HILGARDIA

A Journal of Agricultural Science Published by the California Agricultural Experiment Station

VOLUME 21 MARCH, 1952 NUMBER 11

EFFECTS OF 2,4-D AND RELATED SUBSTANCES ON FRUIT-DROP, YIELD, SIZE, AND QUALITY OF VALENCIA ORANGES

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During 1947 and 1948, in various districts throughout southern California, 29 comparisons were made between fruit-drop from non-sprayed Valencia orange trees and that from trees sprayed with 2,4-D at concentrations from 4 to 48 p.p.m. Application of 2,4-D at low volumes was made six months before drop, as well as after drop had begun. While the average reduction in fruit-drop from the sprayed trees was 35.1 per cent, in some cases it was as high as 64, and in others, as low as 5 per cent.

Studies were also made of the possibility of increasing fruit size of Valencias by use of 2,4-D. In an experiment begun in 1948, 17 different chemicals were applied to Valencia trees at full bloom. Only 2,4-D and 2,4,5-T induced a significant increase in fruit size. Data were obtained from eight additional experiments using actual field-scale applications. Determinations of the effect of the sprays on size and grade of fruit were based on packing house information. As a result of the spray, there was a gain of 28.0 packed boxes of fruit size 220 and larger, and a decrease of 19.8 boxes of fruit size 252 and smaller, per 100 trees sprayed.

Periodic measurements showed that larger fruit sizes resulting from use of 2,4-D were due to an increased growth rate. As fruits grew older, they seemed to become less responsive to 2,4-D. In commercial practice, it is suggested that during the 16-week period after flowering, this diminishing response be compensated for by corresponding increases in the concentration of 2,4-D applied.

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EFFECTS OF 2,4-D AND RELATED SUBSTANCES ON FRUIT-DROP, YIELD, SIZE, AND QUALITY OF VALENCIA ORANGES[1,2]

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INTRODUCTION

IN CALIFORNIA, VALENCIA orange trees flower in the spring, and the fruit is harvested the following year, usually between May 15 and November 15. Generally, the bulk of the harvest is completed by October 15. Toward the end of the season a severe fruit-drop may occur as a result of maturity and unfavorable environmental conditions, such as high temperatures, wind, and so forth. Preliminary studies reported in 1947 showed that mature fruit-drop of Valencia oranges could be reduced by application of foliage sprays of 2,4-D (Stewart and Klotz, 1947).[6] In those studies it was also found that relatively high concentrations of 2,4-D (75 to 225 p.p.m.), applied in June to Valencia orange trees bearing young fruit, induced various modifications in fruit growth, including an increase in fruit size. This was of particular interest because the fruit size of the Valencia orange crops since 1944 has been subnormal. For this reason, and because of consumer demand for large sizes, means of producing larger fruits have become important. Studies of the possible use of 2,4-D and related plant growth regulators for this purpose are reported here, with further data on the use of 2,4-D to reduce mature fruit-drop.

EXPERIMENTAL

Mature Fruit-drop.—During the harvest seasons of 1947 and 1948, in various districts throughout southern California, 29 comparisons were made between fruit-drop from nonsprayed trees and that from trees receiving drenching water sprays of 2,4-D. Counts were made by removing any fruits on the ground after spraying, and counting all subsequent fruit-drop, includ-

[1] Received for publication May 21, 1951.

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[6] See "Literature Cited" for citations, referred to in the text by author and date.

TABLE 1

EFFECT OF 2,4-D SPRAYS ON FRUIT-DROP OF VALENCIA ORANGES IN VARIOUS LOCATIONS IN SOUTHERN CALIFORNIA

Location of experiment	Spray date	Fruit-drop to:	Number of trees per treatment		Fruit-drop per tree		Concentration of 2,4-D	Form of 2,4-D	Reduction in fruit-drop
			Nonsprayed (control)	Sprayed with 2,4-D	Nonsprayed (control)	Sprayed with 2,4-D			
1947 harvest:*							*p.p.m.*		*per cent*
Arlington	12/30	9/17	11	11	76	60	8	diethanolamine salt	20.8
Camarillo I†	5/1	10/24	18	15	128	74	8	ammonium salt	63.1
	6/1		18	20	111	69	8	ammonium salt	38.0
	7/1		18	20	95	56	8	ammonium salt	41.6
	8/1		18	15	73	28	8	ammonium salt	61.5
	9/1		18	20	39	20	8	ammonium salt	50.3
Camarillo II	5/1	10/15	25	25	118	93	8	diethanolamine salt	20.6
	6/1		25	25	107	61	8	diethanolamine salt	42.9
	7/1		25	25	94	58	8	diethanolamine salt	37.8
	8/1		25	25	58	48	8	diethanolamine salt	17.3
	9/1		25	25	34	21	8	diethanolamine salt	38.1
Camarillo III	5/15	10/24	10	10	130	123	8	ammonium salt	5.4
Santa Paula I	7/26	9/2	217	106	54	37	4	sodium salt	32.1
				109		36	8	sodium salt	33.9
Santa Paula II	7/26	9/2	230	116	48	42	4	sodium salt	12.3
				115		41	8	sodium salt	14.6
Santa Paula III	7/26	9/2	111	84	37	16	4	sodium salt	57.6
				81		15	8	sodium salt	59.8
Santa Paula IV	8/14	10/15	11	11	63	30	8	ammonium salt	52.0
Spadra	6/19	10/7	10	10	44	30	8	diethanolamine salt	32.3
Fontana	6/19	8/15	10	5	37	28	8		24.4
Downey	5/26	9/16	12	12	144	100	8	diethanolamine salt	30.7
				12		123	16	diethanolamine salt	14.7
Anaheim I	6/9	8/13	24	12	127	89	8	diethanolamine salt	30.2
Anaheim II	11/4	12/2	3	3	61	49	24	diethanolamine salt	18.5
Santa Ana	6/6	9/23	3	3	123	66	8	diethanolamine salt	46.3
				3		82	16	diethanolamine salt	33.6
El Toro	6/1	10/10	6	6	67	88	8	diethanolamine salt	....
				6		45	16	diethanolamine salt	32.2
				6		39	24	diethanolamine salt	41.3
San Juan Capistrano	6/6	11/5	3	3	371	257	8	diethanolamine salt	30.7
				3		144	16	diethanolamine salt	61.3

1948 harvest:‡									
Rivera	2/20	5/19	10	10	55	35	8	isopropyl ester	35.6
Fullerton	6/10	10/21	10	10	47	32	8	isopropyl ester	31.5
				10		39	24		17.7
Anaheim	6/8	9/10	12	12	87	57	8	isopropyl ester	34.7
				12		63	16	isopropyl ester	27.5
Santa Ana	6/12	8/16	10	10	77	36	8	isopropyl ester	52.7
				10		25	16	isopropyl ester	67.8
Tustin	6/11	9/14	12	12	313	232	8	isopropyl ester	25.7
				12		270	16	isopropyl ester	13.6
				12		202	24	isopropyl ester	35.4
Fullerton	7/23	9/17	..	14	...	79	48§	isopropyl ester	....
				14		55	48‖	isopropyl ester	30.4
				13		28	48¶	isopropyl ester	64.3

* All trees sprayed and harvested in 1947, except Arlington experiment which was sprayed 12/30/46.
† Trees sprayed during first week of the month.
‡ All trees sprayed and harvested during 1948.
§ 2 gallons per tree.
‖ 4 gallons per tree.
¶ 16 gallons per tree.

ing both sound and cull fruits. The location of these experiments and the results obtained are summarized in Table 1. It was found that in all except one comparison, 2,4-D was effective in reducing fruit-drop. The average reduction in drop was 35.1 per cent. Applications of 2,4-D on Washington Navel orange trees reduced fruit-drop, on the average, 56.0 per cent (Stewart, Klotz, and Hield, 1951). The difference in apparent effectiveness of 2,4-D on these two varieties may be due to the difference in the amount of fruit dropped. For example, the average fruit-drop from nonsprayed navel orange trees was 140.8 fruits per tree in 31 experiments, whereas from Valencia orange trees it was 97.1 fruits.

Time of 2,4-D application was not critical. Sprays applied six months or more before harvest were apparently as effective in reducing fruit-drop as those applied only a month before.

In some instances, applications of 2,4-D in oil sprays for pest control were also effective in reducing mature fruit-drop, of Valencia oranges and of grapefruit, that occurred nearly a year after application (Stewart, Riehl, and Erickson, unpublished). The maximum duration of effectiveness of 2,4-D in reducing fruit-drop of Valencia oranges has not been determined. It was found that a 5 p.p.m. 2,4-D spray applied in early June was effective until late December, in reducing fruit-drop of grapefruit, but after that time it failed to reduce the drop (Stewart and Parker, 1947).

Sprays of 2,4-D are outstandingly effective in retarding preharvest drop of Stayman Winesap and Winesap apples, and in comparison with naphthaleneacetic acid, they have a longer duration of effect as well as a greater intensity (Thompson and Batjer, 1948).

In one experiment of randomized block design, water sprays containing 48 p.p.m. 2,4-D (as the isopropyl ester) were applied on Valencia orange trees on July 23, 1948, at 2, 4, or 16 gallons per tree. At these dosages, fruit-drop per tree to September 17, 1948, averaged 78.6, 54.7, and 28.1, respectively. These figures are for 14 trees per treatment. The least significant difference, at 5 per cent and 1 per cent, was 19.0 and 28.8, respectively. From these data it appears that, while low-volume applications are effective in reducing fruit-drop, it would be desirable to use more than 4 gallons per tree for a commercial 2,4-D application. Low-volume applications of 2,4-D to reduce mature fruit-drop of navel oranges, grapefruit, and lemons have been successfully used commercially since 1947 (Stewart, Klotz, and Hield, 1947; Stewart and Parker, 1947; Stewart and Hield, 1950*b*).

In 1948, instructions for the use of 2,4-D to reduce mature fruit-drop were made available to growers (Stewart, 1948*b*). Since that time, a considerable acreage of Valencia orange trees has been treated commercially with 2,4-D. Most of these applications were in combination with other spray chemicals (zinc, manganese, cryolite, and the like). In no case has the 2,4-D been reported to be incompatible with other spray materials or ineffective in reducing fruit-drop.

