry period when it is practically dormant. This is broken by blossom showers, and then coffee is in bloom and leaf drop occurs. If tonic sprays were applied on the trees in March, or during the early part of those rains, the expected leaf drop was much reduced. If spray was put on in late May, the leaves were also well retained. The flush of young leaves started by the blossom showers had had a chance to mature and harden by this time and the tonic spray was most effective. However, if spraying was delayed until July, there was only a little benefit, and there were no good effects from sprays in September, October, or November. Spraying was actually detrimental at the turn of the year. If put on in January, for example, it induced heavy leaf fall; leaves on trees treated in the cold dry season were stunted, the new stem growth was shortened, and this injury remained noticeable for several months.

The ultimate result of leaf fall is dieback, and several workers in Costa Rica *(20, 21, 26, 58, 59, 94, 100)* have made specific studies leading to its control. Numerous fungicides were used in these trials. Bordeaux gave fairly good results, except for toxic injuries and difficulties in preparation due to climatic effects on supplies of materials before the mixture was made. Copper-containing fungicides produced some injury to coffee, but treated trees were much better than those unsprayed. Even good Bordeaux did not control dieback as well as applications of Fermate and Orthocide [captan (*N*-trichloromethylthiotetrahydrophthalamide)]. Fermate controlled *Colletotrichum* but not *Cercospora.*

Pink Disease and Brown Eyespot

Two diseases are of relatively minor importance, except when they suddenly became acute, usually for a short while. The reasons for these surprising increases in severity are still not thoroughly understood. Both organisms may be present in plantations, as almost benign in character for long periods and then abruptly cause unusual and drastic damage.

Symptoms of the two maladies are very different. Pink disease *(Corticium salmonicolor* B. and Br.) gets its name from the pink color of the organism that covers branches and stems of trees and causes malformations, angular and irregular lesions, killing of buds, fans of the fungus growing over the bark, and roughened cankers. In severe cases leaves on affected branches are killed and fruits drop quickly; but when tree tops are only mildly attacked growth is stunted, branch internodes are shortened, adventitious buds grow out, and a witches'-broom type of growth develops. Nurseries can also be badly attacked by pink disease. The brown eyespot *(Cercospora coffeicola* Berck. and Cke.) is solely a leaf and fruit spot problem. Leaf eyespot is commonly minor in occurrence year after year, yet it is consistently present. It ordinarily escapes attention unless it is being critically hunted. Although spots may not be numerous—only one or two on a leaf—under certain conditions they can cause severe defoliation, which is often much more severe in nurseries and seedbeds than in older trees established in the field. There are probably some 200,000 acres of coffee that should be sprayed for the control of pink disease and brown eyespot.

Spraying to control pink disease is fairly common in Colombia and in Central America. Any of the available copper-containing fungicides are good for its control, although they may cause some toxic effects. Individual trees with pink disease are sprayed at almost any time of the year, providing the air is sufficiently free from moisture to give the fungicide a chance to dry before it is washed away by rains. Under severe conditions eyespot may need special attention in seedbeds when spraying can be used for its control.

Work is in progress on these problems. Copper sprays have been used to advantage in seedbeds and nurseries. Recent tests *(24–26)* have shown that in the especially difficult lowland area of Turrialba in Costa Rica *Colletotrichum* leaf in-

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jury is well eliminated by organic fungicides such as Orthocide 50. In the wet lowlands, Orthocide is better for this than Fermate, and Fermate is better than a copper fungicide. In the highland area of Costa Rica, where conditions are less difficult and there is not such severe *Cercospora* attack, the eyespot was readily controlled by use of Fermate *(58)*.

Stickers in Coffee Fungicides

From the very first applications of fungicidal sprays in the temperate zone were made under conditions which were favorable for drying and leaving the sprays on dry plant surfaces. Sprays remained long enough to protect for some period. In the tropics conditions may be different. In general, the relative humidity of the air is high. There, especially in the wet seasons, leaf surfaces may never be actually dry. This puts a severe strain on the reputations of otherwise good fungicides that need dry surfaces for adherence and work miracles under temperate zone conditions. The one character that gives to expertly and successfully made Bordeaux mixture its high place as a fungicide in the tropics is its excellent sticking qualities.

The coming great field for expansion in fungicides is in the tropics. Its future depends upon the development of proper stickers. A large number of fungicides have excellent immediate effects, but they lack the staying qualities that make them practical for use under the more rigorous conditions in the warm moist countries. Manufacturing specialists will have to develop the needed additive material through close relations with trained spray pathologists working under severe and trying tropical conditions.

The importance of stickers for coffee fungicides is not a new idea. Mayne and others 20 and more years ago *(35, 47)* had begun to add stickers to Bordeaux to increase efficiency in control of leaf rust. Mayne saw that in one series of experiments his unsprayed trees showed 88% leaf infection. When he applied a copper dust that had no sticker it gave only 73, but a good Bordeaux, which had sticking qualities, reduced it to 51%. In another experimental series, his unsprayed trees showed 87% leaf infection. When a plain Bordeaux was applied, infection was reduced to 49, and when the sticker casein was added to this Bordeaux, the infection went down to 42%. Resin soda sticker reduced infection to 36, and with linseed oil as sticker it was 37%. Other work was also being done with oils added as either stickers or spreaders to increase the fungicidal value of Bordeaux on coffee.

Eventually proprietary copper fungicides were being manufactured in quantity and made available for use on coffee. Thomas and coworkers *(60, 76, 81)* found at first that Bordeaux was a better fungicide than Perenox. Later they could demonstrate little difference in the results from their applications. Work was repeated with stickers added to Bordeaux, and it was proved that stickers improved the protectant value of the spray. On the other hand, spreader addition alone seemed to give no significant advantage in rust control over plain Bordeaux. A newer copper fungicide, Sandoz, was supposed to have unusual physical characters, but when tried on leaf rust of coffee, it was not so good as Bordeaux.

Havis and coworkers in Costa Rica recently have been experimenting with stickers *(26)*. Some of these experiments have studied sticker addition to a coffee spray fungicide called Orthocide. This fungicide has excellent immediate disinfecting characteristics, but it is of relatively ephemeral value under the trying conditions of the moist tropics. Their studies were carried on testing the material's capacities to control coffee seedling attacks by *Cercospora* and *Colletotrichum*. They found nonsprayed seedlings had 16% disease-free leaves; when Orthocide alone was applied every 20 days it gave 43% protection, when the experimental sticker RDA 156 was added plants had 82% healthy leaves, and when Goodrite Peps was added the mixture gave 74%. They showed further, through bioassay methods, that the best additive for Orthocide was experimental sticker RDA-156-B10, although Peps and stickers RDA-156 and RDA-212 gave fair to good results. When Vancide sticker was used the fungicide coagulated, giving much trouble in sprayers, although when emulsifiers were added the physical properties were improved but to the detriment of the fungicide. With Orthocide, the poor stickers were found to include Triton E-1956, Du Pont spreader-sticker, Filmfast, Dow Latex X2527, Dow Latex 512K, Armour sticker, Monsanto Latex 620X, powdered charcoal, dried milk, wheat

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flour, and water extract of cactus. In further studies, with the largest numbers of healthy leaves indicating best control, Havis and coworkers found that when Peps was added to Fermate, it produced over 100, Fermate by itself gave below 70; Peps with Perenox gave 62, while Perenox alone gave 5 to 10 below the treatment with added sticker; and in comparison nonsprayed gave only 24 healthy leaves.

Toxicity in Coffee Fungicides

Toxic effects have not stopped copper spraying, because toxicities have been far outweighed by good results from disease control. However, toxic effects need more serious study. They may be more noticeable in warm moist coffee regions than in the dried cooler parts.

The first leaf symptom of copper toxicity is small yellowish spots that later turn tawny and brownish in color. They are rounded and scattered over the leaf blade without any special pattern, although in some cases spots seem to congregate around the edges and toward the tips of the leaves. Under excessive spraying, leaf tissues show evidence of abnormal hardening, and a crinkle and malformation of the leaf. If the spray is continued, and put on at rather short intervals, a whitish chlorosis exists. In extreme cases defoliation sets in and branches may die. Lowered production would be hardly unexpected. This also has seemed evident from a study of the literature.

In India some of the early work was toward refinement of spraying to control leaf rust and the researchers started their studies with strong Bordeaux sprays. Munro and Sandararaman showed *(46)* that uncontrolled leaf disease reduced the coffee harvest very seriously, but that although 10–10–50 Bordeaux materially controlled the disease it depressed the fruit crop. With Bordeaux of formulas 5–5–50 or 2½–2½–50, the crop increase was one half to one third more than that produced under 10–10–50 Bordeaux or under no spray.

Rayner, in studying effects of spraying on chronic leaf fall in coffee *(61–64)*, found that fall was increased immediately during the first month after spraying with copper fungicide, but no fall resulted from parallel noncopper applications. In one year's rating leaf fall of unsprayed trees as 100, the copper-containing Bordeaux treatment resulted in 81 and the noncopper lime-sulfur in 60. In another year, Bordeaux and lime-sulfur results were almost alike, so that conditions affecting copper toxicity must have varied. Rayner stated that "yellow spotting due to spray damage was shown by copper-sprayed trees," and that the spots became necrotic.

Toxic effects are evident from stronger formulas of Bordeaux in other data reported by Munro and Sandararaman *(46)*. Jones reported results from 5 years of study *(30)*, from which it was evident that among the copper sprays at 1, 2.5, and 4% concentrations, the 2.5 was better than the others. The higher concentration reduced production. Spray studies in Costa Rica have given the author a chance *(94, 100)* to make observations on symptoms of copper toxicity; all the copper sprays are, to a certain extent, toxic to coffee.

Important Insect Pests Controlled by Chemicals

In much of the Western Hemisphere, coffee growers believe that their plantations are, and will remain, practically devoid of danger from insect damage. However, in the Eastern Hemisphere, where coffee is indigenous, and is grown with a good deal of intensity in some localities, many obvious and serious coffee-attacking insects can be seen. The literature indicates that *Coffea* trees are as susceptible to their own complex of insect inhabitants as are trees of almost any other genus. In the Western Hemisphere, insect troubles on coffee will undoubtedly increase; indeed, they are increasing at the present time. This is a natural course of events as coffee cultivation passes from the extensive and almost silvicultural method of growing to the plantations of more intensified orchard types. The insect pests are numerous on coffee on both sides of the world. Pinto de Fonseca *(57)* lists 39 coffee insect species in the western coffee country of Brazil and Bredo *(9)* lists 67 species on coffee in the eastern coffee country of the Belgian Congo.

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Scales, Aphids, Green Bugs

The small, relatively unmoving sucking scales, aphids, green bugs, and similar insects (*Saissetia* spp., *Coccus viridis* Green, *C. Africanus* Newst., *Lecanium* spp., etc.) are found typically on fresh new growths of coffee. These growths that shoot up from old trees that have become temporarily unbalanced are specially susceptible to such attack. The insects of this group may also be serious at times in the nurseries, and likewise in young trees set out in permanent plantations.

These insects have attendant ants that relish their honeydew, protect them from predators, keep them clean, and move them from old to new tissues when the older stems harden or become exhausted from too much insect feeding. There are several species of these sucking insects, distributed wherever coffee is grown. They have even caused damage in Hawaii, which is almost free from coffee pests.

There are probably considerably more than 150,000 acres of coffee in the world that are troubled with scales and aphids. In many cases, natural control methods take care of the problem. In others, spraying and other treatments are not readily given, because these insect attacks are in small patches and often on scattered individual seedlings or young trees. If they are on old trees, good elimination of water suckers will diminish the trouble greatly. If the attendant ants can be reduced in numbers, their protection of the aphids and scales will be stopped and the predators and other natural enemies will move in and destroy any heavy infestations. However, even with special work on the ants, this does not always occur. In such instances, chlordan, aldrin, and similar insecticides can be sprayed about the bases of scale-, aphid-, and green bug–infested trees. Ant attendance will be sharply curtailed through insecticidal applications. When ants are eliminated, in a matter of 2 weeks or so, the injurious sucking insects should have mostly disappeared.

Where treatment, aimed at eliminating the ants, is for some reason impractical, in Central America oil emulsions have been used *(6, 7)*, with satisfactory results. Those readily obtained are Orthol K, Carbolineum 2, Eisaclor 74, and the old favorite kerosine emulsion. In India *(60, 79)*, Derriphyton gave complete kill in 7 days, while fish oil–rosin soap solution with soda ash gave equally good results, but took 10 days for a good kill. Melville *(43)* found in Kenya that *Coccus africanus* became very severe followin treatments of coffee with DDT for other insects. His recommendation was the use of oil emulsion sprays after the DDT treatments, if necessary, to get rid of the *Coccus* infestations.

Large Stem Borers

The large stem borers (*Bixadus sierricola* White, *Anthores leuconotus* Pasc., *Xylotrechus quadripes* Cav., *Apate monacha* Fabr., *Dirphya sp.*, etc.) are one of the most feared insect pests on coffee. They are considered by some eastern hemisphere planters as more dangerous than any of the fungus diseases *(91)*. There are large stem borers that attack any of the coffee species, but they seem to prefer *Arabica* varieties *(74)*. Old trees with poorly shaded trunks are most often attacked. The borer work is not seen at first, but after a while it becomes noticeable as holes appear in trunks with excrement and wood dust extruding from the openings. Underbark ridges, going in all directions, when sufficient in numbers will girdle a tree. Affected trees are weak and may wilt and collapse.

Thomas has reported *(80)* that in one year in south India 4595 acres of coffee were destroyed by borers, out of a total of 81,000. He considered that about twice that amount is lost annually in the region of which he spoke. In many places the borer situation is just as serious, and Sanders has recently noted *(68)* that they are increasing in Tanganyika.

Toward the beginning of this century, infestations of the borers had become severe in India following rust damage. This excess infestation occurred on trees that were badly defoliated. Spray studies developed methods to control rust, and one of the side values of spray results was learned *(38)* to be keeping the coffee tree trunks well shaded, which appears to be a potent factor in reducing borer infestation. Some other sound methods of control *(74–76, 80)* have been: regular surveys and prompt destruction of infested trees just prior to flight seasons; maintenance of an even shade over the coffee; keeping the loose bark rubbed off of old coffee trunks and later using swabs of Mortegg and 4% DDT. In some countries, it is a common practice *(9, 42, 43)* to search out the larger borer holes and either dig out the borers with knife and wire or insert a wad of cotton wool soaked in a fumigant. This fumigant is a mixture of 1 part of 75% ethylene dichloride and the rest carbon tetrachloride and 1 part of lead-free aviation gasoline. After the cotton is pushed into tunnels, the holes are plugged with wet clay.

In more recent work on control *(41, 42, 54, 76, 79, 81)* attempts have been made to use benzene hexachloride washes on coffee tree trunks. A common recommendation is use of 8 pounds of 50% benzene hexachloride of gamma isomer in 40 gallons of water. Somewhat less than 40 gallons is enough for an acre, and it is applied about three times a year. In some places, benzene hexachloride powder is dusted on the trunks at the rate of 6 to 12 pounds per acre. These have both been effective treatments. Treatments with strong DDT have given fair results, but not so good as those with benzene hexachloride. This also has been better than the survey and tree-destruction technique, digging out borers, or putting fumigant in tunnels. However, the use of benzene hexachloride has posed a problem, because it is much less persistent in coffee than DDT and thus destroys fewer predators, and it imparts an unpleasant "bricky" flavor *(42, 43, 66)* to coffee harvested from benzene hexachloride-treated trees. Some of the new deodorized benzene hexachloride compounds are now being tested both for borer control and for effect on flavor change in the coffee picked from treated trees.

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Antestia and Lygus

The damage from antestia and lygus bugs *(Antestia orbitalis* var. *lineaticollis* Stal., *A. orbitalis* var. *faceta* Germ., *Lygus coffeae* Chin., and *L. simonyi* Reut.) has given some coffee growers in Africa even more concern than the leaf disease. The symptoms of severe attack by these small pentatomids are not always obvious to superficial examination. The insects feed by sucking the juices out of buds of flowers and shoots, and from tender young fruits. The results are stunting, small malformations, bud drop, supernumerary branching, discolorations of seeds by the bugs injecting the fungus *Nematospora* into the endosperm, and bad effects on flavor. Antestia occurs in Africa and the Orient, and has been known in Kenya *(14)* since the first coffee was grown there. It has been difficult to estimate the acreage of coffee attacked by these bugs. In about eight countries where it is fairly common about a quarter of the more than 1,000,000 acres are probably involved.

The most approved method of disinfesting *(9, 33, 43)* has been dusting with pyrethrum powder. Trained pest control teams in Africa make routine rounds in the coffee plantations and carry out standardized tests on random-selected trees. These trees are enclosed with trade cloth and sprayed inside with rapid-acting pyrethrum extract. Dead bugs are counted and when they average more than four from a tree, pyrethrum powder is applied throughout the whole plantation. In some regions where the history of antestia shows it to be severe, the routine test rounds are made at weekly intervals to watch for time to begin dusting. Where the bugs are of less concern, testing need not be done more than twice a month. Where the dust is not obtainable, pyrethrum extract is made from well dried fresh newly ground flowers in kerosine. This is applied in a very fine fog and about 3 gallons are sufficient for an acre of trees.

Spraying has also been done with some of the newer insecticides *(43, 67, 68)* on antestia and lygus, and it has been found that DDT spray or benzene hexachloride will eliminate them. While these treatments are resorted to under severe bug conditions, these sprays bring with them considerable hazards. Not only does benzene hexachloride affect the flavor of coffee unfavorably, but it does other damage. Both it and DDT may have a ruinous secondary effect by eliminating natural enemies of some of the other coffee insects. There seems to be increasing evidence that the indiscriminate use of such insecticides on a crop like coffee that has such a large and complex population of insects associated with it, raises many difficulties.

Thrips

The coffee thrips *(Diarthrothrips coffeae* Williams) is almost microscopic in size. The genus to which it belongs is well known for several species that cause

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much damage to many cultivated crops. In some localities, under particular conditions, the coffee thrips may be the most important of all coffee insects. This thrips was said to appear *(14)* in Kenya in 1915, and it is known in several different countries in the Eastern Hemisphere. When it attacks in force it defoliates trees completely *(40, 50)* and it sometimes kills them if the weather is dry and hot and they are not sprayed in time. The old well tested and recommended spray consisted of 8 ounces of Paris green mixed with 10 pints of molasses in 40 gallons of water. This gives good control if used on turgid coffee foliage, but not if leaves are somewhat wilted. In the midst of the worst drought conditions it is necessary to use DDT spray. Some of the earliest recommendations were lime-sulfur sprays, with a density of 1° Baumé. This insecticide has since been discarded and a 1% DDT solution introduced *(40–43)*. This works well and handled in such weak concentration it has a residual effect of only about 3 weeks. Tests showed that benzene hexachloride was ineffective against thrips. When DDT was used, it had to be handled with some consideration of what might come later, because aphids often are said to move in with special vigor after DDT sprays have been used for coffee thrips.

