Chemicals in Crop Production

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Blights, plagues, weeds, and insects always have dogged man's attempts to produce food, feed, and fiber. Sometimes he has been able to control the pests. When he has not been able to do so, his society has suffered or perished.

An example is the late blight in Ireland in 1845 and 1846 that all but destroyed the potato crops on which the Irish were almost wholly dependent as a major source of food. As a consequence, a million people died from starvation or from disease.

Before 1870, Ceylon was preeminent in coffee production. The coffee rust fungus, a serious parasite on wild coffee trees, then invaded the plantations, and yields became so low that coffee was abandoned as a crop and was replaced by tea. South America, particularly Brazil, then became the coffee empire of the world.

In the Philippines, cadang-cadang has become the most serious disease in coconuts, and if control measures are not developed, the livelihood of one-third of the population is hurt.

In the Tropics and other regions of high rainfall, crop plantings are lost year after year because of heavy weed competition despite adequate hand labor. Some crops can no longer be grown in places that have become infested with such perennial weeds as nutsedge, quackgrass, and field bind-

weed. Aquatic weeds, such as Salvinia, threaten production of rice in Ceylon, and transportation on the Nile River is restricted because of the clogging of the river by water-hyacinth.

Plant parasitic nematodes undoubtedly cause crop damage throughout the world, but the extent of their damage is not known. The Incas in Peru had a custom that forbade the planting of potatoes year after year in the same fields. We know now that the golden nematode of potatoes has long been present in Peru, and it is assumed that the presence of nematodes accounted for the long rotations between crops.

History is full of other examples of the ravages of pests. Necessity has forced farmers to adopt chemicals for controlling their plant diseases, nematodes, and weeds, because chemicals generally are more effective and economical than other methods.

Native vegetation in its natural environment will not support large numbers of livestock or people. As they increase, it becomes necessary to replace native vegetation in many places with more productive plants. When native vegetation is disturbed or cultivated fields are abandoned, weeds take over.

To produce crop plants, farmers must utilize all available technology to stabilize the vegetation at a high productive level and prevent it from returning to a less productive level. The control of weeds is a basic, essential, and important aspect of this fundamental ecological process. The costs of weed control, together with reduced crop yields and quality caused by weed competition, constitute some of the highest costs in the production of crops. The control of weeds is one of the most important practices in modern farm management.

For a long time farmers had to rely on crude tools and handweeding.

Rotation of crops was recognized more than a half century ago as a valuable supplement to tillage methods of controlling weeds. It still is important.
The use of chemicals to control weeds also has a long history. Common salt was used a century ago. Between 1895 and 1909 investigators in the United States and Europe studied copper sulfate, salt, iron sulfate, sulfuric acid, and carbolic acid as chemicals for controlling weeds.

The discovery of the selective herbicidal properties of certain dinitro dye compounds by workers in France in the thirties was an important step. No marked acceptance of chemical control methods occurred until about 1948, but early discoveries of selective chemicals, such as the dinitro compounds, demonstrated the feasibility of chemical control of weeds and stimulated continued search for chemicals that would kill some plants and not others—crop plants, that is. We call it selective action.

The discovery of the selective herbicidal action of the phenoxyacetic acids, typified by 2,4-dichlorophenoxyacetic acid (2,4-D), in 1944 had far-reaching effects in weed control. Within 5 years after its discovery, 2,4-D was being used to control weeds on more than 18 million acres of small grains and 4.5 million acres of corn in the United States.

Chemical industries in the United States and elsewhere began then to synthesize and evaluate the weed-killing properties of hundreds of chemicals. As a result, instead of three or four herbicides of commercial significance in the midforties, 181 million pounds of herbicides, representing 6 thousand formulations of more than 100 organic chemicals, were shipped for use in the United States in 1962. In 1962-1963, herbicides comprised 20 percent of the total organic pesticide production in the United States. In 3 years from 1959 to 1962, the value of exports of 2,4-D, 2,4,5-T, and other herbicides from the United States increased from 6.7 million dollars to 22.4 million dollars.

