CHEMICAL AND NATURAL CONTROL OF PESTS

by E. R. DE ONG

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PREFACE

Maximum success in the control of pests, particularly insects and plant diseases, is possible only by understanding the value of natural control forces. These factors, when operating alone, seldom result in the degree of control satisfactory to our high standards of production. Hence it is often necessary to supplement natural control with chemical control. The purpose of this book is to assist manufacturers, research workers, instructors, and farmers in evaluating the two methods.

Excessive use of insecticides, especially the more toxic forms, may lead to the almost complete extinction of the beneficial insects present, the development of insect resistance to chemicals, and abnormally high chemical residues. It is for this reason that an introduction is given to the importance of weather, resistant plants, insect diseases, and insect parasites and predators in retarding the development of injurious insect populations and outbreaks of plant diseases.

For illustrative purposes, mention is made of many materials, both those in common use and in experimental procedure; but this is not to be taken as a final guide. The status of the various chemicals changes and so does their usage in different parts of the country. The State Experiment Station or local agricultural officers should be consulted for the latest procedure.

E. R. de ONG

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1. INTRODUCTION

Pest control is primarily natural control. The forces of nature, however, must be supplemented by the use of chemicals if the highest standards of protection are to be achieved. Pests—including insects, plant diseases, weeds, and rodents—are subject to adverse extremes of temperature and humidity, severe rains, flood, drought, high winds, and variable supplies of food. There is constant struggle between groups and among their members. Insect preys upon insect, while the plant-feeders attack every form of vegetation. Plants compete with each other for food, light, and moisture, while insects, fungi, and viruses attack each type of plant. It is only through struggle between the various groups that a natural balance is achieved. Although these forces war continually upon each other, extermination rarely occurs. A small percentage of each group persistently survives. Man must take up the struggle where nature's work ends.

We have but to remember the Irish famine in 1845 and 1846, when for two years the potato crop in that country was almost totally destroyed by late blight, to understand the terrible physical misery and desolation which plant disease can cause if unchecked. Millions of people either died from malnutrition or were forced to emigrate. A similar disaster struck the farmers in portions of the Mississippi Valley from 1874 to 1877 when great hordes of grasshoppers migrated from the Colorado foothills, devouring green vegetation, and forcing the settlers to leave their homes. There have also been the terrible scourges caused by disease-carrying insects—malaria, yellow fever, bubonic plague, and many others less well known. These diseases have been checked in part during recent years but still persist in large areas. Famine and wide destruction from pest attack is now rare, but losses ranging from 5 to 50 per cent of every crop, either in the field or storeroom, are not infrequent.

The farmer or commercial gardener does not willingly sacrifice 10 to 40 per cent of his crop to encroaching weeds, insect damage, or the ravages of disease. Substandard crops are unmarketable or at least unprofitable, but the demand for high-quality food is permanent.

The attacks of pests may be persistent but almost unnoticed—a few mice feeding in the storehouse, termites working in the basement, or a slight attack of rose mildew. Again, the attack may come in sweeping

waves of grain rust, as an outbreak of potato blight, or as an invasion of armyworms. Each form of attack means loss of food or fiber, or an injury to the garden. Cattle, attacked by swarms of biting flies, lose weight or lessen milk flow. A 10 per cent loss of the apple crop results from an infestation of codling moth and apple scab. Millions of bushels of corn are lost annually from the attack of the European corn borer. The world's growing demand for food and the increasingly higher standards of its quality can be met only by recognizing and co-operating with natural forces and the increased use of pesticides, together with trained people to direct the farmer in their use.

Insects

The term *pests,* as commonly used, includes not only the plant-feeding insects and those attacking man and livestock but also many of the lower forms of plants—fungi, bacteria, and viruses—together with the unwanted plants or "weeds" of field and garden, rats and mice of the storehouse, and ground squirrels and prairie dogs of the open fields.

As the growing of food crops became general, the conspicuous attack of insects soon led to their recognition as man's chief competitor. Their abundance, rate of reproduction, adaptability (learned through ages of development), and wide distribution are almost beyond comprehension. The number of known species in the world approaches one and a half million. The number of individuals within one of the larger species is beyond calculation. It has been shown that the offspring of a single aphid or a pair of flies would in one season, if unchecked, cover the earth to a considerable depth. Only the continuous force of natural control agents hold this potential mass of insects from burying the earth.