Root Mealy Bug, Leaf and Stem Mealy Bug, Palomillo

The mealy bugs *(Pseudoccoccus citri* Risso, *Ps. lilacinus* Ckll., *Ps. kenyae* Le Pell., *Ps. filamentosus* Ckll., *Neorhizoecus coffeae* Green, *Geococcus coffeae* Laing) are small, more or less immovable, sucking insects, covered with a light colored powdery substance. They are found underground on roots, above ground on leaves, on succulent stems, and within bunches of young green fruits. They occur in both the Eastern and Western Hemispheres *(9, 17, 39, 40, 68, 86, 87)*, and are capable of attacking all three of the commercially used species of coffee—the Arabian, the Robusta, and the Liberian—and their varieties.

Ants attend the mealy bugs, and these ants are of special importance. The genus *Pheidol* occurs in the Eastern Hemisphere, and *Acropiga* in the Western. These insects carry the mealy bugs from place to place, protect them from predators, keep them free from disease and dirt, and are most important in their life economy. Without ant help the mealy bug colonies cannot flourish.

Symptoms of severe root attack by mealy bugs are weakened trees, chlorotic leaves, spindly and ropy stems, and very poor production. On digging at the bases of attacked trees where ants are found, the mealy bugs may be seen colonized just below ground level at the crown of the root, or farther down. With mealy bugs that occur above ground, besides the appearance of the pallid little insects with their powdery covering and with ants in attendance, there are nearly always also present quantities of black fungus growth caused by the honeydew-invading saprophyte *Capnodium*. The harmless looking insects may be serious in their depredations, and control is not an easy matter.

In Africa and India, mealy bugs are commonly thought of as insects that attack foliage. They are the types that give the most trouble in those parts of the world. An understanding of the relationships between these pests and their attendant ants indicates a method of control. If the ants can be stopped from attendant services, the mealy bugs must eventually disappear. To assist in this, planters use grease-, creosote-, and poison-banding techniques *(9, 28, 39–42)* against the attendant ant in the Congo, Kenya, and other parts of east Africa. With ants reduced in activity, an important feature has also been increase of natural parasites on the mealy bugs. The work of Melville in Kenya has led in much of this and, in some cases, parasites are reared and introduced to augment those naturally present. Where mealy bug infestations remain stubbornly active, 3% DDT in kerosine is applied to the bases of trees and the adjacent soil, at weekly intervals for about 6 weeks, to get rid of the ants. Both benzene hexachloride and DDT stem washes are known to control attendant ants in Kenya. While DDT has continued in use, benzene hexachloride was abandoned because of the bricky flavor imparted to coffee gathered from trees thus treated. Dieldrin gave promising results on foliage mealy bug control when a 6% emulsion was put on guard cloths fastened around the bases of coffee trees to stop ants.

When control of the underground type of mealy bug is attempted, the planter has

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a somewhat more difficult problem, but it is still related to the stopping of work by the attendant ant. While the root mealy bug is far from being confined to the American tropics *(18, 32, 39, 68, 87, 88)*, it has recently had considerable attention by Western Hemisphere entomologists. The coffee root mealy bugs of Africa and India have caused considerable damage, but are more or less held in check through cultural practices, and spray applications at the bases. One of the oldest recommendations *(39)* was a tobacco-soap solution watered on the soil. In Costa Rica and other parts of Latin America, the root mealy bugs can be found in considerable numbers in certain regions. They seem to be increasing, and are apparently worse in comparatively dry areas, and in coffee roots growing in soils with a not too heavy texture. Locally they cause serious reductions in yield. In Costa Rica, Colombia, and Brazil they have driven coffee growing out of certain sections, and other crops have had to be introduced to replace coffee. Control thus far attempted has been by dieldrin emulsion, aldrin emulsion, and benzene hexachloride suspension mixed with soil used to fill the holes around new plants at transplanting time. Treatments with the insecticides on the walls of the holes for replanting coffee were also tested. Mixing the insecticides in the soil gave long-time protection, while the spraying of transplant holes protected new supplies for only 9 months. In Colombia they have been using water solutions of chlordan, a Creolin and DDT mixture, a potassium cyanide and DDT mixture, and a native plant extract. All are prepared as weak solutions and watered around the base of infested coffee trees every 15 days until observations indicate that the mealy bugs have been controlled.

Berry Borer, Broca, Fruit Borer

The coffee berry or fruit borer *(Stephanoderes hampei* Ferr., *S. seriatus* Eich., *Araecerus fasciculatus* De Geer), or broca, is a serious pest in Brazil. It has embarrassed Brazilians in their coffee shipment because other peoples feared danger from movement of infested coffee in international commerce. It is a common insect in coffee all over Africa, it occurs in India, and is also found in the Asiatic islands and other oriental coffee lands. Brazil is the only country in the Western Hemisphere where it has been seen. It was first discovered in Brazil *(49)* in 1925, and since that date it has caused extremely large losses. The insects bore into the coffee fruits and into seeds on the tree and in storage. This results in larger quantities of poor coffee in the supply for market. Borer-attacked coffee is manifestly unfit for sale, from the standpoint of appearance or effect on flavor.

The most intensive work on control of *Stephanoderes* has been done in Brazil, although it has been studied in Africa and other countries. In many places, the producers simply live with the seed borer, pick over the harvest, and market only the sound coffee beans. Where work has developed means of control, the main method has been *(44, 49, 57, 69, 83)* to clean up plantations, using lubricating oil sprays around bad infestations, collecting all fallen berries, collecting berries remaining on trees after harvest is concluded to eliminate sources of borer carry-over in the field, and fumigating harvested coffee for storage and sometimes just prior to shipment. Materials used for fumigation are carbon bisulfide, carbon tetrachloride, and ethylene dichloride at the rate of about 2.5 gallons to 1000 cubic feet of space.

Field spray studies have been carried on using benzene hexachloride and similar insecticides. In Brazil benzene hexachloride appeared to have a toxic effect on coffee trees. It has been the source of a bad flavor in coffee in Africa and also in Brazil, which was a further reason for abandoning its use. Work with so-called deodorized benzene hexachloride compounds and other insecticides is now in progress.

Miscellaneous Insect Problems

The leaf miner, *Leucoptera* spp., white grubs, and the tree cricket or chacuatete, *Idiarthron subquadratum* S. and P., also present problems.

The leaf miners occur on coffee throughout the tropics. They are more injurious in certain areas than others, and excessive attack seems more in evidence in dry regions or in the dry months in countries where there is a marked difference between the wet and dry seasons. Even in the more moist regions where leaf miners have

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existed for a long time but have been almost rare in occurrence, they have appeared in large numbers following persistent applications of fungicides on coffee foliage.

Symptoms of leaf miners are leaf spots that are irregular and dark brown in color, becoming lighter with time. These spots have a loose skin that can be picked away. They ordinarily form in green tissue as a large blemish with an irregular tail or trail leading off from the large spot. When examined carefully against the light, leaf miner spots are seen to be made up of part of the leaf which has had the insides chewed but the upper and lower epidermises left intact. The spots have some fine grains inside, which are excrement of the small insect that has eaten out the spot. These spots can result in considerable defoliation and even attacked leaves that do not drop are injured as photosynthetic organs and thus reduce the vigor of the tree. There have been no widely adopted and successful methods for the control of this pest. The introduction and encouragement of natural insect enemies are being studied. Certain insecticides such as nicotine sulfate and lindane, with spreaders added, have been recommended.

White grubs are the larvae of beetles and may cause severe injury to the base of young and small transplants, or to young seedlings in seedbeds and nurseries. The grubs have strong mouth parts that chew the green cortex, and may eat even deeper. Such injury weakens small trees, and, in some cases, completely girdles them and causes death. Nurseries are often badly attacked where they have been made in old grass pasture land. The distribution of white grubs is practically world wide, but usually they have more tender and palatable plant fare to eat, so that they do not touch coffee. It is when coffee is being most carefully tended and when grasses and other weeds are not allowed to grow in land infested with the grubs that those insect larvae may resort to coffee and cause damage. In some areas where the grubs are very serious, an occasional catch row of grass and broad-leaved weeds left at intervals will attract the grubs away from the young coffee. Considerable work has been done on soil applications with such insecticides as lindane and benzene hexachloride, with promising results. One of the most practical of the old methods *(39)* in India is preparing manure pits for beetle traps spaced at regular distances. These are cleaned out regularly and are kept especially renovated during periods of beetle flight.

Every once in a while new diseases or insects attack coffee. A recent example arose in El Salvador *(7, 19)*, when there was trouble with an indigenous tree cricket or chacuatete. Heretofore it has lived on wild or weed trees and only recently has it attacked coffee. Its distribution in El Salvador is becoming greater, and it may soon be found in other countries. The cricket lays eggs in the coffee tree stems and feeds on the leaves and fruits. It has been destructive in certain plantations, where it reduced the harvest considerably. Infestation amounts to 50 or 60% of the trees in plantations, and the severity seems to be increasing. Mulch on the soil between rows of coffee trees favors the insect and one of the control measures has been to eliminate ground trash. This is, however, an expensive procedure, not a complete control, and it is bad practice for the soil. Plantation owners insisted on developing other means of reducing infestations. At first an arsenate of lead spray was used, about 3.5 ounces of the poison to 5 gallons of water. This spray has been replaced by dusting with toxaphene, chlordan, aldrin, and a gammexane gamma isomer compound. The most satisfactory recommendation has been toxaphene, which has shown no bad effects on flavor of the coffee from treated plants, and has been a potent insecticide for this pest.

Weed Control by Chemicals

Of all the pests that are unfavorable to coffee, the most costly to keep under control are the weeds. There is only one good thing about them. They are well known and understood and their presence does not cause panic in the minds of coffee planters.

Weeds vary from low and succulent broad-leaved weeds that grow best in wet shady areas and the hardier coarse types that are found in drier, more exposed soils, to vines that clamber over coffee trees and smother them with injurious growth, to useless woody bushes that come up between the coffee trees, and tough grasses that compete for both moisture and soil nutrients. In Kenya and Brazil it is essential

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that no weeds be allowed to become established in the coffee plantings. There, as well as in some other countries, not only do the weeds compete for nutrients, but the soil moisture cannot support both coffee and weeds. In other countries, weeds, especially grasses, have to be kept in check to leave the nutrients available for the growing coffee tree and its burden of fruit.

Wherever coffee is grown intensively, it must be given cultivation, whether by use of a long knife slashing weeds between the rows, by a tined or forked hoe to chop the ground, by use of a heavy solid-bladed hoe to dig the soil, by cultivation with animal- or tractor-drawn narrow plows or disk harrows, or by slicing off the top soil and turning it over with a sharp broad-bladed shovel. Mostly it has been done through hand labor in the past, and in spite of other mechanical developments in many other lines of tropical agriculture, mechanical methods of cultivation and slashing in coffee are still making slow progress in most countries. Meanwhile, hand labor becomes more costly year by year, and with the popularization and newer study of herbicidal chemicals, special attention has been given to "weedicide" applications in plantations to solve one of the coffee grower's potentially serious problems. The one country where coffee is commercially weeded by chemical methods is Hawaii *(91)*, where practically all of this work is done by spraying with fortified oil emulsions. Results are excellent and the gains worth while because of the high coffee production and high cost of labor in the islands. High labor costs are becoming a threat in other coffee countries, and as hand labor becomes more difficult to obtain chemical weed control will be more and more used.

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In recent years, a whole series of weed-control chemicals have been tested in India and Costa Rica *(23, 51, 71, 78)*. In India, they sprayed with Shell weed killer in equal volumes of Diesel oil; with 1 part of Stanvac weed killer in 1 part of water; with 1 pound of Femoxone in 50 gallons of water; and with 1 gallon of Agroxone in 100 gallons of water. All were said to give good weed kill, with Shell and Stanvac best. However, costs of applications and costs of materials came to more than hand labor. In Costa Rica, chemicals were put on from standard knapsack sprayers after weeds had been shoveled off and turned over in the rows between coffee trees. From many screening tests and combinings and final formulations, it was determined that good control could be secured with sodium pentachlorophenate (sodium pentachlorophenol) at 4 pounds per acre mixed with the butyl ester of 2,4-D acid equivalent to 1 pound per acre, in a carrier of combined commercial Diesel oil and heavy aromatic naphtha. Another formulation that gave good kill was the proprietary material Sinox General fortified with the butyl ester of 2,4-D in heavy aromatic naphtha and water. The other mixture was of isopropyl xanthate, heavy aromatic naphtha, an emulsifier, and water.

It was comparatively easy to kill the broad-leaved weeds, the dicotyledonous plants, and some of the softer monocotyledonous types like *Commelina.* However, grasses remained a serious problem and they were by far the most dangerous weeds for coffee. Havis and coworkers found that, in Costa Rica, grasses that had special storage organs were able to withstand much chemical treatment. These grasses extended themselves, filled in, and were specially serious where contact herbicides had eliminated broad-leaved weeds. These especially difficult grasses were finally eliminated by large applications of chloroIPC [isopropyl *n*-(3-chlorophenyl) carbamate]. While this killed the noxious grasses, it was an impractical grass killer in coffee and a cheaper method for control was devised, which combined some hand labor with chemical applications. The bad grasses were dug out and shoveled into mounds between coffee rows, and to these mounds was applied sodium TCA (sodium trichloroacetate), dissolved in water at 40 pounds to 100 gallons and applied at the rate of 25 gallons to the acre.

In many crops where weed killers are used, applications must be made with care or the crop being weeded may suffer. This takes some attention. Coffee showed characteristic injuries *(22, 51)* from applications of the weed killers 2,4-D, TCA, and CMU [3-(*p*-chlorophenyl)-1,1-dimethylurea]. On the other hand, as in other tree crops, further work on coffee proved that, if properly handled, weed sprays did not result in important permanent harm to the trees. Some of the most recent work has shown *(22)* that amine salts and butoxyethanol esters of 2,4-D caused less injury on coffee than the isopropyl ester, and that applications in Diesel oil emulsions improved weed kill and reduced damage to coffee trees.

Discussion

There are considerably more than 13,000,000 acres of tropical land planted to coffee in the world. It is probable that in over 10,000,000 of these the coffee should be treated with chemicals for control of diseases or insects. Specialists in coffee pest control may be able to combine economically sprays of different sorts for different purposes, as is being done in other crops. Recent ideas must be studied for application in the tropics. Some newer fungicides and methods of application combine very finely divided fungicide concentrates with dust blown out at great speed. There is also to be considered the application in sprays of mixtures of fungicides, insecticides, and minor elements, which are being proved of considerable importance in coffee *(18, 45)*. The largest amounts of sprays are applied for control of leaf rust in India and Africa. As copper is apparently toxic, more attention should be given, in the Orient, to the use in antirust sprays of the newer fungicides of nonmetallic materials. Such sprays may also have a real place in control of chronic defoliation and dieback.

Spraying of coffee is an established practice in parts of Africa and the Orient, but too little is done in the Western Hemisphere. Nevertheless, it is increasingly evident that, as coffee growing becomes a more highly intensified horticultural pursuit, the diseases and insects will increase. There will be more and more need for chemical control of the enemies of that crop. The coffee industry is in the midst of a period of expansion. Rapid improvement also is being made in use of new coffee varieties and new methods of growing. The spreading of plantings into new lands means that coffee is, and will be, planted more and more on marginal types of soils. These are the soils that allow more favorable conditions for insect and disease attacks. Such development will call for even better insect and disease control by chemical applications. While at present chemical weed eradication is more expensive than other methods, it will have to work toward more favorable acceptance in the future. Once the advantages of spraying become known, it develops into a popular operation. Successful spraying or dusting brings on more of it and more study of the problems.

Work is needed on toxicity and stickers with fungicides and with insecticides, and on phytotoxicity of insecticides. There are experimental indications *(69)* that not all insecticides can be used on coffee without regard to phytotoxic reaction. In the moist tropics especially, stickers are most important. Dusts do not serve in some tropical pest problems because they do not have long sticking qualities, but this should not deter dust studies. Experimental attack is much needed on fungicide and insecticide materials as dusts for use in the tropics. In many coffee countries, water is not easily obtained for spraying purposes, and it is difficult to haul heavy liquid-using machines over rough terrain. It was pretty well proved in India that the old types of copper dusts were not deposited on upper leaf surfaces. Some of the newer materials in modern machines may give a different result. Some diseases are confined to under surfaces of coffee leaves. Some are characteristically found only on upper leaf surfaces. So this upper surface placement of dusts, coupled with what can be done with dusts in powdering of branches, may be an actual advantage over liquid sprays for certain diseases or insects.

One feature related to chemical control of diseases in coffee has been given comparatively little thought. With greater interest in mechanization, there is going to be change in the design of coffee plantings. These design studies must take into consideration convenient arrangements to allow the best spraying or dusting with fixed spray nozzles. Intensive work must soon be carried on to adapt some of the best spray machines to the coffee tree, and to consider the coffee tree form as related to chemical applications for pest control.

The chemical applications on coffee pose problems that can be solved to the mutual advantage of the coffee grower and the manufacturer of spray machines and chemicals. The problems cannot be left solely to either party. Through the service of technical men working in the tropics, the manufacturer will need to carry on close relations with the field. The evolution of spray science in the tropics, under condi-

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tions so much more difficult than those encountered in temperate zones, may give an entirely new view of what can be done with sprays and dusts in the rest of the world.

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Use of Chemicals for the Control of Rice Pests

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The present and future role of chemicals in the control of rice pests—diseases, weeds, and insects—should receive more attention and recognition, as rice is one of the most important food crops in the world. A brief summary of the present uses for chemicals for control of pests in rice production is presented in this paper,

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Rice pests are important economic factors in rice production. Diseases have been one of the major factors contributing to famines in the Orient. Weeds may reduce yields to the point where the production costs may exceed the total value of the crop. Insects reduce yields and in combination with fungi may reduce milling quality.

Diseases

Seed Treatments. Seed treatments *(6, 27)* are recommended in most countries where rice is produced for the control of seed decay and seedling diseases. Various organisms *(Helminthosporium oryzae* Breda de Haan, *Fusarium* spp., *Pythium* spp.) reduce stands, especially when soil temperature and moisture are unfavorable for the optimum growth of young seedlings. In general, work has shown that the mercurial compounds, such as Ceresan M [*N*-(ethylmercuri)-*p*-toluenesulfonanilide], Panogen [cyano (methylmercuri) guanidine], Agrox (phenylmercuriurea), and Aagrano (ethyl mercury bromide), give the best results under conditions where *H. oryzae* is the principal causal organism. Other compounds, however, such as Arasan [bis(dimethylthiocarbamyl) disulfide], Spergon (chloranil), and yellow Cuprocide (cuprous oxide) significantly increase stands and may be recommended. Climatic conditions and the microflora of rice seed and soil vary in different countries, so that experiments should be conducted in the localities where seedling blight is serious, in order to determine the most economical and effective compound to recommend.

White-tip *(Aphelenchoides* sp.). White-tip is a serious, seed-borne disease of rice in the United States and Japan. The disease also has been observed in Panama and Korea and may be present in other countries, as the disease can be easily disseminated by rice seed. Because this nematode disease is primarily seed-borne *(4)* and not soil-borne, much work on the control of the disease has been focused on seed treatment with various chemical compounds.

