Historic, archived document

Do not assume content reflects current scientific knowledge, policies, or practices.

4C

Circular No. 862

March 1951 • Washington, D. C.

UNITED STATES DEPARTMENT OF AGRICULTURE

Some Plant Responses to Certain Insecticides in the Soil

By ARTHUR C. FOSTER, *senior pathologist, Division of Fruit and Vegetable Crops and Diseases, Bureau of Plant Industry, Soils, and Agricultural Engineering, Agricultural Research Administration*¹

CONTENTS

	Page		Page
Summary	1	Greenhouse experiments—	
The problem of chemical residues in soils	4	Continued	
Nature of the inquiry	5	Results with parathion	25
Review of literature	5	DDT-treated soils exposed to weathering	27
Asenical residues	5	Materials and methods	27
Synthetic organic substances	6	Results	28
DDT	6	Field experiments	30
BHC	8	Materials and methods	30
Other substances	9	Results	31
Greenhouse experiments	10	Greenhouse study of orchard soil	33
Materials and methods	10	Materials and methods	33
Analysis of data	13	Results	34
Results with DDT	14	Discussion of toxicity of insecticides	35
Responses of species and varieties	14	General	35
Influence of soil conditions	17	DDT	36
Responses to components of DDT	19	BHC	37
Results with BHC	21	Other substances studied	38
Results with chlordane	21	Conclusions	38
Results with toxaphene	23	Literature cited	39

SUMMARY

Extensive greenhouse and field experiments on the effects of DDT, BHC, and certain other insecticides upon plant growth when mixed with the soil have been in progress at the Plant Industry Station at Beltsville, Md., since late in the summer of 1945. This circular summarizes the results obtained primarily in studies with DDT but includes some data on BHC, chlordane, toxaphene, and

¹ The author acknowledges the assistance of Victor R. Boswell, principal horticulturist and assistant head of the Division, in connection with the planning of the work, the analysis of data, and the preparation of the manuscript for publication; of Drs. H. L. Haller, R. C. Roark, R. H. Carter, L. Koblitsky, C. A. Weigel, and R. D. Chisholm, of the Bureau of Entomology and Plant Quarantine, with chemicals, chemical analyses, and helpful counsel.

parathion. The period covered by this report extended through May 1949.

Most of the work involved the growing of a large number of crops and varieties from seed sown in replicated small plots of treated soils in benches in the greenhouse and noting the effects of treatment on germination, stand, and growth of young plants. The numerous crops were grown in the greenhouse in rapid succession; most of them were harvested and the average plant weights were determined about a month to 6 weeks after planting.

Studies of effects of DDT were conducted on four soils in the greenhouse: Chester loam, Sassafras sandy loam, Evesboro loamy sand, and an acid muck from New Jersey. Other substances were studied only on Chester loam.

Treatments consisted of single applications of carefully measured amounts of the test substance thoroughly mixed with the soil of each plot. Typical treatments involved 0, 25, 100, 400, and 1,000 pounds per acre of DDT and of toxaphene; 0, 100, 200, and 400 pounds of BHC; 0, 25, 100, and 400 pounds of chlordane; and 0, 1.5, 3.0, 6.2, 12.5, 25.0, 50.0, and 100.0 pounds per acre of parathion. All materials were applied on the basis of weight per unit area of soil approximately 6 inches deep in the beds.

Two years' data are presented on a field experiment with DDT established in 1947 and chiefly involving replicated plots treated with DDT at 0, 25, 50, 100, and 200 pounds per acre.

Species and varieties differ markedly in their sensitivity to DDT in the soil. Abruzzi and Rosen rye and Stringless Black Valentine bean are among the most sensitive observed. They are consistently and significantly depressed in growth by 100 pounds or more of DDT per acre on mineral soils. Pound for pound, DDT was much less toxic on the acid muck than on the mineral soils used. Effects upon such very sensitive species were produced by as little as 25 to 50 pounds of DDT in carefully controlled experiments. Other beans, beets, most legumes, cucurbits, and tomatoes were moderately to highly sensitive. Most grains, including corn, members of the cabbage family, and Irish potatoes were moderately to highly tolerant. Two varieties of sweet corn showed no reduction in growth on soil containing 1,000 pounds per acre of DDT. It will require years to learn the relative tolerance of all the more important crop varieties.

In general, DDT had but slight effect upon germination and stand, even among species that are sensitive after emergence. At concentrations of 400 and 1,000 pounds per acre, however, stands were significantly depressed.

DDT showed no decrease by chemical analysis or decline in toxicity on mineral soils over the 4-year duration of the work reported here.

The o,p' isomer of DDT appeared about four times as toxic as the p,p' isomer in limited tests. The 20 pounds of the former that is present in 100 pounds of technical DDT depressed growth as much as the 75 pounds of the latter.

Technical BHC is generally harmful to germination and stand of all crops tested at 400 pounds per acre. Only the more sensitive crops were harmed at 100 and 200 pounds. It appeared

more toxic to later growth than DDT, pound for pound, and no highly tolerant crops were noted, as were observed with DDT. Two hundred pounds per acre of technical BHC was highly toxic to subsequent growth of all crops tested, although it was more toxic to some than others. One hundred pounds was harmful to a majority of crops tested.

Highly purified gamma isomer of BHC, more than 99 percent pure, applied at the same rates as the technical grade, had no effect on germination and stand. It did, however, appear to depress growth of most crops tested as seriously as did the technical grade, pound for pound. In practice only about one-eighth as much pure gamma isomer needs to be used as if technical BHC is applied for insect control.

Less extensive tests indicated that chlordane was even more harmful to germination and stand than BHC soon after putting it into the soil in amounts of 100 pounds per acre or more. Most vegetable crops tested were significantly depressed in stand by as little as 25 pounds per acre. Corn appeared tolerant. Honey Dew melon appeared especially sensitive. In subsequent growth, 100 pounds per acre or less appeared to be without consistent effect, but 400 pounds reduced growth of most cucurbits, tomato, and beet markedly. Beans, members of the cabbage family, sweet corn, and cotton appeared somewhat tolerant.

Limited tests on toxaphene, all within 4 months of its mixing into the soil, indicated that amounts of 100 pounds or more per acre depressed somewhat the germination of all vegetable crops tested except sweet corn. Only tomato and watermelon were affected significantly. In subsequent growth cucurbits and tomato were significantly depressed in growth while corn and beans were not at 400 pounds per acre of toxaphene.

Also in rather limited tests, relatively heavy doses of parathion appeared to have a slight but temporary depressing effect on germination and stand. In a few tests run soon after application, tomato, muskmelon, and snap bean were depressed in growth by 50 or 100 pounds per acre. Crops planted some months after soil treatment were quite unharmed.

Extensive data on persistence of these substances in the soil are presented only for DDT. DDT was found to be very highly persistent in its toxic effects on plants, no measurable decrease in toxicity occurring after 4 years. BHC is less persistent than DDT, but it is believed to be persistent enough to accumulate temporarily to a harmful degree in the soil under some conditions of practical use. After 3 years about half of a 100-pound application had disappeared.

Chlordane is said to be less persistent than DDT. Its persistence as an insecticide suggests, however, that it is persistent enough to accumulate to some extent in the soil. Toxaphene has been shown to be susceptible to breakdown by soil organisms, and is believed to be relatively unstable in the soil, therefore, it is less likely than some other insecticides to accumulate harmful residues. Parathion is evidently unstable and is used in such small amounts per acre that it is not now an object of concern as a potential harmful residue in the soil.

THE PROBLEM OF CHEMICAL RESIDUES IN SOILS

The remarkable new insecticide DDT (dichlorodiphenyl trichloroethane) first became available for agricultural use in 1945. Because of its apparent stability and its unusual potency as an insecticide the question immediately arose as to whether its prolonged and repeated use on crops might result in the accumulation of harmful residues in the soils of fields receiving DDT dusts or sprays for insect control.

The same question soon arose about technical benzene hexachloride, hereinafter called BHC, of which the insecticidal fraction usually consists of 10 to 12 percent of the gamma isomer of 1,2,3,4,5,6-hexachlorocyclohexane. Because of the strong and persistent odor of technical BHC a further problem of the impairment of food properties through "off" flavors of some commodities was presented. In the 5 years after World War II numerous other new and potent insecticides, fungicides, and herbicides rapidly appeared in commerce. Some of these are known to be relatively unstable, and they are therefore not expected to create a soil-residue problem. Others, such as TDE, are claimed to have persistent insecticidal qualities in the soil and are therefore presumed relatively stable and likely to accumulate upon repeated use.

The harmful effects of arsenical residues in the soils of certain orchards in Washington (23, 24, 43)² and cottonfields in South Carolina (2, 11, 12, 33), after many years' use of lead arsenate or calcium arsenate, suggested that similar troubles might be encountered sooner or later if DDT, BHC, chlordane, or some toxic decomposition products of them, or some impurity, should prove to be highly stable in the soil. Plantsmen, entomologists, and manufacturers of insecticides all have been, therefore, interested in several practical questions, some of which follow.

Is DDT toxic to certain plants when mixed with the soil in which the plants are to be grown? If it is toxic, how much can different kinds of plants tolerate in the root zone without showing any measurable effect? Once DDT reaches the soil how long will it persist? Is it so stable that small annual residues will accumulate to produce a harmful effect after a number of years? If it will accumulate to a harmful degree, will a given accumulation be more harmful in some soils than in other soils? Will it accumulate faster in some soils than in others, assuming that equal amounts reach the specified soils each year? If a residue that is harmful to certain crops should accumulate, can anything be done to correct the trouble? What component part of the DDT mixture of different chemical substances is most toxic to plants?

For each of the new chemicals having established value as insecticides, fungicides, herbicides, or other agricultural use it is important to know whether or not they are toxic to plants, either when applied to the plant or when incorporated into the soil. It is also important to know whether or not they persist in the soil, whether they are broken down by organisms, or whether they are leached from the soil. Research on such questions is important

² Italic numbers in parentheses refer to Literature Cited, p. 39.

with all chemicals that are applied to crops. In this circular the data obtained from the summer of 1945 to the summer of 1949 are summarized for several series of tests with DDT, BHC, chlordane, toxaphene, and parathion.

This circular is primarily a progress report of work done on response of several vegetable and field-crop plants to a number of insecticides in the soil, at the Plant Industry Station, Beltsville, Md., from late 1945 through the summer of 1949. The greater part of the work was upon DDT. Some data were obtained in similar studies upon BHC, chlordane, toxaphene, and parathion, with some few observations on specific isomers and impurities of DDT. New studies involving additional substances were initiated in the summer of 1949.

NATURE OF THE INQUIRY

The parts of these investigations that are reported herein have two major objectives: (1) To determine how specific crop plants are affected at each of a wide range of concentrations of a particular chemical in the soil, supposing that chemical to be stable enough to accumulate from repeated applications over a period of years; and (2) to get some idea of the persistence of whatever effect is produced on plants by the addition of a known amount of a chemical to a soil.

From the very nature of the problem it is hardly possible to obtain many partial answers in a short time. Large amounts as well as small amounts of chemicals have been applied in the many treatments to determine which crops may be highly tolerant. Although it is recognized that adding large amounts of DDT, for example, to the soil at one dose may not produce the same plant response as applying one-tenth as much each year for 10 years, it is the most practical way of learning promptly how plants will react to such an amount of DDT in the soil. In view of the apparent chemical stability of DDT, BHC, and some other compounds the large amounts added in certain of these experiments are of considerable practical importance. If their apparent stability is confirmed, large and harmful residues of some substances may accumulate in as short a time as 5 years under some conditions of heavy use, as on orchards, on cotton, and on some truck crops grown under intensive succession-cropping systems.

REVIEW OF LITERATURE

ARSENICAL RESIDUES

Crop injury associated with accumulation of arsenic spray or dust residues in orchard or field soils has been studied by many workers since the early 1900's.

Headden (21), Vandecaveye and others (43), Jones and Hatch (23, 24), Morris (31), Snyder (41), Blodgett (4), and Vincent (44) have all dealt with toxic accumulations of arsenic in orchard soils of the West. Their several findings showed that arsenic accumulations in the surface soil were largely responsible for increasing difficulties in the growing of certain cover crops, although the deep-rooted orchard trees remained unharmed. Most

vegetable crops failed or were injured when planted on orchard sites from which the trees had been recently removed after many years of spraying with lead arsenate. Peach and apricot trees planted on old apple orchard land sometimes showed typical arsenic injury. Arsenic toxicity in such soils slowly decreased over a period of many years after arsenic applications were discontinued.

Paden and Albert (33), Cooper and others (11, 12), Albert (2), Reed and Sturgis (36), and Fleming and others (15) all have shown that some annual crops are injured by arsenic residues in the soil following the use of lead arsenate or calcium arsenate for insect control on cotton and other crops other than orchard trees. Although many years' residue accumulation or massive doses of arsenical insecticides to the soil are required to produce crop injury under most conditions of use, that is not always true. On some light soils that are low in iron content as little as 50 to 150 or up to 300 pounds per acre of calcium arsenate has impaired growth of rice, soybeans and other legumes, and other crops. The grain crops and potatoes are usually fairly tolerant to arsenic, but most vegetable crops are sensitive. In view of all the evidence it is probable that many less striking instances of harm from arsenic residues have escaped attention or have been wrongly ascribed to other causes.

SYNTHETIC ORGANIC SUBSTANCES

Since 1945 many reports have appeared concerning the effects of several of the newer organic insecticides on plants when those substances became mixed into the soil. The preponderance of reports showing injury is due partly to the fact that numerous investigators purposely included large dosages of the materials being studied in order to find the maximum amounts of each that a given plant would tolerate in the soil without harm. In general, the reports show clearly that these new insecticides are definitely harmful to plants when present in the soil in large amounts. They also show that some are injurious in amounts that are not very large and which may be encountered under conditions of practical use—or misuse.

The reports cited here refer to an extremely wide range of crops, soils, methods, materials, and even purposes for which the respective studies were made. No two studies were conducted exactly alike, and, therefore, none are very closely comparable. It is not feasible here to present enough details about each one to permit the reader to make his own evaluation or interpretation of the results mentioned. Only the general trends of the findings are given, with citations, in an effort to suggest the pattern of plant responses that is beginning to emerge from the heterogeneous mass of gradually accumulating evidence.

