RESEARCH BULLETIN 491 MARCH, 1952

UNIVERSITY OF MISSOURI COLLEGE OF AGRICULTURE
AGRICULTURAL EXPERIMENT STATION
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Weed Control in Horticultural Crops

I. Chemical Weed Control in Strawberries

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Publication authorized February 7, 1952

COLUMBIA, MISSOURI

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INTRODUCTION

Weed control has been one of the first problems to be dealt with since man began to cultivate crops. Until the latter part of the nineteenth century farmers had no methods to control weeds except by mechanical and manual destruction or suppression. Such methods are expensive and time consuming. In periods of labor shortage it is sometimes impossible to control weeds manually. Many times it is unprofitable to reduce the weed population by mechanical means because of the narrow margin of net profit.

The discovery of the so-called "selective" chemical herbicides in the late 1930s marked the beginning of a new era of weed control in cultivated crops. This is a particularly important development because weed control in most horticultural crops requires large amounts of hand labor.

Strawberries, in particular, require large amounts of hand labor from the time plants are set until the first crop of fruit is harvested. In some cases strawberries are fruited only one year because weeds overrun the fields (18).* In other instances the weeds interfere to such an extent that the second crop is low in both yield and quality; consequently, the returns do not pay production costs.

A means of controlling weeds adequately, economically, and without serious injury to the strawberry plants or fruits would encourage many farmers to grow additional acreages with increased profits. Also there are those now growing strawberries who would be able to produce higher quality fruits, with less labor, and maintain the fruitfulness of a planting for more years.

Many chemicals are now being produced for the control of weeds in both horticultural and field crops. Their killing action and effectiveness vary greatly under field conditions. Because of these differences the methods and times of application must be varied. A chemical may be effective only if applied to foliage, killing by contact alone. Such chemicals are suitable only for application when the crop is growing. Other chemicals may possess residual properties, and are effective for a longer period of time. They not only kill weeds at time of spraying but also kill those which germinate at a later time. Chemicals with these properties can be applied before the crop

*See list of references, page 32.

is planted and still be effective for a considerable time after germination. They may also be applied to a growing crop which is tolerant to their action.

The effect of most herbicides on weeds as well as strawberry plants cannot be predicted except by field trials. In order to determine a practical, economical, and effective means of controlling weeds with a minimum of hand labor several chemicals with herbicidal properties were applied to strawberry plantings at various times throughout the year.

Fig. 1.—Untreated plots showed an abundance of common milkweed, nodding spurge, clammy ground cherry, bull nettle, grasses, etc.

Fig. 2.—Sodium 2,4-dichlorophenyl "Cellosolve" sulphate used at the rate of two pounds per acre on June 21 and August 16 did not effectively control broad-leaved weeds during summer months.

REVIEW OF LITERATURE

History of Selective Herbicides

The use of chemicals that show selective herbicidal properties dates back to the last half of the nineteenth century. During the first part of the twentieth century in France, Germany, and America, copper salts were being used to control broad-leaved plants in cereal crops. During this period iron sulfate was also found to possess selective herbicidal properties when used on broad-leaved weeds in cereals. Sulphuric acid, sodium nitrate, ammonium sulfate, and potassium salts were also found to be more effective on broad-leaved

plants than narrow-leaved plants. The use of these chemicals for weed control continued for some years. Later it was found that Kainite (salt of magnesium sulfate and potassium chloride) would also act as a selective herbicide and in addition furnish fertilizer for the crop on which it was used (33).

Dinitro compounds, such as dinitro-ortho-cresylate (Sinox) were developed in France in 1933. This group of materials showed broad selective properties. Organic compounds, like the dinitros, slowly decompose in the soil and leave no toxic residues. These materials are comparatively slow in killing plants; however this does not alter the effectiveness of the compounds because the materials are readily absorbed by plants. Sinox has been used on a wide variety of crops such as: flax, onions, peas, corn, alfalfa, various grasses, and garden crops (32).

During the late nineteen-thirties a group of plant growth-regulating substances was found to have herbicidal value. These substances were developed for herbicidal use in 1940. This development marked the beginning of a new era in weed control. 2,4-dichlorophenoxyacetic acid (2, 4-D) is one of the most promising of this group of chemicals. This material applied under certain conditions shows a wide selectivity in controlling broad-leaved plants.

Fig. 3.—Two summer applications of dichloral urea at the rate of six pounds per acre were ineffective in weed control.

Fig. 4.—Endothal at the rate of two pounds per acre eliminated practically all runner growth.

The Nature of Selectivity and Mode of Action

No simple explanation can be given for the fact that certain plants are killed by selective herbicides while others are not seriously damaged. The growing points of broad-leaved plants are usually terminal and exposed while those of grasses, usually located near the base of the plant, are protected by older leaves (14). The early herbicides killed by caustic action and/or cell plasmolysis as well as by denaturing plant proteins (33). The successful use of the early herbicides was dependent upon the different types of growth between broad-leaved and narrow-leaved plants.

The dinitro compounds, although highly toxic, are not readily translocated and depend upon their contact and burning effect to give herbicidal action. The selectivity of these chemicals is due largely to the differences in the wetting of foliages of different plants (34). Robbins *et al.* (32) state that the sodium salt forms of the dinitro compounds are soluble in the cuticle layer of weeds and thus are able to penetrate into the protoplasm rapidly. This group of materials shows greatest selectivity between broad-leaved plants and grasses. These compounds also display different degrees of toxicity on different broad-leaved plants; that is, annual broad-leaved plants are more easily killed than perennials. Some difference of selective toxicity is also shown on grasses. Some of this variation may be the result of translocation after the material enters the plant (13).

2,4-D and similar compounds (plant growth regulators) do not depend upon the structural differences of the plant to give selective herbicidal action, but depend more upon the physiological nature of the plant. 2,4-D and similar plant growth-regulators enter the plant cells by being absorbed by the cuticle of the plants. After the material enters the plant cell it moves or is translocated in the same way as naturally occurring plant hormones (17). Ryker (34) states that 2,4-D readily penetrates the leaves and moves throughout the entire plant with injury or death resulting. Crafts (13) states that the plant growth-regulating chemicals depend upon the difference of the reactivity of the plant protoplasm to give herbicidal selectivity. 2,4-D affects such processes as photosynthesis and respiration; also, metabolic substances may accumulate which act as poisons.

Seed as well as growing plants may be injured or killed by the growth-regulating compounds such as 2,4-D. Experiments conducted by Crafts (14) indicate that 2,4-D will persist in the soil for a considerable time when the rainfall is limited. He further found applications to the foliage to be more desirable than applications to the soil.

The Use of 2,4-D on Strawberry Plants

Studies by Carlson (5) in 1945 and 1946 indicated that 2,4-D could be used on strawberries at rates up to 1,000 parts per million without serious injurious effects. Bindweed, wild carrots, and yellow dock were controlled with this concentration of 2,4-D. Thirteen varieties were treated in these experiments. The everbearing varieties sprayed during time of blossoming produced deformed fruits.

Fig. 5.—Two summer applications of 2,4-D at rate of one pound per acre gave very effective control of weeds.

Fig. 6.—Maleic hydrazide at rate of eight pounds per acre did not effectively control weeds, yet reduced runner plant production.

