A STUDY OF SOME OF THE EFFECTS OF CERTAIN ARYLOXY HERBICIDES ON STRAWBERRY PLANTS

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Ronald Wayne Campbell

AN ABSTRACT

Submitted to the School of Graduate Studies of Michigan State University in partial fulfillment of the requirements for the degree of

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A STUDY OF SOME OF THE EFFECTS OF CERTAIN ARYLOXY HERBICIDES ON STRAWBERRY PLANTS by Ronald Wayne Campbell

This study was an attempt to determine the influence of various formulations of 2,4-dichlorophenoxyacetic acid (2,4-D) and the related sodium, 2,4-dichlorophenoxyethyl sulfate (sesone), on yields and on the physiological and morphological development of strawberries. Only Blakemore variety plants were used.

The transpiration rates of plants growing in the greenhouse were not affected by treatments each of the amine salt,
at a rate equivalent to 1 pound per acre; the ethyl, butyl,
isopropyl or butoxyethanol esters of 2,4-D, at a rate equivalent to 0.5 pound per acre; and sesone, at a rate equivalent
to 6 pounds per acre. Transpiration rates were significantly
reduced when the ethyl and butoxyethanol esters were applied
to plants at rates equivalent to 1.5 pounds each per acre.
At that rate, both esters induced severe hyponasty of leaves
and closing of some of the stomata, which reduced the loss of
water vapor.

Five esters of 2,4-D (methyl, ethyl, butyl, butoxyethanol, and propylene glycol butyl ether forms) were applied
to strawberry plants growing in the greenhouse to determine
if the length and structure of the alcohol portion of the
molecule affected the activity of the ester. These esters

were formulated to possess the same 2,4-D acid equivalent. The dry weights of the shoots and roots of the plants treated at 1 milligram per plant were not significantly different from the unsprayed controls. There was no evidence of an exact relationship between the molecular weight of any ester and dry weight of the shoots and roots when esters were applied at this rate. However, spray applications of 4 milligrams per plant of the same materials significantly reduced the dry weights of the shoots and roots. This repressive effect on growth bore a definite relationship to the molecular weight of the ester. As the molecular weight increased, the dwarfing effect decreased.

The pentyl ester of 2,4-D was applied to plants growing in the field to study the effect of different dates of application on the relative growth and development of crowns and roots, as measured by dry weight. Spray applications of the pentyl ester reduced the dry weight regardless of the date of application; however, these sprays did not significantly change the proportion of crown to roots.

The ethyl, pentyl, and polyethylene glycol esters of 2,4-D, the amine salt of 2,4-D, and sesone were applied in the field to spring planted strawberry plants to determine their effect on runner plant formation and subsequent yield. Spray applications of each material were made in late spring, early summer, and late summer. Also three spray treatments were made with each material applied at the times just indicated. The results showed a highly positive correlation

(r = 0.959) between runner plant production and yield when plots receiving the single spray applications at 4, 8, or 16 weeks after planting were compared. All forms of 2,4-D applied in early summer most severely reduced the number of runner plants; this date coincides with most active runner plant initiation and formation. These results suggest the use of an amine salt preparation at the rate of 1 pound per acre to be more feasible than any of the ester formulations tested at 0.5 pound per acre for spring or summer applications to control broad-leaved weeds in strawberry plantings. The 2 and 4 pound rates of sesone were used without seriously affecting plant stand or yield.

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INTRODUCTION

In the growth and development of the strawberry plant two general phases, the vegetative and the reproductive, are involved. These phases are not clear cut and tend to overlap and vary greatly due to a variety of factors. The strawberry as grown commercially is propagated vegetatively by off-sets or by runner plants and thus the hereditary factors are transmitted directly from the mother to daughter plant. Except when mutations occur, the genetic composition of a variety or clone remains constant. Regardless of the habitat in which they are growing whether in a greenhouse or in a field, strawberry plants are affected by a complexity of environmental factors. These factors which influence both reproductive and vegetative growth, include light, temperature, available soil water and soil solutes, the physical nature of the soil, and plant spacing. Within the past ten years chemicals applied to strawberries to control insects, diseases, and those used to control weeds and to regulate runner plant formation may be added to this list of factors which influence vegetative and reproductive growth. Probably one most widely publicized chemical for weed control has been 2.4-dichlorophenoxyacetic acid (2,4-D).

A report by Hamner and Tukey (27) in 1944, to the effect that the selective plant-growth regulator 2,4-D would kill some weeds yet certain crop plants would remain unburt, stim-

ef crep preduction. Since Carlson (5) first reported on the pessibility of using 2,4-D for the centrel of weeds in strawberries, a number of chemical formulations of this material have preven effective in the centrel of some common broadleaved weeds in this crep. Though there may be a wide range in the susceptibility of different plant species to 2,4-D effects, it has been reported (64) that the growth regulating preperties are expressed at much lower concentrations than are the texic effects.

It has been shown that with proper timing and the correct concentration 2,4-D amine salt sprays can be used to central strawberry runner preduction (9). Other effects of this chemical upon the strawberry plants have been studied in a general way as reperted by Denisen (17), Carlson (7), Gilbert (25) and Viehmeyer (61). Hewever, these effects have not been shown to be related to a specific influence of the chemicals on the physiological and morphological development of the strawberry plant. As the 2,4-D compounds used for weed control have exhibited growth regulating properties (10), (44) and (64), it was assumed that certain formulations might have a greater unfavorable influence on plant growth and yield than others. Also, since the molecular structure of the various formulations are variable, it can be expected that the various formulations might differ in their influence on the physiological and developmental processes of the strawberry. Thus a study was undertaken to determine the influence of various 2.4-D

formulations and the related compound, sodium 2,4-dichlorophenoxyethyl sulfate (sesone), on (1) the transpiration rate of treated plants, (2) the time and extent of development of the root system, (3) runner plant formation and (4) yield.