Application of 2,4-D to trees with young, tender leaves generally resulted in a curling and distortion of the leaves. This was minimized or avoided by spraying between growth flushes when there were few young leaves present. No reduction in fruit quality or production was observed, even when very

severe leaf curling occurred, if the spray did not coincide with the period when the trees were in bloom.

It has been observed that 2,4-D sprays to reduce mature fruit-drop also significantly reduced fruit-stem dieback (Klotz and Stewart, 1948). This condition often occurs to a serious extent in Valencia orange trees, especially toward the end of the harvest season. The stem may die back a few inches to several feet from the fruit, thus reducing fruit-bearing wood for the following year. The fruit dries, shrivels, and has little value. The 2,4-D reduces the amount of fruit-stem dieback apparently by inducing the abscission tissue to remain alive.

A commercial storage test of fruit harvested October 7, 1947, from Valencia orange trees sprayed with 2,4-D at 8 p.p.m. on June 19, 1947, to reduce mature fruit-drop, showed no unfavorable effects of the 2,4-D. In fact, a striking reduction in the number of severely granulated fruits was found when they were cut after storage (Stewart, 1948*a*). Recently it has been found that 2,4-D sprays applied in October may retard the color change that usually occurs in November or December in Washington Navel oranges (Erickson, unpublished). These findings, along with the effect of 2,4-D in reducing fruit-drop, are some indication that the spray, when applied on mature or nearly mature fruit, may modify its physiology. Thus, the use of 2,4-D to delay granulation may have more possibilities than at first appear.

Fruit Size

Chemical Fruit Thinning.—To determine the possibility of increasing the size of Valencia oranges by fruit thinning with chemical sprays, a survey experiment was established in two locations during April, 1948. One location was near Fillmore; the other, near Anaheim. The chemicals used were those reported to be effective in thinning fruit on various other tree crops as well as materials generally recognized as reducing fruit set of citrus. They were applied at full bloom as drenching sprays. Only one half of each tree was sprayed, the nonsprayed half serving as control. At each location, each treatment was applied in this manner to two trees, alternate west and east halves being sprayed. The effects of the various treatments on fruit growth were determined at harvest in July, 1949. The treatments applied and results obtained are summarized in Table 2.

As the fruits began to grow, following the sprays, it became apparent that those on trees sprayed with 2,4-D or 2,4,5-T (2,4,5-trichlorophenoxyacetic acid) were showing the typical responses—retention of floral parts, and so forth (Stewart and Klotz, 1947). In November, the increases in size as a result of these sprays were quite evident (fig. 1). It was also noted that there was a delay in maturity of the fruit as shown by the persistence of green rind on sprayed fruits after those on the nonsprayed halves of the trees had become yellow, then orange in color. Even in September, 1948 (before the fruits on the nonsprayed halves began to lose their green color), those on the halves of trees sprayed with 20 p.p.m. 2,4-D or 2,4,5-T were a more intense, darker green than were fruits on the nonsprayed halves.

At harvest, in both locations, the largest fruits were obtained from the halves of trees sprayed with 2,4-D or 2,4,5-T. Expressing the size increase as

TABLE 2

EFFECT OF VARIOUS CHEMICAL SPRAYS ON YIELD AND SIZE OF VALENCIA ORANGES*

(Anaheim and Fillmore experiments)

Spray		Size, as weight per fruit		Yield					
				As fruits per tree		As weight of fruits per tree		As field boxes per tree	
Material	Conc.	NS	$\frac{S - NS†}{NS}$	NS	$\frac{S - NS†}{NS}$	NS	$\frac{S - NS†}{NS}$	NS	$\frac{S - NS†}{NS}$
		gm	*per cent*	*fruits*	*per cent*	*kg*	*per cent*	*boxes*	*per cent*
DN No. 1‡	0.25%	101.3	+ 0.6	1,086	−11.2	185.7	−11.2	6.9	− 9.1
DN No. 2§	0.25%	102.2	+ 4.0	1,773	+ 3.4	172.7	+ 6.1	6.4	+ 4.4
Triiodobenzoic acid	25 p.p.m.	121.2	− 9.7	1,070	−19.9^{ns}	127.4	−29.1^{S5}	4.9	−23.1
DN No. 289‖	0.50%	116.4	− 3.5	1,285	− 3.4	140.7	− 6.2	5.4	− 6.2
DN No. 111¶	1.25%	101.6	+ 6.7^{ns}	2,375	−17.5	238.9	−12.1	8.6	−17.6^{ns}
Elgetol**	1.25%	109.0	+ 3.6	1,774	− 1.1	179.1	+ 6.2	6.7	+ 1.4
Sodium cyanamide	0.10%	113.6	− 0.9	1,818	− 4.5	190.3	− 3.6	6.8	− 2.0
2,4-D as butyl ester	20 p.p.m.	117.0	+14.9^{S1}	1,811	−43.1^{S1}	146.7	−34.2^{ns}	7.3	−31.8^{ns}
P.e.p.s. + Zeram††	2.50%+0.12%	111.0	+ 2.6	1,932	−13.0	196.3	− 8.6	6.9	− 6.4
Tricapryldiphenyloxide	0.75%	104.4	+ 0.9	2,124	−40.2^{S5}	210.4	−40.2^{S5}	8.1	−37.6^{ns}
Copper bordeaux	6–6–100	114.4	+ 7.6^{ns}	2,428	−42.6^{S5}	247.1	−36.3^{ns}	8.7	−40.4^{ns}
Ferrous sulfate	0.10%	107.3	− 3.5	1,788	−25.1^{ns}	268.9	−22.2	6.5	−20.8^{ns}
Spray oil, LM-TNK‡‡	1.00%	120.4	− 3.2	1,529	−37.5^{S5}	164.3	−33.3^{ns}	5.9	−33.2^{ns}
Naphthaleneacetic acid	25 p.p.m.	107.2	− 2.8	1,508	+ 3.3^{ns}	153.0	− 1.5	5.9	− 3.2
2,4,5-T as butyl ester	20 p.p..m	119.7	+14.8^{S1}	1,881	−41.4^{S5}	203.7	−32.3^{S5}	7.5	−29.9^{ns}
Copper bordeaux + 2,4-D as isopropyl ester	10 p.p.m.	111.7	+12.9^{ns}	1,913	−46.2^{S5}	198.5	−39.6^{S5}	7.6	−39.5^{ns}
2,4-D, as isopropyl ester	10 p.p.m.	105.1	+10.0^{ns}	1,642	−17.4^{ns}	163.9	− 9.3	6.0	− 4.8

* Trees sprayed at full bloom, in 1948. Fruit harvested in 1949. Chemical fruit-thinning experiments. Figures average alternate halves (east and west) of two trees at each location. NS is nonsprayed; S is sprayed. Statistically significant differences between nonsprayed and sprayed are indicated by S5 for 5 per cent, S1 for 1 per cent and ns for no significance.

† Differences between sprayed and nonsprayed, as percentage of nonsprayed.

‡ Contains 40 per cent dinitro-ortho-cyclohexylphenol.

§ Contains 40 per cent dinitro-ortho-cresol.

‖ Contains 23 per cent triethanolamine salt of dinitro-ortho secondary butyl phenol.

¶ Contains 20 per cent dicyclohexylamine salt of dinitro-ortho-cyclohexylphenol.

** Contains 20 per cent sodium dinitro-ortho cresylate.

†† Polyethylene polysulfide plus zinc dimethyl dithiocarbamate.

‡‡ Light medium, tank mix emulsion, oil.

percentage of the weight per fruit on the nonsprayed half, it was found to average 14.9 per cent larger on halves sprayed with 20 p.p.m. 2,4-D, 14.8 per cent at 20 p.p.m. 2,4,5-T (both significant at 1 per cent by the *t* test), and 12.9 per cent at 10 p.p.m. 2,4-D in oil (not significant). The fruit size increase was 10.0 per cent (not significant) as a result of the 10 p.p.m. 2,4-D spray in water. The effectiveness of oil as a carrier probably accounts for the difference between this value and that given above for the 10 p.p.m. 2,4-D spray applied in oil.

Of the other treatments, although many resulted in a considerable decrease in number of fruits per tree, none induced a size increase of more than 7.6 per cent (not significant).

At harvest it was found that some of the fruits on halves of trees sprayed with 25 p.p.m. triiodobenzoic acid had failed to develop the usual turgid juice vesicles but had instead dry interiors containing apparently nondeveloped vesicles. In these fruits, the rind content as part of the total fruit, by weight, was about 50 per cent higher than in fruits from the nonsprayed halves. The percentage of rag (pulp) was increased about fourfold, while the juice was decreased to about one fifth of the normal content, and of course the fruits were worthless. These responses to triiodobenzoic acid occurred in both locations. The degree to which various fruits on a sprayed half responded may be the result of different stages of development at the time of spraying. The differences resulting from the spray were outstanding.

Analyses of the fruit and juice quality were made in 1949 on fruits of equal size from the sprayed and nonsprayed halves of some trees at the Anaheim location. These data are shown in Table 3.

It was found that on July 12, 1949, there were no appreciable differences between the fruits (including juice quality) from halves of trees sprayed with 10 p.p.m. 2,4-D and those from the nonsprayed halves. However, fruits from halves of trees sprayed with 20 p.p.m. 2,4-D or, especially, 2,4,5-T, had a tendency to develop heavier rinds and less juice than did those on the nonsprayed portions. These differences were more pronounced on May 18 than on July 12, and it is possible that they would have disappeared altogether if harvest had been made at a still later date. There were no appreciable differences between juice quality of fruits from nonsprayed halves and that of fruits from halves of trees sprayed with 20 p.p.m. 2,4-D. Juice of fruits from halves of trees sprayed with 2,4,5-T had a lower percentage of soluble solids than did that from the nonsprayed halves of the same trees. This difference in juice quality, as with that in fruit quality, may be the result of a delay in maturity of the fruits, and would probably disappear if the fruits were harvested later in the season.

