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TOXICITY OF INSECTICIDES AND ACARICIDES TO THE PAPAYA, *CARICA PAPAYA* L.

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TOXICITY OF INSECTICIDES AND ACARICIDES TO THE PAPAYA, *CARICA PAPAYA* L.

Martin Sherman and Minoru Tamashiro

INTRODUCTION

The papaya (*Carica papaya* L.), variously known as papaw, papaia, papeya, and papia, apparently is a plant of West Indian or Central American origin (de Candolle, 1864) that is now grown throughout most of the tropical and subtropical countries of the world. It has been reported distributed between 32 degrees north and south latitude. The papaya was introduced into Hawaii from the Marquesas Islands between 1800 and 1823 by an early Spanish settler (Storey, 1941), and has since become the most popular breakfast fruit in Hawaii.

Although banana still surpasses papaya in total acreage, the papaya ranks first in production and market value among fruits cultivated primarily for the fresh fruit market in Hawaii. Aside from pineapple, papaya has been the only fruit that has been shipped to the continental United States in any appreciable volume. Both production and export have been rapidly increasing during the past few years.

The papaya is a large dicotyledonous plant that can produce fruit continuously for 25 years or longer. In commercial production, however, because of the reduced yield obtained and the difficulties and hazards involved in harvesting fruit from tall old trees, the trees are replaced after 2 or 3 years of production (Hamilton, 1954). Orchards come into production about a year after transplanting. Almost all commercial plantings are of the hermaphroditic Solo variety.

The great majority of the pesticides utilized in Hawaii are formulated in the continental United States and tested for phytotoxicity on the crops that are grown there. Most of the information obtained, therefore, is not directly applicable to Hawaii, which is subtropical in climate and has crops which are characteristic of subtropical areas. Thus, it is necessary to study these formulations locally in order to obtain information on their performance under Hawaiian conditions. Partially because of the increasing importance of the papaya, its widespread distribution throughout the tropical and subtropical world, its availability, and its reported sensitivity to some of the widely used insecticides and acaricides, this plant was selected as the test organism to determine whether commercial pesticides formulated in the continental United States had any detrimental effects when applied under the more tropical conditions existing in Hawaii.

Pests of Papaya

Although the papaya is relatively free of pests, there are a few species of mites and insects that can become very destructive if control measures are not instituted promptly. The broad mite, *Hemitarsonemus latus* (Banks), in extremely heavy infestations, has been known to kill plants. This species is rather difficult to see with the naked eye; the adult females, the larger of the sexes, measuring only .20 to .25 mm. The whitish, translucent mites are found primarily on the lower surface of the younger leaves which become severely distorted from the feeding of these mites. Infested leaves are smaller, leathery in appearance with the edges curled downwards. The veins are whitish and stand out from the rest of the greenish or greenish-yellow leaves. The symptoms (fig. 1*a*) are very distinctive and once seen cannot easily be confused with other abnormalities. At temperatures existing in most Hawaiian papaya growing regions, the broad mite may deposit up to seven eggs daily and can complete its life cycle in 4 to 5 days. This may partially account for the rapidity with which extensive damage may occur in a grove (Holdaway, 1941).

The two-spotted spider mite, *Tetranychus telarius* (L.), in contrast to the broad mite, usually is found on the lower surface of the older foliage. In heavy infestations, leaves become matted with webbing and chlorotic spots resembling stippling may be visible on the upper surface of the leaf (fig. 1*b*). The entire leaf takes on a yellowish cast. Eggs are laid among the webbing and the adult stage may be attained in a little over 8 days at an average temperature of about 75° F. (Cagle, 1949). Each female may lay up to 190 eggs.

Brevipalpus phoenicis (Geijskes) is the third important mite of papaya. Until 1955, this mite had been recorded in the Hawaiian literature as *Tenuipalpus bioculatus* McGregor and the common name "privet mite" had been used in referring to this mite. However, this mite has recently been identified as *B. phoenicis* (Pritchard and Baker, 1951). Since the common name privet mite is applied only to *B. inornatus* (= *T. bioculatus*) in the official list of common names of insects approved by the Entomological Society of America (Sailer, *et al.*, 1955), this common name cannot be correctly applied to our species. *B. phoenicis* is a cosmopolitan species and has been recorded from a wide variety of hosts.

Although *B. phoenicis* is generally not too injurious to the papaya plant itself, it causes a scarification of the fruit (fig. 1*c*) which greatly reduces its market value. Affected areas which normally occur where the fruit touches the trunk, appear as brownish, scaly, sunken areas.

Until the advent of the organic acaricides, sulfur was the only material used for the control of the three important species of mites on papaya. It has been, and still is, one of the best and most economical materials for the control of the broad mite and *B. phoenicis*. The two-spotted mite, although

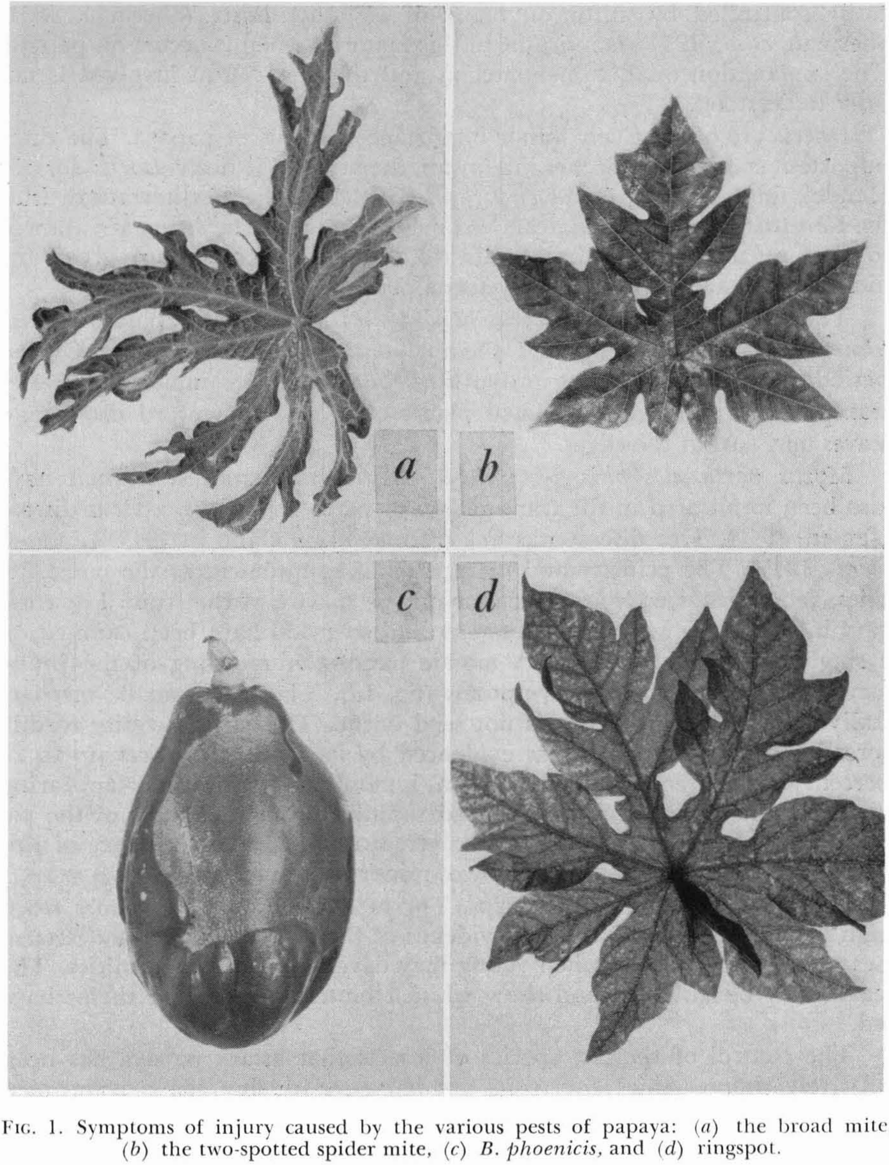

FIG. 1. Symptoms of injury caused by the various pests of papaya: (*a*) the broad mite, (*b*) the two-spotted spider mite, (*c*) *B. phoenicis*, and (*d*) ringspot.

easily controlled by sulfur on many of its other hosts (Sherman, 1951; Sherman, *et al.*, 1954), is resistant to this material when it occurs on papaya. The explanation of this phenomenon and the mechanism involved is not fully understood.

Insects are of relatively minor importance as pests of papaya. The three important species of fruit flies in Hawaii, the oriental fruit fly, *Dacus dorsalis* Hendel, the melon fly, *Dacus cucurbitae* Coq., and the Mediterranean fruit fly, *Ceratitis capitata* Wied., can become damaging if the fruits are allowed to ripen on the tree, but since fruits are normally picked mature green, the flies do not have an opportunity to oviposit in the fruits.

The green peach aphid, *Myzus persicae* Sulz., the potato aphid, *Macrosiphum solanifolii* (Ashm.), and the melon aphid, *Aphis gossypii* Glover, periodically reach damaging proportions in young trees immediately after transplanting. Petioles of infested plants take on a downward droop and leaves may curl at the edges.

Myzus persicae, Aphis gossypii, A. medicaginis, and *A. rumicis* have also been implicated in the transmission of papaya ringspot, a virus disease (Jensen, 1949). This disease was first discovered on Oahu in 1945 (Lindner, *et al.*, 1945). The primary and most striking symptom is, as the name implies, yellow rings with green centers on the surface of the fruit. The rings vary in size up to 3/4 inch in diameter and over 150 have been counted on a single fruit (Jensen, 1946). A mosaic pattern or mottling of the young leaves comprises the foliar symptoms (fig. 1*d*). The virus can be mechanically transmitted easily but is not seed borne. The virus is quite readily spread throughout orchards as evidenced by its ability to infect up to 25 percent of the trees in an orchard in 1 month. After initially appearing in the Kailua area, the disease spread rapidly throughout most of the papaya growing regions of Oahu. However, since 1950, the incidence of this disease has diminished and it is now of minor importance.

Populations of the onion thrips, *Thrips tabaci* Lind., sometimes reach high enough levels so that overt evidence of their presence can be detected. Leaves that are infested when young may develop serious deformities. The leaves may be distorted and show whitish blotches where the thrips have fed.

The control of the few species of insects that attack papaya has been relatively simple. Since the fruits are harvested during the mature-green stage of development, prior to becoming attractive ovipositional sites, there has been no necessity to spray for fruit flies. Aphids and thrips have been kept in check with nicotine sulfate. Since phytotoxicity is a problem on papaya, only materials that have been proven to be nonphytotoxic should be used. Nicotine sulfate has been efficient in the control of these pests and has shown itself to be nonphytotoxic, so farmers have frequently used this material on papaya.

EXPERIMENTAL METHODS

The Solo variety of papaya was used throughout these experiments. Seeds were germinated in vermiculite and the seedlings transplanted into No. 2½ cans containing sterilized soil. The plants were supplied with adequate water and fertilized regularly to promote vigorous growth. Treatments were initiated when the seedlings had attained heights ranging from 9.0 to 21.5 cm. In initial experiments, plants which were taller than 20 cm. were used but it was discovered that smaller, younger plants increased proportionately greater in height during the 5-week period required to complete an experiment. Also, when younger plants were used, growth differences were more pronounced between affected and normal plants. Therefore, in all subsequent experiments, plants averaging 11 cm. in height were used.

Prior to the initial spray treatment, the potted plants were brought into the laboratory and were assigned randomized treatment and replication numbers. The height of the seedlings was also measured at this time. This height was taken to be that distance from a point on the trunk, at the same level as the top of the container, to the base of the terminal growing point of the plant. A waxed cardboard plate, slotted to partially encircle the trunk, was laid on the top of the container. The point of contact between the plate and the trunk served as the lower reference point for the measurement. This procedure obviated accounting for differences in soil levels among the containers.

Spray Chamber

The plants were treated in a specially designed spray chamber (figs. 2, 3). This chamber was a rectangular structure fabricated of 16-gauge sheet metal and was provided with sliding wooden doors. The doors contained glass windows which permitted constant observation of the plants during the spraying operation. An exhaust fan, vented in the ceiling, removed the excess mist and toxic vapors after a treatment had been applied.

The airtight brass spray tank was composed of a removable cylinder and a screwlid which was bolted to the chamber. The compressed air intake hose, the liquid output hose, and an electrically-powered agitator were connected through the lid.

Two adjustable spray booms, each fitted with one spray nozzle, were arranged to direct the spray from above and below the passing plant.

The performance of the spray apparatus was determined under various conditions to select a satisfactory nozzle and pressure for the experimental work. The time required to deliver 500 ml. of tap water at different pressures and using various types of nozzles was measured. The data in terms of milliliters delivered per minute are shown in figure 4.

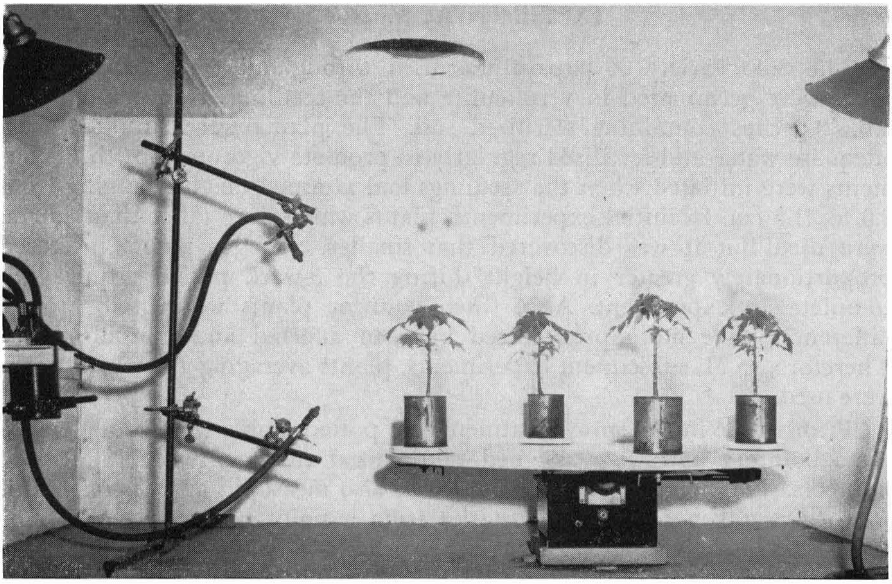

FIG. 2. The spray chamber.

The substitution of a 0.2 percent oil emulsion or a 1.25 percent sulfur suspension for tap water did not alter the delivery rate of this apparatus. A Teejet spray nozzle 1/4 T3 (Spraying Systems Co., Bellwood, Ill.) which delivered a hollow cone spray was selected for spraying the papaya plants. At 60 p.s.i. pressure, this nozzle delivered 488 ml. per minute. A volume of 800 ml. of each suspension or emulsion to be tested was used since this volume insured sufficient material to give complete coverage of the plants.