In 1962, of the United States herbicide exports totaling more than 22 million pounds, more than 8 million pounds of herbicides were exported to Canada; 1.7 million pounds to the Netherlands; 1.3 million pounds to Colombia; 1.1 million pounds to the Republic of South Africa; 0.9 million pounds to Venezuela; 0.6 million to Japan, Mexico, and West Germany; and more than 225 thousand pounds each to Costa Rica, Pakistan, Sweden, Spain, the United Kingdom, and Australia.

The use of herbicides in the United States more than doubled between 1959 and 1963. Herbicides were applied on an estimated 85 million acres, or about 20 percent of the Nation’s cropland, in 1962. Most of the grain crops in the United Kingdom are treated with herbicides. More than 70 percent of the summer cereals of West Germany are chemically treated for weed control.

The chemical control of weeds (and other pests) hinges on the property some substances have of affecting only certain species. Selective toxicity—the basis for synthesis and formulation of effective herbicides that kill weeds and leave the crop unharmed—often is achieved through techniques of application that bring the herbicides in closer contact with weeds than with crop plants.

Sometimes the selectivity operates through differential behavior and biochemical reactivity of weeds and specific crop species to particular herbicides. Scientists in England, the Netherlands, and West Germany, as well as those in the United States, have contributed to a better understanding of the bases for selective action of herbicides.

An example of a selective herbicide is propanil (3,4-dichloropropionanilide), which is effective against barnyard grass (Echinochloa crusgalli) and other annual weed grasses and sedges in ricefields. Rice, a no-till crop, is not injured by propanil at any stage of growth, but propanil is most effective on the weeds soon after they emerge. Increases in yield after treatment with propanil range from 325 to 5,300 pounds of rough rice an acre. Average
Chemical weed control can improve farm efficiency. Gains reported in five States were $1,000 to $2,000 pounds. Chemical control also lowers costs of production, reduces the amount of hand labor, and increases mechanized production. Chemical control of weeds in strawberries has reduced costs from $200 an acre for handweeding to less than $30 an acre. The use of herbicides in cotton reduces the cost of weed control from $24 an acre to about $8 an acre and reduces man-hours from 35 to 12.

We have estimates that chemical weed control in such non-till crops as wheat, oats, barley and on grazing lands has raised their productivity 10 to 20 percent. Labor for hoeing and pulling weeds in many tilled crops, such as corn, soybeans, sugar beets, sugar cane, cotton and vegetables, is no longer available at costs the farmers can afford.

Chemical weed control has facilitated mechanized production. When poisonous weeds and brush are killed, productivity of pastures and range lands is greater and leads to improved management of livestock and better milk and meat.

Herbicides also can control weeds that clog irrigation and drainage canals and interfere with the use of ponds, lakes, and streams. All this is not an American monopoly. Other countries use agricultural chemicals and have done much to improve them. For some countries, chemical weedkillers are or can be a way to increase production and make more efficient use of labor.

In the heavy rainfall areas of tropical zones in Central and South America, chemical weed control has increased productivity of rice, maize, and other food crops. Herbicides are being used increasingly in African nations to control brush on rangeland and to clear waterways of water-hyacinth. New Zealand and Australia make extensive use of herbicides to control weeds and brush on grazing lands.

We believe herbicides will be used more extensively throughout the world to help improve farming efficiency and productivity of crops.

**Blight, Smuts, Scabs, Wilts, Mildews, Ruts, Mosaics, and Other Diseases**

Blight, smuts, scabs, wilts, mildews, rusts, mosaics, and other diseases are caused by fungi, bacteria, and viruses. Every crop plant is affected by one or more of the diseases.

They affect seeds, seedlings, stalks, roots, leaves, tubers, fruits, and flowers. They kill many plants outright and may reduce crop production to zero. The quantity and quality of the crop may be severely curtailed by fungal, bacterial, and viral attacks in the field and after harvest.

Many virus diseases are systemic in the plant. Many may be carried by insects. Some viruses must spend a part of their cycle in the insect host before the insect is capable of transmitting them to another plant. Others are transmitted merely by mechanical contact. Bacteria can be disseminated by splashing rain, insects, and man through contact. Fungi are disseminated in many ways—most of them as spores, which are windborne or carried in drops of splashing water. Others migrate through the soil through normal growth or may be disseminated by rain and irrigation water. Some organisms attack a particular host; other parasitic organisms have a wide range of host plants.