REVIEW OF LITERATURE

The cultivated strawberry belongs to the family Rosaceae and the genus Fragaria.

It is a low growing, nearly evergreen perennial herb which is propagated easily by runners and seed. The vegetative portions of a strawberry plant include the crown, the runners and the roots.

The crown is first a short fusiform body which may later, by apical growth, according to White (62), become cylindrical and eventually fork into two or more divisions. Above ground, the crown is enclosed with leaves which closely encircle it for some three-fifths of its circumference.

Darrow (14) describes a runner as a much elongated stem with greatly lengthened internodes. The first node bears a solitary leaf which often remains rudimentary. A bud potentially capable of development as a crown or runner is borne in the axil of each such leaf. White (62) found after the runner has grown diagetropically for several centimeters, that its tip becomes negatively geotropic, turning up just beyond the second node and undergoing considerable thickening. It then puts forth adventitious roots and soon becomes established as a daughter crown.

Varieties of strawberries vary greatly in their ability to produce runners, according to Carlson (5). He lists the varieties Blakemore, Dunlap and Robinson as active runner pro-

ducers while the varieties Midland, Catskill and Fairfax produce comparatively few runners. Although the strawberry is considered a short-day plant Darrow (15) found that runners are initiated during long days by most varieties.

waldo (60) found that soil moisture had a definite effect on the number of runners formed during a growing season. In studying the effects of irrigation on runner production, he observed that with no irrigation there were considerably fewer plants per acre than when irrigation was used. Loree (38) observed that the nutrient level also had an effect on runner production. He found that the influence of applications of commercial fertiliser on increased runner production depended on the condition of the plants at the time of the application. Several workers have stressed the necessity of developing runner plants early in the season in order to obtain maximum production.

Strawberry roots of runner plants as described by Mann (41) are of two kinds, the adventitious or primary roots and the lateral or secondary roots. He reports that the adventitious roots which give rise to the entire root system of all except seedling plants develop apparently from the central cylinder of the crown probably from a group of cells which lie between pericycle and medulla. However, White (62) while agreeing that these roots come from the central cylinder suggests that they arise from the pericycle. Van Tiegham and Douliet (57) decided that the adventitious roots developed from the central cylinder only at the two sides of a median leaf trace.

As a new shoot or runner begins to grow, it was observed by Mann and Ball (40), that the large adventitious roots develop very rapidly. The crown of the young plant grows rapidly and additional adventitious roots form, usually in small groups. These roots are white in color with few branches and may develop a considerable length by the end of the growing season. During the summer, the older portions of these roots turn from white to yellowish brown and numerous fibrous laterals appear. New white adventitious roots are produced until growth stops in the fall.

Mann (41) found that the fibrous roots which consitute the bulk of the absorbing system of the plant in the spring and early summer become functionless as soon as new roots are developed in late summer. These functionless fibrous roots rapidly decay, and a new system of absorbing lateral roots is developed on the vigorous adventitious roots arising from younger portions of the rhisome, while the original main roots continue to increase in thickness. He describes the chief functions of the main adventitious roots as first, to penetrate the soil rapidly and to constitute a framework upon which the absorbing system of fine fibrous roots is built up to support the plant during the following season, and secondly, to develop specialized tissues which function mainly as storage and anchoring organs in the subsequent life of the plants.

It has been demonstrated by Tucker (57) that there is a steady increase in the bulk of the root system from the time

of planting in the spring to late in the fall. Maximum root growth occurs in the late summer and early fall. The most rapid development of roots generally follows an earlier increase in the crowns. Mormally the increase in the root system occurs approximately one month after the increase in the shoot.

It was found that the periods of new root formation follew periods of starch accumulation and a corresponding high percentage of dry matter in the plant as a whole. The development of roots at both periods is accompanied by a rapid disappearance of accumulated carbohydrates and a decrease in the percentage of dry matter of both roots and rhisomes.

A number of factors are known to affect the vegetative growth of the strawberry. The effect of the system of culture used on root distribution has been studied extensively. It has been shown by Schrader (51) that most of the strawberry roots are found in the upper 12 inches of the soil. The greatest concentration of roots is found in the upper three-inch sone. Roots are more concentrated in the region of greatest plant population under the matted row system of culture as well as in the immediate region of the spaced plant when a spaced system is used. This pattern follows into the lower layers of soil as well. Spaced plants develop a greater percentage of roots in lower soil layers than do the matted row plants. The greater root development of matted row plants before fruiting may at least be partially responsible for the smaller fruit size under the crowded matted row that many

strawberry varieties develop, compared to the larger fruit size from thinned rows.

Other comparisons of the root development of plants grown in the matted row system and spaced plants (58), show a significant increase in the size of the root systems expressed in dry weight of the plants grown under the spaced system. Similar relations were seen in the length of roots. Further, it was noted that the dry weight increase of roots in the matted rows ceased about September 1 while the roots of the spaced plants showed a continued increase until October 6.

The nutrient level of the soil has been shown by Gardner (24) to affect the extent of root development. A definite response to a complete fertilizer treatment regardless of time of application as compared to no fertilizer treatment was shown by the increased dry weight of roots grown under the matted row and the spaced plant system.

The removal of all Blakemore runners thereby fruiting only the original plants during the second fruiting year, was found by Crane and Haut (13) to result in much greater yields than were obtained from either a conventional renewal practice or by permitting the thinned rows to revert to a matted row condition. This increase in yield was primarily due to the fact that the thinned plants were able to accumulate larger leaf areas, root systems and food reserves as reflected by the dry weight data presented.