A modification of the Cornell Turntable (Hansberry, 1943) was used to facilitate the coverage of the potted plants. The turntable, which is shown in operation in figure 2, was made of 3/4-inch plywood, 39 inches in diameter, and contained four 3/8-inch shaft bearings. Each of four rotatable wooden disks approximately 6 inches in diameter, upon which the potted plants were placed, had attached to it a metal shaft to fit the bearings. Fastened to the lower end of the shaft was a hub from which projected three L-shaped arms spaced 120° apart (fig. 5). Each hub was removable since it was attached to the shaft by means of a set-screw.

The lower surface of the turntable had a flat circular metal plate which acted as a bearing surface for the turntable support rollers. A short shaft which rested in the turntable shaft bearing extended from the plate. This arrangement was superior to a direct drive mechanism since an accidental jarring of the turntable would not damage the transmission gears.

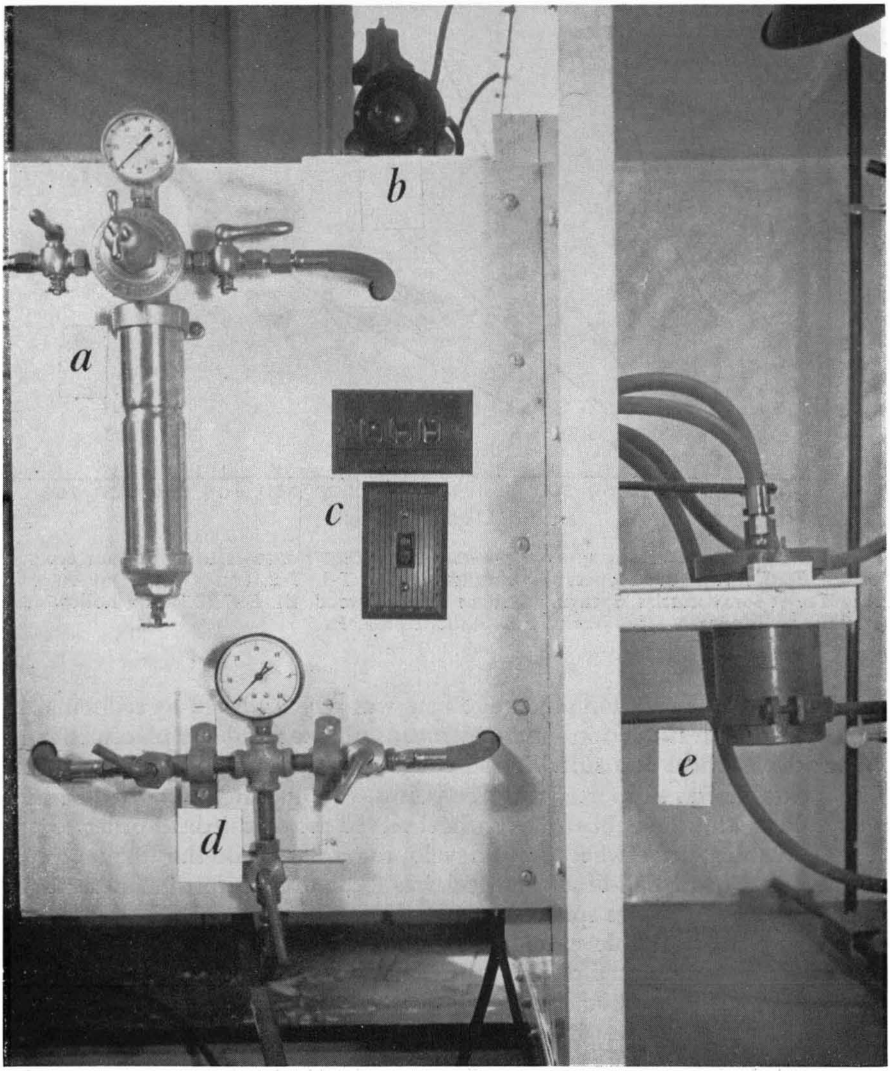

FIG. 3. Control panel for the spray chamber: (*a*) intake compressed air filter and pressure regulator; (*b*) variable speed control for spray agitator; (*c*) switches for turntable, lights, exhaust fan, and spray agitator; (*d*) pressure gauge and control valves for spray from tank to nozzles; (*e*) spray tank.

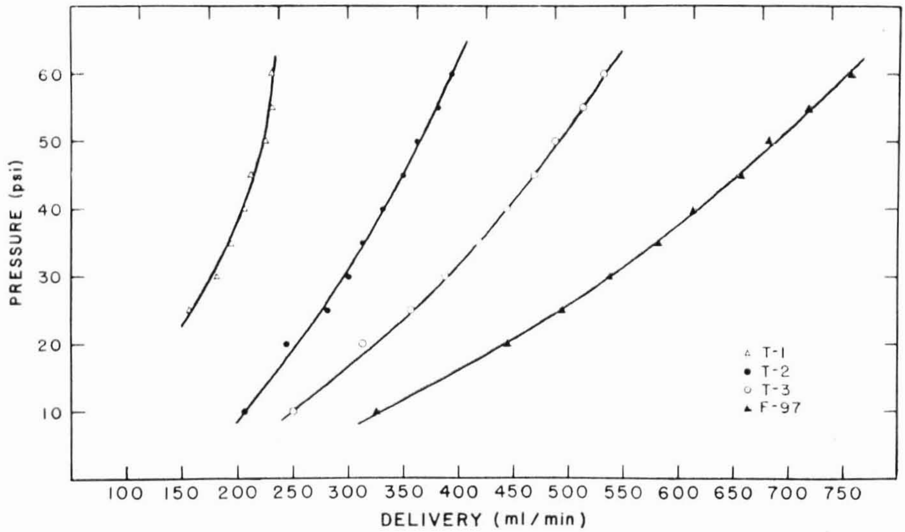

FIG. 4. Liquid delivery by spray apparatus at different pressures using various types of nozzles. Both spray booms operating simultaneously. T-1, T-2, and T-3 are hollow cone spray Teejet spray nozzles, Spraying Systems Co., Bellwood, Ill. F-97 (6.4) is a hollow cone spray nozzle, Monarch Mfg. Works, Inc., Philadelphia, Pa.

The turntable rotation speed of 3 rpm was accomplished by reducing the shaft speed of an induction motor by means of gears and the placement of a rubber drive wheel at a suitable radius from the turntable axis of rotation. The turntable was supported at three points, two of which were ball-bearing idler rollers, and the rubber drive wheel served as the third. In order to prevent the rubber drive wheel from developing a flat while the turntable was not in use, a third ball-bearing wheel was located close to the rubber drive wheel. This bearing was spring loaded on an arm so that the spring tension would lift the turntable enough to clear the rubber drive wheel. When potted plants were placed on the four wooden disks, their combined weights were sufficient to overcome the spring tension and allow the turntable to rest on the rubber drive wheel.

Figure 6 is a top view, cutaway diagram of the turntable operation. Upon rotation of the turntable, the vertical portion of the L-shaped arm of the disk entered the 1/4-inch-wide groove at point B of the *disk rotator*. This entry was facilitated by the curved *guide rail* whenever the entering L-shaped arm of the disk was slightly out of position. The *guide rail* was so curved that the distance of its tip (A) from the path of rotation of the center axis of the disk was greater than the length of the horizontal portion of the L-shaped arm. Thus, if the disk was out of position it would be guided into the proper path of rotation.

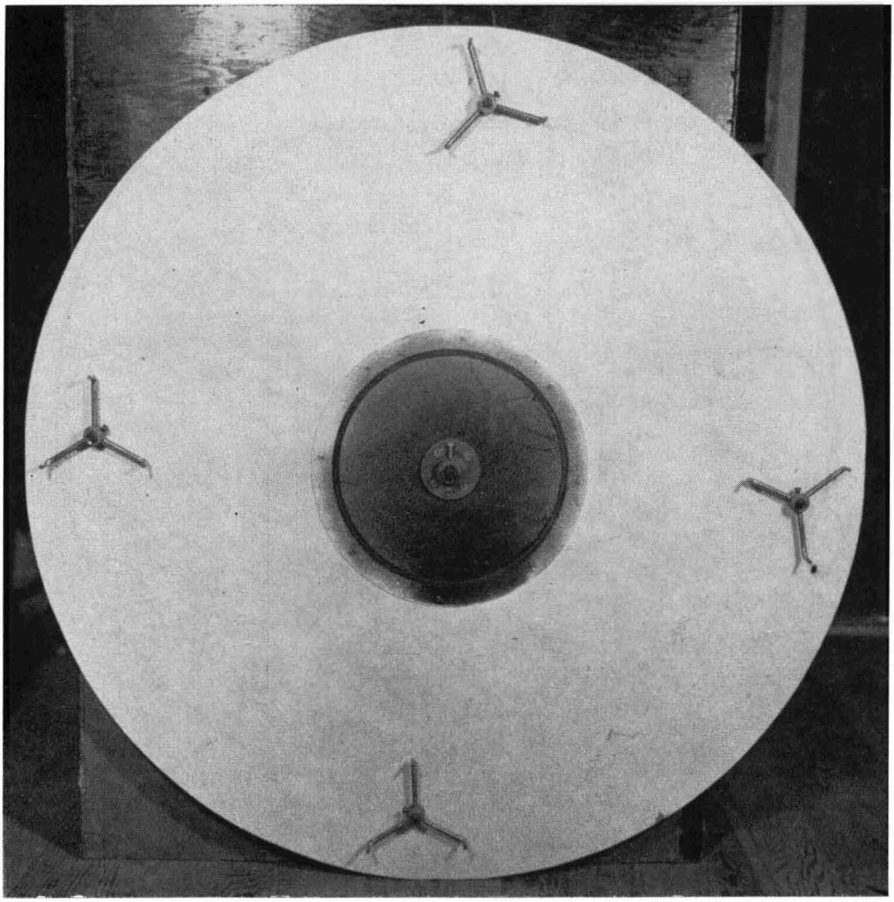

FIG. 5. Lower surface of turntable showing L-shaped arms and metal bearing surface for turntable support rollers.

Further rotation of the turntable caused the arm to slide within the groove, at the same time slowly rotating the disk. The arm entered the V-portion of the groove at position C. At this time, the disk was at the furthest point from the sprayer itself. There was a spring at this V-portion of the groove the purpose of which was to apply sufficient pressure on the vertical member of the L-shaped arm to insure its movement to the next leg of the V-portion of the groove. Without this spring, assuming that there was sufficient clearance for the vertical member of the arm to move across, there was a possibility that jamming would occur just prior to clearing the apex of the V due to imperfect machining. To further prevent jamming of the

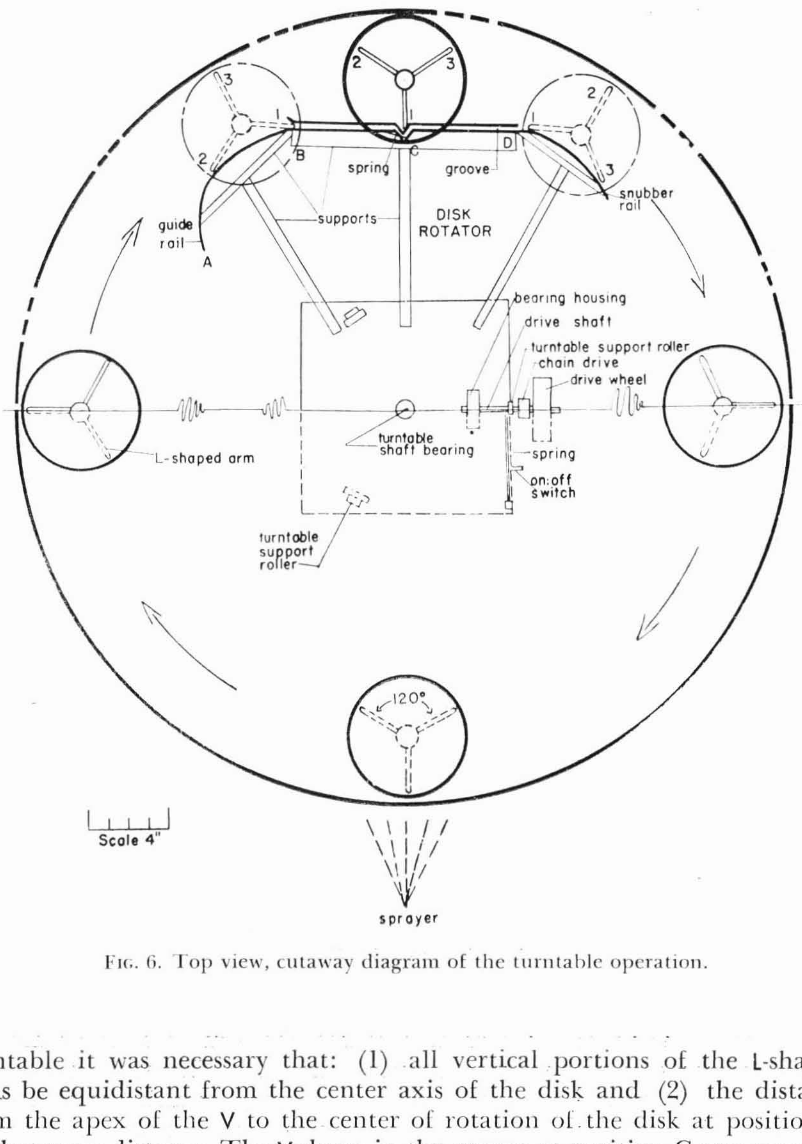

FIG. 6. Top view, cutaway diagram of the turntable operation.

turntable it was necessary that: (1) all vertical portions of the L-shaped arms be equidistant from the center axis of the disk and (2) the distance from the apex of the V to the center of rotation of the disk at position C be that same distance. The V-shape in the groove at position C was essential for the successful 120° rotation of the disk.

Upon still further rotation of the turntable, the arm left the groove at position D where the *snubber rail* prevented the disk from coasting by coming in contact with arm 3 and thus acting as a brake. At this point, the independent rotation of the disk ceased and as the turntable rotated to the spray position, the potted plant on the disk had been rotated through 120°. Thus one-third of each plant was exposed to the spray during each revolution of the turntable.

Materials Tested and Procedures

The phytotoxicity of formulations of the following pesticides singly or in pairs was determined: parathion, EPN, malathion, schradan, demeton, TEPP, Aramite, Chlorobenzilate, ovex, aldrin, DDT, dieldrin, heptachlor, sulfur, and the triethanolamine salt of dinitro-o-sec-butyl phenol. These are the accepted common names of pesticides designated by the Committee of Insecticide Terminology of the Entomological Society of America (Haller, 1957). Each treatment was applied to four plants and repeated at weekly intervals for 3 weeks unless otherwise noted. A commercial depositing agent and sticker,[1] composed of modified phthalic glycerol alkyd resin, was added at the rate of 1:2000 to all treatments including controls. After treatment, the plants were allowed to dry before they were placed outdoors on tables in a randomized block arrangement.