The quality differences between fruits from the sprayed and nonsprayed halves of trees on which naphthaleneacetic acid was used were found to be the same as those noted when 2,4,5-T was used. In the naphthaleneacetic acid-sprayed fruits, however, maturity (as shown by rind color) was not visibly delayed, as it was in those sprayed with 2,4,5-T, nor was there a comparable increase in size. Further observations are necessary to determine whether this apparent response to naphthaleneacetic acid is reproducible and also whether it is actually a result of delayed maturity but without the

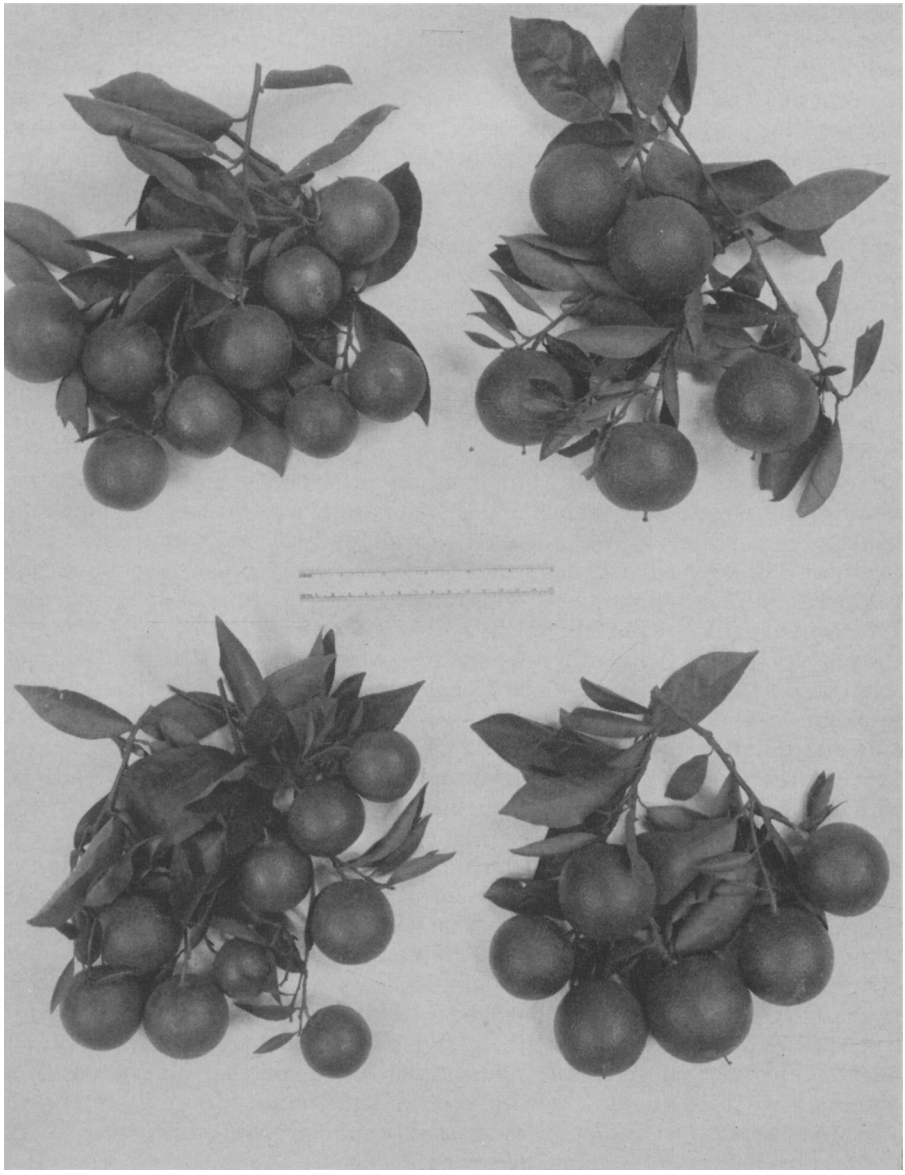

Fig. 1. Fruit size increase observed in November, 1948, as a result of spray application to halves of trees at flowering (April 20, 1948). Upper right: 2,4-D applied at 20 p.p.m., as the butyl ester, in a lanolin formulation. Lower right: 2,4,5-T applied at 20 p.p.m., as the butyl ester. Left, top and bottom: fruits from corresponding nontreated halves of trees. Note presence of style on treated fruits.

corresponding expression in rind color. A response of this type might be useful in reducing granulation of Valencia oranges (Bartholomew, Sinclair, and Turrell, 1941).

On the basis of the effectiveness of 2,4-D and 2,4,5-T in significantly increasing fruit size in these two locations (as well as in previous studies, Stewart and Klotz, 1947; Stewart and Parker, 1947), and the lack of a comparable response from any of the other treatments, studies were continued exclusively on the use of 2,4-D and 2,4,5-T to increase citrus fruit size.

Applications of 2,4-D on Young Fruits.—To determine the possibility of using 2,4-D spray commercially to increase Valencia orange fruit size, nine experiments were initiated in 1948. Four of the experiments were in Orange County, one in San Bernardino County, one in Los Angeles County, and three in Ventura County. In eight of the experiments, packing-house records were obtained of the distribution of sizes and quality of fruits from the various treatments; in the ninth, average size was determined, in the field at harvest, by measuring the diameter of every tenth fruit from one field box per tree. Four of the experiments involved 10 acres of trees each while three acres was the minimum used. The trees in all experiments varied in height from 8 to 24 feet and in age, from 10 to 50 years or more.

A randomized block design of three to eight replications was used in four of the experiments, and in two of these, the packing-house data were obtained for each treatment in each replicate. In the other two experiments, the fruits were graded in the packing house according to treatment, but were not kept separate according to replicate.

Drenching sprays of 2,4-D were applied during June and July, 1948, using standard orchard spray equipment.

It was found that in all cases the percentage of large fruits was increased as a result of the 2,4-D sprays (figs. 2 and 3). On the average, 33.9 per cent of the fruits on the nonsprayed trees was packing-house size 220 (2.625 inches in diameter) or larger, compared with 46.2 per cent in this category on the trees sprayed with 2,4-D. This is an increase of 36 per cent. There was also a gain in yield, per 100 trees, of 28.0 boxes (packed) of fruit size 220 and larger, and a loss of 19.8 boxes of size 252 (2.5 inches in diameter) and smaller. Thus there was a net yield increase of 8.2 boxes per 100 trees, resulting from the increased number of boxes of large fruits.

Fruit quality, as determined by packing-house grading, was lowered slightly (1.6 per cent) by the 2,4-D sprays, and the amount of loose (nonpacked) fruit, such as juice fruit, culls, and rots, was increased slightly (1.0 per cent). In a market favoring large fruits, these differences would not be sufficient to be of importance. They are of significance, however, in warning of consequences from application of excessive amounts of 2,4-D.

In two of the experiments in Orange County (Tustin and Fullerton), packing-house data were obtained for the fruits harvested in 1948, the year the 2,4-D was applied, and for those harvested in 1949. It was found (fig. 4) that in the data for the Tustin experiment, for which analyses of variance were possible, there were no significant differences, among the treatments, in the size or yield of fruits harvested September 17, 1948 (table 4). These fruits were mature, or nearly mature, at the time of spraying. However,

TABLE 3

EFFECT OF SPRAYS CONTAINING VARIOUS PLANT GROWTH REGULATORS ON GROWTH AND QUALITY OF VALENCIA ORANGES*

(Anaheim experiment)

Spray		Fruit growth 11/9/48-7/7/49	Fruit quality						Juice quality						Ratio soluble solids to total acid	
Material	Conc.		Rind		Rag		Juice		Soluble solids		Total acid		pH			
			5/18	7/12	5/18	7/12	5/18	7/12	5/18	7/12	5/18	7/12	5/18	7/12	5/18	7/12
	p.p.m.	*mm*	*per cent*	*per cent*	*per cent*	*per cent*	*per cent*	*per cent*	*per cent*	*per cent*	*per cent*	*per cent*				
No spray, control	0	11.3	45.7	39.9	2.1	1.8	52.1	56.2	11.43	12.51	1.65	1.39	3.18	3.53	6.93	9.00
No spray, control	0	11.5	46.6	40.2	1.7	1.3	51.1	55.5	11.57	12.17	1.75	1.37	3.13	3.54	6.61	8.88
2,4-D in 1% LM-TNK oil†	0	11.6	50.7	44.4	3.9	5.1	44.0	49.8	11.23	11.63	1.83	1.45	3.11	3.48	6.14	8.02
2,4-D in 1% LM-TNK oil	10	12.2	49.3	43.9	3.0	3.6	45.9	50.0	11.03	11.37	1.65	1.39	3.20	3.50	6.68	8.18
2,4-D as isopropyl ester	0	11.5	51.2	45.5	3.8	4.7	44.0	47.5	10.03	11.57	1.58	1.41	3.20	3.50	6.78	8.21
2,4-D as isopropyl ester	10	13.0	50.9	44.3	2.7	4.0	45.6	51.0	11.17	11.71	1.87	1.38	3.14	3.50	5.97	8.49
2,4-D as butyl ester	0	10.1	48.6	42.6	2.9	3.4	48.6	51.1	10.83	11.91	1.67	1.47	3.20	3.53	6.49	8.10
2,4-D as butyl ester	20	15.4	52.3	44.7	2.7	2.9	45.2	50.6	11.03	11.91	1.69	1.45	3.18	3.53	6.53	8.21
2,4,5-T as butyl ester	0	11.5	49.9	41.9	2.0	2.4	47.6	52.1	11.51	12.43	2.01	1.60	3.10	3.47	5.73	7.77
2,4,5-T as butyl ester	20	16.3	53.5	45.1	3.1	3.1	43.4	48.7	10.11	11.57	1.79	1.53	3.17	3.50	5.65	7.56
Naphthaleneacetic acid	0	....	....	46.0	....	3.5	....	49.3	.....	12.23	....	1.41	....	3.54	....	8.67
Naphthaleneacetic acid	25	....	....	50.2	....	3.9	....	44.0	.....	11.83	....	1.39	....	3.52	....	8.51
Triiodobenzoic acid	0	....	....	45.1	....	2.9	....	53.5	.....	11.63	....	1.39	....	3.56	....	8.37
Triiodobenzoic acid, sound‡	25	....	....	51.0	....	8.5	....	40.6	.....	12.11	....	1.26	....	3.61	....	9.61
Triiodobenzoic acid, dry	25	....	....	73.6	....	13.3	....	10.6	.....	.....	....	....	....	....	....	....