The nematodes in infested seed are between the hulls and kernel, and most chemicals, used as seed treatments, have been ineffective or too toxic to rice seed. A few chemicals, however, including N-244 (3-*p*-chlorophenyl-5-methylrhodanine), ridsaan II (*p*-phenylenebisrhodanine), endrin, isodrin (1,2,3,4,10,10-hexachloro-1,-4,4a,5,8,8a-hexahydro-1:4,5:8-endo endodimethanenaphthalene), parathion, and systox (ethyl mercaptoethyl diethyl thiophosphate) *(5, 7)* have shown promise in screening tests. N-244, the most promising compound screened to date, has been used in field tests and has satisfactorily controlled white-tip when used as a seed treatment at the rate of 4 ounces (10% formulation) per bushel of rice seed. This compound, when used on heavily infested seed of susceptible varieties, has increased yields by 10 to 15 bushels per acre. Good control of white-tip has also

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been obtained by soaking rice seed for 6 hours in bichloride of mercury at the concentration of 0.75 gram per liter of water.

The use of methyl bromide fumigation as a control for white-tip has been suggested *(4)*. Tests with infested Arkrose rice seed have shown that the optimum dosage, when the moisture content of the seed is around 13%, is about 1.25 pounds of methyl bromide per 1000 cubic feet of space for a 12-hour exposure. The amount of methyl bromide required, however, varies with the moisture content of the seed. More methyl bromide is required when the moisture of seed is low than when the moisture content is high. Also, methyl bromide is more injurious to rice seed when the moisture content of the seed is high, than when the moisture content is low. In view of the fact that the moisture content of rice seed varies with different seed lots, as well as within bins of the same seed lot, it is difficult to standardize dosage rates and methyl bromide fumigation has never been used extensively for the control of white-tip.

Applications of Fertilizers for Control of Rice Diseases. In general, the application of fertilizers cannot be relied upon to solve all our major rice disease problems; however, the application of properly balanced fertilizers reduces the severity of certain major diseases. Work on stem rot *(Leptosphaeria salvinii* Catt.) in Arkansas *(3)* and Japan *(26)* shows that the severity of stem rot can be reduced by increasing the potassium levels of soils in the problem areas. In Arkansas it has been shown that the application of nitrogenous fertilizer significantly increases stem rot severity, whereas the application of potassium fertilizer alone or in combination with nitrogenous fertilizers decreases stem rot severity. Consequently, in Arkansas the application of potassium fertilizer is widely practiced for stem rot control.

Fertilizer balance is also reported to influence the severity of blast *(Piricularia oryzae* Catt.) and brown spot *(H. oryzae) (21–23, 26)*. Nitrogenous fertilizer increases the severity of blast, whereas potash salts appear to increase resistance. Potash salts are also reported to increase resistance to brown spot.

Use of Fungicides for Control of Rice Diseases. Fungicidal sprays and dusts, except when used for the control of blast, have never been used extensively for the control of rice diseases. Reports from the Orient indicate, however, that a number of diseases can be controlled by this method. In Japan *(30)* Bordeaux mixture has been used for the control of blast. A 1-2/3–3-1/3–50 formula may be used when applications are made at the seedling and tillering stage, and a 1-1/4–3-3/4–50 formula at the booting and heading stage. Chattopadhyay *(2)* reports that three sprayings with Perenox (cuprous oxide) between tillering and flowering of rice were more effective than comparable sprayings with Dithane Z-78 [zinc salt of ethylenebis(dithiocarbamic acid)] in reducing brown spot infection on three susceptible rice varieties. Hashioka *(11)* reports that bacterial leaf blight *(Bacterium oryzae* Uyeda and Ishiyama) is partially controlled by spraying with copper fungicides. Hashioka *(13)* reports the control of the rice stripe virus disease of rice by controlling the vector *(Delphacodes striatella)* with dust applications of BHC (benzene hexachloride). Hashioka also *(12)* reports that field applications of Bordeaux mixture and uspulum (0.5% solution) are more effective than Dithane Z-78 (0.5% solution) for the control of sheath rot *(Hypochnus sasakii)*.

Control of Weeds

Research work has shown that broad-leaf weeds in rice fields can be controlled with compounds such as 2,4-D and 2,4,5-T. These compounds are now used extensively by farmers in the United States and other countries; however, the application of these herbicides to rice fields may result in injury not only to rice *(20)* but to crops such as cotton in nearby fields. Experiments are now in progress at different experiment stations to find chemicals that possess greater selectivity and lower vapor activity.

One of the major problems in rice production is grass control. Various grasses compete with rice and drastically reduce yields. Results of preliminary experiments in Venezuela *(9)* indicate that rice yields may be increased by the application of dinitrophenol as a pre-emergence herbicide, even though rice stands are reduced by this chemical. Additional research is needed in this field, as the possibility exists that both broad-leaf and grass weeds may be controlled in rice fields by the application of pre-emergence herbicides.

Insect Pests

It is very fortunate for the rice producers of the United States that rice, as compared to most crops, is relatively free from insect pests. Metcalf and Flint *(24)* list 30 species of insects as being injurious to corn, 20 to wheat, rye, and barley, 31 to leguminous crops, and 23 to cotton, as compared to but 4 for rice. The fact that rice fields are flooded a large portion of the growing season results in ecological conditions unfavorable to numerous insects that otherwise would probably attack this crop.

Mosquito Control. Cultural practices commonly followed in the production of rice over most of the rice-producing areas of the southern states have created such favorable conditions for the multiplication of certain species of temporary water mosquitoes that the mosquito is probably the most important insect problem of this area.

The draining and reflooding of the fields create optimum conditions for the breeding of the two common species of mosquitoes. According to Horsfall *(14)*, these species *(Psorophora confinnis* and *P. discolor)* constitute from 89 to 94% of the entire mosquito population of the area. Trapping records of the writer indicate as high as 97% at the height of emergence, when mosquito problems are most severe. This is of importance because it indicates that if these species are controlled, those remaining would be of comparatively minor significance as pests. If all rice fields in a given area were drained and reflooded at the same time, mosquito populations would not build up to such serious proportions. But in actual practice the draining and reflooding of fields are practically continuous from late May or early June until early August. Usually comparatively few larvae are found in the first fields to receive a second flooding. Because of the continuous floodings, mosquitoes that emerge from the first fields receiving second waterings find very favorable conditions and multiply rapidly. Each succeeding flight likewise finds favorable conditions for rapid multiplication so long as drained fields are available. These conditions bring about a rapid build-up of mosquito populations.

The rice field mosquitoes cease to occur in serious numbers within 2 to 4 weeks after drainage and reflooding of fields are completed. While the period of heavy infestation varies from year to year according to the time of draining and reflooding rice fields, typically heavy infestations appear in late June or early July, start tapering off in late August, and drop to low numbers during the month of September. During periods of heavy infestations, one frequently finds rice fields with an average of 50 larvae to the square foot following the second flooding, and occasionally even more. Considering the number of square feet to the acre and the number of acres of rice grown, one can readily see that sufficient numbers of mosquitoes are produced to create serious mosquito problems.

Whitehead *(31)* was unable to obtain satisfactory control of these mosquitoes consistently by spraying or dusting the rice fields with any of the chlorinated hydrocarbon insecticides when the larvae were present. His experiments indicated that, after the rice reached a height of 12 or more inches above the water, the dusts or sprays failed to penetrate the vegetative cover sufficiently to obtain satisfactory control. He found that by the use of granular or pelleted insecticides good penetration and very satisfactory control could be obtained. The granular insecticide was prepared by spraying a xylene solution of the insecticide over a 20- to 40-mesh granular clay as it was being rotated in a concrete mixer. His work indicated that the greater amount of water the clay absorbed, the better it released the insecticide into the water and the more satisfactory the results. Of the clays tested, Wyoming bentonite was found most satisfactory. Granular bentonite clay containing 5% dieldrin applied at the rate of 2 pounds per acre (0.1 pound of dieldrin) was found to give excellent control.

Whitehead also found the proper timing of such applications to be very important. The best results were obtained when the applications were made the first or second day after starting the flooding of the fields the second time.

He lists the advantages of this type of insecticide:

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The pellets are inexpensive, and incorporating insecticides into them is a simple and inexpensive operation.

Because they are heavier than fine dusts, fine sprays, or aerosols, they drift less and therefore can be applied from greater heights. There is no necessity for an airplane applying these materials to fly lower than tree-top height. This quality makes it feasible to use lower-powered, smaller, and cheaper airplanes. A high percentage of the airplanes now used for applying materials are large high-powered machines which must charge $30.00 to $60.00 an hour for their services. The smaller, less expensive planes can be operated at a profit for only a fraction of this cost. Because 2 pounds of this material to the acre suffices, any plane capable of carrying 200 pounds can treat 100 acres before it is necessary to reload, and this makes a considerable saving in ferrying time.

Because of the nondrifting qualities of the granular materials, they can be applied under conditions of greater air movement than fine sprays or dusts. This means that airplanes are not limited to operating a few hours at dawn or dusk but can be used many more hours a day. This in turn should permit more efficient use of airplanes. Each of the above factors should result in lower costs of application of mosquito control materials and make practical the use of control measures over greater areas.

Most insecticides, including those used in these experiments, are highly toxic to higher animals, including man. When toxic materials are mixed with these granules, they are less dangerous to handle than when mixed with liquids or fine dusts. After toxicants have been incorporated into the granules, there is less danger of the fine poison-coated particles floating in the air being breathed than when they are used as fine dusts or sprays. It is also evident that there is less possibility of injurious amounts adhering to and being absorbed by the skin when this form is used. In this or any other form, however, they are definitely toxic and must be handled accordingly.

These granules have excellent flowing qualities. No agitator was used in the airplane hopper at any time during the course of these experiments, and though the opening through which the granules flowed was as small as ¼ × ⅞ inch, no stoppage difficulties were encountered.

These granules store well. Some of the materials were stored in a damp basement in paper sacks for more than 2 months, but they still retained excellent flowing qualities.

Rice Water Weevil *(Lissorhoptrus simplex)*. Isely and Schwardt *(16)* who worked with this insect from 1930 to 1933, inclusive, state, "The rice water weevil is the most important insect pest of rice in Arkansas." It seems likely that this statement also applies to most of the other rice-producing areas of the southern states. Although the adult weevils feed to a considerable extent on rice leaves, the principal injury is caused by the larvae feeding on the rice roots. Under conditions of heavy infestations practically all the roots are destroyed approximately 4 to 5 weeks from the time of the first flooding of the fields. Normally, even under such conditions, the rice is not killed and when the larvae have matured and ceased feeding, the plants produce a new set of roots and will still produce a crop. The severe setback given the plants during this period naturally results in a marked reduction in yield.

These entomologists *(16)* also established the fact that if the fields are drained and dried as the larval feeding approaches its peak, much of the injury may be avoided. The larvae being aquatic in nature are unable to survive in dry soil and thus the larval population is greatly reduced. The experiments of these workers showed an average increase in yield of 17.8% when fields were drained at the proper time over that of undrained fields. Since the publication of these results, the draining and reflooding of fields have become an almost universally adopted practice among the rice growers of Arkansas.

Such a practice is very favorable to the multiplication of rice field mosquitoes. It therefore becomes evident that if some method of weevil control other than drainage could be devised, it might be possible to control both insects with a single operation.

In an effort to develop some such control for weevils, a number of insecticides were tested to determine their effectiveness. In these tests aldrin, chlordan, dieldrin, and heptachlor at certain strengths each gave 90% or better control when applied to rice just previous to the first flooding.

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Dieldrin was then used in a series of 27 quarter-acre plots during the summer of 1953. A third of the plots were treated with dieldrin at the rate of 4 ounces per acre just previous to the first flooding and they were flooded continuously the balance of the season. One half of the untreated plots were drained as larval root feeding approached its peak (July 15) and then reflooded when the soil became dry (July 31). The balance of the untreated plots were continuously flooded. Counts of weevil larvae were taken in each plot twice each week from July 7 to August 14.

These counts *(32)* clearly show that the treated plots contained far fewer larvae than either those drained for weevil control or the untreated and continuously flooded plots. The cost of the insecticidal treatment is believed to be less than half as much as draining, drying, and reflooding fields. Counts of mosquito larvae in all plots taken 4 days after the drained plots were reflooded showed less than 1% as many mosquitoes in the undrained plots as in those drained and reflooded. Less water was required for continuous flooding than for draining and reflooding.

Previous work at this station had shown that when heavy weevil infestations were present, drainage properly timed to control weevils resulted in higher yields. Evidence has also been found that drainage in the absence of heavy infestations depresses yields. The yield data on the experimental plots showed that the undrained plots, both treated and untreated, yielded almost 5 bushels more per acre than the drained plots. The weevil infestation in the plots was very light in 1953, which probably accounts for the fact that yields were not increased by controlling weevils by the use of insecticides.

When heavy infestations of weevil are controlled with insecticides rather than by drainage, the depressing effects on yield of drainage and of root destruction by weevils would be avoided. While it remains to be proved, it would appear that under conditions of heavy infestations insecticidal control without drainage should materially increase yields. Should future work show that similar results may be regularly obtained, we may conclude that insecticidal control of the rice water weevil is more effective, is cheaper, produces higher yields, requires less water, and will materially lessen the mosquito populations of the rice area.

Rice Stink Bug *(Solubea pugnax* FAB). The rice stink bug is probably present in all rice fields of the southern rice-producing areas every year. It is during the milk and dough stages of the rice development that the bugs are particularly attracted to the rice and are most numerous. Their piercing mouth parts are inserted into the developing kernel and sufficient material is withdrawn so that the kernel thus fed upon cannot develop normally. Those fed upon in the milk stage produce little more than the hull of the kernel, while those fed upon in the dough stage develop into an incomplete kernel marked by a dark colored spot, commonly referred to as "pecky" rice. Control measures are justified only in that small percentage of the fields where unusually large numbers of bugs are present. Normally only a small number is present.

There has not been sufficient work done on the control of these bugs to justify the making of definite recommendations for their control. In a very small number of fields observed during the past season, dieldrin at 0.25 pound and toxaphene (chlorinated camphene) at 1.5 pounds, applied by airplane, reduced the number of bugs to the point that serious injury was averted.

Rice Stem Borers

According to Ingram *(15)*, two stem borers *(Diatraea saccharalis* FAB and *Chilo plejadeilus* Zinc.) are frequently serious pests of rice in the extreme southern edge of the rice-growing areas of the southern states. Their boring and feeding in the rice stems not only cause the heads to die prematurely in the more severely damaged plants but greatly weaken the stems of many more, causing much lodging with resultant loss of rice. Damage is typically heavier in the large stemmed varieties of rice.

No successful experiments are known to have been conducted in the United States in the control of these insects by means of insecticides. Grist *(10)*, reporting on the work of Van der Laan, indicates the possibility of control of the white stem borer *(Scirpophaga innotata)* in Indonesia by spraying seed beds with 0.04% DDT emulsion.

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Fall Army Worm *(Laphygma frugiperda* A. & S.). Although it is only occasionally that the fall army worm becomes a pest of rice, there are seasons in which numerous fields are attacked by large numbers of this pest, with serious injury resulting. Any one at all familiar with army worms will readily understand the destruction caused by this insect in unflooded fields of rice. It probably would be surprising to those who have never witnessed it how effectively these worms are able to get to new plants in a field heavily flooded.

Although flooding has been recommended for the control of fall army worms in rice, in the writer's experience this method is not effective. Toxaphene applied as a spray at the rate of 2 pounds per acre has been found to constitute good control.

Leaf Miner *(Hydrellia scapularis)*. The rice leaf miner *(28)* has caused damage to rice in California. Good control has been obtained by spraying fields with dieldrin at the rate of 0.5 pound per acre in 10 gallons of water.

Other Pests

Certain birds, mammals, and crustaceans must be classified as rice pests. In California the tadpole shrimp *(Apus oryzaphagus)* *(29)* may damage rice. The shrimp not only attack the young rice plants but keep the water in a muddy condition, which results in poor rice growth. Promising control results were obtained in the laboratory with copper sulfate and DDT, and in the field with copper sulfate.

Many birds such as sparrows, blackbirds, rice birds, grackles, and cowbirds can cause heavy loss of grain in rice fields. Because the use of poisoned baits in some countries is often restricted by law or popular opinion, the information presented does not constitute a recommendation on any specific chemical. The use of strychnine-poisoned rough rice *(17, 18, 25)* against blackbirds, grackles, cowbirds, and English sparrows, wherever the use of poison is permitted, can be effective. Many other toxic chemicals will kill these birds; however, domestic poultry and game bird species are relatively much less susceptible to strychnine than to other toxic materials. Therefore, we have in strychnine a fairly effective selectivity which other toxic materials do not offer.

Many of the older toxic chemicals tried on birds were those containing color, such as London purple and Paris green. These chemicals did not result in effective kills of birds. It has now been demonstrated that birds are color-conscious and this phase of the use of chemicals has been studied during recent years, with interesting results *(1, 8, 19)*—for example, dyes have been used to prevent birds feeding upon grains poisoned for control of noxious rodents. Rice growers near Stuttgart, Ark., claim that yellow Cuprocide seed treatment lessens bird attack on seed at planting time.

The use of chemical repellents to prevent bird attack on maturing grain is under investigation and apparently holds considerable promise. No publications are known to be available on this subject.

Summary

Chemicals are playing an increasingly important role in the control of disease, insect, and weed pests in rice culture. Fertilization with potassium is reported to reduce the severity of stem rot *(Leptosphaeria salvinii)*, brown spot *(Helminthosporium oryzae)*, and blast *(Piricularia oryzae)*. Seed treatment with Ceresan, Panogen, Agrox, Arasan, Spergon, and yellow Cuprocide is a common practice for the control of seedling diseases. N-244 (3-*p*-chlorophenyl-5-methylrhodanine) has been recommended as a seed treatment for the control of white-tip, a seed-borne nematode *(Aphelenchoides* sp.) disease of rice. Fungicides such as Bordeaux mixture and Perenox (cuprous oxide) have been used in the control of brown leaf spot and blast. Postemergence herbicides (2,4-D and 2,4,5-T) are used for the control of broad-leaf weeds, while the use of pre-emergence compounds such as dinitrophenol holds considerable promise for control of grasses. Examples of control of insects with insecticides are: rice water weevil *(Lissorhoptrus simplex)* with aldrin, chlordan, dieldrin, and heptachlor; stink bug *(Solubea pugnax)* and fall army worm *(Laphygma frugiperda)* with toxaphene; chinch bug *(Blissus leucopterus)* with DDT; and leaf hopper *(Delphacodes striatella)*, which is the insect vector for virus stripe disease, with BHC.

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Although chemicals are now used extensively in the control of rice pests, the demand for chemicals in this field is expected to be much greater in the future. Many chemicals now available have not been tested in countries where severe losses occur. In the developmental field, more satisfactory herbicides are needed for the control of broad-leaf weeds and grasses, better fungicides are needed to supplement breeding work for the control of foliar rice diseases; more effective seed-treatment chemicals are needed for rice sown in water; and satisfactory chemical repellants are needed to prevent losses from bird pests on maturing rice.

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Pesticides in Banana Culture

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Insects and diseases caused by fungi and bacteria bring about widespread losses in banana culture by reducing production, depreciating market value of the fruit, and even destroying the industry. Thousands of tons of fungicides and hundreds of tons of insecticides are required yearly to control banana pests. New pesticides, better formulations, and improvement of existing pesticides are needed. Specific banana pests and the possibility of their control are discussed.