Very few of this great host of insects are known to be injurious, and many are beneficial. The former, or "pest" types, attack field crops, orchards, forests, gardens, livestock, and humans. The latter include the insect parasites and predators that attack the plant-feeding insects (see Chapter 2); the scavengers of field and forest—termites, flesh flies and springtails—that break down plant material and the bodies of animals; bees, flies, and moths that assist in pollinating the flowers; and even a tiny group that destroy certain weeds.

Injurious Insects. Injurious insects are divided into two groups: those with sucking mouth parts that feed on the fluids of plants and animals, and those with biting mouth parts that consume tissue.

Examples of the first group are the scale insects and their relatives the mealybugs. These are usually fixed in one position as adults, being attached to a leaf or twig by the sucking beak. Common examples are the San José scale and the European fruit scale. Scale insects are rated as

among the most injurious insects, especially to orchard trees, but also to the oak, elm, and certain pines. Aphids (plant lice) attack almost every type of plant. They are even more prolific than scale insects, but are often held in check by their many enemies. Certain of the leafhoppers are carriers of serious plant diseases, such as curly top of beets and tomatoes.

Mosquitoes, because of their wide distribution, annoyance to man and other animals, and carrying of malaria and yellow fever, are generally recognized as dangerous enemies. Stable and horn flies of livestock and the black flies of running streams are also well-known examples of sucking insects. Fleas are pests of both man and beasts throughout much of the world. Besides the annoyance they cause, they are also known as carriers of bubonic plague.

The second group of insects are those with biting mouth parts in either the immature or adult form or both. Grasshoppers, beetles, roaches, and termites have similar feeding habits in both the adult and immature stage. Moths and butterflies are injurious only in the larval stage, because they then have biting mouth parts.

Grasshoppers are extremely destructive; their abundance and record of injury dates from Biblical times to the present. Even today great hordes of these insects develop in dry ground or in the foothills and migrate into the cultivated valleys, eating all vegetation unless checked by the application of insecticides.

Roaches (cockroaches) vie with man for food in his home. Termites are wood-destroyers. The subterranean form infests buildings and timbers exposed on damp soil. The dry-wood termite feeds on the dry lumber of the upper stories of buildings. The codling moth has for many years been the most persistent and injurious enemy of apples and, to a less extent, of pears, and is now attacking other fruits and the English walnut. In addition to moth enemies of growing crops, there are the destructive enemies of stored crops, the Indian-meal moth and the Mediterranean flour moth. These cause severe losses of stored grain and its products and of dried fruit and nuts.

The beetles include many well-known injurious species. The more prominent ones are the leaf-feeding forms, such as the Japanese beetle and the Colorado potato beetle. In addition to those which attack growing crops, there are others that feed on stored products—the grain and rice weevils, the flour beetles, and the saw-toothed grain beetle.

The above examples are only a few of the many insect species that are constantly preying upon crops and domestic animals. Variability in the feeding habits of the insect pests and in susceptibility to insecticides and to natural control presents a puzzling picture both to the chemical manu-

facturer and those directing the use of pesticides. Advances in the types and skillful use of insecticides, together with a better understanding of natural control, will lead to increased consumption of chemicals with a corresponding decrease in crop loss.

Beneficial Insects. Accumulated tree trunks, roots, and leaves would soon cumber the earth if they were not converted into their original compounds and elements. This is accomplished by the combined attack of various insects, supplemented by several types of bacteria and fungi. Dead bodies of insects and larger animals are attacked by flesh flies, burying beetles, hide beetles, and bacteria. The combined attack on vegetative and animal matter results in the formation of humus and various chemical compounds which serve as food for soil bacteria and plant growth.

The bees, both native species and the honey bee, together with many of the flies and moths, are important agents in the cross-pollination of flowers. Pollination (transfer of pollen from the flower's anthers to the pistil) is necessary before fertilization can take place. Many plants require the pollen of another type of plant to complete fertilization; others are self-pollinated. Many varieties of orchard trees and field crops, including alfalfa, clover, and cotton, are cross-pollinated and hence may require the help of pollinating insects. Cross-pollination and the development of hybrids have added much to our agricultural wealth and the beauty of our gardens (Wansell, 1952; Bohart, 1952; Green, 1957).