Since roots of plants are dependent on their shoots for the carbohydrates essential to growth, whatever affects photosynthesis and the use of carbohydrates in the shoot will affect also root growth. Reciprocally, any injury to or inadequacy of the root system will hinder shoot growth. Kramer (56) reports that root and shoot growth are rather closely correlated and, if the development of one is modified, growth of the other is likewise modified. Reduction in photosynthetic surface resulting from injury to leaves by hail, insects or fungi will be reflected also in reduced growth of the root system.

A comparison of the root and top development of 18 strawberry varieties by Hanson (30) showed considerable variation between varieties. In general there is a relationship between top and root development. Varieties with poor root systems have been reported by Shoemaker (52) to be shallow with little branching, to possess a larger percentage of dead roots and root tips, to have a limited spread, to lack root hairs and to show a general lack of thriftiness.

The use of chemical sprays on the shoots has been reported by Fults and Payne (23) as affecting the roots of the common bean. It was found that spraying bean shoots with DDT increased the number of branch roots.

The chemical, sodium 2,4-dichlorophenoxyethyl sulfate (sesone), has come rapidly to the fore as a weed-killer in strawperries (20), (35), (52). Data of its effect on runner formation have been reported by Carlson (9) and Denisen (17). This material, according to King (35), has little effect on plants until it comes in contact with the soil where it is

changed into a chemically active form by the soil microorganisms; then it can be absorbed by the plant roots. Audus (2) found evidence that the soil microorganisms acting upon this compound generated only one toxic compound which, due to its behavior, he thought to be 2,4-D acid.

Widespread use has been made of 2,4-dichlorophenoxyacetic acid (2,4-D) to control weeds in strawberry plantings since it was first reported as a strawberry herbicide in 1947 by Carlson (5). Numerous workers (5), (6), (25), (47), (54), (60) have shown that while varieties of strawberries differ in tolerance to the action of 2,4-D, these differences in tolerance did not appear important within the range of the concentrations necessary for satisfactory weed control. Carlson (6) suggested 1/4 to 1/2 pound of 2.4-D acid per acre. Davidson (16) applied 1/2 pound and 1 pound of 2.4-D acid in the forms of the sodium salt and an amine and reported that while the 1 pound rate produced slight formative effects, later growth and fruiting appeared normal. Gilbert (25) found that 2 pounds per acre of 2,4-D acid as a preplanting treatment followed by 1 and 1 1/2 pounds as post planting treatments gave good weed control without injury to the strawberry plants. Slife and Ball (54) who applied an amine at rates from 1/2 to 3 pounds of 2,4-D acid per acre on the variety Premier reported that the higher rates caused greater growth effects but that all treated plots were normal in appearance after one month. The isopropyl ester of 2.4-D at 1 pound acid equivalent per acre produced epinasty of the petioles and runners according to Denisen

(17). However, yields were not reduced significantly the following spring.

A beneficial reduction in runner plants was obtained by Carlson (9) when two applications of 2,4-D were made at the rate of 1 1/2 pounds per acre. He reported that the inhibiting chemicals had proved most effective when applied during the initiation and early differentiation of the runner. In first year plantings it was suggested that the first application should be made immediately after the flowers have been removed. A second application was suggested to be made about one month later. In fruiting beds the first application was suggested after harvest and after the planting has been rejuvenated. This application is followed by a second spray three to four weeks later.

This reduction in runner plants as a result of 2,4-D sprays was verified by Denisen (17). He suggests that a reduction of rooted runners of the plants sprayed with 2,4-D may result from the active material on the soil which may inhibit root primordia for several days after application.

The effect of .01 percent aqueous solutions of 2,4-D on the stem anatomy of selected species of plants has been reported by Skoog et al. (53). They found the most common responses to be a swelling of the stems and the presence of lateral roots in treated species which included Coleus, Verbena, and sweetpotato. In these plants the tissues responsible for proliferation and root formation were the cambium, phloem parenchyma, ray cells, and pericycle. It was

reported by Swanson (56) that applications of 2,4-D acid greatly stimulated root formation in the young kidney bean.

Lee (37) found that 2,4-D applications to corn resulted in an abnormal development of brace or aerial roots including fasciation, to produce a collar like effect around the base of corn plants. Hansen and Buckholz (29) took note of the reduction of primary root length in several inbred lines of corn treated with 2,4-D. The younger portions of roots of strawberry plants sprayed with 2,4-D amine at 2 pounds per acre were observed by Carlson (6) to swell to approximately twice their normal diameter. He reported the plants as being severely stunted for about three weeks following the spray application but that the plants appeared fully recovered at the end of the season.

The effect of spray applications of 2,4-D acid on the rate of transpiration of bean seedlings was investigated by Brown (4). He found a definite decrease in the rate of water loss in the sprayed seedlings and reported this to be associated with the marked curling of the leaves, the decrease in the rate of leaf expansion, the decrease in the rate of accumulation of water and solid materials within the leaves, and an ultimate wilting of the leaves. Carlson (5) reported a slight browning of the roots of some strawberry plants which he attributed to 2,4-D treatments.

Sprays applied during bloom may result in the production of button berries according to Hibbard and Hemphill (32).

Carlson (6) found that 2,4-D sprays had an inhibitory effect

on strawberry flowers and suggested that the material might be used to eliminate the flowers in first year plantings.

The toxicity of 2,4-D in the soil according to Ahlgren et al. (1) is directly affected by (1) decomposition by microorganisms, (2) leaching, (3) absorption of the soil colloids, and (4) soil reaction. They suggest the first two factors are directly related to moisture and temperature.