* Sprays applied April 27, 1948, at full bloom. Fruit harvested July 12, 1949. Figures average alternate halves (east and west) of two trees sprayed per treatment. Chemical fruit-thinning experiment.

† As isopropyl ester (technical grade in 1 per cent, light medium, tank-mix oil).

‡ Sound are values for 22 fruits of sample which were the least dry; remaining fruits of sample (28) are listed under dry.

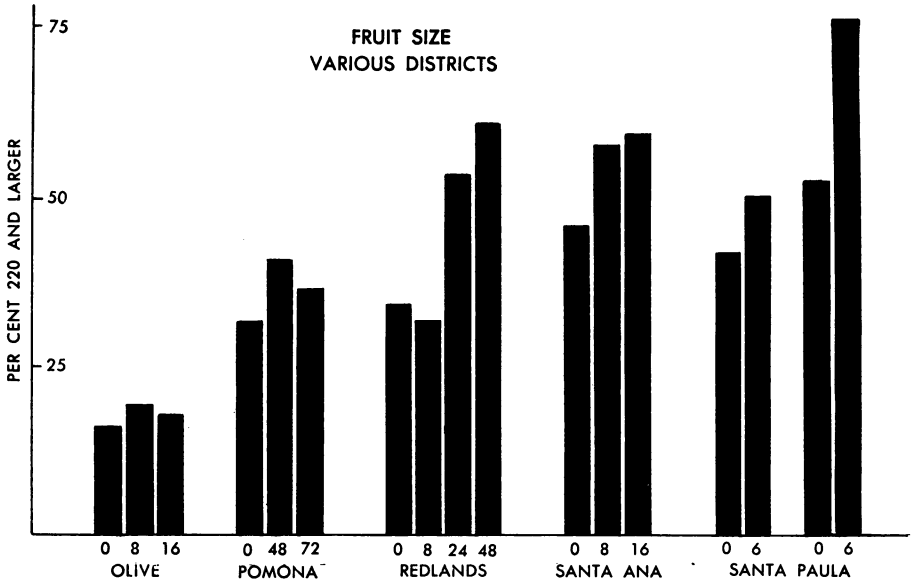

Fig. 2. Fruit size distribution as per cent of total packed boxes size 220 (2.625 inches diameter) and larger harvested in 1949 following application of 2,4-D in June, 1948. Concentrations of 2,4-D as p.p.m. in spray solution are shown above locations of experiments.

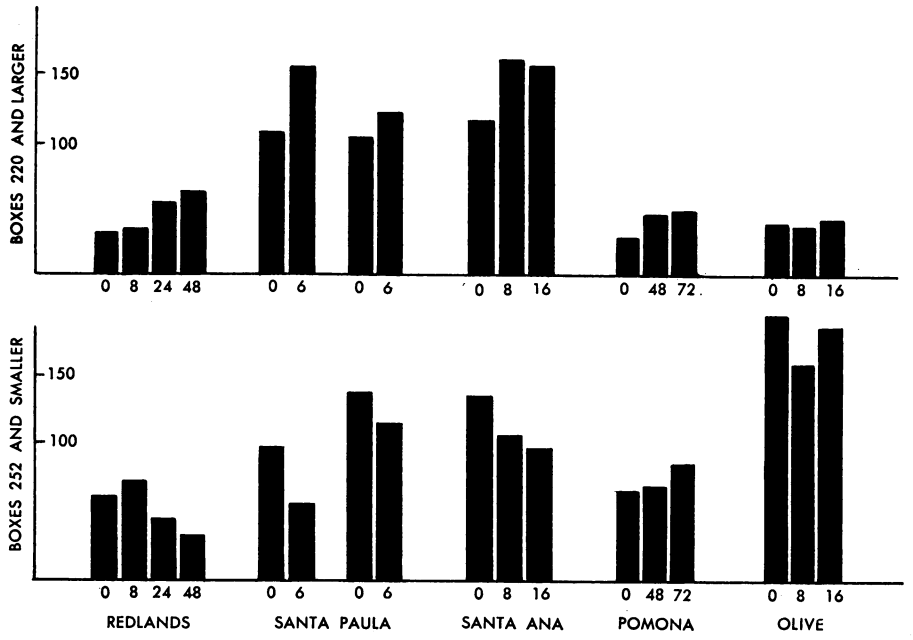

Fig. 3. Yield, in 1949, as packed boxes of fruit per 100 trees, from trees sprayed with 2,4-D in June, 1948. Boxes of size 220 (2.625 inches diameter) and larger are shown above, and boxes of size 252 (2.500 inches diameter) and smaller, below. Data are for the same trees and harvests as those shown in figure 2. Concentrations of 2,4-D as p.p.m. in spray solution are shown above locations of experiments.

TABLE 4

EFFECT OF 2,4-D ON YIELD, SIZE, AND GRADE OF VALENCIA ORANGES*

(Experiment near Tustin, Orange County)

Spray treatment	Number of trees	Fruit yield per 100 trees										First-grade fruit (per cent of packed boxes)	Loose fruit† (per cent of field boxes)
		Field boxes	Packed boxes										
			Fruit size (number per box)										
			126	150	176	200	220	252	288	344	392	Total	
None (control)	196	334	0.00	1.07	3.47	9.69	20.15	31.73	41.33	19.54	6.02	133.01	95.2	41.5
2,4-D, 8 p.p.m.	199	341	0.05	0.85	3.17	8.44	18.54	27.03	42.16	19.90	4.97	125.12	95.8	42.0
2,4-D, 16 p.p.m.	196	386	0.00	1.38	3.98	10.20	22.40	32.86	51.84	27.14	9.29	159.08	96.0	47.6
2,4-D, 24 p.p.m.	196	345	0.05	1.27	3.83	9.69	19.54	31.84	45.71	21.38	4.49	137.81	95.9	41.9

* Trees sprayed June 11, 1948. Fruit harvested September 17, 1948.
† Juice fruit, culls, and similar nonpacked fruits.

TABLE 5

EFFECT OF 2,4-D ON YIELD, SIZE, AND GRADE OF VALENCIA ORANGES*

(Same experiment as Table 4, but fruit harvested following year)

Spray treatment	Number of trees	Fruit yield per 100 trees										First-grade fruit (per cent of packed boxes)	Loose fruit† (per cent of field boxes)
		Field boxes	Packed boxes										
			Fruit size (number per box)										
			126	150	176	200	220	252	288	344	392	Total	
None (control)	196	342	0.00	1.17	5.67	14.18	25.97	37.19	34.43	23.36	5.36	147.33	80.2	37.4
2,4-D, 8 p.p.m.	197	346	0.15	2.54	8.43	12.69	29.90	36.95	31.22	23.21	7.41	152.50	76.3	36.9
2,4-D, 16 p.p.m.	196	398	0.26	4.19	13.32	18.01	34.70	41.27	30.97	20.25	3.88	166.85	78.3	37.4
2,4-D, 24 p.p.m.	196	384	0.20	2.19	10.97	15.41	33.83	40.00	34.39	21.99	7.30	166.28	78.3	41.7

* Trees sprayed June 11, 1948. Fruit harvested September 19, 1949. Average fruit diameter at time of spraying, 0.589 cm. Experiment near Tustin, Orange County.
† Juice fruit, culls, and similar nonpacked fruits.

fruits harvested the following year, on September 19, 1949, from the same trees, showed significant increases in size and yield as a result of the 2,4-D sprays (tables 5 and 6). These fruits were approximately 6 weeks old at the time of spraying in 1948.

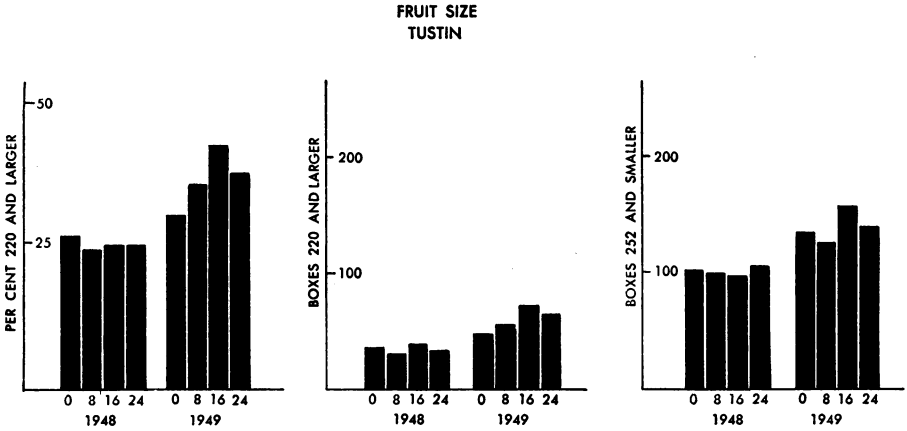

Fig. 4. Fruit size distribution as per cent of packed boxes of fruit size 220 (2.625 inches diameter) and larger, and yield, as boxes per 100 trees, of large-sized fruits (220 and larger) and small-sized fruits (252, 2.500 inches diameter and smaller), in 1948 and 1949. Trees sprayed June 11, 1948, with 2,4-D concentrations at p.p.m. indicated. Fruit harvested September 17, 1948, and September 19, 1949, from same trees as in 1948. The 1949 harvest shows the influence of the 1948 2,4-D spray in increasing fruit size. Experiment located near Tustin.

Similar results were obtained in the Fullerton experiment (fig. 5) although here the packing-house data did not allow a statistical determination of significance of the increases in size and yield resulting from the 2,4-D (tables 7, 8, 9, and 10).

