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Title: THE USE OF 2, 4-D, PARAQUAT AND DINOSEB FOR CONTROL OF FILBERT (CORYLUS AVELLANA L.) SUCKERS

Abstract approved: Harry B. Lagerstedt

The control of filbert (Corylus Avellana L.) suckers by means of herbicides was investigated in three phases during 1968 and 1969. (1) Screening trials, on canned filbert trees in the greenhouse, to determine the effectiveness of various herbicides and concentrations in controlling vegetative growth. (2) A summary experiment in the greenhouse to quantitatively evaluate the effectiveness of the three most promising herbicides selected from the screening trials. (3) Field trials to determine the effectiveness of the three herbicides at various concentrations under field conditions in a mature filbert orchard.

One quart of 2, 4-D, one quart of paraquat, or three pints of dinoseb per 100 gallons of solution gave satisfactory control of filbert suckers. Paraquat and 2, 4-D controlled the appearance of regrowth to a greater extent than dinoseb. Use of oil with dinoseb enhanced the effect of the herbicide.

Filbert suckers should be treated when less than one foot in height and thoroughly covered with spray to obtain satisfactory kill. The herbicide 2, 4-D gave better control of larger suckers than either paraquat or dinoseb. No evidence of injury to mature filbert trees was seen where the above rates were used.

The Use of 2, 4-D, Paraquat and Dinoseb for Control of Filbert (*Corylus Avellana* L.) Suckers

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INTRODUCTION

The United States filbert production is centered in the Pacific Northwest with the Willamette Valley of Oregon producing 97 percent of the total crop. Annual production of filberts in the United States averages over 14 million pounds, but does not supply half of the U. S. consumer demand. The potential that exists for increased filbert production is tremendous.

The habit of the commercial European filbert (*Corylus Avellana* L.) is to form a shallow-rooted, multi-stemmed large shrub or small tree, 10 to 20 feet in height. Each growing season, suckers arise from buds at the base of the trunk and from roots near the ground line. These shoots provide a natural replacement for the old stems as they deteriorate with age.

For easier control of weeds and for mechanical harvesting purposes, the preferred practice of growers in the U. S. is to maintain the filbert as a single-trunked tree. The filbert tree will continue sending up large numbers of suckers from the crown and roots annually during the entire growing season. The single-trunk training system makes it necessary that these suckers be eliminated as they arise. In the past, suckers were removed by hand, which was laborious and time-consuming. Large suckers were grubbed out during the dormant season, a practice which caused extensive root and stem injury.

Chemical sucker control by use of herbicides is the best means of control available in terms of cost and labor. Any herbicide used must effectively control the emerging suckers and yet not damage the living tissues of the trunk and roots. Any translocated herbicide must not move down into the root system or up into the tree in quantities sufficient to cause undesirable side effects.

The time and labor involved in annual sucker control practices has become one of the factors limiting the size of orchard a grower can adequately manage. Even with the use of herbicides, each tree in the orchard must be treated from three to five times during the growing season. Suckers which escape treatment must be grubbed out by hand during the dormant season. Thus sucker control is a major problem of filbert orchard management and improved techniques or chemicals are essential to reduce labor, time and cost of sucker control.

HISTORICAL DEVELOPMENT OF FILBERT SUCKER CONTROL

For many years following the introduction of the filbert to the Pacific Northwest, suckers were removed by hand periodically during the year (16, 17, 19, 26, 30, 32, 33). It was not until 1953 that the use of herbicides for sucker control was first reported in the annual Proceedings of the Nut Growers Society of Oregon and Washington. In that year, R. E. Kerr (21) reported on trials he made using diesel oil fortified with isopropyl N-(3-chlorophenyl)-carbamate (CIPC) or 4,6-dinitro-2-s-butylphenol (dinoseb). Using two gallons of CIPC in 53 gallons of oil or three quarts of dinoseb in 55 gallons of oil, he obtained successful control of suckers. No injury was observed underneath the bark of one-year-old suckers or that of the parent trees. However, he noted that portions of the suckers below the ground line were not killed, making periodic treatments necessary during the growing season as these portions re-sprouted. Costs were calculated to be less than one and one-half cents per tree per application, including material, labor and machine costs.

Carl Marnach (27) reported at the same time that he had been treating 11 acres of trees for ten years following planting with 2,4-dichlorophenoxy acetic acid (2,4-D) at the rate of two tablespoons per gallon of water (equivalent to 3 1/8 quarts per 100 gallons) and had noticed no sign of injury to the trees. He stated that suckers should be treated when only a few inches high as he had repeatedly observed shoots one-and-one-half to two feet in height were injured insufficiently to prevent regrowth, even from above-ground portions.

In 1954, Kerr (22) reported further results with the use of CIPC or dinoseb in diesel oil. He experienced difficulty in control of suckers in May of that year due to a masking effect of large suckers present as a result of inadequate coverage the month before. These large suckers prevented adequate coverage of newer suckers by the May sprays. Kerr also reported definite injury of small, scrubby trees possessing blight lesions or bark injuries where the lesions or injuries were contacted by the dinoseb oil spray. Several trees of less than two inches trunk diameter were killed because the spray material had spread along the cambium enough to completely girdle the trees. No injury to larger trees was observed. Hand removal of large suckers remaining after the summer spray treatments was necessary at the end of the season. This operation cost an average of 1.9 cents per tree.

Roberts (31), Yamhill County Extension Agent, reported on tests made with 2,4-D amine, 2-methyl-4-chlorophenoxy acetic acid (MCP) and ammonium sulphamate (Ammate). The 2,4-D amine was used at the rate of two tablespoons per gallon of water (3 1/8 quarts per 100 gallons), MCP at the rate of four tablespoons per gallon (6 1/4 quarts per 100 gallons) and Ammate at the rate of one pound per gallon of water. Trees in a ten-year old orchard were sprayed on May 27 and August 12, 1954. All three herbicides gave good kill of suckers at the earlier date, when the suckers were four to six inches high, and fair kill on the second spraying, when suckers were much larger. The Ammate gave the fastest kill of suckers, being a contact type herbicide. Less regrowth was seen with it than with 2, 4-D or MCP. However, Roberts considered that this might be due to injury to the parent tree and that the Ammate concentration could be cut in half. The use of 2, 4-D and related hormonal herbicides in filbert orchards had caused no apparent injury to the trees. Roberts emphasized caution in the use of 2, 4-D in the orchard due to the drift hazard. He recommended that suckers be sprayed when six inches or less in height. These will wither up and disappear, while larger suckers even when killed will remain physically present and must be removed by hand.

Peary (29) reported good sucker control with sprays of CIPC at the rate of two gallons in 53 gallons of diesel oil on suckers up to 30 inches in height. However, the larger suckers persisted while the smaller ones disappeared. Follow-up sprays of 2, 4-D at the rate of two tablespoons per gallon of water (3 1/8 quarts per 100 gallons) gave continued control of suckers. Peary reported costs of sucker control had been cut 65% by spraying instead of hand removal in a 40-acre orchard of ten-year-old trees. Hand removal of suckers in this orchard had involved costs of over $300 a year.

In 1967, Lagerstedt reported on attempts to control filbert suckers by burning with a propane torch (23). While effective on young suckers, damage to large suckers by flame girdling was seldom extensive enough to kill them. Even when these large suckers were completely girdled, death was very slow to occur.

In a 1968 report, Lagerstedt and Crabtree discussed the use of ten commercially prepared sprout-inhibiting paints (24). Each paint had been formulated with one or two percent naphthalene acetic acid (NAA) salts or esters in different carriers and was applied as a trunk paint. Results ranged from no control to good control of suckers. Further testing was considered to be necessary due to trunk injury obtained in some of the treatments.

Twenty-three experimental paints consisting of various growth regulators were then formulated in white latex and white oil-base paint. Various concentrations of NAA, water-soluble and oil-soluble forms of 2, 4-D, maleic hydrazide, triiodobenzoic acid and 2, 4, 5-trichlorophenoxy acetic acid (2, 4, 5-T) were tried. The higher levels of NAA and 2, 4-D showed some growth inhibition, but results were generally poor (24).

A number of experiments testing several herbicides on filbert plants in the greenhouse were also conducted (24). Dinoseb, paraquat, 2, 4-D, various weed oils and other herbicides in the form of derivatives of cacodylic acid, benzoic acid (dicamba) and picolinic acid (picloram) were used. These experiments showed dinoseb to be effective at rates as low as three pints of concentrate per 100 gallons of solution. Addition of a surfactant or surfactant and oil improved the effectiveness of the herbicide. Paraquat was observed to give effective shoot kill at a concentration of one quart per 100 gallons of solution. Regrowth of shoots was much slower than when dinoseb was used. Use of a surfactant increased the effectiveness of paraquat also. Effective shoot kill was obtained with water- and oil-soluble forms of 2, 4-D at concentrations as low as one-half pint per 100 gallons of solution. Marked symptoms and injury were observed at lower concentrations, although killing was often incomplete. Lagerstedt noted that occasional undesirable side effects had been observed in orchard trees where suckers had been treated with high rates of 2, 4-D. These effects included delayed nut drop, premature catkin development and twisting and curling of shoot tips and young leaves. Concentrations of weed oils, cacodylic acid, dicamba and picloram used in the greenhouse tests were not stated, but many had exhibited some degree of sprout control. Dinoseb and paraquat are registered for use for weed control on the filbert orchard floor. No chemicals or herbicides are registered for use on filbert suckers.

In further discussion of the filbert sucker problem, Lagerstedt reported that the practice of propagating filberts by layering contributed to the production of suckers. In layering, roots are developed on a buried portion of stem. This buried portion of stem readily produces shoots when the new tree is planted out. He also observed that if underground portions of suckers are not physically removed at their point of origin or killed to that point by herbicides, they will rapidly sprout new suckers. He emphasized that mechanical or chemical control of suckers was most effective when done before they exceeded six to nine inches in height.

Lagerstedt considered that the ultimate answer to the sucker problem in the filbert would be development of a non-suckering root-stock. The Turkish filbert (Corylus colurna) does not sucker, but there is some question as to its long term suitability as an understock for the Barcelona filbert, the principal commercial variety. Efforts were being directed at developing a non-suckering hybrid of the Turkish and European filberts for use as a rootstock.

METHODS AND MATERIALS

The first experiments in filbert sucker control by means of herbicide sprays were conducted primarily by the grower in his own orchard. These experiments served to reveal the ability of a few herbicides to control suckers. However, little work has been done to screen the wide range of available herbicides and determine the lowest effective concentrations of each. This investigation logically divided itself into three phases: 1. preliminary screening trials in the greenhouse, 2. a detailed experiment summarizing the greenhouse screening work and 3. a field application of the results obtained from greenhouse data.

Descriptions of Herbicides and Oils Used in Screening Trials

Paraquat, 1,1'-dimethyl-4,4'-bipyridylium ion, was developed by the Dyestuffs Division of Imperial Chemical Industries in 1959 (20). Paraquat is a strong, nonselective contact herbicide. It is highly water-soluble, due to its strong cationic nature, and is formulated commercially as aqueous concentrates of the dichloride or dimethylsulfate salts (10, 20).

Diquat, or 6,7-dihydropyrido(1,2-a:2',1'-c)pyrazidinium, is an effective broad-spectrum contact herbicide similar to paraquat, to which it is closely related. This material was developed by I.C.I. in

1955 and is available as an aqueous concentrate of the dibromide salt (10, 20). Diquat and paraquat are sold in the United States by the Chevron Chemical Company.

Dinoseb, or 4, 6-dinitro-o-sec-butyl phenol (formerly known as DNBP), is one of the most toxic of the substituted-phenol herbicides (13, p. 214). This material was developed by the Dow Chemical Company and first described as a weed-killer in 1945 by Crafts (11). Like diquat and paraquat, dinoseb is a strong, nonselective contact herbicide. It is available as the oil-soluble parent molecule in an emulsifiable concentrate or as water-soluble alkanolamine salts in aqueous concentrates.

