INHIBITION OF RUNNER PLANTS IN THE STRAWBERRY (FRAGARIA SPP.) BY CHEMICAL TREATMENT

By

Robert F. Carlson

AN ABSTRACT

Submitted to the School of Graduate Studies of Michigan State College of Agriculture and Applied Science in partial fulfillment of the requirements for the degree of

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INHIBITION OF RUNNER PLANTS IN THE STRAWBERRY (FRAGARIA SPP.) BY CHEMICAL TREATMENT

Many of the horticultural strawberry varieties have a tendency to produce a super-abundance of runner plants creating a need for thinning and spacing by manual methods. Inhibiting runner formation by chemical treatment seemed logical for the elimination of excess runner plants.

Several strawberry varieties were treated under greenhouse and field conditiona with certain chemicals including dichloral urea, phenoxyethyl trichloroacetate, sodium 2,4-Dichlorophenoxyethyl sulfate, isopropyl N-phenylcarbamate, maleic hydrazide and 2,4-Dichlorophenoxyacetic acid. These materials were applied to the plants by various methods; spraying, leaf-emersion, drop-method, pouring and by soil applications; and at different concentrations ranging from 5 to 25 milligrams per plant and equivalent amounts in pounds per acre in the field.

The strawberry runners were inhibited most when a certain chemical was applied twice at the time of runner initiation. Dichloral urea, phenoxyethyl trichloroacetate and 2,4-Dichlorophenoxyacetic acid were most effective in reducing runner formation, whereas, isopropyl N-phenylcarbamate and maleic hydrazide were less effective depending on the concentration used. 2,4-Dichlorophenoxyethyl sulfate did not significantly inhibit any runners from plants either in the greenhouse or in the field. The percentage inhibition under greenhouse conditions ranged from 10 to 80 per cent depending on variety and concentration. In the field the percentage inhibition was greater.

The chemicals that were effective in inhibiting runner formation were also effective in killing many of the germinating weed seeds, thus serving a dual purpose in the field.

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ROBERT FRITZ CARLSON

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INTRODUCTION

The production of runners by the strawberry plant (hybrids of *Fragaria virginiana*, *F. chiloensis* and *F. ananassa*) represents the vegetative phase of reproduction. The production of too many runner plants by a variety may result in reduced yield of fruit. Thus, the number of runners may vary from 2 or 3 to as many as 20 or more per plant, depending on the variety and on environmental conditions.

It has been demonstrated with the Klondike and Missionary varieties that the mother plants will produce about 100 crates of fruit per acre more than will the runner plants (18). Morrow has shown that strawberry beds which are renovated may produce a large number of runner plants, which are less productive than the mother plants (19). Commercial growers have indicated, also, that the mother plant may remain productive for as long as 8 years. Waldo observed that (1) allowing runner plants to develop reduces the fruit-producing capacity of the mother plants; (2) mother plants, if now crowded or devitalized by runner plants, are more fruitful per plant than early-established runner plants; (3) the available water and mineral nutrients in the soil are utilized more effectively by relatively small numbers of plants per acre than by larger numbers of plants; and (4) with fewer plants per acre there is less shading and greater photosynthetic activity per plant (27).

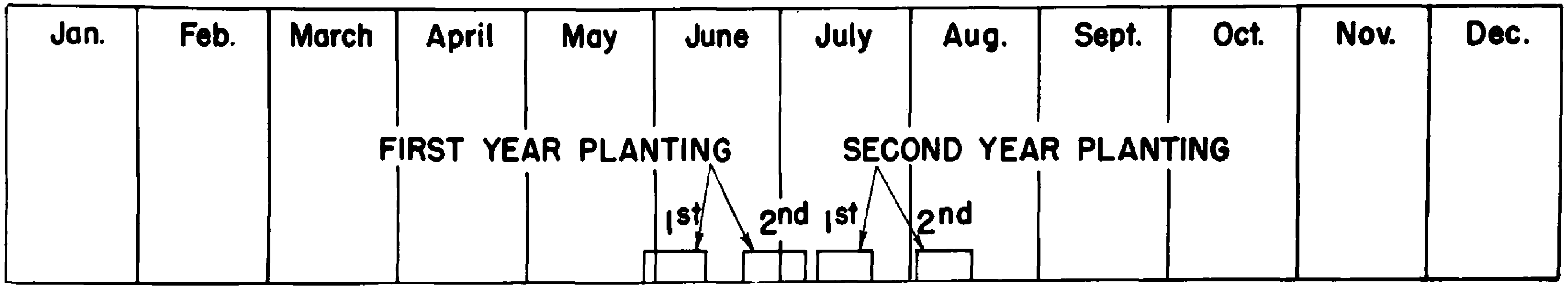
Since the mother plants appear to be more productive than runner plants, it would seem desirable to devise some means for control of runner formation and plant set. In commercial strawberry production, the number of runner plants in a planting is often controlled by clipping of all runners except the first ones formed and by spacing these plants equidistant around the mother plant. This method often results in an increase in yield over the matted row system of culture, in which plants are permitted to form and establish themselves at random. But the expense of clipping and spacing does not warrant its use in many cases.

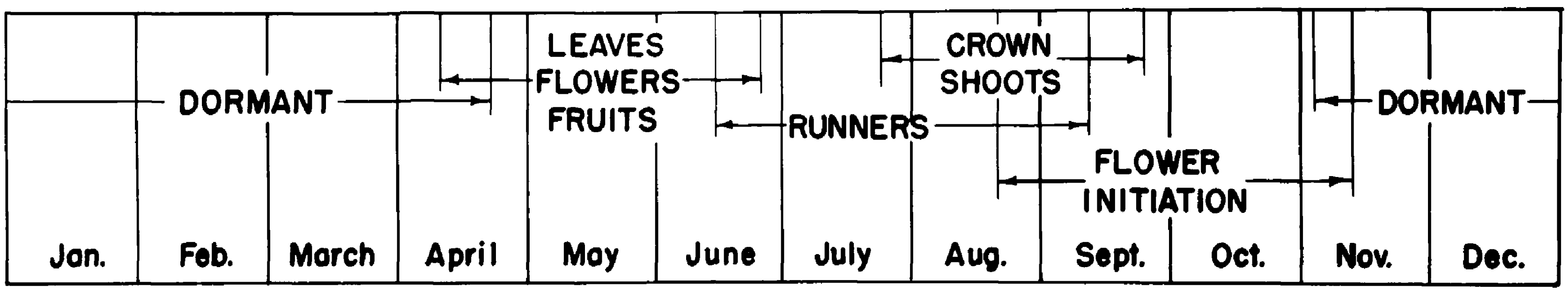
In work with herbicides it had been observed that some chemicals affected runner formation (4). With these factors in mind, the research problem here reported was undertaken to test the influence of several chemical substances on the inhibition of runners.