All are influenced by soil texture, structure, and the amount of organic matter present.

Harvey and Robbins (31) concluded that warm, moist soils generally hasten the decomposition of the 2,4-D making it non-toxic to plants as these conditions favor the growth and multiplication of the microorganisms which are able to decompose the chemical. They also reported that more 2,4-D is retained by heavy soils than by a light one.

It was found by Hanks (28) that water leached from soils treated with 2,4-D contained phytotoxic amounts of 2,4-D.

Weaver (63) determined that in the soil both cation exchangers and anion exchangers absorbed much 2,4-D acid and also much of its salts. He found that when 2,4-D is absorbed it is relatively non-toxic. It was observed by Crafts (11) that the rate of decomposition of the 2,4-D molecule is increased by an increase in soil acidity. Therefore toxicity remains for a longer time in soils high in lime.

Many experiments indicate the similarities between plant hormones and 2,4-D compounds. The latter are reported by Crafts (10) and Lucas and Hamner (39) as being readily absorb-

ed by leaves and are apparently taken up and transported most readily in the nondissociated form. Mitchell and Brown (44) found that after having been absorbed by leaves, 2,4-D in association with sugars is transported away from the leaf, on which it has been applied, to other parts of the plant.

Numerous references are available on some effects of 2,4-D on the strawberry and other plant species. No studies were found relating the effects of the molecular structure of 2,4-D compounds to the physiological and morphological development and yield of the strawberry. This information is lacking also for sesone which has been reported by Audus (2) as being decomposed to 2,4-D acid by the soil microorganisms.

MATERIALS AND METHODS

Experiment One

The transpiration studies were conducted with the Blake-more variety. The plants were dug in the fall after they had become dormant and were stored at 33° F. for a minimum of eight weeks or until they were planted in the greenhouse.

In February 1954, six weeks prior to the start of the experiment, the plants were removed from storage and planted in five-inch unglazed clay pots. The roots were pruned uniformly and all plants were pruned to four leaves per plant. The soil mixture used consisted of three parts of loam, one of sand, and one of peat. At the beginning of the experiment the average moisture content of the soil was 55 percent of its moisture holding capacity. The plants were well established by the time the experiment began. The unglazed pots in which the plants were grown were lowered into one-gallon tin cans onto blocks that held the top of the clay pots to a level one-fourth inch above the top of the cans. The space between the surface of the potting soil and the top of the pots was partially filled with coarse sand.

The potted plants were sealed in the cans with waterproof oil cloth covers. Two holes, each one-half inch in diameter, were cut in the covers. One hole in the center of the cover allowed for fitting the covers around the crown of the plants and the second hole was used for addition of water to the pot.

The covers were placed around the plants by slitting the covers from one side to the center hole and later sealing with waterproof tape. Figure 1 shows typical plants sealed in this manner.

Water added to the pots during the course of the experiment spread through the sand layer and uniformly into the soil below. The space inside the cans around the pot provided for aeration. At the close of each experiment, the plants were found to have their roots well distributed throughout the soil mass.

The plants were weighed daily and water was added every third day to restore them to their original weight. A solution balance with an accuracy of ± one gram was used for these measurements.

A continuous record of the bench level temperatures was recorded by a thermograph throughout the experiment.

Twelve days after the spray applications were made, the leaves from all plants were removed, blueprinted and the image areas measured with a planimeter. In calculating transpiration rates, the water loss was based on the area of leaf surface at the close of the experiment. This procedure was used based on the assumption made by Miller (41) that any change in leaf area throughout the experiment is proportional for all plants and any increase in weight is very insignificant, when compared to the large loss in weight due to transpiration.

The greenhouse study on transpiration was divided into two parts. Forty-eight plants were used in the first study. The daily weight losses were recorded for a ten-day period



Figure 1. Typical plants sealed in the manner used in the transpiration studies.

prior to treatment with the chemical. On the basis of the water losses during this period, the plants were divided into three levels: low, medium, and high. Two plants were then selected from each "level" group so that each treatment group consisted of six plants. Each plant received 10 milliliters of solution. Except for the sesone which was poured onto the soil in each pot, the 2,4-D materials were applied as sprays using a half-pint atomizer. Each plant received 10 milliliters of solution. The oil cloth covers were removed during the spraying treatment and the discharge was directed so that all of the drip fell into the pots.

Materials included in this study were the ethyl, butyl, isopropyl, and butoxyethanol esters of 2,4-D at 0.7 millimerams per plant; the amine salt of 2,4-D at 1.4 milligrams per plant; and sesone at 4.2 milligrams per plant. All rates of the chemical materials presented in this paper are based on the active ingredient in each compound.

In a second test, strawberry plants were divided also as described in the first study into three levels of transpiration based on the rate of water loss established during a preliminary period and six plants were used per treatment. The treatments were made up of the ethyl and butoxyethanol esters of 2,4-D used at the rates of 0.7, 1.4, and 2.1 milligrams per plant, making six groups of treated plants.

l Ten milligrams per square foot is equal to 1 pound per acre. Thus if a plant container with 0.20 square foot surface receives 2 milligrams, the rate per acre is equal to 1 pound.

Supplemental light was applied as needed to produce a twelve-hour photo-period, which has been shown by Darrow (15) to be optimum for general growth of strawberry plants.

Experiment Two

Greenhouse Studies

An experiment was conducted in the greenhouse to study the effect of various 2,4-D ester formulations on the time and extent of root development of strawberry plants.

Blakemore plants which had been dug the last of October 1952 and stored at 33° F. were planted the following March in one-gallon cans in the greenhouse and provided with conditions favorable for growth. After they were established, and prior to treatment, all but six leaves were removed from each plant in order that the plants would be as uniform as possible initially.