The herbicide 2, 4-dichlorophenoxyacetic acid or 2, 4-D was discovered in the early years of World War II, but results of experimentation with it did not begin to be published until after the war's end (2, p. 14; 12, p. 52). It is primarily effective on a wide range of broadleaf plant species and is relatively non-toxic to cereal grains and other grass species. It is readily translocated in plants and is able to affect portions of susceptible plants distant from the point of application. Unlike paraquat, diquat and dinoseb, 2, 4-D is a hormone-type weed killer and not a contact material. A wide variety of commercial formulations, including water-soluble metallic and amine salts and oil-soluble amines and esters, are available from several manufacturers.

A closely-related compound, 2, 4, 5-trichlorophenoxyacetic acid (2, 4, 5-T) was developed simultaneously with 2, 4-D. It appears to exhibit many of the same characteristics as 2, 4-D, but is more effective on many woody species and some weeds resistant to 2, 4-D (2, p. 14; 13, p. 303). It is available in a variety of formulations similar to those of 2, 4-D.

Dicamba, or 2-methoxy-3, 6-dichlorobenzoic acid, also exhibits growth-regulator-like activity in plants. It is effective on a somewhat different spectrum of broadleaf species than 2, 4-D and gives pre-emergence control of annual broadleaf and grassy weeds (13, p. 235; 20). It is available as an aqueous concentrate of the dimethyl amine salt from the Velsicol Chemical Corporation.

One of the most potent growth-regulator herbicides available is 4-amino-3, 5, 6-trichloropicolinic acid or picloram. As with 2, 4-D, 2, 4, 5-T and dicamba, it is primarily effective on a wide range of broadleaf plants, including woody perennials, and is relatively non-toxic to grassy species (20). Picloram is registered only for non-cropland use due to its high toxicity to many crop plants (1). This herbicide is available under the trade name Tordon from the Dow Chemical Company as an aqueous concentrate of the potassium salt.

Cacodylic acid is an organic arsenical herbicide (dimethyl-arsinic acid) effective as a contact killer on a wide variety of plant species (10; 12, p. 209-210; 13, p. 314; 20). It is available as an aqueous concentrate of the sodium salt from the Ansul Company.

Cypromid, or 3',4'-dichlorocyclopropanecarboxanilide, is a contact herbicide used for broad-spectrum weed control in non-crop areas or selective weed control in directed applications (20). Cypromid is sold by the Gulf Oil Corporation as an emulsifiable concentrate of the parent molecule.

Many different herbicidal oils are available for use in weed control. The phytotoxicity of an oil is related to its aromatic content and volatility (2, p. 19; 12, p. 13; 13, p. 196). Oils of low aromatic content (less than about 25%) and comparatively high volatility are often used as selective herbicides in carrots and other oil-resistant crops. Chevron Weed Killers 349 and 357 are of this type. Conversely, oils with an aromatic content of 65 to 85% and relatively low volatility, exert a strong herbicidal effect and find use as nonselective vegetation killers. Chevron Weed Oil and Phillips Weed Killers 7 and 11 fall into this category. Oils such as Chevron WTL Base Oil (aromatic content 35%) show phytotoxicity intermediate between the above general groups. Diesel oil possesses a low aromatic content (about 20%) and has been used primarily as a carrier for other herbicides.

Screening Trials

Screening trials were established to obtain information on the relative effectiveness of nine herbicides, six herbicidal oils and diesel oil upon filbert shoots. The different oils were used alone and as carriers for dinoseb. In later stages of the screening trials, paraquat and 2, 4-D were tested together in combination sprays. The herbicides, oils and concentrations used are listed in Tables 1 and 2. The relative concentrations used in the paraquat-2, 4-D and dinoseb-oil combination sprays are shown in Tables 3 and 4. All herbicide and oil concentrations listed were calculated for 100 gallons of solution with eight ounces of X-77 surfactant added.

Table 1. Herbicide concentrations used in screening trials.

	Amount per 100 gallons of solution			
Common name	Ounces	Pints	Quarts	Gallons
Paraquat	-	1	1, 2, 3	-
Dinoseb	-	3	2, 3, 4, 5	-
2, 4-D*	-	1	1, 2	1, 2
2, 4-D**	1, 2, 4, 8	1	1, 2	1, 2
2, 4, 5-T	½, 1, 2, 4, 8	1	-	-
Dicamba	1, 2, 4, 8	1	1	-
Picloram	½, 1, 2, 4, 8	1	-	-
Diquat	-	1	1, 2	-
Cacodylic Acid	-	1	1, 2	1, 2, 5
Cypromid	8	1	1, 2	1, 2

*Dimethylamine salt.

**Heptylamine salt.

Table 2. Oil concentrations used in screening trials.

Oil	Gallons used per 100 gallons of solution
Diesel	4, 8, 10, 12, 25, 50, 100
Chevron Weed Killer 349	5, 10, 25, 50, 100
Chevron Weed Killer 357	5, 10, 25, 50, 100
Chevron WTL Base Oil	5, 10, 25, 50, 100
Chevron Weed Oil	4, 5, 10, 25, 50, 100
Phillips Weed Killer 11	5, 10, 15, 20, 25, 50, 100
Phillips Weed Killer 7	1, 5, 10, 15, 20, 25

Table 3. Paraquat and 2, 4-D combinations used in screening trials.

Herbicide	Ounces used per 100 gallons of solution									
Paraquat	8	4	2	1	16	24	16	24	32	24
	+	+	+	+	+	+	+	+	+	+
2, 4-D	1	2	4	8	16	16	24	24	24	32

Table 4. Dinoseb and oil combinations used in screening trials.

Oil	Pints of dinoseb per 100 gallons of solution	Gallons of oil per 100 gallons of solution
Diesel	1	8
"	2	4, 8, 12
"	3	1, 4, 5, 8, 12
"	4	4, 8
"	5	4, 8
"	6	4, 12
"	8	4, 12
Chevron Weed Killer 349	2	4, 8, 12
Chevron Weed Killer 357	2	4, 8, 12
Chevron WTL Base Oil	2	4, 8, 12
Chevron Weed Oil	2	4, 8, 12
"	3	4
Phillips Weed Killer 11	3	1, 2, 3, 4, 5
Phillips Weed Killer 7	3	1, 3, 5

The screening trials were conducted in the greenhouse on container-grown filbert trees. These were one-year-old seedlings two to three feet tall and two-year-old commercially-propagated trees four to six feet in height. Trees that possessed actively-growing shoots resembling typical filbert suckers were used. Winter screening trials were accomplished by using a forcing technique on two-year-old trees. These were cut to a height of six inches and placed in cold storage for two months at 32°F to satisfy winter chilling requirements. After chilling, the canned trees were placed in a 70°F greenhouse to force one or more active new shoots. This technique allowed sucker control research to continue uninterrupted the year around.

The solutions were applied to the foliage of the subject plants with hand sprayers to the point of run-off. Effects of the treatments were observed over succeeding days and weeks. Evaluation was by visual observation. In evaluating the effectiveness of a particular material at a given concentration, the extent of damage to the leaves and dieback of the shoots was noted. Acceptable effect was taken to be death of the treated leaves and dieback of the shoots by one-third or more of their length without damage to stem portions one year old or older. The amount and rapidity of appearance of regrowth from unkilled portions was also noted.

Following initial trials of a given material, subsequent trials centered around the approximate lowest effective concentration. One to three plants were used for each herbicide or oil concentration treatment made in each screening trial. Twenty-one individual trials involving from one to ten herbicides and/or oils each or a total of 270 separate tests were conducted between April 1968 and May 1969.

Summary Herbicide Experiment

The screening trials indicated that four herbicide treatments appeared particularly promising for use in filbert sucker control. An additional experiment was designed to obtain specific data on foliar and shoot kill and subsequent vegetative regrowth. This summary experiment was conducted in the greenhouse on container-grown filbert trees in May and June 1969 prior to using the screening data in field tests.

The herbicide treatments used were: paraquat, and 2, 4-D, each at the rate of one quart per 100 gallons of solution, dinoseb at the rate of three pints in 100 gallons of solution, and dinoseb at the above rate plus eight gallons of diesel oil per 100 gallons of solution. The heptylamine salt of 2, 4-D was used. The surfactant X-77, at the rate of eight ounces per 100 gallons of solution, was used in each of the above treatments.

The subject plants were all two-year-old trees four to six feet in height growing in one-gallon cans. The randomized-block design was used with four replications of four trees each in each treatment. Leaf counts and shoot measurements were made on each tree prior to treatment.

Two weeks after treatment, leaf-injury evaluations were made on the trees in each treatment. Each leaf was placed in one of four classifications: 1) 0 to 25% dead, 2) 26 to 50% dead, 3) 51 to 75% dead, and 4) 76 to 100% dead. At three weeks following treatment, the portion of each shoot remaining alive was measured and the amount of dieback determined. New shoots appearing were counted and measured at four and six weeks after treatment. A temperature-recorder was used to obtain a continuous record of temperatures in the greenhouse during the first three weeks following the application of the herbicides.

Field Testing

At the conclusion of the greenhouse experiments in early June of 1969, certain herbicide treatments were selected for testing under actual growing conditions in the field. A mature filbert orchard with trees bearing large numbers of vigorous suckers ranging from one-half inch to seven feet in height was selected for the field trial. The treatments used included those used in the summary herbicide experiment plus two other 2, 4-D concentrations and a series of paraquat-2, 4-D combination sprays. The list of treatments is shown in Table 5. All solution concentrations were calculated for 100 gallons of solution with eight ounces of X-77 surfactant added.

The herbicide treatments were applied on July 14, 1969. Ten trees were used for each treatment and sucker counts made for each tree prior to application of the sprays. A two-gallon hand sprayer was used to thoroughly wet the foliage of the suckers of each tree up to a height of 12 to 18 inches.

Table 5. Field trial treatments. Concentrations per 100 gallons of solution.

1.	Paraquat-1 quart
2.	2, 4-D-1 pint
3.	2, 4-D-1 quart
4.	2, 4-D-2½ pints
5.	Dinoseb-3 pints
6.	Dinoseb-3 pints + Diesel Oil-8 gallons
7.	Paraquat-1 quart + 2, 4-D-½ pint
8.	Paraquat-1½ pints + 2, 4-D-½ pint
9.	Paraquat-1 pint + 2, 4-D-1 pint
10.	Paraquat-1 quart + 2, 4-D-1 pint
11.	Paraquat-1 pint + 2, 4-D-1½ pints
12.	Paraquat-½ pint + 2, 4-D-1½ pints

Five trees were randomly selected from each treatment for evaluation after five weeks. Sucker counts were made again for each tree at this time and the numbers and heights of new suckers arising during this period were determined. In addition, the numbers and lengths of new shoots sprouting from living portions of suckers above the soil surface during this period were also determined. Results were totaled and averaged per tree. A total of 100 incompletely-killed suckers were selected randomly from the five trees and measured for amount of dieback. These figures were averaged for each treatment.

RESULTS

Screening Trials

Paraquat and dinoseb exhibited a strong burning effect on leaves and terminal shoots of canned filbert trees in the greenhouse, with dinoseb producing the effect more rapidly than paraquat. Dinoseb-treated leaves turned uniformly brown within a few days. Young leaves treated with paraquat turned a dull, mottled brownish-green in about a week. Old leaves treated with paraquat tended to be killed in irregular patches, with living green portions existing for several weeks.

Terminal shoot kill was comparable between the two herbicides with one-quarter to one-third or more of a given shoot being killed back. Regrowth from lateral buds appeared very slowly or not at all from paraquat-treated plants, whereas regrowth appeared rapidly and vigorously from dinoseb-treated plants. Neither material appeared to injure stem tissue below the point where soft succulent tissue occurred.