In 1947 Neville *et al.* (29) applied both sodium and iso-propyl ester forms of 2,4-D as foliage applications to Catskill, Fairfax, and Premier varieties of strawberries. 2,4-D used at two pounds per acre caused considerable deformative effects on the foliage of the plants, with the ester forms causing considerable more modification and injury than did the sodium salt formulation. In one month's time the plants treated with both forms of 2,4-D returned to a normal condition. In the same year Carlson (6) reported that most weeds in strawberries could be controlled by the use of 2,4-D without serious injury to the plants.

In 1948 Alban (1) reported the use of alkyl ester and sodium salt forms of 2,4-D on strawberry plants. These materials when used at one and two pounds acid equivalent per acre respectively did not give adequate control of weeds when applied as a pre-planting treatment. Carder (4) stated that one pound per acre acid equivalent of the butyl ester form of 2,4-D reduced dandelions (Taraxacum palustre) seventy per cent without injury to strawberry plants, while two pounds per acre acid equivalent of the butyl ester form of 2,4-D caused severe injury to the strawberry plants.

Nylund (30) reported that two pounds acid equivalent 2,4-D in sodium salt form and one pound acid equivalent in the iso-propyl ester form gave

good control of weeds when applied as a foliage spray. No damage was noticed from the use of the sodium salt; however the iso-propyl ester caused severe deformation of the plants.

Gilbert (24) reported good control of grass and weeds by the use of two pounds 2,4-D per acre while Danielson (19) failed to control grasses, although good control of broad-leaved weeds was obtained.

In 1949 Nylund (31) reported that 2,4-D could be used in the strawberry field in the early summer if the fruits had set to control broad-leaved weeds without injury to the strawberry plants. Yields were not adversely affected by this treatment. In 1949 Davidson (22) reported that strawberries could tolerate moderate quantities of 2,4-D but applications should not be made during bloom periods or immediately after setting the plants. Experiments by Jones (26) indicate that one cultivation of strawberries may be eliminated by applying 2,4-D immediately after setting plants and again when weeds begin to germinate. Crab grass as well as broad-leaved weeds was controlled best by timing applications to contact the seeds immediately after germination (16).

Danielson (20) in 1949 reported that 2,4-D could be used as foliage application to control over-wintering weeds. One application applied in late fall was sufficient to control such pests.

Differences in resistance of strawberries to 2,4-D have been reported by a number of workers (7, 29, 35, 36, 37). Robinson, Sparkle, Temple, Premier, Blakemore, and Fairfax have been reported to be tolerant to 2,4-D.

Fig. 7.—Plants treated with maleic hydrazide eight pounds per acre, were stunted, chloratic and the internode length between runners was reduced.

Conditions Under Which the Use of 2,4-D May Be Undesirable

At certain stages in the growth of the strawberry plant the tolerance to 2,4-D is low and applications at these stages should be avoided. Under adverse climatic and soil conditions the application of 2,4-D also should be avoided.

Davidson (21) reported slight formative effects of foliage when 2,4-D was applied in spring as new growth of the strawberry plants was beginning to appear. Davidson (22) reported plants to be more resistant to 2,4-D when they have been growing one month or more and discouraged treatment soon after setting. Carlson (11) reported the use of activated charcoal to protect plants from pre-planting applications of 2,4-D.

Carlson (6) found that strawberry plants sprayed with 2,4-D in the early spring would bear misshapen fruits, and cautioned against the use of 2,4-D until after harvest. Curtis (18) also observed the injury of fruits and slight reduction of yields when 2,4-D was applied early in the spring immediately after mulch was removed. Hard, seedy, and sometimes misshapen fruit was reported by Danielson (19) following the application of 2,4-D during the time of flowering and fruiting.

Gilbert and Wolf (25) found the application of 2,4-D during fruit bud differentiation to cause injury of fruit the following spring. This injury was reported to vary from a slight fasciation of some fruits to a complete encircling

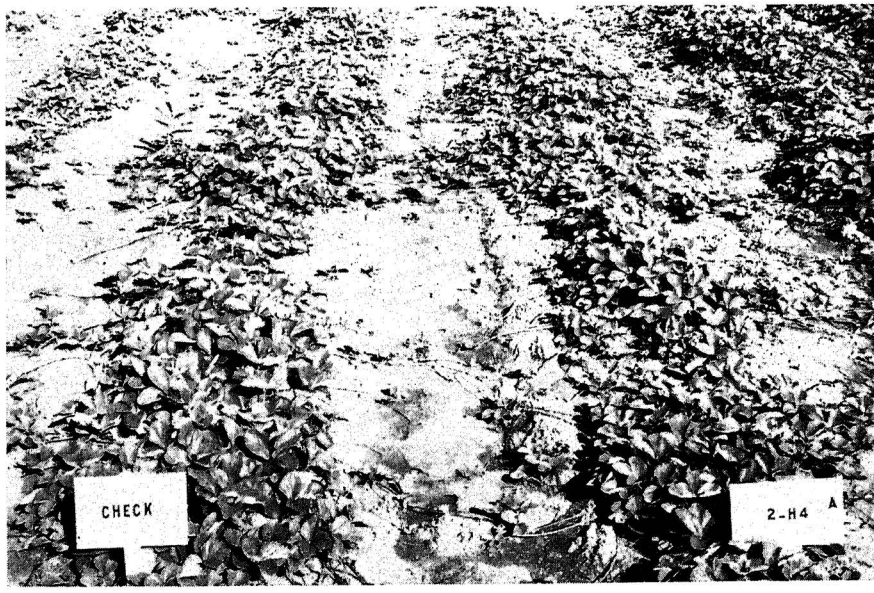

Fig. 8.—Plant stands in plots treated with 2,4-D were comparable to those of untreated plots.

injury on others. Also clusters of fruits were grown together. They also found that 2,4-D when applied during an extended drought period, caused injury to strawberry plants. Dry weather, as well as very sandy soils, was found by Carlson (8) to accentuate the effectiveness of 2,4-D on weeds and also to cause more injury to strawberry plants.

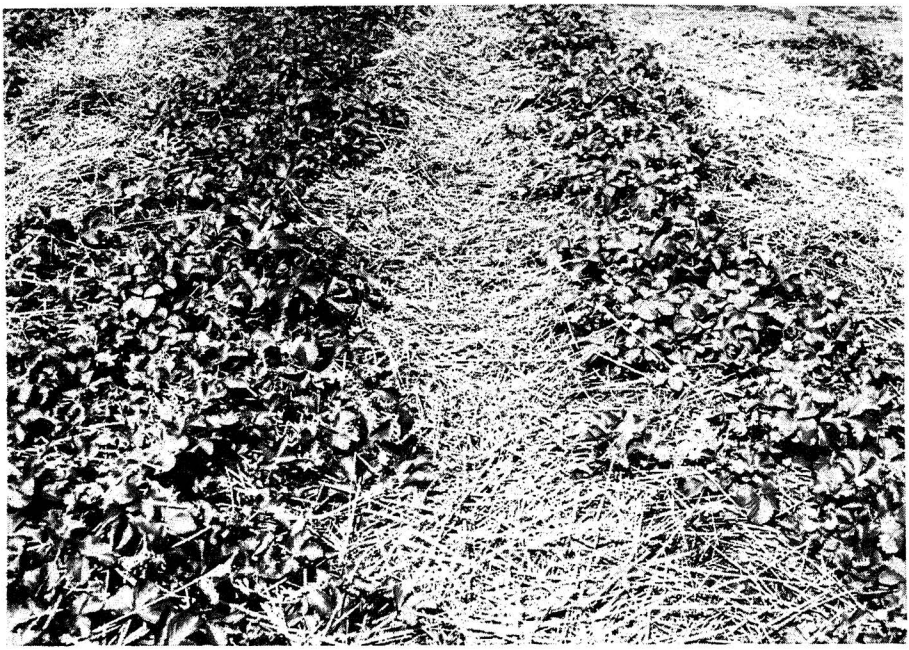

Fig. 9.—Plants treated on May 3, 1951 with maleic hydrazide during 1950 had more than five times as many open flowers as those in untreated plots.