In this experiment, growth measurements were made of fruits on non-sprayed trees and on trees sprayed with 24 p.p.m. 2,4-D. On November 2, 1948, fruits on the outside of the tree (i.e., not inside the leaf canopy) were selected at random, tagged, and measured at monthly intervals. A record

TABLE 6
EFFECT OF 2,4-D ON QUALITY OF VALENCIA ORANGES*
(Same experiment as Table 5)

Spray treatment	Rind	Rag	Juice				
			Total juice	pH	Total soluble solids	Total acid	Ratio soluble solids to total acids
	per cent	*per cent*	*per cent*		*per cent*	*per cent*	
None (control)	44.0	2.0	52.9	3.33	10.71	1.19	9.00
2,4-D, 8 p.p.m.	42.8	2.9	54.3	3.33	10.97	1.19	9.22
2,4-D, 16 p.p.m.	42.2	2.7	54.5	3.34	10.71	1.19	9.00
2,4-D, 24 p.p.m.	42.3	3.3	54.1	3.33	10.63	1.22	8.71

* Trees sprayed June 11, 1948. Fruit harvested September 19, 1949. Experiment near Tustin, Orange County.

TABLE 7

EFFECT OF 2,4-D ON YIELD, SIZE, AND GRADE OF VALENCIA ORANGES*

(Experiment near Fullerton, Orange County)

Spray treatment	Number of trees	Fruit yield per 100 trees										First-grade fruit (per cent of packed boxes)	Loose fruit† (per cent of field boxes)
		Field boxes	Packed boxes										
			Fruit size (number per box)										
			126	150	176	200	220	252	288	344	392	Total	
None (control).....	211	329	0.14	0.66	2.13	4.93	12.27	19.24	50.28	44.59	26.87	161.11	90.2	34.7
2,4-D, 8 p.p.m.....	254	385	0.00	0.47	1.81	5.28	17.56	27.91	66.14	46.34	29.88	195.39	86.4	31.4
2, 4-D, 24 p.p.m.....	215	321	0.05	0.33	1.49	3.81	13.58	28.19	64.46	33.39	23.25	168.55	89.4	20.6

* Trees sprayed June 10, 1948. Fruit harvested October 21, 1948.
† Juice fruit, culls, and similar nonpacked fruits.

TABLE 8

EFFECT OF 2,4-D ON YIELD, SIZE, AND GRADE OF VALENCIA ORANGES*

(Same experiment as Table 7, but fruit harvested following year)

Spray treatment	Number of trees	Fruit yield per 100 trees										First-grade fruit (per cent of packed boxes)	Loose fruit† (per cent of field boxes)
		Field boxes	Packed boxes										
			Fruit size (number per box)										
			126	150	176	200	220	252	288	344	392	Total	
None (control).....	211	646	0.05	0.95	9.59	14.88	36.87	59.10	127.62	87.29	42.18	378.54	89.0	20.8
2,4-D, 8 p.p.m.....	254	690	0.08	3.27	9.52	26.70	57.28	80.47	108.07	67.95	28.26	381.60	90.2	21.2
2,4-D, 24 p.p.m.....	215	765	0.52	4.37	12.84	32.74	59.67	87.62	90.88	68.74	23.16	380.54	89.4	17.4

* Trees sprayed June 10, 1948. Fruit harvested August 10, 1949. Average fruit diameter at time of spraying, 0.569 cm.
† Juice fruit, culls, and similar nonpacked fruits.

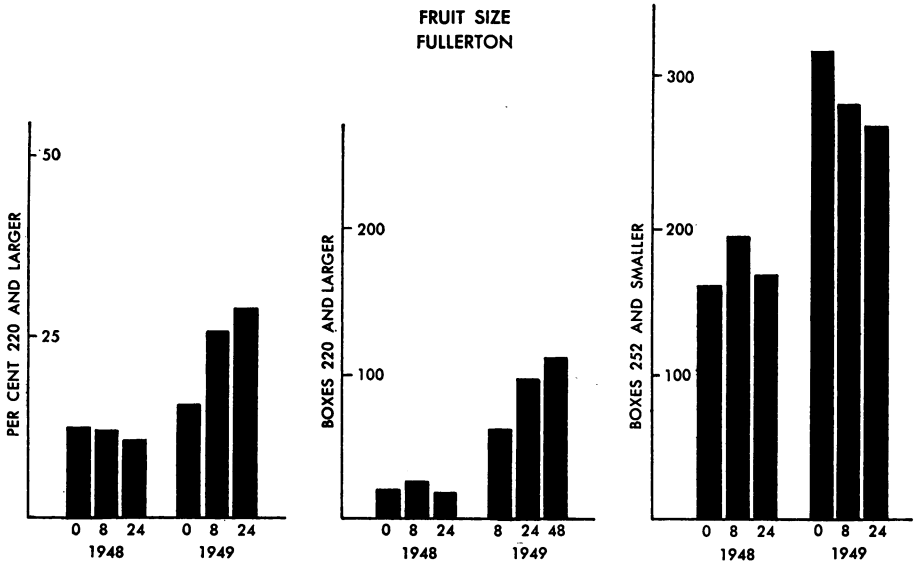

Fig. 4. Fruit size distribution as per cent of packed boxes of fruit size 220 (2.625 inches diameter) and larger, and yield, as boxes per 100 trees, of large-sized fruits (220 and larger) and small-sized fruits (252, 2.500 inches diameter and smaller), in 1948 and 1949. Trees sprayed June 11, 1948, with 2,4-D concentrations at p.p.m. indicated. Fruit harvested October 21, 1948, and August 10, 1949, from same trees as in 1948. The 1949 harvest shows the influence of the 1948 2,4-D spray in increasing fruit size. Experiment located near Fullerton.

was also kept of the quadrant of the tree in which the fruit was located. Results obtained are shown in Table 7.

It was found that during every month, the fruits on the trees sprayed with 2,4-D grew at a greater rate than did those on the nonsprayed trees. There was less increase in growth rate during January, February, June, and July than at other times. It was noted on January 10, 1949, that 66 per cent of the fruits being measured on the trees sprayed with 2,4-D was green colored, compared with 53 per cent on the nonsprayed trees. Fruits having 50 per cent or more of the rind area green were classified as green.

TABLE 9

EFFECT OF 2,4-D ON QUALITY OF VALENCIA ORANGES*

(Same experiment as Table 8)

Spray treatment	Rind	Rag	Juice				
			Total juice	pH	Total soluble solids	Total acid	Ratio soluble solids to total acids
	per cent	*per cent*	*per cent*		*per cent*	*per cent*	
None (control).....	37.3	1.9	60.5	3.40	12.51	0.91	13.15
2,4-D, 24 p.p.m.....	39.6	2.0	58.2	3.33	13.12	0.97	13.60

* Trees sprayed June 10, 1948. Fruit harvested August 10, 1949. Experiment near Fullerton, Orange County.

TABLE 10

EFFECT OF 2,4-D ON FRUIT GROWTH OF VALENCIA ORANGES*

(Same experiment as Tables 8 and 9)

Spray treatment	Number of fruits measured	Fruit diameter on Nov. 11, 1948	Monthly growth									Fruit diameter Aug. 2, 1949	Net growth, Nov. 11, 1948, to Aug. 2, 1949	Green-colored fruit†	Net growth green-colored fruit	Net growth yellow-colored fruit‡
			Dec., 1948	Jan., 1949	Feb.	Mar.	Apr.	May	June	July	Aug.					
		mm	*mm*	*mm*	*mm*	*mm*	*mm*	*mm*	*mm*	*mm*	*mm*	*mm*	*mm*	*per cent*	*mm*	*mm*
None (control)...	312	48.51	3.03	.64	1.27	1.27	.99	.86	.45	1.11	.69	58.81	10.30	53.0	11.82	8.67
2,4-D, 24 p.p.m.....	288	48.22	3.46	.65	1.40	1.69	1.29	1.17	.61	1.18	1.05	60.73	12.51	66.0	13.49	10.34
			(+.43)§	(+.01)	(+.13)	(+.42)	(+.30)	(+.31)	(+.16)	(+.07)	(+.36)		(+2.21)			(+1.67)

* Trees sprayed June 10, 1948. Fruit harvested August 10, 1949. Experiment near Fullerton, Orange County.
† 50 per cent, or more, of rind green colored on January 10, 1949.
‡ 50 per cent, or more, of rind yellow colored on January 10, 1949.
§ Numbers in parentheses are differences between growth of fruit on nonsprayed trees and on trees sprayed with 2,4-D.

TABLE 11

EFFECT OF 2,4-D ON YIELD, SIZE, AND GRADE OF VALENCIA ORANGES*

(Experiment near Santa Ana, Orange County)

Spray treatment	Number of trees	Fruit yield per 100 trees										First-grade fruit (per cent of packed boxes)	Loose fruit† (per cent of field boxes)
		Field boxes	Packed boxes										
			Fruit size (number per box)										
			126	150	176	200	220	252	288	344	392	Total		
None (control).....	795	438	0.39	6.61	16.26	38.99	52.44	53.25	50.02	24.15	8.37	250.48	93.0	18.4
2,4-D, 8 p.p.m.....	676	435	1.55	15.85	29.68	56.54	54.29	48.98	38.33	15.37	4.76	265.35	92.8	17.9
2,4-D, 16 p.p.m.....	649	432	2.39	20.57	28.87	54.17	51.73	42.17	35.53	15.58	5.09	256.10	92.9	18.6

* Trees sprayed June 8, 1948. Fruit harvested September 26, 1949. Average fruit diameter at time of spraying, 0.551 cm.
† Juice fruit, culls, and similar nonpacked fruits.

Apparently maturity, as indicated by loss of green color, had been delayed as a result of the 2,4-D. The green and yellow fruits were marked so that subsequent growth of these two classes could be determined. It was found (table 7) that: (1) Whether on 2,4-D-sprayed trees or not, the green fruits grew more than the yellow fruits; and (2) The fruits (either green or yellow) on the trees sprayed with 2,4-D grew more than those of corresponding color on nonsprayed trees. These differences were all significant at the 1 per cent level by the *t* test. Similar growth results were obtained in the chemical thinning experiment (see table 3, p. 310).