Phytotoxicity was measured in two ways: (1) effect on growth and (2) gross leaf pathology which included observations on defoliation, chlorosis, necrosis, curling, and other apparent abnormalities.

Final height measurements were taken 5 weeks after the initial treatment. The growth of the treated plants was compared with that of the control plants using the analysis of covariance (Snedecor, 1946).

The observations on the gross pathology of the leaves were made at frequent intervals during the course of each experiment.

In addition to the experiments with the papaya seedlings, an orchard was treated to determine the toxicity of pesticides to papaya flowers and fruits. The details of the experimental methods used in the fruit toxicity test will be discussed together with the results under the section entitled, "Effect of Pesticide Formulations on Fruit."

EXPERIMENTAL RESULTS

Effect of Pesticide Formulations on Seedlings

A total of 12 experiments were conducted to determine the phytotoxic effects of the acaricidal and insecticidal formulations on papaya. These formulations were tested initially at concentrations usually recommended for field application. Whenever these initial concentrations were toxic enough to significantly retard the growth of papaya, lower levels were used in subsequent experiments. As a result, certain materials such as parathion, EPN, demeton, and TEPP were studied in several experiments.

[1] Triton B-1956. Rohm and Haas Co., Philadelphia, Pa.

ORGANIC PHOSPHATE MATERIALS

These materials are active as both miticides and insecticides.

Parathion

Parathion was, by far, the most phytotoxic material studied. Table 1 summarizes the effect of treatment with a 25 percent wettable powder and an emulsifiable formulation containing 2 pounds of technical parathion per gallon on the growth of papaya. Suspension concentrations at 0.004 percent and emulsion concentrations as low as 0.002 percent caused significant re-

TABLE 1. Effect of parathion on the growth of the Solo papaya

Formulation[1]	Concentration actual lb./100 gal.	Percent actual parathion	Mean ht. (cm.) pre-spray[2]	Mean increase ht. (cm.) 2 weeks after 3rd spray[3]
		Expt. A		
25% W. P.	0.38	0.047	18.8	4.7**
	0.25	0.031	21.4	5.6**
	0.13	0.016	20.5	8.8**
25% E. (2 lb. act./gal.)	0.38	0.047	18.2	3.6**
	0.25	0.031	19.4	4.9**
	0.13	0.016	18.8	6.2**
Control	—	—	19.2	14.4
			L.S.D. (1%):	3.0
		Expt. B		
25% W. P.	0.063	0.0079	10.5	3.0**
	0.032	0.0039	10.7	4.1**
	0.016	0.0020	10.8	5.5
25% E. (2 lb. act./gal.)	0.063	0.0079	11.1	3.0**
	0.032	0.0039	11.8	4.3**
	0.016	0.0020	11.2	5.0**
Control	—	—	11.6	6.3
			L.S.D. (1%):	1.3
		Expt. C		
25% E. (2 lb. act./gal.)	0.016	0.0020	10.8	10.9
	0.008	0.00098	10.7	10.8
	0.004	0.00049	10.2	10.8
	0.002	0.00024	10.8	10.8
	0.001	0.00012	9.5	11.6
Control	—	—	11.5	10.9

[1] W.P.=wettable powder; E.=emulsifiable concentrate. Sprays were applied as follows: Expt. A, Aug. 26, Sept. 2, and Sept. 9, 1954; Expt. B, Jan. 13, 20, and 27, 1955; and Expt. C, June 7, 14, and 22, 1955.
[2] Measurements made just prior to 1st spray application.
[3] Final measurements were taken on: Sept. 23, 1954; Feb. 10, 1955; and July 5, 1955 for experiments A, B, and C, respectively.
** Growth significantly inferior to that of control plants.

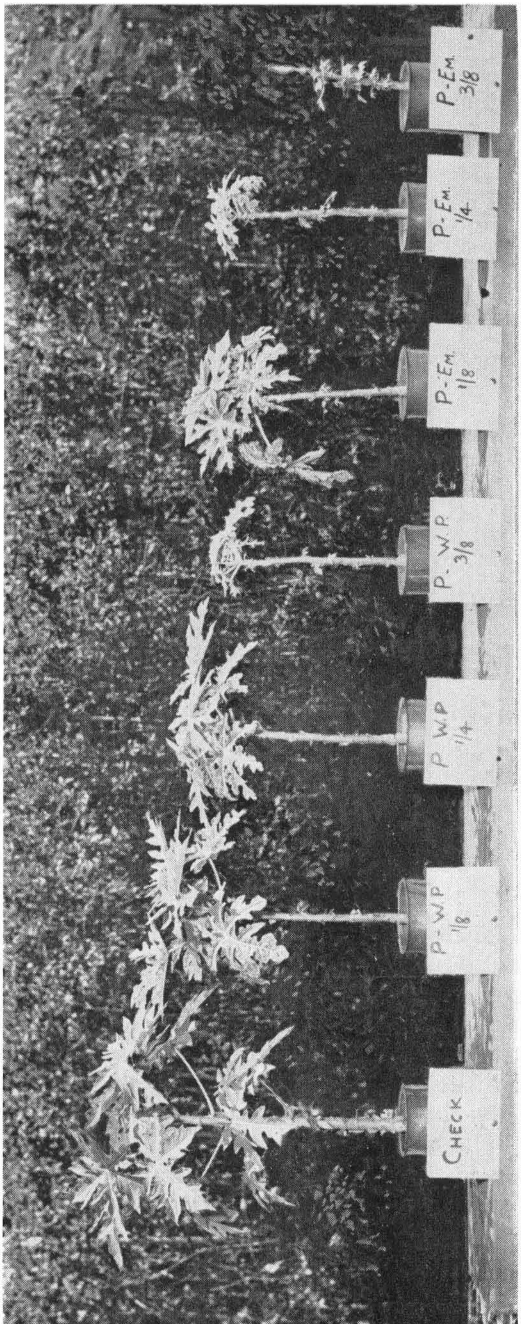

FIG. 7. Effect of three weekly applications of parathion on the growth and foliage of papaya. A comparison between wettable powder and emulsifiable formulations applied at concentrations equivalent to 1/8, 1/4, and 3/8 pound of actual parathion per 100 gallons. Note the "umbrella effect" shown by most of the treated plants.

FIG. 8. Severe defoliation (right) caused by three applications of 0.05 percent parathion emulsion. Untreated plant at left.

tardation of growth. These are far below the concentrations usually recommended for insect and mite control. In Experiment C, however, the emulsion at a concentration of 0.002 percent had no significant effect on growth. Whether this difference in effect was due to time of application or biological heterogeneity is not known. This concentration should, therefore, be considered detrimental to the papaya. In addition to being shorter in height, the plants were spindly; the diameter of the trunk measuring only one-half that of the untreated plants.

Parathion also caused very severe foliar injury (figs. 7 and 8). Within 2 days after the first application of insecticide, at concentrations greater than 0.016 percent parathion, dark spots appeared on the older leaves and gradually spread until the entire leaf turned black and died. Young leaves became mottled, presenting a crinkled appearance but in general were not as severely affected by parathion as were the older leaves. In both young and old leaves, abscission layer formation seems to have been initiated since a slight jarring, application of moderate pressure, or a moderate breeze was sufficient to cause almost complete defoliation of the plant. The younger leaves, however, seemed to withstand the effect of these external forces better than did the older leaves. With increasing dosages of parathion, defoliation progressed from the lower leaves to the upper ones, until at the highest dosage even the growing tip was killed in some of the plants. The plants that had only the terminal leaves left resembled an opened umbrella. The term "umbrella effect" is used to describe this condition which was also characteristic of the effect of some of the other organic phosphates. The very few leaves that remained on the plants treated with 0.047 percent parathion were fernlike in appearance. After the third application, because of this "umbrella effect" and the mottled appearance of the few leaves still attached, the parathion-treated plants were easy to separate visually from the rest of the plants in the experiment.

All concentrations of parathion greater than 0.004 percent caused moderate foliar injury. Although the wettable powder and emulsion formulations elicited similar symptoms, the emulsions were generally quicker acting and more severe in their effects than the equivalent concentrations of wettable powder.

EPN

Table 2 summarizes the effect on growth of treatment with 27 and 25 percent EPN wettable powder formulations. Treatment with concentrations as low as 0.0085 percent caused significant retardation of growth. However, this concentration in Experiment C had no significant effect on growth. Whether this was attributable to differences in formulation, time of application, or biological heterogeneity is not definitely known. This is the same phenomenon that occurred in the parathion-treated plants. With both parathion and EPN, the plants treated during the winter were more severely affected than those treated in the summer. It appears, therefore, that the time of application was a major factor in effecting this difference, and its role in phytotoxicity should not be overlooked even in a subtropical region. This concentration should be considered phytotoxic to papaya.

Foliar injury was caused by all concentrations greater than 0.004 percent.

In general, the symptoms exhibited by EPN-treated plants were similar to, although not as severe as, those shown by the parathion-treated plants. The older leaves seemed to be affected earlier than the young leaves. There was also a chlorotic area formed around the veins of the leaves resembling the "vein clearing" present in plants infected with certain virus diseases.

At the highest concentration there were very few leaves, the terminal growing tips were injured, and the remaining leaves were brown and distorted.

TABLE 2. Effect of EPN on the growth of the Solo papaya

Formulation[1]	Concentration actual lb./100 gal.	Percent actual EPN	Mean ht. (cm.) pre-spray[2]	Mean increase ht. (cm.) 2 weeks after 3rd spray[3]
		Expt. A		
27% W. P.	2.16	0.28	20.4	7.4**
	1.08	0.14	18.6	9.4**
	0.54	0.069	20.1	10.9**
Control	—	—	19.2	14.4
			L.S.D. (1%):	3.0
		Expt. B		
27% W. P.	0.27	0.034	10.2	2.0**
	0.14	0.017	11.5	3.5**
	0.068	0.0085	11.0	4.0**
Control	—	—	11.6	6.3
			L.S.D. (1%):	1.3
		Expt. C		
25% W. P.	0.068	0.0085	9.9	11.4
	0.034	0.0042	10.2	11.4
	0.017	0.0021	10.1	12.0
	0.0085	0.0011	10.7	11.0
	0.0043	0.00053	9.7	10.8
Control	—	—	11.5	10.9

[1] W.P.=wettable powder. Sprays were applied as follows: Expt. A, Aug. 26, Sept. 2, and Sept. 9, 1954; Expt. B, Jan. 13, 20, and 27, 1955; and Expt. C, June 7, 14, and 22, 1955.
[2] Measurements made just prior to 1st spray application.
[3] Final measurements were taken on: Sept. 23, 1954; Feb. 10, 1955; and July 5, 1955 for experiments A, B, and C, respectively.
** Growth significantly inferior to that of control plants.

Malathion

Table 3 summarizes the effect on growth of treatment with a 25 percent wettable powder and an emulsifiable concentrate containing 5 pounds of technical malathion per gallon. No retardation of growth occurred. Malathion was the only organic phosphate tested that did not significantly affect growth at concentrations normally recommended for the control of pests.

Malathion caused no damage to the leaves when applied as a wettable powder, but the emulsifiable concentrate at 0.25 percent caused some minor tip burn after the second spray application.

TABLE 3. Effect of malathion on the growth of the Solo papaya

Formulation[1]	Concentration actual lb./100 gal.	Percent actual malathion	Mean ht. (cm.) pre-spray[2]	Mean increase ht. (cm.) 2 weeks after 3rd spray[3]
25% W. P.	2.0	0.25	20.1	14.8
	1.0	0.13	16.6	16.2
	0.5	0.063	19.0	16.1
55% E. (5 lb. act./gal.)	2.0	0.25	16.3	15.2
	1.0	0.13	17.6	13.9
	0.5	0.063	17.5	15.2
Control	—	—	17.5	14.4

[1] W.P. = wettable powder; E. = emulsifiable concentrate. Sprays were applied on Aug. 24, Aug. 31, and Sept. 7, 1954.
[2] Measurements made just prior to 1st spray application.
[3] Final measurements were taken on Sept. 21, 1954. No significant difference in growth was found.

Schradan

Table 4 summarizes the effect on growth of an emulsifiable formulation containing 4 pounds of technical schradan per gallon. Growth was significantly retarded by a concentration of 0.13 percent. This concentration was the only one causing severe foliar injury. There was no excessive leaf drop as was characteristic of parathion poisoning, but all of the leaves had necrotic edges. A concentration of 0.031 percent caused only minor chlorotic spotting.

One week after the third spray application, the broad mite, *Hemitarsonemus latus* (Banks), was discovered infesting the plants treated with 0.016,

TABLE 4. Effect of schradan on the growth of the Solo papaya

Formulation[1]	Concentration actual lb./100 gal.	Percent actual schradan	Mean ht. (cm.) pre-spray[2]	Mean increase ht. (cm.) 2 weeks after 3rd spray[3]
E. (4 lb. act./gal.)	1.0	0.13	11.8	3.9**
	0.25	0.031	11.5	6.8
	0.13	0.016	12.2	7.1
	0.063	0.0078	11.2	6.9
	0.031	0.0039	12.0	6.4
Control	—	—	11.6	6.3
			L.S.D. (1%):	1.3

[1] E. = emulsifiable concentrate. Sprays were applied Jan. 13, 20, and 27, 1955.
[2] Measurements made just prior to 1st spray application.
[3] Final measurements were taken on Feb. 10, 1955.
** Growth significantly inferior to that of control plants.

0.0078, and 0.0039 percent schradan. One of the untreated control plants was also infested. The infestation was so slight, however, that it had no detectable effect on the growth of the plants in the 1 week that the infestations were present before the final observations were made.

Demeton

Table 5 summarizes the effect on growth of treatment with an emulsifiable formulation containing 2 pounds of technical demeton per gallon. At 0.0039 percent, the lowest concentration studied in this experiment, significant retardation of growth occurred. On the other hand, a concentration of 0.0078 percent did not significantly retard growth. This apparent aberrance is no doubt due to biological variation. The limit of safety probably is at a concentration below 0.0039 percent.

In general, the symptoms exhibited by demeton-treated plants were also similar to, but not as severe as, those shown by the parathion-treated plants. The older leaves seemed to be affected earlier than the young leaves. At the highest concentration there were very few leaves, the terminal growing tip was injured, and the remaining leaves were brown and distorted. This browning of the leaves decreased with a decrease in concentration.