Plant diseases are controlled by the use of resistant varieties, proper crop management, and the use of chemicals. Plant pathologists and plant breeders are constantly developing resistant varieties. Frequently the organisms themselves mutate and form new and more virulent races, and plant breeders must then develop varieties which will be resistant to these new races.

The biological control of plant diseases may moderate their destructive effects, but the use of artificial biological control methods has not been entirely successful. Losses caused by some of the insectborne virus diseases, such as the curlytop disease, which is spread by the beet leafhopper, have been reduced by spraying the
overwintering sites with an insecticide before it migrates into beetfields in the spring.

Chemical control and development of resistance are the chief measures to control plant diseases. We have no effective way to control bacterial plant diseases, although the antibiotic streptomycin has been used with success against fireblight of apples and pears. A search has been underway for some time for an effective viricide.

The value of bordeaux mixture was discovered in France about 1882. It became a mainstay in plant disease control for many years. Copper sulfate, mainly bordeaux mixture, was used on potatoes to the extent of 20 million pounds a year by the time of the Second World War and almost that much was applied to apples to prevent bitterrot and blackrot. Two major companies that supply the American market with bananas have spent an estimated 18 million dollars a year for bordeaux mixture to control the Sigatoka disease of bananas in the Tropics. The disease is so severe that banana plantations must be sprayed 15 to 17 times a year.

There has been a shift away from the use of copper for controlling Sigatoka to the use of oil sprays. This has resulted in a tremendous reduction in our export of copper sulfate. In 1957, for example, 56.6 million pounds of copper sulfate were shipped from the United States to the four banana-producing countries, Guatemala, Honduras, Costa Rica, and Panama, whereas in 1962 only Honduras imported as much as 70 thousand pounds, a drop from the 20,272,000 pounds Honduras imported in 1957.

Now there is a shift back to bordeaux mixture or to the organic fungicides, since continued use of the oil sprays appears to result in smaller bunches of bananas in many areas.

The organic mercury compounds were introduced into the United States from Germany as seed treatments in 1913. Previously most cereal seed and potato seed diseases were treated with formalin. Much of the early research and development on the use of organic mercurials as seed-treating materials was done in Germany. It has been estimated that 15 million pounds of organic mercurials have been used annually in the United States for treating seed and that more than 60 million acres were planted with treated seed. Farmers used to rely on copper, sulfur, and mercury compounds, but greatly improved organic fungicides have been developed since 1945.

Some of them evolved from compounds used in making automobile tires. A patent was issued in 1934 for an alkyl dithiocarbamate as a fungicide, but it was almost 10 years before dithiocarbamate fungicides became available to the public. During this period, the fungitoxicity of chloranil (tetrachloro-p-benzoquinone) was demonstrated, but it was considered too expensive at first. Later, however, it was shown that from an investment of 70 cents an acre required to treat pea seeds, a return of as much as 21.25 dollars could be realized at 1951 prices.

Nearly all seed peas in the United States are treated.

The nitropyrazoles, the amino triazoles, the s-triazines, the quinolines, and the phenols also have been widely studied as fungicides, but only a few have come into widespread commercial use. Most fungicides have been developed as protective chemicals. Applied to the plants before spores of the causal fungus are deposited, they can prevent the development of disease if good coverage by the fungicide is obtained.

Fungicides are used to control plant diseases in many countries. They are applied to the seed to prevent rotting or to foliage as sprays or dusts to protect the plant by destroying the spores of the fungi before they penetrate the foliage and cause infection.

The dollar value of exports of fungicides from the United States has been climbing rapidly. The value of fungicides exported was 8 million dollars in 1959 and 26 million dollars in 1962.
In western Africa, especially in Nigeria, the black pod disease of cocoa (caused by *Phytophthora palmivora*) is a serious pest. This disease is practically universal wherever cocoa is grown commercially. Spraying with copper compounds of various kinds, including bordeaux mixture, is the principal control measure employed. Extensive control programs for this disease are underway in Nigeria and spray applications often are made every month.