DDT

Patrick and others (34) reported that dry seeds may be dusted or coated with dry DDT without impairing the viability or vigor

of the seeds. Brooks and Anderson (7), however, found that heavy coating with DDT and a "sticker" before planting reduced germination and stand of lima bean about 40 percent and one variety of sweet corn about 33 percent.

Smith and Wenzel (40) and Wilson and Choudhri (45) found DDT to have very little, if any, significant effect on numbers of soil micro-organisms or on nitrifying or ammonifying power of the soil.

Most workers found one or more species of plants to be injured at one or more of soil dosages of DDT with which they worked.

Chapman and Allen (8) noted retarded germination of corn, beans, and cucumber at 6.25, 25, and 100 pounds per acre in sawdust. Corn was later stimulated, but cucumbers were injured. Goldsworthy and Dunegan (18) found progressive reduction in number and weight of strawberry plants produced by mother plants in soil with 12 up to 100 pounds of DDT per acre; p,p' DDT was about one-third to one-fourth as toxic as technical DDT (16). Young and Gill (47), using 10, 25, and 100 pounds of DDT per acre, found rye, tomato, and strawberry most sensitive, and collard, eggplant, and onion less so. Morrison and others (32) reported bush and pole beans were seriously stunted by 138 pounds per acre of DDT. Using no more than 25 pounds of DDT per acre, Fleming (14) noted injury to strawberry, tomato, lima bean, snap bean, onion, and spinach. Certain herbaceous ornamentals were injured, but when the 25 pounds of DDT per acre was applied to the surface of soil in which woody perennials were already well established, they were uninjured. Many vegetables also were uninjured by 25 pounds. Roberts (38) injured germination of corn and cotton by adding 0.1 gram of DDT per 8-inch pot of soil before planting.

Goldsworthy (17) observed progressive reduced growth of 1-year-old peach trees in sand culture containing from 25 to 1,000 pounds of DDT per acre, but in soil 200 pounds or more was required to retard growth significantly. Kulash (26) stated that 200 and 400 pounds per acre retarded germination and early growth of corn. Allen and others (3) observed no significant effect of DDT up to 100 pounds per acre on tobacco, cotton, or cowpeas, but rye was seriously reduced in yield by 40 and 100 pounds.

Investigators who found no injury or other pronounced plant response to the amounts of DDT used in their respective studies are listed in the following two paragraphs, together with brief notations on the nature or conditions of their work.

Wilson and Choudhri (45) conducted a small laboratory test, using tumblers of treated soil containing 250 to 10,000 pounds of DDT per acre to grow plants for 35 days during midwinter with the aid of artificial light. No effect of DDT was noted on alfalfa, red clover, soybean, or vetch.

Lane and others (28), Kulash (27), and Riherd (37), working with various amounts of DDT per acre in the soil, found no injury to corn up to 10 pounds, to lima beans up to 20 pounds, and to potatoes up to 40 pounds. Lhoste and Ravault (29) found no effect on wheat up to 300 kilograms per hectare. Grayson

and Poos (20) worked 200 pounds per acre of DDT into the top 2 inches of a light soil and immediately planted corn, cotton, soybeans, and peanuts. Germination of the seeds was not affected.

BHC

BHC in the soil has proved more toxic and toxic to more plants than DDT. Except at very low concentrations it has generally interfered with germination.

Brooks and Anderson (7) coated corn and bean seed with BHC in a "sticker"; seeds carrying more than 4 ounces technical BHC per bushel were seriously injured. Four pounds per acre dusted into the row on the seed before covering them depressed germination of corn and lima bean. Wilson and Choudhri (46) found 3 p. p. m. of technical BHC in soil toxic to red clover, soybean, and hairy vetch; 30 to 1,000 p. p. m. caused serious injury. Clausen and Gunthart (10) indicated that 130 kilograms of technical BHC per hectare was harmful to clover, grasses in sod, and newly transplanted cherry trees. According to Bonnemaison (5) 20 to 48 kilograms per hectare was toxic to oats, barley, wheat, beets, and potatoes. Aguilar and Grison (1) claimed some potato varieties were not injured, while other varieties were variously reduced in yield as much as 89 percent by 20 kilograms per hectare of technical BHC. Kostoff (25) suggested that BHC might result in varietal deterioration if seed is saved from plants grown in treated soil because it induces chromosome irregularities as well as growth abnormalities. Riherd (37) obtained only a 9 percent stand of corn that was dusted with 5 percent gamma BHC and 95 percent pyrophyllite, in the row, over the seed before covering with soil. The check gave 52 percent stand. Grayson and Poos (20) worked 100 pounds of technical BHC per acre into the surface 2 inches of a light soil and immediately planted corn, cotton, soybeans, and peanuts. Corn was nearly completely killed, and 44 to 80 percent of the other plants died. Kulash (27) reported 3.2 to 32 pounds of technical BHC per acre retarded corn germination. Allen and others (3) found 17 pounds per acre of technical BHC annually for 2 years harmless to tobacco, cotton, cowpeas, and rye, but 50 or 80 pounds in 1 year seriously injured tobacco and reduced stands of cotton the first year; differences were not significant the second year. It appeared to stimulate cowpeas. Morrison and others (32) reported approximately 220 pounds of technical BHC destroyed a majority of the vegetable crops planted, suppressed weeds for several months, and that few vegetables—chiefly crucifers—escaped injury. Corn, cucurbits, and legumes were largely killed. Stitt and Evanson (42) applied 1.5 and 6.0 pounds of technical BHC (36 percent gamma) and 0.5 and 2.0 pounds of pure gamma BHC to the soil. The higher dosages of each reduced stands of cucumber and turnip; and 6.0 pounds of technical reduced bean, beet, and chard germination. All test crops were affected. Sakimura (39) found 25 to 100 pounds of technical BHC per acre to injure peas, with increasing severity as the dosage increased. Chulski (9) mixed 5, 10, 20, and 40 pounds per acre of technical BHC in the upper 3 inches

of soil in pots. Corn was nearly destroyed by the higher dosages, but radish and cucumber were undamaged. McLeod (30) found 0.1 gram of technical BHC in 2 pounds of soil caused abnormal germination, injury, and poor growth of onion.

Wilson and Choudhri (46) found no significant effect of 300 p. p. m. of technical BHC on the micro-organisms of the soil. Smith and Wenzel (40) showed, however, in a far more comprehensive study that 50 and 250 p. p. m. of BHC in soil were strongly and persistently fungicidal; also that the nitrifying bacteria were killed off for the 98-day duration of the study.

A number of reports indicated no adverse effects of BHC in the particular tests involved. Kulash (27) observed no effect of 1.6 or 3.2 pounds of technical BHC per acre on corn. Bourne (6) reported that 8 pounds of technical BHC per acre applied in fertilizer to open rows before dropping and covering seed pieces of sugarcane hastened the emergence of shoots. Jameson and others (22) stated that 8 to 15 pounds of technical BHC per acre is harmless to grain crops. Pepper and others (35) found 80 pounds of technical BHC per acre to have no effect on growth or yield of potatoes, although it did impart the BHC odor and flavor to the tubers. Roberts (38) found that 4 grams of 4.5 percent technical BHC powder per hill of muskmelons caused no injury, although the same dosage per 8-inch of pot soil injured germination of corn and cotton. Goldsworthy (16) noted no harmful effects of technical BHC on strawberries, up to 400 pounds per acre, but a possible stimulative effect from 12 to 300 pounds.

OTHER SUBSTANCES

Smith and Wenzel (40) found that chlordane at 100 and 500 pounds per acre was somewhat fungicidal in the soil but less strongly or persistently than BHC. It temporarily suppressed nitrite formers, then stimulated them, and temporarily suppressed nitrate bacteria. It was less toxic than BHC to the soil bacteria. Toxaphene at 100 and 500 pounds was easily attacked as a source of food by the micro-organisms and therefore considered non-persistent in the soil. Allen and others (3) detected no response of tobacco, cotton, cowpeas, or rye to 20 pounds of toxaphene per acre annually for 2 years.

Bourne (6) reported that 4 pounds of chlordane per acre in fertilizer applied in the open row before dropping and covering sugarcane seed pieces stimulated shoot emergence. Morrison and others (32) found that 28 pounds per acre of chlordane stunted lima beans slightly. Fleming (13) stated that 20 to 25 pounds per acre of chlordane had no effect on a wide range of grasses, although 40 to 80 pounds caused some temporary injury. Doses of 10 and 20 pounds were harmless to rye, soybean, and corn. Germination of about 20 vegetables was unaffected by 20 pounds per acre of chlordane, but subsequent growth of squash was depressed by 5 pounds, celery by 10 or more, and many others by 20 pounds per acre. Some varieties of strawberries were retarded by 10 pounds, and some not by 20. Of 20 annual flowers tested at 5 to 20 pounds all were unharmed but poppy and snap-

dragon, which were injured at 5 pounds, and pinks at 20 pounds. The 10-pound treatment had lost no insecticidal value in 1 year, but the 5-pound treatment began to lose at 10 months. Stitt and Evanson (42) reported that 35 pounds per acre of chlordane reduced stands of cucumbers, beans, beets, chard, and turnip, while 5 pounds was without effect.

Goldsworthy and Wilson (19) found that parathion from 6 to 100 pounds per acre progressively stimulated growth of strawberries.

Kulash (27) recorded no effect on corn of 4 pounds per acre of chlordane, 1 or 2 pounds of parathion, or 10 pounds of toxaphene.

Goldsworthy (16) noted no harmful effect of toxaphene or of chlordane, from 12 to 400 pounds per acre, upon strawberries.

GREENHOUSE EXPERIMENTS

MATERIALS AND METHODS

Unless otherwise specified the DDT used in the earlier years of this work was of the technical grades as manufactured and supplied by the Geigy Co., Inc., and the E. I. Du Pont de Nemours & Co., Inc., in late 1945. It contained approximately 75 percent p,p' DDT, 20 percent o,p' DDT, 5 percent p,p' TDE, 0.05 percent bis(p-chlorophenyl) sulfone, and trace amounts of other closely related chemicals. Preparations of later manufacture have since been used that are higher in content of p,p' DDT and less toxic to most plants than the material received in 1945. The highly purified isomers and the isolated impurities, bis(p-chlorophenyl) sulfone and p,p' TDE, were furnished by the courtesy of Drs. H. L. Haller and R. C. Roark, of the Bureau of Entomology and Plant Quarantine; Grasselli Chemicals Department, E. I. Du Pont de Nemours & Co., Inc., and Hercules Powder Co., Wilmington, Del.; and the Geigy Co., Inc., New York.

The technical BHC contained approximately 12 percent of the gamma isomer and was obtained from Hooker Electro Chemical Co. in 1946. The other substances on which data are presented were obtained in the year indicated from the respective firms that originated them: Chlordane from the Velsicol Corp. in 1946 and Julius Hyman & Co. in 1948; toxaphene from Hercules Powder Co. in 1946; and parathion from American Cyanamide Co. in 1948.

Except for minor variations the several greenhouse studies (fig. 1) on DDT were conducted as outlined briefly in the following paragraphs.

Repeated tests were run on four different soils, Chester loam, Sassafra sandy loam, Evesboro loamy sand, and a New Jersey muck. Each soil completely filled to a depth of 6 inches one or more benches approximately 4 feet wide and 30 feet long. The benches were divided crosswise by wooden partitions into nine plots of equal size of which one received no DDT and the other eight received DDT at the rates of 25, 100, 400, and 1,000 pounds per acre in duplicate. Treatments were randomized within benches, and soils were randomized among benches in each of two

FIGURE 1.—Plot arrangement of tests of toxicity of certain chemicals in the greenhouse, Beltsville, Md.

large compartments of the greenhouse. Additional untreated plots were on other beds in the same greenhouse section.

As the benches were filled with soil the amount of DDT required for each plot was weighed in the form of a 25 percent pyrophyllite powder. The powder was dusted evenly over the soil of the plot and mixed with it by cutting and turning with hand shovels 20 times.³ After each crop was removed the soil was again thoroughly mixed and turned, but no more DDT was added. At the time of applying the DDT all plots received a 5-10-5 commercial fertilizer at the rate of 1,000 pounds per acre. The fertilizer was thoroughly mixed with the soil incidental to the mixing of the DDT. The check plot received pyrophyllite at 800 pounds per acre.

Single plots usually consisted of 1 row each of about a half dozen species or varieties, the number of rows differing somewhat among crops, depending upon the space requirements of the plants to be grown. Depending also upon the size of the species to be grown, either 50 or 100 seeds were planted per row across the bench. The plots were watered, weeded, and otherwise cared for as uniformly as possible, in accordance with ordinary greenhouse practice. No DDT or other chlorinated

³ For some of the later established plots the DDT or other chemical was mixed with the soil in a rotating drum before the soil was put into the greenhouse benches.

hydrocarbon insecticide was used or required for insect control on any of the plots.

The seedlings or small plants were usually harvested from an entire bench or set of benches at the time the plants on the check plots were large enough to become a little crowded in the rows. Total number and weight of seedlings per row per plot were recorded, and notes were made of any visible symptoms associated with treatment. Original stand counts were made soon after seedling emergence and at time of harvest. With the exception of potato tubers all plants were lifted from the soil with a hand trowel, the soil was shaken from roots, and the entire plant weight was taken. This procedure facilitated examination of the roots for any effects of the DDT treatment.

Any given operation for a single species or variety in an entire bench was carried out by a single operator to minimize error, but despite precautions some instances of inequalities in watering or localized attacks by pathogenic organisms caused undesirably large experimental errors. To correct partially for loss of plants by damping-off, the yields were expressed as weight per plant.

Several tests were conducted by methods as described above to compare the relative toxicity of the principal constituents of technical DDT: o,p' DDT, p,p' DDT, p,p' TDE. These substances were each applied to duplicate plots at rates per acre corresponding to the approximate amounts present in 100 pounds and in 400 pounds of technical DDT. (See p. 20 and table 4 for the amounts.) Other duplicates received a corresponding amount of bis(p-chlorophenyl) sulfone from 100 pounds of DDT, and a last treatment involved the sulfone and the o,p' DDT equivalent to 400 pounds of DDT per acre.

