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EXPERIMENTS WITH DDT FOR CONTROL OF INSECTS ATTACKING
CEREAL AND FORAGE CROPS IN THE FIELD AND IN STORAGE

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Experiments conducted with DDT (1-trichloro-2,2-bis(p-chlorophenyl) ethane) during 1944 for the control of various insects that attack cereal and forage crops in the field, and grains, seeds, and milled cereal products in storage, are briefly summarized in this paper. In considering these results it should be clearly understood that no recommendations are being made for the practical use of DDT on any of these crops or against any of these insects. Many questions remain unanswered relative to best mixtures or solutions to use, dosages to apply, application schedules, residue hazards, effects on beneficial insects, and results when used under conditions different from those prevailing in this year's experiments. Further investigations are necessary in order to obtain the answers to these questions.

Grasshoppers

In field trials by J. R. Parker, E. J. Hinman, and C. C. Wilson, various concentrations and dosages of DDT in pyrophyllite were applied as dusts to alfalfa and range grasses in Arizona, California, and Wyoming. The results indicated that very high mortality of grasshoppers, including Melanoplus mexicanus (Sauss.), M. bivittatus (Say), M. femur-rubrum (Deg.), and Camnula pellucida (Scudd.), can be obtained from a single treatment with 15 to 20 pounds per acre of dusts containing 15 to 20 percent of DDT. Good control was also obtained with sprays made from a dust containing 10 percent of DDT in pyrophyllite mixed with water to give 0.36 to 0.48 percent of DDT. The results of very limited trials of an aerosol containing 3 percent of DDT and 1.5 percent of pyrethrum extract were inconclusive.

Fair to good mortality of grasshoppers was obtained by Mr. Wilson from a single application, at the rate of about 20 pounds per acre, of a bait mixture containing the following proportions: 3 pounds of powdered technical DDT, 100 pounds of wheat bran, 1 gallon of molasses, and 1-1/2 gallons of water.

Chinch Bug

In field tests conducted by P. Luginbill and C. Benton near Lafayette, Ind., barrier lines of dust containing 5 percent or more of DDT in pyrophyllite, applied at the rate of about 1 pound per rod, gave excellent protection of corn from immature chinch bugs (Blissus leucopterus (Say)) migrating to it on foot from adjacent wheat. The dust did not act as a repellent or prevent some of the bugs from reaching the corn, but it killed them before they were able to injure the corn materially. Dusts containing lower percentages of DDT were not tested but may be found effective.

Heavy applications of dusts containing 1 to 5 percent of DDT in pyrophyllite directly to the infested portions of the corn plants and the surface of the soil close to them gave excellent control of the bugs without discernible injury to the plants.

Lygus Bugs Attacking Seed Alfalfa

In control experiments with Lygus spp. conducted by F. V. Lieberman on seed alfalfa at Gandy, Utah, one application of a pyrophyllite dust containing 10 percent of DDT at $27\frac{1}{2}$ pounds per acre of the dust produced 135 to 725 pounds of thresher-run seed per acre, with an average of 428 pounds as compared with practically complete loss of the seed crop in undusted areas. The seed matured earlier in the DDT-treated plots and was riper and cleaner than that produced in plots treated with other insecticides. Owing to an early frost, seed from most of the plots treated with other insecticides was badly blackened and all seed in them that might have matured in the cocks was shriveled. The results were affected, however, by uneven soil moisture in the various plots and the abnormally early frost, so that the comparative effectiveness of the different treatments could not be closely evaluated. The DDT was applied during the pre-bloom stage after the buds had formed but before many flowers had opened, in order to avoid killing wild bees essential to pollination. No domestic bees were present in the area.

So far as could be observed the DDT had no repellent effect on, and caused no mortality of, the wild bees. The experiments indicated the possibility that DDT can be used without appreciable harm to domestic or wild bees provided application during the main blooming period is avoided, but further observations are necessary for the settlement of this question. Large aphid and thrips populations in the treated plots were virtually eliminated. Other insects, such as coccinellid beetles and larvae, nabid nymphs and adults, grasshoppers, flies, and lepidopterous larvae, were killed. The highly migratory species constantly reinfested the plots, but their numbers were usually less in DDT-treated than in untreated plots, indicating that this insecticide has a lasting residual effect.