Intensive culture of bananas, as with many other crops, is beset with many problems. Even in isolated plantings, pests of one kind or another reduce the potential crop or even destroy it entirely. In the majority of cases pest control has been confined to large acreages in more intensified banana culture. Many factors have contributed to retarding the use of pest control, such as weather and ground conditions that prevent the use of portable equipment without expensive road systems, small plantations, lack of finances, indifference on the part of grower, and no local demand for quality fruit.

Bananas are grown in every tropical country and some subtropical areas throughout the world. The total acreage involved is considerable when all plantings, from 1 acre upward, are taken into consideration. Pest control is largely confined to the Caribbean area, Central and South America, Australia, and to some extent the Cameroons, Liberia, and Israel. Other areas in most cases grow bananas for local consumption, where strict demand for economic production and quality fruit is not recognized.

Banana pests have developed with the crop in the old world and spread with it to new lands. Root and leaf diseases and insect pests first observed in the Indian Ocean countries and the Pacific Islands spread to the Caribbean area and then to the Cameroons. As is true in most cases of pest dissemination, man has been the culprit, though innocent in his ignorance. These pests were readily spread in his eagerness to develop plantations of the new fruit for foreign markets early in the twentieth century. The important pests may be separated into plant diseases and insects. Also there are other minor pest problems resulting from local cultural or environmental conditions. Grass and weed growth in banana plantations and railroad rights of way, weeds and bush in livestock pastures, ticks, flies, mosquitoes, termites, powder post beetles, weevils, leaf-cutting ants, and rodents are probably the most important of the minor pests.

Diseases of Banana Plants and Fruit

Table I lists the diseases of the banana by common name, scientific name, and parts of the plant attacked. The diseases are discussed under their common and most recognized name in the industry.

Panama wilt, first observed in 1890, developed to epidemic proportions in Panama in 1903. Today it is widespread in most all banana-producing areas where the susceptible varieties of commerce are grown. In fact, it is the limiting factor in the commercial production of bananas in Central America. In Honduras alone approximately 4000 acres are lost from production yearly because of this pathogen. With the discovery of flood fallowing in 1938 it has been possible to reclaim some

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of these infested soils. Currently the flood procedure is expensive and it must be repeated every 6 to 8 years. Efficiency of this procedure could be increased if methods could be found to reduce spore carry-over in the flood water and on the surface of flooded soil. Fungicide treatment of the water is not feasible because of the volume involved. Fungicide treatment of the surface soil, however, immediately after flooding may be practical because depth of penetration is not required. Many fungicides have been tested, but only a few such as Crag 974 (copper zinc chromate) and Dithane D-14 [disodium salt of ethylenebis(dithiocarbamic acid)] show promise of economic control. The need is for a soil fungicide having high residual effectiveness or an economic water treatment to kill the organism surviving in the water or on the soil surface.

Table I. Diseases of the Banana

Common Name	*Scientific Name*	*Parts Attacked*
Panama	*Fusarium oxysporum* f. *cubense* (Syn. & Hans.)	Vascular system
Moko	*Pseudomonas solanacearum* EFS	Vascular system
Sigatoka	*Cercospora musae* Zimm. (*mycosphaerella musicola*)	Leaves
Heart rot	*Fusarium moniliforme* Sheld. and bacteria	Young plant
Cigar-end	*Stachylidium theobromae* Turc.	Growing fruit
Sooty mold	*Capnodium* species	Growing fruit
Stem-end rot	*Thielaviopsis paradoxa* (De Seynes) Von Horn	Ripening fruit
Colombia stem-end rot	*Gloeosporium musarum* Cke. & Massee	Ripening fruit
Bunchy-top	Virus (*Pentalonia nigronervosa* Coq., aphid vector)	Growing plant (Pacific area only)

Moko, also causing wilt of the banana plant, has a history of sporadic outbreaks, usually causing no long-term damage. However, in some cases large areas of banana plants have been destroyed. Though harbored in the soil, it is believed that its spread from plant to plant occurs by means of cultural practices such as pruning and cleaning. Disinfecting tools with formaldehyde is an effective control. No economical means, however, is known to eradicate the organism in the soil. Control measures require that infected plants be completely destroyed as rapidly as possible. Although 2,4-D has been used, repeated treatment is necessary to kill all sucker growth. This is a disadvantage, as the suckers harbor further development of the organism.

Sigatoka, like Panama wilt, is equally destructive to the banana industry. Plants attacked by the organism will not produce marketable fruit and the plantation will eventually die out. First recognized in Java in 1903, it became serious in 1910 when it reduced Fiji exports from 1,300,000 stems to 100,000 within a few years. First infections appeared in Honduras in August of 1935 and eliminated production from 22,000 acres within 16 months.

Bordeaux mixture 10–10–100 is the most effective fungicide for the control of Sigatoka. Other copper-containing fungicides, such as Perenox (copper oxide) and Tennessee tribasic copper sulfate, have provided control. These mixtures do not stay in suspension as does the Bordeaux mixture and they settle out in fixed spray systems that have miles of pipe installations over the farms. Sulfur and organic fungicides, notably the dithiocarbamates, provide control in the drier areas but so far they have failed in areas of high rainfall, probably because of inferior weathering and sticking qualities.

New Sigatoka fungicides are needed that would have less bulk. This would facilitate transportation and storage and they would be easier to use and would provide better and longer periods of control. This pest still offers an open field for development of a specific fungicide. Bordeaux must be applied at the rate of about 200 gallons per acre, 16 to 22 times a year. Spreading and sticking agents are needed to improve application, spreading, and tenacity of the fungicide to the waxy surface of the banana leaf.

Stem-end rot can be controlled by a combination of fungicide paste applied to the cut surface of the fruit and by observing sanitary practices with conveying equipment. Although epidemic upon occasions, this problem is now of little significance.

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Colombian stem-end rot, resulting from fungus invasion of cracked fruit stems and fruit peel in handling operations, however, is still of considerable importance. Some type of nonpoisonous fungicide dip is needed to control this problem.

Sooty mold is sometimes troublesome by causing an unsightly appearance of the fruit. The mold growth follows the feeding of mealy bugs and aphids on the inside of the fingers of the bunch of bananas and is usually not seen until the fruit is ready for sale. Economic field control measures should be developed.

Cigar-end rot is always present to a minor extent in banana-producing areas, but in the last few years has become epidemic in the Cameroons. Control measures with fungicides are being studied.

Bunchy-top, a virus, is epidemic in Australia and the Pacific Islands but has not spread from that area. Control of the banana aphid vector and roguing of infected plants has so far kept this pest under control.

Insect Pests

Table II lists the insects that cause important damage to the banana plant or fruit. Thrips and scale insects cause most damage by impairing the appearance of the fruit, but they do not impair its food quality.

Table II. Insects Attacking Bananas

Common Name	*Scientific Name*	*Damage*
Banana borer	*Cosmopolites sordidus* Germ.	Tip-over of plants
Red rust thrips	*Chaetanophothrips orchidii* (Moulton)	Discolors fruit
Flower thrips	*Frankliniella parvula* Hood	Disfigures fruit
Red scale	*Chrysomphalus aonidum* (Linne)	Discolors green fruit
Yellow scale	*Aspidiotus destructor* Sign.	Discolors green fruit
Red spider	*Tetranychus bimaculatus* Harvey	Leaf damage
Caterpillar	*Ceramidia butleri* Moeschler	Leaf damage
Grasshoppers	*Schistocerca paranensis* Burm.	Leaf damage
Oriental fruit fly	*Dacus dorsalis* Hendel	Infects ripe fruit
Banana aphid	*Pentalonia nigronervosa* Coq.	Vector of bunchy-top

Banana borers destroy portions of the rhizome of the plant by tunneling and feeding in the grub stage. This results in tip-over of the plant as its fruit increases in size, but before it reaches maturity. Adult borers are active outside of the plant. At this stage they can be killed by dieldrin, aldrin, and heptachlor, but not by DDT. Borers are widespread and the population is kept down by clean cultivation, but even so fruit losses are considerable.

Red rust thrips cause a red discoloration of the fruit peel as it approaches maturity. This greatly reduces the attractiveness of the product on a competitive market. The insects injure the peel tissue in feeding and oviposition which takes place over an extended period of time. The degree of injury is in direct proportion to the thrips population. Three possibilities are available for control of this insect—by spraying either the fruit or the ground with an insecticide, or by encasing the young fruit in a paper bag for a third of its maturing period. Spraying the fruit may lead to considerable trouble because of phytotoxicity of insecticide formulations. All chlorinated insecticides are effective in either dust or emulsion, but in actual practice dieldrin is more effective than DDT. Airplane application of dieldrin pellets has provided control because the insect pupates in the ground. Three pounds of actual dieldrin per acre have been found satisfactory.

Flower thrips usually make small punctures on the fruit during oviposition. This blemish does not harm the fruit in most cases; however, there are many instances where the number of punctures is so great that the fruit is unmarketable. No insecticidal control of this insect has yet been achieved.

Red scale is a problem in many of the drier banana growing areas. The damage is occasioned by injury to leaves, but the most noticeable damage is in the yellow spotting of the green fruit where the scale has been attached. So far the only control for red scale has been oil emulsion sprays similar to those used in the citrus industry. Highly toxic insecticides, such as used on citrus, cannot be used on bananas because the fruit is harvested almost every day.

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Yellow scale, though present in many areas, has not been serious on bananas except where sulfur fungicides were used experimentally for Sigatoka control. Biological control has usually held this insect in check.

Caterpillars and grasshoppers cause localized damage to banana foliage. Bordeaux coverage of the banana leaf surfaces, however, acts as a partial repellent to these insects.

Red spider mite epidemics at periods of excessive dry weather in areas of heavy rainfall may be serious, but, so far, the duration of the invasions has been short in banana farms. Weather and natural enemies have, to date, quickly brought this pest under control.

The oriental fruit fly and the banana aphid vector of bunchy-top have so far been found only in the Pacific, the former as far east as Hawaii and the latter in Australia. Control measures for the fruit fly are insecticidal sprays and biological control. Bunchy-top is being held under control with insecticide spray of banana aphids and roguing of diseased plants.

Miscellaneous Pests and Suggestions for Control

Ground covers in banana plantations are favorable for retention of moisture. A desirable ground cover consists of broad-leafed plants, but grasses predominate in many areas. Chemical control of grasses is not favored because banana plants are sensitive to chemicals, so the areas are hand chopped at frequent intervals. The banana plant is a rapid growing, highly succulent, perennial herb that is easily damaged with as little as 7.5 pounds of CMU [3-(*p*-chlorophenyl)-1,1-dimethylurea] per acre applied in a semicircular strip within 2 feet of the plant. This plant is sensitive to 2,4-D and can be injured by low concentrations.

Camalote *(Paspalum fasciculatum)* grass and water plants fill drainage ditches and canals and require frequent expensive cleaning. Although 2,4-D will kill water plants, it and other chemicals will not control the grass which is the predominant pest.

Railroad rights of way subjected to heavy rainfall are usually covered with Bermuda grass, the predominant pest. Control measures with weed burner, oils, and chemicals have been tried. Burning is not satisfactory because of the short period of control. Oils and fortified oils with pentachlorophenol and chemical hormones have not been effective except at high application rates per year. Many of the herbicides at the concentrations used in the United States and other temperate zones with good results are not applicable in the tropics. This is probably due to a number of causes—continuous rapid growth, leaching of herbicides from the soil, and a more rapid breakdown of the herbicides as a result of higher temperatures and greater microbiological action. The most promising of the herbicides tested appears to be a combination of 50 pounds of CMU plus 112.5 pounds of Ammate (ammonium sulfamate) per 160 gallons of water per acre. This concentration has kept a section of the railroad rights of way free of most vegetation for more than 6 months. Unfortunately, the cost of CMU is still too high for general use. The fire hazard of chlorates and the animal toxicity of arsenicals limit the use of such materials.

Grazing lands for work stock, dairy, and beef cattle are a necessary adjunct of any banana operation. Para and Guinea grasses are desirable, but in many instances are crowded out by weed and bush *(Mimosa pigra)* growth. Most of the weeds can be controlled by application of 2,4-D at recommended concentrations. The bush may be killed by Ammate spray at a dosage of 1 pound per gallon of water. The use of mechanical spray equipment is limited because of the rough terrain. Knapsack spraying is not economical. Hand chopping is usually resorted to for control of obnoxious plant growth in pastures.

Ticks in pastures are controlled in many instances by burning during the dry season at the height of the infection. Cattle sprays and dips containing toxaphene as the active ingredients are more often used with positive results. Fly control is established at the same time. Fly and mosquito control is carried out as a public health measure by medical investigators with chlorinated insecticides. Since all three of these pests affect both animal and man, the widespread control programs affect the entire field of tropical agriculture.

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Termites and powder post beetles cause many thousands of dollars loss of wood installations. Creosoting and vacuum-pressure impregnation of Wolman salts into pine lumber provides protection; however, there exist many structures where in situ protection against termites would be of value.

Grain and foodstuffs are constantly attacked by weevils. Fumigation with carbon bisulfide, methyl bromide, and Chlorosol fumigant (a carbon tetrachloride–ethylene dibromide mixture) provides effective control where storage areas are built to handle these materials. Such storage equipment is limited, so there is need for an insecticide with low mammalian toxicity in order to achieve continuous protection by direct application.

Leaf-cutting ants cause no direct damage to bananas, but they are a constant threat to the plantation. They build their nests in river levees and the underground tunneling renders the structure ineffective against rising water. Chlordan is an effective insecticide when all openings to the nest can be treated.

Rodents, such as rats that build nests in the hanging fruit and pocket gophers that undermine the plants while feeding on the roots, are prevalent in some banana-producing areas. Warfarin-treated baits will eliminate the rats, but there are no effective means to combat the gophers except by flooding with water and trapping. Both methods are difficult to put into operation. Baiting and chemical fumigation have proved ineffective.

Summary

Insects, fungi, and bacteria bring about widespread losses in banana culture. Insects may either reduce production or depreciate the market value of the fruit. Bacteria and fungi cause more serious trouble, either reducing the market value of the fruit or completely destroying the industry. Fungus infection of the leaf can be controlled by Bordeaux mixture, but if not controlled, it reduces production and ruins the market value of fruit. Soil-borne diseases, which are more difficult to control, continue to destroy bananas in many areas of the tropical world, although there are some possibilities for control in many instances. Weeds, grass, and minor insects need both more effective and more widespread control.

Millions of pounds of fungicides and thousands of pounds of insecticides are required yearly to control banana pests. New pesticides, better formulations, and improvement of existing pesticides are indicated.

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Use of Pesticides for Stored Products in Tropical Countries

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Insects, fungi, and rodents cause a loss in stored products, especially stored food, that is unquestionably one of the most important problems in pest control in the world. Unfortunately, the tropical areas where the problem is most serious have given it the least attention, although improvements have been observed in recent years. Scientists in addition to entomologists are needed. Real progress in reducing the present high losses will require marked improvement in the facilities and management now available for storage and handling, as well as the use of pesticides. In all areas consideration must be given to the varying local conditions.

The loss caused by pests in stored products, especially stored food, is unquestionably one of the most important problems in pest control in the world. Its importance is reflected in the amount of world-wide attention given in recent years to research for its control. An average of these losses indicates roughly that 10% of the world's entire food production is lost in storage.

Various estimates have been made of the actual amount of loss caused by pests to stored products. In 1947 an estimate was requested from the 50 or more member countries of the Food and Agriculture Organization of the United Nations regarding the loss from pests in major cereals and legumes only. The average, as was to be expected, was highest in tropical and subtropical countries. Subsequent observations in many of these countries made it clear that the extent of loss had not been overestimated. Losses ranging from negligible amounts to total destruction were found, depending on the local conditions, crops stored, and period of storage. A few tropical countries have two or more crops per year, which reduce the storage period and the percentage lost.

The importance of the problem and its recognition is indicated by notable work in this field being done by various organizations including the United Nations' Food and Agriculture Organization; The Inter-American Institute of Agricultural Sciences at Turrialba, Costa Rica; the former Institute of Inter-American Affairs, now a part of the Foreign Operations Administration; and the numerous national agricultural or food groups.

While it is well known to those interested that the group of insects affecting stored products is cosmopolitan and well distributed throughout the world, it is frequently overlooked that local conditions and crops, means of transportation, cost of labor, method of use, and many other factors vary. Therefore, a method of insect control satisfactory in a section of the United States may not necessarily be an economic control even with adaptation to a tropical location. For example, the heavier-than-air fumigant which may be sufficient with one application per year to control insects in a good farm bin of wheat in Kansas would give no economic control even if applied ten times per year in the common corn storage shed in Honduras. The fungi which cause heating are generally controlled by drying the grain in any country. Rodents vary in species and habit. Ratproofing, found in much of the United States to be effective against the Norway rat, would be so much wasted effort against roof-dwelling rats. Often it would be simpler and cheaper to rebuild the storage

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building than to attempt to ratproof it completely. Differences in different areas point up the need for careful study before broad recommendations are made for unknown problems.

Better Storage Facilities Needed

After six years of study on the problem of grain storage in 40 different countries, the writer arrives at the conclusion that the use of pesticides is one of the important phases of protection of stored products, but not the most important in the solution. The primary need is for better facilities in which to store grain or other products so that pesticides can be used effectively. If better facilities cannot be obtained, at least better management is needed before pesticides can be used satisfactorily. This is in the interest of efficient, continued, and increased use of pesticides.

At present the poorest storage unit in use for grain is the jute bag or its fiber equivalent. Its use is most prevalent in these areas where the loss is greatest. A poor unit for storage, the bag gives no protection from moisture, insects, or rodents. On the contrary, bags in piles or stacks furnish harborage and nesting material for rodents and facilitate complete infestation by insects. The spaces between the bags provide rapid access to the entire stack. The handling cost is high per unit but the bag is convenient and cost is unimportant in small quantities. When large tonnage is involved, however, the handling cost in the aggregate is very high. Finally, the part commonly overlooked is the easily proved fact that these inadequate bags actually cost more per year than concrete, steel, or good wooden structures with bulk grain-handling equipment. Furthermore, the bags in stacks frequently have to be protected by concrete floors and some type of roof, all of which increases the cost but contributes little to increased efficiency. There is little question that in many countries there would be a net gain by storage of grain in large open heaps rather than in bags. Better still, of course, would be bulk storage and handling facilities suited in design and capacity to the needs of the particular country and located strategically.

Surplus, Subsistence, Deficit Storage Needs

Fundamentally there are three broad classifications of countries with regard to the needs for grain and grain storage. These classifications are: surplus, subsistence, or deficit. Their needs are fundamentally different. In the first, typified by the United States and Canada, the system normally is basically one of handling. A surplus must move rapidly and at low cost from production areas to points of consumption, either domestic or foreign. Any given unit in the system, from the country elevator to the terminal port elevator, handles much more tonnage of grain than its static capacity. This may vary from three to twenty times, depending on the type and location of the equipment.

In the subsistence country, typified by several Central American countries, the production is roughly that needed by the country and relatively little grain is either imported or exported. Here true storage units are needed as crops are stored from crop year to crop year. With one crop the storage plant receives and stores its static capacity. Only where two crops are produced in the calendar year can the quantity of grain handled exceed the static capacity. Handling equipment of relatively less capacity than that needed in surplus countries is adequate. Care must be taken, however, in determining the size and location of the storage equipment to avoid any need for double transportation.