The tests on substances other than DDT were confined to the Chester loam, and were on a far less extensive scale. Usually only two benches were used for a given series of rates per acre of one substance or to a group of substances at a constant rate per acre. Although many crops were grown, there were fewer repeated runs of a single species or variety. There also were duplicates on only one soil instead of on each of three or four soils. Thus, the data on these other substances are only exploratory and are less precise than those on DDT.

Methods of growing the test crops were essentially the same as for the DDT work.

The several isomers of different substances and the technical grades of toxaphene, chlordane, and BHC were applied by spraying onto the soils in acetone solution with an atomizer, in successive portions as the soil was mixed and re-mixed. Check soils were sprayed with acetone alone. Parathion was applied as a 25 percent dust in talc.

Varietal responses of some crops were marked enough to be significant and to justify specific mention regarding their reaction to DDT. Although numerous varieties of several crops were grown on the several treatments with the several substances, most of the varieties of a single crop were too few, tested too few times, or showed too little difference among them to justify

a presentation of the results on a varietal basis. Therefore, for the purpose of this circular, the data are presented in most tables by kinds or species only. Instances in which specific varieties appeared notably different from others are mentioned in discussing the results.

The varieties of the several crops shown in eight of the tables were as follows:

In tables 1 and 2.—Barley, Poland; lima beans, Henderson Bush, Fordhook 242, and Fordhook; snap beans, Blue Lake, Stringless Black Valentine, and Tendergreen; beet, Detroit Dark Red; broccoli, Italian Green Sprouting; cabbage, Early Jersey Wakefield and Golden Acre; sweet corn, Country Gentleman and Golden Cross Bantam; cotton, Acala P-18; cucumber, A & C; muskmelon, Hale Best and Honey Dew; pumpkin, Connecticut Field; summer squash, Yellow Summer Crookneck; winter squash, Warty Hubbard; tomato, Marglobe and Rutgers; spinach, Long Standing Bloomsdale; turnip, Purple Top Globe; watermelon, Florida Favorite and Tom Watson; potato, Katahdin.

In table 4.—Snap beans, a breeding line later released as Topcrop, Blue Lake, Stringless Black Valentine; broccoli, Italian Green Sprouting; cabbage, Golden Acre; sweet corn, Country Gentleman and Golden Cross Bantam; cotton, Acala P-18; pea, Thomas Laxton; peanut, Virginia Runner; pumpkin, Cushaw and Mammoth (actually a squash); squash, Yellow Summer Crookneck; tomato, Rutgers and Marglobe; turnip, Purple Top Globe.

In table 5.—Barley, Poland; lima bean, Fordhook and Sieva; snap bean, Tendergreen and Kentucky Wonder; beet, Detroit Dark Red; cabbage, Golden Acre; sweet corn, Country Gentleman and Golden Cross Bantam; cotton, Acala P-18; cucumber, A & C; muskmelon, Hale Best and Honey Dew; pumpkin, Connecticut Field; summer squash, Yellow Summer Crookneck; winter squash, Warty Hubbard; tomato, Marglobe; watermelon, Florida Favorite and Tom Watson.

In table 6.—Lima bean, Henderson Bush and Fordhook; snap bean, Tendergreen; beet, Detroit Dark Red; cabbage, Golden Acre; sweet corn, Golden Cross Bantam and Country Gentleman; cotton, Acala P-18; cucumber, A & C; muskmelon, Hale Best and Honey Dew; pumpkin, Connecticut Field; squash, Yellow Summer Crookneck; tomato, Marglobe; watermelon, Florida Favorite and Tom Watson.

In table 7.—Snap bean, Kentucky Wonder; sweet corn, Country Gentleman; summer squash, Yellow Summer Crookneck; winter squash, Warty Hubbard; tomato, Marglobe; pumpkin, Connecticut Field; watermelon, Florida Favorite and Tom Watson.

In tables 8 and 9.—Lima bean, Jackson Wonder, King of the Garden, Fordhook, Fordhook 242, Florida Butter Speckled, Henderson Bush, Peerless; snap bean, Stringless Black Valentine; cucumber, A & C, Chicago Pickling, National Pickling, Clark Special, Improved Long Green, Cubit, Straight Eight, Marketer; muskmelon, Powdery Mildew Resistant No. 5 and No. 45; peas, Perfection, Laxtonian, Pride, Alderman, Laxton Progress, Commando, Hundredfold, Thomas Laxton; peppers, California Wonder, Early California Wonder, Ruby King, World Beater, Pimiento; rye, Abruzzi, Rosen, Balbo; squash, Acorn; tomato, Marglobe and Rutgers.

ANALYSIS OF DATA

When several species had been grown simultaneously within plots the data for each species were analyzed separately, treating each bench as two randomized blocks at a single location. Four soils in as many benches were involved in a large number of the tests planted or harvested on a single day. There were rarely any replications of soils with a given species in any one test, but most crops were grown on each of two benches of a given soil at some time during the course of this series of tests.

It is neither necessary nor practicable to present here the results of each of the hundreds of separate variance analyses

involving the several thousand observations recorded. For the several repeated tests of various species, through the range of seasons and on different soils, the trend of the results can be shown dependably in summary tables. To indicate the confidence that may be placed in any line of averages in the tables of combined results the number of tests involved in each line is shown, except in table 3, together with the number of single tests within which significant differences were evident. In the tables of less extensive accumulations of data, the least significant differences are shown for each set of comparisons among treatments. Overall variance analyses of appropriate parts of several tables in their present form were run to derive a generalized value for the response—or lack of response—of a whole group of plants to DDT or other chemical in the soil.

RESULTS WITH DDT

RESPONSES OF SPECIES AND VARIETIES

Marked differences in response to DDT in the soil were shown among species and among varieties within species. This feature of the results to date is one of the most striking that has emerged. Because there is a large number of cultivated varieties of each of the crops tested no exhaustive studies of varieties could be made within species. Enough has been done, however, to show without a doubt that some varieties of some species are far more sensitive than others.

To emphasize the differences that exist among species the reactions of the more sensitive and of the less sensitive species are shown in separate parts of tables 1 and 2. First, it will be seen in table 1 that DDT in the mineral soils affects the stand of plants very little. A barely significant reduction is evident, from an average of 54 percent for the sensitive species on the controls to 50 percent on the 400-pound treatments. The further reduction to 45 percent on the 1,000-pound treatment confirms the generally small and relatively unimportant effect of DDT upon the germination process. In later experiments where conditions were more favorable for pre- and post-emergence damping-off, DDT did have a marked effect on stands of beans.

In these experiments the germination and stand of the three kinds of beans, of beets, and of spinach appeared to be depressed more than the other crops shown that are rated as generally sensitive. At the same time there seems to be no marked effect of DDT on germination at concentrations below 400 pounds per acre. Among the less sensitive crops observed there was no significant effect of the DDT on germination and stand.

The growth responses shown in table 1 are far more striking than the effects on germination and stand. For the average of the 11 crops rated as sensitive the application of 400 pounds of DDT in the fall of 1945 reduced plant growth nearly one-half during the succession of crops grown over a period of 2 years. The average reduction on the 100-pound plots was significant, and the reduction for several individual crops—snap beans, lima beans, spinach, beet, and tomato—was especially severe. On the

TABLE 1.—Stand and early growth of 17 crop plants on mineral soils¹ in the greenhouse, treated with different amounts of DDT, Beltsville, Md., 1945-46

SPECIES, OF WHICH VARIETIES TESTED WERE DEFINITELY SENSITIVE

Crop	Tests	Stand in response to pounds per acre of DDT shown					Growth in response to pounds per acre of DDT shown					Duplicate tests, showing significant differences in growth	General rating: ²
		Percent					Grams						
		0	25	100	400	1,000	0	25	100	400	1,000		
Bean (lima)	Number	71	69	66	55	53	8.4	6.6	4.8	3.8	3.9	6	HS
Bean (snap)	8	82	74	76	68	63	9.6	8.8	6.5	4.6	3.7	6	HS
Bean (soybean)	3	26	32	39	21	12	15.6	13.7	9.1	10.3	13.3	1	S
Beet	10	45	43	46	35	25	3.8	3.4	4.1	1.4	.7	4	HS
Cotton	4	16	39	41	36	40	11.4	9.6	6.7	9.3	6.4	1	S
Cucumber	7	55	59	56	51	43	13.6	11.6	14.9	10.1	6.5	4	S
Peanut	2	24	35	38	36	27	20.0	12.3	12.9	9.4	9.1	1	S ³
Pumpkin	7	88	85	88	85	82	23.1	18.0	19.4	7.8	5.6	6	HS
Spinach	6	44	37	33	26	18	4.3	4.2	2.7	1.1	.6	3	HS
Squash, bush	10	69	68	68	63	58	32.6	30.8	24.1	20.1	13.7	8	HS
Tomato	4	76	74	79	70	68	3.7	3.2	1.8	1.0	.7	3	HS
Mean ⁴	-----	54	56	57	50	45	13.3	11.1	9.7	7.2	5.8	-----	-----

SPECIES, OF WHICH VARIETIES TESTED WERE LESS SENSITIVE OR TOLERANT

Broccoli	9	90	80	86	86	86	6.9	6.4	7.1	6.3	5.0	2	SS
Cabbage	9	59	59	61	60	55	6.0	5.8	5.7	4.8	3.7	1	SS
Corn, sweet	5	90	90	89	87	88	14.6	18.0	17.4	16.2	15.0	1	T
Muskmelon	7	61	59	56	51	48	3.2	3.5	4.6	5.2	3.3	0	T
Turnip	5	68	53	62	56	62	9.5	10.1	10.1	11.6	8.1	0	T
Potatoes (tubers)	1	-----	-----	-----	-----	-----	123.7	137.5	109.7	120.1	74.7	1	SS
Mean ⁵	-----	73	68	71	68	68	8.0	8.7	8.9	8.8	7.0	-----	-----

¹ The mineral soils used were Chester loam, Sassafras sandy loam, and Evesboro loamy sand.

² HS = highly sensitive, S = sensitive, SS = slightly sensitive, T = tolerant.

³ One other test suggested tolerance, but stands were quite variable and results not significant.

⁴ Least significant difference between means: Of stands, 5.7 percent; of growth, 2.7.

⁵ Excluding potatoes. Difference at 19 to 1 not significant for stand or growth.

TABLE 2.—Stand and early growth of 16 crop plants on muck soil in the greenhouse, treated with different amounts of DDT, Beltsville, Md., 1945-46

SPECIES, OF WHICH VARIETIES TESTED WERE DEFINITELY SENSITIVE ON MINERAL SOIL

Crop	Tests	Stand in response to pounds per acre of DDT shown					Growth in response to pounds per acre of DDT shown					Duplicate tests, showing significant differences in growth
		0	25	100	400	1,000	0	25	100	400	1,000	
		Percent	Percent	Percent	Percent	Percent	Grams	Grams	Grams	Grams	Grams	Number
Bean (lima)	2	65	68	64	58	54	10.1	9.3	9.6	8.0	6.9	1
Bean (snap)	4	91	90	94	86	86	14.0	14.1	14.0	12.3	7.5	2
Bean (soybean)	1	66	36	48	55	44	18.5	21.3	21.8	20.2	17.0	0
Beet	4	77	55	63	62	64	2.7	3.7	3.1	3.9	4.4	1
Cotton	1	48	51	48	52	52	15.7	15.1	17.8	19.1	18.6	0
Cucumber	4	62	68	72	67	62	18.4	16.8	15.2	16.0	15.9	0
Peanut	1	48	41	42	44	46	17.7	18.9	19.4	19.8	16.7	0
Pumpkin	2	78	80	80	81	78	31.9	33.7	33.8	29.1	13.4	0
Spinach	2	33	47	49	41	38	4.2	4.8	3.5	3.9	3.9	0
Squash	4	54	70	66	61	64	32.6	30.8	24.1	20.1	13.7	0
Tomato	2	58	60	65	62	64	7.0	4.6	4.4	3.1	2.2	1
Mean ¹		62	60	63	61	59	15.7	15.7	15.2	14.1	10.9	

SPECIES, OF WHICH VARIETIES TESTED WERE LESS SENSITIVE OR TOLERANT

Broccoli	4	82	88	89	87	85	8.1	6.8	7.2	8.0	8.4	0
Cabbage	4	59	59	61	60	55	9.1	8.8	9.2	9.5	9.8	0
Corn, sweet	1	86	89	93	91	91	34.5	31.0	35.6	36.5	44.3	0
Muskmelon	4	69	62	77	67	57	3.8	3.9	3.6	4.7	6.4	0
Turnip	2	62	69	58	65	73	13.5	13.2	15.0	12.5	13.0	0

¹ Least significant difference at the 5-percent level, for growth, 3.3.

average the plant weight of those sensitive crops was reduced about 25 percent by the mixture of 100 pounds of DDT per acre in the soil.

Examination of the roots of seriously affected plants in the several experiments with any form of DDT showed them to be short, often thickened and stubby, and abnormally numerous. It appeared that toxic concentrations of DDT tended to stop root growth and stimulated the starting of new roots that in turn were retarded, whereupon still others made their short excursions into the toxic soil.

It should be pointed out that these results are probably more extreme than usually will be found under field conditions with equal amounts of DDT per acre in the soil. In these greenhouse studies the soil was only about 6 inches deep in the benches. Repeated working of the soil in the benches could not, therefore, further dilute the concentration of the DDT by mixing it with still deeper layers or larger volumes of soil as would be done in plowing and working a field soil to a depth of 8 inches or more. Furthermore, under field conditions, deep-rooted plants probably would grow through the DDT-soil mixture into soil without DDT and be less affected. It is also recognized that harvesting these plants at an early stage of growth affords only a rough index of the effects of DDT upon those parts of the respective crops normally harvested at maturity. The results do show, however, that some crops are sensitive to DDT mixed with certain mineral soils in amounts no greater than 100 pounds per acre and are seriously retarded in growth by as much as 400 pounds. The data further indicate the relative susceptibility of several crops to DDT in the soil.

A later section (pp. 27 to 30) contains data on a few crops grown to maturity on different soils containing different amounts of DDT.