It proved more difficult to establish a consistently effective minimum concentration for 2,4-D. Acceptable kill was obtained at rates as low as one pint per 100 gallons of solution in these greenhouse tests, but not consistently. Symptomatically, curling of actively-growing terminal shoots occurred within a few days, but actual death of leaves and terminals did not occur for several weeks. The 2, 4-D treatments caused more injury to stem tissue one year old or older than did paraquat or dinoseb. Some old trees were killed completely at concentrations as low as one pint, but rates of one or two quarts were more consistently effective. Regrowth, when it did appear, was generally weak and present only far below killed portions.

The growth-regulator herbicides 2, 4, 5-T and dicamba were not any more effective than 2, 4-D and were tested no further. Picloram, on the other hand, appeared too potent for use in filbert sucker control. Seedling trees were killed at concentrations as low as four ounces in 100 gallons of water.

The contact herbicides diquat, cacodylic acid and cypromid were not as effective as paraquat or dinoseb and were dropped from consideration.

Of the oils tested, Chevron Weed Oil and Phillips Weed Killers 7 and 11 exhibited strong phytotoxicity at concentrations of 10 to 25 gallons or more per 100 gallons of solution. Chevron WTL Base Oil showed acceptable killing effect only as an undiluted oil spray. Chevron Weed Killers 349 and 357 and diesel oil caused only occasional injury to the extreme tips of shoots even when applied as undiluted oil sprays. Addition of any of the oils in amounts of four gallons or more per 100 gallons of solution noticeably increased the effectiveness of dinoseb sprays upon filbert shoots.

Paraquat and 2, 4-D in combination sprays were completely ineffective at concentrations of less than one pint of each per 100 gallons of solution. At higher levels, the two herbicides appeared to act independently and not synergistically. Symptoms of paraquat injury and 2, 4-D injury in a given treatment reflected the individual concentrations of the two herbicides present in the spray.

At the conclusion of the screening trials in May 1969, paraquat, dinoseb and 2, 4-D were selected as the most promising of the materials tested. Paraquat at a concentration of one quart in 100 gallons of solution, dinoseb at a concentration of three pints in 100 gallons of solution and 2, 4-D at a concentration of one quart in 100 gallons of solution appeared to be the lowest concentrations, respectively, that would consistently give acceptable shoot kill.

Summary Herbicide Experiment

Paraquat, 2, 4-D, dinoseb and dinoseb-plus-diesel oil treatments were applied to the canned test trees in the greenhouse on May 13, 1969. Weather conditions consisted of heavy overcast and rain. The temperature in the greenhouse was 65°F at the time of treatment. By noon the following day, the sky was clearing and remained sunny or partly cloudy through May 28. Greenhouse temperatures were generally high during this period. A graph of the daily maximum and minimum temperatures recorded in the greenhouse during the course of the experiment is shown in Figure 1. The high temperatures of 100°F or greater recorded on May 16, 21 and 22 were of brief duration only.

The paraquat-treated plants showed some curling of leaf edges (Figure 3) and faint spotting 24 hours after treatment. Forty-eight hours after treatment, leaves were showing extensive dull-green spotting, young leaves were strongly curled and damage to the shoot tips was becoming evident (Figure 4). Killing of leaves and shoot tips was essentially complete after four days (Figure 5). Although leaf kill was extensive, scattered portions of leaf tissue in many older leaves remained alive and healthy for several weeks (Figure 8). This response by filbert shoots to the application of paraquat was much more rapid than in those screening trials conducted during the winter months.

New lateral bud growth from paraquat-treated trees was first noted three weeks after treatment. These new shoots were weaker and paler in color in comparison to normal healthy shoots or regrowth from dinoseb-treated trees. Many leaves exhibited a lighter shade of green in the tissue bordering the midrib and lateral veins than in the remainder of the laminar tissue. Some of these lighter-colored areas became necrotic soon after expansion of the blade.

Shoot terminals of the 2,4-D-treated plants were beginning to curl noticeably 24 hours after treatment (Figure 3). By the second day, immature leaves below the shoot tips were starting to cup upwards strongly (Figure 4). This curling of the shoot tips and immature leaves is a typical filbert response to 2, 4-D and increased in severity during the next four days (Figure 5). About the fourth day after treatment, some of the older leaves began exhibiting large ill-defined brownish necrotic areas in the center of the leaf blade, covering about one-third to one-half of the blade area. This condition was never exhibited by the majority of the leaves and little noticeable change occurred until the ninth day when the majority of the leaves rapidly began dying (Figure 6). By the end of the second week, the majority of the foliage of the trees was dead (Figure 7). Dead leaves remained a dark mottled green in color and did not turn brown. No regrowth ever appeared (Figure 11) and when shoot dieback was measured at the end of the third week, it was found that all 16 trees were completely dead.

The foliage of the trees sprayed with dinoseb exhibited a brownish cast and injury to the shoot tips and immature leaves by the morning following treatment (Figure 3). The symptoms in the dinoseb-plus-oil-treated trees were similar but more severe (Figure 3). After a few days, dinoseb-treated leaves dried out and remained a light yellow-brown in color. Addition of the diesel oil to the dinoseb spray appeared to accelerate the development of injury symptoms and increased the extent of injury to the stems. Leaf and shoot kill was essentially complete after two days in the dinoseb-plus-oil trees (Figure 4) and four days with dinoseb alone (Figure 5). As with paraquat, response of the filbert shoots to the application of dinoseb, particularly without added oil, was more rapid than in the screening trials conducted during the winter months.

Regrowth was visible by the end of the second week in both dinoseb treatments, although fewer shoots developed on the trees sprayed with dinoseb plus oil than on those treated with dinoseb only (Figures 8, 9, 10 and 11). Unlike the regrowth from the paraquat-treated plants, the new shoots in both dinoseb treatments appeared normal in color and vigor.

The data in Tables 6 through 9 represent the average percent of leaves per tree, in each replication of four trees, in which a given percentage of the leaf blade was killed in the two-week period following treatment. These data show that at the end of two weeks, leaf kill was less complete with paraquat than with the other three treatments. The one exception to this occurs in Table 5 and is due to a single 2, 4-D-treated tree which had very little leaf kill at two weeks after treatment.

In terms of shoot killback, 2, 4-D had by far the greatest effect, due to the death of the entire trees. Shoot kill of trees sprayed with either paraquat or dinoseb alone was similar but amounted to only half as much as that in trees sprayed with dinoseb plus oil. Shoot kill results are shown in Table 10 as averages per tree in each replication.

Table 6. Summary herbicide experiment. Leaves killed 0 to 25% after two weeks.

Treatment	Average percent of leaves per tree — Replication 1	2	3	4	Mean
Paraquat 1 qt.	3.1	0.6	0.0	2.8	1.6
2,4-D 1 qt.	15.8	3.3	4.4	2.6	6.5
Dinoseb 3 pt.	0.5	1.6	0.0	0.0	0.5
Dinoseb 3 pt. + Diesel Oil 8 gal.	0.0	0.0	0.0	0.0	0.0

Treatment means not significant at 5% or 1% levels.

Table 7. Summary herbicide experiment. Leaves killed 26 to 50% after two weeks.

Treatment	Average percent of leaves per tree — Replication 1	2	3	4	Mean
Paraquat 1 qt.	4.5	6.2	5.1	5.3	5.3
2,4-D 1 qt.	0.8	2.0	6.0	2.7	2.9
Dinoseb 3 pt.	0.6	0.7	0.0	0.0	0.3
Dinoseb 3 pt. + Diesel Oil 8 gal.	0.0	0.0	0.0	0.0	0.0

Treatment means significant at the 1% level
LSD .05 = 1.9
.01 = 2.8

Table 8. Summary herbicide experiment. Leaves killed 51 to 75% after two weeks.

Treatment	Average percent of leaves per tree — Replication 1	2	3	4	Mean
Paraquat 1 qt.	12.9	14.3	17.7	13.1	14.5
2,4-D 1 qt.	1.6	6.3	7.7	6.1	5.4
Dinoseb 3 pt.	4.0	5.6	0.0	0.0	2.4
Dinoseb 3 pt. + Diesel Oil 8 gal.	0.5	0.5	0.0	0.0	0.3

Treatment means significant at the 1% level.
LSD .05 = 3.7
.01 = 5.3

Table 9. Summary herbicide experiment. Leaves killed 76 to 100% after two weeks.

Treatment	Average percent of leaves per tree — Replication 1	2	3	4	Mean
Paraquat 1 qt.	79.6	79.0	77.3	78.9	78.7
2,4-D 1 qt.	81.8	88.4	81.9	88.7	85.2
Dinoseb 3 pt.	95.1	92.1	100.0	100.0	96.8
Dinoseb 3 pt. + Diesel Oil 8 gal.	99.5	99.5	100.0	100.0	99.8

Treatment means significant at the 1% level.
LSD .05 = 4.6
.01 = 6.6

Table 10. Summary herbicide experiment. Average shoot dieback after three weeks.

	Inches per shoot per tree				
	Replication				
Treatment	1	2	3	4	Mean
Paraquat 1 qt.	2.6	5.3	3.2	3.4	3.6
2,4-D 1 qt.	14.1	20.6	20.0	15.1	17.5
Dinoseb 3 pt.	4.0	3.7	5.1	5.5	4.6
Dinoseb 3 pt. + Diesel Oil 8 gal.	9.6	12.9	9.0	7.2	9.7

Treatment means significant at the 1% level.
LSD .05 = 3.0
.01 = 4.3

After four weeks, the trees treated with dinoseb alone averaged approximately three times as many new shoots as in those trees treated with paraquat alone or dinoseb plus oil (see Table 11). The latter two treatments did not differ significantly in this respect, but the length of the new shoots on paraquat-treated trees averaged only about half as long as those in either dinoseb treatment (see Table 12). Representative trees from each treatment are shown in Figure 10, showing regrowth after four weeks.

Differences in regrowth were more pronounced after six weeks. The number of new shoots in either of the two dinoseb treatments did not increase significantly while the number on paraquat-treated trees doubled. At this time, the paraquat-treated trees averaged about twice as many new shoots as those treated with dinoseb plus oil but only about half as many as those trees treated with dinoseb only (see Table 13). Relative differences in new shoot lengths did not change between the four and six week evaluations as shown in Table 14. Actual differences in shoot length increased to the point where those of trees treated with dinoseb plus oil became significantly longer than those on trees treated with dinoseb alone. Representative new shoot development in each treatment is shown on single terminal shoots in Figure 9 and on entire trees in Figure 11 after six weeks.

Table 11. Summary herbicide experiment. Regrowth after four weeks.

	Average number of new shoots per tree				
	Replication				
Treatment	1	2	3	4	Mean
Paraquat 1 qt.	5.5	1.8	2.3	4.0	3.4
2,4-D 1 qt.	0.0	0.0	0.0	0.0	0.0
Dinoseb 3 pt.	9.0	10.0	11.5	10.5	10.3
Dinoseb 3 pt. + Diesel Oil 8 gal.	2.8	2.5	2.5	3.0	2.7

Treatment means significant at the 1% level.
LSD .05 = 1.7
.01 = 2.5

Table 12. Summary herbicide experiment. Average new shoot length after four weeks.

	Inches per shoot per tree				
	Replication				
Treatment	1	2	3	4	Mean
Paraquat 1 qt.	0.7	0.9	1.4	0.6	0.9
2,4-D 1 qt.	0.0	0.0	0.0	0.0	0.0
Dinoseb 3 pt.	2.3	2.1	2.4	1.7	2.1
Dinoseb 3 pt. + Diesel Oil 8 gal.	2.7	3.8	2.7	1.7	2.7

Treatment means significant at the 1% level.
LSD .05 = 0.7
.01 = 1.0

Table 13. Summary herbicide experiment. Regrowth after six weeks.