Five 2,4-D esters of varying molecular weight were used to determine if the length and structure of the alcohol portion of the molecule would affect the activity of the ester. These esters were formulated to possess the same 2,4-D acid equivalent and included the methyl, ethyl, butyl, butoxyethanol, and the propylene glycol butyl ether forms. Twenty plants were used for each chemical treatment with each plant receiving 10 milliliters of solution. Each ester was applied at concentrations of 1 and 4 milligrams per plant thus making a total of ten groups of treated plants. These materials were sprayed over the plants with a hand atomizer, with the

excess being allowed to drop on the soil surface around the plant. A second application was made at these rates 18 days after the first application.

The plants were allowed to grow for 60 days following the first treatment after which they were removed from the cans and washed carefully. The roots were cut from the crown and, together with the above-ground portion of the plant, were dried in an oven at 85° C. Thus, the dry weights of the shoots and roots were obtained.

Field Studies

In this experiment the pentyl ester of 2,4-D was applied at different times during the growing season to determine the effect of the spray on root growth and development. Dry weights of the crowns were obtained as a measure of possible effects of sprays on growth of the above-ground portion of the plant.

Approximately twelve hundred Blakemore plants were set April 2, 1953 at intervals of 24 inches between plants and 48 inches between rows. The plants were divided into replicates of 75 plants each. Four treatment blocks each consisting of four replicates were selected at random. Three different times of application of the pentyl ester of 2,4-D were compared. Three blocks were sprayed with 0.5 pound acid equivalent on May 11, two blocks on July 6, and one on September 1. No runner plants were allowed to root. Plants were lifted in batches of 20 at intervals of four weeks beginning on May 11 and continuing through October 4. Control plants were also

lifted at each of the six sampling dates. In lifting the plants, a cylinder of soil 18 to 24 inches in diameter and about 15 inches deep was removed. The plants were then soaked in a tub of water and the soil was carefully washed from the roots. The leaves were all removed so that only the petiole bases remained attached to the crown. The roots were cut from the crowns and both crowns and roots were placed immediately into a drying oven at 85° C. Dry weights of the crowns and roots were recorded.

Experiment Three

The influence of various forms of 2,4-D and of sesone on the inhibition of runner plants has been reported by Carlson (9) and Denisen (17) but little information is available on the relationship between runner plant set and yield as affected by these materials. This study was designed to determine the effect of several 2,4-D formulations and of sesone on runner plant production in a first year planting and on subsequent yields the following spring.

On April 15, 1952 Blakemore strawberry plants were set 18 inches apart in the rows spaced at four foot intervals. The planting included the control plants and a total of 29 treatment blocks, each consisting of four replicates of 20 plants per replicate. Each herbicide was applied as a single spray on May 13, four weeks after planting; on June 10, eight weeks after planting; and on August 5, 16 weeks after planting. An added treatment was included for each herbicide con-

sisting of three spray applications made at 4, 8, and 16 weeks after planting.

The chemicals included the ethyl ester, the pentyl ester, the polyethylene glycol ester, and the amine salt formulation of 2,4-D. This made a total of 16 different treatments of 2,4-D which were compared. The ester formulations were applied at the rate of 1/2 pound acid equivalent and the amine salt at 1 pound acid equivalent per acre. In the sesone study, plots received three applications of spray and other plots single spray applications at the times indicated for the 2,4-D chemicals at rates of 2, 4, and 6 pounds per acre, making a total of 12 sesone treatments. All the chemicals were applied by knapsack sprayer at a volume of 40 gallons per acre.

At the end of the growing season, a count was made of the total number of runner plants produced in each replicated plot. During the harvest season of 1953, yield records were taken from all the plots.

RESULTS

Experiment 1

In the first phase of the transpiration studies, Blakemore runner plants, pruned to four leaves and transplanted into five-inch pots, were divided into high, medium, and low
level groups based on their rates of transpiration determined
in a preliminary study.

Chemicals used included the ethyl, butyl, isopropyl, and butoxyethanol esters of 2.4-D applied at 0.7 milligrams per plant, the amine salt of 2.4-D at 1.4 milligrams per plant and sesone at 4.2 milligrams per plant. The plants were weighed daily and water added every third day to restore them to their original weight. The rate of transpiration was expressed as grams per square centimeter of leaf area. An analysis of variance of the data indicated that there were no significant differences in transpiration rates between the plants treated with the various chemicals or between the sprayed plants and the unsprayed control plants. The average rate of transpiration per unit of leaf area decreased after spraying in all cases except on those plants to which sesone was applied. However, none of the changes were great enough to be statistically significant. When plants of various levels of transpiration were considered, significant differences were found between plants of some levels (Table 1).

It was found that in the high level group those plants

Table 1. The effect of various forms of 2,4-D and sesone on the daily transpiration rates of Blakemore strawberry plants. The plants were divided into three levels on the basis of the rate of transpiration during a ten day period prior to spraying

: Actual chemical : Mean rate of transp :applied per plant: (grams/centimeters					
Treatment	: (milligrams)	: High	Medium	Low	
Sesone	4.2	2.13	1.80	1.08	
Butoxyethanol ester 2,4-D	0.7	1.51	1.57	1.02	
Butyl ester 2,4-D	0.7	1.44	1.49	1.21	
Ethyl ester 2,4-D	0.7	2.04	1.52	1.19	
Isopropyl ester 2,4-D	0.7	1.82	1.48	1.29	
Amine salt 2,4-D	1.4	1.48	1.45	1.27	
Control	0.0	1.78	1.51	1.31	

L.S.D. 5% - 0.69

sprayed with sesone had a transpiration loss significantly greater than the plants sprayed with the butyl ester form of 2,4-D. However, none of the water losses of any of the treated plants were significantly different from the controls.