The short list of less sensitive crops in table 1 shows no significant differences in growth among the several DDT treatments. The figures for cabbage at the 1,000-pound level suggest sensitivity, but 1,000 pounds is a very heavy treatment. In only one of the nine tests with cabbage were significant differences found, and in that instance the effect of the 400-pound treatment was not especially marked.

In a single test Irish potato appeared rather highly tolerant, showing no significant reduction in tuber yield at 400 pounds or less of DDT per acre. The 1,000-pound treatment, however, reduced the yield about 40 percent.

INFLUENCE OF SOIL CONDITIONS

Table 2 contains the data for plants grown on muck soil treated with DDT at the same rates as the mineral soils shown in table 1. Much greater amounts of DDT can be mixed with muck soil without affecting sensitive crops than in the instance of the mineral soils observed. On muck there was no effect of the DDT treatments on germination and stand of either the less sensitive or more sensitive crops. At amounts of 25 to 400 pounds of

DDT, inclusive, there was no significant reduction in growth. In only 9 of the 27 separate tests of sensitive species on muck did significant differences appear, and they occurred only at the high levels of DDT.

It should be pointed out that several tests were run on a second lot of muck of unknown origin that contained a large amount of silt and that had a pH of approximately 6.0. All DDT-sensitive plants grown on this muck showed a somewhat greater response to DDT than when grown on the New Jersey muck on which most of the tests were run. Even at the 1,000-pound level growth of sensitive crops on the unlimed New Jersey muck was as good as on the average of the mineral soil controls. The average of the two muck soils receiving 1,000 pounds of DDT (table 2) showed little more relative reduction below the muck controls than the 100-pound treatment on mineral soils showed below the mineral soil controls.

The five crops that are rated as less sensitive (according to their response on mineral soils) grew as well or better on the DDT-treated muck as on the muck controls. The sweet corn appeared to be benefited somewhat by the 1,000 pounds of DDT on the muck, but the difference was not significant. This suggestion of stimulation of sweet corn by DDT in the soil appeared also in the field work to be described later. Although there are significant increases in growth of sweet corn accompanying increasing amounts of DDT above the control in the mineral soil, there are no significant increases above the 25-pound treatment.

Although the DDT on the plots of acid muck from New Jersey showed no measurable effect on plant growth during the first two series of tests, the soil was so highly acid that certain acid-sensitive crops such as beets and spinach could not be grown satisfactorily. Therefore, over a period of months dolomitic limestone was added in successive moderate amounts, gradually raising the pH of the muck from approximately 4.5 to 5.7. There were a few indications that this rise in pH was accompanied by some increase in toxicity (or emergence of toxicity) of DDT at the highest levels of treatment. The number of tests with the same varieties on this soil both before and after liming was, however, too small to give conclusive results on this point. On the silty muck soil having the higher original pH (6.0) several levels of DDT appeared more toxic than on the other muck. It is not now possible to say to what extent pH might have affected these results and to what extent other, and unknown, factors affected them.

At the termination of about 2 years the soils were transferred from the greenhouse to a coldframe. The two muck soils were mixed and lime was added to raise the pH to a range of 6.3 to 6.6. It will be seen in the section describing the coldframe crop data that the limed, DDT-treated muck mixture was rather highly toxic to the plants at the 400- and 1,000-pound levels of DDT.

Table 3 was prepared from the same data that were used in the preparation of tables 1 and 2. The figures for the several species in a group of plants were combined for each DDT treatment of each of the four soils. The table shows that among the three

TABLE 3.—*Effect of kind of soil on plant response to DDT in soil in the greenhouse, Beltsville, Md., 1945-46*SPECIES, OF WHICH VARIETIES TESTED WERE DEFINITELY SENSITIVE¹

DDT applied per acre (pounds)	Percent stand and plant weight on kind of soil shown							
	Chester		Sassafras		Evesboro		Muck	
	Stand	Weight	Stand	Weight	Stand	Weight	Stand	Weight
	<i>Percent</i>	<i>Grams</i>	<i>Percent</i>	<i>Grams</i>	<i>Percent</i>	<i>Grams</i>	<i>Percent</i>	<i>Grams</i>
0	58.3	9.86	53.0	13.16	66.3	10.74	63.2	12.92
25	56.5	8.08	50.5	11.64	71.0	8.92	62.5	15.42
100	59.3	7.34	54.8	8.71	67.5	8.53	64.9	14.73
400	53.0	4.47	43.5	6.91	60.0	4.16	62.5	13.57
1,000	49.8	3.32	40.1	5.63	48.2	3.44	60.6	10.35

SPECIES, OF WHICH VARIETIES TESTED WERE LESS SENSITIVE OR TOLERANT²

0	62.1	4.46	53.9	13.64	62.6	10.15	63.9	11.01
25	56.8	4.40	55.0	10.13	64.1	8.90	62.0	10.46
100	58.8	5.80	55.3	9.80	62.6	9.28	67.9	11.39
400	54.1	4.99	49.9	12.23	60.1	9.09	64.5	11.54
1,000	55.1	3.73	46.8	11.26	53.5	6.93	64.8	12.49

¹ Means based on 92 tests involving lima bean, snap bean, beet, cucumber, pumpkin, summer squash, spinach, tomato, soybean, and cotton.² Means based on 70 tests involving broccoli, cabbage, carrot, muskmelon, onion, turnip, and corn.

mineral soils the growth on the Chester loam and the Evesboro loamy sand was similar for any one treatment. The Sassafras sandy loam, however, not only produced larger plants on the control plots than did the other two mineral soils, but also on the respective treated plots. The successive reductions in growth accompanying the increasing amounts of DDT were slightly less severe for the species tested on the Sassafras than those on the Chester and Evesboro soils. This difference in response on the mineral soils is not explained. It seems reasonable to suggest, however, that the much lower toxicity of DDT on the muck soil may be due to the adsorption of the DDT by the organic colloids of which the soil is largely composed. Soil acidity may also be a factor.

RESPONSES TO COMPONENTS OF DDT

Table 4 shows that among those species classified as less sensitive to DDT none showed significant responses to the amounts of o,p' DDT, p,p' DDT, p,p' TDE, or bis(p-chlorophenyl) sulfone added to the soil in these tests. Among the sensitive species soybeans, cotton, and peanuts showed only slight and nonsignificant results. Reference to table 1 shows that, although these three plants are listed among the sensitive species, their responses to technical DDT were less marked and consistent than the other sensitive ones.

In general, it appears that the sensitive species are depressed as much or slightly more by the 20 percent of o,p' DDT present in technical DDT as by the 75 percent of p,p' DDT that it contains. The p,p' TDE present in 400 pounds per acre or less of the technical material appeared to have no effect whatever, but of course larger amounts might be toxic. The results of sulfone plus o,p'

TABLE 4—Effect on 12 crop plants of isomers and impurities of technical DDT when added to soils in the greenhouse at Beltsville, Md., 1949, at rates equivalent to the quantity of the substance normally present in technical DDT

Plant weight per isomer and impurity of technical DDT when grown in soil at rate of—												
Crop	Test	None (check)	100 pounds per acre					400 pounds per acre			2 pounds sulfone, plus 80 pounds o,p' DDT	Least signi- ficant dif- ference
			20 pounds o,p' DDT	75 pounds p,p' DDT	5 pounds p,p' TDE	½ pound sulfone	80 pounds o,p' DDT	300 pounds p,p' DDT	20 pounds p,p' TDE			
Bean (snap) Bean (soybean) Cotton Pea Peanut Pumpkin Squash Tomato Mean 2	Number	Grams	Grams	Grams	Grams	Grams	Grams	Grams	Grams	Grams	Grams	Grams
	8	7.36	6.88	5.51	7.77	6.80	4.64	4.20	8.23	4.46	0.93	
	2	11.40	11.70	8.00	11.20	10.20	9.20	11.40	12.90	8.50	(1)	
	3	5.18	3.61	3.43	4.84	3.88	4.65	2.65	4.07	3.75	(1)	
	4	3.19	2.89	2.58	3.14	3.48	2.22	2.94	3.11	1.84	(1)	
	2	13.60	12.10	12.80	12.40	12.20	13.10	12.20	13.40	10.60	(1)	
	2	21.50	17.30	23.50	22.90	21.40	14.60	22.90	24.60	12.00	7.19	
	3	18.20	15.60	14.60	19.10	19.70	5.00	8.50	16.40	4.90	5.00	
	3	5.36	2.63	4.75	6.04	5.07	1.47	5.65	4.53	.89	2.46	
	Mean 2	10.72	9.09	9.40	10.92	10.34	6.86	8.81	10.91	5.87	---	
Broccoli Cabbage Corn Turnip Mean 2	5	1.89	1.67	1.53	1.97	1.52	1.72	1.96	2.21	1.95	(1)	
	5	3.89	4.18	3.53	3.92	3.86	2.73	3.13	3.04	2.99	(1)	
	3	8.83	9.70	9.27	9.63	8.73	12.37	9.93	8.47	---	(1)	
	4	8.21	6.62	5.82	7.94	7.16	8.82	8.19	7.65	6.93	(1)	
	Mean 2	5.71	5.54	5.04	5.87	5.32	6.41	5.80	5.34	---	---	

1 No significant differences.

2 Means not weighted.

DDT for 400 pounds suggest that the effects of these two constituents together are roughly equal to the sum of their separate effects.

RESULTS WITH BHC

Table 5 shows technical BHC to be outstandingly different from DDT in three important respects when compared on a pound-for-pound basis of total substance in the technical grade of the materials: (1) Technical BHC appears more harmful to germination and stand than is DDT; (2) all crops tested appear to be seriously injured by 200 pounds per acre or more of technical BHC, while several crops appear to be relatively unaffected by that amount of DDT; and (3) large amounts of BHC—200 pounds per acre or more—appear far more toxic to growth than corresponding amounts of DDT.

In these tests most of the cucurbits appeared very sensitive to technical BHC, the complete inhibition of a stand of plants of some of them at the 400-pound level contributing largely to the low average of all crops tested, at this level. Honey Dew muskmelon is especially sensitive.

DDT at 1,000 pounds per acre reduced the average growth of sensitive crops little more than half and tolerant crops by no significant amount. Technical BHC, however, at 400 pounds virtually eliminated all growth, and 200 pounds reduced it to a fourth of the control on the average. Beans and cabbage may be less sensitive than most crops, but the limited number of tests here preclude close comparisons.

The highly purified gamma isomer of BHC (not the commercial grade of gamma BHC) in a separate set of tests appeared to have no adverse effect upon germination and stand up to 400 pounds per acre. Pound for pound, it appeared to be as toxic to young plant growth, however, as did the technical form. On the average of the limited tests made 100 pounds of pure gamma isomer reduced growth about 25 percent below the control, and the technical grades did the same. At 400 pounds, both forms reduced growth to about 8 to 9 percent of the control. Beans and cabbage appeared less sensitive than the other crops, although they too were very hard-hit by rates of 200 pounds or more.

Although the gamma isomer appears as toxic, pound for pound, as the technical BHC, only about one-eighth as much of it needs to be used to control most pests against which BHC is used. Unfortunately, these studies reveal nothing on the effect of BHC, technical or gamma, upon the food or feed value or flavor and taste of crops grown on soils containing appreciable quantities of it. This problem has suddenly become a very pressing one. These exploratory studies do, however, show that an accumulation of 100 pounds per acre of technical BHC may be expected to reduce growth and yield of many crops significantly; at 200 pounds per acre growth was reduced to only one-fourth of the control.

RESULTS WITH CHLORDANE

Exploratory tests with chlordane (1,2,4,5,6,7,8,8-octachloro-2,3,3a,4,7,7a-hexahydro-4,7-methanoindene) suggest that, except

TABLE 5.—*Response of seedlings to BHC mixed with soil in the greenhouse, Beltsville, Md., 1946-47*

TECHNICAL BHC

Plant grown	Germination and stand of plants in response to pounds per acre BHC shown					Mean weight per plant in response to pounds per acre BHC shown					Duplicate tests
	0	100	200	400	L.S.D.1	0	100	200	400	L.S.D.1	
	Percent	Percent	Percent	Percent	Percent	Grams	Grams	Grams	Grams	Grams	
Bean, lima	45	44	44	37	2.5	11.8	11.4	5.0	2.6	1.19	2
Bean, snap	41	31	44	31	(2)	7.8	8.2	3.7	1.0	1.98	3
Beet, garden	40	47	62	6	(2)	2.3	.8	.1	<.1	.40	1
Broccoli, sprouting	73	86	87	0	12.2	1.8	3.6	1.2	0	.63	1
Cabbage	72	63	75	53	(2)	6.5	5.5	2.6	.2	2.16	1
Corn, sweet	87	90	82	44	9.0	4.7	2.4	.8	.4	1.06	2
Cotton	46	30	30	29	(3)	2.8	1.5	.8	.4	.55	1
Cucumber	72	36	60	0	42.3	6.2	3.4	.3	.2	1.24	1
Muskmelon, Hale Best	93	69	80	0	10.6	1.2	2.1	.2	0	.42	2
Muskmelon, Honey Dew	40	19	0	0	22.2	5.2	3.2	0	0	1.56	1
Pumpkin	70	58	66	61	(3)	11.7	9.2	1.7	1.3	1.10	3
Squash, summer	85	85	90	92	(2)	13.7	7.0	.8	.5	3.50	2
Squash, winter	79	62	79	61	(2)	9.4	6.1	1.0	1.1	3.80	1
Tomato	75	76	71	58	11.6	2.4	1.0	.1	<.1	.38	2
Watermelon	69	67	9	0	16.7	2.9	1.4	.5	0	.43	2
Mean 3	66	58	59	31	---	6.0	4.5	1.3	.5	---	---

HIGHLY PURIFIED GAMMA BHC

	0	25	100	400	L.S.D.	0	25	100	400	L.S.D.	Duplicate tests
Barley	68	62	69	71	5.7	43.8	43.9	38.6	1.3	16.10	1
Bean, lima	38	40	59	61	(2)	4.5	3.9	4.4	1.6	1.63	1
Bean, snap	74	72	78	82	(2)	6.0	5.0	5.0	2.9	1.09	1
Corn, sweet	58	55	65	59	(2)	10.9	11.7	5.9	.5	3.77	2
Cucumber	50	49	59	61	(3)	5.7	4.2	2.6	.2	2.88	1
Muskmelon, Hale Best	65	58	73	63	(2)	1.6	1.3	1.3	.2	.50	1
Pumpkin	75	68	82	79	(2)	15.5	14.7	7.8	.9	6.46	1
Squash, summer	62	60	74	71	(2)	9.7	8.6	6.4	.6	1.06	1
Squash, winter	33	10	10	12	(2)	15.0	10.4	8.7	1.5	12.40	1
Mean 3	58	53	63	62	---	12.5	11.5	9.0	1.1	---	---

¹ Least significant difference at the 5-percent level.² Differences among treatments not significant.³ Means not weighted.

with the highly sensitive cucurbits, its presence in the soil reduces plant growth to about the same extent that DDT does (table 6). Its interference with germination and stand, however, appeared to be even more severe than that of technical BHC on most crops tested. One hundred pounds per acre produced significant reductions in stand with 10 of the 15 crops observed. On the average, 100 pounds reduced stand more than a third below the control, and 400 pounds nearly two-thirds. The cucurbits were extremely hard-hit at 400 pounds.