	Average number of new shoots per tree				
	Replication				
Treatment	1	2	3	4	Mean
Paraquat 1 qt.	8.8	5.5	4.5	8.3	6.8
2,4-D 1 qt.	0.0	0.0	0.0	0.0	0.0
Dinoseb 3 pt.	9.8	11.3	12.0	12.3	11.4
Dinoseb 3 pt. + Diesel Oil 8 gal.	2.8	2.5	2.5	3.0	2.7

Treatment means significant at the 1% level.
LSD .05 = 1.6
.01 = 2.3

Table 14. Summary herbicide experiment. Average new shoot length after six weeks.

Treatment	Inches per shoot per tree — Replication 1	2	3	4	Mean
Paraquat 1 qt.	1.7	1.6	3.2	1.7	2.1
2,4-D 1 qt.	0.0	0.0	0.0	0.0	0.0
Dinoseb 3 pt.	4.3	3.6	4.0	3.5	3.9
Dinoseb 3 pt. + Diesel Oil 8 gal.	5.8	7.1	6.2	2.7	5.5

Treatment means significant at the 1% level.
LSD .05 = 1.6
.01 = 2.3

Figures 2 through 8 represent a photographic record of the development of injury symptoms in the summary experiment. These figures show four selected terminal shoots before, and at various times following treatment. Regrowth from lateral buds on these same shoots is shown in Figure 9. Pictured in Figures 10 and 11 are three trees from each treatment, showing typical regrowth at four and six weeks after treatment.

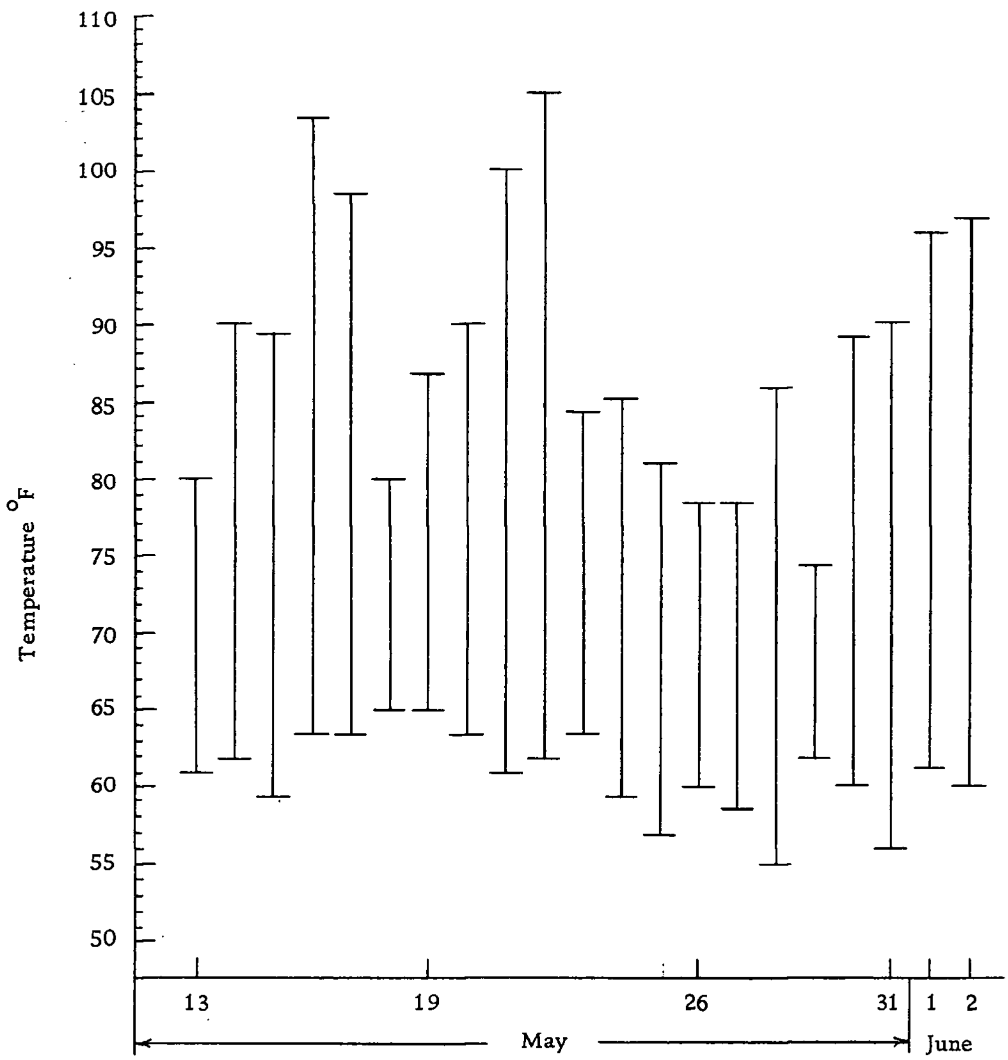

Figure 1. Summary Herbicide Experiment. Daily temperature ranges in the greenhouse during the three weeks following herbicide application.

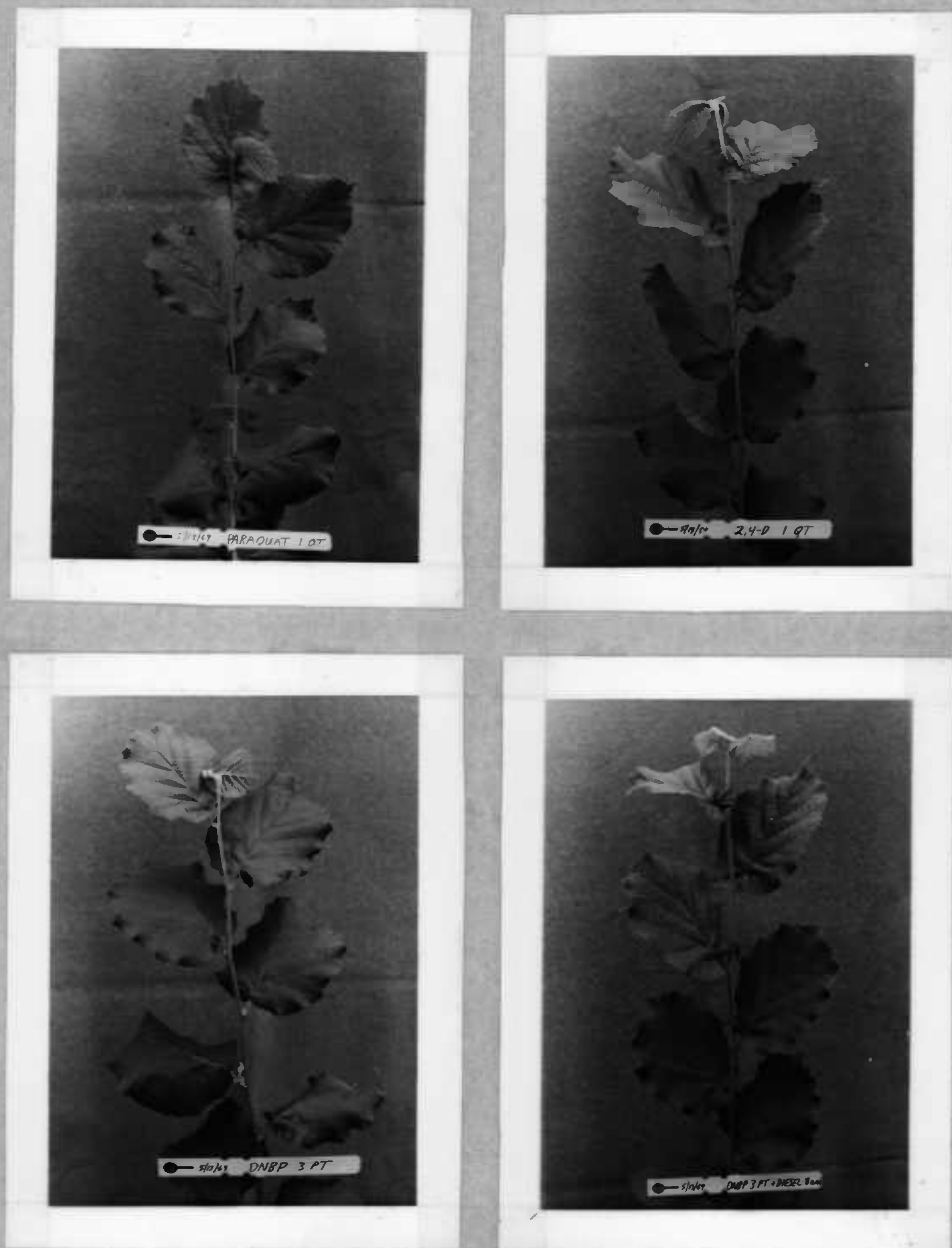

Figure 2. Summary Herbicide Experiment. Representative terminal shoots before treatment. Each of the above shoots is pictured on following pages to show progression of herbicide effects.

Figure 3. Summary Herbicide Experiment. Injury to leaves is evident in paraquat and dinoseb treatments after 24 hours. The tip of the 2,4-D-treated shoot is beginning to curl.

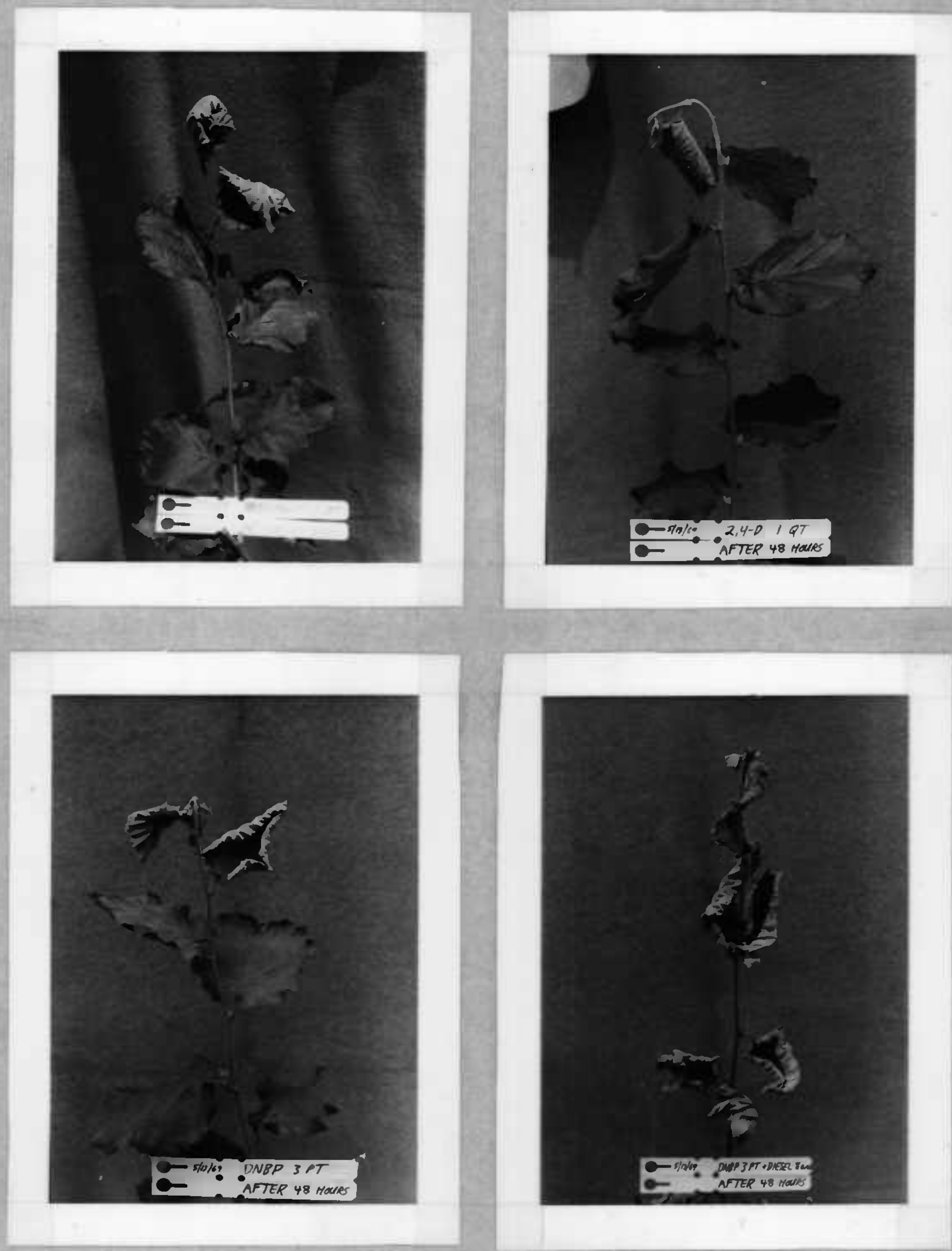

Figure 4. Summary Herbicide Experiment. The dinoseb-plus-oil-treated shoot is dead. The immature leaves of the 2,4-D-treated shoot are beginning to curl.