Weed-Destroying Insects. Two notable instances of weed control by means of introduced insects are those of the Klamath weed, or St.-Johnswort, on the northwestern ranges of the United States and those of the prickly pear cactus in Australia.

Klamath weed thrives where there is abundant winter moisture but the summer is dry. It spreads rapidly where overgrazing weakens the native growth. Desirable grazing plants are now reoccupying the range as the Klamath weed is checked. Besides displacing valuable food plants, the weed itself is somewhat poisonous to livestock. Animals feeding upon it become scabby, sore-mouthed, and unthrifty but are seldom killed (Sampson and Parker, 1930).

Klamath weed (*Hypericum perforatum*) is a native of Europe which was introduced into Australia and our northwestern states. Chemical control of the weed is impractical because the infestation extends over hundreds of thousands of acres of low economic value (Holloway and Huffaker, 1952).

Australia first attempted control of this weed through the use of beetles introduced from Europe. Many years of investigation are required to establish successful colonies because there must first be careful preliminary work to determine the possibility of an introduced plant-feeder at-

tacking valuable crops. Two species of leaf-feeding beetles, *Chrysolina hyperici* and *C. gemellata*, were established in Australia and from this source taken to California. In 1946, preliminary feeding tests on economic plants were completed and the species *C. gemelleta* has since been widely established (Holloway and Huffaker, 1952).

Cactus plants, commonly known as prickly pear, were introduced into Australia about 1787 to be used in culturing the cochineal insect as a source of red dye. Unguarded plants spread quickly in the absence of natural enemies and by 1925 had affected 60 million acres, making much of it valueless. After many introductions of insects from North and South America, the original home of these cacti (Hamlin, 1924), a moth (*Cactoblastis cactorum*) from Argentina was found to be successful in checking the spread. Seven years after the moth was first introduced, the dense growth of prickly pear was destroyed and the land again brought into production. The total cost of introducing and successfully establishing the moth amounted to less than one penny per acre (Bishopp, 1952).

These quiet insect friends are working continuously around us, usually unrecognized, to benefit the soil, increase our crops, and protect us against injurious insects.

Plant Diseases

Disease is a broad term referring to any cause which checks growth and normal functioning. Plant disease may refer to infection by a pathogenic organism or to stunted growth caused by an unfavorable environment. Any agent which seriously disturbs the natural growth of our crops is a factor with which we must contend. Symptoms of disease include wilting, spotted foliage, fruit decay, cankers, and stunted or distorted growth.

In the early stages of agriculture, few crops were grown and an outbreak of disease such as potato blight or wheat rust might destroy the food crop over a large area, becoming a veritable scourge followed by starvation or migration. The increased use of pesticides, resistant crops, and greater variety in cropping now prevent such tragic losses.

The parasitic form of plant disease is caused by infection with organisms such as fungi, bacteria, and viruses. The nonparasitic form is caused by conditions unfavorable to growth or by irregular nutrition. The latter may arise from a lack of food elements and of minor nutrients, such as copper or borax. Drought or "water stress" is a common disturbance, either from a lack of soil moisture or from a soil so dense that roots cannot penetrate it. In the southwestern areas, alkaline soils render large acreages barren or at least unprofitable for production.

Fungi are a form of plant life that lack the green pigment, chlorophyll, by which the higher forms of plants produce sugar. They are forced to

draw food from the plant or other host upon which they feed. The parasitic form of fungi penetrates the cellular structure of leaves, stems, and roots of living plants, absorbing food from the host plant and even breaking down the tissue. Enormous numbers of these fungi occur, for they attack practically every known plant and even living animals. They are known to develop new forms readily, apparently by mutation, as it is called in the case of the higher plants. The new forms, as found among those causing grain diseases, also show variability in susceptibility to chemicals, which increases the difficulty of control. Nonparasitic fungi (saprophytes), which feed on dead vegetation and other substances, are not included among the causes of plant diseases.

Fungi reproduce by means of spores (seed-like bodies), which are released in enormous numbers and drift about in air currents, sometimes being carried great distances. The fruiting bodies from which the spores are released vary in size, shape, and color and are used as a means of identification.