Other Chemicals of Possible Herbicidal Value in Strawberries

Sodium, 2,4-Dichlorophenyl "Cellosolve" Sulfate*—This chemical causes little or no epinastic or formative effects when used on the foliage of plants (3). It was developed as a seed toxicant to be used on large seeded crops immediately after seeding. This material has been suggested for use as a soil treatment for the control of germinating weed seed of both grasses and broad-leaved plants. Experiments conducted by Gilbert and Wolf (25) show that rates of three and six pounds per acre of the above material applied to the foliage of eleven varieties of strawberry plants caused no injurious effects and weeds were controlled for six weeks.

Dichloral Urea—This material is a toxicant for germinating weed seeds and young seedlings, and is particularly effective on grass seeds. If applied

*This compound is now known as sodium 2,4-dichlorophenoxyethyl sulfate. It is also known by the trade names EH1, SES, and Crag Herbicide 1.

to the foliage of plants it affects the growing points, arresting shoot elongation and prevents normal leaf development (2). King (27) states that Dichloral urea will effectively control grasses such as crabgrass, rye, and brome grass; while rye grass, beets, and turnips are quite resistant.

3,6-Endoxohexahydrophthalic Acids and Salts—The acid and salt forms of this material have shown unusual plant response properties. It will cause

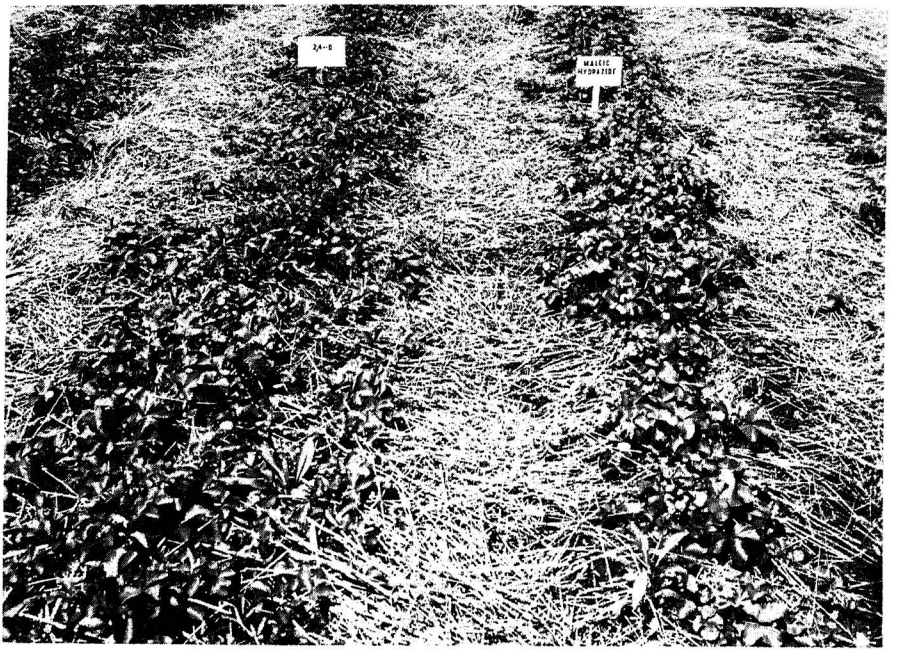

Fig. 10.—Plants in plots treated with maleic hydrazide in 1950 bloomed earlier than those in plots treated with 2,4-D. 2,4-D plots were comparable to untreated plots.

defoliation of cotton, lima and string beans, holly, hydrangeas, apple, and peach. The salts of this acid are effective as herbicides of certain species of grassy weeds. The material is reported to be readily translocated within treated plants, and also absorbed by the roots of plants.

Maleic Hydrazide—This has been found to have unusual plant growth inhibiting properties. Experiments conducted by Crafts *et al.* (15) showed that such plants as lettuce, tomatoes, lima beans, sweet corn, flax and grasses were affected by application of this material. These effects ranged from stunted growth of some plants to death of flower parts and even entire plants of others.

Isopropyl-N-phenyl Carbamate (I.P.C.)—This material has shown certain desirable selective herbicidal properties. Carlson (9), and Carlson and Moulton (12) have reported that chickweed can be controlled satisfactorily

by the use of 15 pounds of this material per acre. Rates as high as 25 pounds per acre result in injury to the plants.

PROCEDURE AND MATERIALS

In the early spring of 1950 four chemicals, Sodium 2,4-dichlorophenyl "cellosolve" sulfate, Dichloral urea, 2,4-dichlorophenoxyacetic acid (2,4-D), and Maleic hydrazide were tested on potted plants in the greenhouse.

After completion of the greenhouse tests experimental plots were established at the Midway Horticultural Experimental Farm near Columbia, Missouri. These tests included the aforementioned chemicals along with Endothal (3-6-Disodium endoxohexa-hydrophthalate). These chemicals were applied both as pre-planting and foliage applications. All chemicals were used separately and 2,4-D was used in combination with the other four materials. 2,4-D was also applied to strawberry plants during October to observe the effect of this material when applied during the period of fruit bud differentiation. An application of 2,4-D was also made in early spring as the mulch was removed from the plants.

In addition to these test plots a commercial strawberry field at Exeter, Missouri, was used for further testing of certain chemicals. These chemicals were applied with field equipment, and under such conditions it was possible to evaluate them on a commercial basis.

Greenhouse Tests

Table 1 shows the rates of application for the chemicals used in the greenhouse studies.

Midway Tests: Spring and Summer

The Midway plots were established on soil that previously had been in bluegrass for many years. Plots consisting of 25 feet of row were used for each treatment. Three randomized replications of each treatment were used.

Pre-planting applications of herbicides were made April 10 and eight Blakemore strawberry plants were set in each 25-foot plot a few hours after treatment. Summer foliage applications were made June 21 and August 16.

The rates and dates of application are summarized in Table 2.

Treatments on a Fruiting Strawberry Bed—Just after the mulch had been removed from the strawberry plants and before new growth had begun (April 14), 2,4-D was applied to the strawberry plants to observe the effect on foliage and fruit. No chemicals had been used on these plants the previous year. This rate of application was 1½ pounds of 2,4-D in 40 gallons of water per acre.

Midway Tests: Fall

In addition to the chemicals used in the Spring and Summer, 2,4-D was applied to strawberry plants in the fall during time of fruit bud initiation. The rate of application was 1½ pounds per acre, applied on October 4 and 23.