TABLE 5. Effect of demeton on the growth of the Solo papaya

Formulation[1]	Concentration actual lb./100 gal.	Percent actual demeton	Mean ht. (cm.) pre-spray[2]	Mean increase ht. (cm.) 2 weeks after 3rd spray[3]
		Expt. A		
23% E. (2 lb. act./gal.)	1.0	0.13	17.8	5.8**
	0.5	0.063	21.5	9.3**
	0.25	0.031	19.4	11.3**
Control	—	—	19.2	14.4
			L.S.D. (1%):	3.0
		Expt. B		
23% E. (2 lb. act./gal.)	0.13	0.016	11.2	4.8**
	0.063	0.0078	11.4	5.8
	0.031	0.0039	11.0	4.9**
Control	—	—	11.6	6.3
			L.S.D. (1%):	1.3

[1] E. = emulsifiable concentrate. Sprays were applied as follows: Expt. A, Aug. 26, Sept. 2, and Sept. 9, 1954; and Expt. B, Jan. 13, 20, and 27, 1955.
[2] Measurements made just prior to 1st spray application.
[3] Final measurements were taken on: Sept. 23, 1954 for Expt. A and Feb. 10, 1955 for Expt. B.
** Growth significantly inferior to that of control plants.

TEPP

Table 6 summarizes the effect on growth of treatment with a 20 percent emulsifiable formulation of TEPP. Growth was retarded by treatment with 0.2 and 0.1 percent concentrations.

TEPP at 0.2 percent caused severe phytotoxic symptoms (fig. 9) in addition to the retardation of growth. The lower half of the trunk of TEPP-treated plants exhibited a white scarification. Serious defoliation resulted in an "umbrella effect," and the remaining leaves were badly distorted, having white necrotic areas and severe edge and tip burn. There was a tendency for the leaves to curl upward. At 0.1 percent the damage caused was less severe but still serious. Fewer lateral leaves were lost so that the foliage had a fuller appearance, but serious tip and edge burn and curling of the leaves still occurred. There were also white necrotic areas on the trunk. Plants treated with 0.05 percent showed some minor spotting on the leaves, but those treated with 0.025 percent were perfectly normal.

TABLE 6. Effect of TEPP on the growth of the Solo papaya

Formulation[1]	Concentration actual	Percent actual TEPP	Mean ht. (cm.) pre-spray[2]	Mean increase ht. (cm.) 2 weeks after 3rd spray[3]
20% E.	1–500	0.2	10.7	5.1**
	1–1000	0.1	10.2	9.6**
	1–2000	0.05	9.5	11.3
	1–4000	0.025	11.3	10.9
	1–8000	0.013	12.4	10.1
Control	—	—	11.5	10.9
			L.S.D. (1%):	1.2

[1] E. = emulsifiable concentrate. Sprays were applied on June 7, 14, and 22, 1955.
[2] Measurements made just prior to 1st spray application.
[3] Final measurements were taken on July 5, 1955.
** Growth significantly inferior to that of control plants.

ORGANIC ACARICIDES

In this category are included those materials which are generally regarded to be specifically miticidal and relatively nontoxic to insects.

Aramite

Table 7 summarizes the effect on growth with a 15 percent wettable powder and an emulsifiable formulation containing 2 pounds of technical Aramite per gallon. Growth was not adversely affected by any of the concentrations tested.

FIG. 9. Effect of treatment with 0.2 percent (left) and 0.1 percent TEPP (center) on growth and foliage of papaya. Untreated plant on right.

Although the wettable powder formulation did not cause any foliar injury, the emulsion at 0.038 percent caused tip burn. At the higher concentration, 0.075 percent, there was a crinkling in some of the leaves in addition to a more severe case of tip burn.

Chlorobenzilate

Table 7 summarizes the effect on growth of treatment with a 25 percent wettable powder and an emulsifiable formulation containing 2 pounds of technical Chlorobenzilate per gallon. No retardation of growth occurred. Although minor tip burn occurred on some of the older leaves in those plants treated with a 0.13 percent concentration of the emulsion, the young leaves did not show this condition.

Chlorobenzilate caused a mosaic type of chlorosis which increased at the higher concentrations. Symptoms were more severe with the emulsion than with comparable concentrations of wettable powders (fig. 10).

Ovex

Table 8 summarizes the effect on growth of treatment with a 50 percent wettable powder and an emulsifiable formulation containing 1.6 pounds of technical ovex per gallon. The wettable powder formulation caused no re-

TABLE 7. Effect of Aramite and Chlorobenzilate on the growth of the Solo papaya

Formulation[1]	Concentration actual lb./100 gal.	Percent actual miticide	Mean ht. (cm.) pre-spray[2]	Mean increase ht. (cm.) 2 weeks after 3rd spray[3]
Aramite, 15% W. P.	0.6	0.075	17.6	15.3
	0.3	0.038	20.0	15.4
	0.15	0.019	17.5	14.0
Aramite, 25% E. (2 lb. act./gal.)	0.6	0.075	17.8	13.4
	0.3	0.038	20.4	14.4
	0.15	0.019	19.7	14.4
Chlorobenzilate, 25% W. P.	1.0	0.13	17.0	15.1
	0.5	0.063	19.9	14.7
	0.25	0.031	17.4	15.0
Chlorobenzilate, 25% E. (2 lb. act./gal.)	1.0	0.13	20.4	14.9
	0.5	0.063	18.2	14.7
	0.25	0.031	19.2	16.1
Control	—	—	17.5	14.4

[1] W.P. = wettable powder; E. = emulsifiable concentrate. Sprays were applied on Aug. 24, Aug. 31, and Sept. 7, 1954.
[2] Measurements made just prior to 1st spray application.
[3] Final measurements were taken on Sept. 21, 1954. No significant difference in growth was found.

TABLE 8. Effect of ovex on the growth of the Solo papaya

Formulation[1]	Concentration actual lb./100 gal.	Percent actual ovex	Mean ht. (cm.) pre-spray[2]	Mean increase ht. (cm.) 2 weeks after 3rd spray[3]
		Expt. A		
50% W. P.	2.0	0.25	19.8	14.7
	1.0	0.13	22.3	14.1
	0.5	0.063	20.4	15.8
Control	—	—	19.2	14.4
		Expt. B		
E. (1.6 lb. act./gal.)	2.0	0.25	10.3	2.1**
	1.0	0.13	11.6	4.5**
	0.5	0.063	11.6	5.9
Control	—	—	11.6	6.3
			L.S.D. (1%):	1.3

[1] W.P. = wettable powder; E. = emulsifiable concentrate. Sprays were applied as follows: Expt. A, Aug. 26, Sept. 2, and Sept. 9, 1954; and Expt. B, Jan. 13, 20, and 27, 1955.
[2] Measurements made just prior to 1st spray application.
[3] Final measurements were taken on: Sept. 23, 1954 for Expt. A and Feb. 10, 1955 for Expt. B.
** Growth significantly inferior to that of control plants.

FIG. 10. Foliar injury caused by three applications of 0.13 percent Chlorobenzilate wettable powder (center) and emulsion (right).

tardation of growth at any of the concentrations used. The emulsifiable formulation, however, caused significant retardation of growth at concentrations of 0.25 and 0.13 percent.

Only the emulsifiable formulation caused foliar injury. The two highest concentrations caused severe leaf injury within a week of the first spray application. After the third application, all concentrations caused damage. At 0.25 percent, the terminal growing tip was badly distorted, the plant lost most of its leaves, and the few remaining were entirely brown. Growing point damage, leaf spotting, and tip burn were still evident at a concentration of 0.13 percent. At 0.063 percent, tip burn was visible on the leaves.

CHLORINATED HYDROCARBON INSECTICIDES

This group of materials is generally considered to be effective primarily against insects and relatively innocuous to mites. The effects on growth and foliage of papaya by four chlorinated hydrocarbon insecticides were determined.

DDT

Table 9 summarizes the effect on growth of a 75 percent DDT wettable powder formulation. No retardation of growth was evident after treatment with concentrations as high as 1 percent. However, some minor brown spotting of the leaves was caused by concentrations greater than 0.25 percent.

TABLE 9. Effect of DDT on the growth of the Solo papaya

Formulation[1]	Concentration actual lb./100 gal.	Percent actual DDT	Mean ht. (cm.) pre-spray[2]	Mean increase ht. (cm.) 2 weeks after 3rd spray[3]
75% W. P.	8	1.0	11.3	11.9
	4	0.5	10.5	11.8
	2	0.25	10.7	12.3
	1	0.13	10.0	12.1
Control	—	—	11.5	10.9

[1] W.P.=wettable powder. Sprays were applied June 7, 14, and 22, 1955.
[2] Measurements made just prior to 1st spray application.
[3] Final measurements were taken on July 5, 1955. No significant difference in growth was found.

Aldrin

Table 10 summarizes the effect on growth of treatment with an emulsion formulation containing 2 pounds of technical aldrin per gallon. No retardation of growth occurred. However, 0.5 percent caused a slight crinkling of the edges of the lower leaves.

TABLE 10. Effect of chlorinated hydrocarbon insecticides on the growth of the Solo papaya

Formulation[1]	Concentration actual lb./100 gal.	Percent actual insecticide	Mean ht. (cm.) pre-spray[2]	Mean increase ht. (cm.) 2 weeks after 3rd spray[3]
Aldrin, 23% E.	4	0.50	10.1	10.9
(2 lb. act./gal.)	2	0.25	11.0	9.5
	1	0.13	11.3	10.7
	0.5	0.063	11.5	10.1
Dieldrin, 50% W. P.	4	0.50	12.3	9.8
	2	0.25	11.3	10.0
	1	0.13	11.7	10.0
	0.5	0.063	10.4	10.2
	0.25	0.031	10.4	10.4
Dieldrin, 15% E.	4	0.50	11.1	8.8
(1.5 lb. act./gal.)	2	0.25	11.2	9.4
	1	0.13	11.2	9.7
	0.5	0.063	11.3	10.2
	0.25	0.031	10.9	10.7
Heptachlor, 25% W. P.	4	0.50	11.2	9.6
	2	0.25	11.0	11.0
	1	0.13	11.3	10.4
	0.5	0.063	11.1	10.3
Heptachlor, 2 E.	4	0.50	11.2	9.6
(2 lb. act./gal.)	2	0.25	10.7	10.7
	1	0.13	10.7	10.2
	0.5	0.063	11.1	10.3
Control	—	—	11.0	9.9

[1] W.P. = wettable powder; E. = emulsifiable concentrate. Sprays were applied on June 8, 14, and 22, 1955.
[2] Measurements made just prior to 1st spray application.
[3] Final measurements were taken on July 5, 1955. No significant difference in growth was found.

Dieldrin

Table 10 summarizes the effect on growth of treatment with a 50 percent wettable powder and an emulsifiable formulation containing 1.5 pounds of technical dieldrin per gallon. None of the treatments caused any retardation of growth.

Although the wettable powder caused no foliar injury, the emulsion at 0.5 and 0.25 percent caused moderate and minor tip burn, respectively. The lower concentrations caused no damage.

Heptachlor

Table 10 summarizes the effect on growth of treatment with a 25 percent wettable powder and an emulsifiable formulation containing 2 pounds of technical heptachlor per gallon. None of the concentration levels used caused any retardation of growth.

The emulsion at 0.5 percent caused slight tip and edge burn but none of the other concentrations caused foliar injury. The wettable powder caused no foliar injury.

COMBINATIONS OF ORGANIC ACARICIDES

The combination of pesticides is often resorted to in order to increase the efficiency of insect and mite control methods by eliminating the need for separate applications of insecticides and/or miticides. Care must be exercised, however, that such combinations are not phytotoxic. An experiment was conducted in order to determine the effects of various combinations of Aramite, Chlorobenzilate, malathion, and ovex formulations on papaya. The formulations used in this experiment were exactly the same as those described in the previous experiments except for the Aramite emulsifiable formulation. This formulation contained 90 percent or 8 pounds per gallon of technical Aramite and 10 percent emulsifier. This was a noncommercial formulation but was considered by the manufacturer to be less phytotoxic than their commercial emulsifiable product. The combinations were limited to similar types of formulations, i.e., emulsions with emulsions and wettable powders with wettable powders. The concentrations of the materials selected to be combined were those which had caused no retardation of growth when used singly in previous experiments.

Table 11 summarizes the effect of these combinations of pesticides on growth. In all cases, the combinations which were sufficiently toxic to cause retardation of growth were so at their respective highest concentration. The following treatments caused significant retardation of growth:

Wettable powders—0.13 percent Chlorobenzilate in combination with either 0.075 percent Aramite, 0.13 percent malathion, or 0.13 percent ovex.

Emulsions—0.13 percent Chlorobenzilate plus either 0.13 percent malathion or 0.075 percent Aramite; and 0.13 percent malathion in combination with 0.075 percent Aramite.

All three of the toxic combinations of wettable powder formulations included 0.13 percent Chlorobenzilate as one of the ingredients. It seems, therefore, that Chlorobenzilate was incompatible with Aramite, malathion, and ovex at the concentrations used. This incompatibility seemed to be purely an additive effect due to the combination of the two highest concentrations rather than the effect of a chemical reaction between Chlorobenzilate and the other materials. The combined chemical level apparently was sufficiently high to cause retardation of growth. Combinations of the other materials in the form of wettable powders had no retarding effect on the growth of papaya.

Although spraying with the emulsifiable formulations did not present as clear a pattern as did the wettable powders since no one material was

TABLE 11. Effect of combining miticides on the growth of the Solo papaya

Formulation[1]	Concentration actual lb./100 gal.	Percent actual miticide	Mean ht. (cm.) pre-spray[2]	Mean increase ht. (cm.) 2 weeks after 3rd spray[3]
Aramite + Ovex, W.P.	0.6 +1.0	0.075+0.13	10.5	11.0
	0.3 +0.5	0.038+0.063	11.4	11.5
	0.15+0.25	0.019+0.031	11.4	10.7
Aramite + Ovex, E.	0.3 +0.5	0.038+0.063	10.3	9.5
	0.15+0.25	0.019+0.031	10.3	10.9
Aramite + Chlorobenzilate, W.P.	0.6 +1.0	0.075+0.13	8.9	8.9**
	0.3 +0.5	0.038+0.063	9.4	12.2
	0.15+0.25	0.019+0.031	9.7	12.8
Aramite + Chlorobenzilate, E.	0.6 +1.0	0.075+0.13	10.3	5.5**
	0.3 +0.5	0.038+0.063	9.3	11.5
	0.15+0.25	0.019+0.031	9.0	13.7
Aramite + Malathion, W.P.	0.6 +1.0	0.075+0.13	11.3	10.6
	0.3 +0.5	0.038+0.063	12.2	11.2
	0.15+0.25	0.019+0.031	11.3	11.1
Aramite + Malathion, E.	0.6 +1.0	0.075+0.13	12.4	7.7**
	0.3 +0.5	0.038+0.063	11.4	10.2
	0.15+0.25	0.019+0.031	11.2	11.1
Chlorobenzilate + Ovex, W.P.	1.0 +1.0	0.13 +0.13	10.1	7.5**
	0.5 +0.5	0.063+0.063	9.6	12.2
Chlorobenzilate + Ovex, E.	0.5 +0.5	0.063+0.063	9.8	10.0
Chlorobenzilate + Malathion, W.P.	1.0 +1.0	0.13 +0.13	12.3	8.7**
	0.5 +0.5	0.063+0.063	10.0	11.4
Chlorobenzilate + Malathion, E.	1.0 +1.0	0.13 +0.13	12.0	8.1**
	0.5 +0.5	0.063+0.063	12.1	10.8
Malathion + Ovex, W.P.	1.0 +1.0	0.13 +0.13	11.0	11.7
	0.5 +0.5	0.063+0.063	10.3	12.8
	0.25+0.25	0.031+0.031	11.8	11.2
Malathion + Ovex, E.	0.5 +0.5	0.063+0.063	10.0	11.7
	0.25+0.25	0.031+0.031	11.1	12.6
Control	—	—	11.5	12.0
			L.S.D. (1%):	2.3

[1] W.P. = wettable powder; E. = emulsifiable concentrate. Sprays were applied on June 6, 13, and 21, 1955.
[2] Measurements made just prior to 1st spray application.
[3] Final measurements were taken on July 5, 1955.
** Growth significantly inferior to that of control plants.

present in all of the toxic combinations, 0.13 percent Chlorobenzilate emulsion when combined with the other materials did cause retardation of growth. Ovex emulsion, the only material not involved in any toxic combination, was originally included at a concentration of 0.13 percent. However, the results of experiments which were incomplete when this experiment was planned showed that ovex alone at this concentration was toxic. Therefore, all combinations including 0.13 percent ovex had to be discarded. Since this concentration of ovex was combined with the highest nontoxic levels of the other materials, elimination of these data necessarily also removed emulsion combinations with 0.075 percent Aramite, 0.13 percent Chlorobenzilate, and 0.13 percent malathion. The application of a combination of 0.13 percent Chlorobenzilate and 0.063 percent ovex probably would result in growth retardation of papaya.