NORMAL RUNNER DEVELOPMENT

The strawberry plant is capable of exogenously initiating buds which are modified branch structures of three types; runner-shoot, crown-shoot and flower-shoot. These buds occur in the axils of the leaves on the short stem of the well-developed plant, whereas leaf formation occurs at the apex of the same stem. The sequence of occurrence of these different branch structures depends on the genetic constituion of the variety, and the environment. According to Darrow, the growing points of seedlings of horticultural varieties first produce shoots, then runners, and then inflorescences, in that order (5). Spring-set strawberry plants in northern regions begin to produce runners in late May, or usually 3 to 4 weeks after planting, following new leaf production and flowering. Fruiting strawberry plants, on the other hand, usually produce runners after the fruit has been harvested. The actual time of runner production varies more or less with the variety. New runners are produced over a considerable period from late May into early September, depending on the variety, when the plants were set, and the environment. The general growth cycle of strawberry plants in northern regions is shown in the lower half of Figure 1.

WHEN TO APPLY RUNNER INHIBITING MATERIALS





GENERAL GROWTH CYCLE OF THE STRAWBERRY PLANT IN THE NORTHERN STATES

Fig. [illegible] [illegible] of the annual growth cycle of the strawberry plant together with approximate time that treatment should be made for maximum inhibitory effect on the [illegible].

FACTORS INFLUENCING RUNNER PRODUCTION

Runners are produced in the sequence of the annual growth cycle of the strawberry plant, progressing in order from spring to spring as follows: (1) leaf growth, flowering and fruiting; (2) runner initiation and runner development; (3) crown-shoot formation and development; (4) flower initiation; and (5) dormant phase (Fig. 1). These phases are not clear cut, and tend to overlap and vary among the horticultural varieties, and with location of culture. This is the general situation with the strawberry plant, irrespective of age. However, if flowers are removed from plants the first year they are set, as is usually done in commercial plantings, runners are produced earlier. It has been demonstrated that the roots of strawberry plants have a cyclic development, most of them showing maximum growth in late summer and fall, which bears a relationship to runner production (17). The general growth cycle may be modified by external conditions, such as daylength, temperature, moisture, and nutrient levels, and internal factors.

The strawberry plant is classified as a short-day plant, the flowers initiating during September and October in the northern latitude (22 and 26). Runners, on the other hand, are initiated during long days, as in July and August, in most varieties (5). For example, a 20-hour photoperiodic cycle (10 hours light and 10 hours darkness) does not produce runners, but a 28-hour photoperiodic cycle (14 hours light and 14 hours darkness) will produce runners (10).

The relation of daylength to runner production is affected by temperature, especially at the extremes, which interfere with the metabolic activity of the plant (10). In greenhouse tests, runners were produced at 60° F. on a 14-hour and 16-hour light period, whereas at 55°, fewer runners were formed under the same daylength (6). Under controlled environmental conditions, Hartmann found that flowers were initiated under a long photoperiod (15 hours) at 60° F., and that no runners were formed under the same photoperiod at 70° F. (11).

The nutrient level also has an effect on runner production. Spring applications of nitrogen, alone or in combination with phosphoric acid or phosphoric acid and potash will increase runner production (15), depending on the condition of the plants at the time of the application. For example, a strawberry bed showing deficiency symptoms may respond more readily than one exhibiting a vigorous condition. The use of "starter solutions" with analysis of 0-52-34, 6-25-15 or 10-52-17 applied near the plant at the time of planting has been found by Reath (21) to produce earlier plant growth and earlier runner formation under both greenhouse and field conditions. Other workers, however, were unable to increase the number of runners with the addition of nitrogen alone, or with complete fertilizer, whereas stable manure alone, at the rate of 32 tons per acre, gave an increase in the number of runners (15, 25).

Moisture also has an effect on the number of runners formed during a growing season. In studying the effects of irrigation on runner production, it was found that with no irrigation there were fewer plants per acre than with three irrigations (27). The limited soil moisture evidently weakened the mother plants to the extent that they lost the power to produce as many runners as the plants which received ample moisture.

Varieties of strawberries vary greatly in their ability to produce runners. Varieties such as Fairfax, Catskill, and Midland produce comparatively few runners, whereas varieties like Robinson, Dunlap, and Blakemore are active runner producers. Differences in runner production are easily observed in a planting of seedling strawberries where each plant is different genetically.

MATERIALS AND METHODS

Since the introduction of a 2,4-Dichlorophenoxyacetic acid (2,4-D) in 1944 (9) as a herbicide and in 1947 as a material for control of weeds in strawberries (1), a great deal of data has been reported on the influence of this material on the strawberry plant in general, but no specific data on its effects on runner formation (8, 20, 25). Accordingly, since 2,4-D is now widely used in strawberries, a study was made of the effect of this material on runner production. In the greenhouse 2,4-D was used at a range of concentrations of 2.5, 5.0, 7.5, 10.0 and 12.5 milligrams per plant, and in the field at 0.5, 1.0, and 2.0 pounds per acre.[1] In the greenhouse each plant was plotted in 1-gallon tin cans.

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[1] All rates of the chemical materials reported in this paper are based on the active ingredients in the compound: 2,4-D, amine salt containing 40 per cent 2,4-Dichlorophenoxyacetic acid equivalent; IPC, a wettable powder containing 50 per cent isopropyl N-phenylcarbamate; EH-1, sodium salt containing 92 per cent 2,4-Dichlorophenoyethyl sulfate; DCU containing 73 per cent dichloral urea and 24 per cent clay diluent and 3 per cent wetting agent; PE-TCA, containing 60 per cent phenoxyethyl trichloroacetate and the remaining percentage a carrier and wetting agent and MH, diethanolamine salt containing 30 per cent maleic hydrazide.

Isopropyl N-phenylcarbamate (IPC) was first reported in 1949 as being effective in controlling common chickweed (Stellaria media) in strawberry plantings without any serious effect on either the plant or the yield (2, 3). In detailed studies with ethyl phenylcarbamate, it has been shown that the growth of the apical meristems of plants is inhibited, and that nuclei in the metaphase, anaphase and telophase are affected (12). A later report in 1951 gave some indications that repeated application of IPC affected runner production (4). This material was used at the rates of 5, 10, 15, 20 and 25 milligrams per plant in the greenhouse, and 5, 10 and 15 pounds per acre in the field.