Of the plants that became established and grew, the 100-pound treatment significantly reduced yield in but one instance, muskmelon. Treatments of 400 pounds, however, reduced young plant growth significantly in 11 of the 15 sets of comparisons. Beans, corn, cabbage and broccoli, and cotton appeared definitely less sensitive than beets, the cucurbits, and tomatoes. Effects at 400 pounds ranged all the way from nonsignificant to complete killing of the plants, with an average reduction of about 50 percent below the control.

The stability of chlordane is not definitely known. Although believed to be somewhat persistent in soil, there are some indications that it is less stable than DDT.⁴ There appears to be a possibility of developing residues that will be harmful to sensitive crops, but until more is known of the stability of chlordane in soil, the probability of developing harmful residues cannot be predicted.

RESULTS WITH TOXAPHENE

Unlike the tests with DDT, which have continued for years after a single treatment of the soil, the few exploratory tests with toxaphene were suspended 3 to 4 months after starting them. Toxaphene, a chlorinated camphene, is generally believed to be far less stable or persistent in the soil than the chlorinated hydrocarbons DDT, BHC, and chlordane (40). Table 7 shows, however, that for a few months at least, large amounts of toxaphene in the soil are toxic to some crops.

At 100 pounds per acre small, nonsignificant, but rather consistent depressions in germination and stand were noted for beans, cucurbits, and tomatoes. At 400 pounds the results were more pronounced, averaging a reduction of about one-third below the control, but they were significant only for tomato and watermelon. Corn was unaffected in germination and stand even at 1,000 pounds of toxaphene per acre.

In growth of young plants high variability within treatments reduced the significance of results, although the means for corn and winter squash suggest toxic effects. Snap beans appeared tolerant. Pumpkin, summer squash, watermelon, and tomato all showed significant reductions in growth at 400 and at 1,000 pounds per acre. If toxaphene breaks down in the soil within a year and its decomposition products are nontoxic, these figures will become of only academic interest—no such amount as 400 pounds is likely to develop as a residue from normal use.

⁴ Unpublished data obtained by R. D. Chisholm, Bureau of Entomology and Plant Quarantine.

TABLE 6.—*Effect of chlordane in soil in the greenhouse on growth of seedlings, up to 7 months after application, Beltsville, Md., 1946-47*

Crop grown	Germination and stand in response to pounds per acre of chlordane shown					Plant weight in response to pounds per acre of chlordane shown					Duplicate tests
	0	25	100	400	L.S.D. ¹	0	25	100	400	L.S.D. ¹	
	Percent	Percent	Percent	Percent	Percent	Grams	Grams	Grams	Grams	Grams	
Bean, lima	46	46	45	43	3	11.5	11.7	10.5	9.1	1.8	Number 2
Bean, snap	44	36	30	23	7	8.4	9.2	8.9	6.2	.9	3
Beet, garden	75	10	10	0	11	1.6	3.2	2.9	0	2.3	1
Broccoli, sprouting	84	75	67	51	(2)	1.4	2.7	2.7	2.6	1.3	1
Cabbage	70	44	54	18	49	6.5	9.0	9.7	4.3	(2)	1
Corn, sweet	89	88	86	83	(2)	4.4	5.1	4.6	3.3	.8	2
Cotton	37	34	15	10	27	3.1	3.1	3.5	1.8	(2)	1
Cucumber	64	11	8	0	28	15.7	19.7	12.2	0	7.0	1
Muskmelon, Hale Best	81	47	39	6	9	1.6	1.7	1.1	.7	.4	2
Muskmelon, Honey Dew	29	16	0	0	22	2.9	3.1	0	0	3.1	1
Pumpkin	79	66	66	44	8	15.4	18.0	16.6	12.3	3.5	3
Squash ³	82	66	56	40	16	8.8	11.9	8.4	6.7	(2)	2
Squash ⁴	85	51	41	11	31	40.2	45.2	38.4	13.3	10.9	1
Tomato	73	62	54	44	11	2.8	4.8	2.7	1.5	1.0	2
Watermelon	74	40	9	2	18	3.3	4.3	2.7	1.0	2.3	2
Mean ⁵	67	46	38	25	-----	8.5	10.0	8.3	4.2	-----	-----

¹ Least significant difference at the 5-percent level.² Differences among treatments not significant.³ Tests run 2 and 5 months after soil treatments.⁴ Test run 7 months after soil treatment.⁵ Means not weighted.

TABLE 7.—*Effect of toxaphene in soil in the greenhouse on stand and growth of seedlings within 4 months of application, Beltsville, Md., 1947*

GERMINATION AND STAND

Crop	Duplicate tests	Response to pounds per acre of toxaphene shown					
		0	25	100	400	1,000 ¹	L.S.D. ²
Sensitive plants:	<i>Number</i>	<i>Percent</i>	<i>Percent</i>	<i>Percent</i>	<i>Percent</i>	<i>Percent</i>	<i>Percent</i>
Bean, snap -----	2	88	85	85	71	61	(3)
Pumpkin -----	1	68	72	64	57	64	(3)
Squash, summer -----	2	60	46	45	45	42	(3)
Squash, winter -----	1	52	57	38	29	24	(3)
Tomato -----	1	90	66	67	48	42	40
Watermelon -----	1	28	31	37	7	0	13
Mean -----		65	60	56	43	39	12
Less sensitive plant:							
Corn, sweet -----	1	98	94	97	94	94	(3)

WEIGHT PER PLANT

	<i>Number</i>	<i>Grams</i>	<i>Grams</i>	<i>Grams</i>	<i>Grams</i>	<i>Grams</i>	<i>Grams</i>
Sensitive plants:							
Pumpkin -----	1	24.7	16.9	16.7	15.1	13.8	6.7
Squash, summer -----	2	17.5	16.1	7.7	6.4	3.4	9.1
Tomato -----	1	4.7	5.5	4.5	2.2	.8	.8
Watermelon -----	1	5.7	7.3	3.1	.9	-----	2.9
Mean -----		12.9	11.5	8.0	6.2	6.0	-----
Less sensitive plants:							
Bean, snap -----	2	10.1	10.7	9.8	10.1	9.3	(3)
Corn, sweet -----	1	7.2	6.0	4.9	4.8	3.3	(3)
Squash, winter -----	1	12.9	11.8	8.3	4.9	-----	(3)
Mean -----		10.1	9.5	7.7	6.6	6.3	-----

¹ The 1,000-pound treatment is not included in the variance analysis, because there was no replication of treatment.

² Least significant difference at the 5-percent level.

³ Differences among treatments not significant.

RESULTS WITH PARATHION

Parathion (O,O-diethyl para-nitrophenyl thiophosphate) is a compound of remarkable toxicity to insects and to man and animals. Its insecticidal properties persist for only a few days after it has been sprayed or dusted onto crops, and it is now believed to decompose into harmless products. In 1948, however, its amazing potency as an insecticide and the lack of definite information about how it might behave in soil called for its inclusion in these studies.

Table 8 shows that amounts of parathion from 1.5 pounds up to 100 pounds per acre had no consistent and significant harmful effects on a wide range of vegetable crops, with the possible exception of snap beans and muskmelons. In a few instances, as tomatoes and rye on the 50-pound plot, there appeared to be significant increases above the control. Two such instances are not surprising in a table of 88 items, considering that in a random sample 2 items may be a little above and 2 a little below the "5-percent level."

TABLE 8.—*Effect of parathion in the soil in the greenhouse on the growth of seedlings, up to 17 months after application, Beltsville, Md., 1948-49 (see also table 9)*

Crop grown	Duplicate tests	Seedling weight in response to pounds per acre of parathion shown								L.S.D. ¹
		0	1.5	3.0	6.2	12.5	25.0	50.0	100.0	
	Number	Grams	Grams	Grams	Grams	Grams	Grams	Grams	Grams	Grams
Bean, lima ²	1	6.7	6.8	7.0	6.7	6.6	6.8	6.8	6.7	(³)
Bean, lima ⁴	1	10.9	12.7	11.7	12.6	12.0	12.0	11.0	9.8	(³)
Bean, snap ⁵	3	14.3	15.3	15.3	14.7	14.0	14.3	9.7	10.9	2.8
Cucumber ⁴	1	5.3	5.9	6.8	10.1	9.5	7.7	14.1	14.7	(³)
Cucumber ⁶	1	7.9	8.9	13.0	8.2	8.2	12.0	9.3	9.3	(³)
Muskmelon	2	2.3	2.1	2.3	2.7	3.2	3.1	2.3	.9	2.2
Peas, garden ⁷	1	2.4	2.3	2.5	2.4	2.6	2.2	2.6	2.3	(³)
Peppers ⁸	-----	2.0	1.3	1.2	1.1	1.4	1.8	1.1	1.7	-----
Rye ⁹	3	3.8	3.8	4.1	4.4	5.0	3.9	5.5	5.0	1.3
Squash ⁴	1	33.8	29.7	44.3	43.9	48.8	53.0	31.9	34.7	(³)
Tomatoes ¹⁰	3	8.0	10.3	11.1	10.8	11.6	11.7	13.4	6.0	4.0
Mean ¹¹	-----	6.4	7.0	7.5	7.4	7.4	7.6	7.6	6.7	-----

¹ Least significant difference at the 5-percent level.² 7 varieties.³ Differences among treatments not significant.⁴ 1 variety.⁵ Tested within 6 months of soil treatment.⁶ 8 varieties. Variation that is evident is associated with random variations in stand, $r = -.93$.⁷ 8 varieties.⁸ 5 varieties, not replicated.⁹ 3 varieties.¹⁰ 2 varieties.¹¹ Values for squash omitted. Means not weighted.TABLE 9.—*Effect of parathion mixed with soil, November and December 1947, on germination and stand of certain seeds, Beltsville, Md., 1948-49 (see also table 8)*

Crop	Date sown	Stand of plants in response to pounds per acre of parathion shown								L.S.D. ¹
		0	1.5	3.0	6.2	12.5	25	50	100	
		Per-cent	Per-cent	Per-cent	Per-cent	Per-cent	Per-cent	Per-cent	Per-cent	Per-cent
Tomato	Jan. 7, 1948	73	61	57	56	41	46	27	30	13
Bean	do	72	71	59	71	59	46	62	43	28
Mean	-----	73	66	58	64	50	46	45	37	10
Tomato	Feb. 27, 1948	59	70	61	48	60	62	51	46	(²)
Bean	do	65	67	49	56	62	69	49	18	40
Mean	-----	62	69	55	52	61	66	50	32	13
Rye	Feb. 27, 1948	50	65	43	50	44	55	43	35	(²)
Bean	do	65	67	49	56	62	69	49	18	40
Mean	-----	53	66	46	53	53	62	46	27	12
Rye	Apr. 14, 1948	52	47	46	52	39	51	43	31	(²)
Bean	do	94	88	95	89	94	97	77	64	(²)
Mean	-----	73	67	71	70	66	74	60	47	17
Peas	Jan. 17, 1949	58	66	61	62	60	46	69	33	(²)
Do	do	54	45	43	65	40	33	46	45	(²)
Cucumber	Apr. 4, 1949	65	41	37	51	48	20	69	39	(²)
Do	do	42	39	14	31	45	39	23	48	(²)
Lima bean	May 2, 1949	95	95	97	94	95	95	97	95	(²)
Do	do	95	95	92	94	95	91	92	94	(²)

¹ Least significant difference at the 5-percent level.² Differences among treatments not significant.

With successive crops grown on these plots for nearly 1½ years from the time of applying parathion to the soil, it may well be that some of the test crops failed to encounter toxicity, although parathion was temporarily toxic. Be that as it may, table 8 shows no important persistent toxic effects on growth.

Table 9 suggests a temporary toxic effect of parathion on germination and stand. In the tomatoes sown immediately after soil treatment germination was depressed significantly by 3 pounds or more of parathion per acre. Seven weeks later in a succeeding planting the 100-pound treatment did not depress stand significantly. In beans planted immediately after treatment the heaviest treatments depressed stand, 100 pounds being significantly lower. This effect on beans did not persist significantly in sowings made more than 2 months after starting the tests. Sowings of rye 2 and 4 months after treatment showed some trend toward poor stand following the larger amounts of parathion, but they were not significant. None of the sowings made a year or more after treatment showed definite trends or significant differences.

The high variability in the parathion tests is believed to be due, in part, to the difficulty of mixing very low concentrations of parathion with large volumes of soil.

Hazard to personnel also interfered somewhat in getting the best mixtures with the soil.

DDT-TREATED SOILS EXPOSED TO WEATHERING

MATERIALS AND METHODS

Late in 1947 it appeared desirable to replace the series of soil treatments in the greenhouse, discussed in the preceding section, and to set up additional and different studies. The treated soils and their respective check plots were transferred quantitatively from the greenhouse benches to an open coldframe, 6 by 100 feet, where they have since been planted with various crops and continuously exposed to natural weathering. The several soils and treatments of each were placed in the frames in duplicate at random. Two plots from duplicate blocks were combined to make larger plots in the frames than in the greenhouse benches.

In 1948 the plots were planted with Abruzzi rye, but were so surprisingly damaged by rodents and dogs as to render the harvest weights of little or no value. Observations of the plots before the crop was damaged indicated that the growth of the rye was affected by the treatments very much like the growth of the sensitive species in the greenhouse.