Among the better-known diseases caused by fungi are apple scab, caused by the fungus *Venturia inaequalis*, tomato anthracnose caused by *Colletotrichum phomoides*, peach brown rot caused by *Monilinia fructicola*, and wheat leaf rust caused by *Puccinia rubigo-vera tritici*.

Bacteria are microscopic vegetative organisms which multiply by fission and spore formation. Like fungi they depend upon other organisms or substances for food. Those attacking living organisms are known as *parasites*. One hundred and seventy forms of bacteria are recognized as attacking flowering plants (Riker and Hildebrandt, 1953)—a very much smaller number than that of fungus enemies.

Bacterial infection of plants may occur through the stomata (breathing pores of the leaf), lenticels, opening flowers, or wounds. Bacteria are distributed by the sap stream and through broken tissue. Infection usually causes recognizable symptoms such as retarded growth, wilting, decay, and the formation of galls. Well-known examples of bacterial diseases are crown gall of the stone fruits, caused by the bacterium *Agrobacterium tumefaciens*, and fire blight (pear blight) of the apple and pear. The bacteria that attack living plants are of a selective type, infecting only closely related forms. The condition and state of growth of the host plant may determine the possibility of infection. Fire blight, for example, usually invades during the blooming season and period of greatest growth.

Viruses are to an increasing extent being recognized as the cause of many plant diseases, as well as those of the higher animals and of insects. Only within recent years, and especially since 1900, have virus diseases of plants been identified as causing severe crop damage. This is in part due to a wider distribution of plants and to the extremely small size of

the virus itself, which hinders identification. The largest recognized form of plant virus is smaller than any bacterium now known. It was only through the development of the electron microscope that the particles of certain of the disease-producing viruses could be seen and identified (Bennett, 1953).

Transmission of virus-infected diseases may be caused by means of cuttings from infected plants. The use of buds and scions, even though showing no visible signs of disease, may infect the nurseries and orchards where they are used. Virus diseases are also in many cases carried by sucking insects such as leafhoppers and aphids. A well-known example of this form of transmission is that of the curly top disease of the sugar beet. Other well-known virus diseases are aster yellows, tobacco mosaic, and peach yellows.

Weeds

From ancient times to this day, "the ground has brought forth thorns and thistles." Weeds (which are plants out of place) are a continuous drain upon our growing crops and gardens. They occupy some of our most fertile soil. Under the favorable growing conditions found in many river-bottom lands, weeds have become such pests that, were it not for the newly developed herbicides, the fields would be lost to cultivation. Perennial weeds such as Johnson grass (*Sorghum halepense*) and bindweed or wild morning glory (*Convolvulus arvensis*) are found in our orchards and fields and on the banks of irrigating canals absorbing vital supplies of moisture and plant food. Our grain fields and pastures are often giant flower beds of hardy weeds. The tremendous cost of row crop cultivation is largely due to the necessity of weed control. Any farmer or gardener knows the toll that weeds take and the effort required to control them.

Introduced plants such as the Klamath weed (described by Sampson and Parker, 1930), the Russian knapweed (*Centaurea repens*) of the Pacific Coast, and the prickly pear of Australia are examples of the danger of introduced pests. Such introductions frequently assume serious proportions before their potential danger is recognized, thus necessitating heavy expense in their control.

The value of weeds in certain situations, however, should be recognized. They may check erosion, conserve soil nitrates, or act as cover crops and as soil conditioners. Following brush fires in the western semiarid districts, black mustard, (*Brassica niger*) is sometimes seeded on steep hillsides to aid in holding the soil and to prevent severe erosion during the winter rainy season. Mustard seeds germinate quickly and soon form flat rosettes that are effective in checking runoff. Weedy growth following

harvest absorbs available nitrates and thus prevents their loss by leaching during heavy rains. The weeds, when plowed under, soon decompose and release the nitrates for the following crop. Mallow or cheese weed (*Malva*) is an example of a common deep-rooted weed that assists in breaking up plow sole and withdraws soluble plant food from the subsoil to replenish the surface soil.