The material, 2,4-Dichlorophenoxyethyl sulfate (EH-1), which is now recommended as a herbicide in strawberries, was used in some of the detailed studies (4, 13 and 14). This material is not active chemically to a great extent on green plant foliage, but when in contact with the soil solution, it is converted into a form which becomes active. This material was used at 5.0, 10.0, 15.0, 20.0 and 25.0 milligrams per plant in the greenhouse, and 2, 3 and 4 pounds per acre in the field.

Dichloral urea (DCU) was found in preliminary studies to have promise both as a herbicide and as a runner inhibitor (4, 13). This substance was used at 5.0, 10.0, 15.0, 20.0 and 25.0 milligrams per plant in greenhouse tests, and 3, 6, and 9 pounds per acre in field experiments.

Phenoxyethyl trichloroacetate (PE-TCA) was also found in preliminary tests to have effects similar to DCU (4, 13). This material was applied at 5.0, 10.0, 15.0, 20.0 and 25.0 milligrams per plant in the greenhouse tests, and 1, 2, and 3 pounds per acre in the field.

Maleic hydrazide (MH) was used in some of the greenhouse tests at 48.0, 96.0, 144.0, 192 and 240 milligrams per plant, and in the field at 1,500 and 2,000 ppm. This material has been used to inhibit sprouting of onions and potatoes (23, 28).

The materials were applied to the strawberry plants in various ways. In the greenhouse tests the solutions (emulsions in some cases) were (1) poured over the soil surface only, (2) poured over the plant only, (3) poured over both the plant and the soil surface, and (4) sprayed over the plant and the soil surface. Usually 10 ml. of the solution was applied to each plant so as to insure wetting of the leaves and contacting of the growing points in the leaf axils. Various other methods of application such as lanoline paste, drop-method and leaf-emersion were tried, but these did not prove as effective as spray and pouring applications.

Since difficulty is often experienced in growing strawberry plants under greenhouse conditions, it is important to consider some of the factors responsible for good growth. Varieties differ; for example, the Premier variety produces only a limited number of flowers and runners under greenhouse conditions, whereas the Robinson variety produces flowers and runners typical of field-grown plants.

The growth of most varieties in the greenhouse approaches typical growth in the field if the plants have been properly preconditioned and if they are provided with favorable growing conditions, including soil, moisture, temperature and light. For optimum growth in the greenhouse, the plants should be allowed to remain in the field until they have reached a dormant stage (usually the latter part of October, depending on the season), and then dug and stored for at least two months in a moist medium at 35° F. After they are transplanted into containers and placed in the greenhouse, supplemental light is required so as to provide about 10 hours for flower initiation, 14 hours for runner initiation, and 10 to 12 hours for general growth and fruiting. It has, however, been shown by Darrow and Hartmann that low temperature may induce flower initiation on a long day (7, 11).

The Premier and Robinson varieties and certain seedling selections were used extensively. The plants usually were dug the last part of October, or after they appeared dormant, and then stored at 35° F. for 6 to 8 weeks. They were then transplanted into one-gallon tin cans filled with a soil mixture of loam, peat and sand. The plants were treated at various stages of development to determine the most sensitive runner-inhibiting period. Supplementary light was given from 4:00 p.m. to 11:00 p.m., which produced about a 14-hour optimum photoperiod for runner production during December, January and February.

In the field, the materials were applied by a conventional knapsack sprayer at a volume of 40 gallons per acre. Both single and double applications were made on different plants in the field to determine the influence on runner inhibition of each application. About one-half acre of the Premier variety was planted May 25 on a Hillsdale sandy loam. The materials were applied June 4 and July 18. A second-year planting of Sparkle, Red Star, Fairpeake and Premier was treated July 29, and again August 16, 1951, to see the effect of the materials on older plants. Runner counts were made at regular intervals during the remainder of the growing season.

RESULTS

Runner Inhibition Under Greenhouse Conditions

During three years, over 4,000 strawberry plants were individually treated in the greenhouse. Each treatment with a certain concentration of a certain chemical was set up in duplicates and repeated several times. Only the most significant data are presented.

In one test, twenty plants each of the Premier, Robinson and NY 23502 were treated with phenoxyethyl trichloroacetate at 4.0 and 8.0 milligrams per plant, a same number with dichloral urea at 6.0 and 12.0 milligrams per plant and similarly with 2,4-D at 1.0 and 2.0 milligrams per plant (Table I). The plants received a second application at these rates 15 days after the first. Each plant received these amounts of the chemical in 10 ml. of solution poured over the individual plants. In this manner some of the liquid seeped into axils of the leaves and down over the crown and onto the soil. The plants were runner plants from the field that had been dug October 20 and stored at 35° F. for two months. At that time they were planted

Table I. The effects of PE-TCA, DCU and 2,4-D on runner production, shoot-root ratio, and shoot-crowns of three strawberry varieties. These are average results of 20 plants of each treatment. The plants were treated twice, 15 days apart at the rates indicated.

Materials	Amt. Appl. Per Plant (mgms.)	Runners			Shoot-root Ratio		Shoot-crowns		
		Treated	Con-trol	Per Cent Decrease	Treated	Con-trol	Treated	Con-trol	Per Cent Increase
				Robinson Variety					
PE-TCA	4.0	4.9	7.3	33	1.85	1.82	6.0	3.4	44
PE-TCA	4.0	3.8	7.2	47	1.35	2.01	6.7	3.2	52
DCU	6.0	4.6	6.5	30	2.57	2.32	7.0	3.6	49
DCU	12.0	4.6	7.0	34	3.07	2.52	5.8	3.1	47
2,4-D	1.0	5.0	7.5	31	1.72	1.76	7.1	3.6	49
2,4-D	2.0	3.6	6.8	47	1.69	1.73	6.6	3.4	49
				Premier Variety					
PE-TCA	4.0	3.2	5.5	42	1.79	1.86	4.0	3.1	23
PE-TCA	8.0	2.9	5.2	44	1.29	2.00	3.5	2.4	32
DCU	6.0	3.8	6.2	39	2.23	2.28	3.9	3.0	23
DCU	12.0	3.6	6.0	40	2.90	2.42	4.1	2.9	29
2,4-D	1.0	3.1	5.4	43	1.78	1.80	4.5	3.2	29
2,4-D	2.0	3.0	5.1	41	1.81	1.82	4.1	3.0	27

Table I (Continued)

Materials	Amt. Appl. Per Plant (mgms.)	Runners			Shoot-root Ratio		Shoot-crowns		
		Treated	Con-trol	Per Cent Decrease	Treated	Con-trol	Treated	Con-trol	Per Cent Increase
				NY23502 Selection					
PE-TCA	4.0	0.6	3.2	81	1.82	1.79	4.1	3.3	20
PE-TCA	8.0	0.1	2.2	96	1.37	2.13	3.3	2.3	31
DCU	6.0	0.8	2.3	65	2.42	2.39	4.0	3.0	25
DCU	12.0	0.8	2.8	71	2.93	2.48	3.8	2.8	26
2,4-D	1.0	0.9	3.0	70	1.78	1.79	3.0	2.2	27
2,4-D	2.0	0.7	3.2	88	1.68	1.71	2.9	2.1	28

in the greenhouse and allowed to flower and fruit. Supplementary light was supplied to induce runner formation. The first treatment was made when the first sign of runner formation appeared. This was done by careful daily observations of some of the buds in the leaf axils. If new flower branches occurred they were removed, to encourage runner formation. Since runners were still being produced on control plants and a few on treated plants a second application at the same rate was made 15 days after the first treatment.