After taking measures to protect later crops from depredations of animals, the plots were planted with Henderson Bush lima bean and Stringless Black Valentine snap bean in 1949 for obtaining yield and quality data (table 10). Rows of lima beans were planted half as far apart as they were intended to grow to maturity, with the purpose of removing the plants of alternate rows for recording plant weights at an early stage of growth.

When the beans reached a stage at which they are normally harvested for canning or freezing, all pods were removed from

TABLE 10.—*Plant weights and yields of beans on soil in small outdoor beds treated with DDT approximately 4 years before planting, Beltsville, Md., 1949*

Plant grown and data recorded	Soil on which plants grown	Plant response to pounds per acre of DDT shown					Least significant difference ¹
		0	25	100	400	1,000	
Henderson Bush lima bean: Weight per plant 40 days after planting.	Chester loam -----	Grams 11.5	Grams 9.6	Grams 4.6	Grams 2.4	Grams 1.9	} 2.2
	Sassafras sandy loam -----	11.0	10.7	7.9	4.5	2.8	
	Evesboro loamy sand -----	8.3	8.1	4.6	3.8	2.4	
	Mean -----	10.3	9.5	5.7	3.6	2.4	1.3
	Muck -----	13.9	13.1	13.5	7.7	5.1	2.2
Seed yield per plant.	Chester loam -----	6.3	5.6	5.5	2.0	1.8	} 2.0
	Sassafras sandy loam -----	5.4	7.4	6.7	4.7	2.4	
	Evesboro loamy sand -----	4.8	6.8	4.9	2.8	1.1	
	Mean -----	5.5	6.6	5.7	3.2	1.8	1.2
	Muck -----	5.5	6.4	5.3	7.7	4.8	2.0
Stringless Black Valentine snap bean: Weight per plant without pods.	Chester loam -----	16.2	14.6	6.4	3.3	2.2	} 3.2
	Sassafras sandy loam -----	17.5	17.6	9.8	6.1	3.6	
	Evesboro loamy sand -----	15.4	11.7	7.2	4.9	3.0	
	Mean -----	16.4	14.6	7.8	4.8	2.9	1.8
	Muck -----	18.6	21.0	20.0	11.4	7.3	3.2
Weight of green pods per plant.	Chester loam -----	25.4	19.2	1.5	0	0	} 5.5
	Sassafras sandy loam -----	20.0	20.8	7.8	0	0	
	Evesboro loamy sand -----	20.2	11.2	2.6	0	0	
	Mean -----	21.9	17.1	4.0	0	0	3.2
	Muck -----	19.8	17.8	15.8	1.5	0	5.5

¹ At the 5-percent level.

all the plants. The lima beans were removed from the pods and weighed from each plot, and the snap bean pods, per plot, were weighed as harvested. The snap bean plants from which the pods had been removed were also weighed.

Soil samples were drawn in 1949 from the respective treatments for determination of DDT.

RESULTS

Analyses of these four soils for DDT content were made by Louis Koblitsky, of the Bureau of Entomology and Plant Quarantine, in January 1950, more than 4 years after the single application of DDT. Since DDT was applied on the surface-acre basis and there was approximately 6 inches instead of 6 $\frac{3}{4}$ inches of soil in the greenhouse benches, the DDT content in parts per million was slightly higher than one-half the number of the pounds per acre applied.⁵ Table 11 indicates that DDT in these soils is highly stable and that there was no significant disappearance during 4 years. Since parts per million (p.p.m.) is calculated on a volume-weight basis, the apparent content of DDT in the light, bulky muck soil is much higher than in the mineral soils.

⁵ One pound per acre of the surface 6 $\frac{3}{4}$ inches of soil weighing 2,000,000 pounds is approximately $\frac{1}{2}$ part per million.

TABLE 11.—*DDT content of soil from the coldframes 4 years after adding DDT to the soil, Beltsville, Md., January 1949*¹

Rate of applying DDT to soil in 1945		Parts per million of DDT found in soil shown				
Per acre	Per million ²	Sassafras sandy loam	Chester loam	Evesboro loamy sand	Mean of 3 mineral soils	New Jersey muck ³
<i>Pounds</i>	<i>P.p.m.</i>	<i>P.p.m.</i>	<i>P.p.m.</i>	<i>P.p.m.</i>	<i>P.p.m.</i>	<i>P.p.m.</i>
25 -----	13.9	15.6	10.3	12.0	12.6	19.3
100 -----	55.4	54.1	55.6	53.3	54.3	117.3
400 -----	222.0	211.0	225.6	186.6	207.7	448.1
1,000 -----	554.0	551.2	555.5	487.4	531.4	1,430.6

¹ Analyst, L. Koblitsky.² Calculated as parts per million in the surface 6 inches of an acre of soil, assuming a depth of 6½ inches for the surface 2,000,000 pounds of typical mineral soil.³ Because a relatively dry muck soil is only ½ to ⅓ as heavy per unit volume as are the mineral soils, the addition of 1 pound per acre of a substance will give parts per million equivalents that are 2 to 3 times as large as for mineral soils.

Table 10 shows the weights of the plants and pods of beans harvested in 1949 from the coldframes containing the four kinds of soil that had been treated with the different amounts of DDT in 1945. It will be noted that the reductions in growth and yields of snap beans on the several DDT treatments were even more serious than the relative reductions in growth of young plants observed in the greenhouse. The DDT had lost no noticeable degree of its toxicity on these plots during a period of approximately 4 years. It appears that the extreme reduction in early growth of lima bean plants was, in part, only a retardation, and that the reduction in yield was less severe. It is probable that, as the deep-penetrating roots of the lima bean plants finally reached through the soil containing DDT into uncontaminated earth below, the retarded plants were able to recover to a large degree. Nevertheless, the 400 pounds of DDT produced significant reductions in yield upon the Chester and the Evesboro soils, and upon the mean yield for all three mineral soils. The growth of young plants on the muck soil was significantly reduced at the 400-pound rate, but the seed yield was not reduced. Injury was more persistent and was significant at the 1,000-pound rate in the frames where the pH of the mixture of the two mucks had been raised to nearly 7.0.

The Stringless Black Valentine variety of snap bean is highly sensitive to DDT in the soil. The reductions in plant weight at increasing dosages of DDT appeared to be relatively greater than those observed for the young plants in the greenhouse tests. Applications of 100 pounds per acre, 4 years before, resulted in significant reductions in weight of plant (without pods) on each soil. Even 25 pounds of DDT appeared to depress plant growth of this variety to a degree that bordered significance, on the Chester and Evesboro soils.

The effects of DDT upon weights of snap bean pods harvested are rather startling. There were no pods to be harvested on either the 400- or the 1,000-pound treatments on any of the mineral soils, and almost none on the 100-pound treatments of the Chester and Evesboro soils. The nearly complete barrenness of

the plants on the 400-pound muck plots was also striking, in view of the amount of plant growth made in those plots and in view of the early plant growth in earlier greenhouse trials. The data in table 10 give no indication that the toxicity of DDT in the soil has decreased noticeably during a period of 4 years, at least to sensitive crops.

It is planned to keep these soils in place in the coldframes for many years, cropping them annually to a range of species of differing sensitivity to DDT. It is hoped that some of the moderately sensitive or slightly sensitive crops may later reveal a decrease in toxicity that may be still too high to be revealed by a very sensitive indicator crop like Stringless Black Valentine bean

FIELD EXPERIMENTS

MATERIALS AND METHODS

With the tentative information afforded by the earlier phases of the greenhouse work upon the probable crop response to DDT in certain soils, it appeared feasible to design a comprehensive study having potentialities for answering several practical questions under field conditions. The difference in response of sensitive crops on muck versus mineral soils suggested that increasing the organic-matter content of the soil might tend to lessen the toxicity of DDT present in the soil. The results also suggested that lime content of pH of the soil may be important. Therefore, a split-block design was planned to include four replicates with two sub-blocks receiving manure and no manure, and each sub-block containing five levels of DDT: 0, 25, 50, 100, and 200 pounds per acre. These 40 plots, each 40 by 44 feet, were split in two for treatment with limestone at a low and a high rate, respectively.

Through an error in machine operation in preparing the field, the manure for the sub-blocks was not placed as shown in the design. The result is that instead of having four true replicates for manure the field consists of two contiguous blocks within each of two replicates. While this does not upset the precision of the measurements planned for DDT effects and lime effects, it seriously reduces the precision of measuring the single effect of manure.

The manure, DDT, and lime treatments were applied to a field of moderately heavy bottom land soil near a small creek in the early summer of 1947, and the plots were deeply cultivated repeatedly through the summer to mix the added materials thoroughly with the soil. The required amount of DDT for each plot was weighed out as a 50-percent dry talc powder. It was mixed with fertilizer and limestone and applied to the surface of the well-marked plots by means of a small row-type fertilizer distributor. Care was taken to avoid drift, to apply the mixture uniformly, and to deliver the entire weighed quantity to the appropriate plot. The plots were disked eight times, including cross diskings, before planting.

Winter grains were sown in the fall of 1947 and harvested in the early summer of 1948, followed by simultaneous crops of lima beans, snap beans, and potatoes. In 1949 spring crops of peas

and cabbage were followed by lima beans, snap beans, and sweet corn.

Manure will be applied to the appropriate sub-blocks at 2- or 3-year intervals and lime as may be necessary to establish and maintain definite difference in soil reaction between the split plots. Soil reaction in 1949 averaged 5.0 on the no-lime plots, 5.2 on the limed plots. Ten tons of manure per acre were applied in 1947 and 20 tons in 1949. By withholding lime from the low-lime plots or adding small amounts, and by adding further quantities carefully to the high-lime plots the desired differences in pH can be gradually produced. Meanwhile, dependable data on the effects of DDT levels alone are being obtained. The experimental value of this field in relation to effects of DDT is expected to increase for many years.

No chlorinated hydrocarbons have been or will be used to control insects in these experiments. Rotenone and ryania insecticides only have been used. No fungicides have been used.

RESULTS

Table 12 presents the results of the 1948 and 1949 crops from the DDT field plots.

Of the cereals tested the Abruzzi and the Rosen varieties of rye are by far the most sensitive to DDT. As little as 25 pounds per acre of DDT produced a small but significant depression in the yield of the full-grown but not ripe and dry plants; 100 pounds significantly depressed the yields of ripe, dry straw plus grain. During the fall and winter of 1948 the rye plants on the 100- and 200-pound plots were of a slightly abnormal color, with a tinge of faint purplish red. The smaller size of the plants on the heavy treatments was easily evident to the eye during most of their development.

There was no significant effect of the DDT on growth of either of the two varieties of wheat or of Fulghum or Oklahoma oats. Lee oats was significantly depressed in yield at 100 and 200 pounds of DDT. Sunrise barley was not injured, but Wong barley appeared somewhat sensitive.

Lima beans were somewhat sensitive and snap beans highly sensitive to the DDT treatments in both 1948 and 1949, the depression of growth appearing somewhat greater in the latter year. In the 200-pound treatment the weights of lima bean plants without pods were reduced significantly below those of the control plots, but pod yields were not. Both plant weight and pod yield of Stringless Black Valentine snap beans were markedly reduced by amounts of DDT of 100 pounds per acre or more. In the 200-pound plots pod yields were only about one-half to one-third as large as the yields of the controls. As with lima beans, the effects of the DDT at the several levels were as serious in 1949 as they were in 1948 in these tests.

The potato showed no significant differences in yield of tubers due to the soil treatments with DDT. Other data indicate that this potato variety is relatively tolerant to considerable amounts

TABLE 12.—*Response of crop plants to DDT in soil in the field, Beltsville, Md., 1948 and 1949*
[DDT applied to soil in June 1947]

Year, crop, and variety	Harvested part	Yield per plot in response to pounds of DDT per acre shown					Least significant difference ¹
		0	25	50	100	200	
1948							
Cereals:		Pounds	Pounds	Pounds	Pounds	Pounds	Pounds
Barley:							
Sunrise -----	Straw plus grain	6.44	5.85	6.48	6.59	6.64	0.56
Wong -----	do -----	18.28	17.13	17.75	19.46	16.25	1.71
Oats:							
Fulghum -----	do -----	8.87	9.20	9.13	9.09	9.13	(2)
Oklahoma -----	do -----	18.95	17.69	18.07	17.92	17.53	(2)
Lee -----	do -----	24.58	21.19	22.52	21.33	20.97	2.49
Rye:							
Abruzzi:							
Plants not mature -----	do -----	24.69	21.06	19.53	19.99	15.91	2.33
Plants mature, dry -----	do -----	8.83	8.24	8.48	8.06	6.90	.77
Rosen -----	do -----	15.46	13.71	13.64	12.57	10.78	1.74
Wheat:							
Kay -----	do -----	14.36	14.50	14.92	15.08	14.12	(2)
Trumbull -----	do -----	17.81	16.74	17.67	17.81	17.66	(2)
Beans:							
Lima:							
Fordhook -----	Plants only -----	13.84	14.51	13.93	14.21	11.81	1.92
Do -----	Pods -----	3.13	2.78	2.95	3.01	2.80	(2)
Snap:							
Stringless Black							
Valentine -----	Plants only -----	40.10	29.51	31.88	26.11	19.36	8.28
Do -----	Pods -----	16.79	13.45	14.29	11.53	8.02	3.06
Potatoes:							
Irish Cobbler -----	Tubers -----	61.74	58.07	62.56	63.47	65.99	(2)
1949							
Beans:							
Lima:							
Henderson Bush -----	Plants only -----	12.21	13.28	13.27	12.52	9.78	1.48
Do -----	Pods -----	12.37	13.59	14.06	14.11	11.32	1.68
Snap:							
Stringless Black							
Valentine -----	Plants only -----	20.11	20.88	18.91	16.69	11.30	1.91
Do -----	Pods -----	15.78	15.56	13.76	11.18	5.34	1.80
Burpee Stringless							
Green Pod -----	Plants only -----	15.98	16.49	15.74	13.81	9.18	1.22
Do -----	Pods -----	9.43	10.00	9.58	7.43	3.50	1.14
Cabbage:							
Early Jersey Wakefield -----	Heads -----	24.24	23.73	21.60	23.27	21.60	(2)
Golden Acre -----	Pods -----	27.34	30.58	27.93	28.23	23.59	(2)
Corn, sweet:							
Country Gentleman							
Golden Cross Bantam -----	Ears plus stover	59.3	71.1	74.6	78.3	77.7	8.42
Do -----	do -----	52.5	62.6	68.4	72.2	71.0	8.42
Do -----	Ears only -----	6.26	7.14	7.42	7.55	8.06	(2)
Peas:							
Garden:							
Alaska -----	Vines plus pods	20.74	22.89	24.94	21.46	19.56	3.44
Thomas Laxton -----	do -----	17.80	19.51	19.66	17.51	12.60	2.87

¹ At the 5-percent level.