In the deficit countries, typified by England or Israel, a high percentage of grain must be imported. Here again, handling is most important and very little true storage is needed beyond a reserve to safeguard the supply through possible delays in delivery.

True Storage Facilities Improvement

Much progress has been accomplished in the past 10 years in true storage equipment. In Central America before 1947, there were no storage facilities except for inadequate warehouses for bagged grain. In 1947, a steel plant of 9000-ton capacity was opened in San José, Costa Rica, by the Consejo Nacional de Produccion. The

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use of pesticides was begun about the same time and losses at this plant have been negligible ever since. The problem still exists, however, in the country. Corn and beans are both field infested, but loss is stopped when the material arrives at the plant for treatment. Tonnage has been increased by a 20,000-ton plant at Barranca and Nicaragua began the operation of a 7000-ton plant in 1953. El Salvador started a 10,000-ton plant in 1952 and Guatemala is constructing a 14,000-ton plant. Negotiations are under way for a small plant in Panama. Since 1949 Venezuela and Colombia have been installing units in a system to cover much of the country.

In Asia, Turkey has built and is building more good storage units. The same is true of Pakistan. Some construction has been started in Iraq. Egypt has been badly in need of good grain storage plants and is planning several large storage plants in addition to present facilities. This partial list of new facilities shows that some action is being taken for improvement. The use of pesticides will increase with these facilities.

Improved Management Essential

Where improved facilities are not available, better management of present facilities, no matter how inadequate, is needed before the use of pesticides will increase. Management is a broad term. A few examples will demonstrate its faults—namely, placing badly infested grain in storage with clean grain, failure to dispose of old infested lots of grain, failure to clean thoroughly the premises, if only physically, before storing the new crop. Another factor is the failure to appreciate the actual damage caused by pests in stored grain. A common fault where bags are used is to put clean grain in infested bags. Frequently wet grain is stored before it is properly dried.

Even with good facilities, good management is essential. In one instance, where beans had been fumigated properly in a partially filled steel bin, it was learned that the following morning the manager added heavily infested beans to the same bin.

Another example of the need for good management is that of a large bin of corn that was being fumigated frequently. Examination showed that bruchids were entering from adjacent infested beans, but the man in charge did not know bruchids from the moths or weevils which attack corn. The dark bruchids were more readily seen on the light yellow corn than on the black beans, so the corn was needlessly refumigated.

Pesticides for Insect and Rodent Control

Pesticides are in use against pests of stored products in tropical countries, but their use is often restricted because of lack of facilities or inefficient because of lack of knowledge. An outstanding example of effective control, even though costly because of lack of facilities, is found in the control work by the Ministry of Food in India. Grain is stored in bags in warehouses but in stacks that can be covered with large gas-tight tarpaulins under which methyl bromide is applied to give satisfactory control. The same method is used on a smaller scale in many other countries including Lebanon, Costa Rica, and Colombia. Where bag storage is used, methyl bromide is the best suited fumigant, provided a gas-tight tarpaulin and good concrete floor are used. Also because of the small quantity used—one pound per 1000 cubic feet usually—the freight rates are in its favor. Much of the fumigation can be done outside or under open sheds where there is little danger if simple precautions are taken.

In Egypt and Pakistan the use of the 3 to 1 mixture of ethylene dichloride–carbon tetrachloride is well established. In both countries improved storage is needed in addition to that now available. The fumigant has been used in tight bins, tight warehouses, and with tarpaulins. In Pakistan several shiploads of wheat have been fumigated just before leaving port. This fumigant is also being used in Central America where, pricewise, methyl bromide is still the most economical. Carbon bisulfide is available in a few tropical countries, but the dangers in its use offset its benefits.

Fumigants alone cannot be considered the answer to pest control in tropical countries. Even with good facilities, more than fumigation is needed in chemical

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control. Along with good sanitation or clean up, residual insecticides have a place on a wider scale than will be found in the United States. DDT, chlordan, and technical BHC (hexachlorocyclohexane) are all being used, but not in the manner nor extent of potential effectiveness. From limited observations, these materials are used mostly as wettable powders or dusts. Directive literature does not indicate the effective use possible for the premises where spilled grain is a continual source of infestation and the debris furnishes a harborage for the insects. Outside conditions are favorable for the insect development throughout the year.

Technical BHC, because of its odor, is not generally used except in the Far East. In Pakistan, India, Burma, and Malaya, it is used liberally on bags of milled rice. In Pakistan it was observed being applied to bags of milled rice with a small scoop. This left, not a light dust covering over the bags, but dust in handfuls here and there, with most of the bags untouched.

Special sprays of fogs are not generally used, but a combination of pyrenones and chlordan applied with a TIFA machine has been used effectively in Thailand for treatment of the holds of ships before and after loading milled rice. Over 400,000 tons of rice per year have been treated in this manner. The rice milling industry is concentrated in Bangkok and storage of the milled rice is in congested sheds. At any time of the day, several species of insects infesting rice can be seen in flight in the sheds. This fogging method could be extended to the sheds with good results. There has been no problem of residue after several years of this method in operation.

A third promising method of insect control is the direct addition of material to the grain. In Egypt this was done 25 years ago with rock phosphate and sulfur. More recently, DDT, lindane, or pyrenones have been added directly to the grain. There has been considerable latitude in the use of DDT and lindane in several countries, particularly Switzerland, Denmark, England, France, and Argentina. How far this has extended in the tropical countries is unknown. The use of pyrenones avoids the residue problem and has much promise for use, especially in bagged grain. Dosages and therefore the cost must be increased in the tropics.

Rodents constitute a continual problem in stored products, especially grain. In so far as grain is concerned, construction of steel or concrete structures practically eliminates the rodents. For other products, the rodents remain a problem even in the best of warehouses. Various methods have been observed for control, including trapping, some attempted ratproofing, predators such as cats or snakes, and poisons. Little good resulted except with the poisons and among these warfarin was outstanding. For the conditions commonly found in the tropical countries this rodenticide seems to approach the ideal. It is safe and can be used as a preventive. How extensively it is being used now, however, is not known.

Conclusions

The use of pesticides in stored products in tropical countries cannot be separated from the broader field of economics and engineering. In order to use more pesticides efficiently, storage structures must be built. They, in turn, must be suited to the needs of the country and located so that they may be used economically. The jute bag is a poor, but costly storage unit. Its cost should be compared with steel or concrete over a period of 30 or 40 years. With improved facilities, a steady increase in the use of pesticides will be seen. Management must be improved also to install sanitary practices along with efficient and sensible use of pesticides. Because of the distances involved, freight rates are important and because of the small dosages required, methyl bromide is favored thereby.

Residual sprays and dusts now in use should be extended to cover more of the premises and could be used more frequently than is now common. Fogs have possibilities in certain areas if used frequently. Direct addition of safe pyrenones have much promise for bagged grain but will require a higher dosage than in the United States.

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Pest Control in Citrus Production in Tropical and Subtropical America

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The pest control situation in California and Florida is reviewed, with particular attention to mechanical developments and the introduction of new fungicides and insecticides, such as the insoluble coppers and parathion, and the outstanding unsolved problems such as control for nematodes which will not injure the plant and the need for a systemic material which will control virus diseases. Emphasis is on needed lines of investigation. Pest control problems in Central America, the Caribbean Islands, and South America are discussed, with special reference to lack of suitable equipment and material because of dollar exchange problems.

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Among certain misconceptions concerning fungicides and insecticides which seem common to chemists is the belief that the ideal insecticide would kill 100% of all the insects in reach without harming either the plant or the consumer of the plant product. In reality, a 100% kill is almost never obtained at one application, nor is it desirable to kill all insects. There is at all times a delicate balance in nature between the fungi which cause commercial harm to plants and beneficial fungi or bacteria which kill injurious insects. By the same token, injurious insects have both parasites and predators of insect nature which prey upon them. Among all these, there is a precarious balance which sometimes frees the crop of harmful effects and at other times results in heavy losses. The trick with insecticides and fungicides is to tip this balance in favor of the producer.

Thus, a fungicide should give commercial control of a plant disease without too greatly reducing the population of friendly fungi which help keep insects under control and without leaving residues which mechanically favor insect development. A good example of this relationship can be seen in the history of the use of copper sprays for the control of melanose and scab in Florida. Early recommendations were for 5–5–50 or 3–3–50 Bordeaux, which resulted in extensive increases in scale insect populations. Concentrations were gradually reduced to 3–3–100, which gave commercial control of the diseases and much less scale trouble. This was followed by the use of the so-called neutral or insoluble coppers, so that today we are able to supply the same amount of copper in 1 to 1.5 pounds of neutral copper, thus reducing the residue materially from the 6 pounds of residue present in 100 gallons of 3–3–100 Bordeaux and further reducing the insect problem, while still giving commercially profitable control of melanose and scab.

The same sort of balance must be maintained in the use of insecticides. DDT furnished an excellent example in Florida. It killed the young scale insects, but it also killed so many of the parasites and predators that terrific scale populations resulted, which were difficult to bring under control. Obviously, selective insecticides are needed, which kill only injurious insects. Lacking this perfect answer, however, insecticides are used which are relatively less damaging to the friendly insects as compared to their effect on deleterious insects.

This problem of natural balance is, of course, less noticeable in annual crops of short season than in perennial tree crops, where the results of an unfortunate application may show up 9 months to a year later. Sometimes also this business of

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balance is lost sight of in the heat of competition between the disciples of chemical control and the disciples of natural control. They often work separately, each striving to eliminate the other, when they might better work together.

This problem of balance has much to do with the basic difficulties in Central and South American countries. In both California and Florida, the experiment stations labor with the problems and finally put out recommendations which are fitted to their particular areas. Growers in other areas, where stations are not active, are apt to apply these recommendations to their own situations, frequently with disastrous results. The recommendations made for one area, with due regard to timing in relation to stages of the insect and the activity of its enemies, may be all wrong for the timing in other areas. Scalicide applications should be made, for instance, when there are few eggs under the mother scales. As this condition is difficult for a grower to recognize, the station entomologists study the life history of the insect and set up calendar schedules for the area. In Peru, however, the scales may use another calendar and applications based on Florida schedules will fail. Insecticide companies usually label their products with information obtained by research workers in the United States, without attempting to analyze local situations. Thus, the biggest problem facing citrus producers in Central and South American countries is a lack of information concerning their particular problems, either from experiment stations or from commercial companies. Since the development of the stations can come about only slowly, the commercial companies might do well to study the problems in the areas where they are attempting to sell their products. They would then be in a position to give advice, keyed to the local situation, on the use of their products.

In most countries in South America, there is also the problem of a shortage of exchange dollars. This is further complicated by the fact that the dollars available for imports are bureaucratically controlled with a tendency to assign dollars on a basis of past usage, thus eliminating the newer materials. In many countries this problem is likely to continue for a long time. It probably would be desirable for insecticide companies to make arrangements for the manufacture of their products on a royalty arrangement within the country in question wherever possible. The seeming casualness with which companies in the United States frequently arrange for representation in foreign countries and the general lack of progressive export policies are currently driving many Central and South American users and potential users to trade with European manufacturers.

Diseases

Virus Diseases. The outstanding disease problem of the past 25 years in citrus has been the liquidation of millions of citrus trees in Argentina and Brazil by a virus disease variously known as "tristeza," "podredumbre de las raicillas," and "quick decline." To a lesser extent, it has affected trees in Paraguay and Uruguay, but lesser only to the extent that these countries had fewer susceptible trees. Today it is ravaging the citrus plantings of Peru. It is present in California and Florida, but to date it has been less damaging because of the lack of an effective insect vector.

This virus kills orange, grapefruit, and mandarin trees budded on certain stocks, the most important of which is sour orange. This has been widely used because of its resistance to another disease (foot rot) which girdles trees at the soil line. Trees on other stocks, such as sweet orange, rough lemon, mandarin, and *P. trifoliata*, are affected to some degree but are commercially useful.

The effective vector is the black citrus aphid (*Aphis citricidus*, Kirk), which is present in most of South America. The virus was brought to Argentina about 1928 in citrus nursery stock budded on a tolerant stock, rough lemon, and immediately started to kill millions of trees budded on sour orange. It appeared in Brazil near Santos about 1937 and in a few years has killed about 80% of the trees in São Paulo State and 40 to 50% of the trees in Rio de Janeiro. The remaining trees are on tolerant stocks. In the same period, trees on sour orange in Uruguay and Paraguay had been liquidated and about 4 years ago the disease was brought into Peru in infected budwood and liquidation of Peru's industry has started. Should the black citrus aphid gain a foothold in either California or Florida, a very rapid

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loss of trees would result, whereas the aphids now present are very inefficient vectors and the disease is moving slowly.

Replanting with tolerant stocks has also revealed the presence of two other viruses in Argentina and Brazil—xyloporosis, which dwarfs trees on sweet lime stock, and exocortis, which ruins trees on trifoliate stock. Xyloporosis may have been brought in with tristeza.

The time-honored method of controlling insect-borne virus diseases is by breeding resistant varieties. This has been practical in annual crops, but is hopelessly slow in tree crops, where it may take 20 years or more to test a new variety. What is needed desperately is some sort of treatment which will control the virus, probably a systemic treatment, as the virus works within the plant cells. This is not a new idea and work has been done along this line by many workers. A sense of urgency is inevitable, however, when 500 to 600 acres of citrus can be wiped out completely in 3 to 5 years' time, followed by an expensive replanting job and a wait of 5 to 6 years to get back into production. This is the outstanding problem at the present time and may need years to answer.

Fungus Diseases. The enforced change in rootstocks that has taken place has brought back to the forefront the problem of foot rot caused by the soil-borne organism, *Phytophthora* spp., since the stocks tolerant to tristeza are susceptible to this disease. Planting the young trees high, so that the crown roots will be kept fairly dry, plus copper sprays applied to the trunk and crown roots, gives good control, but a fungicide which would last longer in an active form in the soil would be invaluable.

Control of melanose and scab is a standardized procedure in Florida, using the so-called neutral or insoluble copper materials at low poundage to reduce the scale problem. In both Argentina and Brazil, these diseases are very important—including sweet orange scab, not known in Florida—but generally must be controlled with Bordeaux because of the inability to import the newer materials. In the drier areas, these diseases are not so important.

Fruit Decay. Finally in the field of diseases are the decays of fruit in transit. Much of the Brazilian fruit is exported, giving a long period from harvest to utilization and in Argentina a slow rail transport plus the use of uninsulated metal cars adds to the problem. Stem-end rot (*Diaporthe citri* Wolfe and *Diplodia natalensis* Pole-Evans) plus blue and green molds (*Penicillium italicum*, Wehmer, and *P. digitatum*, Sacc.) are rampant, and while the Dowicide A (sodium orthophenyl phenate)-Hexamine (hexamethylenetetramine) treatment worked out in Florida is satisfactory, import difficulties stand in the way of obtaining needed materials.

Insects

Rust Mite. The rust mite (*Phyllocoptruta oleivora* Ashm.) is the most general pest of citrus from Florida through Central America and most of South America. It makes a smooth brown marking on the fruit, known as russeting, and it can also damage leaves, resulting in leaf drop. In Florida, it is controlled with sulfur, mostly in the form of wettable sulfur (finely ground sulfur, 325-mesh or smaller, to which a suitable wetting agent is added). Some dusting sulfur and lime-sulfur are used. Sulfur is kept on the trees most of the time, by means of four or five applications per year. The total amount applied per acre is frequently 200 to 300 pounds per year. While sulfur is cheap as compared to other insecticides and its residual effect great, it nevertheless presents a considerable problem in the unbuffered acid sandy soils of Florida. As a result, considerable amounts of dolomite must be applied to neutralize the acidity resulting from the oxidation of the high percentage of sulfur which eventually reaches the ground.

In Cuba and the Central American countries, russeting represents no particular problem, as they produce fruit only for the internal market and the buyers are accustomed to it. In fact, many of the buyers prefer it, under the impression that it is sweeter—a belief that is not without foundation, since the rust mites tend to destroy the resistance of the peel to water loss, resulting in a more concentrated juice through the evaporation of water from the fruit. However, rust mites tend to reduce fruit sizes and also the size of the crop, so control is desirable.

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In Brazil, which is a heavy exporter, and Argentina, where the public demands bright fruit, rust mite control is a considerable problem and control must be practiced. However, there is a shortage of finely ground sulfur combined with import problems. In parts of São Paulo State during the 1954 season, there were rust mites in abundance where they had never given much trouble previously and experiments have been started on their control. A similar outbreak occurred in Peru. Whether these areas will continue to be plagued with rust mites is an open question. However, in many other areas, rust mites will be a constantly recurring problem and the shortage of grinding facilities plus import restrictions will continue to be a limiting factor in control.

Scale Insects. Scale insects are one of the big problems in almost every citrus-growing area of the world. Under humid, tropical conditions, natural control commonly takes over and keeps them under fair control if nothing is done in the way of pest control. However, if copper must be used for melanose or scab control, or sulfur for mite control, the balance sometimes is sufficiently upset to result in scale build-up and consequent necessity for control. Classically for many years, hydrogen cyanide gas was used for control in dry areas such as Spain and parts of California and oil emulsion under humid conditions. Unfortunately, some scale insects have tended to produce races resistant to hydrogen cyanide, with the result that concentrations have had to be increased to the danger point for the trees. Even this fails to give sufficient control in some areas, and a change is made to oil emulsion. The application of oil emulsion is a shock to the tree and reduces the sugar content of the fruit, thus stimulating a search for a substitute scalicide. Parathion has come into wide use in Florida and to a lesser degree in California. In Florida, it is usually used alone for control of the scales common to Florida, but in California it has been found that California red scale [*Aonidiella aurantii* (Mask.)] is more resistant to it than purple scales [*Lepidosaphes beckii* (Newm.)] or Florida red scales [*Chrysomphalus aonidum* (L.)] and it was found desirable to mix it with oil emulsion. Because parathion is dangerous to the operators of spray equipment, the type of equipment available has much to do with its use. The spray gun in the hands of a laborer is rather dangerous because of the possibility of leaks in the control mechanism and the danger of inhaling or being wet by the mist. As a consequence, both Florida and California have turned largely to mechanical sprayers, which eliminate much of the labor and avoid contact with the solution on the part of the operator. Such equipment is not yet in use in South America and the limited use of parathion is confined to standard equipment.

California red scale, or Australian red scale as it is called in Argentina, possibly was imported into Argentina along with the tristeza virus and since that time has spread throughout Argentina and is present in Peru and Brazil. Great difficulty has been experienced in controlling it, even though some growers used three to five oil applications in one year, which did extensive damage to the trees. Apparently, the oil emulsions commonly sold in South America are much tighter than the emulsions sold in the United States and oil deposits have been too low—three to five applications in one year of oil emulsion properly made would practically have killed the trees; also the same basic oils made into emulsions using Florida formulas have given excellent control.

Better oil emulsions, better spray equipment, and better education in the application of oil emulsions are all badly needed throughout South America. Fortunately, natural control appears to be taking hold in many districts in Argentina, as it has with Florida red scale, and this will greatly aid the situation.