Phenoxyethyl trichloroacetate (PE-TCA) reduced the number of runners by over one-third in the Robinson and Premier varieties, and by 90 per cent with the NY 23502 seedling selection (Table I). The differences between concentrations were not great; however, the higher concentration produced more injury to the plants, as was observed in increased marginal ''burning'' of the leaves and degree of stunting of the plant. The plants soon outgrew the burning and stunting effects, as was determined at first by visual observation and later by measurement of the shoot-root ratio. The shoot-root ratio indicates that there was a reduction in foliage or a possible increase in roots, the former being the most likely condition, since the material showed contact foliar injury. The material PE-TCA also produced a condition which caused more shoot-crowns to be formed. There were nearly 50 per cent more shoot-crowns produced in the Robinson variety and about 30 per cent more in both the Premier variety and the NY 23502 seedling as compared with untreated plants (Table I and Fig. 2).

Dichloral urea (DCU) caused a decrease in number of runners and an increase in shoot-crowns similar to PE-TCA with all the three varieties tested in this experiment (Table I). The effect of DCU on the plants was not as pronounced as that of PE-TCA, but some bronzing of the leaves occurred about 10 days after each treatment. At the higher concentration, 12.0 mgms. per plant, there appeared to be some root injury since the shoot-root ratio was higher in these treatments. Spray applications at the same rate of either one of these materials were as effective as when the materials were poured onto the plants. Spray sufficient to wet the foliage, appeared to produce inhibitory effects (Fig. 3).

Differentiated runner "tips" appearing in the axils of the leaves were checked in their further development by PE-TCA and DCU. There was a noticeable blackening and withering of

Fig. 2 The effect of two applications of 8 milligrams each of PE-TCA three weeks apart on Robinson strawberry plant. The treated plant (right) produced six crown-shoots and two "dwarf" runners, whereas, the untreated plant (left) produced no shoot-crowns and five runners.

Fig. 3 Inhibitory effects on the Premier strawberry plant (left) produced by two applications of 12 milligrams each of DCU. Temporary stunting often results from the treatment, but recovery is rapid. Right, untreated plant.

the terminal growing points of the runners (Fig. 4). Both PE-TCA and DCU produced these effects; however, PE-TCA was more potent in that it produced withering of runner "tips" up to one inch in length (Fig. 5). Runner shoots which had developed to a length of over 2 inches at the time of treatment exhibited a browning on the sides about 10 days later; however, they continued to grow. Many of the runner shoots which were over one inch in length at the time of application were only checked in their development and later grew apparently into normal runner plants. Apparently, the most effective time to inhibit further growth and development of the runner shoot is when the bud first appears in the leaf axis. The chance of inhibition is decreased from the bud stage up to the time the runner shoot is one inch in length. Beyond the one-inch stage, the chemicals produced only a delay in runner formation. Since this one-inch growth often was produced within one day, it was necessary to time the applications so as to contact as many of the young buds and shoots as possible. Two applications were more effective than one.

The material, 2,4-D, produced effects, as far as runner production is concerned, which were similar to those from PE-TCA and DCU (Fig. 6). The average reductions in runners were about