² No significant differences.

of DDT in the soil, up to 400 pounds per acre or more in the soils employed in some of this work.

As in the greenhouse tests, cabbage appeared relatively tolerant to DDT in the soil. Although there was a slight drop in yield of the 200-pound plots, the difference from the controls was not significant.

All the DDT treatments showed higher yields of sweet corn plants (stover plus ears) than did the controls. Although there appeared to be a tendency for the plant weights to increase with

increasing amounts of DDT in the soil, none of the amounts above 25 pounds produced significantly greater weight than the 25-pound treatment. This result suggests that the increased growth resulted from the control of some soil-borne pest rather than from any direct stimulation. Even if there is no stimulation, corn appears quite tolerant to the amounts of DDT used in these tests.

The results on the two varieties of garden peas were not consistent. The Alaska variety appeared tolerant up to the 200-pound treatment, while the Thomas Laxton showed a significant reduction in yield on that treatment. Both varieties showed a little higher plant plus pod weights on the 25- and 50-pound plots than on the controls, but further experience is needed with these and other varieties of peas to help evaluate these data.

Beans, cabbage, and potatoes from certain plots in the field and beans from the coldframes were cooked and tested for flavor by a group of fellow workers. In a few instances samples from high-DDT plots were reported by some of the judges to be somewhat lacking in the characteristic flavor exhibited by the controls. Other judges were unable to detect differences due to treatment. No foreign or objectionable flavor was ever detected. Those sensitive species that were seriously depressed in growth and yield might well show such lack of quality as is characteristic of any crop that has made very poor growth and yield because of infertile soil, disease, insect attack, or bad weather.

Incidentally, in this connection, we have noted no reports proving that DDT can enter the plant from the soil and thereby affect the quality of edible portions by its presence in the tissues. Plant materials from these studies have been analyzed for DDT by workers in the Bureau of Entomology and Plant Quarantine. No DDT was found in any of the tissues analyzed.

GREENHOUSE STUDY OF ORCHARD SOIL

MATERIALS AND METHODS

One of the peach orchards at the Plant Industry Station had received the recommended quantity of DDT in the spray schedule, approximately 25 pounds per acre of technical DDT in wettable powder, $\frac{1}{4}$ pound per tree, per year from 1946 to 1949, inclusive. In 1946 6 pounds of the gamma isomer of benzene hexachloride had also been used per acre, applied in the form of technical BHC in a wettable powder in two foliage sprays, and involving some 50 pounds per acre of the technical product. For a dozen years the orchard had received lead arsenate in the spray schedule, to a total of about 300 pounds per acre, and some 400 pounds of zinc as zinc sulfate in zinc-lime spray.

In the fall of 1948 there was serious difficulty in obtaining a stand of a cover crop of Abruzzi rye beneath the trees of this orchard, although good stands had been obtained in preceding years. Growth was acceptable in the "middles" between the trees, but the plants failed completely within roughly circular areas that coincided with the spread of the branches. Because of the recent finding that Abruzzi rye is highly sensitive to DDT it appeared

possible that DDT drip and residues from the fallen leaves had accumulated under the trees to a harmful degree. Since, however, the weather had been unusually dry for several weeks before and also after the sowing of the rye, it was possible that the failure was due to the serious depletion of the soil moisture in the area of root spread of the trees (approximately the same as the spread of the branches).

To determine whether harmful amounts of DDT and other chlorinated hydrocarbon insecticide compounds had accumulated in the soil of this orchard and to eliminate water deficiency and other effects as controlling factors in the tests, an experiment was set up in the greenhouse in September 1949 as follows: Soil was removed from beneath representative trees in the orchard to the depth of 3 to 4 inches, the normal depth of cultivation on that soil, a Sassafras loam. Soil was similarly removed from areas between the trees where the growth of rye appeared good, and a third lot of soil of the same type was removed from sites just beyond the limits of the orchard. Each soil was put into a separate plot at random in each of the four blocks in greenhouse benches and planted with rye and wheat, essentially as described for other greenhouse studies reported in this circular.

Samples of the three lots of soil were analyzed for arsenic by R. D. Chisholm, of the Bureau of Entomology and Plant Quarantine; for zinc by Ellsworth Shaw; and for DDT by Viron V. Jones, of the Division of Soil Management and Irrigation. The three lots of soil are identified here as "under trees," "between trees," and "control."

RESULTS

Table 13 contains the results of the chemical analyses of the three lots of soil. It appears that the known amounts of DDT applied to the trees over the 3-year period were largely recovered from the soil under them. The amount of DDT found between the trees was small. The amount found in the controls is within the limits of error. Moderate amounts of arsenic were found both

TABLE 13.—*Content of arsenic, zinc, and DDT in soil from peach orchard that had been sprayed with arsenicals, zinc-lime, DDT, and BHC, Beltsville, Md., 1949*

Substance determined	Amount of various substances found in soil from the location shown ¹		
	Control	Between trees	Under trees
	<i>P.p.m.</i>	<i>P.p.m.</i>	<i>P.p.m.</i>
Arsenic trioxide ² -----	18	222	385
Zinc ³ -----	26	168	51
DDT ⁴ -----	3	11	127

¹ 1 pound per acre is roughly equivalent to $\frac{1}{16}$ part per million in the surface $6\frac{3}{4}$ inches of soil. Residue accumulations under trees will be higher, and between trees lower than the rate per acre because the spray materials are applied almost entirely to the trees.

² Total estimated amount of As_2O_3 equivalent applied as lead arsenate from 1936 to 1949, 45 pounds per acre. Analyst, R. D. Chisholm.

³ Total estimated amount of Zn equivalent applied as zinc-lime from 1936 to 1949, 430 pounds per acre. Analyst, E. Shaw.

⁴ Total estimated amount of DDT applied from 1946 to 1949, 130 pounds per acre, on or beneath the trees. Analyst, V. V. Jones.

under and between trees, and larger amounts of zinc were found under the trees than in the controls.

In the greenhouse test (table 14) the growth of rye was very poor on the soil from under the trees, was good on that from between the trees, and best from the same soil lying outside the limits of the orchard. Not all the difference in response between the controls and "between trees" and "under trees" plots is properly ascribable to DDT alone, or any other single known factor. Wheat grew equally well on all three soils. Although there were differences in arsenic content of the soil lots, they were not great enough to affect the growth of wheat. Thus it appears that the accumulations of chlorinated hydrocarbon insecticides DDT and BHC, in a period as short as 4 years, seriously affected the capacity of this particular orchard soil to produce a satisfactory cover crop of rye.

TABLE 14.—*Plant response to soils from peach orchard receiving arsenic, DDT, and BHC sprays over a period of years, Beltsville, Md., 1949-50*

Crop and variety	Plant weight per plot from soil of source indicated			Significance
	Under trees	Between trees	Control	
	<i>Grams</i>	<i>Grams</i>	<i>Grams</i>	
Rye, Abruzzi, test 1.....	621	1,192	1,591	(1)
Rye, Abruzzi, test 2.....	143	413	489	(2)
Wheat, Tenmarq.....	584	518	577	(3)

¹ Differences significant at the 5-percent level.

² Differences significant at the 1-percent level.

³ Differences not significant at the 5-percent level.

DISCUSSION OF TOXICITY OF INSECTICIDES

GENERAL

Each of several of the insecticides reported upon here has one or more properties that make it very superior to insecticides used before 1945. The small amounts required to control some pests and the persistence of the effects of treatment make DDT, BHC, chlordan, and perhaps others unusually effective and economical. One or more of these substances has given remarkable control of serious pests not satisfactorily or economically controllable before 1945. There is no doubt as to their effectiveness in the killing of certain insects.

For the present some phenomenal increases in yield or quality of crop, or both, are being obtained with chlorinated hydrocarbon insecticides that are persistent. Individual farmers have continued to use a particular chemical—when it was obtainable—until it appeared to them that some other chemical or practice was more profitable; it is not improbable that such a human tendency will continue. If DDT, BHC, or other persistent substance is effective in such small amounts that it can be used at low levels for many years without danger of accumulating a toxic level in soil or affecting crop quality there is no reason why it should not be used carefully within those safe limits of methods of use, rate,

and time. It should be remembered, however, that there are limits.

There is no reason at this time to suppose that a toxic amount of DDT, BHC, or chlordane, as examples, will be accumulated in the soil any sooner than suggested by the studies reported in this circular. If only 2 to 3 pounds of DDT per acre are applied per year it will take 10 to 15 years or more to accumulate enough to be detected in a sensitive crop such as Stringless Black Valentine bean. Many crops, however, are treated at rates of 5 to 10 pounds of DDT annually, suggesting that sensitive crops on land receiving such amounts might be definitely depressed in yield after 5 to 10 years. A crop as tolerant as corn, however, might remain unaffected following such applications for 100 years. But 15-, 20-, and 30-pound annual applications can be expected to cause trouble in 3 to 5 years on some crops.

Substances less persistent than DDT, such as BHC or chlordane, will, of course, accumulate less rapidly than implied above if equal amounts are applied. Too few years have elapsed since these new toxic substances have been used in common practice to know how long a time will be required for a harmful residue of the more or less persistent ones to accumulate.

Excessive or other improper use of such substances is to be strongly discouraged in the interest of economical and efficient crop production. If the most efficient methods of application are used with the best dosages known, strictly in accordance with sound recommendations, less material of a possibly harmful nature will be accumulated in the soil over a period of years than if it is used carelessly.

DDT

Because of the great persistence of the toxicity of DDT and its relatively high toxicity to many crops on the mineral soils on which it has been tested, it appears that harmful residues will accumulate under some conditions of use in as short a time as 3 to 5 years. It is probable that residues harmful to some cover crops have been developed already in certain orchards in which 30 to 40 pounds or more have been applied per acre per year. In orchards the toxic effect should be first noticeable on the cover plants under the trees where the DDT has accumulated from drip, and fall of leaves. In areas where the DDT has been applied uniformly to crops over a field there will be no localized concentration, as in orchards, to emphasize or make clear its toxic effects. In the absence of any specific symptoms a more or less uniform reduction in growth over the field may thus escape detection until it has gradually progressed to a serious degree. The lack of clear-cut symptoms of injury and the lack of control, or untreated areas, within single fields probably will delay discovery of injury until considerable damage has been done to the productivity of fields that regularly receive substantial dosages.

Although certain crops commonly treated with DDT appear highly tolerant to it, as many grains, sweet corn, and Irish potatoes, some other crops commonly grown in rotations with them are highly sensitive, as Abruzzi rye, tomatoes, squash, and snap

beans. Well-established orchard trees have tolerated as much as 3,000 pounds per acre of DDT applied on top of the soil beneath the spread of the branches, with no evident effect on the tree, but as little as 100 pounds per acre has seriously interfered with the growth of rye, a popular winter cover crop in orchards and truck crop fields in general. Thus, although there is no fear that the productivity of a field will be seriously impaired for all crops within a few years' time, it appears that DDT may interfere with established rotations, cover crop systems, or culture of the more profitable crops normally grown in a particular situation.

Kinds of crops, varieties, kinds of soil, and doubtless other factors have a bearing upon how toxic any stated amount of DDT might prove to be in a field soil. Meager evidence, however, suggests that it accumulates almost as fast as it is applied to the crops. If this is borne out by further work it will mean that it is necessary to find some less persistent, relatively unstable compounds to use in place of DDT for a large number of crops.

BHC

One determination of BHC in a greenhouse soil 3 years after treatment with 100 pounds per acre showed about half of it remaining. This does not mean, of course, that all of it will have disappeared in 6 years. It may take longer or less than 6 years for all of it to disappear from the soil, but how long is unknown.

Suppose, however, that about 15 percent of an amount added, within rather wide limits, shall be destroyed per year in the soil. Where as much as 40 to 50 pounds of technical BHC (about 5 to 6 pounds of gamma BHC) is added per acre per year, a residue of about 165 pounds will have accumulated in 6 years. If 40 pounds is added every 2 years, more than 100 pounds will have accumulated in 6 years. Reference to table 5 shows that amounts of technical BHC as high as 100 pounds may be expected to produce a reduction in growth of 25 percent or more in many crops. Although it is not proved in actual practice that this is happening now (1950), or will happen in the next 3 to 5 years, the results of these investigations strongly suggest potentialities for serious losses in productivity following continued heavy annual use of technical BHC. A less persistent substance is needed to replace it.

Technical BHC in the soil poses another problem that is of immediate importance. The objectionable odor and flavor of technical BHC are imparted to potatoes and other crops, the edible parts of which develop in the soil to which it has been applied. Losses to potato growers in some areas have been very heavy because of their inability to sell bad-flavored potatoes from soils treated with BHC. Some State agencies have warned growers and members of the peanut and fertilizer trades against the application of BHC to the soils, in fertilizer or otherwise, in which peanuts are to be grown. It has been known for several years that BHC in the soil will give a bad flavor to root crops grown in such treated soil. It has never been recommended as a soil treatment for insect control immediately before growing any root or tuber crop.

There is no sound evidence, as yet, that BHC from the soil is taken up by the crop plant and translocated to stems, leaves, or fruits above ground, thereby contaminating those parts and giving them a bad flavor. It is well known, however, that applications to above-ground parts of plants must be discontinued long before harvest if fruit contamination is to be avoided. It is not recommended for use on crops the leaves and stems of which are eaten.

OTHER SUBSTANCES STUDIED

Too little information has been obtained in these particular studies to warrant generalizations about chlordane and toxaphene. Fairly extensive new work has been established on these and a number of other substances that should yield some valuable information within 2 or 3 years, but quick results are hardly possible in studies of persistence. Since toxaphene has been reported to be relatively unstable (40) and parathion is known to be highly unstable, they are not expected to cause trouble by accumulating as residues in the soil.