Vetch Bruchid

Field experiments near Oregon City and Dayton, Ore., indicated DDT to be very promising for the control of the vetch bruchid (Bruchus brachialis Fahraeus) attacking hairy vetch seed. L. P. Rockwood and M. M. Reeher found that on hairy vetch two applications of a dust containing 5 percent of DDT in pyrophyllite, at rates of 22 to 25 pounds of the dust per acre as the pods began to set and 15 days later, gave excellent control of the vetch bruchid without visible injury to the plants; and were significantly better than two applications of a dust containing 1 percent of rotenone at approximately the same rates per acre. The DDT remained effective much longer than the rotenone, and it seemed probable that three or four applications of the latter would have been necessary to equal two applications of the DDT in effectiveness. A single application of a dust containing 3 percent of DDT in pyrophyllite, at the rate of 22 to 25 pounds per acre applied 10 days too late for best results on 5 acres of hairy vetch at Dayton gave commercially profitable although not full control. The season's results indicate that one well-timed application of 3 percent DDT dust at 25 to 35 pounds per acre may give adequate control of the vetch bruchid. Several other species of insects, including coccinellid beetles, were killed by the DDT, and also by the rotenone dust and by an arsenical bait spray that was being tested. Very few aphids and no syrphid or coccinellid larvae appeared to have been affected. No dead bees were found nor could any decrease be noted in the number of live honeybees swept from the dusted plots. Bees may be an aid to good pollination of hairy vetch, however, and more conclusive observations are necessary to determine what effect the application of DDT to this crop may have on them.

Velvetbean Caterpillar

Excellent control of the velvetbean caterpillar (Anticarsia gemmatilis (Hbn.)) on peanuts and soybeans was obtained by H. C. Young, of this Bureau, and L. L. English, of the Alabama State Agricultural Experiment Station, in field tests with single applications of DDT dusts and sprays. A dust containing 3 percent of DDT in pyrophyllite was effective and the results indicated that more dilute dusts might also be satisfactory. Further information is needed to determine the best dust and spray preparations and dosages to apply for control of this insect. Mr. Young observed that the residue of several applications of a concentrated DDT spray, obtained by mixing 10 percent DDT-pyrophyllite dust in water containing a small percentage of spreader, to peanuts in July, for control of the white-fringed beetle, was effective against an infestation by the velvetbean caterpillar which developed in mid-September.

Potato Leafhopper on Alfalfa and Peanuts

At Beltsville, Md., F. W. Poos obtained a great reduction in numbers of the potato leafhopper (Empoasca fabae (Harr.)) on alfalfa and peanuts by two applications 9 days apart of a dust containing 2 percent of DDT in pyrophyllite, or of a spray consisting of a mixture of 0.66 percent of DDT in dust form with water, with a spreader added. Material increase in yield and quality of hay was obtained in the treated alfalfa plots. Two applications 16 days apart of the same spray and dust to peanuts resulted in great reduction of the leafhopper population but no increase in yield because of severe leaf spot infection on both treated and untreated plots late in the season.

Tobacco Thrips on Peanuts

Observations and experiments by F. W. Poos, at Beltsville, Md., have indicated that the tobacco thrips (Frankliniella fusca (Hinds)) is the chief cause of the widespread injury to young peanut plants commonly known as pouts. In an effort to determine primarily how much effect this injury has on yields, seven applications of 2 percent DDT-pyrophyllite dust were made at 3- to 8-day intervals to one series of plots, 8 applications at 4- to 6-day intervals of a spray containing 0.66 percent of DDT, obtained by mixing a 10 percent DDT-pyrophyllite dust with water and a small percentage of spreader, to another series, and 8 applications at 4- to 6-day intervals of an aerosol containing 10 percent of DDT to a third series. Good control of the thrips and decided increases in yield resulted from all these treatments, with no evidence of injury to the plants.