TABLE 12

EFFECT OF 2,4-D ON QUALITY OF VALENCIA ORANGES*

(Same experiment as Table 11, but fruit sampled following year)

Spray treatment and date of analysis, 1949	Rind	Rag	Juice				
			Total juice	pH	Total soluble solids	Total acid	Ratio soluble solids to total acids
	per cent	*per cent*	*per cent*		*per cent*	*per cent*	
None (control):							
August 25	40.2	2.5	56.6	3.34	10.57	1.07	9.88
September 26	36.6	7.0	56.8	3.34	10.43	1.10	9.46
2,4-D, 8 p.p.m.:							
August 25	42.3	2.2	54.8	3.30	10.57	1.17	9.08
September 26	39.0	7.1	55.7	3.31	10.11	1.08	9.33
2,4-D, 16 p.p.m.:							
August 25	41.6	2.0	55.3	3.32	10.31	1.14	9.07
September 26	34.8	7.5	58.8	3.31	11.23	1.12	10.01

* Trees sprayed June 8, 1948. Fruit sampled August 25 and September 26, 1949. Experiment near Santa Ana, Orange County.

It was also observed that fruits on young trees (6 years of age or less) increased in size in response to 2,4-D more than did fruits on older trees (50 years of age). This difference was apparent visually and was substantiated by measurements.

The third experiment in Orange County was near Santa Ana. As in the Tustin experiment, the data were analyzed for significance of differences among the treatments. Increases in fruit size and in yield of large-sized fruits as a result of the 2,4-D spray were found to be significant at the 1 per cent level. These results are shown in Tables 11 and 12.

The fourth Orange County experiment was near Olive. Of the eight experiments for which packing-house records were obtained, this one showed the least increase in size and yield of large fruits as a result of using 2,4-D spray (table 13). As in the other experiments, there was also an apparent reduction in the yield of small fruits from the trees sprayed with 2,4-D. None of these differences were assumed to be significant since they were relatively small. The data did not allow calculation of significance.

Packing-house data obtained from the four experiments in other counties are summarized in Tables 14, 15, 16, and 17, and in figures 2 and 3. They

TABLE 13

EFFECT OF 2,4-D ON YIELD, SIZE, AND GRADE OF VALENCIA ORANGES*

(Experiment near Olive, Orange County)

Spray treatment	Number of trees	Fruit yield per 100 trees										First-grade fruit (per cent of packed boxes)	Loose fruit† (per cent of field boxes)
		Field boxes	Packed boxes										
			Fruit size (number per box)										
			126	150	176	200	220	252	288	344	392	Total		
None (control)	290	387	0.00	0.34	2.62	13.48	22.21	56.96	58.27	65.89	15.79	235.56	69.2	31.5
2,4-D, 8 p.p.m.	151	326	0.00	0.60	2.91	13.38	21.33	48.61	45.30	51.73	13.11	196.97	73.8	29.2
2,4-D, 16 p.p.m.	140	401	0.00	0.43	2.93	14.43	23.21	57.71	56.22	60.07	13.29	228.29	67.8	36.3

* Trees sprayed June 8, 1948. Fruit harvested July 15, 1949. Average diameter of fruit at time of spraying, 0.450 cm.
† Juice fruit, culls, and similar nonpacked fruits.

TABLE 14

EFFECT OF 2,4-D APPLICATION BY SPRAY-DUSTER MACHINE* ON YIELD AND SIZE OF VALENCIA ORANGES†

(Experiment near Pomona, Los Angeles County)

Spray treatment	Number of trees	Fruit yield per 100 trees										
		Field boxes	Packed boxes									
			Fruit size (number per box)									
			126	150	176	200	220	252	288	344	392	Total
None (control)	40	227	0.60	1.55	4.27	10.25	12.00	18.95	22.60	15.70	9.40	95.32
2,4-D, 48 p.p.m.‡	23	252	2.44	4.39	9.05	15.75	16.09	18.92	23.58	13.79	11.53	115.54
2, 4-D, 72 p.p.m.‡	19	279	1.11	4.79	9.63	12.26	20.99	25.14	28.40	17.15	13.31	132.78
2,4-D, 48 p.p.m.§	23	217	0.48	0.91	3.31	4.91	11.96	13.27	23.71	13.05	12.44	84.04

* Application at rate of 300 gallons per acre. Spray applied July 21, 1948. Fruit harvested November 30, 1949.
† Per cent first-grade quality not determined because of severe rind scarring by ice and wind.
‡ As isopropyl ester.
§ As triethanolamine salt.

TABLE 15

EFFECT OF 2,4-D ON YIELD, SIZE, AND GRADE OF VALENCIA ORANGES

(Experiment near Santa Paula, Ventura County)

Experiment and spray treatment	Number of trees	Fruit yield per 100 trees										First-grade fruit (per cent of packed boxes)	Loose fruit* (per cent of field boxes)
		Field boxes	Packed boxes										
			Fruit size (number per box)										
			126	150	176	200	220	252	288	344	Total		
Experiment 1†													
None (control)	122	402	0.82	4.10	22.13	24.59	56.55	53.27	32.78	9.84	204.08	57.0	28.9
2,4-D, 6 p.p.m.‡	114	412	3.51	21.93	50.87	39.47	39.64	31.58	16.66	6.14	209.80	53.8	21.8
Experiment 2†													
None (control)	128	568	0.00	3.12	17.19	24.22	57.82	73.44	50.00	14.84	240.63	59.7	40.7
2,4-D, 6 p.p.m.‡	128	556	1.56	7.81	26.56	29.69	55.47	66.41	39.85	10.16	237.51	58.6	42.1

* Juice fruit, culls, and similar nonpacked fruits.
† Experiment 1: trees sprayed July 27, 1949. Experiment 2: trees sprayed August 31, 1949.
‡ As isopropyl ester.

TABLE 16

EFFECT OF 2,4-D AND 2,4,5-T ON YIELD AND SIZE* OF VALENCIA ORANGES†

(Experiment near Redlands, San Bernardino County)

Spray treatment	Number of trees	Fruit yield per 100 trees											
		Field boxes	Packed boxes										
			Fruit size (number per box)										
			100	126	150	176	200	220	252	288	344	392	Total
None (control)	298	254	0.27	1.04	2.38	5.77	9.13	12.82	17.48	24.83	11.01	7.31	92.05
2,4-D, 8 p.p.m.	149	264	0.00	0.54	2.08	6.24	10.47	13.62	20.40	28.73	13.02	8.32	103.42
2,4-D, 24 p.p.m.	149	256	0.54	3.69	4.77	11.54	16.71	15.64	17.79	18.25	6.31	2.62	97.85
2,4-D, 48 p.p.m.	109	254	2.20	4.22	5.69	12.84	15.69	13.58	14.31	13.58	3.58	2.20	87.89
2,4,5-T, 10 p.p.m.	73	244	0.00	1.10	2.19	7.53	5.34	13.84	22.47	20.27	6.44	3.15	82.33

* Per cent first-grade quality not determined due to severe rind scarring from wind and ice.
† Trees sprayed June 9, 1948. Fruit harvested November 16, 1949. Average fruit diameter at time of spraying, 0.450 cm.

substantiate the results from the Orange County experiments and show that the effectiveness of 2,4-D in inducing an increase in fruit size is not restricted to any particular district in southern California.

The experiment near Pomona, Los Angeles County, was of particular interest since the applications were made with a "spray-duster" machine at 300 gallons per acre. (Spray-duster application is usually less expensive than spraying by hand.) Increases in fruit size and yield were similar, with this type of application, to those resulting from hand spraying (table 14).

In the Redlands, San Bernardino County, experiment, an application of 2,4,5-T at 10 p.p.m. was included along with the 2,4-D sprays. The 2,4,5-T

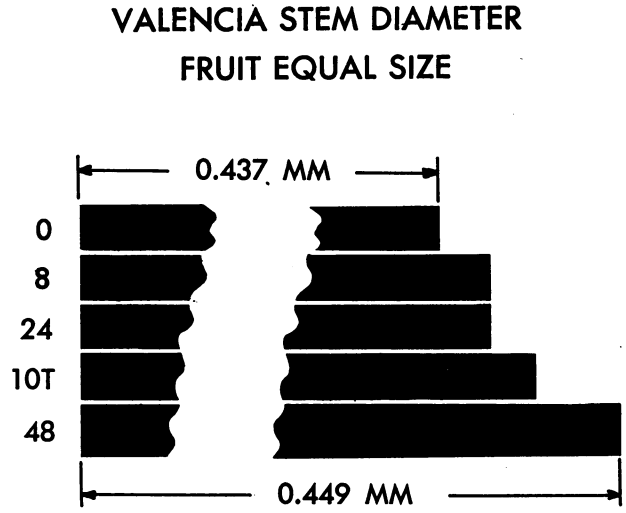

Fig. 6. Fruit-stem diameter per centimeter fruit diameter as determined in November, 1949, for Valencia oranges of equal size on trees sprayed in June, 1948, with 2,4-D concentrations at p.p.m. indicated on ordinate. 10 T is a spray of 10 p.p.m. 2,4,5-T. Comparing fruits of equal size, note increased stem diameter as a result of the treatments.

induced an appreciably greater increase in percentage of fruit size 220 and larger than did the 8 p.p.m. 2,4-D spray. The yield of large-sized fruits, however, was slightly lower than that from the nonsprayed trees (table 12). This may indicate that 2,4,5-T has a greater thinning effect than 2,4-D.

It is generally recognized that large-sized fruits have thicker stems than do small fruits. This was confirmed by measurements made in February of stem and fruit diameters of 120 nonsprayed Valencia oranges. A correlation coefficient of 0.57 was found significant at the 1 per cent level.

In the Redlands experiment, just prior to harvest, measurements were made of fruit-stem and fruit diameters on one of the largest-sized fruits on every fourth tree per treatment. Fruits were selected alternately on north and south sides of the trees. It was found that with increasing concentrations of 2,4-D, the ratio of stem diameter to fruit diameter increased (fig. 6, table 12). Thus, in addition to inducing an increase in fruit size, the 2,4-D sprays induced an increase in the thickness of the stem in relation to the size

of the fruit. Comparing fruits of equal diameter, the stem would be thicker on fruits from the 2,4-D-sprayed trees than on those from nonsprayed trees. The ratio of fruit-stem diameter to fruit diameter was greater on trees sprayed with 10 p.p.m. 2,4,5-T than on those sprayed with 24 p.p.m. 2,4-D.