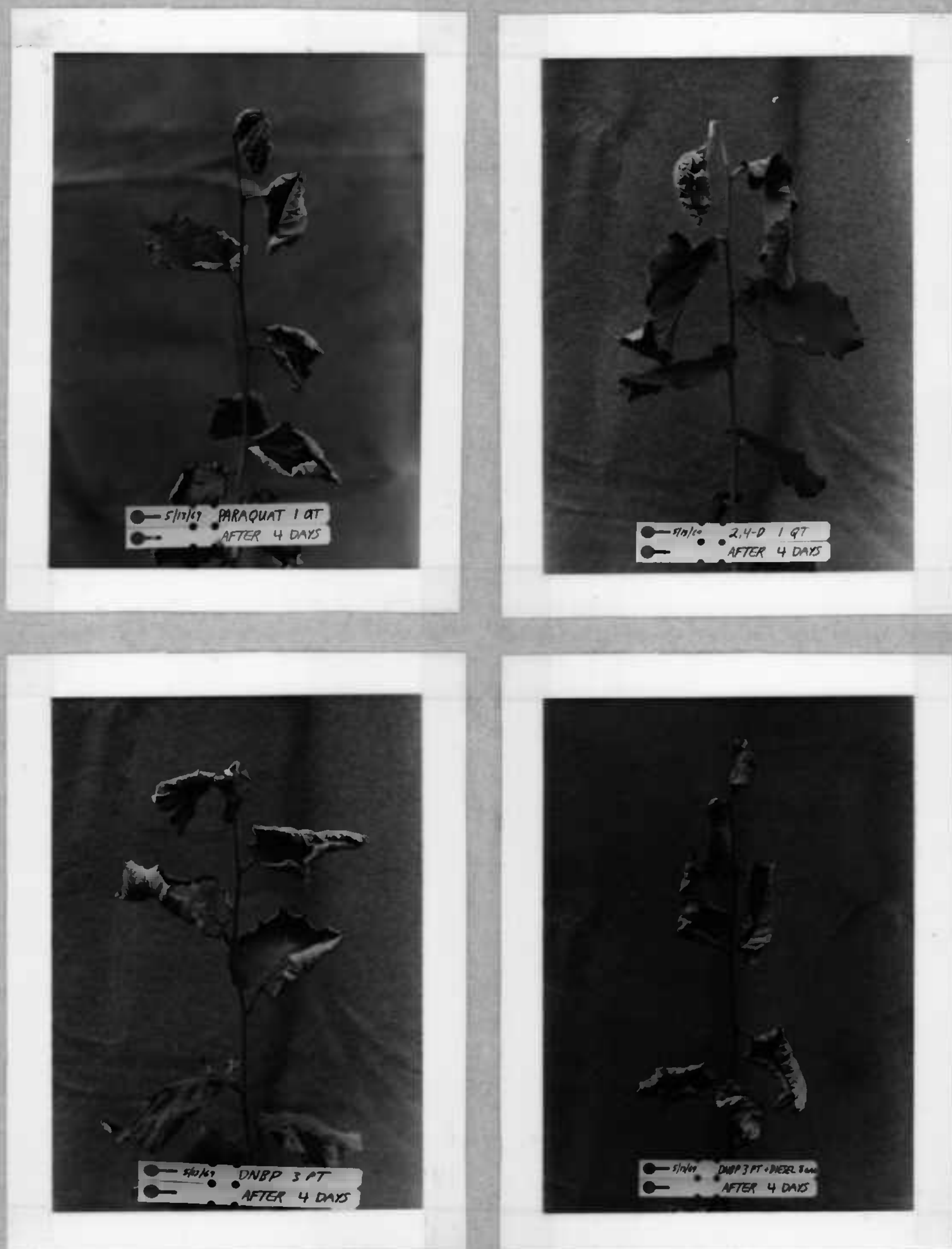

Figure 5. Summary Herbicide Experiment. Terminal one-third of shoots treated with paraquat or dinoseb alone are dead. No necrosis apparent after four days in foliage of shoot treated with 2, 4-D.

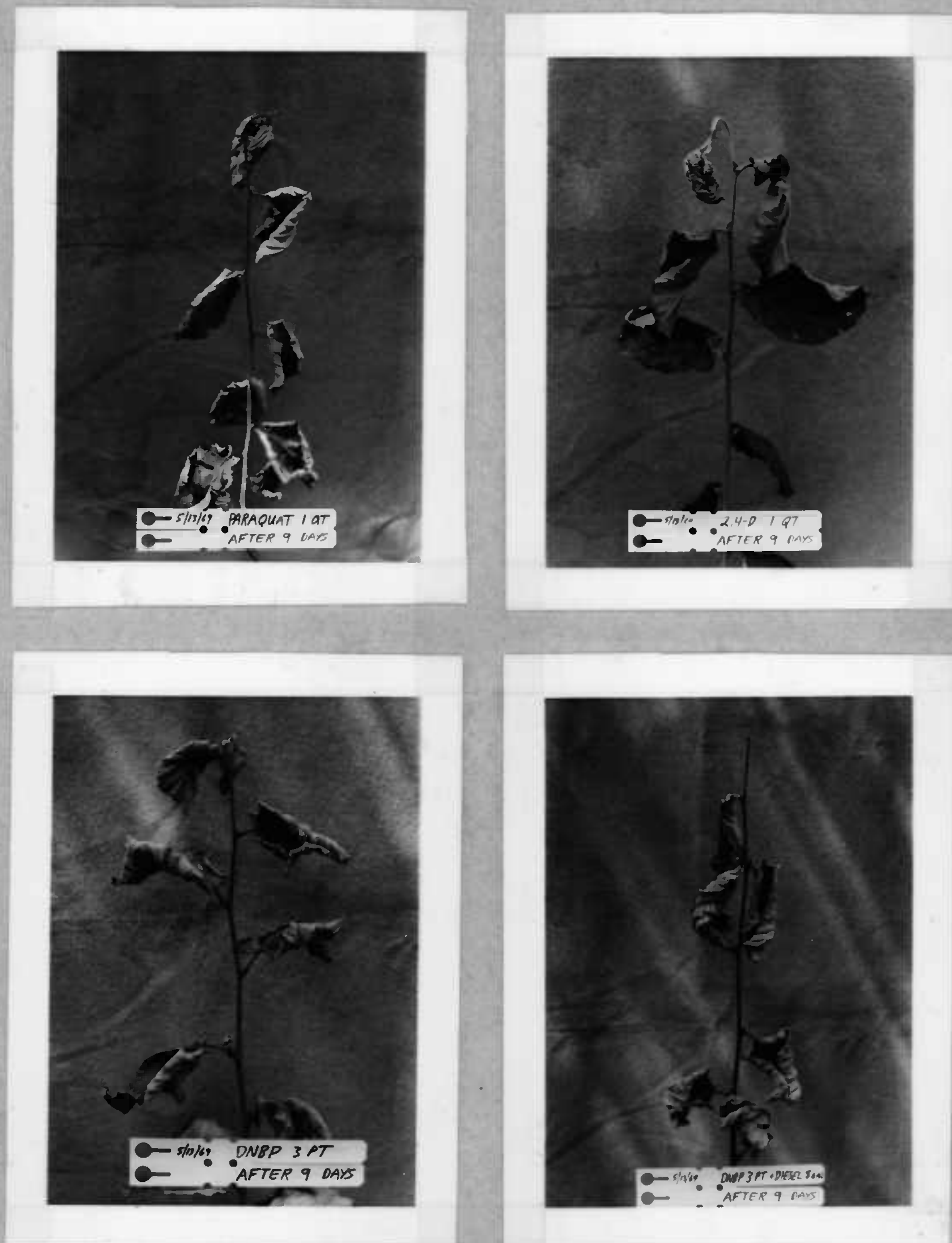

Figure 6. Summary Herbicide Experiment. Leaves of 2,4-D-treated shoot are beginning to die. The tip of the dinoseb-plus-oil-treated shoot was broken off in handling.

Figure 7. Summary Herbicide Experiment. Leaves of 2, 4-D-treated shoot are dead and the stem is dying. Buds on shoot treated with dinoseb alone are starting to break.

Figure 8. Summary Herbicide Experiment. Note darker, still-living portions of lower-left leaf on paraquat-treated shoot and new growth on the shoot treated with dinoseb alone.

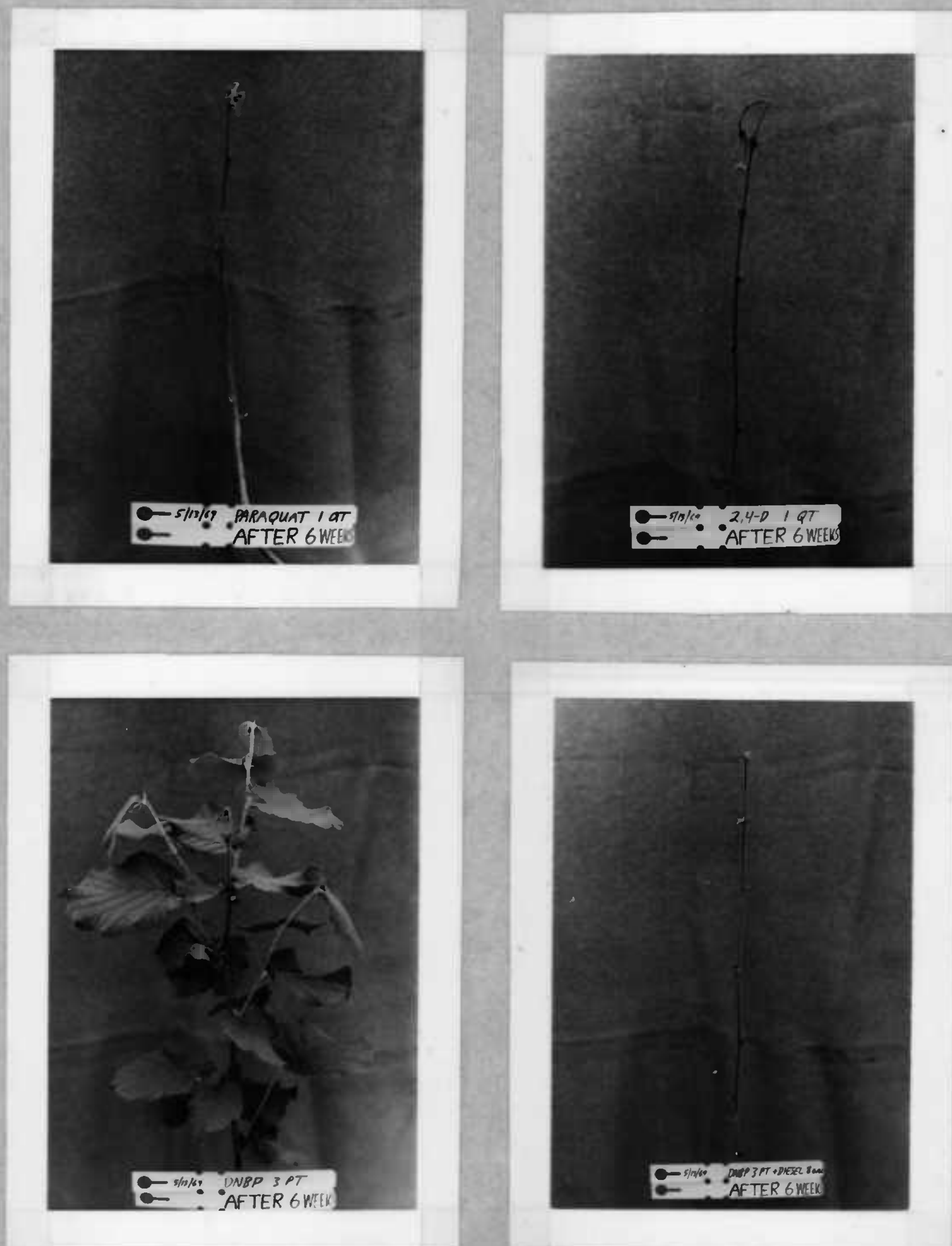

Figure 9. Summary Herbicide Experiment. All leaves originally present at the time of treatment have been removed to show regrowth more clearly where present.