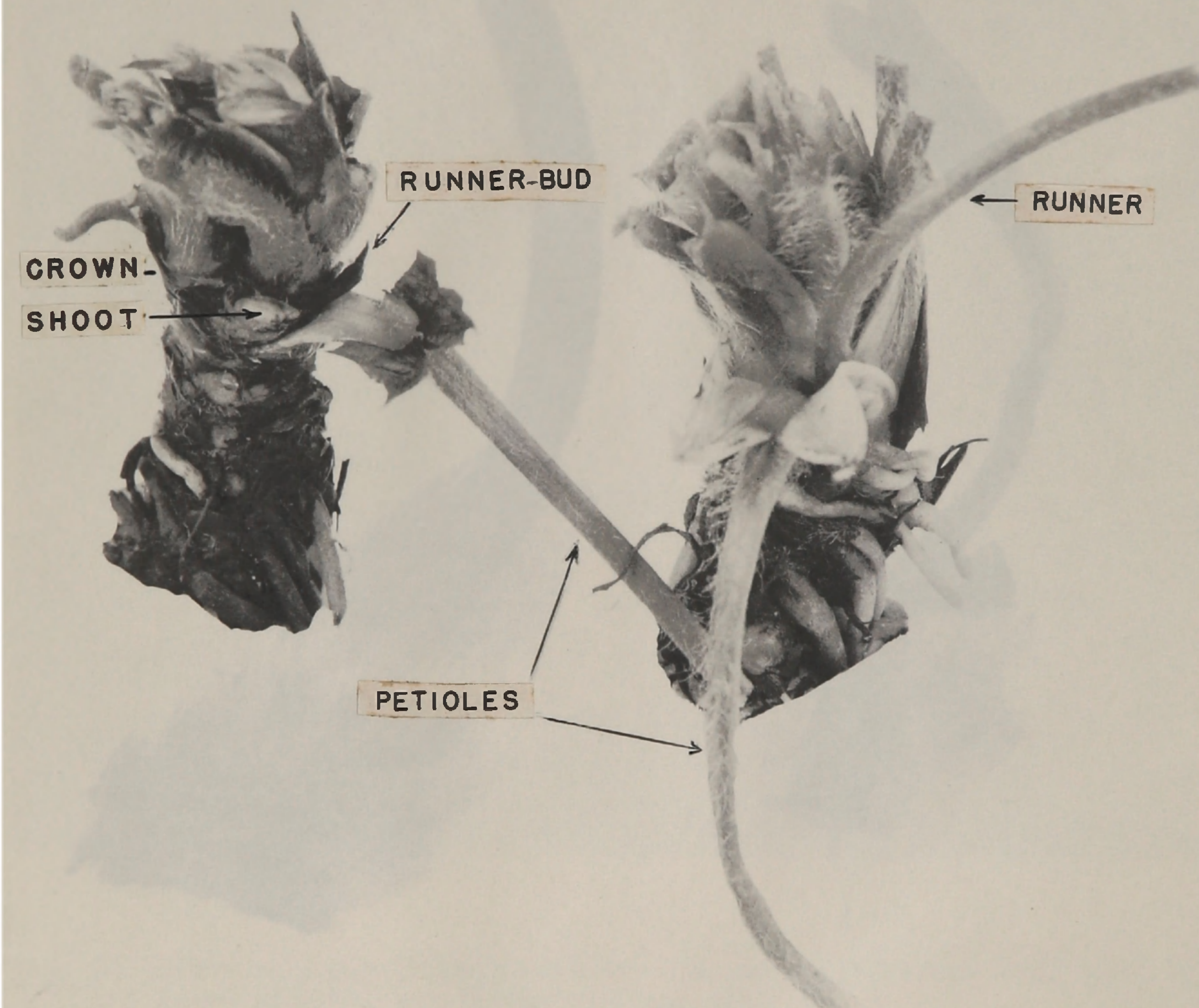

Fig. 4 Strawberry crowns showing a runner-bud inhibited from two treatments of 12 milligrams each of DCU (left) and untreated (right). Note some darkening also of the stipule.

Fig. 5 Runner-shoot (right) inhibited in its early development with two applications of 8 milligrams of PE-TCA, and runner from untreated plant (left).

Fig. 6 Robinson plant (right) treated with two applications of 2 milligrams of 2,4-D and untreated plant (left).

40 per cent with the Robinson and Premier varieties, and about 80 per cent with the NY 23502 selection (Table I). The increase in shoot-crowns compared favorably to that from PE-TCA and DCU. There appeared some loss in foliage vigor a few days after treatments; however, the plants soon recovered. The shoot-root ratio indicates that no serious effects due to treatments were found in either leaves or roots; however, newly formed roots showed some swelling.

From the greenhouse studies, there is an indication that each variety responded differently to the materials tested. This was especially true for varieties that ordinarily produce few runners such as the NY 23502. Naturally, the more runner-shoots present in a variety, the more difficult to contact the young shoots with the spray. No appreciable difference occurred, however, between the Robinson and the Premier varieties in this respect.

The materials, 2,4-Dichlorophenoxyethyl sulfate (EH-1), isopropyl N-phenylcarbamate (IPC) and maleic hydrazide (MH), included in succeeding experiments did not inhibit runner formation as much as the compounds previously mentioned. First, it is important to note that EH-1 and IPC were not effective in controlling runner production (Table II). EH-1 produced no ill effects on the strawberry plants at the low concentrations used, whereas at the higher concentrations considerable wilting was very noticeable for six to eight days after application. The plants soon recovered, however, and grew normally as compared to untreated plants. IPC, at the higher rates used, produced some chlorotic symptoms on the new strawberry leaves that unfolded about 15 days after the applications. The lower concentrations induced no visible effects on plant growth (Table II).

Maleic hydrazide (MH) inhibited runner formation to a limited extent but the material also slowed down growth and normal development of the plants more than any of the other compounds tested. The stunting symptoms remained for two to three weeks following treatments, but the plants eventually outgrew the effects (Table II).

Effect of Chemicals on Flowering and Plant Growth

For certain chemicals to be useful in inhibiting strawberry runners it is essential to know what effects they may have on flowers and general growth of the plant. For this reason, a series of tests of some of the materials were made to determine

Table II. The effect of two applications made 15 days apart of EH-1, IPC and MH on runner of formation and plant growth. The materials were applied at the rate of 10 ml. per plant at the time of runner initiation and formation.

Material	Amt. Appl. Per Plant (mgms.)	Av. No. Runners Per Plant		Per Cent Decrease	Condition of Treated Plants
		Treated	Control		
EH-1	5.0	7.6	7.5	0.0	Normal
	10.0	7.0	7.3	4.0	Normal
	15.0	7.5	7.4	0.0	Slight wilting - recovered
	20.0	7.1	7.2	1.4	Slight wilting - recovered
	25.0	6.8	7.0	2.9	Severe wilting - recovered
IPC	5.0	6.9	7.0	1.4	Normal
	10.0	7.1	7.1	0.0	Normal
	15.0	7.0	6.8	0.0	Dark green leaves
	20.0	6.8	6.9	1.4	Dark green leaves
	25.0	7.2	7.4	2.6	New leaves slightly chlorotic
MH	4.8	6.4	7.3	12.3	Slight stunting of the plants
	9.6	6.3	7.3	13.4	Slight stunting of the plants
	14.4	5.9	6.9	14.5	Slight stunting of the plants
	19.2	5.6	7.0	20.0	Some stunting of the plants
	24.0	4.8	7.2	33.4	Severe stunting of the plants

the degree of injury to the strawberry plant. Robinson plants which had been preconditioned previously in the field and in the storage for flower induction were planted in the greenhouse and provided with conditions favorable to growth and development. Prior to treatment, all but ten leaves were removed from each plant. This was done so as to have an index of growth in the unfolding of new leaves. Five concentrations of each material were used and the plants were individually treated by adding 10 ml. of the solutions poured over the plant and soil surface in one case and only over the soil surface in another (Table III).

When the material was applied only to the soil surface, the plants were not affected as much as when the application was made by pouring on both the plant and the soil. This was true with all the materials tested (Table III). The higher concentrations of 2,4-D caused severe injury to the entire plant, especially when the material was applied over both the plant and the soil. The other materials (IPC, DCU, EH-1, MH, and PE-TCA), although retarding growth at the higher concentrations, were not as injurious, because the plants eventually outgrew the effects of the chemicals.

Table III. The effect of 2,4-D, IPC, DCU, EH-1, MH, and PE-TCA on leaves, flowers and runners when applied to strawberry plants that had been preconditioned and all but 10 leaves removed. The data are the cumulative results up to 6 weeks following treatment with 10 ml. of the indicated concentration.