Table 1--Chemicals Tested for Herbicidal Use in Strawberries (Greenhouse--Spring, 1950)*

Chemicals	Rate Pounds Per Acre
Dichloral urea	2
Dichloral urea	4
Dichloral urea	8
Maleic hydrazide	2
Maleic hydrazide	3
Maleic hydrazide	4
Sodium 2, 4-dichlorophenyl "Cellosolve" sulfate	2
Sodium 2, 4-dichlorophenyl "Cellosolve" sulfate	4
Sodium 2, 4-dichlorophenyl "Cellosolve" sulfate	8
2, 4-D (Amine salt)	2
2, 4-D (Amine salt)	3
2, 4-D (Amine salt)	4

*Chemicals applied before plants were set.

Exeter Experiments

Spring and Summer Applications—Experimental plots were established in a 20-acre apple orchard which was being intêr-cropped with strawberries. The soil previously had been in cultivation and had an abundance of weed seed. Each plot was approximately half an acre in area. 2,4-D was used as a pre-planting application at the rates of two, three, and four pounds per acre with three plots being treated at each rate. A series of three summer rates of 1, 1¼ and 1½ pounds per acre was applied to plots which had received the 2, 3, and 4-pound rates. Arrangements of plots and applications are shown in Table 3.

The equipment used to apply the chemical in this test was a boom-type sprayer powered by tractor power take-off. The sprayer was calibrated to deliver 15 gallons of liquid per acre. Shields were constructed on the boom of the sprayer to prevent drift of spray.

Fall Applications — In the fall, additional chemicals were applied on the strawberry planting at Exeter. 2,4-D, Sodium, 2,4-dichlorophenyl "cello-solve" sulfate, and Isopropyl N-phenylcarbamate were applied to test their

Table 2--Weed Control Treatments* (Midway Plots, 1950)

Chemicals and Combinations	Pre-Planting Application April 10		First Foliage Application June 21		Second Foliage Application August 16	
	Pounds Per Acre					
Herbicide I (Sodium 2, 4-dichlorophenyl "Cellosolve" Sulfate)**	2		1		1	
	3		1 1/2		1 1/2	
	4		2		2	
	(Herb. I & Herb. IV)		(Herb. I & Herb. IV)		(Herb. I & Herb. IV)	
Combination I and IV (2, 4-D)	2	2	1	1	1	1
	3	2	1 1/2	1	1 1/2	1
Herbicide II (Dichloral Urea)**	4		2		2	
	8		4		4	
	12		6		6	
	(Herb. II & Herb. IV)		(Herb. II & Herb. IV)		(Herb. II & Herb. IV)	
Combination II and IV	4	2	2	1	2	1
	8	2	4	1	4	1
Herbicide III (Endothal)†	1		1/2		1/2	
	3		1		1	
	5		2		2	
	(Herb. III & Herb. IV)		(Herb. III & Herb. IV)		(Herb. III & Herb. IV)	
Combination III and IV	1	2	1/2	1	1/2	1
	3	2	1	1	1	1
Herbicide IV (2, 4-D) ‡	2		1		1	
Herbicide V (Maleic Hydrazide)††	4		4		4	
	8		6		6	
	12		8		8	
	(Herb. V & Herb. IV)		(Herb. V & Herb. IV)		(Herb. V & Herb. IV)	
Combination V and IV	4	2	4	1	4	1
	8	2	6	1	6	1
Check Plots						

*All applications replicated three times.

**Manufactured by the Carbide and Carbon Chemical Corporation.

†Disodium 3, 6-endoxohexahydropthalate, Manufactured by Sharples Chemicals Inc.

‡The amine salt form of 2, 4-dichlorophenoxy-acetic acid. (Dow-Formula 40)

††Manufactured by the Nagatuck Chemical Division of the United States Rubber Co.

Table 3--Planting Plan of Field Plots, Exeter, Missouri, 1950--Herbicidal Treatments With 2, 4-D (Amine Salt).

Plot	Time of Application	Amount Applied (lbs. per Acre)	North →
1	Pre-planting	3	
	Summer	1	
2	Pre-planting	3	
	Summer	1 1/4	
3	Pre-planting	3	
	Summer	1 1/2	
4	No treatment		
5	Pre-planting	4	
	Summer	1	
6	Pre-planting	4	
	Summer	1 1/4	
7	Pre-planting	4	
	Summer	1 1/2	
8	Pre-planting	2	
	Summer	1	
9	Pre-planting	2	
	Summer	1 1/4	
10	Pre-planting	2	
	Summer	1 1/2	

Each block represents eight rows of strawberries 640 feet long.

herbicidal value on over-wintering weeds. Rates of application are shown in Table 4. The same equipment was used in this test as was used for the spring and summer applications.

RESULTS

Greenhouse Studies

Results of preliminary greenhouse trials are shown in Table 5. 2,4-D as a pre-planting application gave better control of broad-leaved weeds and grass than other chemicals, but it caused considerable injury to the strawberry plants. Maleic hydrazide gave partial control of broad-leaved weeds and

Table 4--Treatments for Control of Over-Wintering Weeds
(Exeter, Fall, 1950)

Chemicals	Pounds Per Acre
2, 4-D Amine Salt.	1 1/2
2, 4-D Amine Salt.	2
Sodium 2, 4-dichlorophenyl "Cellosolve" sulfate	3
Sodium 2, 4-dichlorophenyl "Cellosolve" sulfate	6
Isopropyl-N-phenyl carbamate	15
Control--no treatment	

grass, but the strawberry plants turned yellow and rate of growth was reduced. Dichloral urea gave no control of grass and only limited control of broad-leaved weeds. Slight burning of the strawberry plants resulted. Sodium 2,4-dichlorophenyl "cellosolve" sulfate gave some control of both types of weeds, but control of broad-leaved weeds was better than that of grass. No detectable injury to the strawberry plants resulted.

Weed Control Studies At Midway

Pre-planting Applications—The control of weeds by pre-planting applications of different herbicides is shown in Table 6. As indicated in this table the 2 and 3 pound rates of Sodium 2,4-dichlorophenyl "cellosolve" sulfate gave little control of grass and moderate control of broad-leaved weeds. At the 4-pound rate, excellent control of grass resulted; however, the control of broad-leaved weeds was not increased. No injury to plants occurred from the use of this material.

Dichloral urea gave similar results except that control was somewhat lower than given by Sodium 2,4-dichlorophenyl "cellosolve" sulfate. Endothal at 1 and 3 pound rates was not satisfactory for broad-leaved weed or grass control, while the 5 pound rate gave good control of both broad-leaved weeds and grass, with severe injury to the strawberry plants. Neither Maleic hydrazide nor 2,4-D gave satisfactory control of broad-leaved weeds or grass. When 2,4-D was used in combination with Dichloral urea the effectiveness of both chemicals was improved. 2,4-D, when used with other chemicals, did not increase their effectiveness.

Summer Foliage Applications—Weed control obtained by the first foliage applications is shown in Table 7. One pound per acre of 2,4-D gave the best control of grass of any treatment as well as good control of broad-leaved weeds. Dichloral urea showed some promise as a foliage spray. The other materials used did not give satisfactory control. When 2,4-D was used in combination

with Dichloral urea good control of both broad-leaved weeds and grass was obtained. Combinations of other chemicals with 2,4-D were no more effective than 2,4-D alone.