European Corn Borer in Sweet Corn

Following favorable results from preliminary trials of DDT by D. D. Questel in 1943 for the control of the European corn borer (Pyrausta nubilalis (Hbn.)) in sweet corn, experiments were continued in 1944 near Toledo, Ohio. In field-plot tests conducted by C. H. Batchelder, in which different strengths and dosages of DDT in pyrophyllite were applied with ground equipment, borer reductions of 72 to 91 percent were obtained by four applications at 5- to 7-day intervals of dusts containing 3 to 6 percent of DDT, at 1.2 to 2.4 pounds of DDT per acre-application. Four aerial applications at 3- to 5-day intervals of a dust mixture of 3.75 percent DDT in pyrophyllite, at approximately 1.5 pounds of DDT per acre-application, gave borer reductions of 74 percent in the plants and 82 percent in the ears. Excellent control was obtained on the sweet corn variety Evergreen from four aerial applications at 3- to 5-day intervals of a concentrated spray containing 8.9 percent of DDT dissolved in a horticultural oil, at the rate of about 2 pounds of DDT per acre-application.

Three applications at 5-day intervals of sprays containing approximately 0.05 percent of DDT were made by Mr. Questel in another series of plots, at the rate of 0.76 pound of DDT per acre-application. These sprays were made by mixing a pyrophyllite dust containing 10 percent of DDT with water and a small percentage of spreader. The treatments resulted in 92 to 98 percent reductions in numbers of borers in the plants as compared with the populations in check areas.

Corn Earworm in Sweet and Seed Corn

Injection of white mineral oil containing 1 percent or more of DDT into the silks of sweet corn ears produced 85 to 99 percent of worm-free ears, in experiments conducted by J. Wilcox, of the Division of Truck Crop and Garden Insect Investigations in southern California fields heavily infested with the corn earworm (Heliothis armigera (Hbn.))

A variety of oil solutions and emulsions of DDT in concentrations of 0.5 to 2 percent were tested by R. A. Blanchard in Illinois on ears of sweet corn and on dent corn grown for seed, by injection into the silks and atomization on them, for the control of the earworm. From 91 to 100 percent of worm-free ears were obtained by either injection or atomization of 2 percent of DDT in undiluted white mineral oil. Various degrees of control were obtained with the different emulsions. The results indicate that one may be found that will give high protection from the earworm when it is atomized on the ears, at comparatively low cost and with no injury to the ears or plants.

Corn Flea Beetle

Good protection of young sweet corn from the corn flea beetle (Chaetognema pulicaria Melsh.) and considerable reduction in the bacterial wilt which it transmits were obtained in experimental plots of a wilt-susceptible and a wilt-resistant variety conducted by F. W. Poos at Beltsville, Md. Following 5 applications of 0.66 percent DDT spray, obtained by adding 10 percent DDT-pyrophyllite dust to water containing a small percentage of spreader, at intervals of 3 to 6 days, only 2 beetles were found on a treated row of corn as compared with 128 on an untreated row. In the susceptible variety a much better stand was maintained in the treated rows than in the untreated rows.

White-fringed Beetle

The high effectiveness of DDT obtained in preliminary tests by H. C. Young and staff during 1943, both as a stomach and a contact poison for the white-fringed beetle (Pantomorus leucoloma (Boh.)), was substantiated by various experiments carried on by them at Florala, Ala., in 1944. In these tests a dust containing 10 percent of DDT in pyrophyllite was used in the preparation of all dusts, sprays, and soil treatments.

Sprays containing 1/8 pound or more of DDT and 0.1 pound of a wetting agent per 100 gallons of water, applied to peanut and chrysanthemum foliage as a stomach poison, gave mortalities of adult beetles in excess of 90 percent, and were as effective as a spray containing 8 pounds of synthetic cryolite (approximately 90% sodium fluoaluminate) and 0.1 pound of wetting agent per 100 gallons of water. Sprays containing 1/2 pound of DDT in dust form per 100 gallons of water with wetting agent gave an average mortality of 93 percent of adults when applied as a contact poison.

DDT dusts applied as a contact poison against the adults of the white-fringed beetle showed that lighter dosages gave greater mortalities when applied to the surface of the soil on which the beetles crawled than when applied to the beetles themselves. Heavier dosages were more effective when applied to the beetles. Pyrophyllite dust containing 5 percent of DDT applied to the beetles and on the soil at the rate of 0.774 pound of DDT per acre gave 88 percent mortality. The fact that DDT applied to the surface of the soil is effective as a contact poison against the adults is considered the most important finding of the 1944 season.