There were no significant differences between treatments or between treatments and controls in either the medium or low level groups of plants.

When the plants of the various levels were compared, it was found that the low level plants transpired significantly less than the high level plants receiving the chemical treatments sesone and the ethyl ester form of 2,4-D. There were no other significant differences between plants of the different levels treated with any of the spray materials.

The results of the second phase of the study pertaining to the influence of certain chemicals on the transpiration rate of strawberries using the ethyl ester and butoxyethanol ester of 2,4-D at the rates of 0.7, 1.4, and 2.1 milligrams per plant on Blakemore plants are given in Table 2. Here also the transpiration rates of the plants had been determined during a ten-day preliminary period and each treatment contained plants with similar transpiration rates.

The transpiration rates of the plants treated with 0.7 and 1.4 milligrams of each of the ethyl and butoxyethanol esters were not significantly different from those of the controls. The plants treated with each 2,4-D ester at 2.1 milligrams per plant showed a significant reduction in transpiration rate when compared with the controls and with the other

Table 2. The effects of various concentrations of the ethyl and butoxyethanol esters of 2,4-D on the daily transpiration rates of Blakemore strawberry plants.

Treatment	: Actual chemical : :applied per plant: : (milligrams) :(Average rate of transpiration (grams/centimeters ² /day)
Ethyl ester 2,4-D	0.7	2.67
Butoxyethanol ester 2,4-D	0.7	2.33
Ethyl ester 2,4-D	1.4	2.42
Butoxyethanol ester 2,4-D	1.4	2.31
Ethyl ester 2,4-D	2.1	1.89
Butoxyethanol ester 2,4-D	2.1	1.87
Control	0.0	2.44

treatments. In all instances the transpiration rate was higher for the plants receiving the ethyl ester 2,4-D spray than for those sprayed with the butoxyethanol ester form although these differences were not significant.

All 2.4-D treatments caused marked formative response similar to that described by Zimmerman and Hitchcock (66). The degree of response induced was in direct relationship to the concentration of 2.4-D applied. The plants sprayed with the lowest concentration. 0.7 milligrams of the ester forms. showed only slight curvature of the younger leaves and petioles. This effect had nearly disappeared at the end of ten days. The plants sprayed with 1.4 milligrams of the ester forms were intermediate in the amount of hyponasty induced. The young leaves were quite severely curved upward toward the midribs while most of the petioles exhibited some twist-The plants sprayed with 2.1 milligrams of the ester forms exhibited extreme formative effects. The petioles were twisted quite severely and there was considerable hyponasty exhibited by the leaves. This condition persisted until the end of the experiment and it made blueprinting of the leaves difficult.

A microscopic examination showed a number of stomata closed in those areas where the formative effects were pronounced. This would explain in part the decrease in transpiration noted when 2.1 milligrams of the esters were applied to the plants.

Experiment 2

Greenhouse Studies

A study was made to determine the effect of various 2,4-D ester formulations on the time and extent of root development of Blakemore runner plants growing in the greenhouse after having been transplanted from the field into gallon cans.

Five esters of 2,4-D, the methyl, ethyl, butyl, butoxyethanol, and the propylene glycol butyl ether esters, were
each applied. Concentrations each of 1 and 4 milligrams of
each material were used with 10 milliliters of solution being
sprayed over the plant. All plants received a second application at these rates 18 days after the first.

The spray applications of all of the ester forms produced considerable formative effects on the leaves and petioles of treated plants. All the leaves of the plants receiving the first spray applications March 6 at the 1 milligram concentration showed hyponastic effects. The younger leaves curled considerably more than the older ones; all of the petioles showed some twisting. These formative effects had completely disappeared when the second spray applications were made on March 24, 18 days later. Following the second applications, hyponasty of the leaves and twisting of the petioles as described above were noted. The younger leaves of the plants sprayed with the ethyl and butyl ester forms showed some curling at the end of 18 days indicating the dwarfing effect to be greater than after the first spray application. With the ex-

ception of persistence, it was impossible to visually detect any pronounced difference in induced formative effects on the plants treated with the 1 milligram concentrations of the various 2.4-D esters.

All ester sprays applied at the rate of 1 milligram per plant, excepting the propylene glycol butyl ether ester, decreased the dry weight of the roots and shoots when compared with the controls (Table 3). However, none of these differences were statistically significant. Further, there were no significant differences between treatments. The average dry weight of the shoots and the roots of the plants receiving the butyl ester spray were respectively 2.59 and 1.40 grams. with a shoot-root ratio of 1.85. This compared with an average dry weight of 2.74 grams for the shoots and 1.52 grams for the roots of the plants sprayed with the propylene glycol butyl ether ester form, and a shoot-root ratio of 1.80. The plants sprayed with the butyl ester formulation were the smallest and those sprayed with the propylene glycol butyl ether ester the largest of all the treated plants. The shootroot ratio of the plants sprayed with the latter material was the lowest of all the spray treatments applied at the 1 milligram concentration. This ratio indicated a proportionately larger root system in those plants sprayed with the propylene glycol butyl ether ester of 2,4-D than was found in the other sprayed treatments. This was in addition to the absolute difference in size as mentioned above.

Malformation of the leaves and petioles of the plants re-

The effects of two applications made 18 days apart of 2,4-D esters of varying molecular weight on growth of the roots and shoots of Blakemore plants under greenhouse conditions. The chemicals were applied at the rate of 10 milliliters per plant. Table 3.