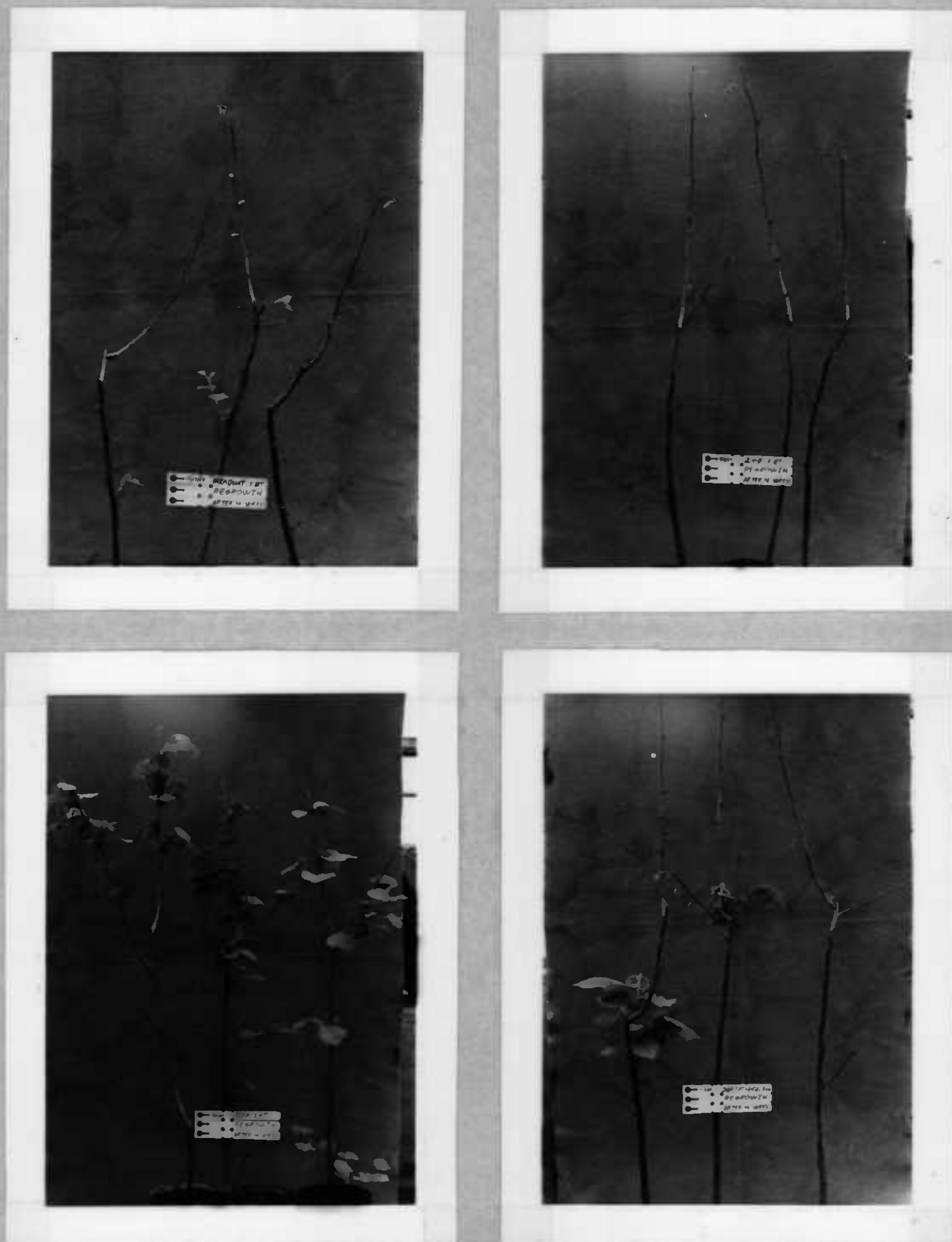

Figure 10. Summary Herbicide Experiment. All leaves originally present at the time of treatment have been removed to show differences in regrowth more clearly.

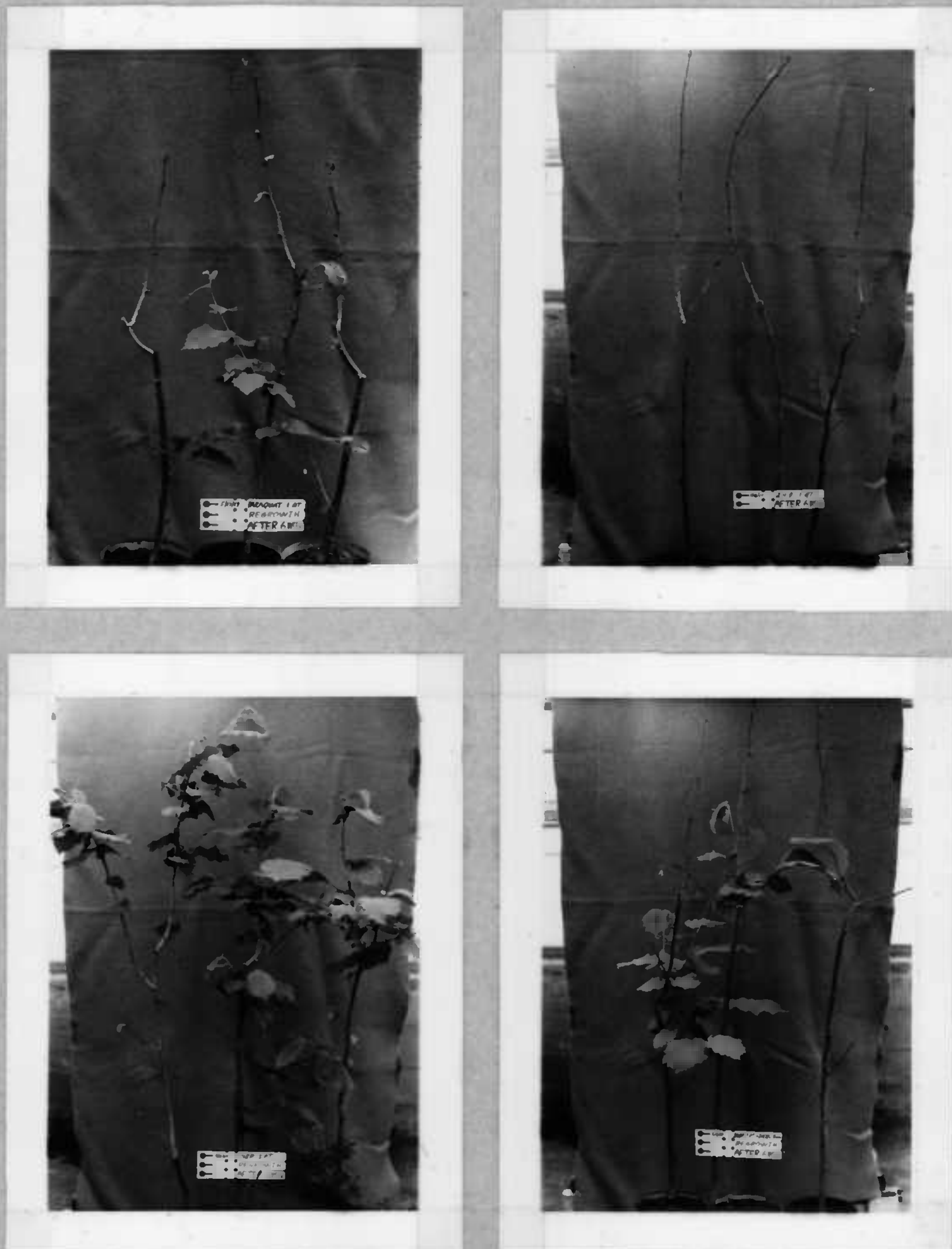

Figure 11. Summary Herbicide Experiment. The same trees shown on the preceeding page two weeks later. The differences in amount of regrowth are readily apparent.

Field Testing

On July 14, the field-test treatments were applied to the suckers of mature filbert trees in the orchard. Suckers were thoroughly wetted up to a height of 12 to 18 inches by use of a two-gallon hand sprayer. The temperature during the day ranged from a low of 55°F to a high of 74°F. The sky was clear with a light breeze blowing. Daily maximum temperatures over the following five weeks of the experiment ranged from 72°F to 94°F. A graph of the daily maximum and minimum temperatures recorded in the orchard from July 14 through August 17 is shown in Figure 12. No measurable rain fell during this period except for 0.05 inch recorded in the central Willamette Valley during the fourth week.

Three days after treatment, sucker leaves and terminals in all treatments except those involving 2,4-D alone showed severe browning and the beginning of necrosis. At the end of the first week, nearly all sprayed leaves and terminal portions of suckers were completely dead in the above treatments with the exception of those combination treatments containing less than one quart of paraquat. Paraquat injury to old sucker leaves was less complete in these combination treatments, but they were eventually killed when the 2,4-D exerted its effect.

In comparison to the rapid burning effect seen with paraquat and dinoseb, 2,4-D took from two to four weeks to cause death of sucker terminals and old sucker leaves. The high concentration of 2, 4-D acted more quickly than the lower concentrations. Treatments containing one pint or more of 2, 4-D, alone or in combination with paraquat, affected untreated terminals and immature leaves of suckers up to seven feet in height. Death of the growing point and youngest leaves occurred in some instances. No effect on tall suckers was seen in the case of paraquat or dinoseb, although some stems were so weakened at points of spray injury that they consequently fell over. No visible signs of injury to the parent trees was noted after five weeks.

Results of sucker dieback at the end of the five-week period are shown in Table 15. The figures shown are averages of a total of 100 incompletely-killed suckers. The treatments containing three pints of dinoseb plus eight gallons of diesel oil and one quart of paraquat plus one-half pint of 2, 4-D caused significant sucker dieback.

New sucker production which occurred during the five-week period of the experiment is shown in Table 16 as numbers per tree. The trees selected for evaluation averaged 128 suckers per tree at the time of treatment and 145 per tree after five weeks, an average increase of 17 suckers per tree. The trees whose suckers were treated with one quart of 2, 4-D alone, one-half pint of paraquat plus one and one-half pints of 2, 4-D or one quart of paraquat plus one-half pint of 2, 4-D produced significantly low numbers of new suckers.

The trees whose suckers were treated with three pints of dinoseb alone, three pints of dinoseb plus eight gallons of diesel oil or one quart of paraquat plus one pint of 2,4-D produced significantly high numbers of new suckers.

Average heights of these new suckers after five weeks are shown in Table 17. The overall average height of new suckers at that time was 4.5 inches, but they ranged from one-half inch to 23.5 inches in length.