Table 5--Control of Weeds and Injury to Strawberry Plants by Pre-Planting Application of Herbicides. (Pot Experiments in Greenhouse, Spring, 1950--Counts Made Four Weeks After Applications)

Chemicals Used	Rate (Pounds Per Acre)	Per Cent Control Weeds * Broad-leaved	Grass	Injury to Plant
Dichloral Urea	2	28%	0%	Slight Burning
Dichloral Urea	4	59%	0%	Slight Burning
Dichloral Urea	8	39%	0%	Slight Burning
Maleic Hydrazide	2	31%	49%	Slowed Growth
Maleic Hydrazide	3	11%	71%	Slowed Growth
Maleic Hydrazide	4	42%	79%	Slowed Growth
Sodium 2, 4-dichloro-phenyl "Cellosolve" Sulfate	2	58%	35%	None
Sodium 2, 4-dichloro-phenyl "Cellosolve" Sulfate	4	78%	54%	None
Sodium 2, 4-dichloro-phenyl "Cellosolve" Sulfate	8	87%	56%	None
2, 4-D (Amine Salt)	2	82%	93%	Severe Distortion
2, 4-D (Amine Salt)	3	69%	85%	Severe Distortion
2, 4-D (Amine Salt)	4	45%	93%	Severe Distortion

*Calculated from counts in untreated plots.

Weed control obtained by the use of the same chemicals in the second summer spray is recorded in Table 8. Sodium 2,4-dichlorophenyl "cellosolve" sulfate, Dichloral urea, and Endothal appear to control grasses more effectively than broad-leaved weeds. 2,4-D gave good control of both broad-

Table 6--Effectiveness of Pre-Planting Applications of Herbicides (Midway Experimental Plots, 1950, Treated April 10, Counts Made May 10)

Chemicals and Combinations	Rate (Pounds Per Acre)		Per Cent Control Weeds* Broad-leaved	Grass
Herbicide I (Sodium 2, 4-dichlorophenyl "Cellosolve" sulfate)	2		18	26
	3		57	34
	4		55	90
Combination I and IV (2, 4-D)	Herb. I and Herb. IV			
	2	2	44	26
	3	2	53	38
Herbicide II (Dichloral Urea)	4		0	0
	8		0	39
	12		25	79
Combination II and IV	Herb. II and Herb. IV			
	4	2	42	39
	8	2	53	77
Herbicide III (Endothal)	1		2	20
	3		34	46
	5		71	68
Combination III and IV	Herb. III and Herb. IV			
	1	2	41	0
	3	2	79	54
Herbicide IV (2, 4-D--Amine Salt)	2		37	15
Herbicide V (Maleic Hydrazide)	4		0	0
	8		0	66
	12		0	50
Combination V and IV	Herb. V and Herb. IV			
	4	2	13	57
	8	2	22	75

*Calculated from counts in untreated plots.

leaved weeds and grass. Maleic hydrazide gave no control at the four and six pound rates; however at the eight pound rate it exhibited some herbicidal value. When 2,4-D was used with Sodium 2,4-dichlorophenyl "cellosolve" sulfate, Dichloral urea, and Endothal the effectiveness of these chemicals was

Table 7--Effectiveness of First (June 21) Foliage Application of Herbicides
(Midway Experimental Plots, 1950, Counts Made August 14)

Chemicals and Combinations	Rate (Pounds Per Acre)		Per Cent Weed Reduction* Broad-leaved	Grass
Herbicide I (Sodium 2, 4-dichlorophenyl "Cellosolve" sulfate)	1		67	15
	1 1/2		73	36
	2		67	29
Combination I and IV (2, 4-D)	Herb. I and Herb. IV			
	1	1	70	28
	1 1/2	1	79	28
Herbicide II (Dichloral Urea)	2		12	0
	4		58	0
	6		64	57
Combination II and IV	Herb. II and Herb. IV			
	2	1	79	29
	4	1	79	72
Herbicide III (Endothal)	1/2		61	0
	1		58	29
	2		58	43
Combination III and IV	Herb. III and Herb. IV			
	1/2	1	70	7
	1	1	82	57
Herbicide IV (2, 4-D--Amine Salt)	1		70	79
Herbicide V (Maleic Hydrazide)	4		24	0
	6		34	0
	8		34	0
Combination V and IV	Herb. V and Herb. IV			
	4	1	67	29
	6	1	79	50

*Calculated from counts in untreated plots.

improved. Increasing the rates of application improved the effectiveness of all materials.

On August 16 all plots were hoed and hand weeded and all plots except check plots were chemically treated. The effectiveness of these chemical treatments was measured when plots were hoed and hand weeded September

Table 8--Effectiveness of Second (August 16) Foliage Application (Midway Experimental Plots, 1950, Counts Made September 19)

Chemicals and Combinations	Rate (Pounds Per Acre)		Per Cent Weed Reduction* Broad-leaved	Grass
Herbicide I (Sodium 2, 4-dichlorophenyl "Cellosolve" sulfate)	1		53	75
	1 1/2		53	83
	2		63	92
Combination I and IV (2, 4-D)	Herb. I and Herb. IV			
	1	1	72	77
	1 1/2	1	72	77
Herbicide II (Dichloral Urea)	2		49	75
	4		47	83
	6		58	77
Combination II and IV	Herb. II and Herb. IV			
	2	1	51	50
	4	1	81	100
Herbicide III (Endothal)	1/2		22	27
	1			
	2		56	73
Combination III and IV	Herb. III and Herb. IV			
	1/2	1	68	70
	1	1	79	77
Herbicide IV (2, 4-D--Amine Salt)	1		77	81
Herbicide V (Maleic Hydrazide)	4		0	33
	6		0	0
	8		47	65
Combination V and IV	Herb. V and Herb. IV			
	4	1	51	38
	6	1	60	48

*Calculated from counts in untreated plots.

19. The pounds of weeds, calculated on an acre basis, which grew during the period August 16 to September 19 in each of the chemically treated and untreated plots are recorded in Table 9. Applications of 2,4-D reduced the

Table 9--Effectiveness of Foliage Applications on Summer Weed Control (Midway Experimental Plots, September, 1950, Applied August 16, Weights Taken September 19)

Chemicals and Combinations	Rate (Pounds Per Acre)		Fresh Weight of Weeds Removed Pounds Per Acre
Check Plot			2871
Herbicide I (Sodium 2, 4-dichlorophenyl "Cellosolve" sulfate)	1		3929
	1 1/2		1332
	2		4377
Combination I and IV (2, 4-D)	Herb. I and Herb. IV		
	1	1	2284
	1 1/2	1	734
Herbicide II (Dichloral Urea)	2		2828
	4		951
	6		4078
Combination II and IV	Herb. II and Herb. IV		
	2	1	509
	4	1	509
Herbicide III (Endothal)	1/2		2936
	1		2012
	2		1361
Combination III and IV	Herb. III and Herb. IV		
	1/2	1	1577
	1	1	14
Herbicide IV (2, 4-D--Amine Salt)	1		13
Herbicide V (Maleic Hydrazide)	4		1930
	6		1332
	8		2202
Combination V and IV	Herb. V and Herb. IV		
	4	1	462
	6	1	1006

pounds of weeds to 13 as compared to 2871 for the untreated plots. Endothal and 2,4-D used in combination did not give any further reduction. Sodium 2,4-dichlorophenyl "cellosolve" sulfate, Dichloral urea and Maleic hydrazide when used with 2,4-D reduced the amount of weeds removed from one-half to one-sixth of that in the untreated plots. The same materials used without 2,4-D did not reduce the amounts of weeds. Weeds found in plots at this time were: Nodding Spurge (Euphorbia maculata), Milk Purslane (Euphorbia supina), Clammy Ground Cherry (Physalis heterophylla), Bull Nettle (Solanum Carolinense), Common Milk Weed (Asclepias syriaca), Iron Weed (Vernonia altissima), Crab Grass (Digitaria sanguinalis), Foxtail Barley (Hordeum jubatum), and Witch Grass (Panicum capillare).