Fruit Flies. Fruit flies, the Mediterranean [*Ceratitis capitata* (Wied.)] and West Indian [*Anastrepha acidusa* (Walk.)], are probably the most difficult insect problem in South America. The adult female fly punctures the peel and deposits her eggs within the fruit. These eggs hatch into maggots within the fruit and later emerge and burrow into the soil to pupate. The eggs and larvae are protected within the fruit and the pupae are in the soil, so the adult fly is the only form easily reached by insecticides. Unfortunately, the flies have many hosts in both cultivated and wild fruits, so that a constant supply of adults is available and problems of control are acute. Fortunately, oranges are not one of the favored

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hosts and during the cool winter months, when reproduction of the flies is slow, oranges can be matured and harvested without too much difficulty, but when warm weather comes in the spring, losses can be very heavy. For this reason, the production of late oranges must be limited in many areas and this has a limiting effect on both the marketing situation and the possibility of developing cannery and concentrating facilities. With grapefruit, the situation is much worse, as it is a favored host. There is practically no grapefruit production in Brazil, but in Argentina, where there is considerable production, fruit flies constitute a limiting factor in some areas.

One large company in Argentina has invested much money in fruit fly control and has attained considerable commercial success, though the cost is high. Lacking a contact spray with long-time residual effect, frequent applications of a bait spray are made and dropped fruits are picked up and destroyed to eliminate as many larvae as possible. Suitable stomach poisons for the bait spray are available elsewhere, but difficult to obtain in Argentina; however, the big lack is an attractant. Vinegar is a good attractant but too volatile for spray use. The company is now financing a program of research for an attractant which is reasonably stable and long lasting, chiefly in the hope of reducing costs. It is favored with an area in which there are few other host fruits, but a really successful control would be of great value to Brazil and might be used in this country, should the fruit fly be reintroduced and gain a foothold.

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Nematodes

The latest development in the field of citrus pests involves nematodes. The citrus nematode (*Tylenchulus semipenetrans* Cobb) has been known for many years in California, Florida, and Argentina and probably exists in most other areas. Whether it could do much damage to healthy citrus trees is a moot point. In recent years, however, more and more workers in California have been inclined to blame it for poor tree condition and their inability to replant citrus with citrus satisfactorily. The idea that nematodes are of importance has been stimulated by the finding in Florida that the cause of spreading decline is the burrowing nematode, *Radopholus similis* (Cobb) Thorne. This nematode, hitherto unknown as a citrus pest, destroys the feeder roots particularly below a depth of about 2 feet and has been found to a depth of 14 feet. In the course of this work a number of other nematodes, hitherto unreported on citrus, have been found and at least some of these appear to damage citrus roots. The indications are that nematodes are going to be one of the real citrus problems of the future.

The nematode problem in citrus is very different from the problem in vegetables and other annuals, where the soil can be fumigated between crops. The final solution of this problem will require either a resistant rootstock or a treatment which will tip the balance in favor of the tree. This latter might be either a systemic which will move downward in the tree and make the roots either poisonous or distasteful to nematodes or a soil treatment which will penetrate to great depths and destroy the nematodes without seriously injuring the trees. Either type of control is a big order. Standard known rootstocks are all attacked and an entirely new rootstock might require 25 years to test thoroughly, while in the chemical field there is no precedent in other crops.

Conclusion

This discussion covers the field only briefly. Numerous diseases and insects have been omitted which are tied more to certain areas. That the problems are important is attested by the fact that citrus production is the largest world-wide fruit-producing industry, while in the United States it exceeds the total of apples, pears, and peaches combined. As citrus is grown so extensively in so many areas where organized research is lacking, technical information is of paramount importance.

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Weed Control in Puerto Rico

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In the past 10 years, chemical weed killers have replaced the machete and the hoe to a large extent in the tropics, especially in sugar cane fields. More than any other chemical, 2,4-D and its derivatives are used. Herbicides could also be used profitably to a greater extent in crops such as pineapple, rubber, rice, coffee, pastures, and lawns. Methods and chemicals used in Puerto Rico are described and results are compared with other areas.

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The warm and humid conditions which prevail in many tropical regions encourage luxuriant growth of weeds. Newly plowed fields often become covered with a thick blanket of weeds within a few days. Many of the species persist even after hand-hoeing or cutting by machete. Such practices often serve as a means of propagation by cutting the plants into smaller pieces which are able to grow and form new plants.

Ten years ago, weed control in Puerto Rico was done almost entirely by hand. The rising cost of labor has made it economically unsound to continue the ancient practice of manual weeding. The tropical agriculturist, especially in sugar cane, has been squeezed on one hand by rising costs and often on the other by lower prices for his product. Because chemical herbicides have successfully controlled many of the more troublesome weeds, most of the large sugar cane companies and some of the smaller farmers are now using them in their cultural practices. Still, resistance to change is so strong that even today weed control is done entirely by hand on some large plantations.

Weed Control in Sugar Cane

Of all of the tropical crops, sugar cane is the one in which chemical weed control is used most widely. By far the most popular herbicides are the derivatives of 2,4-dichlorophenoxyacetic acid (2,4-D). Other selective and contact herbicides are being tested and their use will undoubtedly increase. The Chamber of Commerce of Puerto Rico gives the following figures for the importation of weed killers: 1951, 982,600 pounds; 1952, 994,600 pounds; 1953, 1,603,800 pounds. Earlier figures are not available. The increase from 1951 to 1953 is correlated with pressure for higher wages and a scarcity of labor as more and more workmen migrate to the United States or find employment in the Puerto Rico industrial program.

The customary method of applying herbicides is by means of the 5-gallon knapsack sprayer strapped on the laborer's back and pumped by hand. An example of the type of sprayer used is shown in Figure 1. Experiments with mechanized application have been made in Hawaii *(20, 21)* and in Australia *(9, 56)*. Attempts in Puerto Rico have so far been unprofitable. For example, a spray rig was developed by Luce and Co. at Aguirre, which would cover seven to eight rows simultaneously, but it was not as economical as the knapsack sprayer. It has been estimated *(14)* that a man with a hoe can weed approximately ¼ acre per day. At Aguirre, it was said that men applying 2,4-D pre-emergence sprays in ratoon cane averaged 7.2 acres per day per man. The average for contact sprays was considerably less (2.1 acres), because of the greater care required to avoid spraying the cane during application. In other areas of Puerto Rico it appears that laborers spraying 2,4-D average about 1 acre per day.

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Figure 1. Knapsack sprayer

Applying contact herbicide (pentachlorophenol and aromatic distillate) to sugar cane by 5-gallon knapsack sprayer. Pressure is maintained by pump at right-hand side. Herbicide is being applied to ground virtually bare of weeds.

More than one form of 2,4-D is used and several applications are often given. In the early studies in Puerto Rico, the ammonium salt was used *(56–58)*, but this has since been replaced by other forms. Pre-emergence treatments are given at the rate of 2 to 8 pounds of acid equivalent in aqueous solution per acre. For this purpose the amine salt is most widely used. The low volatile butoxyethanol ester has come into use in a few areas. It was found that 2-methyl-4-chlorophenoxyacetic acid (MCP) was superior to the sodium or the amine salt for pre-emergence sprays in Mauritius *(43)*. In Hawaii *(22)* and Puerto Rico, however, it was approximately equal to 2,4-D in action, and more expensive in price. In Trinidad *(4, 19)*, several applications of the sodium salt or the amine salt of 2,4-D are made at 4- to 6-week intervals, using knapsack sprayers fitted with low-volume nozzles. In Puerto Rico, the amine salt or the isopropyl ester is used for postemergence sprays at the rate of about 2 to 8 pounds of acid equivalent per acre. Some plantations spray at 4- to 6-week intervals until the cane closes over. Nearly all applications of 2,4-D are made in aqueous solution, although dissolving in an aromatic oil *(37)* or in a pentachlorophenol emulsion *(14)* has been recommended. Some farmers apply as little as 20 gallons per acre of herbicides, whereas others use as much as 50 to 100 gallons per acre. In Hawaii, 2,4-D has been pelleted for experimental airplane drop to avoid the danger of excessive drift *(20)*. This method would seem to be worthy of further study, especially if it could be combined with helicopter application. Application of 2,4-D together with fertilizer has been made *(10)*, thus saving one operation and it may be possible to extend this to mixing it also with insecticides.

Cane Resistant to 2,4-D. In Puerto Rico, 2,4-D is regarded as noninjurious to the sugar cane, although Nolla *(36)* reported that certain varieties of cane became bent when 2,4-D was applied to the culms. In Mauritius *(43)*, pre-emergence sprays of the isopropyl and butoxyethanol esters severely retarded the growth of sugar cane, whereas postemergence sprays gave variable responses.

The resistance of sugar cane to 2,4-D may be due to a number of factors. Van Overbeek *(56)* pointed out that sugar cane is physiologically not comparable to germinating rice, barley, or oats. Sugar cane is commercially propagated by means of cuttings, technically known as "seed pieces," or it is allowed to "ratoon" from the

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rhizomes remaining in the ground after harvest. The metabolism of these shoots more closely resembles that of adult plants than that of seedling plants. Thus it is understandable why young cane plants are more resistant to 2,4-D than seedling plants of other members of the grass family.

Nolla *(36)* suggested that resistance of the cane to 2,4-D was of two types: physiological resistance in which some clones, such as M. 275, showed little injury from 2,4-D even when the chemical was applied directly to the intercalary meristem, whereas under the same conditions, a sensitive clone such as P.O.J. 2878 suffered bending and breakage; and temporary resistance resulting from protection by the leaf sheaths when the cane is under 2 months of age. Guiscafré-Arrillaga *(18)* reported gall formation from injection of 2,4-D into the terminal bud of cane. In Louisiana *(5)*, Brown and Holdeman reported that 0.1 or 0.2% ethyl ester of 2,4-D applied after flame cultivation induced abnormal nodes, but the yield from treated plots was higher than from the check plots. These results all suggest that damage may occur. When used properly, however, the advantages of 2,4-D far outweigh the disadvantages.

Pre-emergence Sprays. The action of the amine and sodium salts of 2,4-D as pre-emergence sprays may be due to their remaining in the upper layers of the soil *(32)*. Thus, a film of 2,4-D is formed through which the germinating weeds must penetrate. The disappearance of 2,4-D from the soil is probably due to decomposition by microorganisms *(1)*. It has been shown that 2,4-D loses its potency more rapidly in plots which had been sprayed the previous year than in those previously unsprayed. This suggests a build-up of the number of microorganisms capable of breaking down 2,4-D and may possibly lead to reduced effectiveness of 2,4-D after numerous applications *(34)*.

Most broad-leaf weeds in sugar cane, such as the "bejucos" *(Ipomoea* or *Convolvulus* species), "pica pica" *(Stizolobium pruritum* [Wight] Piper), "bledo" *(Amaranthus dubius* Mart. and *A. spinosus* L.), and "cohitre" *(Commelina longicaulis* Jacq. and *C. elegans* H.B.K.) are easily controlled by 2,4-D. Nutgrass *(Cyperus rotundus* L.) can be controlled with this chemical but not killed. Mature grasses are not much affected, although seedling grasses are injured.

Problems of Resistant Grasses. In one sense, the use of 2,4-D has created a more serious problem in some areas, because the resistant grasses have multiplied and now dominate the weed flora. These often have fibrous root systems in the same soil level as the cane and compete more for nutrients and water than do tap-rooted broad-leaf plants. Bermuda grass *(Cynodon dactylon* [L.] Pers.), "malojillo" *(Panicum purpurascens* Raddi), "pendejuelo" *(Digitaria sanguinalis* [L.] scop.), "arrocillo" *(Echinochloa colonum* [L.] Link.), "pata de gallina" *(Eleusine indica* [L.] Gaertn.), and others can be found in large numbers in some fields. This problem was foreseen by Van Overbeek *(56)*, who recommended hand hoeing in addition to 2,4-D. This practice is still followed in many places.

Crafts *(13)* recommended a pentachlorophenol emulsion as a contact herbicide which would kill grasses but could also be used as a carrier for 2,4-D. In Hawaii, CADE (chemically activated Diesel emulsion) has replaced 2,4-D entirely on some plantations *(20, 21)*. Nolla *(37)* used 2,4-D in aromatic oil in Puerto Rico and found it superior to pentachlorophenol emulsion or concentrate 40 (arsenic trioxide, sodium pentachlorophenate, sodium chlorate) for killing grasses. Care had to be taken not to spray the sugar cane. Creosote and Diesel oil combined with 2,4-D are used in Australia to control young grasses *(55)*. At Luce and Co. in Puerto Rico, 6CA-4, a contact herbicide composed of pentachlorophenol and aromatic distillate *(33)*, has long been used. At the present time, 1.5 to 2 pounds of the amine salt of 2,4-D per acre are applied immediately after harvest in a single application. Following this, several applications (five to six) of 6CA-4 are made as soon as any weeds appear, as shown in Figure 1. This method has been in use for several years in this area, with claims of excellent weed control (Figure 2) and is said to have reduced the total weed problem to a fraction of what it was 5 years ago. These results have not been duplicated in other areas in Puerto Rico.

Other Chemicals. Sodium chlorate has been used to control the composite *Artemisia vulgaris* L. in Mauritius *(43)*. This chemical is cheap but hazardous to use because of the danger of fire. It was used in the early days of chemical weed control in Puerto Rico but never proved satisfactory *(35)*.

Sodium trichloroacetate (TCA) has been found useful for controlling a number of grass weeds *(20, 33, 38, 43)*. In Puerto Rico, it is used to control grasses along the edges of the fields and ditches and for occasional spot spraying (Figure 3). This chemical tends to corrode equipment, although it was reported *(20)* that sodium chromate is a useful corrosion inhibitor. In Puerto Rico, the action of TCA was much improved by combining it with a contact herbicide such as aromatic oil *(30)*.

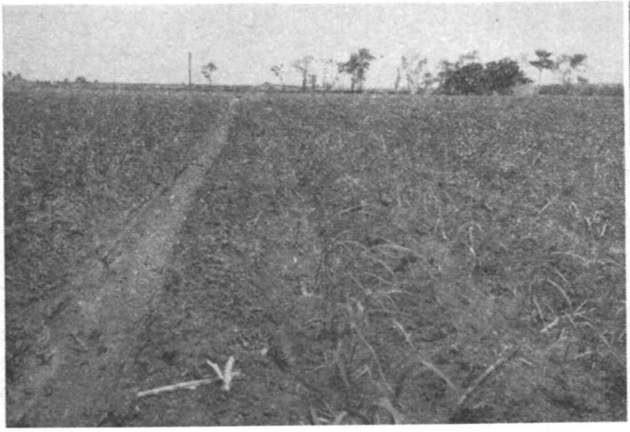

Figure 2. Treated cane field

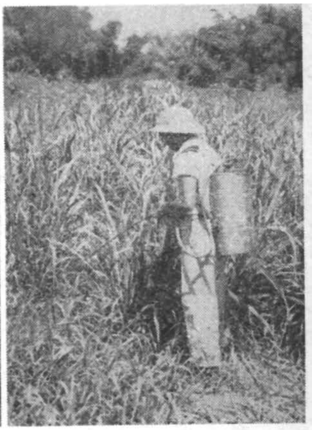

Figure 3. Spot spraying

Figure 2—Sugar cane about 6 weeks old which has had one spray of 2,4-D amine and 2 sprays of 6CA-4. Weed control is excellent both in irrigation ditches and within rows of cane.

Figure 3—Applying sodium trichloroacetate at edges of cane and along ditches to control malojillo or para grass (Paspalum purpurascens Raddi). For spot sprays of this type, TCA is mixed at 0.5 pound per gallon of water.

Similar results were reported in Hawaii *(20)*, where TCA combined with CADE was more effective than TCA alone, and in Malaya *(44)*, where it was combined with sodium pentachlorophenate. In Station experiments in Puerto Rico, pentachlorophenol was one of the least effective combinations and aromatic oil was one of the most effective. The persistence of TCA in the soil is affected by various environmental factors such as heat, moisture, and organic matter. It persisted longer in clay than in sandy soil *(26)* and may last for several months under dry conditions. In contrast to 2,4-D, TCA enters mainly through the roots. In relation to the amount of rainfall, TCA moves down in the soil where it is absorbed and then translocated throughout the plant. It is a slow-acting chemical and usually exhibits no effect for several days after application. Sugar cane is apparently highly resistant. A preplanting spray of 60% TCA at 100 pounds per acre did not affect the germination or growth of cane planted on the same day or later *(25)*. For effective control of most grasses, it is necessary to use this chemical at the rates of 30 to 60 pounds per acre. It is usually mixed at a rate of 0.5 to 1 pound per gallon for spot sprays. At its present price of approximately 45 cents per pound in Puerto Rico, it is prohibitively expensive for large-scale spraying.

CMU (3-*p*-chlorophenyl-1,1-dimethylurea) has also been tested in Puerto Rico and Hawaii *(27)*. This chemical has given preliminary results of great promise. Excellent weed control was obtained in an experiment in which CMU was applied at 3, 6, or 9 pounds per acre (Figure 4). It seems equally toxic to both broad-leafs and grasses and is most effective when applied to bare soil before the weeds have emerged. It remains in the upper layer of the soil and the degree of persistence is affected by heat, moisture, and percentage of organic matter *(27)*.

Response of cane to CMU is variable and may possibly be correlated with the amount of rainfall or soil pH. In the dry (30 to 40 inches of rainfall) alkaline (pH 8) areas of Puerto Rico, where sugar cane is irrigated, damage to cane has

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been reported at application as low as 3 to 5 pounds per acre. In the Añasco valley where rainfall averages about 80 inches per year, and soil tends to be acid (ranging from pH 4 to 6), no damage was found up to 20 pounds per acre. Damage to cane was reported at 8 pounds per acre in Hawaii *(20)*.

Figure 4. CMU weed control

Excellent weed control obtained with CMU applied experimentally at 9 pounds per acre 5 weeks previously when cane was planted. Applications at 3 pounds per acre were much cheaper and nearly as effective. Untreated controls are being hand-hoed in background.

Despite the advantages of this chemical, it is doubtful if it will find a very wide use at its present price of approximately $3 per pound in Puerto Rico. Mechanical difficulties in maintaining this material in suspension mitigate against its use, although new formulations may be helpful in this respect. CMU does not dissolve readily and is usually sprayed as a slurry. In Hawaii, it has been dispersed in CADE, where it remains in suspension for several days, and there are indications that this combination may be superior to CMU in water *(21)*.

It is possible that the resistance of certain plants to this chemical may reduce its effectiveness in the future, as the more susceptible weeds are killed and the resistant ones multiply. In Hawaii, *Panicum repens* was not killed even at 80 pounds per acre. *Digitaria*, nut grass, and Bermuda grass show some resistance in Puerto Rico. On one farm treated with CMU at 4 pounds per acre, almost pure stands of *D. sanguinalie* have appeared in some areas.