+	*	Actual Chemical Applied Per	Average Dry (grams)	ry Weight : ms)	Shoot-Root Ratio
MA COLTAIN	. Weight :	: Plant (milligrams): :		Shoots	
Methyl ester 2,4-D	234	1.0	1.45 1.09	2.70 1.63	1.86 1.49
Ethyl ester 2,4-D	248	0.1	1.42	න - භ අ භ අ	1.86
Butyl ester 2,4-D	276	000	4.0	0 00 C	1.85
Butoxyethanol	320	0 00	4 4.	0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0	1 L C
Propylene glycol butyl ether ester 2,4-D	8. 48.8	2	20°-1	0 0 1) (
Control	• •	0.4	1.52 1.34	2. 3. 4. 4. 4. 4. 4. 4. 4. 4. 4. 4. 4. 4. 4.	1.67
1	•) 	1.49	2.74	1.84
L.S.D. at 1% between	between treatment av	average average	0.15	0.81	

ceiving 4 milligrams of the various ester forms was very pronounced. As a result of the first spray application on March 6, hyponasty occurred in all leaves. Many of the younger leaves were severely curled with the leaf margins folded toward the midrib. The petioles were badly twisted: in some cases the leaves were completely inverted for a few days. A definite dwarfing effect was noted on all sprayed plants. A differential browning of the margins of some of the leaves was noted. The tips of the leaves were most commonly injured with the browning seldom extending more than three-eights of an inch from the apex of the leaf. For the most part the necrosis was confined to the serrations of the leaflets. This type of injury is shown in Figures 2 to 6. Considerable leaf curvature was still in evidence 18 days after the first spraying although new leaves were being produced and most of the petioles had straightened. In every case, the second spray application made on March 24 at the rate of 4 milligrams per plant produced effects very similar to those caused by the first application. On some plants young leaves which had just emerged from the crown were killed. In general the injury to both the leaves and petioles was more severe thus reflecting the im reased concentration. The dwarfing effect was pronounced.

The 4 milligram applications produced rather severe injury to the roots (Figures 7 and 8). The youngest roots were more susceptible to injury than were the older ones. Also, injury was observed to be greatest in the youngest or tip



Figure 2. The effect of two applications of 4 milligrams each of the butyl ester of 2, 4-D, made eighteen days apart, on the petioles and leaves of Blakemore strawberry plants. The two upper plants were untreated.



Figure 3. The effect of two applications of 4 milligrams each of the ethyl ester of 2, 4-D, made eighteen days apart, on the petioles and leaves of Blakemore strawberry plants. The two upper plants were untreated.



Figure 4. The effect of two applications of 4 milligrams each of the propylene glycol butyl ether ester of 2, 4-D, made eighteen days apart, on the petioles and leaves of Blakemore strawberry plants. The two upper plants were untreated.



Figure 5. The effect of two applications of 4 milligrams each of the butoxyethanol ester of 2, 4-D, made eighteen days apart, on the petioles and leaves of Blakemore strawberry plants. The two upper plants were untreated.



Figure 6. The effect of two applications of 4 milligrams each of the methyl ester of 2, 4-D, made eighteen days apart, on the petioles and leaves of Blakemore strawberry plants. The two upper plants were untreated.

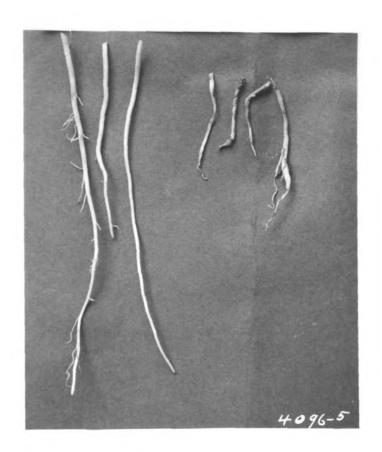


Figure 7. The primary roots on the right are from Blakemore strawberry plants that received two applications of 4 milligrams each of the butyl ester of 2, 4-D. The sprays were applied eighteen days apart. The roots on the left are from untreated plants.

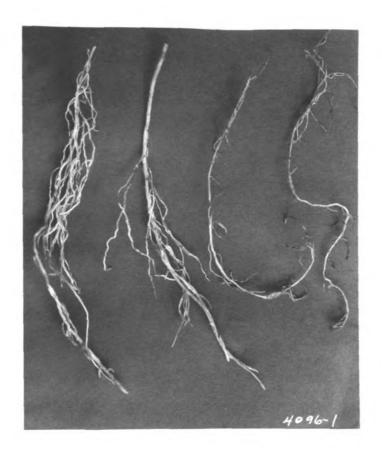


Figure 8. The roots on the right are from Blakemore strawberry plants that received two spray applications of 4 milligrams each of the ethyl ester of 2, 4-D. The spray treatments were made eighteen days apart. The roots on the left are from untreated plants.

portion of the individual root. Secondary roots were killed back more severely than the primaries. Little growth was noted until three weeks after the second spray application. The plants sprayed with either the methyl or ethyl ester formulations appeared to be more severely injured than the plants sprayed with the other ester forms. This is reflected by dry weights of the treated shoots as seen in Table 3.

All of the esters applied at the rate of 4 milligrams per plant significantly decreased the dry weight of the roots and the shoots when compared with the controls.