Rodents

These animals in various forms range from the Atlantic to the Pacific Coasts and from Canada to Florida. They are in our fields, or storehouses, and our homes. No district is entirely free from them. In addition to our native rats, mice, gophers, ground squirrels, and rabbits, we have three species of rats and the house mouse introduced from the old world. The latter are the ones usually found in our homes and warehouses. The most common and by far the most destructive is the brown or Norway rat (*Rattus norvegicus*). The roof rat (*Rattus rattus alexandrinus*) and the black rat (*Rattus rattus rattus*) are of less importance. The house mouse (*Mus musculus*) is very widely distributed throughout our country (Storer, 1952). A number of native species of mice and the wood rat of the foothills and the mountains are also troublesome. Since the rats and mice found about buildings have been known to carry disease, it is very desirable to exclude them from the grounds.

The plains and foothills of the western states are often populated by numerous forms of ground squirrels and prairie dogs. These are destructive to grain fields and the range alike. The pocket gopher (*Thomomys*) is another common rodent in the western states infesting alfalfa, cultivated fields, and orchards. They feed principally on roots and hence are very destructive.

NATURAL CONTROL AGENTS

Weather

Weather and variable food supplies are two of the most important factors in checking the potential increase of plant diseases and of insects. The latter are also subject to heavy attacks by parasitic and predaceous members and by insect diseases.

Weather comprises rain, snow, dew, atmospheric humidity, temperature, cloudiness, sunlight, wind, and evaporation. One or more of these agents may affect the growth and distribution of insects and the diseases caused by fungi, bacteria, and viruses. Soil temperature and moisture absorption is affected by soil composition and texture, which also influence the plants it supports and soil-inhabiting insects. Weather varies from hour to hour and from day to day, and the averages of these conditions constitutes the

climate. Crop areas are limited largely by the distribution of temperature and moisture (Miller, 1953).

The insect world, dormant during the winter, responds to the warmth of the early spring days. Hibernating moth eggs hatch, and young caterpillars attack the opening leaf buds. Other forms, safely hidden under sheltering leaves, are stimulated into activity, development being regulated largely by temperature. Grasshoppers are especially susceptible to their environment. The eggs, enclosed in a watertight capsule, are laid in hard, dry soil in small openings made by the female grasshopper. These, being near the surface, readily absorb the warmth of the sunshine and may hatch before settled weather arrives. Prolonged rain, snow, and hail chill the tiny hoppers, or they are swept away in floods. Many of the eggs are destroyed by birds and predaceous flies and beetles; if from any cause the capsule is broken, the eggs are exposed to attack by fungi.

Aphid development and growth are directly related to rising temperature and possibly to the degree of moisture present. Reproduction is rapid at maximum temperatures of 60° to 70°F for only a few hours a day, and if this persists for three or four weeks, the increase may be enormous. However, a rapidly rising temperature also stimulates the parasites and predators which attack the aphids and may bring the former out in such numbers as to hold the latter in control. Hence a prolonged cool spring usually results in a heavy population of aphids, until the higher temperatures of early summer check the rate of reproduction or their enemies develop in sufficient numbers to check them.

The attack of parasitic fungi on crops starts in the early spring with rising temperatures and, with continued favorable weather, may develop into a severe outbreak. Dry weather and yet higher temperatures may check an incipient attack before it assumes alarming proportions. Moisture is also a dominating factor in the development of a fungus attack, as well as in maintaining growth. The spores of some fungi require the presence of free or liquid moisture for germination. Others may germinate at about 99 per cent relative humidity, while still other develop at a much lower dgeree of moisture in the air. The contrast between the prevalence of fungus and bacterial diseases of plants in the humid areas of the Atlantic Coast and central West, and their relative absence in the semiarid West, is a further demonstration of the effect of summer rains and high humidity in the former.

Well-known examples of the influence of the weather on the spread of fungus-caused plant diseases are evident in the cases of potato late blight, blue mold of tobacco, cereal stem rust, and apple scab.

Potato late blight attacks in cool, moist weather. The earlier in the season the outbreak begins, the greater the possibility of a severe attack, provided weather conditions are satisfactory and susceptible plants are

present. The very conditions that favor the spread of the fungus may also hinder the application of a fungicide and thus make control doubly difficult. The severity of the attack by blue mold (downy mold) on tobacco is influenced by the prevailing temperature in January. High temperature in this month stimulates early infection, while low temperature retards development. The spread of grain rusts is also recognized as dependent on favorable weather conditions (Miller, 1953). Apple scab is a very serious disease in the northeastern states, where cloudy, rainy weather prevails during the early growth of buds and leaves. By contrast, the apple-growing districts of California are almost free from this disease, except in portions of the fog belt along the Pacific Coast.