Observations on foliar injury were made just prior to the second spray application. As was shown in earlier experiments foliar injury occurred at concentrations lower than those required for growth retardation.

Ovex and Aramite when combined as wettable powders caused no injury to the younger leaves. The older leaves, however, exhibited crinkling and browning of the upper epidermis at the highest concentration level tested. However, at the lowest concentration level no injury occurred. In the emulsion form, this combination caused damage similar to, but more severe than, that caused by comparable concentrations of the wettable powders. The lower concentration level caused a slight brown spotting of the leaves.

Chlorobenzilate and Aramite when combined as wettable powders caused no injury to the younger leaves but severely burned the older leaves at the highest concentration used. The two lower dosage levels caused only slight leaf spotting. As an emulsion, this combination at the highest dosage level caused more severe symptoms than the corresponding wettable powder dosage; the edges of the older leaves were necrotic. At the lower levels, the injury was slight.

Chlorobenzilate and ovex when combined as wettable powders caused a mosaic type of injury compounded with tip burn which decreased with concentration. The emulsions caused similar but more severe symptoms; i. e., they caused greater injury than did the wettable powders at twice the concentration.

The combination of malathion and Chlorobenzilate as wettable powders resulted in only minor symptoms of tip burn and a chlorotic mosaic-type spotting. The emulsion combination caused the same but more severe symptoms.

The combination of malathion and Aramite as wettable powders at the highest levels used resulted in severe crinkling of the leaves, chlorosis, and necrosis on the older leaves but plants treated with the lowest levels appeared to be normal. The emulsions, at the highest level used, caused severe tip burn in the older leaves with a great deal of necrotic area originating

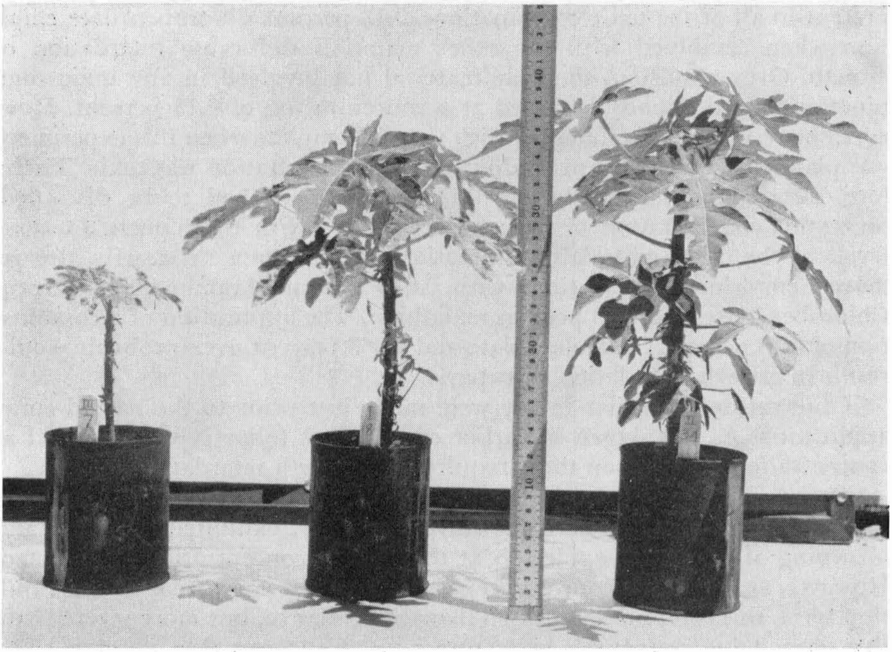

FIG. 11. Effect of combining Chlorobenzilate and Aramite wettable powders at 1.0 and 0.6 (left) and 0.5 and 0.3 (center) pound of actual per 100 gallons, respectively, on the growth of papaya. Plant on right is untreated.

at the edge of the leaf, progressively expanding towards the midrib. The younger leaves were badly curled. The lowest concentration appeared to be almost normal except for some brown spotting on the lower leaves.

The combination of malathion and ovex as wettable powders or emulsions caused only insignificant abnormalities.

There appears to be no doubt that care should be exercised in the combining of these miticidal materials. The combination of these materials at concentrations which are nontoxic to the plant when applied alone, may have an injurious effect. Chlorobenzilate, in particular, appears to be hazardous when combined with other materials at concentrations usually recommended for mite control.

Symptoms of injury caused by the wettable powder and the emulsion combinations were generally similar. The emulsion combination, however, caused much greater damage than was caused by comparable concentrations of the wettable powders. This was generally true whether the materials were applied singly or in combination.

Further observations on foliar injury were made 2 weeks after the third spray application.

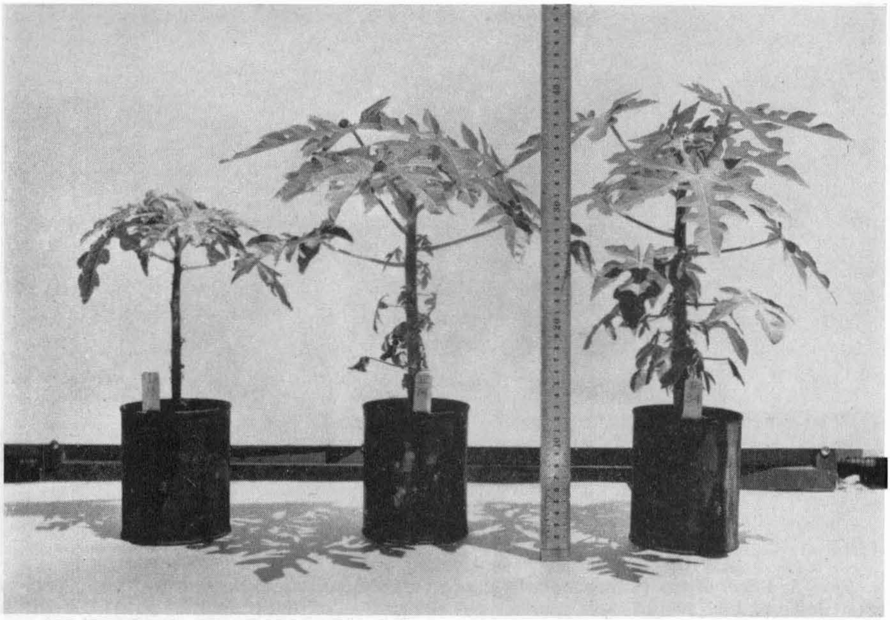

FIG. 12. Effect of combining Chlorobenzilate and ovex wettable powders at 1 pound each (left) and 0.5 pound each (center) per 100 gallons on the growth of papaya. Plant on right is untreated.

The combination of ovex and Aramite as wettable powders resulted in damage similar to that reported above. There was good retention of leaves at the highest concentration. The brown spots, however, had turned white. The damage caused by the emulsions was much greater than that reported earlier. At the highest concentration the sprayed leaves were smaller than normal, badly distorted, and had a large amount of white necrotic areas The lowest level was almost normal with only minor spotting.

The combination of Chlorobenzilate and Aramite as wettable powders caused considerable leaf loss at the highest concentration. The plants showed the "umbrella effect" (fig. 11) with very young small lateral leaves adhering to the trunk. The leaves were crinkled and necrotic especially at the tips. The affected leaves were smaller than normal. There was considerably less injury at the lower dosages. The effect of the emulsions was similar.

The combination of Chlorobenzilate and ovex as wettable powders at the higher concentration showed considerable leaf drop, also resulting in the "umbrella effect" (fig. 12). The emulsion combination also caused considerable leaf drop and the leaves that remained attached to the trunk were distorted and necrotic.

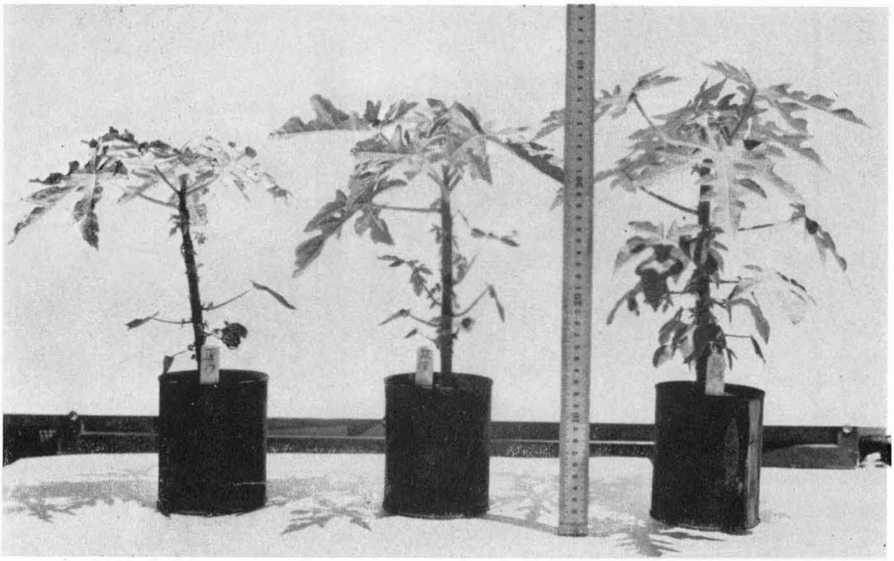

FIG. 13. Effect of combining malathion and Chlorobenzilate wettable powders at 1 pound each (left) and 0.5 pound each (center) per 100 gallons on the growth of papaya. Plant on right is untreated.

The combination of malathion and Chlorobenzilate as both wettable powders and emulsions resulted in symptoms similar to but more intense than those reported earlier (fig. 13).

The combination of malathion and Aramite as either wettable powders or emulsions caused little change in the general foliar symptoms described earlier. However, the leaves showed a greater degree of necrosis than earlier.

The combination of malathion and ovex as either wettable powders or emulsions caused the same symptoms as described earlier.

DN-289

It was reported[2] that excellent control of adult mites was obtained by the addition of small amounts of DN-289 (the triethanolamine salt of dinitro-o-sec-butyl phenol) to ovex, a compound which is more effective as an ovicide than against adult mites. The dinitro compounds, however, are thermoreactive and notoriously phytotoxic. They are normally applied only to plants in the dormant state, in order to control overwintering forms of mites and insects. Despite the fact that the papaya never undergoes dormancy

[2] Personal communication by Mr. H. H. Lembright, Dow Chemical Co., San Francisco, California.

and, therefore, would appear to be too sensitive to this material, an experiment was conducted to determine the concentration of DN-289 which would cause phytotoxicity. This material was used singly and in combinations with sulfur, ovex wettable powder, and ovex emulsion. The DN-289 formulation used in this experiment was an emulsifiable concentrate containing 2 pounds of the triethanolamine salt of dinitro-o-sec-butyl phenol per gallon.

The plants were treated with six concentrations of DN-289 ranging from 0.002 to 0.02 percent. These same concentrations of DN-289 were also combined with 0.71 percent sulfur and 0.063 percent ovex.

Table 12 summarizes the effect of these treatments on the growth of the papaya.

TABLE 12. Effect of DN-289 singly and in combination with other miticides on the growth of the Solo papaya

Formulation[1]	Concentration actual lb./100 gal.	Percent actual miticide	Mean ht. (cm.) pre-spray[2]	Mean increase ht. (cm.) 2 weeks after 3rd spray[3]
DN-289, E. (2 lb./gal.)	0.16	0.020	13.2	6.2**
	0.094	0.012	12.6	8.1**
	0.062	0.0078	13.0	9.5
	0.047	0.0059	12.8	10.0
	0.031	0.0039	12.5	10.1
	0.016	0.0020	12.6	10.3
DN-289, E. + Sulfur, 95% W.P.	0.16 +5.7	0.020 +0.71	13.9	5.9**
	0.094+5.7	0.012 +0.71	13.5	7.8**
	0.062+5.7	0.0078+0.71	14.3	9.5
	0.047+5.7	0.0059+0.71	13.6	9.7
	0.031+5.7	0.0039+0.71	13.1	9.7
	0.016+5.7	0.0020+0.71	12.4	10.6
DN-289, E. + Ovex, 50% W.P.	0.16 +0.5	0.020 +0.063	13.8	6.7**
	0.094+0.5	0.012 +0.063	12.5	8.6**
	0.062+0.5	0.0078+0.063	12.3	9.7
	0.047+0.5	0.0059+0.063	13.0	9.5
	0.031+0.5	0.0039+0.063	12.4	10.2
	0.016+0.05	0.0020+0.063	14.2	10.6
DN-289, E. + Ovex, E. (1.6 lb./gal.)	0.16 +0.5	0.020 +0.063	10.8	2.5**
	0.094+0.5	0.012 +0.063	12.2	5.2**
	0.062+0.5	0.0078+0.063	11.4	6.1**
	0.047+0.5	0.0059+0.063	12.4	8.7**
	0.031+0.5	0.0039+0.063	13.0	10.0
	0.016+0.5	0.0020+0.063	13.9	10.1
Control	—	—	12.1	10.2
		L.S.D. (1%):		1.3

[1] W.P. = wettable powder; E. = emulsifiable concentrate. Sprays containing 0.020 percent DN-289 were applied on Aug. 3 and 10, 1955; all other sprays were applied on Aug. 3, 10, and 17, 1955.
[2] Measurements made just prior to 1st spray application.
[3] Final measurements were taken on Aug. 31, 1955.
** Growth significantly inferior to that of control plants.