The hand labor required to remove the weeds which grew during this period (August 16 to September 19) in the chemically treated and control plots is shown in Table 10.

On an acre basis, 72.5 hours were required to hand weed the untreated plots, while those treated with 2,4-D required only 8.7 hours. Sodium 2,4-dichlorophenyl "cellosolve" sulfate and Maleic hydrazide were not as effective in reducing the labor requirements as were Endothal and Dichloral urea. The value of all chemicals in saving labor was increased when used in combination with 2,4-D.

Runner Plant Production as Affected by Herbicidal Applications—The effects of chemical treatments on runner production are shown in Table 11. The year 1950 was a favorable one for runner production and an abundance of runner plants was produced by September in untreated plots. All chemical treatments except 2,4-D reduced runner production considerably. Plots treated with this chemical showed less than 5 per cent reduction of runner plants, which was probably not significant.

Effects of Chemicals on Time of Bloom—The time of blooming as affected by chemical treatment is shown in Table 12. Plots treated with Endothal and Maleic hydrazide in 1950 began to bloom earlier in 1951 than plots treated with other chemicals or untreated plots. Under the climatic conditions of 1951 the time of blooming did not materially affect earliness of ripening.

Yields of Plots Treated With Herbicides in Spring and Summer—Yields of chemically treated and untreated plots and relation of yields to plant stands are shown in Table 11. When plant stands were sharply reduced by such chemicals as Endothal and Maleic hydrazide the total yield was reduced accordingly. Treatments such as 2,4-D, Sodium 2,4-dichlorophenyl "cellosolve" sulfate and Dichloral urea which did not reduce plant stands below 180,000 plants per acre did not materially affect the yields.

Effects of 2,4-D Applied During Time of Fruit Bud Differentiation—Strawberry plants treated with 2,4-D during time of fruit bud differentiation produced deformed berries as shown in Fig. 11. Leaf petioles and runners were fasciated. Injured plants and berries were observed in plot treated October 4, whereas the plot treated October 23 showed very few deformed berries and no deformed runners or leaf petioles as shown in Table 13. Plot treated

Fig. 11.—2,4-D applied during time of fruit bud differentiation (October 4) caused a large portion of the fruit to be deformed. Instead of four or five fruits per cluster, one large misshapen fruit was produced.

October 4 yielded as well as the untreated plot. The plot treated October 23 yielded slightly less than the untreated plot. This application of 2,4-D was for the primary purpose of observing deformities which might result from application during time of fruit bud differentiation and since the experiment was not replicated, emphasis should not be placed upon yields. However, it should be noted that no marked reduction in yield resulted from these fall treatments.

Effects of Early Spring Applications of 2,4-D—Table 13 shows the effects of 2,4-D when applied early in the spring. Applications of one and one-half pounds of 2,4-D immediately after mulch was removed in spring reduced the stand of broad-leaved weeds 52 per cent and grass 82 per cent. Plots treated with 2,4-D yielded 231 crates per acre while the untreated plots yielded 248 crates.

Strawberry plants treated with one and one-half pounds of 2,4-D while in full bloom were badly injured; berries were deformed and yields were low. This plot yielded 62 crates per acre compared with 248 crates from the untreated plot.

Weed Control in Exeter Field Plots

Pre-planting Applications—The effects of different pre-planting rates of 2,4-D on weeds are shown in Table 14. All rates of 2,4-D were effective in

reducing the stand of weeds. These applications appeared to be more effective on broad-leaved weeds than on grass. Under these conditions, increasing

Table 10--Effects of Herbicidal Treatments on Hand Labor Requirements (Midway Experimental Plots, September, 1950)

Chemicals and Combinations	Rate (Pounds Per Acre)*		Man-hours to Weed One Acre**
Check Plot			72.5
Herbicide I (Sodium 2, 4-dichlorophenyl "Cellosolve" sulfate)	1		75.2
	1 1/2		65.2
	2		94.2
Combination I and IV (2, 4-D)	Herb. I and Herb. IV		
	1	1	43.5
	1 1/2	1	50.8
Herbicide II (Dichloralurea)	2		50.8
	4		50.8
	6		65.2
Combination II and IV	Herb. II and Herb. IV		
	2	1	50.8
	4	1	29.0
Herbicide III (Endothal)	1/2		43.5
	1		58.0
	2		36.2
Combination III and IV	Herb. III and Herb. IV		
	1/2	1	50.8
	1	1	5.4
Herbicide IV (2, 4-D--Amine Salt)	1		8.7
Herbicide V (Maleic Hydrazide)	4		58.0
	6		65.2
	8		65.2
Combination V and IV	Herb. V and Herb. IV		
	4	1	36.2
	6	1	14.5

*Applied August 16.
**Weeded September 19.

Table 11--Effects of Herbicidal Treatments on Runner Production and Fruit Yields (Midway, 1951)

Chemicals and Combinations	Rate (Pounds Per Acre) Pre-Planting		Foliage*		Plants Per Acre**	Yield Crates Per A.†
Check Plots					218,606	224
Herbicide I (Sodium 2, 4-dichlorophenyl "Cellosolve" sulfate)	2		1		166,213	179
	3		1 1/2		200,540	199
	4		2		182,473	217
Combination I and IV (2, 4-D)	Herb. I and Herb. IV		Herb. I and Herb. IV			
	2	2	1	1	140,920	223
	3	2	1 1/2	1	121,046	207
Herbicide II (Dichloral Urea)	4		2		186,084	212
	8		4		193,313	231
	12		6		186,086	220
Combination II and IV	Herb. II and Herb. IV		Herb. II and Herb. IV			
	4	2	2	1	166,213	201
	8	2	4	1	115,626	196
Herbicide III (Endothal)	1		1/2		146,340	238
	3		1		130,080	174
	5		2		48,780	71
Combination III and IV	Herb. III and Herb. IV		Herb. III and Herb. IV			
	1	2	1/2	1	139,113	206
	3	2	1	1	61,426	99
Herbicide IV (2, 4-D--Amine Salt)	2		1		209,573	259
Herbicide V (Maleic Hydrazide)	4		4		142,726	183
	8		6		153,566	215
	12		8		86,720	178
Combination V and IV	Herb. V and Herb. IV		Herb. V and Herb. IV			
	4	2	4	1	131,886	178
	8	2	6	1	106,593	178

*Applied June 21 and August 16.
**Counts made September 1950.
†Average of three plots.

the rate of application of 2,4-D from two to four pounds per acre, did not increase weed control.