A method which has given excellent results is that on Nolla *(37)*, who used a pre-emergence spray of CMU at 4 to 6 pounds per acre in plant cane or at 3 to 4 pounds per acre in ratoon cane, followed by a single application of the amine salt of 2,4-D at 1 pound per acre as postemergence treatment. In some instances, where the weeds had initiated growth, the CMU and 2,4-D were combined in a single application. Repeat applications of 2,4-D were made to a few areas, perhaps 30% of the sugar cane. He found that nut grass *(Cyperus rotundus)* was resistant to CMU but was controlled by 2,4-D. Bermuda grass frequently appeared after CMU treatment but was controlled by spot application of TCA. No further spraying or hoeing was necessary.

Less widely used chemicals, such as isopropylphenylcarbamate (IPC) have given promising preliminary results as a pre-emergence spray at Aguirre and at Central Igualdad *(35)*. Dalapon (α,α-dichloropropionic acid) appears to be valuable for postemergence spraying of grasses. TCA acid is far superior to any of its salts but is too dangerous to use.

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Weed Control in Other Crops

Chemical weed control has great possibilities for use in tropical crops other than sugar cane. The scarcity and high cost of labor are making the use of herbicides increasingly more important. Coffee, for example, is resistant to 2,4-D and at least three producers in Puerto Rico are currently testing herbicides. With 2,4-D many of the worst pests of coffee can be controlled, such as "jazmin" *(Clerodendrum fragrans* Vent.), the dumbcane, "rábano cimarrón" *(Dieffenbachia seguine* [Jacq. Schott]), and the nettle, "ortiga brava" *(Urera baccifera* [L.] Gaud.), if the chemical is properly applied *(58)*. Other pests, such as grasses, may be controlled with contact herbicides. Various 2,4-D combinations have shown promise in Brazil and in Costa Rica *(17, 51)*. In Kenya, 2,4-D caused tainting of the coffee crop and TCA proved deleterious to the trees *(41, 42)*.

Rice. Rice, a major food crop in the tropics, is highly resistant to 2,4-D at most periods of growth. Although chemical weed control is widely used in the United States, relatively little has been done in the tropics. Some chemical weed control in rice has begun in Cuba *(18)*, Philippines *(39)*, Malaya *(6)*, and Venezuela *(16)*. Both dinitrophenol and pentachlorophenol were effective as pre-emergence treatments in Venezuela, and CMU gave very promising preliminary results.

Forest Nurseries. In forest nurseries in Puerto Rico, applications of TCA and 2,4-D were useful as preplanting treatments to beds later sown with broad-leaf mahogany *(Swietonia macrophylla* King) and Australian pine *(Casuarina equisetifolia Stickm)*. It was found that the mahogany could be sown 1 week after spraying, and the Casuarina could be sown 2 weeks after application. Fifty to 100 pounds of TCA and 4 to 8 pounds of 2,4-D per acre were optimum. The combination was more effective than either one alone. For pre-emergence studies, TCA applied promptly after sowing was most effective. When applied 2 or 3 weeks after sowing, the young seedlings were burned. Weeds such as *Digitaria* and *Gomphrena* were temporarily eliminated *(59)*.

Rubber. In rubber [*Hevea brasiliensis* Willd. ex A. Juss (Muell. Arg.)] plantations in Malaya, sodium arsenite has been widely used. This material is cheap and efficient but dangerous to handle. The rates of application varied from 60 to 435 pounds per acre, depending on the density of weed growth *(46)*. TCA combined with sodium pentachlorophenate gave good results on lalang (cogon grass) *(Imperata cylindrica* Beauv.) and grasses, as did CMU; but both were too expensive. Siam weed *(Eupatorium odoratum* L.) was killed by a mixture of 2,4-D and 2,4,5-T esters but was not affected by either one sprayed singly *(44)*. The form, *Nephrolepis biserrata* (Sw.) Schott, was killed by ammonium sulfamate in a 10% solution. *Mimosa pudica* L. was controlled by MCP at 6 pints per acre applied in 100 gallons of water *(46)*. Mixtures of 2,4-D and 2,4,5-T isopropyl esters were very effective against this weed in Puerto Rico.

Herbicides have been used in rubber for purposes other than weed control. Sodium arsenite has been used to poison old rubber trees in the Far East prior to replanting. Trees in coastal areas were more difficult to kill than trees growing on hilly inland terrain. A seasonal effect has also been noted. In May, before wintering, applications of 2.2 ounces of sodium arsenite per tree were required to cause death of large trees (50 to 60 inches in girth), but during the hot dry weather of August, 1.5 ounces was sufficient. Adjacent trees were sometimes killed by arsenite drawn from treated trees through root grafts *(45)*. Normal butyl 2,4,5-trichlorophenoxyacetate in Diesel oil applied in a 2% solution at 1 gallon per acre by airplane completely defoliated mature rubber trees. Another use of 2,4-D and 2,4,5-T is in increasing the yield obtained from tapping the rubber trees. Concentrations of 1% of the sodium salts of 2,4-D and 2,4,5-T in palm oil applied to a 3-inch strip of lightly scraped bark below the tapping cut gave 149 and 177% increases, respectively. Substituting the normal butyl esters for the sodium salt gave yields of 152 and 200% over a 4-month period *(22)*.

Other Tropical Crops. Herbicides have also been used on a small scale on a number of other tropical crops—for example, 2,4-D and 2,4,5-T have been used in pastures *(9, 56)*. In establishing lawns of Manila grass *(Zoysia matrella* [L.] Merr.) at the station in Puerto Rico, pre-emergence application of 2,4-D materially

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reduced the weed problem, and postemergence sprays combining the isopropyl esters of 2,4-D and 2,4,5-T controlled many weeds without injury to the lawn. Infected abaca plants have been eliminated by use of 2,4-D *(11)*, and CMU gave excellent control of lady's sorrel *(Oxalis corniculata* L.) in orchids *(2)*. CMU at 4 to 6 pounds per acre controlled weeds in pineapples for 90 days *(12)*. Pentachlorophenol and sodium pentachlorophenate are used in Australia for weed control in pineapple plantations. A pre-emergence spray of sodium pentachlorophenate, 20 pounds per acre, kept the land free of weeds for 3 months *(8)*.

Some Special Weed Problems

Certain weeds are a serious problem throughout the tropics. They compete for water, space, and nutrients and have actually made some large areas virtually unusable. In addition, some of them actually penetrate into the roots and tubers of crop plants, thus making wounds through which microorganisms enter as well as interfering with a normal growth *(3, 47, 52)*.

Nutgrass. Nutgrass *(Cyperus rotundus* L.) is one of the more serious pests, and, as a result, has received a great deal of attention *(7, 31, 40, 49, 56, 60)*. Crafts *(13)* has stated rightly that some of the early reports on the eradication of this weed with 2,4-D were overoptimistic. These reports were apparently based on an inadequate consideration of the underground tubers. In a tall-growing crop, such as sugar cane or sorghum, nut grass can be controlled by a single spray of 2,4-D at 3 to 5 pounds per acre. The herbicide kills the leaves and basal bulb of the growing plants and the crop shades out the lower tubers before they sprout to any extent. The underground tubers, however, are not killed and they remain dormant.

Studies in Puerto Rico on this plant have demonstrated that successful control methods utilized in a dry area are not necessarily suitable under humid conditions. Davis and Hawkins *(15)* were able to kill nut grass in Arizona by plowing the fields repeatedly, thus bringing most of the tubers to the surface, where they dried out. Such a treatment under Mayaguez conditions (average 80-inch rainfall) served only as a means of propagation. In one experiment, some plots were plowed, others were both plowed and sprayed with 5 pounds per acre of isopropyl ester of 2,4-D, while others were sprayed only or left untreated. The sprayed plots were treated 3 weeks after the first sprout appeared, because previous studies *(31, 49)* showed that new tubers were formed within 3 weeks after sprouting. Plowing was repeated at intervals of about 10 days after spraying. This rotation was continued for 16 months. The results are shown in Figure 5. Plowing increased the population, whereas plowing plus spraying was successful in reducing the stand about 90%. Spraying without plowing reduced the number of live tubers only slightly more than in the control, although this area soon became covered with a dense stand of Bermuda grass and no visible sprouts of nut grass could be seen. By visual methods of observation only, these would have appeared to be the best plots.

Numerous other chemicals have been tested on nut grass. TCA delays the germination of tubers but does not materially reduce the stand. A combination of TCA and 2,4-D was superior to either chemical in Brazil *(40)*. Methyl bromide has proved excellent for the control of nut grass in the United States *(23)* and on a small scale in Puerto Rico. Unfortunately, it is expensive and difficult to apply. CMU kills nut grass, especially if applications are alternated with plowing, but leaves the soil unusable for crops for an extended period and is too expensive for large scale application *(28)*.

Water Hyacinth. Water hyacinth *(Eichornia crassipes* Solms) has been killed by 0.1% solution of the alkanolamine salt of 2,4-D in Indonesia *(54)*, or in the Philippines by the isopropyl ester in as low as 0.1% solutions *(39)*. In the southern United States, 2,4-D has been widely used to kill this plant. This plant is of relatively minor importance in Puerto Rico. It tends to choke up river mouths and is removed to improve drainage. A single application of the isopropyl ester of 2,4-D has given excellent results on a small scale.

The water fern *(Salvinia auriculata* Aublet) may cover irrigation ditches and obstruct machinery and has assumed pest proportions in Ceylon *(48)*. A similar species *(S. rotundifolia* Willd.) has formed solid blankets over irrigation ditches and ponds in Puerto Rico. It is important in the breeding of the malaria vector in

Panama *(29)*. It was killed in Puerto Rico by the application of aromatic oil alone at 50 to 100 gallons per acre, although a combination of oil and isopropyl ester of 2,4-D or butyl 2,4,5-trichlorophenoxyacetate at 1000 p.p.m. was superior.

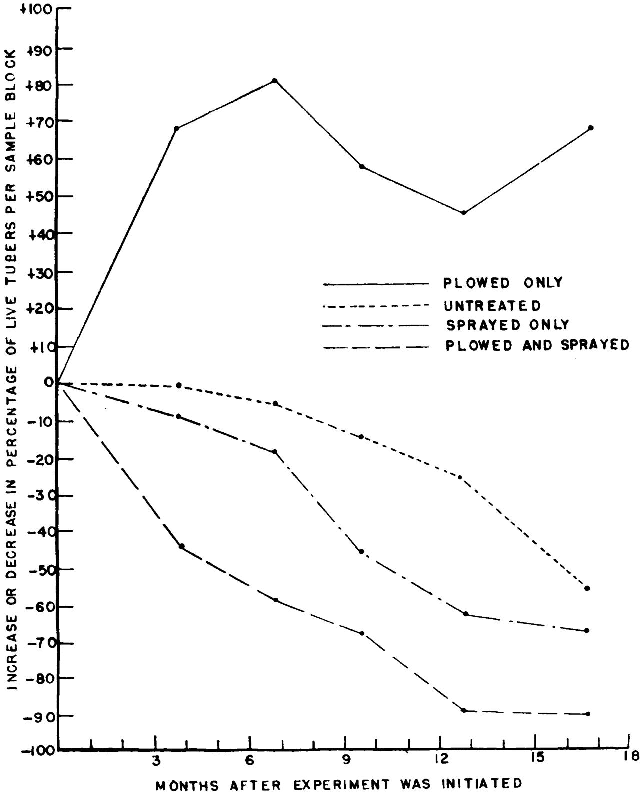

Figure 5. 2,4-D action on live nut grass tubers

Percentage of live nut grass tubers remaining after each spraying with 2,4-D isopropyl ester at 5 pounds per acre. Treatment was alternated with plowing to induce maximum amount of sprouting. 2,4-D was sprayed 3 weeks after first sprouts appeared, before new underground tubers could be formed. Tubers were counted in blocks of earth, 12 × 12 × 9 inches deep. Over 1600 tubers were found in some sample blocks.

Cogon Grass. Cogon grass *(Imperata cylindrica* Beauv.), or lalang, is especially serious in the Far East, where it covers large areas. It propagates rapidly by seed and vegetatively and may completely take over fertile areas within a few years *(52)*. It is a bad pest in rubber plantations. Fires often run through it, severely damaging the rubber trees. It also serves as a cover for the trombiculid mites which transmit scrub typhus *(6)*. Excellent control was obtained in Puerto Rico by mowing it to a 4-inch stubble and applying a contact herbicide, then burning the stubble, and spraying TCA at 100 pounds per acre *(24)*. Sodium arsenite has been used in the Far East on a large scale *(45)*, and TCA and CMU have been tested and found effective but too expensive *(6)*.

Woody Tropical Weeds

Control of woody tropical weeds is usually obtained by the use of 2,4-D or 2,4,5-trichlorophenoxyacetic acid (2,4,5-T) or a combination of the two. The combination is often superior to either used alone. Thimann *(53)* tested 2,4-D on "aroma marabu" *(Dichrostachys nutans* Benth.) and "guao" *(Comocladia dentata* Jacq.) in Cuba. More recent studies have shown that better results can be obtained from applications of mixtures of 2,4-D and 2,4,5-T esters *(17)*. In Puerto Rico, derris *(Derris elliptica* [Wall.] Benth.) which is resistant to 2,4-D and is only slightly affected by 2,4,5-T is defoliated and killed within a short time by a mixture of equal parts (1000 p.p.m.) of the isopropyl esters. Smith *(50)* reported that the reed *(Phragmites communis* Trin.), a major pest of cultivated areas and drainage ditches in Australia, was killed by a combination of the ethyl ester of 2,4-D and the butyl ester of 2,4,5-T. A mixture of 2,4-D, 2,4,5-T, and TCA has been recommended for brush killing in Hawaii. In killing tropical woody shrubs it is important that translocation of the herbicide into the roots take place before the leaves and stems are killed, for many of these weeds have remarkable powers of regeneration. Thus the chemical should be slow-acting and easily absorbed and translocated by the leaves and stems down into the roots.

Discussion

Chemical weed control in the tropics is still in an experimental stage in most crops. With the exception of sugar cane, few applications have been made on a commercial scale. Even in the sugar cane, where 2,4-D is used almost universally, there is considerable variation in the techniques, the kind of 2,4-D employed, and the use of subsidiary chemicals. This is partly due to different environmental conditions in operation at various times and situations, including the types of weeds present, age of the weeds and crop, soil, and rainfall. Personal idiosyncracies are also an important factor.

The question of which herbicide to use is determined by many factors. Among these are cost, effectiveness, selectivity, and ease of mixing and spraying. Cost is very important in the tropics where labor is cheap and the herbicides have to be shipped long distances. For example, the isopropyl ester of 2,4-D is a more effective postemergence spray than the amine salt, but the latter is used more widely because it is cheaper. The amine is preferred to the sodium salt because it is sold in a liquid solution and it is easier to measure volume than weight under field conditions in Puerto Rico. Selectivity, of course, is very important, so that the crop plant is not affected by the herbicide, although the wide use of contact herbicides suggests that care in application can overcome this factor to some extent. Another factor to consider is the degree of weed control desirable for the particular crop. In sugar cane, most operators strive for clean cultivation whereas in other crops, such as in pineapples and coffee, some weeds may be desirable to protect the soil from sun and erosion.

Many changes are occurring in the cultivation of tropical crops, and it is difficult to make any predictions in a field which is undergoing rapid changes. However, the present trend in the use of herbicides appears to be away from the use of single chemicals. Usually the combination of chemicals involves 2,4-D with some other herbicide, although TCA combined with a contact herbicide has been widely used. Some of the newer chemicals, such as TCA and CMU, will probably be used more in the future, especially if the cost can be reduced.

Most of today's practices are based on empirical data. Further investigation into the mechanism of herbicidal action is of fundamental importance in establishing the use of herbicides on a sound basis. More study into the synergistic effects of combining various chemicals is needed, as well as studies on methods of formulation, optimum quantities, times of application, and the influence of environmental conditions on the herbicidal action. Secondary effects, such as the reported tainting of coffee from 2,4-D deserve further inquiry.

Tropical regions are now in the process of evolution from manual to mechanical labor imposed by higher wages and shortage of farm hands. In this evolution, it is likely that chemical herbicides will continue to play an important role.

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Arthropod Parasites in the African and New World Tropics

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Livestock diseases, the casual agents of which are transmitted by ticks or bloodsucking flies, constitute one of the principal deterrents to the progress of tropical agriculture in Africa and Central and South America. Intensive educational and extension programs to increase the use of parasite control measures now known are urgently needed.

Arthropod parasites and the diseases they transmit are among the most important deterrents to the progress of tropical agriculture in Africa and Central and South America. No general agricultural economy can be entirely successful if domestic animals and poultry are excluded or their husbandry for any reason is unprofitable. In many tropical areas the entire livelihood of families or tribes depends on cattle that are used for food, draft, and as a measure of wealth. Outbreaks of parasites or disease epizootics that decimate or debilitate their animals can mean financial disaster or even famine for these people.

Class and Identity of Parasites

The arthropod parasites of livestock may be divided roughly into two categories: those that take blood, feed on the flesh, or simply annoy their hosts, and those that can transmit the organisms of disease. The latter may be necessary intermediate hosts of the causative organisms, or may transmit them mechanically with no essential stage of the organism being developed in the arthropod. The principal arthropod groups involved are the ticks and the bloodsucking flies.

In Africa the most important bloodsucking insects are horseflies *(Tabanidae)*, gnats *(Heleidae)*, stable flies, horn flies, tsetse flies *(Muscidae)*, and mosquitoes *(Culicidae)*. Cattle lice, the mites causing mange and scabies, sheep keds and other louse flies, and the horse bots also are parasites of major importance in both Africa and the American tropics. In addition to the strictly bloodsucking flies, several species feed on the flesh of living animals, making their entrance through wounds or through natural body openings that have become soiled with mucus or bloody droppings. A few species of blowflies develop in the wool of sheep and under some conditions attack the skin and flesh as well as the wool. Many species of flies that are unable to pierce the skin of an animal nevertheless are avid blood feeders and cause livestock much annoyance by hovering about and feeding on blood exuding from wounds made by primary bloodsucking flies, or ticks.

Horsefly

Female horseflies are entirely hematophagous in the adult stage. The larger species may take nearly 0.5 ml. of blood at a meal and feeding occurs at 1- to 3-day intervals during a life of 2 weeks or more. Because the bites are painful to the host, the flies frequently are interrupted while feeding, with the result that a fly may bite several cattle during a single blood meal. This enhances the possibility of mechanical transmission of blood parasites. Horseflies are known transmitters of the organisms of anthrax, anaplasmosis, and several trypanosomes, including the

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causal agent of surra. Wounds made by horseflies remain open for some time, probably because of the anticoagulant injected by the flies. Such wounds are attractive to secondary blood feeders and also to the species whose maggots inhabit open traumatic areas.

Effective control of horseflies is impossible by any practical means now known. In the United States some protection of livestock is accomplished by the use of repellents, among which the synergized pyrethrins are currently the most promising. These are made from either emulsifiable concentrates or oil solutions containing 1% of pyrethins, and 10% of either piperonyl butoxide or the sulfoxide of isosafrole. The emulsifiable concentrates usually are diluted with 14 parts of water and applied with hydraulic sprayers. One to 2 quarts will protect an animal for 3 to 5 days. The oil solutions are applied without dilution as a fine mist, only 2 or 3 ml. being applied daily. Data on the effectiveness of these materials against horseflies have been assembled in temperate America, but their possible usefulness in tropical climates has not as yet been investigated. The high cost of pyrethrin-bearing materials recently has led to tests in which less expensive repellents have been used in combination with the pyrethrins in the concentrates. Two of the most promising diluents are polypropylene glycol butoxide and thanite (isobornyl thiocyanoacetate). High cost and the necessity for frequent individual treatment of animals probably rule out the use of these materials in the tropics.