Most fungicides now in use are inefficient, and large amounts are needed to insure protection. A constant search is being made in a number of countries for more efficient and effective fungicides. There are no effective materials for controlling most root-rotting fungi or fungi that invade the conductive tissues of plants and cause them to wilt.

Therapeutant-type chemicals, which readily move through the plant from one part to another, are easily applied, and are low in cost, are needed. They should prevent the entry of the organisms into the plants or kill them after they enter or (in the case of wilt diseases) offset their wilt effects.

Also needed are fungicides that can be applied to seeds and be absorbed by them and become systemic.

Many of the newest organic fungicides have proved satisfactory for the control of plant diseases in the Tropics. There the potential demand is great, but their widespread use is limited by the relatively low purchasing power of many farmers. Discovery and introduction of more effective and economical chemicals for use against plant diseases will contribute greatly to meeting world problems of food production by insuring a consistent production of healthy crops.

Nematodes also carry several viruses that cause plant diseases. They also incite some fungal and bacterial diseases and cause them to be more severe.

Damage caused by heavy nematode infestation often may reduce yields as much as 75 or 100 percent. Crop losses due to nematodes may amount to 1 billion dollars a year in America.

For many years root knot nematodes and the cyst-forming nematodes were thought to be the worst nematode groups, but nematologists in the South-eastern States demonstrated the severity of damage that can be caused by ectoparasitic nematodes such as the root lesion nematode.

Evidence that species of the root lesion nematode, *Pratylenchus*, are causing substantial crop losses in many parts of the world is accumulating rapidly. For example, the tea industry is of vital importance to Ceylon—providing 60–70 percent of its exports—and research has demonstrated that losses due to this nematode are large.

To grow many crops successfully under present conditions, some type of nematode control is necessary.

Control by nonchemical means, such as crop rotations, fallowing, and growing resistant varieties, undoubtedly has been practiced widely by growers for a long time and still is an important method of control.

Control by chemicals, or nematocides, has become of increased importance in the production of crops. An estimated 100 million pounds of nematocides were used in the United States in 1961, principally on tobacco, pineapple, and vegetable fields.

Although we have known of the damage done by nematodes, high costs and difficulties formerly restricted the use of the available materials and methods, and soil treatment was confined to high-value crops in the greenhouse and nursery. Steam, carbon bisulfide, chloropicrin (tear gas), and methyl bromide were the methods and materials available. Treatments cost 300 to 500 dollars an acre and entailed hazards and inconveniences. Nema-
tode control consequently was achieved through the development of a few resistant varieties and crop rotation.

A significant development was the discovery in the forties of the value of a mixture of 1,2-dichloropropane and 1,3-dichloropropene (D-D mixture) for controlling nematodes in pineapple plantings. D-D mixture, a byproduct of the petroleum industry, is relatively cheap, and land can be treated for one-tenth of the cost of older materials. Ethylene dibromide, another relatively inexpensive material, later was shown to be an effective nematocide. Because these two nematocides could be used effectively and practically on a field scale, farmers rapidly adopted them. Both are widely used in the United States, but low temperatures in Europe apparently restrict treatment to summer.

The treatment of all pineapple plantations in Hawaii with a nematocide before planting has become a standard practice. The major uses for nematocides elsewhere in the United States are for treating land to be planted to tobacco, cotton, and vegetables.

In Rhodesia root knot is widely prevalent even in the veld areas not previously cropped. Tobacco growers there practice nematode control through a combination of crop rotations and the use of nematocides. Yield increases of 400 to 500 pounds an acre are obtained when nematocides are used. Of the 224 thousand acres of tobacco in Rhodesia, 105 thousand were fumigated in 1962.

NEMATOCIDES have been used on only a fraction of the farming sections where they could be applied profitably. Better, more efficient nematocides are needed for general use.

A nematocide generally useful for controlling nematodes in planting stock is needed by nurserymen and by plant quarantine authorities responsible for preventing the introduction of plant pests. Attention should be given to the development of chemicals and methods for treating nematodes on roots several feet below the soil surface and also for controlling nematodes at the surface.