Amt. Appl. Per Plant (mgms.)	Material Applied over the Soil			Material Applied over the Plant		
	No. of Leaves Per Plant	No. of Flowers Per Plant	No. of Runners Per Plant	No. of Leaves Per Plant	No. of Flowers Per Plant	No. of Runners Per Plant
2,4-D						
0.0	17.4	18.9	8.3	18.6	17.0	7.5
2.5	15.0	19.3	7.5	12.3	6.6	3.0
5.0	17.0	4.0	7.6	3.7	0.7	1.0
7.5	11.3	2.3	4.3	2.0	0.0	0.0
10.0	12.7	1.0	5.2	0.7	0.0	0.0
12.5	7.0	0.3	3.1	0.0	0.0	0.0
IPC						
0.0	18.0	18.5	7.4	17.9	18.8	8.1
5.0	13.0	10.7	6.5	13.0	9.7	6.9
10.0	17.0	0.3	8.2	10.0	2.7	7.0
15.0	18.0	0.3	5.4	18.3	0.3	6.3
25.0	18.7	0.0	6.9	14.3	0.7	5.4

Table III (Continued)

Amt. Appl. Per Plant (mgms.)	Material Applied over the Soil			Material Applied over the Plant		
	No. of Leaves Per Plant	No. of Flowers Per Plant	No. of Runners Per Plant	No. of Leaves Per Plant	No. of Flowers Per Plant	No. of Runners Per Plant
DCU						
0.0	18.2	19.0	8.6	17.5	19.3	8.5
5.0	16.8	18.8	8.2	18.0	15.0	7.9
10.0	17.3	7.2	7.3	17.7	11.0	7.3
15.0	16.0	6.3	7.0	15.3	7.8	6.9
20.0	15.8	9.5	7.2	14.4	4.2	5.6
25.0	15.0	7.2	6.0	14.0	4.1	5.2
EH-1						
0.0	18.0	15.0	8.0	18.2	17.0	7.0
5.0	14.3	14.3	7.5	16.3	12.0	6.9
10.0	17.7	14.7	6.5	11.3	10.7	7.2
15.0	17.3	9.7	7.6	19.0	11.3	5.8
20.0	19.0	4.3	5.9	17.3	4.7	6.0
25.0	16.3	2.3	6.0	12.3	1.3	5.2
MH						
0.0	18.6	19.0	7.9	17.0	18.0	6.3
4.8	18.3	4.0	8.0	16.0	16.0	7.2
9.6	17.0	7.7	6.5	17.0	4.7	6.0

Table III (Continued)

Amt. Appl. Per Plant (mgms.)	Material Applied over the Soil			Material Applied over the Plant		
	No. of Leaves Per Plant	No. of Flowers Per Plant	No. of Runners Per Plant	No. of Leaves Per Plant	No. of Flowers Per Plant	No. of Runners Per Plant
MH						
14.4	21.3	3.7	5.9	13.3	0.3	5.2
19.2	16.3	3.0	7.3	16.7	2.7	4.0
24.0	18.3	4.0	5.2	15.0	0.3	4.2
PE-TCA						
0.0	18.6	19.2	8.4	18.2	18.5	8.4
5.0	17.4	17.0	8.3	19.3	17.2	6.9
10.0	16.1	12.3	7.9	15.5	15.0	7.1
15.0	15.5	8.2	6.7	16.3	11.4	5.7
20.0	13.2	2.9	5.5	14.5	9.7	6.0
25.0	9.0	2.3	5.2	15.3	5.5	6.3

Whether applied directly to the soil surface or to the plant, all the chemicals had an inhibiting effect on flowering (Table III and Figs. 7 and 8). The effect increased with increasing concentration, so that at the higher concentrations used, nearly all flowers were inhibited. At the lower levels of concentration, flowering appeared normal where EH-1, DCU and PE-TCA were used. The lower rates of the chemicals used in these tests approach actual herbicidal concentrations used in the field.[2] The data indicate that some of these materials (2,4-D, IPC and MH) could be used to advantage to reduce the number of flowers formed in the first-year strawberry bed, provided the right concentration of the chemical is used and it is applied at the proper time.

Runners were not adversely affected in these tests because they were produced about two months following treatments. The reduction of runners indicated is probably due to loss of vigor of the plant at the higher concentration (Table III).

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[2] Ten milligrams per square foot is equal to 1 pound per acre. Example: If a plant container with 0.25 sq. ft. surface area receives 10 milligrams, the rate per acre is equal to 4 pounds.

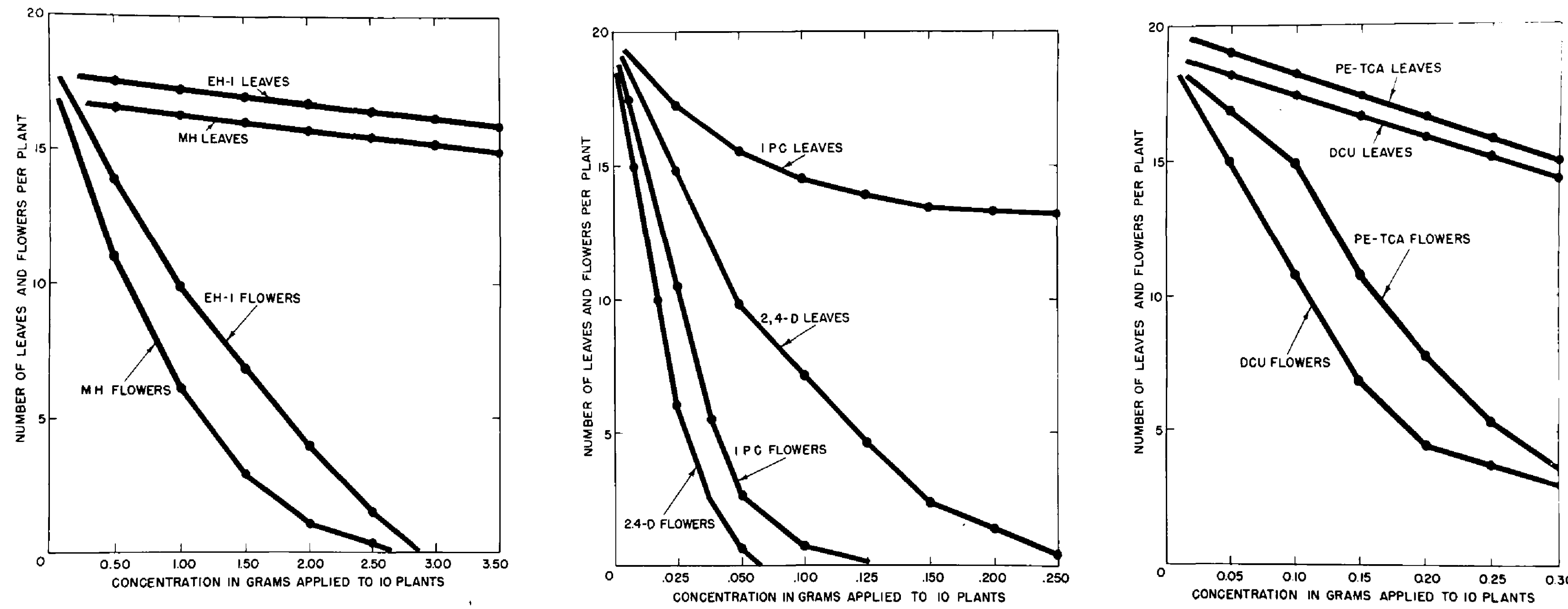

Fig. 7 The effect of 2,4-D, IPC, DCU, EH-1, MH, and PE-TCA at several concentrations on general growth and flowering of Premier strawberry plants. The data are the cumulative results for six weeks following treatment.