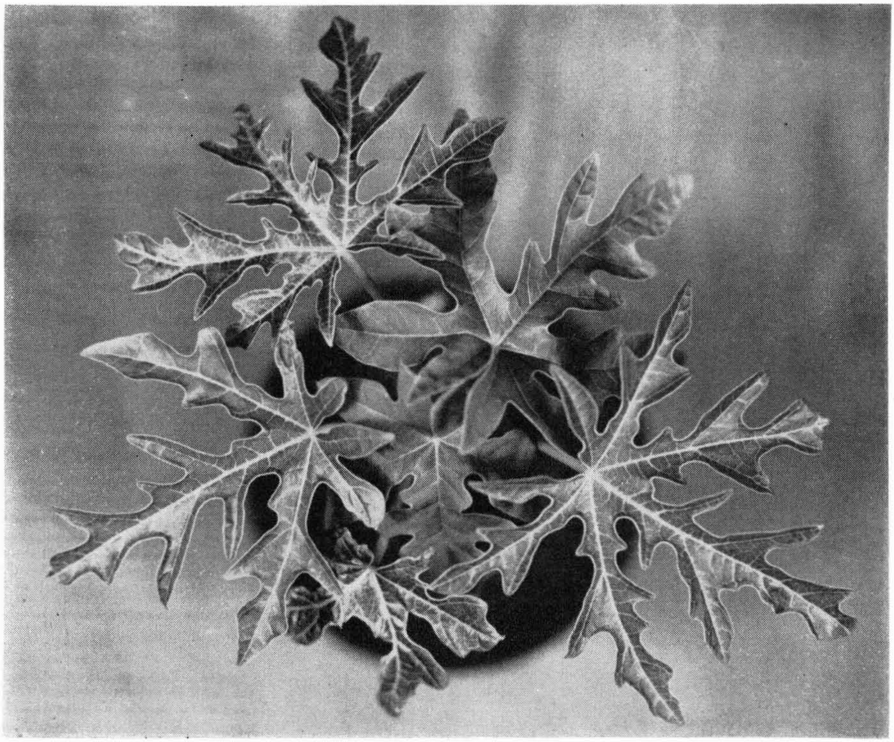

FIG. 14. Distorted papaya leaves resulting from treatment with a combination spray of 0.020 percent DN-289 and 0.063 percent ovex emulsion per 100 gallons.

DN-289 caused a significant retardation in growth at concentrations of 0.02 and 0.012 percent. The addition of sulfur and ovex in the form of wettable powders to the various concentrations of DN-289 apparently had no effect on the toxicity of the dinitro-compound. The combination of ovex emulsion and DN-289, however, caused significant retardation of growth at concentrations as low as 0.0059 percent DN-289. That it is dangerous to add oil to DN-289 was shown by Hammer (1949). A 0.1 percent aqueous solution of DN-289 was not injurious to apple, cherry, or plum as a dormant spray but when 0.5 percent oil was added injury resulted. These data seem to bear out this conclusion.

Serious foliar injury was apparent within 24 hours of treatment. Sprays containing 0.02 percent DN-289 injured every leaf on the plant. Sprays containing 0.012 and 0.0078 percent DN-289 caused less severe injury, i. e., a spotting over the entire leaf surface. Sprays containing the lower concentrations of DN-289 caused moderate to very slight tip burn. The addition of sulfur or ovex wettable powder did not change the symptoms. The addition of ovex emulsion, however, intensified the damage especially at the higher concentrations.

Further observations on foliar injury made 2 weeks after the third spray application showed that, as before, the addition of sulfur and ovex wettable powders had no significant effect in compounding the injury caused by DN-289. DN-289 at the lower concentrations of 0.002 to 0.0059 percent progressively intensified tip burn in the form of expanding white necrotic areas.

The addition of 0.063 percent ovex emulsion caused similar but more severe symptoms at DN-289 levels of 0.0020 to 0.0059 percent. At the higher concentrations of DN-289, this combination caused injury which was more severe than that caused by equivalent concentrations of DN-289 applied alone or in combination with either sulfur or ovex wettable powders. Excessive defoliation occurred and the leaves still attached were very small. The combination of 0.020 percent DN-289 with ovex emulsion caused the leaves to appear much narrower than normal (fig. 14). The white necrotic areas were irregular in shape, bordered by brown areas, and very brittle.

COMBINATION OF SULFUR AND ORGANIC PESTICIDES

Sulfur has been used for many years to control mites on papaya (Pope, 1930) since it is very effective against the broad mite, *Hemitarsonemus latus* (Banks) and *Brevipalpus phoenicis* (Geijskes). However, as mentioned earlier, it does not seem to be effective against the two-spotted spider mite, *Tetranychus telarius* (L.), when it occurs on papaya although it gives good control of this mite when it occurs on many other crops. Therefore, information regarding the compatibility of sulfur with other materials which could be useful in controlling the two-spotted spider mite or insect pests of papaya is desirable. Consequently, the phytotoxicity of wettable sulfur applied at the rate of 5.7 pounds of sulfur per 100 gallons in combination with varying amounts of Aramite, Chlorobenzilate, malathion, ovex, and TEPP was determined. These materials were added to the sulfur sprays at concentrations which when applied singly had no significant effect on growth.

Table 13 summarizes the effect of these sulfur combinations on the growth of the papaya.

None of the pesticides caused a significant retardation of growth of the papaya when combined with sulfur.

Observations on foliar injury made 2 weeks after the third spray application revealed that the combination of sulfur plus 0.13 and 0.25 percent ovex wettable powder caused a black spotting on the older leaves, while the addition of 0.062 percent ovex emulsion caused minor chlorosis on the upper surface of the leaf.

The combination of sulfur and 0.13 and 0.25 percent wettable malathion, and 0.063 percent emulsifiable malathion caused no foliar injury but the emulsion at 0.13 and 0.25 percent caused slight tip burn.

TABLE 13. Effect of combining sulfur wettable powder with various miticidal formulations on the growth of the Solo papaya

Formulation[1]	Concentration actual lb./100 gal.	Percent actual	Mean ht. (cm.) pre-spray[2]	Mean increase ht. (cm.) 2 weeks after 3rd spray[3]
Aramite, 15% W.P.	0.6	0.075	13.4	11.2
	0.3	0.038	13.5	10.8
Aramite, 90% E.	0.6	0.075	14.0	9.7
	0.3	0.038	14.7	11.1
	0.15	0.019	12.7	10.5
Chlorobenzilate, 25% W.P.	1	0.13	14.4	11.8
Chlorobenzilate, 25% E.	1	0.13	13.0	11.0
	0.5	0.063	13.5	11.9
	0.25	0.031	12.9	11.8
Malathion, 25% W.P.	2	0.25	13.7	10.7
	1	0.13	14.8	11.3
Malathion, 55% E. (5 lb./gal.)	2	0.25	13.5	9.9
	1	0.13	14.1	9.9
	0.5	0.063	14.4	9.8
Ovex, 50% W.P.	2	0.25	14.5	12.4
	1	0.13	12.7	11.9
Ovex, E. (1.6 lb./gal.)	0.5	0.063	14.9	11.4
	0.25	0.031	13.0	10.4
TEPP, 20% E.	1-2000	0.05	14.1	10.1
	1-4000	0.025	12.1	10.1
	1-8000	0.013	13.1	10.5
Sulfur, 95% W.P.	5.7	0.71	13.3	10.9
Control	—	—	13.0	11.2

[1] W.P. = wettable powder; E. = emulsifiable concentrate. 95% sulfur W.P. was added to each material at the rate of 5.7 lb. actual sulfur per 100 gallons. Sprays were applied on Aug. 4, 11, and 18, 1955.
[2] Measurements made just prior to 1st spray application.
[3] Final measurements were taken on Aug. 31, 1955. No significant difference in growth was found.

The combination of sulfur and 0.013 or 0.025 percent TEPP caused no leaf injury but with 0.05 percent TEPP caused a white necrosis along the edge of the leaves.

The addition of Aramite wettable powder to sulfur caused a progressively expanding spotting with an increase in concentration and the emulsion, as was usually the case, caused even greater damage. The leaves were crinkled with small white and brown spots distributed over the entire surface (fig. 15).

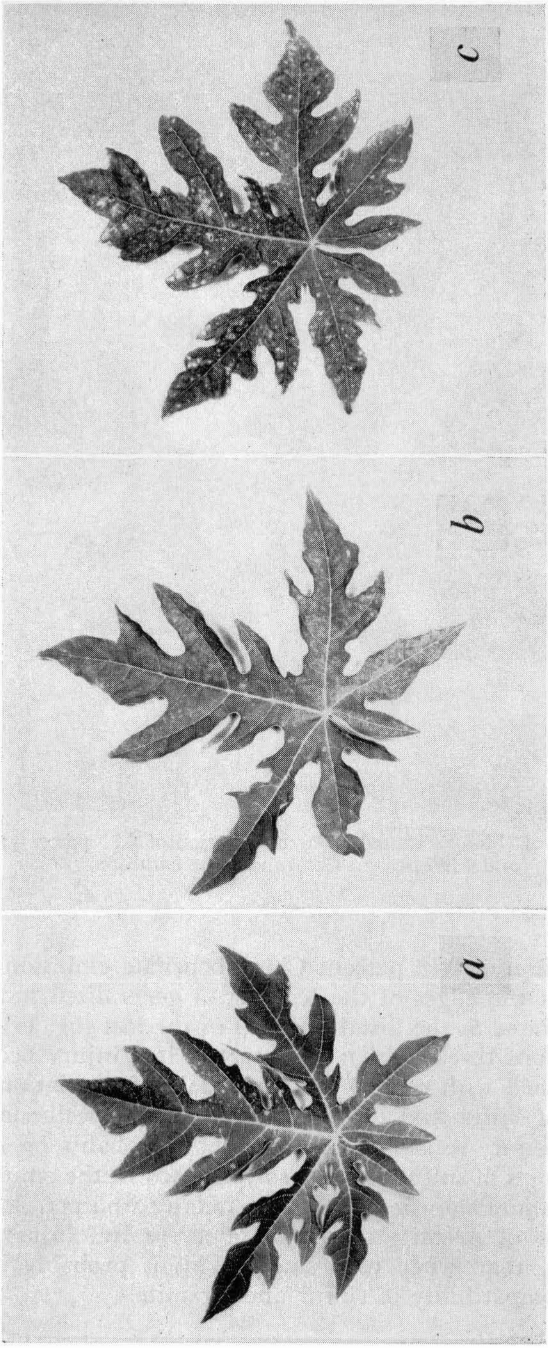

FIG. 15. Foliar injury caused by a combination of 0.71 percent wettable sulfur with: (*a*) 0.075 percent Aramite wettable powder, (*b*) 0.019 percent Aramite emulsion, and (*c*) 0.075 percent Aramite emulsion.

FIG. 16. Mosaic type of chlorosis caused by a combination of 0.71 percent wettable sulfur and 0.125 percent Chlorobenzilate emulsion.

The combination of 0.13 percent Chlorobenzilate emulsion with sulfur caused necrosis at the edges of the leaf and a generalized mosaic type of chlorosis concentrated at the distal portions of the leaf (fig. 16).

The observations revealed that the greatest leaf injury occurred when sulfur was combined with one of the emulsifiable formulations. Since the incompatibility of sulfur and the petroleum oils is a well-established fact (Shepard, 1939), injury to the plants could most probably be attributed to the reactive products of sulfur and the solvent used in the emulsifiable concentrate. The Aramite emulsion, however, contained no petroleum oils, but both formulations of Aramite caused more severe leaf injury when combined with sulfur than when used singly. This is probably indicative of the inherent incompatibility of sulfur and Aramite.

Effect of Pesticide Formulations on Fruit

The experiment to determine the effect of the pesticides on the fruits and also the flowers of papaya was conducted at the Waimanalo Substation. An orchard of mature bearing trees ranging 6 to 18 feet in height was used for this experiment. Table 14 contains the formulations and concentrations which were applied to the orchard. The sprays were applied to runoff with either a 3- or 4-gallon Hudson compressed air sprayer. Triton B-1956 was added to each spray mixture at the rate of 1:2000. Care was taken to completely cover all of the fruits and blossoms on each tree. Two applications were made to the trees on October 12 and November 2, 1955. Since the earlier experiments demonstrated the severe phytotoxicity of the organic phosphate insecticides, the concentrations of the initial spray applications of parathion, EPN, schradan, and demeton were below the levels usually recommended for pest control. However, since these concentrations failed to cause injury to the fruits, they were increased at the time of the second spray application. On the other hand, the chlorinated hydrocarbon insecticides were applied at concentrations appreciably higher than those normally recommended for pest control, since these concentrations caused no retardation of growth of the seedlings and only minor foliar symptoms.

Four days after the first spray application, the trees in the orchard were inspected for fruit injury. The following treatments in terms of pounds of active ingredients per 100 gallons represent the highest concentration at which no damage was observed:

Wettable powders—parathion, 0.032; EPN, 0.07; malathion, 2.0; Chlorobenzilate, 0.5; ovex, 2.0; aldrin, 4.0; DDT, 8.0; dieldrin, 4.0; and heptachlor, 4.0.

Emulsions—parathion, 0.032; malathion, 2.0; schradan, 0.5; demeton, 0.03; and aldrin, 2.0.

Aramite wettable powder at all concentrations and Chlorobenzilate wettable powder at its highest concentration only, caused damage to the fruit. None of the other wettable powder formulations caused injury.

The emulsions of the chlorinated hydrocarbon insecticides appeared to be especially phytotoxic to the fruit. The most common reaction to the insecticides was the active discharge of latex from the fruit.

Heptachlor emulsion at 4 pounds per 100 gallons caused a severe reaction in the fruit. Large quantities of latex flowed from fruit on all sides of the tree. Dried latex was present primarily where the spray droplets collected and concentrated. Damage decreased with a decreasing concentration of insecticide. The flowers appeared to be unaffected.