Figure 18 shows numbers of new shoots developing from lateral buds above the soil surface on treated suckers at the end of five weeks. Treated suckers in either dinoseb treatment produced highly significant numbers of new shoots while those in the remainder of the treatments produced very few or none at all. None of the paraquat, 2,4-D, or combination treatments produced more than three new shoots from the suckers of five trees, in comparison to more than 150 in each dinoseb treatment.

The average lengths of these new shoots after five weeks are shown in Table 19. The two dinoseb treatments did not differ significantly in this respect.

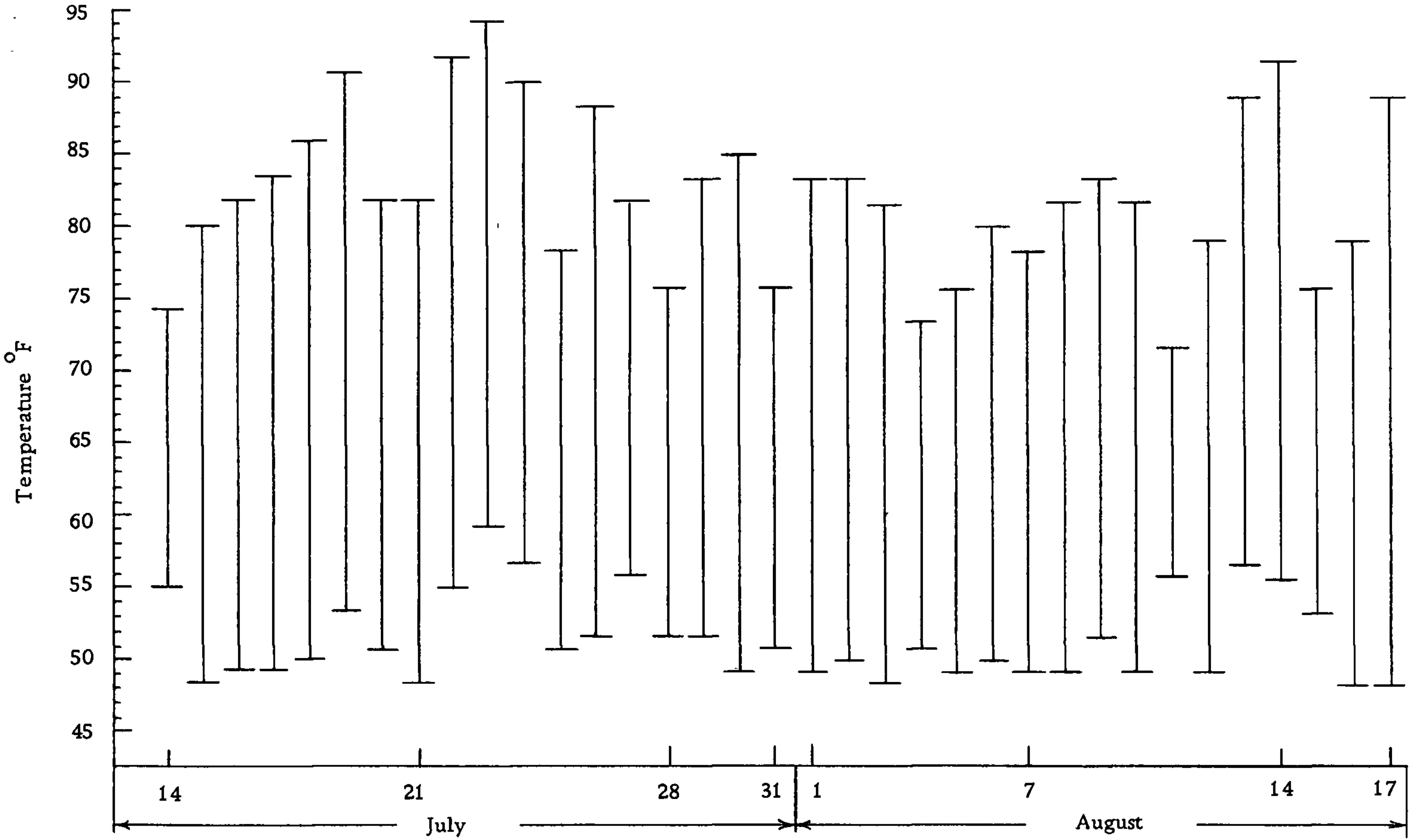

Figure 12. Field Test. Daily temperature ranges in the orchard during the five weeks following herbicide application.

Table 15. Field test. Average dieback, in inches, of 100 treated suckers after five weeks.

Treatment	Dieback	Range	Spread
Paraquat 1 qt.	10.48	2-22	20
Paraquat 1 qt. + 2,4-D ½ pt.	12.15**	3-35	32
Paraquat 1½ pt. + 2,4-D ½ pt.	9.55	3-29	26
Paraquat 1 pt. + 2,4-D 1 pt.	7.52	1-25	24
Paraquat 1 qt. + 2,4-D 1 pt.	9.55	2-18	16
Paraquat 1 pt. + 2,4-D 1½ pt.	7.18*	2-21	19
Paraquat ½ pt. + 2,4-D 1½ pt.	6.42**	1-20	19
2,4-D 1 pt.	3.72**	1-16	15
2,4-D 1 qt.	9.92	2-24	22
2,4-D 2½ pt.	7.70	2-20	18
Dinoseb 3 pt.	9.45	3-25	22
Dinoseb 3 pt. + Diesel Oil 8 gal.	13.65**	6-30	24

*Significant at the 5% level.

**Significant at the 1% level.

Table 16. Field test. Number of new suckers per tree five weeks following herbicide application.

	Suckers per tree					
	Replication					
Treatment	1	2	3	4	5	Mean
Paraquat 1 qt.	28	28	4	16	13	17.8
Paraquat 1 qt. + 2,4-D ½ pt.	5	15	13	3	12	9.6*
Paraquat 1½ pt. + 2,4-D ½ pt.	8	34	13	6	2	12.6
Paraquat 1 pt. + 2,4-D 1 pt.	16	8	15	6	11	11.2
Paraquat 1 qt. + 2,4-D 1 pt.	62	22	11	26	8	25.8**
Paraquat 1 pt. + 2,4-D 1½ pt.	26	22	8	13	10	15.8
Paraquat ½ pt. + 2,4-D 1½ pt.	5	21	6	1	0	6.6**
2,4-D 1 pt.	7	11	24	6	18	13.2
2,4-D 1 qt.	17	7	17	8	0	9.8*
2,4-D 2½ pt.	12	2	9	13	17	10.6
Dinoseb 3 pt.	29	30	2	25	33	23.8*
Dinoseb 3 pt. + Diesel Oil 8 gal.	34	47	20	108	0	41.8**

*Significant at the 5% level.
**Significant at the 1% level.

Table 17. Field test. Average heights of new suckers five weeks after herbicide application.

Treatment	Heights in inches Replication 1	2	3	4	5	Mean
Paraquat 1 qt.	4.5	5.4	3.6	4.3	4.0	4.4
Paraquat 1 qt. + 2,4-D ½ pt.	5.4	4.1	4.5	4.2	3.7	4.4
Paraquat 1½ pt. + 2,4-D ½ pt.	4.3	5.9	4.6	6.4	6.5	5.5**
Paraquat 1 pt. + 2,4-D 1 pt.	3.8	3.9	4.2	2.5	3.9	3.7*
Paraquat 1 qt. + 2,4-D 1 pt.	8.4	5.5	3.4	7.7	6.1	6.2**
Paraquat 1 pt. + 2,4-D 1½ pt.	5.8	4.3	4.2	3.7	6.0	4.8
Paraquat ½ pt. + 2,4-D 1½ pt.	6.3	5.5	3.9	2.0	0.0	3.5**
2,4-D 1 pt.	3.4	5.4	4.9	6.6	6.3	5.3*
2,4-D 1 qt.	4.2	2.7	3.4	6.1	0.0	3.3**
2,4-D 2½ pt.	5.1	5.3	4.9	6.9	5.9	5.6**
Dinoseb 3 pt.	5.1	4.2	3.5	3.9	5.1	4.4
Dinoseb 3 pt. + Diesel Oil 8 gal.	3.6	3.0	3.1	4.4	0.0	2.8**

*Significant at the 5% level.
**Significant at the 1% level.

Table 18. Field test. Number of new shoots per tree sprouting from living portions of treated suckers five weeks after herbicide application.

	Shoots per tree					
	Replication					
Treatment	1	2	3	4	5	Mean
Paraquat 1 qt.	0	0	0	0	2	0.4
Paraquat 1 qt. + 2,4-D ½ pt.	0	0	1	0	1	0.4
Paraquat 1½ pt. + 2,4-D ½ pt.	0	0	1	2	0	0.6
Paraquat 1 pt. + 2,4-D 1 pt.	1	0	0	0	1	0.4
Paraquat 1 qt. + 2,4-D 1 pt.	0	0	0	0	0	0.0
Paraquat 1 pt. + 2,4-D 1½ pt.	0	0	0	0	0	0.0
Paraquat ½ pt. + 2,4-D 1½ pt.	0	0	0	0	0	0.0
2,4-D 1 pt.	0	0	0	0	0	0.0
2,4-D 1 qt.	0	1	0	0	0	0.2
2,4-D 2½ pt.	0	0	0	0	0	0.0
Dinoseb 3 pt.	110	38	10	7	20	37.0**
Dinoseb 3 pt. + Diesel Oil 8 gal.	17	3	25	110	0	31.0**

**Significant at the 1% level.

Table 19. Field test. Average length per tree of new shoots sprouting from living portions of suckers five weeks after herbicide application.

	Average length in inches					
	Replication					
Treatment	1	2	3	4	5	Mean
Paraquat 1 qt.	0.0	0.0	0.0	0.0	3.3	0.7
Paraquat 1 qt. + 2,4-D ½ pt.	0.0	0.0	1.0	0.0	5.0	1.2
Paraquat 1½ pt. + 2,4-D ½ pt.	0.0	0.0	4.0	5.3	0.0	1.9
Paraquat 1 pt. + 2,4-D 1 pt.	9.0	0.0	0.0	0.0	7.5	3.3**
Paraquat 1 qt. + 2,4-D 1 pt.	0.0	0.0	0.0	0.0	0.0	0.0*
Paraquat 1 pt. + 2,4-D 1½ pt.	0.0	0.0	0.0	0.0	0.0	0.0*
Paraquat ½ pt. + 2,4-D 1½ pt.	0.0	0.0	0.0	0.0	0.0	0.0*
2,4-D 1 pt.	0.0	0.0	0.0	0.0	0.0	0.0*
2,4-D 1 qt.	0.0	1.0	0.0	0.0	0.0	0.2*
2,4-D 2½ pt.	0.0	0.0	0.0	0.0	0.0	0.0*
Dinoseb 3 pt.	4.5	2.1	1.4	4.2	4.8	3.4**
Dinoseb 3 pt. + Diesel Oil 8 gal.	2.7	3.0	1.6	4.2	0.0	2.3*

*Significant at the 5% level.
**Significant at the 1% level.

DISCUSSION

Certain differences in the appearance of injury symptoms were consistently noted in filbert leaves after treatment with paraquat or dinoseb. Initial discoloration and necrosis in paraquat-treated leaves occurred in irregular spots of varying sizes. In young and mature leaves, these spots merged rapidly and death of the entire leaf occurred. In old leaves, however, the spots often did not merge completely, leaving portions of the leaf blade apparently alive and functional for an indefinite period. Such spotting did not occur in dinoseb-treated leaves. Discoloration and death of leaves occurred uniformly over the leaf blade.