The persistence of chlordane is not known definitely, but it should probably be described as relatively persistent.⁶ The depressive effect of chlordane upon germination and stand appears greater than that of DDT. Its toxicity to later growth appears, in general, about the same as DDT, although some crops may be more sensitive than to DDT, others less so. Until more can be learned about chlordane it should be considered as having potentialities for developing a toxic residue.

CONCLUSIONS

Agricultural chemicals that are to be applied to crops or soils year after year should be either nontoxic to plants when mixed in the soil or nonaccumulative in the soil.

Persistent toxic substances that will accumulate in the soil upon repeated use at short intervals should be replaced by non-persistent or nontoxic substances.

Pending the development of more definite information on the accumulative effects of various new agricultural chemicals under practical field use, such chemicals should be used only when others are known to be ineffective. Dosages and frequency of application should be kept strictly to the minimum recommended by competent specialists. Improvising, improper use, and excessive use by growers are to be firmly discouraged because they often cause serious losses.

Heavy annual use of DDT, technical BHC, and probably other persistent chlorinated hydrocarbons appears to have definite danger of reducing within a comparatively few years the productivity of soils to which they are applied.

Research workers, in both public and private organizations, should investigate the accumulative effects of the new agricultural chemicals as extensively as possible in the immediate future

⁶ W. E. Fleming and R. D. Chisholm, Bureau of Entomology and Plant Quarantine, found 4 to 5½ pounds of chlordane remaining in soil more than a year after applying about 10 and 20 pounds per acre. Unpublished data.

to determine safe limits of use on the different soils for various crops in the several States. It is especially important that these studies be made in order to insure against the use of any persistent substance to the extent that it causes a reduction in soil productivity.

It is similarly important to determine which new substances can be used indefinitely with little or no danger of accumulating harmful residues. The use of valuable and safe substances should be encouraged. The commercial production of such substances should be increased to permit an orderly replacement of persistent toxic substances before trouble is encountered from too long continued use of the latter.

LITERATURE CITED

- (1) AGUILAR, J. D', and GRISON, P.
1948. ETUDE SUR LE PROBLEME DES TAUPINS EN BRETAGNE. Acad. d'Agr. de France Compt. Rendt. 34 : 261-267.
- (2) ALBERT, W. B.
1933. ARSENIC TOXICITY IN SOILS. S. C. Agr. Expt. Sta. Ann. Rpt. 46 : 44-45.
- (3) ALLEN, N., BONDY, F. F., BULLOCK, J. R., and others.
1949. TWO YEARS' RESULTS OF EXPERIMENTS AT FLORENCE, S. C. ON TOLERANCE OF CERTAIN CROPS TO DDT, BENZENE HEXACHLORIDE, AND TOXAPHENE. U. S. Bur. Ent. and Plant Quar., 12 pp. [Unpublished data.]
- (4) BLODGETT, E. C.
1941. A SYSTEMIC ARSENIC TOXICITY OF PEACH AND APRICOT ON OLD APPLE LAND. U. S. Bur. Plant Indus. Plant Dis. Rptr. 25 : 549-551. [Processed.]
- (5) BONNEMAISON, M. L.
1947. ESSAIS PRÉLIMINAIRES DE TRAITEMENTS CONTRE LES TAUPINS. Acad. d'Agr. de France Compt. Rendt. 33 : 556-559.
- (6) BOURNE, B. A.
1948. EFFECTS OF BENZENE HEXACHLORIDE AND CHLORDANE ON THE GERMINATION OF SUGARCANE CUTTINGS. Sugar Jour. 10(8) : 3, 4, 20.
- (7) BROOKS, J. W., and ANDERSON, L. D.
1947. TOXICITY TESTS OF SOME NEW INSECTICIDES. Jour. Econ. Ent. 40 : 220-228, illus.
- (8) CHAPMAN, R. K., and ALLEN, T. C.
1948. STIMULATION AND SUPPRESSION OF SOME VEGETABLE PLANTS BY DDT. Jour. Econ. Ent. 41 : 616-623, illus.
- (9) CHULSKI, K.
1948. THE EFFECT OF BENZENE-HEXACHLORIDE ON SOME CROPS GROWN ON VARIOUS SOIL TYPES. Mich. Agr. Expt. Sta. Quar. Bul. 31 : 170-177.
- (10) CLAUSEN, R., and GUNTART, E.
1946. ESSAI DE LUTTE CONTRE LE VER BLANC (MELOLONTHA MELOLONTHA L.) AVEC L'HEXACHLOROCYCLOHEXANE. Premier Cong. Internat. de Phytopharmacie. Pp. [289]-294. Heverlee, Belgium.
- (11) COOPER, H. P., PADEN, W. R., HALL, E. E., and others.
1931. EFFECT OF CALCIUM ARSENATE ON THE PRODUCTIVITY OF CERTAIN SOIL TYPES. S. C. Agr. Expt. Sta. Ann. Rpt. 44 : 28-36, illus.
- (12) ——— PADEN, W. R., HALL, E. E., and others.
1932. SOILS DIFFER MARKEDLY IN THEIR RESPONSE TO ADDITIONS OF CALCIUM ARSENATE. S. C. Agr. Expt. Sta. Ann. Rpt. 45 : 23-28, illus.
- (13) FLEMING, W. E.
1948. CHLORDAN FOR CONTROL OF JAPANESE BEETLE LARVAE. Jour. Econ. Ent. 41 : 905-912, illus.

- (14) FLEMING, W. E.
1948. EFFECT ON PLANTS OF DDT APPLIED TO SOIL FOR THE DESTRUCTION OF JAPANESE BEETLE LARVAE. U. S. Bur. Ent. and Plant Quar. E-737 (rev.), 45 pp. [Processed.]
- (15) ——— BAKER, F. E., and KOBLITSKY, L.
1943. EFFECT OF LEAD ARSENATE IN SOIL ON VEGETABLES. Jour. Econ. Ent. 36 : 231-233.
- (16) GOLDSWORTHY, M. C.
1948. EFFECT OF SOIL APPLICATIONS OF VARIOUS CHLORINATED HYDROCARBONS ON THE TOP GROWTH OF BLAKEMORE STRAWBERRY PLANTS. U. S. Bur. Plant Indus., Soils, and Agr. Engin. Plant Dis. Rptr. 32 : 186-188. [Processed.]
- (17) ———
1948. EFFECT OF TECHNICAL DDT, INCORPORATED IN QUARTZ SAND AND SOILS ON THE GROWTH OF PEACH TREES. U. S. Bur. Plant Indus., Soils, and Agr. Engin. Plant Dis. Rptr. 32 : 437-441, illus. [Processed.]
- (18) ——— and DUNEGAN, J. C.
1948. THE EFFECT OF INCORPORATING TECHNICAL DDT IN SOIL ON THE GROWTH OF BLAKEMORE STRAWBERRY PLANTS. U. S. Bur. Plant Indus., Soils, and Agr. Engin. Plant Dis. Rptr. 32 : 139-143, illus. [Processed.]
- (19) ——— and WILSON, R. A.
1948. EFFECT OF SOIL APPLICATIONS OF "PARATHION" ON THE TOP GROWTH OF BLAKEMORE STRAWBERRY PLANTS. U. S. Bur. Plant Indus., Soils, and Agr. Engin. Plant Dis. Rptr. 32 : 388-390, illus. [Processed.]
- (20) GRAYSON, J. M., and POOS, F. W.
1947. SOUTHERN CORN ROOTWORM AS A PEST OF PEANUTS. Jour. Econ. Ent. 40 : 251-256.
- (21) HEADDEN, W. P.
1908. ARSENICAL POISONING OF FRUIT TREES. Colo. Agr. Expt. Sta. Bul. 131, 27 pp., illus.
- (22) JAMESON, H. R., THOMAS, F. J. D., and WOODWARD, R. C.
1947. THE PRACTICAL CONTROL OF WIREWORM BY γ -BENZENE HEXACHLORIDE ('GAMMEXANE'): COMPARISONS WITH DICHLORODIPHENYLTRICHLOROETHANE (D.D.T.). Ann. App. Biol. 34 : 346-356.
- (23) JONES, J. S., and HATCH, M. B.
1937. THE SIGNIFICANCE OF INORGANIC SPRAY RESIDUE ACCUMULATIONS IN ORCHARD SOILS. Soil Sci. 44 : 37-63, illus.
- (24) ——— and HATCH, M. B.
1945. SPRAY RESIDUES AND ASSIMILATION OF ARSENIC AND LEAD. Soil Sci. 60 : 277-288.
- (25) KOSTOFF, D.
1948. CYTOGENETIC CHANGES AND ATYPICAL GROWTH INDUCED BY HEXACHLOROCYCLOHEXANE ($C_6H_6Cl_6$). Current Sci. [India] 17 : 294-295.
- (26) KULASH, W. N.
1947. SOIL TREATMENT FOR WIREWORMS AND CUTWORMS. Jour. Econ. Ent. 40 : 851-854.
- (27) ———
1949. FURTHER TESTS WITH SOIL INSECTICIDES TO CONTROL SOUTHERN CORN ROOTWORM. Jour. Econ. Ent. 42 : 558-559.
- (28) LANE, M. C., STONE, M. W., LANCHESTER, H. P., and others.
1948. STUDIES WITH DDT AS A CONTROL FOR WIREWORMS IN IRRIGATED LANDS—PROGRESS REPORT. U. S. Bur. Ent. and Plant Quar. E-765, 9 pp. [Processed.]
- (29) LHOSTE, J., and RAVAUULT, L.
1948. EFFETS SUR BLÉ ET POIS, DE QUELQUES INSECTICIDES ORGANIQUES DE SYNTHÈSES, EMPLOYÉS COMME DESINFECTANTS DU SOL. Rev. Hort. [Paris] (n.s.) 31 : 287-294, illus.
- (30) MCLEOD, W. S.
1946. EFFECT OF HEXACHLOROCYCLOHEXANE ON ONION SEEDLINGS. Jour. Econ. Ent. 39 : 815.

- (31) MORRIS, O. M.
1937. RE-ESTABLISHING AND MAINTAINING COVER CROPS IN APPLE ORCHARDS. Wash. State Hort. Assoc. Proc. 33 : 67-72.
- (32) MORRISON, H. E., CROWELL, H. H., CRUMB, S. E., JR., and LAUDERDALE, R. W.
1948. THE EFFECTS OF CERTAIN NEW SOIL INSECTICIDES ON PLANTS. Jour. Econ. Ent. 41 : 374-378.
- (33) PADEN, W. R., and ALBERT, W. B.
1930. EFFECT OF THE ADDITION OF ARSENICAL COMPOUNDS TO SOILS. S. C. Agr. Expt. Sta. Ann. Rpt. 43 : 31-33, illus.
- (34) PATRICK, S. R., CROSIER, W. F., and HOLT, C. E.
1947. THE TOLERANCE OF SEEDS TO DDT. Assoc. Off. Seed Anal. No. Amer. Proc. 1947 : 166-169, illus.
- (35) PEPPER, B. B., WILSON, C. A., and CAMPBELL, J. C.
1947. BENZENE HEXACHLORIDE AND OTHER COMPOUNDS FOR CONTROL OF WIREWORMS INFESTING POTATOES. Jour. Econ. Ent. 40 : 727-730.
- (36) REED, J. F., and STURGIS, M. B.
1936. TOXICITY FROM ARSENIC COMPOUNDS TO RICE ON FLOODED SOILS. Amer. Soc. Agron. Jour. 28 : 432-436.
- (37) RIHERD, P. T.
1949. DDT AND BENZENE HEXACHLORIDE TO CONTROL SOUTHERN ROOT-WORM. Jour. Econ. Ent. 42 : 992-993.
- (38) ROBERTS, R.
1947. SOIL TREATMENT TO CONTROL *BLAPSTINUS* WIREWORMS. Jour. Econ. Ent. 40 : 571-572.
- (39) SAKIMURA, K.
1948. RESIDUAL TOXICITY OF HEXACHLOROCYCLOHEXANE INCORPORATED IN SOIL. Jour. Econ. Ent. 41 : 665-666.
- (40) SMITH, N. R., and WENZEL, M. E.
1947. SOIL MICROORGANISMS ARE AFFECTED BY SOME OF THE NEW INSECTICIDES. Soil Sci. Soc. Amer. Proc. 12 : 227-233.
- (41) SNYDER, J. C.
1935. CROPS PLANTED IN PULLED ORCHARDS. Wash. State Hort. Assoc. Proc. 31 : 48-54.
- (42) STITT, L. L., and EVANSON, J.
1949. PHYTOTOXICITY AND OFF-QUALITY OF VEGETABLES GROWN IN SOIL TREATED WITH INSECTICIDES. Jour. Econ. Ent. 42 : 614-617.
- (43) VANDECAVEYE, S. C., HORNER, G. M., and KEATON, C. M.
1936. UNPRODUCTIVENESS OF CERTAIN ORCHARD SOILS AS RELATED TO LEAD ARSENATE SPRAY ACCUMULATIONS. Soil Sci. 42 : 203-214, illus.
- (44) VINCENT, C. L.
1939. PROBLEMS IN VEGETABLE AND SMALL FRUIT PRODUCTION ON TOXIC ORCHARD SOILS OF CENTRAL WASHINGTON. Amer. Soc. Hort. Sci. Proc. 37 : 680-684.
- (45) WILSON, J. K., and CHOUDHRI, R. S.
1946. EFFECTS OF DDT ON CERTAIN MICROBIOLOGICAL PROCESSES IN THE SOIL. Jour. Econ. Ent. 39 : 537-538.
- (46) ——— and CHOUDHRI, R. S.
1948. THE EFFECT OF BENZENE HEXACHLORIDE ON SOIL ORGANISMS. Jour. Agr. Res. 77 : 25-32.
- (47) YOUNG, H. C., and GILL, J. B.
1948. SOIL TREATMENTS WITH DDT TO CONTROL THE WHITE-FRINGED BEETLE. U. S. Bur. Ent. and Plant Quar. D-750, 8 pp.
[Processed.]

☆ U. S. GOVERNMENT PRINTING OFFICE: 1951-914042