Most of the well-known chlorinated hydrocarbon insecticides will kill horseflies and the percentages required are small. But none of them will protect livestock adequately from horseflies, as the bites are made and the damage done before these relatively slow acting materials take effect. Probably most horseflies attacking an animal sprayed with DDT, lindane, chlordan, or toxaphene (chlorinated camphene) would eventually die, but the fly reduction thereby made in an area would be insignificant unless all hosts both wild and domestic were treated frequently.

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Stable Fly

Stable flies, *Stomoxys calcitrans*, are among the most cosmopolitan of bloodsucking insects. In this species, as in other bloodsuckers of the family *Muscidae*, both sexes take blood. They are suspected as mechanical transmitters of several pathogenic organisms and have been proved capable of transmitting *Bacillus anthracis* and Surra. The maggots develop in decaying organic matter of many kinds and do not require feces. Where breeding areas are known, and are restricted in extent, spraying with oil solutions or emulsions of DDT will kill the maggots. Usually these conditions do not obtain and the same repellents used against horseflies are the only resort.

Horn Fly

The horn fly, *Haematobia serrata*, so common in North America, is represented in Africa by the closely related species *Haematobia minuta*. Although only half the size of the housefly, these little flies are vicious blood suckers and cause serious losses under favorable climatic conditions. High temperature and high moisture favor them. The immature stages of these flies are spent in cow or buffalo dung but the adults live almost continuously on their hosts. This fact makes them relatively easy to control and monthly applications of DDT or methoxychlor to the host will give practical control. The dosage of insecticide varies somewhat according to climatic conditions, more being required if heavy rains are frequent. Under tropical conditions it is probable that biweekly applications at the 1% level would be required. The species of *Haematobia* are not known to be transmitters of any disease organism.

Blowfly

Chrysomyia bezziana, a blowfly with habits much like those of the screwworm fly of the southern United States, is a pest throughout much of tropical Africa. The flies are attracted to open wounds, where they deposit their eggs. The maggots feed on living tissues surrounding the wound and frequently kill the host. Common sites of attack are the wounds left by biting flies, or ticks, or predatory animals. Navels

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of new-born animals frequently are attacked and surgical wounds of any type are subject to attack. Infestations may occur in the lesions caused by foot and mouth disease. Effective control depends on daily inspection of all animals during the fly season and immediate treatment with any of several washes or smears which kill the maggots and make the wound unattractive to ovipositing flies for several days. The remedy commonly used against the screwworm fly in the United States contains lindane as the toxicant and is designated as EQ 335. Similar formulations are available in Africa.

Screwworm infestation will be reduced if such operations as dehorning, tail docking, and castration are done during the dry season when flies are less abundant.

Blowfly maggots that infest or "blow" the wool of sheep are especially common in warm humid areas, but occur wherever sheep are raised. Several species are involved, but the most troublesome species in Africa is *Lucilia cuprina.* The flies are attracted either to open wounds or to fermenting wool, the latter a condition that arises when sheep in full fleece are subjected to frequent rains during warm weather. While *Lucilia cuprina* apparently confines its attack mostly to the wool and the serous fluid that exudes from the skin of infested sheep, some of the associated species may attack the skin and flesh with serious or fatal result. *Lucilia sericata* has been observed to penetrate the abdominal wall and enter the peritoneal cavity.

Investigators at the Veterinary Research Laboratories, Onderstepoorte, Union of South Africa, report that benzene hexachloride is the preferred material for control of the sheep blowflies. Dips containing 0.5% γ-benzene hexachloride give immediate control and confer practical immunity from new attacks for several days. Wettable powder formulations are preferred, because they do not interfere with normal healing of the wounds and renewed growth of wool. Aldrin, dieldrin, and chlordan also were found effective but higher dosages were required. This and the higher costs of these materials preclude their recommendation at present. DDT and its related compounds and toxaphene gave relatively poor results.

Tsetse Fly

Beginning with the classical pioneer work of David Bruce, the tsetse flies have been studied more thoroughly than any other bloodsucking insects affecting livestock. Approximately 21 species of tsetse flies (*Glossina* sp.) are known and all are limited in distribution to tropical Africa, except *G. tachinoides* which occurs in a small corner of southwestern Arabia. Transmitters of the protozoan complex composed of *Trypanosoma brucei*, *T. congolense*, and *T. vivax* which causes nagana in livestock, the tsetses have been responsible for periodic catastrophic losses of domestic animals in several parts of tropical Africa. The situation is highly complicated by the presence of large numbers of wild animals that serve as reservoirs of the trypanosomes and hosts for flies. During the summer of 1945–46 it was estimated that nagana destroyed 60,000 head of cattle in Zululand alone. In this area the transmitting tsetses were *Glossina pallidipes*, *G. brevipalpis*, and *G. austeni.* In many parts of the tsetse range in Africa much land has remained out of use because cattle could not successfully be raised in the presence of nagana. A second and possibly greater deterrent has been the tsetse-transmitted human sleeping sickness.

The tsetse flies are viviparous. The egg is retained and hatched in the body of the female fly, where it is nourished until full grown, then it is deposited on loose or sandy soil in a shaded place. The larva pupates within a few hours and after several weeks an adult fly emerges. The gestation period in the fly is about 10 days, and the flies may reproduce over a period of several months. Most of the species are limited to fly belts within their respective ranges. Shade and abundant ground cover characterize typical fly belts.

Prior to the advent of DDT, no highly successful chemical control of tsetse flies had been accomplished. In 1945 duToit, Graf, and Theiler of the Onderstepoorte Staff began their investigations on aircraft-distributed DDT for the control of adult tsetses. The site selected was a belt 30 square miles, comprising the Mkuzi Reserve in Northern Zululand, an area well populated with *G. pallidipes.* In the preliminary tests a 5% solution of DDT in furnace oil was applied as a spray at the

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rate of 0.5 gallon per acre. Because of difficulties in getting even distribution, this method was soon abandoned in favor of fog application. For the fogging tests a 16% solution of DDT in toluene and Diesel oil was injected into the extended exhaust stack of the plane engine at the rate of 5 gallons per minute. Covering a swath width of 70 yards, the planes were flown at a speed that deposited 1 gallon of solution per 5 acres or 0.32 pound of DDT per acre. The material was delivered from the stacks as a dense white smoke with a mean mass diameter of 60 microns. After three applications at three-week intervals 92% of the flies had been killed. Similar tests with γ-benzene hexachloride delivered at the rate of 0.08 pound per acre gave approximately equal results. In subsequent routine control operations these dosages continued to give excellent control. Helicopters were used for treatments in inaccessible mountainous regions. The solution was again fed into the exhaust stack, but the rate of feed was variable, so that equal amounts were applied on each acre regardless of the forward speed of the craft.

In April 1947 a large scale control campaign was initiated in an area of 7000 acres comprising several game reserves in Zululand. Heavy breeding was occurring on only 200 of these acres and they received applications of DDT or BHC (hexachlorocyclohexane) at 3-week intervals over a period of 8 months. Adjacent dispersion areas were treated only once or twice. In July 1948 extensive scouting turned up only one fly in the entire area, and during the following year none were found. While aircraft-distributed DDT has given highly successful control of tsetses over limited areas, its general use would be prohibitively expensive.

Gnats

Workers at Onderstepoorte recently have found that small gnats of the genus *Culicoides* can transmit the viruses of blue tongue, a serious disease of sheep, and horsesickness. While the diseases are not contagious, and the gnats are proved transmitters of the viruses, the full relationship between vector and virus is still poorly understood. During early summer in the enzootic areas the gnats are present for several weeks before the disease begins to appear. A reservoir host that makes its appearance concurrently with the onset of the disease is suspected but has not as yet been identified. Both diseases are more prevalent during the wetter part of a summer and losses are greatest during especially wet seasons. Incidence is greater around lowlands, bogs, and swamps. These facts lend considerable weight to the probability that the viruses are dependent on *Culicoides* transmission, since these insects usually are aquatic, or at least inhabit hydrophitic areas during their immature stages. Moreover, it has been demonstrated that horsesickness can be prevented by confining horses in screened barns at night when *Culicoides* are most active. As reasonably effective vaccines have been developed for use against both diseases, and as the known species of *Culicoides* are notoriously difficult to control, little effort has been expended toward the development of control measures against the gnats.

Ticks

Throughout tropical Africa ticks undoubtedly account for more livestock mortality and morbidity than any other group of arthropods. Animal and poultry deaths due to exsanguination by ticks have been recorded. But far more important is their role as vectors of disease organisms. Many pages would be required for even a brief discussion of all the livestock and poultry diseases whose causal organisms are tick-borne. The several most important ones are heartwater of cattle, sheep, and goats; east coast fever of cattle; the piroplasmoses of cattle, sheep, horses, and dogs; anaplasmosis of cattle; and fowl spirochaetosis.

Tick-Borne Diseases

Heartwater is a noncontagious disease caused by *Rickettsia ruminantium* and the organism is transmitted by ticks of the genus *Amblyomma*. In east and central Africa *A. variegatum* is the principal vector, while in South Africa it is *A. hebraeum*. The disease occurs in subclinical form in at least two species of antelope which probably serve as reservoirs of the organism. A larval tick once infected will retain

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its infectiveness throughout the nymphal and adult stages but cannot transmit the organism through its eggs to the succeeding generation. As the disease cannot persist in the absence of the transmitting ticks, their eradication would seem the obvious method of control. But the opinions of investigators differ on the advisability of attempting complete tick control. To accomplish it would require such frequent dippings that the cost would be exorbitant. By contracting heartwater in early calfhood cattle gain immunity. The disease is less serious in calves than in adult cattle, but in nonimmune older cattle it usually is fatal. Complete tick control would result in totally susceptible cattle and any relaxation in dipping might then cause catastrophic losses from heartwater. Reasonably effective vaccines have been developed and Aureomycin saves many cattle.

East Coast fever is caused by the protozoan *Theileria parva*, which is transmitted principally by the brown tick, *Rhipicephalus appendiculatus*. Until recently it was believed that only cattle were susceptible, but the work of Lewis at Kabete has shown that the African buffalo may harbor the organism and show mild symptoms of the disease. In further experiments Lewis proved that ticks fed on a buffalo so infected could transmit the disease to susceptible cattle. Three of four cattle used in the test died of typical East Coast fever. In enzootic areas where tick control is not practised, cattle develop resistance if not immunity to East Coast fever. But if new cattle never before exposed to the disease are brought into such an area, they soon contract the fever and fatalities may run as high as 95%. Control of the transmitting ticks is the only means of preventing losses. East Coast fever is so feared that in some areas infected animals are immediately slaughtered. Some veterinarians believe that slaughter is the only effective means of stopping an outbreak.

Redwater, also known as splenic fever or piroplasmosis, is a protozoan disease caused by *Piroplasma bigemina*, and is usually transmitted by the tick *Boophilus decoloratus*. Two other ticks, *Rhipicephalus evertsi* and *R. appendiculatus*, also are capable of transmitting the organism but usually play a lesser role in the maintenance and spread of the disease. *B. decoloratus*, the primary vector, is able to transmit the organism of redwater fever through its eggs to its progeny. *P. bigemina* attacks the red blood cells of cattle, breaking them down and liberating the red hemaglobin. Some of this is excreted in the urine, giving it the red color that has caused the name redwater to be given the disease.

In many parts of Africa redwater is so common that all calves contract it during the first few weeks of life and thereafter enjoy a high resistance to the effects of the disease. Where a rigid dipping schedule is followed, this does not occur and cattle so treated may later contract redwater in virulent form if the benefits of dipping are even temporarily denied. Nevertheless regular dipping for tick control is highly recommended, as cattle kept free of the disease will mature faster and be more productive. At the same time they will be partially protected from the several other tick-borne diseases.

Redwater is the same cattle disease that brought near ruin to the cattle industry in the southern United States. In 1906 it was estimated that redwater, usually called "cattle fever" or "tick fever" in the United States, had caused cumulative losses of $130,500,000 to southern cattlemen, and that continued annual losses of $40,000,000 were occurring. A tick eradication campaign began that year and it was pursued rigorously until the early nineteen-thirties, when the transmitting tick, *Boophilus annulatus*, finally was entirely eradicated from most parts of the southern United States. The entire campaign cost approximately the same as one year's loss to redwater before control began.

Anaplasmosis, or gallsickness, is caused by the protozoans *Anaplasma marginale* and *A. centrale*, and usually transmitted by *Boophilus decoloratus*, the same tick that is the principal vector of redwater. *Rhipicephalus evertsi* and *R. appendiculatus* also are transmitters of the organism. The symptoms of anaplasmosis resemble those of redwater very closely, except that red urine is not passed. The two diseases are concurrent on most farms where dipping is not practised. If not dipped, calves contract the disease early in life and in them the infection is so mild that it may not produce noticeable symptoms. If immunity is not thus acquired early in life, later attacks suffered by the adult cattle may be severe.

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In common with other arthropods, the ticks have several life stages. The skin is shed between stages. Some ticks spend their entire lives on a single host and are called one-host ticks, while others leave the host for each shedding of the skin, then continue their development on a second or third host. The hosts may or may not be of the same species. The two- or three-host ticks may use a wild animal during one or more life stage and a domestic animal for the remainder of the cycle. It is obvious that a multiple-host tick that spends one or more stages on a wild host will be difficult if not impossible to eradicate with any practical dipping schedule. Where wild hosts are commonly associated with domestic cattle, the one-host tick also will be difficult to control, because dipped cattle may soon be reinfested if they pasture on ground where wild hosts have dropped gravid ticks. The exception is the blue tick, transmitter of the organism of redwater, which is not easily maintained on wild hosts. This tick has been eradicated in parts of the United States and Australia.

Tick Control

According to Matthysse, toxaphene at the 0.25% level is the most effective tick-control measure available in Africa today. High cost, however, limits the use of toxaphene, and benzene hexachloride and arsenic still are in wide use. Dipping is the preferred method of treatment, but power spraying is valuable where vat construction is impractical. BHC at a dosage of 100 or preferably 150 p.p.m. of gamma isomer is effective against several species, but resistance to this material has developed rapidly in the case of *Boophilus decloroatus*. DDT still is effective against some of the species. For Northern Rhodesia, Matthysse has suggested a schedule entailing the use of 0.25% toxaphene during the wet season and 0.1375% DDT during the dry season. It is expected that such a schedule will give reasonable cleanup of most tick species on cattle if used at proper intervals. The preferred intervals between dippings are 1 week during the wet season, and 2 weeks during the dry season. Value of cattle and severity of infestation also are factors determining dipping intervals. The annual cost of insecticides for such an operation on 500 cattle is estimated at about $350.

The need for accurate vat analysis for toxicants used in cattle dipping should be emphasized. Many failures result from reduced concentrations due to inadequate replenishment of the insecticide. Replenishing at regular intervals with a dosage about 50% in excess of that in the original charge will overcome this hazard in part but does not replace a dependable analysis.

Parasites in Tropical Americas

In Central and South America the torsalo, screwworm, and cattle ticks are responsible for a large part of the injury attributable to external parasites. The bloodsucking flies, lice, and mange mites also are present and cause significant losses to growers of cattle and the wooled animals.

The torsalo, also known as the *Berne* in Brazil and *gusano de monte* in Central America, is the larva of the fly *Dermatobia hominis*, a species that will readily attack man as well as his domestic animals. The torsalo fly has the remarkable habit of attaching its eggs to a courier insect rather than to the normal host. The courier frequently is a *Psorophora* mosquito or an *Anthomyid* fly. When the courier with torsalo eggs attached alights on a warm-blooded animal, the eggs hatch immediately and the torsalo larvae bore into the host's skin. After a few days' migration they form a cyst just below the skin surface, where they continue development for about 2 months. Hundreds of larvae may inhabit a single animal and large areas of the skin may be covered with open suppurating lesions. The intense pain and irritation caused by the larvae has been attested by the many human cases, of record, and notably by L. H. Dunn, formerly of Gorgas Memorial Laboratory, who reared six larvae in his own body and made detailed clinical notes on the reactions produced.

Practical control of the torsalo on cattle and other domestic animals still is in the category of a forlorn hope. Tests made by Laake in Brazil showed that rotenone applied as a high-pressure spray and at dosages as high as 0.09% failed to kill the larvae. A 0.12% dosage applied as a wash and brushed into the cysts also

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failed. These dosages of rotenone are more than double those that have been used successfully against the related North American cattle grubs. Toxaphene at the 0.75% level, and a mixture containing 0.25% of benzene hexachloride and 0.50% of DDT also were ineffective against torsalo larvae in Laake's tests.

In South America the tick *Boophilus annulatis microplus* transmits the organism of redwater and the disease is endemic among cattle on most of the northern half of the continent. The standard arsenical sprays no longer control this tick adequately and reinfestation develops rapidly following dipping or spraying with them.

In South America, as in Africa, toxaphene is at present the material of choice for tick control on cattle. Applied as a spray at the 0.25% dosage, toxaphene controls *Boophilus annulatus microplus* for nearly 4 weeks. Raising the dosage to 0.75% produced no significant increase in the duration of control, according to Laake. A mixture containing 0.25% benzene hexachloride and 0.50% DDT was notably less effective than 0.25% toxaphene.

The screwworm fly, a serious pest of livestock in the tropical and subtropical areas of the entire Western Hemisphere, ranks with the fever tick and torsalo as a major factor reducing livestock production in South America. The fly lays its eggs on open wounds and the maggots soon invade not only the wound but surrounding healthy tissues. Fatalities are common when infested animals receive no treatment. Infestation on an animal is always localized, so that treatment is applied only to the infested area. Washes or smears designed to kill the maggots and make the wound unattractive to ovipositing flies have been developed and are highly effective. Unfortunately, their effective use requires almost constant patrolling of the herds during fly season and immediate hand treatment of affected individuals. One of the best of these treatments is EQ 335, developed by the United States Bureau of Entomology and Plant Quarantine.

Although the screwworm fly can overwinter only in very mild latitudes, it spreads into the temperate zones rapidly during summer. Occasional outbreaks occur far from the normal habitat, when cattle infested with young maggots are moved into such areas.

Conclusions

Research on external parasite control in the tropics still is in the preliminary stages. It must, of course, be continued as rapidly as funds and personnel can be provided. But while research is being pressed, the extension of known methods of effective control should be widely encouraged. The control of cattle lice, horn flies, mange and scabies of cattle, hogs, and sheep, and ticks of many species now has been developed to a high degree in the United States and other countries. Immediate use of these methods in the tropics would result in great increases in production. While such extension work usually is a function of governmental agencies, the manufacturers of insecticides can render important assistance by servicing their materials and equipment more thoroughly in their sales areas. Even in the United States this important part of merchandising often is neglected to a certain extent.

Further large increases in the world food supply must come from opening and using underdeveloped areas in the tropics. Livestock must be an important part of any new development plans in these areas. The success of livestock growers in the tropics can never be full scale unless the external parasites of their animals are systematically controlled. It is to be hoped that research and the extension of known methods of control will accomplish this objective in large measure.

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