TABLE 17

EFFECT OF 2,4-D AND 2,4,5-T ON FRUIT QUALITY AND RATIO OF FRUIT STEM DIAMETER TO FRUIT OF VALENCIA ORANGES*

(Same experiment as Table 16)

Spray treatment	Rind	Rag	Juice					Stem diameter (mm) per cm fruit diameter†
			Total juice	pH	Total soluble solids	Total acid	Ratio soluble solids to total acid	
	per cent	*per cent*	*per cent*		*per cent*	*per cent*		
None (control)	40.6	5.3	52.0	3.57	11.11	1.11	10.01	0.437
2,4-D, 8 p.p.m.	41.3	4.2	49.0	3.54	11.43	1.14	10.03	0.438^{ns}
2,4-D, 24 p.p.m.	40.9	4.3	48.3	3.47	10.77	1.18	9.13	0.438^{ns}
2,4-D, 48 p.p.m.	40.2	4.0	50.8	3.51	11.23	1.14	9.85	0.459^{S5}
2,4,5-T, 24 p.p.m.	40.8	4.1	51.2	3.55	10.57	1.08	9.79	0.449^{ns}

* Trees sprayed June 9, 1948. Fruit harvested November 16, 1949. Average fruit diameter at time of spraying, 0.409 cm. Experiment near Redlands, San Bernardino County.

† Number of fruit stems measured were: None, 80; 2, 4, 5-T, 20; all other treatments, 40. Statistically significant differences are indicated by S5 for 5 per cent; ns indicates no significance at 5 per cent.

TABLE 18

EFFECT OF 2,4-D ON SIZE OF VALENCIA ORANGES*

(Experiment near Fillmore, Ventura County)

Factor	Nonsprayed (control)	Sprayed with 2,4-D	
		24 p.p.m.	32 p.p.m.
Number of trees	71	72	71
Number of fruits measured†	1,047	1,041	986
Percentage of fruits that were size:			
176 (2.88 inch diameter) or larger	7.6	10.8	14.3
200 (2.75 inch diameter) or larger	21.2	24.6	30.9
220 (2.62 inch diameter) or larger	45.2	50.0	53.3
252 (2.50 inch diameter) or larger	66.9	73.3	77.8
288 (2.37 inch diameter) or larger	85.7	88.8	89.8

* Trees sprayed July 10, 1948. Fruit harvested July 13, 1949.

† Every tenth fruit in one field box per tree measured.

Packing-house data for fruit size were obtained from the two experiments near Santa Paula in Ventura County (table 15). In the third experiment, near Fillmore, fruit size was determined by measuring the diameter of every tenth fruit in one field box per tree. The distribution of diameters according to packing-house sizes is shown in Table 18. As in the experiments where packing-house data were obtained, it is noted that there was a higher percentage of large-sized fruits harvested from the trees sprayed with 2,4-D. There were no apparent differences between the quality of fruits from the nonsprayed trees and that of fruits from trees sprayed with 2,4-D.

In addition to the Pomona experiment, where 2,4-D was applied at low gallonage with a spray-duster machine, another experiment to study the effect of low-volume 2,4-D applications on fruit size was established in the same grove in Orange County where the Fullerton experiment (see above) was conducted. This experiment was of randomized block design with four replicates. The trees were estimated to be 16 feet in height, and there were two trees per treatment per replicate. The treatments were: (1) nonsprayed, control; (2) 48 p.p.m. 2,4-D applied as the isopropyl ester at 2 gallons per tree, outside foliage coverage only; (3) 48 p.p.m. 2,4-D applied as the isopropyl ester at 4 gallons per tree, inside and outside coverage; and (4) 48 p.p.m. 2,4-D applied as the isopropyl ester at 16 gallons drenching spray

TABLE 19
EFFECT OF 2,4-D ON YIELD AND SIZE OF VALENCIA ORANGES*
(Experiment near Fullerton, Orange County)

Spray treatment	Number of trees	Yield, as field boxes per tree		Size, as fruits per field box	
		1948 harvest	1949 harvest	1948 harvest	1949 harvest
None (control)	16	....	5.69	.....	284.4
2,4-D, 48 p.p.m.:					
2 gals	14	5.14	5.65	299.3	272.0
4 gals	13	4.43	6.75	308.7	259.2
16 gals	13	3.37	6.48	307.0	255.4
Least significant difference:					
At 5 per cent	..	1.57	1.45	37.0	30.67
At 1 per cent	..	2.38	2.08	56.1	44.07

* Trees sprayed July 23, 1948. Fruit harvested August 10, 1949. Average fruit diameter at time of spraying, 2.084 cm.

per tree. The sprays were applied July 23, 1948, with conventional spray equipment, but using small-orifice spray nozzle discs (no. 2) on treatments 1 and 2 to allow uniform distribution of the spray as a mist. A much larger disc (no. 7) was used on treatment 3.

The yield, as field boxes per tree, and the fruit size, as number of fruits per field box, were determined at the harvests in 1948 and 1949. The results are shown in Tables 19 and 20.

There were no significant differences in size among fruits from the sprayed trees at the 1948 harvest. Yield and fruit size from the nonsprayed trees were not obtained. In 1949, however, the size of fruits from trees sprayed with 16 gallons of solution was almost significantly larger (at 5 per cent) than that of fruits from the nonsprayed trees. The size of fruits from trees sprayed with 4 gallons per tree was only slightly smaller than that of fruits from those sprayed with 16 gallons, whereas fruits from the trees receiving 2 gallons of spray were considerably smaller than those from trees sprayed with 4 gallons.

Periodic measurements of fruit growth on the trees sprayed with 16 gallons of spray per tree and on nonsprayed trees were made as described under the Fullerton experiment. The results were similar to those for that experiment and showed (tables 8, 9, 10) that, in comparison with fruits on non-

sprayed trees, those on trees sprayed with 2,4-D grew at a faster rate except for the month of July. Observations on January 10, 1949, also indicated that there was a greater percentage of fruits with green rind color on the 2,4-D-sprayed trees than on the nonsprayed trees. It was found by subsequent measurements that the fruits that were green colored on January 10, 1949, grew more than the yellow colored fruits and that the green and yellow colored fruits on the 2,4-D-sprayed trees grew more in size than corresponding fruits on the nonsprayed trees. These differences were significant at 1 per cent by the t test, and support similar observations in the Fullerton experiment discussed earlier.

During the first half of February, 1949, numerous fruit-size measurements were made in all of the Orange County experiments and in the Redlands experiment. "Outside" fruits were measured. The results are shown in Table 21. In comparison with nonsprayed trees, those sprayed with 2,4-D showed an increase in the percentage of large-sized fruits and a decrease in the percentage of small-sized fruits in all cases. These distributions were similar to those based on the packing-house records obtained after harvest six months or more later. Previous studies have indicated that measurements of Valencia orange fruit size in November could be used to predict the average fruit size of the crop at harvest the following year (Parker, 1934).

DISCUSSION

The significant increase in fruit size observed as a result of 2,4-D application was primarily due to an increase in growth rate. During the period of measurements, the increase was consistent every month. Rapid growth may be a characteristic of young fruits, and it appeared that the fruits on the 2,4-D-sprayed trees actually were physiologically younger than those on the nonsprayed. This was shown not only by the increased growth rate but also in various other ways. For example, at the time of color change, there were more green fruits on the sprayed trees than on the nonsprayed trees. This was observed in numerous experiments, not only with Valencia oranges but also with Washington Navel oranges (Stewart, Klotz, and Hield, 1951). Another example was noted in the Santa Ana experiment where the percentage of soluble solids in the juice of fruits from nonsprayed trees declined from August 25 to September 26, but during the same interval, as in maturing fruits, there was an increase of soluble solids in the juice of fruits from trees sprayed with 2,4-D. Other effects of 2,4-D—ones usually associated with the vigorous growth of young fruits—were an intense, dark green color and a rough, pebbly rind which persisted in some cases for six to eight months following flowering. Responses induced by the 2,4-D which may contribute to keeping the fruits physiologically young are: (1) a thicker fruit stem in proportion to fruit diameter; (2) a direct stimulation of growth of fruit tissues; and (3) a reduction in the number of fruits per tree, that is, a fruit-thinning effect.

It was found that on nonsprayed trees, the diameter of the fruit stem (pedicel) was directly correlated with fruit diameter, and that on those sprayed with 2,4-D, the pedicel diameter was greater in proportion to the fruit than it was on nonsprayed trees. This may allow a greater translocation

TABLE 20

EFFECT OF 2,4-D ON FRUIT GROWTH OF VALENCIA ORANGES*

(Same experiment as Table 19)

Spray treatment	Fruit diameter on Nov. 11, 1948†	Monthly growth (average of 60 fruits)									Fruit diameter Aug. 2, 1949‡	Net growth Nov. 11, 1948, to Aug. 2, 1949	Green-colored fruit§	Net growth green-colored fruit	Net growth yellow-colored fruit‖
		Dec. 1948	Jan. 1949	Feb.	Mar.	April	May	June	July	Aug.					
	mm	*mm*	*mm*	*mm*	*mm*	*mm*	*mm*	*mm*	*mm*	*mm*	*mm*	*mm*	*per cent*	*mm*	*mm*
None (control).....	46.95	2.58	0.64	1.50	1.03	0.64	0.73	0.17	1.33	0.59	56.16	9.21	53.0	10.35	8.53
2,4-D, 48 p.p.m.:															
16 gals.....	46.67	3.10	0.75	1.70	1.66	1.35	1.23	0.80	0.90	1.03	9.19	12.52	73.0	13.46	11.67
		(+0.52)¶	(+0.11)	(+0.20)	(+0.63)	(+0.71)	(+0.50)	(+0.63)	(−0.43)	(+0.44)		(+3.31)		(+2.91)	(+3.14)

* Trees sprayed July 23, 1948. Fruit harvested August 10, 1949. Average fruit diameter at time of spraying, 2.084 cm.