Dieldrin emulsion at 4 pounds per 100 gallons caused fruit injury similar to that caused by the heptachlor emulsion. In addition to the latex flow, however, there was a browning of the fruit epidermis. The flowers and young leaves were also seriously burned. Decreasing concentration decreased

TABLE 14. List of the formulations and concentrations sprayed on Solo papaya fruits and flowers

Formulation[1]	Concentration actual lb./100 gal. 1st application[2]	2nd application[3]
Parathion,	0.031	0.25
25% W.P., Emul. (2 lb./gal.)	0.016	0.13
	0.008	0.063
EPN,	0.068	0.38
25% W.P.	0.034	0.25
	0.017	0.13
Malathion,	2.0	2.0
25% W.P., Emul. (5 lb./gal.)	1.0	1.0
	0.5	0.5
Schradan,	0.5	4.0
Emul. (4 lb./gal.)	0.25	2.0
	0.13	1.0
Demeton,	0.06	0.5
Emul. (2 lb./gal.)	0.03	0.25
	0.01	0.13
Aramite,	0.6	0.6
15% W.P., Emul. (2 lb./gal.) (8 lb./gal.)	0.3	0.3
	0.15	0.15
Chlorobenzilate,	1.0	1.0
25% W.P., Emul. (2 lb./gal.)	0.5	0.5
	0.25	0.25
Ovex,	2.0	2.0
50% W.P.	1.0	1.0
Ovex,	0.5	0.5
Emul. (1.6 lb./gal.)	0.25	0.25
Aldrin,	4.0	4.0
25% W.P.		
Aldrin,	4.0	4.0
Emul. (2 lb./gal.)	2.0	2.0
DDT,	8.0	8.0
75% W.P.	4.0	4.0
Dieldrin,	4.0	4.0
50% W.P.		
Dieldrin,	4.0	4.0
Emul. (1.5 lb./gal.)	2.0	2.0
	1.0	1.0
Heptachlor,	4.0	4.0
25% W.P.		
Heptachlor.	4.0	4.0
Emul. (2 lb./gal.)	2.0	2.0
	1.0	1.0

[1] W.P. = wettable powder. Emul. = emulsifiable concentrate with amount of actual material per gallon of formulation in parenthesis.
[2] Emulsions applied on Oct. 12, and the wettable powders on Oct. 13, 1955.
[3] Nov. 2, 1955.

injury but even at a concentration of 1 pound per 100 gallons, there was an accumulation of latex at the bottom of the fruit.

The fruit appeared to be highly sensitive to Aramite. The 90 percent emulsion which contained no petroleum oil solvents caused the greatest amount of injury. A concentration of 0.6 pound per 100 gallons caused active exudation of latex; the young fruits, especially, were severely affected. The fruits were badly discolored and covered with brown spots. The lowest concentration of 0.15 pound per 100 gallons caused only a slight oozing of latex but resulted in severe fruit scarring. The 25 percent emulsion at the same concentrations caused severe brown spotting but no emission of latex. Even the wettable powder caused serious damage to the fruit and at 0.15 pound per 100 gallons the brown stippling was apparent, especially on the young fruits.

Ovex emulsion at 0.5 pound per 100 gallons caused a great amount of latex to issue from the fruits. The lower concentration of 0.25 pound per 100 gallons, however, caused little damage and the fruit appeared fairly normal.

Chlorobenzilate emulsion at 1 pound per 100 gallons also caused an oozing of latex from the fruits. The young leaves were badly burned at the edges. However, 0.25 pound per 100 gallons caused no injury. The wettable powder at 1 pound per 100 gallons caused a slight oozing of latex from the fruit but the lower concentrations were noninjurious.

Demeton emulsion at 0.06 pound per 100 gallons caused a slight discharge of latex from the fruits but the lower concentrations of 0.03 and 0.01 pound per 100 gallons although noninjurious to the fruit, caused a slight tip burn in the young leaves on the tree.

Subsequently, on October 20, 1955, 3 days after the first observations, the field was reinspected. The symptoms of injury were not as spectacular as they were earlier, since most of the active oozing of latex from the fruit had stopped. However, the injured fruits still had large amounts of dried latex adhering to their surfaces.

By October 28, 1955, 11 days after spraying, the areas on the fruits from which the latex had been exuding were scarred. Much of this brown and white scarification occurred at points where the fruit contacted a leaf, a petiole, or another fruit. These contact points formed pockets where the spray could collect and be concentrated by evaporation.

The second spray application was made on November 2, two days after which the orchard was reinspected. The epidermis of the fruit appeared to be more resistant to this spray than it was to the first application. There was no active flowing of latex from the fruit.

Two weeks after the second spray application the following symptoms were observed:

Heptachlor emulsion at 4 pounds per 100 gallons caused scarification of fruit in all stages of development (fig. 17). Damage to fully ripe fruits was

FIG. 17. Injury caused by heptachlor emulsion (4.0 lb./100 gal.). Upper photo taken 1 week after first spray application. Lower photo taken 2 weeks after second application; from left to right, ripe to green fruit.

characterized by round, brown, sunken scabbed areas with dried latex adhering to the surface of the fruit. The green fruits still showed evidence of recent latex discharge in the form of dried, white scales. Dieldrin emulsion at 4 pounds per 100 gallons (fig. 18) caused severe scorching of the fruit. The entire lower surface of the fruit was scabrous. The very young fruit had depressed sunken areas. At 2 pounds of dieldrin per 100 gallons, the symptoms were similar (fig. 18). The ripe fruits had brown, circular, scabby areas where the treatment had injured the fruit. In one green fruit which was also severely scarred, the path followed by the spray runoff was delineated by a thin sunken strip between two severely blotched areas (fig. 18). Most of the injured areas were circular with a scabby periphery and a relatively smooth center. The Aramite formulations at concentrations as low as

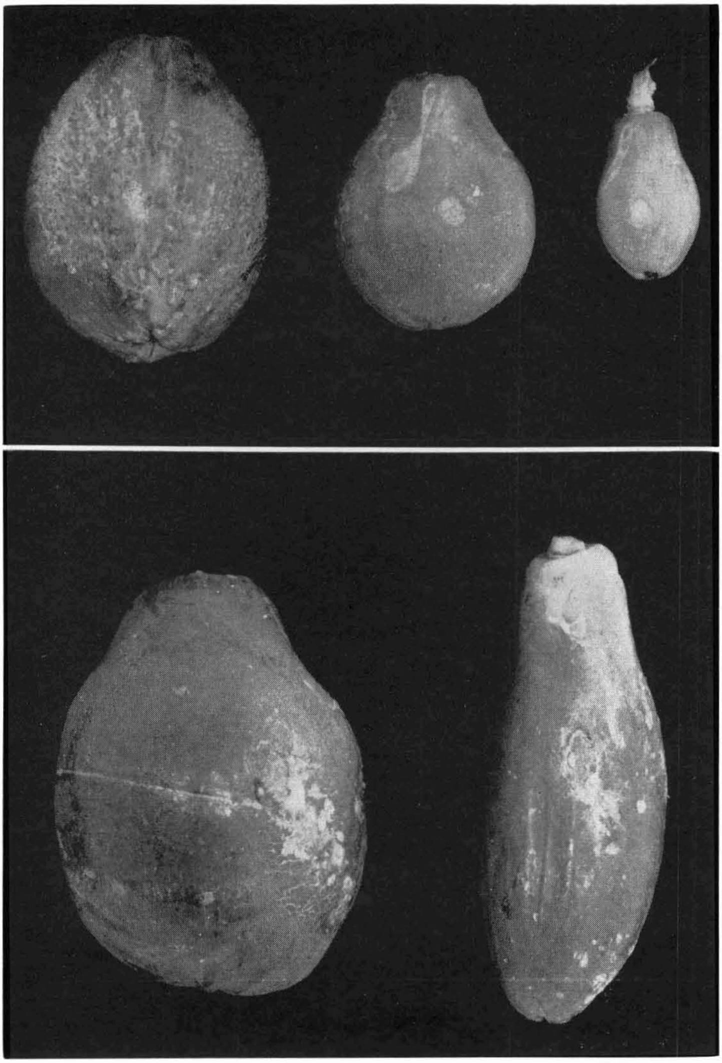

FIG. 18. Injury caused by spraying fruit with dieldrin emulsion at 4.0 (upper) and 2.0 (lower) pounds per 100 gallons.

0.15 pound per 100 gallons produced a characteristic white stippling over the entire surface of the fruit (fig. 19). Chlorobenzilate emulsion, at 1 pound per 100 gallons, caused serious scalding; the wettable powder, at the same concentration, some burning with brown scabby streaks (fig. 20). Ovex wettable powder at 2 pounds per 100 gallons caused scarring on the green

FIG. 19. Typical injury caused by Aramite wettable powder at 0.6 pound per 100 gallons (upper) and 90 percent emulsifiable concentrate at 0.3 pound per 100 gallons (lower).

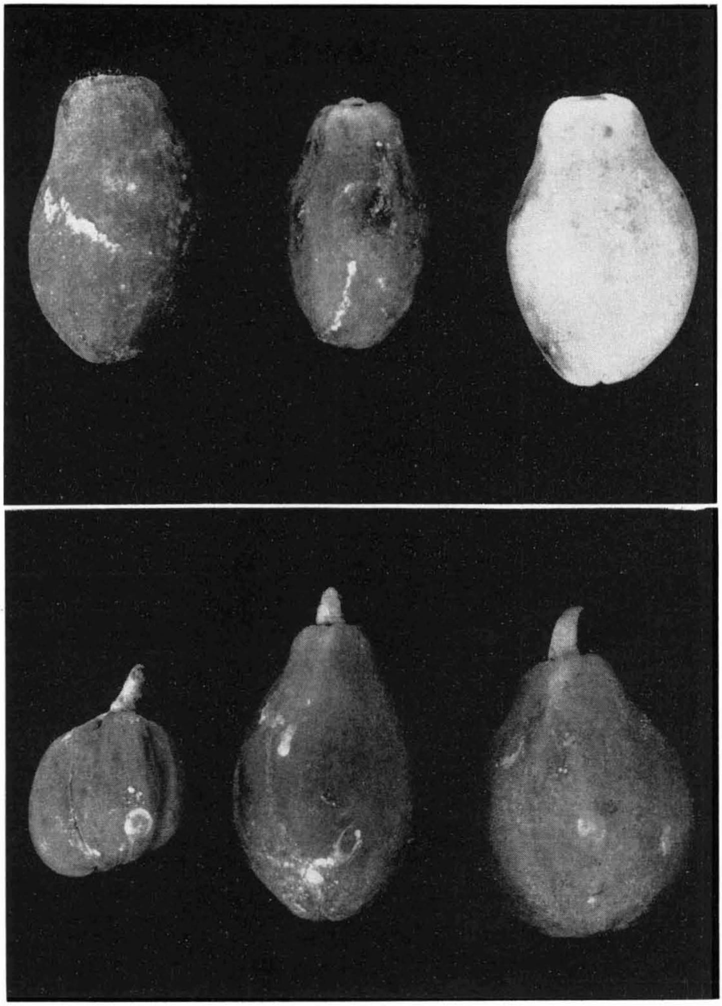

FIG. 20. Injury caused by Chlorobenzilate wettable powder (upper) and emulsifiable concentrate (lower) at 1 pound per 100 gallons.

fruit (fig. 21). EPN, at 0.13 pound per 100 gallons, caused some stippling on the green fruit (fig. 22). Demeton, at 0.5 pound per 100 gallons, produced circular scarred areas where the spray had accumulated at the bottom of the fruit (fig. 23). Schradan-treated fruits, at 4 and 2 pounds per 100 gallons, had some brown scabbing and also some dark, blotchy, slightly raised areas diffused over the entire surface of the green fruit (fig. 24).

FIG. 21. Injury caused by ovex wettable powder at 2 pounds per 100 gallons.

FIG. 22. Injury caused by EPN wettable powder at 0.13 pound per 100 gallons.

FIG. 23. Injury caused by demeton emulsion at 0.5 pound per 100 gallons.

The final observations of the orchard were made 2 months after the second spray application. Fruits in various stages of development were removed from the trees and the external surfaces carefully examined. The fruits were also sliced and seed development observed. In all instances, seed formation appeared to be normal. The toxic effect of these materials to the fruit seems to be associated solely with the external surface.

The following treatments in terms of pounds of active ingredients per 100 gallons resulted in damage severe enough so that the fruits were unmarketable: heptachlor emulsion, 4.0, 2.0; dieldrin emulsion, 4.0, 2.0, 1.0; aldrin emulsion, 4.0; parathion emulsion, 0.25; Aramite emulsion, 0.6, 0.3, 0.15; ovex wettable powder, 2.0; Chlorobenzilate emulsion, 1.0; demeton emulsion, 0.5; and schradan emulsion, 4.0, 2.0.

DISCUSSION

It has long been appreciated that chemicals applied to plants to control insect and mite pests could have an adverse effect on these plants. The general concepts involved in the phytotoxic properties of pesticides are discussed in many textbooks of economic entomology (Bailey and Smith, 1951; Brown, 1951; Shepard, 1939, 1951; etc.).

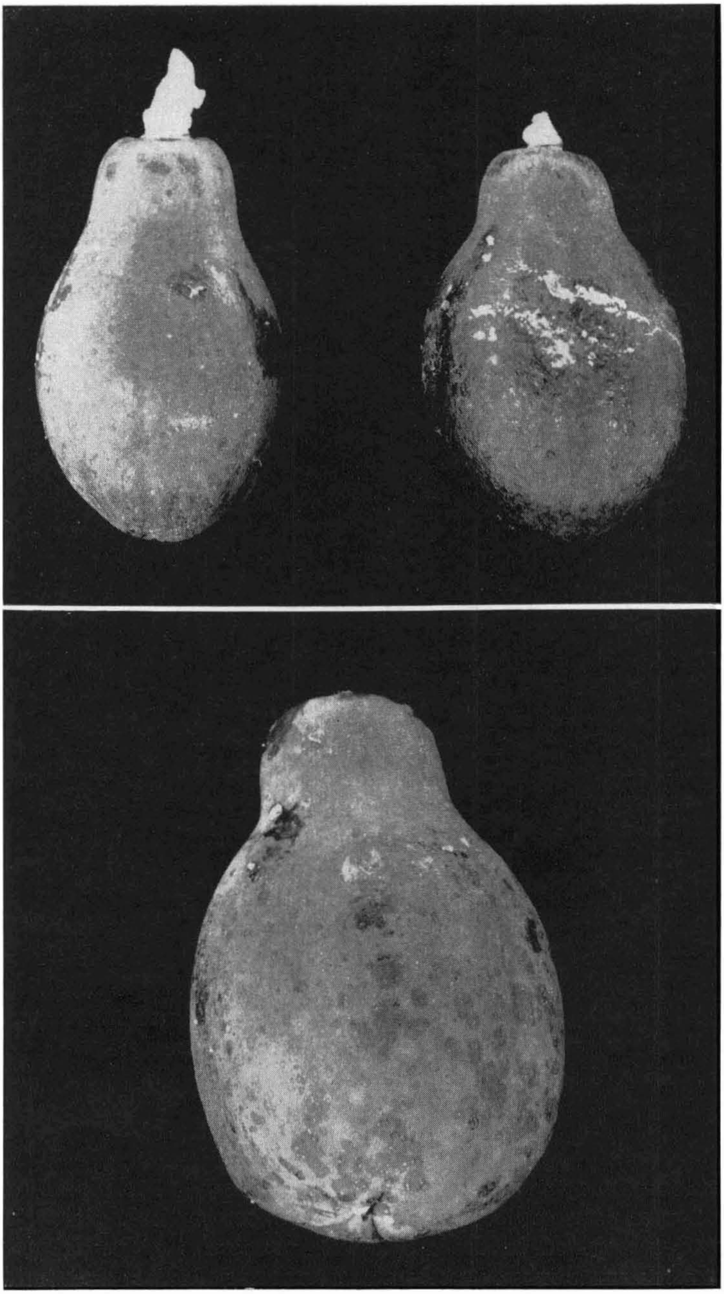

FIG. 24. Injury caused by schradan emulsion at 4.0 pounds (upper) and 2.0 pounds (lower) per 100 gallons.