Fig. 8 The effect of 2 applications of 10 milligrams of IPC on Premier strawberry plants (left) early in flower development, and two untreated plants (right) showing flowers.

Effect of Chemicals Applied to Strawberry Plants in the Field

The materials, 2,4-D at 1/2 and 2 pounds, EH-1 at 2, 3 and 4 pounds, DCU at 3, 5 and 7 pounds, PE-TCA at 1, 2 and 3 pounds, and IPC at 5, 10 and 15 pounds per acre, were applied to a first-year planting of Premier strawberries on June 4 and July 18. The second application coincided with the time of runner formation. Since the plants were set May 20, these applications were made 15 and 42 days, respectively, following planting. The materials were applied at the rate of 40 gallons per acre of the spray. Each treatment was replicated four times and the data presented in Table IV are the averages of these replications.

DCU (dichloral urea) produced 96 per cent reduction of runners with two applications; however, the plants exhibited some retardation of growth for about six weeks following the last application. The injury occurred in the form of bronzing of the older leaves which probably interfered with normal photosynthetic function. The new leaves formed after the last application of DCU, however, appeared normal in color and vigor, so that at the end of the growing season the plants were as

Table IV. Effect of EH-1, IPC, 2,4-D, PE-TCA and DCU on runner inhibition and plant growth applied twice to Premier strawberries in the field. First application was made on June 4 and the second on July 18.

Materials	Pounds Per Acre	Per Cent Runner Reduction	Visible Effects on Strawberry Plants	
			Tops	Roots
Control	0	0.0	Normal	Normal
EH-1	2	6.0	Normal	Normal
EH-1	3	0.0	Normal	Normal
EH-1	4	6.0	Normal	Normal
IPC	5	33.0	Normal	Normal
IPC	10	46.0	New leaves slightly chlorotic	Normal
IPC	15	69.0	New leaves chlorotic	Normal
2,4-D	1/2	46.0	Normal	New roots slightly swollen
2,4-D	2	91.0	Some stunting	New roots swollen
PE-TCA	1	59.0	Normal	Normal
PE-TCA	2	77.0	Some marginal necrosis	Normal
PE-TCA	3	96.0	Some marginal necrosis	Normal
DCU	3	55.0	Normal	Normal
DCU	5	82.0	Slight leaf-bronzing	Normal
DCU	7	96.0	Slight stunting and leaf-bronzing	Normal

vigorous as control plants. The untreated plants had formed several runners producing a matted row in contrast to the spaced-row appearance of the treated rows (Table IV and Fig. 9). The lower concentrations of 3 and 5 pounds of DCU produced 55 and 82 per cent inhibition of runners, respectively. The toxic symptoms at these low rates were not as pronounced as at the high concentration.

PE-TCA (phenoxyethyl trichloroacetate) reduced the number of runners by 96 per cent with two applications of 3 pounds per acre without serious effects on the plants. Some toxic symptoms in the form of marginal necrosis were observed at this concentration. The symptoms were most severe on leaves which were present at the time of the last application, and in much lesser degree on leaves which were formed following the last application. By the end of the growing season these symptoms had disappeared. The lower concentrations of 1 and 2 pounds per acre of PE-TCA produced 59 and 77 per cent inhibition, respectively, without appreciable toxic effects on general plant growth (Table IV).

The chemical, 2,4-D, was also effective in inhibiting runners, especially at 2 pounds per acre; however, at this high

Fig. 9 The left row was treated with 2 applications of 3 pounds per acre of EH-1 and the right row with 2 applications of 5 pounds of DCU on June 4 and July 18. This was a first-year planting of the Premier variety.

concentration the plants were severely injured and a few failed to recover. The plants remained "stunted" for about 3 weeks following the last application, but appeared fully recovered at the end of the season. At this time the roots appeared to be swollen to approximately twice their normal diameter. This was most obvious near the root-tip extending toward the base for about one inch. The two applications of 1/2 pound of 2,4-D per acre, on the other hand, inhibited 46 per cent of the runners without any noticeable injury to plant growth (Table IV).

Considerable reduction in the number of runners was also obtained with two applications of IPC, especially at 15 pounds per acre. Some chlorosis on newly formed leaves was noticed at this rate. The plants, although showing some retardation of growth, soon recovered and appeared normal by fall. The 5- and 10-pound rate of IPC inhibited 33 and 46 per cent of the runners, respectively, and the plants soon recovered from the two applications of this chemical (Table IV).

Two applications of EH-1 (2,4-dichlorophenoxyethyl sulfate), at rates of 2, 3 and 4 pounds per acre, failed significantly to inhibit the strawberry runners of the Premier variety in the field. The plants treated with EH-1 were as vigorous, or more so, than the control plants.

Besides inhibiting strawberry runner plants to varying degrees, the chemicals used in these field tests also controlled the weeds to varying degrees, as previously reported (4). Since the land was required for other purposes, the plants were moved to another location, where they flowered and fruited in a normal manner, indicating that the chemicals had no delayed effects on the plants.

A second-year bed of several varieties was sprayed after harvest, but the data of those tests are not available. However, early observations in the fall of 1951 indicated that the results are comparable to those in the first-year planting.

A chart was prepared from the field data pertaining to the growth cycle of the strawberry plant (Fig. 1). The chart also indicates the approximate time to apply the chemical for maximum runner inhibition. The time to spray strawberry plants to reduce the number of runners will vary with the time of planting, the variety, and the location.

DISCUSSION

Experiments in the greenhouse and in the field clearly indicate that certain chemicals can be used to reduce the number of runner plants produced in some varieties of strawberries. Many strawberry varieties produce a superfluous number of runners to the extent that the plants tend to be overcrowded in the matted row which is formed. Varieties which have a tendency to produce fewer runners perhaps need not be thinned by hand or chemical means.

Some of the chemicals prevented runners from developing rather early in the bud stage. Apparently these buds are very tender and susceptible to these chemicals. DCU and PE-TCA were most effective in this respect. 2,4-D, if applied prior to initiation, evidently prevented the runner buds from forming, since they were not noticeable to the naked eye.