DDT dusts applied to the foliage remained effective against adults for about 5 days or until 0.25 to 0.50 inch of rain had fallen. When no rain fell, the dusts gave fair mortality for more than 5 days. A dilute spray containing 0.2 pound of DDT, 2 pints of fish oil, and 0.1 pound of a wetting agent per 100 gallons of water remained effective for about 10 days. A concentrated spray containing 4 pounds of DDT, 20 pints of fish oil, and 1.14 pounds of a wetting agent per 100 gallons of water gave an average mortality of 66 percent after 10 days' exposure and 5.07 inches of rain, and 56 percent after 15 days' exposure and 7.95 inches of rain.

When mixed with the top 3 inches of soil, DDT at 50 and 100 pounds per acre caused mortalities of 34 and 65 percent of the adults, respectively, by the end of 7 days, in field cages containing potted chrysanthemum plants in untreated soil as food.

In laboratory tests DDT applied to soil at rates of 25 to 250 pounds per acre gave mortalities of larvae in the soil of from 85 to 100 percent. It was more effective against half-grown than against larger larvae. Lead arsenate similarly tested at the rate of 1,000 pounds per acre did not cause any mortality, while DDT at 50 pounds per acre gave 95 percent mortality of half-grown larvae during the 30-day test period.

In small salve-box tests of baits against three-fourths grown larvae in moist sterile soil, peanut meal containing 10 percent of DDT caused 50 percent mortality in 15 days, while ground whole peanuts containing 1 and 5 percent of DDT caused 95 and 100 percent mortality, respectively, in 15 days.

DDT used in a water suspension did not kill the eggs of the white-fringed beetle, but when dissolved in kerosene at rates of 1.6 to 6.4 grams per 100 ml. it was an effective ovicide.

Radishes grown in soil containing 250 pounds of DDT per acre, thoroughly washed, and then fed to three-fourths grown larvae caused no mortality in 33 days.

Germination of cotton, corn, peanut, oat, and cowpea seeds was not affected by treating them with a dust containing 50 percent of DDT in pyrophyllite before planting. Austrian winter peas, peanuts, rice, sweet potato, white potato, cotton, corn, cowpea, soybean, radish, and blue lupine have been grown in soil treated with various dosages of DDT up to 100 pounds per acre, and in the case of some of these crops, up to 250 pounds per acre, without visible injury. On the other hand, injury to young rye plants, consisting of reddening of foliage, twisting of leaves, poor growth, and dying of some plants, occurred in pot and field-plot tests in which DDT was used as a soil insecticide at rates of 10 to 250 pounds of DDT per acre in dust or emulsified form. Where DDT was applied as an emulsion the injury was very pronounced even at the 10-pound dosage. The injury caused by the dust treatments was slight at the 10-pound dosage but increased with the dosage.

Large-scale field trials of DDT in a 2.5-percent dust, a concentrated spray, and a dilute spray were conducted in cooperation with the white-fringed beetle control unit of the Division of Domestic Plant Quarantines, using power ground equipment and an airplane. These preparations were highly effective against the adults, but the complete results will not be available until populations of their larval progeny in treated and check areas can be determined during the spring of 1945.

Insects Attacking Stored Seeds, Grain, and Milled Cereals

Mixtures of DDT with seeds to protect them from insect infestation while in storage have been tested on a laboratory scale at Manhattan, Kans., by J. C. Frankenfeld and R. T. Cotton. They found that as little as 0.05 percent by weight of a pyrophyllite dust containing 3 percent DDT, or 15 parts of DDT per million, mixed with wheat seed containing 12, 14, and 16 percent of moisture was highly effective in protecting the wheat from the common insect pests of stored grain. Wheat seed mixed with as much as 0.2 percent by weight of undiluted technical DDT showed no loss of germination at the end of 4 months. Seed of corn, lettuce, tomato, and watermelon in 1 to 16-ounce paper packages, and bulk sunflower seed in cotton cloth bags, mixed with 0.05 percent by weight of undiluted DDT and exposed to heavy infestation for 2 months in the laboratory and in a seed warehouse, remained practically uninfested by most of the insects that commonly infest stored seed, while untreated checks became heavily infested. Cadelle and dermestid larvae were considerably more resistant than the other insects present. W. B. Cartwright also reported practically no control of dermestid larvae in dry wheat seed heavily treated with DDT dust at Lafayette, Ind.