It is immediately apparent from the results, that in all cases where the pesticide was sufficiently toxic to elicit symptoms, the emulsion caused a more severe reaction than did the equivalent concentration of the wettable powder. A number of factors are involved among which are particle size and solubility. Smaller particles are usually associated with increased phytotoxicity. The size of the emulsion particles is considerably smaller than that of the corresponding suspended solids. Moreover, within an emulsion particle, even if the chemical as synthesized is a solid, it acts as a liquid until the final evaporation of the solvent. The toxicant, therefore, will be in the molecular range and because of its smaller particle size a greater proportion will come in close contact with the leaf than it would in the form of larger suspended solid particles. The greater solubility of the emulsion particle in the cuticle of the leaf, along with its smaller size and correspondingly greater penetration into the leaf tissues, results in more opportunity for reaction with the tissues and interference with the normal physiological processes.

The inherent toxicity of the solvents and surfactants used in the preparation of the emulsifiable formulation also plays a very important role in phytotoxicity. Gast and Early (1956) reported that much of the phytotoxicity caused by agricultural sprays was due to the emulsifier rather than to the solvent or the pesticide. They found that the solvent usually required a concentration five times greater than that needed by the emulsifier to cause the same average injury to sweet corn, cucumber, cotton, lima beans, tobacco, and tomato. Papaya, however, is very sensitive to petroleum oils which are commonly used as solvents in formulating emulsifiable concentrates. An attempt to determine the effect of a highly refined summer-grade petroleum oil on the plant was discontinued because a single application, even at a concentration as low as 0.5 percent oil, caused the leaves to appear translucent or water-soaked. Even the control plants, which were sprayed after the other plants had been treated with oil, showed symptoms of oil injury despite the careful rinsing of the apparatus. None of the control plants of the other experiments which were similarly sprayed showed any evidence of injury. Petroleum oils penetrate the stomata of leaves with ease due to their comparatively low surface tensions (Volck, 1903). In tropical and subtropical regions, plants could be especially sensitive to petroleum oils and therefore to emulsions which contain them, since oil injury increases with a rise in temperature due, in part, to a decrease in oil viscosity. Thus, some of the phytotoxic symptoms produced by the emulsions in these experiments may be a reflection of the ingredients of the emulsifiable concentrate other than the actual pesticide.

Although foliar injury usually occurred at lower dosages than those required for stunting, growth retardation caused by most pesticides was usually correlated with moderate to severe localized foliar injury. The phosphates, however, often inhibited growth at very low concentrations yet caused relatively slight foliar symptoms at these same concentrations. In addition to minor localized lesions, they caused a chlorosis resembling symptoms of some of the mosaic-type viruses.

Severe localized foliar injury without accompanying retardation of growth, however, occurred in several instances with the use of the acaricides. Thus, localized types of injury unless accompanied by extensive defoliation may not in themselves be sufficient to seriously hamper the growth of papaya. This seems to point out that growth retardation rather than foliar injury is the more accurate measure of the phytotoxic properties of a pesticidal formulation.

A 99 percent level of confidence was selected to determine significant retardation of growth by the pesticides. Although in phytotoxicity studies it is preferable to select a conservative level of significance in favor of toxicity, the variability inherent in growth of the papaya rendered the choice of a lower level of significance impractical. In all experiments utilizing single pesticides, however, the selection of this high level of significance did not alter the results or the conclusions that could be drawn from these experiments. Where growth was adversely affected, it was affected severely enough so that the difference was significant at the 99 percent level of probability.

Abscission was also usually associated with severe foliar injury. When the phosphates were applied, however, abscission often occurred before there were any obvious symptoms such as necrosis or chlorosis. Many of the leaves which otherwise appeared normal, dropped at the slightest disturbance. The degree of susceptibility to abscission was directly correlated with the age of the leaf. This, of course, may be associated with the greater auxin content of the younger tissues.

Other types of injury were also related to the age of the leaf. The older leaves were consistently more severely affected than the younger ones by all pesticides. The extremely young leaves, those just at the growing tip, generally showed no signs of injury except at the highest concentrations of very phytotoxic materials such as parathion. This differential susceptibility may be due to a difference in physiology or to the differential wettability of the different aged leaves or to a combination of both.

When applied to the fruits, the pesticides caused three distinct patterns of injury: (1) active flow of latex from localized areas produced by the chlorinated hydrocarbons; (2) stippling over the entire fruit surface, characteristic of Aramite and EPN; and (3) the occurrence of dark green welts over the entire surface of the fruit as caused by schradan. The fruits were more sensitive to the organic acaricides and to the emulsifiable formulations of the chlorinated hydrocarbons than were the seedlings. However, they were more resistant than the seedlings to the organic phosphates; especially parathion.

Fruit injury by emulsions of the chlorinated hydrocarbons was usually evinced by a copious discharge of latex. This active discharge of latex is the usual reaction of immature papaya fruits to mechanical injury. That it was not purely a mechanical effect caused by the spray droplets impinging on the fruit was evidenced by the fact that spraying just water or nontoxic concentrations of pesticides failed to evoke a similar reaction. Apparently, the caustic action of the pesticide at toxic levels injured or destroyed the epidermis, allowing flow from the latex system beneath. This flow is caused by a turgor pressure gradient which is established when the laticifers or latex tubes are opened (Esau, 1953).

Of interest was the apparent resistance of the injured fruits to the second spray application of these chlorinated hydrocarbon emulsions. Latex flow following this application was negligible when compared to that caused by the initial application. Since injury did not occur over the entire surface of the fruit, although the entire fruit was covered by the sprays, there may be specific areas which are especially sensitive to these materials. Or it may be due, in part, to a concentration phenomenon. Two possible explanations for the differential latex flow are: (a) the corking over of these "sensitive areas" after the first application may have resulted in the reduced reaction to the second application; or (b) the latex system of the entire fruit or at least that in the vicinity of the "sensitive areas" may have been depleted of contents after the first spray application and not replenished prior to the second application.

The mode of action of Aramite and EPN appears to be different from that of the chlorinated hydrocarbon emulsions since damage was not limited to certain areas of the fruit and there was no profuse emission of latex. Injury appeared as tiny lesions distributed over the entire fruit. The large scabs usually caused by a concentration of pesticide were also missing.

Malathion was innocuous to papaya whether it was applied as a wettable powder or as an emulsion. Although it is a phosphate, and all other phosphates tested were highly toxic, malathion was noninjurious even at concentrations higher than those usually recommended for pest control. Since malathion controls a wide range of insects and mites and has a relatively low mammalian toxicity, it can be of value in controlling papaya pests.

There is no doubt that all pesticides are potentially phytotoxic provided a sufficiently high concentration is applied to the plant. Where the pesticide is toxic to a wide variety of plants, its use in agriculture is definitely limited. Even if the active ingredient is nontoxic to the plant, care must be exercised in the composition of proprietary formulations, so that the additive materials are also harmless. Often these additives are innocuous in themselves, but when combined with other ingredients can cause plant injury. However, even those formulations that are nontoxic to many plants at the concentrations required for pest control, may be harmful to other species or varieties of plants. Moreover, with the same variety of plant, a formulation which is innocuous when applied singly may cause plant injury when combined with another. This was shown in the experiments combining several of the pesticidal formulations. This poses a very practical problem since it is often necessary to apply two or more such pesticides to control a pest complex. The admixture of pesticides without first determining their toxicity can be dangerous. It is apparent that theoretical considerations alone are insufficient to predict with a high degree of confidence whether a pesticide either singly or in combination with other materials will cause plant injury under a specified set of circumstances. Actual experimental evidence must be presented for such assurance.

SUMMARY

The phytotoxicity of proprietary formulations of the following pesticides to papaya was determined: parathion, EPN, malathion, schradan, demeton, TEPP, Aramite, Chlorobenzilate, ovex, aldrin, DDT, dieldrin, heptachlor, sulfur, and the triethanolamine salt of dinitro-o-sec-butyl phenol.

Phytotoxicity was measured in three ways: (1) effect on seedling growth, (2) gross leaf pathology, and (3) fruit injury. A spray apparatus which was specially developed to apply the formulations to the papaya seedlings is described. The applications to the fruits were made with compressed air sprayers.

The effects of applying pesticides singly are summarized in table 15. The emulsifiable formulation of a pesticide was usually more phytotoxic than the corresponding wettable powder. Most organic phosphates were highly toxic to papaya. Malathion, however, whether applied as an emulsion or as a suspension of a wettable powder was innocuous to papaya.

The fruits were more sensitive to the organic acaricides and to the emulsifiable formulations of the chlorinated hydrocarbons than were the seedlings. However, the fruits were more resistant than the seedlings to the organic phosphates; especially parathion.

The effect of combining certain of these pesticides was also studied. Injury occurred in several instances where materials were combined at concentrations which were innocuous when applied singly. Chlorobenzilate, in particular, appears to be hazardous when combined with other materials at concentrations usually recommended for mite control. Sulfur, although compatible with a large number of pesticides, can cause foliar injury when combined with emulsions.

TABLE 15. Summary of the effect of pesticides on Solo papaya

Pesticide formulation	Concentration actual lb./100 gal.	Retardation of growth[1]	Leaf injury[2]	Fruit injury[3]
Parathion, Emulsifiable Conc.	0.38	+	+++	—
	0.25	+	+++	++
	0.13	+	++	0
	0.063	+	++	0
	0.032	+	+	0
	0.016	+/0	+	0
	0.008	0	+	0
	0.004	0	0	—
	0.002	0	0	—
	0.001	0	0	—
Parathion, Wettable Powder	0.38	+	+++	—
	0.25	+	++	0
	0.13	+	++	0
	0.063	+	++	0
	0.032	+	+	0
	0.016	0	0	0
	0.008	—	—	0
EPN, Wettable Powder	2.16	+	+++	—
	1.08	+	+++	—
	0.54	+	+++	—
	0.38	—	—	+
	0.27	+	+++	+
	0.14	+	+++	+
	0.068	+/0	+	0
	0.034	0	+	0
	0.017	0	0	0
	0.0085	0	0	—
	0.0043	0	0	—
Malathion, Emulsifiable Conc.	2.0	0	0	0
	1.0	0	0	0
	0.5	0	0	0
Malathion, Wettable Powder	2.0	0	0	0
	1.0	0	0	0
	0.5	0	0	0
Schradan, Emulsifiable Conc.	4.0	—	—	++
	2.0	—	—	++
	1.0	+	++	0
	0.5	—	—	0
	0.25	0	+	0
	0.13	0	0	0
	0.063	0	0	—
	0.031	0	0	—

[1] + Significant retardation of growth.
0 No retardation of growth.
— Concentration not tested.

[2] +++ Severe defoliation.
++ Moderate injury: necrosis, chlorosis, tip burn.
+ Slight injury: necrosis, chlorosis, tip burn.
0 Insignificant to no injury, normal leaves, some spotting.
— Concentration not tested.

[3] ++ Surface severely scarred, fruit nonmarketable.
+ Moderate burning or spotting.
0 Insignificant to no injury.
— Concentration not tested.

(Continued)

TABLE 15. *Continued*

Pesticide formulation	Concentration actual lb./100 gal.	Retardation of growth[1]	Leaf injury[2]	Fruit injury[3]
Demeton, Emulsifiable Conc.	1.0	+	+++	—
	0.5	+	++	++
	0.25	+	++	+
	0.13	+	+	+
	0.063	0	+	+
	0.031	+	+	0
	0.01	—	—	0
TEPP, Emulsifiable Conc.[4]	1–500	+	+++	—
	1–1000	+	++	—
	1–2000	0	0	—
	1–4000	0	0	—
	1–8000	0	0	—
Aramite, Emulsifiable Conc.	0.6	0	+	++
	0.3	0	+	++
	0.15	0	0	++
Aramite, Wettable Powder	0.6	0	0	+
	0.3	0	0	+
	0.15	0	0	+
Chlorobenzilate, Emulsifiable Conc.	1.0	0	++	++
	0.5	0	+	+
	0.25	0	0	0
Chlorobenzilate, Wettable Powder	1.0	0	+	+
	0.5	0	0	0
	0.25	0	0	0
Ovex, Emulsifiable Conc.	2.0	+	+++	—
	1.0	+	++	—
	0.5	0	+	+
	0.25	—	—	0
Ovex, Wettable Powder	2.0	0	0	++
	1.0	0	0	0
	0.5	0	0	—
DDT, Wettable Powder	8.0	0	0	0
	4.0	0	0	0
	2.0	0	0	—
	1.0	0	0	—
Aldrin, Emulsifiable Conc.	4.0	0	0	++
	2.0	0	0	0
	1.0	0	0	—
	0.5	0	0	—
Aldrin, Wettable Powder	1.0	—	—	0

[1] + Significant retardation of growth.
0 No retardation of growth.
— Concentration not tested.

[2] +++ Severe defoliation.
++ Moderate injury: necrosis, chlorosis, tip burn.
+ Slight injury: necrosis, chlorosis, tip burn.
0 Insignificant to no injury, normal leaves, some spotting.
— Concentration not tested.

[3] ++ Surface severely scarred, fruit nonmarketable.
+ Moderate burning or spotting.
0 Insignificant to no injury.
— Concentration not tested.

[4] Concentrations of TEPP are given in terms of dilutions.

TABLE 15. *Continued*

Pesticide formulation	Concentration actual lb./100 gal.	Retardation of growth[1]	Leaf injury[2]	Fruit injury[3]
Dieldrin, Emulsifiable Conc.	4.0	0	+	++
	2.0	0	0	++
	1.0	0	0	++
	0.5	0	0	—
	0.25	0	0	—
Dieldrin, Wettable Powder	4.0	0	0	0
	2.0	0	0	—
	1.0	0	0	—
	0.5	0	0	—
	0.25	0	0	—
Heptachlor, Emulsifiable Conc.	4.0	0	+	++
	2.0	0	0	++
	1.0	0	0	+
	0.5	0	0	—
Heptachlor, Wettable Powder	4.0	0	0	0
	2.0	0	0	—
	1.0	0	0	—
	0.5	0	0	—
DN-289	0.16	+	+++	—
	0.094	+	++	—
	0.062	0	++	—
	0.047	0	+	—
	0.031	0	+	—
	0.016	0	0	—

[1] + Significant retardation of growth.
0 No retardation of growth.
— Concentration not tested.

[2] +++ Severe defoliation.
++ Moderate injury: necrosis, chlorosis, tip burn.
+ Slight injury: necrosis, chlorosis, tip burn.
0 Insignificant to no injury, normal leaves, some spotting.
— Concentration not tested.

[3] ++ Surface severely scarred, fruit nonmarketable.
+ Moderate burning or spotting.
0 Insignificant to no injury.
— Concentration not tested.

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