It is important to note that as the runners were inhibited, the number of succeeding crown-shoots was increased. Apparently, with the elimination of some of the runners from the mother plant, a condition was provided which favored crown-shoot development. It is safe to assume that the runner plant depends upon the mother plant for certain nutrients, at least until the runner plant is established on its own roots. Since the mother plant has fewer runner plants to feed, it is capable of producing more crown-shoots. A further explanation of an increase in crown-shoots with the elimination of runners is that the growth cycle of the plant is such that, rather than producing additional runners, crown-shoots are produced. Evidently the plant produces a certain number of runners followed by the production of crown-shoots. Obviously, the mother plant becomes more productive the more crown-shoots it produces, because each crown-shoot initiates flowers after it is formed, thus increasing the fruiting potential of the mother plant. The productivity of the mother plant which has been deprived of normal runner development is an important factor, aside from the other advantages derived from the use of chemicals in strawberry plantings.

With the use of various chemicals for the control of weeds in strawberry plantings, it appears feasible that with proper timing these materials can serve a twofold purpose: (a) to eliminate the weeds and (b) to inhibit strawberry runners. Some of the chemicals used in these tests are effective herbicides and others have shown promise of being effective in killing germinating seeds of both grasses and broad-leaved weeds—2,4-D being an example of the former, and DCU, and example of the latter. Many weed seeds germinate at the same time that runner-shoots are initiating, so that by properly timing the sprays the weeds could be controlled and the number of runner plants reduced.

The work so far completed indicates that strawberry runners are greatly reduced with two applications of the chemical (such as DCU or PE-TCA) in the field, whereas a similar application is not as effective under greenhouse conditions. The most likely reason for this is that strawberry plants (especially some varieties) do not respond satisfactorily to greenhouse culture. That is, the artificial conditions provided are not optimum for maximum runner production. Further, it is easier to predict runner initiation in the field than under greenhouse conditions, by the natural growth cycle of the plant. The sequence is more clear cut in the field. Runners initiate after flowering and fruiting, whereas in the greenhouse the processes are likely to occur simultaneously, especially with some varieties and with a long photoperiod that is provided too soon. For practical purposes, it is significant to note that the chemicals tested are effective in reducing runners under field conditions.

It was further found that two applications were required for most inhibitory effects of strawberry runners. Evidently an accumulative effect is produced with two applications as well as more complete contact with the tissues that produce the runners.

In the first-year strawberry planting the first application of the inhibiting chemical should be made immediately after the flowers have been removed. In many cases this may be the latter part of May or the first part of June, depending on the season, variety, and when the plants are set (Fig. 1). The second application should be made about one month later.

The fruiting bed also requires two applications of the chemical for maximum inhibition. The first application should be made after the fruit is picked and after the planting has been rejuvenated. This is often the middle of July in the northern states. This application is followed by a second spray about 3 or 4 weeks later (Fig. 1).

For practical use of these chemicals it seems advisable to use DCU at the rate of 5 pounds per acre, PE-TCA at 3 pounds, or 2,4-D at 1-1/2 pounds per acre, at each application. Since complete wetting of the foliage is essential, it is advisable to use around 50 gallons of the spray per acre. For best results the plants should be observed daily so as to determine when the first runners are forming. If a great number of runners are produced before material is applied, no favorable results can be expected.

In the greenhouse tests it was found that some of the chemicals had an inhibitory effect on strawberry flowers. Some chemicals produced no serious injury to the plants, but others were injurious to the entire plant (Fig. 7). The fact that flowers were inhibited has a practical importance in that perhaps these chemicals can be used to eliminate the flowers in the first-year planting. In that case the first application for runner inhibition in the first-year planting could be made before the flowers are removed. Or, perhaps three applications would be practical in the first-year planting—the first to remove the flowers and the next two for runner reduction. All these applications would keep most of the noxious weeds from becoming a problem.

SUMMARY AND CONCLUSIONS

1. Several chemicals (DCU, PE-TCA, 2,4-D, IPC, EH-1 and MH) were tested on strawberry varieties (Premier, Robinson, NY 23502, Sparkle, Red Star, and Fairpeake) for the effectiveness in inhibiting runner plants. Some plants were treated at the time of runner formation, while others were treated at the time of flowering to determine possible injury to flowers. Experiments were conducted both in the greenhouse and in the field.

2. DCU, PE-TCA and 2,4-D were most effective in reducing runner formation, whereas IPC and MH were less effective, depending on the concentration used. EH-1 did not significantly eliminate any of the runners from plants either in the greenhouse or in the field. The percentage reduction under greenhouse conditions ranged from 10 to 80 per cent, depending on variety and concentration, whereas under field conditions the reduction was greater.

3. For maximum inhibition of runners, two applications were needed at the time of actual runner initiation and formation.

It was found that timing the application of the chemical materials was extremely important. The first-year strawberry planting should be sprayed the first part of June and then again in July. The second-year, or fruiting bed, should be sprayed about the middle of July (or after rejuvenation of the planting) and then again about 3 weeks later (Fig. 1).

4. The concentrations that were most effective under greenhouse conditions (two applications of each) were as follows: DCU, 12 mgms. per plant; PE-TCA, 8 mgms. per plant; and 2,4-D, 2 mgms. per plant. Under field conditions the most effective concentrations per acre were: DCU, 5 pounds; PE-TCA, 3 pounds; and 2,4-D, 1-1/2 pounds. Ten milliliters per plant under greenhouse conditions, and 50 gallons per acre under field conditions, proved most effective.

5. There was a difference in varietal response. The Robinson and Premier varieties were not affected as much as the NY 23502. This probably is tied up with the number of runners produced by the variety, since the NY 23502 is a sparce runner producer, Premier, medium, and Robinson, very prolific.

6. Some injury in the form of marginal necrosis was observed at the higher concentration of PE-TCA, and some bronzing with DCU. The high concentrations of 2,4-D delayed and dwarfed the plants for about 3 weeks following each application. Some chlorosis appeared on the newly formed leaves on plants treated with IPC. No visible symptoms occurred from EH-1, except some temporary wilting.

7. The runners were inhibited in the early bud-stage of development, appearing as discolored buds and death of the growing point. The materials were effective on young runner-buds and on young runner-shoots less than one inch long. After the runner-shoot was over one inch in length, the chemicals had no effect.

8. The data obtained in the greenhouse and in the field show that runners can be reduced if the chemical is applied when the runners are being initiated or are in the bud stage. This method of reducing runners appears to be practical with varieties that tend to produce an excessive number of runners which causes overcrowding in the row.

9. Other chemicals may be more effective in inhibiting runners, since only a small number of chemicals were tested in these experiments. The tests described in this paper clearly demonstrate that with proper timing and correct concentration of certain chemicals, strawberry runner production can be controlled.

10. The materials that are effective in reducing runner formation are also effective in killing germinating weed seeds, and therefore serve a dual purpose.

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