Table 12--Effects of Herbicidal Treatments on Earliness of Bloom (Midway Experimental Plots, Plants Treated in 1950, Counts Made May 3, 1951)

Chemicals	Rate (Pounds Per Acre) Pre-Planting	Summer*	Open Flowers Per Thousand Plants
Check plot			261
Sodium, 2, 4-dichlorophenyl "Cellosolve" sulfate	2	1	170
	3	1 1/2	188
	4	2	222
Dichloral urea	4	2	199
	8	4	229
	12	6	269
Endothal	1	1/2	443
	3	1	304
	5	2	625
2, 4-D (Amine Salt)	2	1	316
Maleic hydrazide	4	4	588
	8	6	688
	12	8	1001

*Two applications June 21 and August 16.

Yields From Field Plots Receiving 2,4-D in Spring and Summer—Yields from plots receiving various rates of 2,4-D are compared with those from untreated plots in Table 15. Some reduction in yield appears in the plots receiving two pounds of 2,4-D as a pre-planting application and one and one-half pounds in two summer applications; where higher pre-planting rates were used with this summer rate no reduction in yield occurred. This reduction in yield is probably due to variation in plots rather than from the effects of the chemicals.

Effects of Fall Applications of Herbicides on Weeds—One and one-half pounds of 2,4-D applied in late October gave good control of fall-maturing and over-wintering weeds which were present at time of spraying. The following weeds were killed in October: Mouse-ear Chickweed (Cerastium vulgatum), Common chickweed (Stellaris media), Cranesbill (Geranium Caro linianum), Red sorrel (Rumex acetosella), Winter cress (Barbarea vulgaris), Oxalis (Oxalidaceae), and Carpet Weed (Mollugo verticillata). 2,4-D caused wilting and deformity, but not death to Black Nightshade (Solanum nigrum),

Table 13--Effects of 2, 4-D (Amine Salt) on Strawberries When Applied at Different Stages of Development (Midway Plots)

Treatment	Yields Crates Per Acre	Per Cent Weed Control * Broad-leaved	Grass
Check	248		
2, 4-D 1 1/2 pounds per acre (Oct. 4)†	286	71	27
2, 4-D 1 1/2 pounds per acre (Oct. 23)	236	71	4
2, 4-D 1 1/2 pounds per acre (April 14)**	231	52	82
2, 4-D 1 1/2 pounds per acre (while in bloom)	62		

*Calculated from counts in untreated plots.
†Treatment at this time resulted in deformed plants and fruit.
**Applied immediately after mulch was removed.

Wormseed (Chenopodium ambrosioides), Pigweed (Amaranthus hybridus), and Primrose (Oenothera biennis). Pokeweed (Phytolacca Americana), Broad-leaved Dock (Rumex obtusifolius), and Cheat (Bromus secalinus) appeared in the treated plots the following spring. Untreated plots contained all of the weeds named.

Sodium 2,4-dichlorophenyl "cellosolve" sulfate when used at the rate of six pounds per acre killed Carpet Weed (Mollugo verticillata), Mouse-ear Chickweed (Cerastium vulgatum), Common Chickweed (Stellaria media), and produced wilting and deformity on Cranesbill (Geranium Carolinianum), Black Nightshade (Solanum nigrum), Oxalis (Oxalidaceae), and Wormseed (Chenopodium ambrosioides).

Plots treated with Isopropyl-N-phenyl carbamate did not show any reduction in weeds. However, the difficulty of getting the wettable powder through a low volume weed sprayer may partially account for poor weed control.

Yields From Field Plots Receiving Chemical Treatment in Fall—As shown in Table 16 2,4-D and Sodium 2,4-dichlorophenyl "cellosolve" sulfate, when applied late in October did not reduce yields. The one and one-half pound application of 2,4-D gave a yield of 78 crates as compared to 107 crates from an untreated plot. This indicated that fall applications of 2,4-D reduced yields; however, the plots treated with two pounds of 2,4-D per acre yielded 140 crates per acre, thus indicating that there was more variation between plots than between treated and untreated plots.

Table 14--Effectiveness of Different Pre-Planting Rates of 2, 4-D (Amine Salt)
(Exeter Field Plots, Spring, 1950, Applied March 28, Counts Made May 22)

Rate Pounds Per Acre	Per Cent Weed Control* Broad-leaved	Grass
Two	86	69
Three	90	63
Four	88	60

*Calculated from counts on untreated plots.

Table 15--Effects of Pre-Planting and Summer Foliage* Applications of 2, 4-D on Fruit Yields
(Exeter, 1951)

Pounds Per Acre Pre-Planting	Summer*	Yield Crates Per Acre
Check plots		106
2	1 1/4	112
2	1	116
2	1 1/2	90
3	1 1/4	91
3	1	107
3	1 1/2	102
4	1 1/4	110
4	1	113
4	1 1/2	119

*Two summer applications.

Table 16--Effects of Fall Herbicidal Treatments on Yields* (Exeter, 1951)**

Treatment	Rate (Pounds Per Acre)	Yield Crates Per Acre
Check plot		107
2, 4-D (Amine salt)	1 1/2	78
2, 4-D (Amine salt)	2	140
Sodium 2, 4-dichlorophenyl "Cellosolve" sulfate	6	110

*All plots had received pre-planting and summer foliage applications of 2, 4-D.
**Applied October 21, 1950.

DISCUSSION

The chemical weed control studies recorded in this thesis had three objectives: First, to test the effectiveness of a number of herbicides and their toxicity to strawberry plants in the greenhouse. Second, to use previously tested chemicals on experimental plots under field conditions. Third, to determine practicability of use in commercial strawberry fields when applied with field equipment which is readily available to growers.

Greenhouse Tests—Greenhouse climatic conditions are often very different from field conditions. In most cases the chemicals were more phytotoxic under greenhouse conditions than under field conditions. Some factors which may account for this increased plant injury are: The higher humidity often found in the greenhouse may cause plants to be more tender and succulent than field grown plants. Also, the strawberry plant may absorb more of the herbicide due to the higher humidity. During early spring both the day and night temperatures may be higher in the greenhouse than in the field. Soil moisture in the greenhouse may be more uniform and higher, and greater amounts of certain low-soluble chemicals may become soluble. Chemicals are applied in the greenhouse at field rates of application; however, due to the limited area for roots of strawberry plants in pots, the rates of application may not be comparable.

Nevertheless, it is possible to evaluate a new chemical in the greenhouse by using a field tested chemical along with chemicals to be tested and comparing the phytotoxicity of both chemicals.

Experimental Plots and Field Tests—Pre-planting Applications—Results of the experiments reported herein, indicate that many weeds can be controlled for four or more weeks by a pre-planting application. Higher rates of chemicals may be used by applying the material before the strawberry plants are set. This method of application prevents the chemicals from coming into contact with plant foliage, consequently less injury results. Germinating weed seeds or seedlings are more easily killed than older weeds. Since many weeds may be in this stage before plants are set, pre-planting applications sometimes give good control. 2,4-D has been found to give severe damage if applied before newly set plants become established. Normally it is best to delay this application of 2,4-D for four weeks, however, in many seasons weeds will crowd out the strawberry planting if not killed before the end of this four-week period. In particularly wet seasons, weeds may over-run the field before it is possible to spray with 2,4-D or to cultivate. To avoid this condition pre-planting applications of 2,4-D may have an important place in weed control in strawberries.