Possibilities include low-phytotoxic chemicals that can be applied to the plant leaves, where they are translocated to the roots so that they can kill or repel nematodes in the root zone. Also, the synthesis and use of possible attractant or chemisterilant chemicals in the soil might interrupt nematode feeding and reproduction activities either in the absence of host plants or in their presence and thus result indirectly in their control.

F. W. Went’s discovery in 1928 of naturally occurring auxin in plants and P. W. Zimmerman’s discovery in the thirties that certain synthetic chemicals can change the growth of plants in many ways stimulated interest in discovering and developing chemicals to regulate plant growth. These chemical regulators are unlike the fertilizer chemicals, which provide nutrients for plant growth. Instead, they regulate the many physiological processes that take place during growth, fruiting, and maturation.

Now we know of chemicals that stimulate or retard the growth of plants; induce or retard sprouting, rooting, and flowering; increase resistance to cold, heat, and drought; increase or decrease the set of fruit; hasten defoliation; and cause other responses in plants.

Growth-regulating chemicals are applied in minute amounts to control the growth and behavior of crop plants. Naphthaleneacetic acid is used to treat apple trees in the fall to prevent fruit drop and thereby improve the quality. Only one teaspoonful is used on 1 acre of orchard, which produces approximately 200 thousand apples. If this chemical were not used, the grower could lose 50 percent or more of the crop.

Potatoes store best at relatively low temperatures, but the ideal storage is costly and not always possible to maintain. Potatoes sprout profusely and shrivel and deteriorate when they
Sprouting is prevented safely through the use of regulating chemicals. Growth regulators are widely used to induce rooting of the vegetatively propagated plants, with no danger of poisoning animals and people. Some chemicals are used by nurserymen and florists to produce a dwarfing effect. Others can stimulate growth and elongation.

One growth-regulating chemical, gibberellic acid, is used to increase the size and quality of grapes. It has an extremely low animal-toxicity level. Chemicals that cause leaves to fall also are used to prepare cottonfields for mechanical harvesting. Leaf fall normally is associated with physiological aging, but it may be induced also by water stress, certain disease organisms, insect attacks, nutrient deficiencies, light frosts, and other factors, such as mechanical injuries, which injure but do not kill the leaf blades. Chemicals now provide a means of producing defoliation timed to the producers' needs.

Three general types of chemicals fall within this category—defoliants, which induce leaf fall (abscission) but do not kill the plant; desiccants, which cause severe leaf kill, with little or no leaf fall but fast drying of attached leaves; and regrowth inhibitors, which retard or prevent new leaf growth immediately after defoliation or desiccation. Harvest-aid chemicals are used on several million acres of cotton harvested by machine in the United States, but improvements in their reliability and use are being sought.

Further knowledge of the physiological factors within the plant that control abscission and growth is being developed through research that deals with biochemical mechanisms involved in the abscission process; studies of chemical penetration and translocation in the plant and of the distribution and fate of the chemical after it is absorbed; and investigations on cultural and environmental control methods to make chemicals more dependable in action. Desiccants are also widely used before mechanical harvesting of a number of seed crops.

Numerous problems, such as tolerance of crops to frost, drought, and high salt content in the soil, may be solved through the use of chemicals. Tremendous crop losses occur each year as a result of low-temperature injury to economic crop plants. Compounds on the horizon appear capable of increasing the tolerance of plants to low temperatures, particularly in the production of fruit and vegetables. These chemicals may delay flowering until frost hazard is over or may actually increase cold hardiness.

It may be possible that regulating chemicals can be used to lower the water requirements of plants in places of critical water supply and thus conserve water. Regulating chemicals which will increase the tolerance of crops to salt injury and thereby permit their growth in soils with high salt content probably can be developed. Regulating chemicals are being developed that will control the size and shape of plants so as to facilitate the use of machines for harvesting them.

Retardant-type chemicals are in prospect to regulate the size of trees and shrubs along roads and streets that obstruct the visibility of automobile drivers and interfere with electric and telephone wires. Maleic hydrazide is used commercially to stunt grass along highways and thus reduce the number of mowings required for maintenance.

Many crop plants must be harvested during relatively short periods to obtain a high-quality product. There are possibilities of developing chemical methods of extending the time during which these crops can be harvested, thus facilitating harvest, reducing production costs, and improving the quality of the product for the consumer.

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