This difference in effect between paraquat and dinoseb may occur as a result of differences in their ability to penetrate the cuticular layer of the leaves. Plant cuticle is thought to be composed of an inert, waxy outer layer overlying a network of similar material embedded in semi-hydrophilic cutin. This in turn blends into the hydrophilic pectins and cellulose of the epidermal cell walls (18, p. 7-10). A hydrophilic substance such as paraquat may have difficulty penetrating the outer portions of the cuticle and may be limited to entry through cracks and punctures in the cuticle. The thin cuticle of young leaves might be penetrated more easily by paraquat than the thick cuticle of old leaves.

Penetration of the cuticle by a hydrophilic substance may be aided by the addition of a surfactant (15). Surfactants may "solubilize' the cuticle and increase its permeability to hydrophilic substances (18, p. 12). The eight-ounce rate of X-77 surfactant used in all paraquat treatments was not sufficient, however, to overcome the spotting effect seen with paraquat on old filbert leaves.

An oil-soluble substance such as dinoseb might be expected to penetrate the waxy plant cuticle with relative ease and not be limited to entry through actual openings. The addition of oil to dinoseb sprays resulted in a more rapid appearance of injury symptoms and greater extent of shoot kill in filberts. Oils, like surfactants, may 'solubilize' the cuticle and permit more extensive pentration by dinoseb than would occur if only dinoseb and surfactant were present (18, p. 12).

The uniformity of cuticular penetration by 2, 4-D was not immediately revealed through any necrosis of filbert leaves and shoots. Rapid penetration was evidenced by curling of shoot tips within one to three days after treatment. The heptylamine salt of 2, 4-D is an oil-soluble form and would be expected to penetrate the cuticle rapidly and uniformly.

It was observed that injury symptoms following application of paraquat to filbert shoots appeared more quickly in the greenhouse summary experiment and the field trial than during the winter screening trials. This effect may be linked to the mode of action proposed for paraquat by a number of workers (2, p. 29-30; 7; 9; 14). They suggest that the di-positive paraquat ion may be converted to a free radical by the addition of an electron released from the primary photosynthetic process. The paraquat radical is re-oxidized by atmospheric oxygen to regenerate the paraquat ion and form peroxides which accumulate and result in destruction of the plant cell.

Seaman (33) has determined that the action spectrum for paraquat toxicity closely parallels the photosynthetic action spectrum. Bovey and Miller (6) observed greater toxicity of paraquat in green portions of variegated plant leaves than in white portions. The findings in both cases are consistent with the hypothesis that paraquat depends upon photosynthesis for its activity.

The sky in the Willamette Valley during the winter was predominantly overcast and light intensity was low. Photosynthesis proceeds more slowly under these conditions and the rate of paraquat ion reduction may consequently be reduced. Clear skies and bright sunlight prevailed during the greenhouse summary experiment and the field test. Under these conditions, paraquat-ion reduction presumably may be speeded up and peroxide production increased.

As with paraquat, the action of dinoseb on filbert tissue was more rapid during the greenhouse summary experiment and the field trial than during the winter greenhouse screening trials. Temperatures during the months of May through August 1969 were much higher on the average than during the winter months. High temperatures will markedly increase the effectiveness of dinoseb, according to Meggitt, Aldrich and Shaw (28). The dinitrophenols, including dinoseb, are known to stimulate respiration in plant and animal cells (5, p. 110; 13, p. 213; 25, p. 152). These compounds are thought to be able to effectively uncouple the transfer of energy released in the course of oxidation of stored foods in cell mitochondria to adenosine triphosphate (ATP) (2, p. 30-31; 4; 5, p. 110). Cell respiration continues, but ATP formation ceases. When the ATP already present is exhausted, synthetic processes dependent upon ATP as a high-energy source cease, food formation stops and the cell dies (2, p. 393-394; 4). Cell respiration processes move at a faster rate under high temperatures (25, p. 374-375), resulting in a more rapid depletion of stored foods. The protein-coagulating effect of phenols in general may also explain their rapid action under warm, sunny conditions (13, p. 213). In addition, high temperatures may aid the softening effect of surfactants and oils upon the waxy plant cuticle, resulting in increased penetration by dinoseb.

The observed effects of 2, 4-D on filbert shoots may occur as a result of the translocation and mode of action of the herbicide. The first visible symptoms in filbert shoots in all experiments consisted of twisting and curling of the shoot tips and immature leaves within one to three days following treatment. Shoot-tip and leaf deformation would increase in severity slightly over the following one to four weeks with little or no visible necrosis. After this period of time, death of shoots and leaves occurred within two or three days.

Once within the plant, 2, 4-D moves into the phloem and is translocated with the flow of carbohydrate materials out of the leaves (2, p. 81; 12, p. 40; 13, p. 206; 20). The normal flow of food materials is towards sites of active cell division, particularly the apical meristems of roots and shoots. These sites act as sinks, attracting the flow of food materials, and consequently 2, 4-D. Such movement was indicated by the curling and twisting of the tips of suckers as high as seven feet when only the bottom 12 to 18 inches of the suckers were wetted by the spray.

Van Overbeek (2, p. 388-390) considers that 2, 4-D acts as an extremely active and persistent counterpart of the indole auxins naturally present in plants. He observed that normal plant growth processes are dependent upon the relative levels of auxins, gibberellins and cytokinins which are normally present in very small amounts. Introduction of a strong, persistent auxin like 2, 4-D, in large quantities, overpowers the plant growth hormone balance and prevents orderly differentiation of cells. Such effects become apparent in a treated plant by marked deformation of shoot tips and immature leaves and areas of cell proliferation on the stems. Some of these tumor-like stem growths were observed in small seedling filberts during the screening trials. However, none were seen in the greenhouse summary experiment or field trial.

Oswald Kiermayer has proposed that the eventual death of plants treated with 2, 4-D may partially be due to the blocking of the flow of food materials in the phloem due to the proliferation and consequent crushing of phloem parenchyma cells (2, p. 216). It is not known whether this effect of 2, 4-D was a major factor in the delayed killing effect of 2, 4-D observed in the filbert sucker control experiments, however.

A marked difference was observed in the appearance and vigor of regrowth from canned trees treated with paraquat or dinoseb in the greenhouse summary experiment. New shoot growth from paraquat-treated trees emerged a pale-green in color and weaker in vigor than normal filbert shoots. Leaves did not reach normal size and many exhibited marked chlorosis and occasional death of tissue along the basal midvein and lateral veins. In contrast, regrowth from dinoseb-treated trees appeared completely normal in color and vigor.

It may have been that paraquat from the original spraying may have moved into the stems of the trees and emerged with the new shoot growth while dinoseb did not. Dinoseb apparently does not translocate in plants. No residues of dinoseb have been traced to foliar or root uptake (20).

It has been shown, however, that paraquat and a closely-related compound called diquat may be translocated, depending upon light intensity and duration following application (3, 35, 36). The major mode of transport appears to be acropetally in the xylem in the transpiration stream. However, to reach the xylem vessels, paraquat and diquat must penetrate cuticle and living cells. Under high light conditions, these herbicides prove highly toxic to plant tissue and quickly kill the living cells with which they come in contact. This quick kill may block further movement of the herbicides towards the xylem. In the dark or in low light, the toxic action is slowed markedly, allowing movement through the living cells to the xylem. Under these conditions, translocation will occur after exposure to normal light has caused resumption of flow in the transpiration system.

The consistently greater regrowth from canned trees and suckers treated with dinoseb as compared to those treated with paraquat is probably due to the extent of lateral bud injury. It may be that paraquat was translocated more readily than dinoseb and moved into the buds while dinoseb failed to enter the buds either by direct absorption or by translocation. Dinitrophenol compounds have been reported to result in eventual increases in vegetative growth in plants (8; 13, p. 277), possibly through release of nitrogen in useable forms in the course of breakdown of the original molecule. It is not known, however, if this was a factor in the greater regrowth observed in dinoseb-treated filberts.

Marked differences in filbert shoot and sucker dieback occurred between the same treatments used in the greenhouse and in the field test. Sucker kill in the field by either one quart of paraquat or three pints of dinoseb per 100 gallons of water was much greater than the shoot kill in the greenhouse. This may have been due to the much more vigorous growth and tender condition of the suckers in the field, making them more susceptible to penetration and injury by the contact herbicides.

The effect of 2, 4-D in the field was less striking than in the greenhouse. It is possible that translocation of 2, 4-D in the suckers was limited due to their vigorous growth and upward movement of food materials. However, acceptable sucker kill was obtained in the field with 2, 4-D at rates of one quart or two and one-half pints per 100 gallons of water. The restricted root system of the canned trees, the less vigorous growth of the trees and high temperatures in the greenhouse may have combined to allow sufficient translocation of 2, 4-D into the stems and roots to result in death of the trees.

Use of paraquat and 2, 4-D together in an effort to reduce the concentration of one or both of the herbicides necessary for acceptable kill proved no better than using either herbicide alone in an effective concentration. One exception was the treatment containing one quart of paraquat plus one-half pint of 2, 4-D. There did not appear to be either synergistic or antagonistic effect between the two herbicides used in combination.

Previously-noted differences in effects on regrowth from treated filbert shoots by dinoseb, paraquat and 2, 4-D were reflected in new sucker production in the orchard. The trees whose suckers were treated with dinoseb, alone or with oil, produced greater numbers of new suckers than trees whose suckers were treated with paraquat alone, which in turn produced greater numbers of new suckers than where 2, 4-D alone was used. It is not known to what extent these differences in new sucker production may have been caused by the herbicides themselves.

CONCLUSIONS

One quart of 2, 4-D, one quart of paraquat, or three pints of dinoseb in 100 gallons of solution will give satisfactory control of filbert suckers. Use of a surfactant with all three herbicides is recommended for best effect. Use of oil with dinoseb is not necessary for best kill of filbert shoots, but it will enhance the effect of dinoseb when added in amounts as low as four gallons per 100 gallons of solution.

Paraquat and dinoseb are more effective on young, vigorous shoot growth than on older, more mature tissue. Where frequent sprayings are not practical, 2, 4-D at the one quart rate may provide longer-lasting control of large suckers than paraquat or dinoseb.

Dinoseb had much less ability to control the regrowth from treated filbert shoots than either paraquat or 2, 4-D. It may be that dinoseb is less able to translocate into filbert buds than paraquat or 2, 4-D. The problem of regrowth may make more frequent treatments necessary when dinoseb is used.

It does not appear that these three herbicides, when used at the above rates, will cause injury to the filbert trees either through translocation or bark penetration. The greatest danger may lie in careless use of these materials. Use of excessively high concentrations or contact with open trunk wounds or foliage of the tree could be a source of injury. In this respect, 2,4-D may be the most dangerous of the three herbicides due to its volatility. A possible problem, and one on which little definite information exists, is that of accumulative effects from treatments over a number of seasons. Repeated annual treatments of a single herbicide may affect vigor and productivity of the trees through residue buildup in the soil or on the tree trunks. The chance of this occurring might best be alleviated by using minimum effective concentrations and using more than one kind of herbicide during the season.

Several considerations for the use of herbicides in filbert sucker control were discovered as a result of the experiments described in this report. Two of the most important are closely interrelated; suckers should be treated when less than 10 to 12 inches in height and they should be thoroughly covered with spray. If either of these conditions are not satisfied, sucker kill will probably be less than adequate. The observed rate of growth of new suckers would suggest treatments at one-month intervals in an orchard of normal vigor. Once suckers exceed six inches in height, they become more difficult to kill. Even when killed, large suckers will remain as dead sticks which interfere with subsequent sucker control sprays and nut harvest.

The experiments described have provided much-needed information on the use of herbicides for filbert sucker control. The problem of sucker control in the commercial European filbert (Corylus

Avellana L.) has, in part, limited expansion of the filbert industry in Oregon and Washington. The use of herbicides for sucker control will reduce the high cost in labor and time incurred by hand-hoeing suckers. Mechanical injury to tree trunks and roots can be avoided and more acres of trees can be managed by following the recommendations resulting from this research.

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