Food

The abundance and suitability of food for quick growth and development is second only to the weather in its influence on the insect population. The plant-feeding insects are largely restricted to one, or at least related, species of plants and refuse to attack other forms. There are a number of exceptions to this statement, such as in the cases of the green peach aphid (*Myzus persicae*), which attacks orchard trees and vegetables as well as numerous weeds. Most aphids and other sucking insects, however, are quite definitely limited to a few hosts. The cabbage aphid (*Brevicoryne brassicae*) is found on cabbage, cauliflower, radish, and related species. The squash bug (*Anasa tristis*) attacks squash, melons, and pumpkins. The Douglas-fir beetle (*Dendroctonus pseudotsugae*) prefers the Douglas fir but also attacks big-cone spruce and the western larch. The lodgepole pine beetle (*D. murrayanae*) attacks both the lodgepole pine and the Engelmann's spruce (Essig, 1926).

It should be noted, however, that although many types of insects feed on a variety of plants, there may be differences in the rate of growth and development or in the number of viable eggs laid depending on the food eaten.

Parasitic and Predatory Insects

Parasitic insects are closely restricted to a limited number of species as host insects. This is shown in the biological control of insects, where it has been found that an introduced form of injurious insect is quite rarely attacked by native parasites and predators; rather, these must be imported from the country of origin of the host insect.

Plant Disease Organisms

Fungi, bacteria, and viruses which attack plants are subject to a restricted food supply. The familiar powdery rose mildew (*Sphaerotheca*

pannosa) does not attack the snapdragon, nor is the rust of the latter plant found on the rose. Certain fungi even require alternate hosts for their complete development; for example, the white pine blister rust completes one stage of its growth in a species of wild currant or of gooseberry (*Ribes* spp.). Spores developed on the latter host then carry the infection to the pine tree.

The grain rusts also attack numerous grass hosts but are not found on broad-leaved plants. Blight of the Persian or English walnut is caused by the bacterium *Xanthomonas juglandis*. The severity of its infection varies, some seedlings being quite resistant, while a number of the cultivated varieties are decidedly susceptible. The virus causing curly top of the sugar beet is one of the most severe diseases of that crop, but of little importance to the table beet. The disease is also found on the tomato in some regions and also on a number of common weeds.

CROP LOSSES FROM INSECTS, PLANT DISEASES, AND WEEDS

Despite the natural control forces and the use of pesticides, the annual losses from pests in the United States is estimated at from 11 to 12 billion dollars. Damage from insect attack is placed at 3.6 billion dollars, with an added 400 million dollars for control measures (Staff, 1956). Plant diseases and weeds each add a 3-billion dollar loss, with rodent damage amounting to at least another billion dollars.

Cotton continues to be one of the most seriously crops damaged by insects, not only because of its large acreage, but on account of the number and severity of attacks by cotton-feeding insects. The National Cotton Council reports that in 1953 the loss from cotton insects was 1,430,000 bales (500 pounds each) of cotton and 585,000 tons of cottonseed valued at 261 million dollars. In 1952, however, the loss had been 289 million dollars. A trend in reduction has been evident for a number of years (Staff, 1956). Comparing these losses with that for 1950 of 908 million dollars—the highest in history—shows encouraging progress with the new organic insecticides and the handling of crop residues (Haeussler, 1952).

Grasshoppers of 14 states in 1936 caused an estimated crop damage of 102 million dollars. The value of crops saved by control measures in that same year is placed at 26 million dollars. During the next three years, the annual crop losses from grasshoppers ranged from 46 to 66 million dollars. The value of crops saved by control measures, however, ranged from 102 to 176 million dollars. From 1940 to 1950, inclusive, annual crop damage ranged from 13 to 17 million dollars in 18 to 23 states, but the saving by control measures ranged from 7 to 72 million dollars (Haeussler, 1952).

The European corn borer (*Pyrausta nubilalis*) entered this country about 1915 and by 1939 was causing an estimated annual loss of almost