† Least significant difference at 5 per cent, 2.36; at 1 per cent, 3.49.

‡ Least significant difference at 5 per cent, 2.28; at 1 per cent, 3.38.

§ 50 per cent or more of rind green colored on January 10, 1949.

‖ 50 per cent or more of rind yellow colored on January 10, 1949.

¶ Numbers in parentheses are differences between growth of fruits on nonsprayed trees and on trees sprayed with 2,4-D.

of materials into the fruits and permit a greater growth rate than that of fruits on nonsprayed trees. A similar effect of 2,4-D sprays in increasing the ratio of fruit-stem diameter to fruit was observed on Washington Navel orange trees (Stewart, Klotz, and Hield, 1951). In lemons, it was found that 2,4,5-T was more effective in this regard than was 2,4-D (Erickson, unpublished). Also, 2,4,5-T has been observed to increase lemon fruit size and reduce mature fruit-drop more than does 2,4-D (Stewart and Hield, 1950*b*). In a similar comparison with grapefruit, however, there was no appreciable difference between the effectiveness of 2,4-D and that of 2,4,5-T (compared at 8 p.p.m.) in reducing mature fruit-drop or increasing fruit

TABLE 21

EFFECT OF 2,4-D ON FRUIT SIZE DISTRIBUTION OF VALENCIA ORANGES*

Experiment	Spray	Number of fruits measured	Diameter distribution					Average diameter of all fruits
			0.00 cm to 4.60 cm	4.60 cm to 5.11 cm	5.11 cm to 5.59 cm	5.59 cm to 6.10 cm	6.10 cm and larger	
			per cent	*per cent*	*per cent*	*per cent*	*per cent*	*cm*
Fullerton	None (control)	866	8.4	25.3	44.8	19.5	2.0	5.24
	24 p.p.m. 2,4-D	877	6.6	21.0	35.2	29.0	8.0	5.31
Tustin	None (control)	1,715	24.3	32.6	32.8	9.2	1.0	4.99
	24 p.p.m. 2,4-D	1,713	13.9	29.2	36.7	16.9	3.4	5.16
Santa Ana	None (control)	1,898	13.4	20.3	39.7	23.3	3.2	5.18
	16 p.p.m. 2,4-D	1,748	9.4	18.2	32.7	27.7	12.0	5.36
Olive	None (control)	629	24.8	22.2	33.1	17.6	2.2	5.05
	16 p.p.m. 2,4-D	573	17.3	26.5	35.4	17.3	3.5	5.09
Redlands	None (control)	576	20.5	30.4	29.7	14.8	4.7	4.87
	48 p.p.m. 2,4-D	596	17.6	19.0	26.5	21.6	11.9	5.21

* Trees sprayed during period June 1 to 15, 1948. Fruits measured February 4 to 11, 1949.

size. Likewise, 2,4,5-T was no more effective than 2,4-D in reducing mature fruit-drop of Washington Navel oranges.

A more conclusive evaluation of the effectiveness of 2,4,5-T in increasing fruit size of Valencia oranges must await results from experiments now in progress.

Indications of a direct effect of 2,4-D in stimulating growth of fruit tissues were noted in the development of rudimentary seeds in the fruits; rudimentary navels in Valencia oranges and grapefruit and enlarged navels in Washington Navel oranges; and enlarged oil glands in the rind (Stewart and Klotz, 1947). Excessive amounts of 2,4-D applied on young apple fruits also were observed to induce subsequent growth modifications (Bryant, Vincent, and Schafer, 1947).

The effect of 2,4-D sprays in reducing the number of fruits per tree was noted particularly when such sprays were applied at full bloom. Application of 20 p.p.m. 2,4-D or 2,4,5-T at that time resulted in approximately 42 per cent reduction in the number of fruits per tree. Field box production, however, was not correspondingly reduced since fewer of the large fruits were required to fill a box.

Parker (1934) found significant increases in fruit size as a result of hand-thinning the young fruits. Heavy thinning (approximately 45 per cent of

the crop on the tree) induced the greatest size response. A considerable reduction was observed in field box production. In experiments reported here in which 2,4-D was applied on a commercial scale, no reduction in field box yield was observed. In the chemical-thinning experiment, it appeared that although drastic thinning occurred as a result of certain chemical sprays, this was not always accompanied by a fruit size increase.

Crop estimates made in June were observed by Parker (1934) to be sufficiently reliable to allow a grower to decide the probable fruit size of the coming crop and to apply a 2,4-D spray to increase fruit size if desired. He concluded that, mainly because of the excessive cost, hand-thinning of oranges would probably not become a general practice.

TABLE 22
SUGGESTED CONCENTRATIONS OF 2,4-D TO APPLY AT DIFFERENT STAGES OF FRUIT DEVELOPMENT FOR INCREASING SIZE OF VALENCIA ORANGES

Approximate fruit diameter	Approximate fruit age	Concentration of 2,4-D*
inches	*weeks*	*p.p.m.*
3/16	4 to 6	16
3/8	6 to 10	24
1/2	10 to 12	32
5/8	12 to 14	40

* Spray at one stage of development only.

From the packing-house data for the experiments reported here, it was not possible to determine the amount of thinning that resulted when trees were sprayed with 2,4-D six to ten weeks after bloom. Yield, as field boxes per tree, was increased, however, not reduced.

From the yield data, it appears that if there was a reduction in the number of fruits, it may have been of slight magnitude since, in terms of field boxes, there was actually an increase in yield. There was no indication that application of 2,4-D in June influenced the size of fruits harvested the same season. Applications of 2,4-D in oil for pest control during the customary late summer and early fall oil-spray season generally had no effect in increasing the size of the crop harvested the following year (Stewart, Riehl, and Erickson, unpublished). In studies on Washington Navel oranges, it was found that 2,4-D sprays applied as much as six weeks prior to flowering were effective in increasing the fruit size of that year's crop, but also resulted in considerable thinning and an excessive lowering of fruit quality (Stewart, Klotz, and Hield, 1951).

As a working hypothesis, it is suggested that the time of maximum fruit-size response to 2,4-D is approximately at flowering. The fruit-size response diminishes as the fruits grow older until, about 16 weeks after flowering, there is no appreciable size response even to relatively high (100 p.p.m.) concentrations of 2,4-D. The shape of the size-response curve has not been determined. Since fruit size is correlated with numerous other responses, such as fruit-stem diameter, fruit thinning, quality, and the like, it would

be interesting to obtain similar curves for each of these responses. From such data it might be possible to determine the most effective time of 2,4-D application to obtain a maximum fruit-size increase with a minimum of thinning and lowering of quality.

The schedule of 2,4-D application, shown in Table 22 and based on the data presented in this paper, was suggested for the commercial use of 2,4-D during the 1950 season to increase fruit size (Stewart and Hield, 1950*a*).

Recent investigations have shown that increasing the potassium content of citrus trees may increase the size of orange fruits (Chapman, Brown, and Rayner, 1947; Parker and Jones, 1950). It has been noted that the pulp of Valencia orange fruits contained increased potassium as a result of an 8 p.p.m. 2,4-D spray applied the preceding fall (Haas, 1949). It is possible that this may be related to the mode of action of 2,4-D in increasing citrus fruit size. Others have found that, under various conditions, certain plant-growth regulators may alter the mineral nutrition of plants (Swartz, 1941; Hamner, 1941; Struckmeyer, 1949).

SUMMARY AND CONCLUSIONS

During 1947 and 1948, 29 comparisons were made, in southern California, between fruit-drop from nonsprayed Valencia orange trees and that from trees sprayed with 2,4-D. The concentrations varied from 4 p.p.m. to 48 p.p.m. The average reduction in drop was 35.1 per cent. No large differences in reduction of drop were noted among the various forms of 2,4-D applied. Application of 2,4-D at low volumes was successfully made six months prior to drop as well as after the drop had begun. Usually the 2,4-D in combination with other spray chemicals was applied as a complete coverage spray. In no case was 2,4-D found to be incompatible with other spray chemicals.

Studies were made of the possibility of increasing Valencia orange fruit size by the use of 2,4-D. A survey experiment initiated in 1948 indicated that, of 17 different chemicals applied to trees at full bloom, only 2,4-D and 2,4,5-T induced a significant increase in fruit size. To determine the effects of 2,4-D when applied in a commercial manner to increase fruit size, in eight additional experiments, packing-house data were obtained of the fruit size and grade. It was found that, on the average, 33.9 per cent of the fruits on the nonsprayed trees was size 220 and larger, whereas 46.2 per cent was in this category on trees sprayed with 2,4-D. Also, per 100 trees, there was a gain of 28.0 packed boxes of fruit size 220 and larger, and a decrease of 19.8 boxes of fruit size 252 and smaller. There was a slight increase (1.0 per cent) in the number of loose fruits (juice, culls, and rots). The 2,4-D induced only slight differences in quality.

Fruits on young trees seemed to respond with more of a size increase than did fruits on old trees.

Periodic measurements showed that the fruit-size increase resulting from the use of 2,4-D was due to an increased growth rate. Fruits on the 2,4-D-sprayed trees apparently were physiologically younger than those on the nonsprayed trees. This was demonstrated during the period when the fruits were changing color, since there were more green fruits on the treated than on the nontreated trees. Observed growth responses resulting from 2,4-D,

which may contribute to this condition, are: (1) a thicker fruit stem (pedicel) in proportion to the fruit diameter; (2) a direct stimulation of growth of certain fruit tissues; and (3) a reduction in the number of fruits per tree (a thinning effect).

After flowering, and as the fruits grew older, they seemed to become less responsive to 2,4-D until, approximately 16 weeks after flowering, there was no appreciable size response even to relatively high concentrations of 2,4-D. In commercial practice it is suggested that, during the 16-week period, this diminishing response be compensated for by corresponding increases in the concentration of 2,4-D applied.

ACKNOWLEDGMENTS

The authors acknowledge with appreciation the splendid coöperation of the orange grove owners who allowed their trees to be used in this study, and thank the various pest control operators for their help in these experiments. They express thanks to the farm advisors in whose counties the experiments were located, for their participation in the program.

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