Two pounds of 2,4-D showed more promise in commercial fields as a pre-planting application than in Midway plot tests. Soil type and organic matter content were different in the field and plot tests. The higher organic matter content of the Midway plots may have decreased the effectiveness of the 2,4-D. With soils high in organic matter higher rates of application may be necessary to give satisfactory weed control.

An application of Sodium 2,4-dichlorophenyl "cellosolve" sulfate or Dichloral urea a few days after setting the plants just as weed seeds begin to germinate may be better than a pre-planting treatment. This is due to the fact that Sodium 2,4-dichlorophenyl "cellosolve" sulfate and perhaps Dichloral urea can be used as selective foliage sprays at rates high enough to give satisfactory weed control without serious damage to the strawberry plants. However, for these materials to be effective they must be applied before the weed seeds germinate.

Foliage Applications in Newly Established Fields—Results in 1950 indicate that one pound of 2,4-D was more effective than two pounds of Sodium 2,4-dichlorophenyl "cellosolve" sulfate or six pounds of Dichloral urea. These two materials must be used at higher rates to obtain effective weed control and it appears that 2,4-D will be the most economical herbicide to use if it will give sufficient control of grass without serious damage to the strawberry plant. Endothal and Maleic hydrazide were ineffective at low rates of application yet produced a certain amount of plant injury which indicates that neither material is satisfactory for herbicidal use in strawberries.

Work reported by Carlson (10) in late 1950 shows two pounds of 2,4-D to be as effective as three and four pounds of Sodium 2,4-dichlorophenyl "cellosolve" sulfate. He further states that Dichloral urea does not show as much promise as 2,4-D. The results obtained with Endothal agree with Carlson's work (10) and the work of Viehmeyer (38). Some effects of Maleic hydrazide recorded in this paper are similar to those observed by Denisen (23) and Moore (28) in 1950.

Fall Application of Chemicals—2,4-D and Sodium 2,4-dichlorophenyl "cellosolve" sulfate applied in late October gave good control of fall and overwintering weeds. One and one half pounds of 2,4-D appeared to give as good or better control than six pounds of Sodium 2,4-dichlorophenyl "cellosolve" sulfate.

2,4-D should not be applied during the period of fruit bud differentiation. However, it is not known definitely what the effect of 2,4-dichlorophenyl "cellosolve" sulfate would be if applied during this period. Plants treated October 4 produced deformed berries, leaf petioles and runners, while plants treated October 21 and 23 with 2,4-D exhibited only an occasional deformed fruit. No deformed berries or plant parts were observed in plots treated with Sodium 2,4-dichlorophenyl "cellosolve" sulfate at this time (October 21).

In Missouri the period of fruit bud differentiation is from late August until late October. It would be of great advantage to have a material that could be applied during this period. A large number of broad-leaved weeds and grasses germinate during this period when it is unsafe to use 2,4-D. In general fall applications of herbicides appear to have an important place in strawberry production.

I.P.C. (Isopropyl-N-phenyl carbamate) failed to control weeds in strawberries. Carlson (10) and Viehmeyer (38) reported similar results from the use of I.P.C. in 1950.

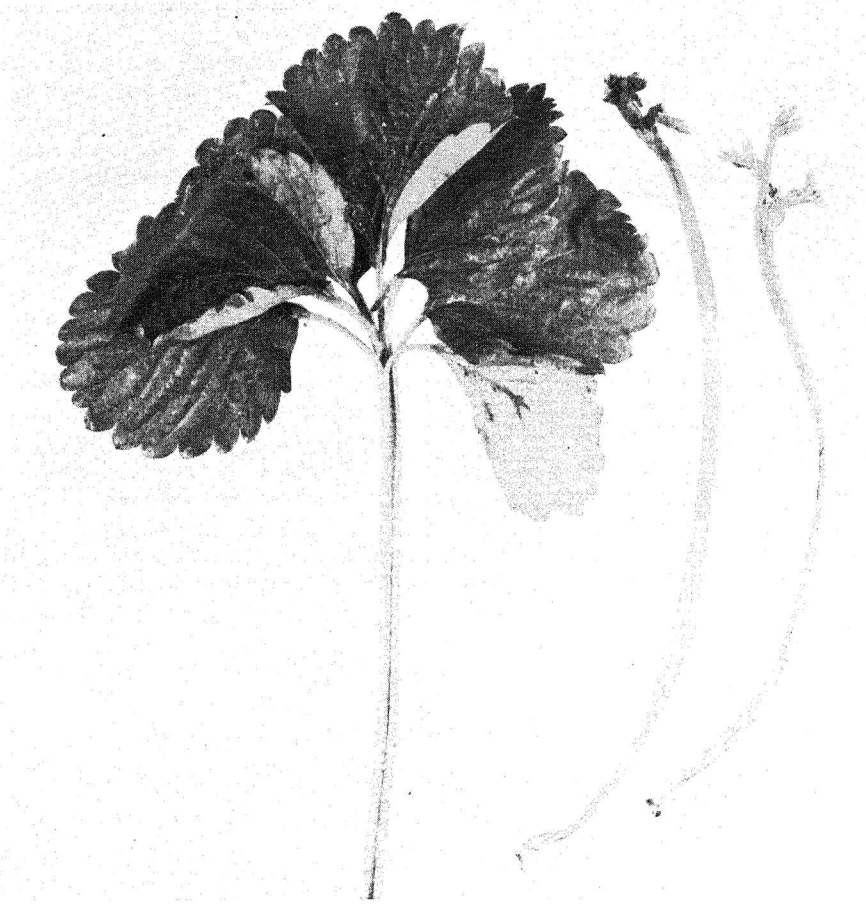

Fig. 12.—Plants treated with 2,4-D on October 4 produced deformed leaves and runners. Leaf petioles and runners were fasciated and many of the leaves had six to ten leaflets.

Early Spring Applications of Chemicals—Early spring applications of 2,4-D before strawberry plants begin to grow are effective in controlling weeds and did not adversely affect yields. If such a spray is used it should be applied immediately after the mulch is removed at the rate of one to one and one-half pounds per acre. Care should be used to avoid applying 2,4-D while plants are in bloom. Application of this herbicide during time of bloom caused small deformed berries and reduced yields markedly.

Phases of Work That Need Additional Study—This investigation has raised certain questions which have not been answered by the present work. Other problems have been touched on lightly and need further investigation.

It is possible that different times of application of various chemicals would improve the over-all weed control. The use of Sodium 2,4-dichlorophenyl "cellosolve" sulfate during time of fruit bud differentiation needs additional study. This material may also give good weed control if used in the spring after mulch is removed. The effects of this material when applied during the period of bloom are not known. Lower rates and more frequent applications of all chemicals might prove more effective than present rates and methods of application.

SUMMARY

The results of this study indicate that 2,4-D has a place in weed control of strawberries. It can be used safely as a pre-planting treatment at the rate of two to four pounds per acre, as foliage applications from four weeks after setting to August 15, at the rate of one to one and one-half pounds per acre, in the fall after fruit bud differentiation and in the early spring as the mulch is removed.

Sodium 2,4-dichlorophenyl "cellosolve" sulfate and perhaps Dichloral urea have a place in weed control of newly set strawberries, but these materials will have to be used at rates higher than used in this study. To be effective these materials must be applied when the weed seeds are germinating or before this process begins. There are problems arising in the use of these chemicals which need further investigation. Suggestions for further study have been made.

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