DDT is one of the most efficient materials yet tested by Cotton and Frankenfeld for making paper or fabric bags and cardboard cartons of cereal products immune to insect attack. Paper bags or wrappers that had been immersed in a 10-percent solution of DDT in acetone or other solvent and dried apparently gave complete protection of the contents and were not cut through by the cadelle or other species which ordinarily penetrate almost any type of wrapping. Cotton cloth bags sprayed with or dipped in a 5-percent solution of DDT in carbon tetrachloride, dried, and filled with flour, were remarkably repellent to insects. Paper or cardboard wrappings coated with varnish containing 5 percent of DDT were also resistant to insect attack. DDT can also be applied in sizing or coating liquors, and there appear to be many possibilities for its use as a repellent in package materials.

Tests in Kansas by Dr. Cotton, H. H. Walkden, and assistants, of a refined odorless kerosene containing 5 or 6 percent of DDT sprayed on the interior walls and woodwork of empty farm grain bins, flour and seed storage rooms, and one story of a flour mill gave excellent control of cadelle, flour beetle, and silverfish infestations. In one empty farm bin approximately 8,000 dead cadelles were swept from the floor at the base of 10 linear feet of sprayed wall. For weeks after the treatment cadelles emerged from the walls and died. The cadelle burrows into the woodwork and walls of farm bins and literally honeycombs them. Many species of grain-infesting insects hide in these burrows and emerge to attack the new grain when it is placed in storage. The resulting damage to farm-stored grains amounts to millions of dollars annually. Milled cereal products in infested box cars or in storage in warehouses are similarly invaded by the cadelle, which will cut through almost any type of bag or container to reach the products within them, and thus permit the entry of other insects as well. The DDT-oil spray appears to offer the best means yet discovered of destroying insect infestations in woodwork of bins, storage rooms, warehouses, mills, and box cars.

Sugarcane Borer

Preliminary tests in southern Louisiana during the fall of 1943 by J. W. Ingram and assistants indicated that DDT was not so effective as undiluted cryolite in controlling the sugarcane borer (*Diatraea saccharalis* (F.)). These results were substantiated by further trials on field plots in Louisiana in 1944. Four weekly applications of an undiluted synthetic cryolite dust and an undiluted natural cryolite dust, both containing approximately 90 percent of sodium fluoaluminate, and a dust containing 10 percent of DDT in pryophyllite were made against first-generation borers in young cane, at the rate of 8 pounds per acre-application. These insecticides gave borer reductions of 81 to 85 percent, 65 to 80 percent, and 11 to 34 percent, respectively, as compared with borer populations in untreated check plots. When the same insecticides were similarly applied at the rate of 10 pounds per acre during midsummer on larger cane against second-generation borers, synthetic and natural cryolite gave reductions in joints bored of 61 and 50 percent, respectively, whereas the DDT plots had 18 percent more joints bored than the untreated check plots. Why DDT is so much less effective against this borer in cane than it is against the European corn borer in corn, since the two species have similar habits, is not apparent.

Yellow Sugarcane Aphid

In a replicated experiment conducted in Louisiana by Mr. Ingram and assistants in the fall of 1943, the number of leaves infested by the yellow sugarcane aphid (Sipha flava Forbes) was six times as great in the plots treated with DDT as in untreated plots, and more than twice as great as in plots treated with synthetic cryolite (approximately 90 percent sodium fluoaluminate). There was very little injury by this aphid in the 1944 experiments against the first-generation sugarcane borer, but in the experiment against the second-generation borer the aphid infestation was considerably greater in the plots treated with DDT than in those treated with cryolite or untreated.

White Grubs

In a single test by P. Luginbill at Lafayette, Ind., a dust containing 5 percent of DDT was applied to the soil in a cage at the rate of 242 pounds of DDT per acre and washed in with a copious sprinkling of water. This treatment had no effect on the white grubs (Phyllophaga spp.) that had been placed in the soil. Young corn plants that were about 8 inches tall when the DDT was applied were visibly affected. All of them appeared sickly and the tips of the leaves turned brown. This was a very preliminary experiment, however, and cannot be considered at all conclusive.

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