The average dry weights of the roots and shoots of the plants treated at the higher or 4 milligram rate with the methyl ester form were 1.09 and 1.63 grams respectively. This was significantly less than the average dry weights of the roots and shoots of the plants sprayed with three of the ester formulations. The average dry weights of the roots and shoots. for the plants treated with the various 2,4-D forms were as follows: butyl 1.24 and 1.90 grams, butoxyethanol 1.32 and 2.08 grams and propylene glycol butyl ether 1.34 and 2.24 grams. The weights of the roots are listed first. The average dry weights of the roots of the plants sprayed with the ethyl ester was 1.14 grams which was significantly less than that of the plants sprayed with either the butoxyethanol or propylene glycol butyl ether forms. It was found that the average dry weight of the shoots of the plants sprayed with the ethyl ester was 1.68 grams. Thus, these shoots were significantly smaller than those sprayed with either the butyl. the butoxyethanol or the propylene glycol butyl ether esters. The butyl ester spray treatment decreased the average dry weight of the roots of sprayed plants when compared to those plants treated with either the butoxyethanol or the propylene glycol butyl ether esters, although this reduction was not significant. However, it was found that the shoots of the butyl ester treated plants were significantly smaller, being 0.18 and 0.34 grams lighter than those of the plants sprayed with the butoxyethanol and the propylene glycol butyl ether forms.

The average dry weights of the roots and shoots were less in all the treatments when the plants received 4 milligrams of active ingredients as compared to 1 milligram, indicating a positive relationship between concentration and growth inhibition.

The differences in average dry weights of the roots and shoots between the plants treated with 1 milligram and 4 milligrams of the three esters of lowest molecular weight, the methyl, the ethyl and the butyl forms were highly significant. For the plants receiving 1 milligram of the methyl ester the average dry weight of the roots and shoots were 1.45 and 2.70 grams respectively or 0.38 and 1.07 grams more than for the plants treated with the same material at 4 milligrams concentration. When the average dry weights of the plants sprayed with the ethyl form at 1 and 4 milligrams were compared, the roots of the plants receiving the lower concentration were on the average 0.25 grams lighter and the

shoots 0.97 grams lighter than those plants sprayed at the 4 milligram concentration. An average dry weight of 1.40 grams and 1.24 grams each was obtained for the roots of the plants receiving 1 milligram and 4 milligrams in that order of the butyl ester formulation. The average dry weight of the shoots were 1.90 and 1.24 grams for the plants sprayed with 1 and 4 milligrams respectively of the same ester.

The plants receiving 4 milligrams each of the higher molecular weight esters, the butoxyethanol or the propylene glycol butyl ether forms, produced shoots with an average weight of 2.08 and 2.24 grams. This was a highly significant reduction of .41 and .50 grams respectively of the shoots of butoxyethanol and the propylene glycol butyl ether sprayed plants as compared to the plants treated with these esters at the rate of 1 milligram. The average weight of the roots of the plants treated with the butoxyethanol ester at 4 milligrams was 1.32 grams or .09 grams less than those plants receiving 1 milligram of this material; this difference was not significant. However, the average dry weight of the roots of the plants receiving 4 milligrams of the propylene glycol butyl ether ester was 1.34 grams as compared to 1.52 grams for the plants treated with 1 milligram. This difference was significant.

These data as presented indicate a positive relationship between the concentration used and the effects of the 5 esters of 2, 4-D upon growth of the plants as reflected by the dry weights of the roots and shoots. With the exception of the

roots of the plants sprayed with the butoxyethanol form, the differences in average dry weights of the roots and shoots between the plants treated with 1 milligram and 4 milligrams of each of these esters were highly significant. A more definite relationship between the molecular weight of the ester and phytotoxicity was obvious in those plants receiving the 4 milligram applications than in those sprayed with 1 milligram. As the molecular weight of the ester increased the average dry weight of the roots and shoots increased in every instance. This relationship was not as absolute in those plants sprayed with the different esters at a concentration of 1 milligram.

A comparison of the shoot-root ratios showed that the 4 milligram application of all the esters reduced the average dry weights of the shoots proportionately more than they affected the roots (Table 3). Further, it was noted that, with the exception of the methyl and ethyl esters, the shoot-root ratio increased with the increase in molecular weight of the chemical. Apparently with the rise in molecular weight, the total dwarfing effect became less as indicated by the increase in total dry weight and the growth of the shoots was inhibited less in proportion to the roots. The 1 milligram application appeared to affect the plants less than the heavier concentrations of 4 milligrams of the various esters of 2,4-D, as the shoot-root ratios were far less variable. The ratios of most of the treated groups were similar to that of the controls. The effect of some of the

2, 4-D esters on the shoot and root development can be seen in Figures 9 and 10.

Field Studies

The pentyl ester of 2, 4-D was applied at the rate of 0.5 pound per acre to a first year planting of Blakemore plants at different times during the growing season in order to see how the material affected the growth of the roots and crowns.

The experiment was planned so that the influence of different numbers of spray could be determined. Comparisons were made of the effect between single, double and three-spray applications. The effects of the spray applications at different dates on the growth of crowns and roots as expressed by total dry weights is shown in Figure 11 and in Table 4. For convenience of reference the plants sprayed May 11 were designated as Group I, those sprayed May 11 and July 6 as Group II, the plants receiving 3 sprays, one each on May 11, July 6 and September 1 are referred to as Group III and the controls as Group IV.

Some twisting of the petioles occurred following each 2, 4-D application. Many of the sprayed leaves showed some formative effects, with the younger leaves showing considerable hyponasty. Numerous leaves were rather severely injured as a result of the May and July spray applications due probably to the abnormally high temperatures experienced. Considerable necrosis was observed at the edges of many leaves and several young leaves were completely killed following these



Figure 9. The plant on the left was treated with two applications each of 4 milligrams of the ethyl ester of 2,4-D eighteen days apart. The plant on the right was not sprayed. These plants are of the Blakemore variety.



Figure 10. The plant on the left received two applications each of 4 milligrams of the propylene glycol butyl ether ester of 2,4-D, eighteen days apart. The plant on the right was not sprayed. These plants are of the Blakemore variety.

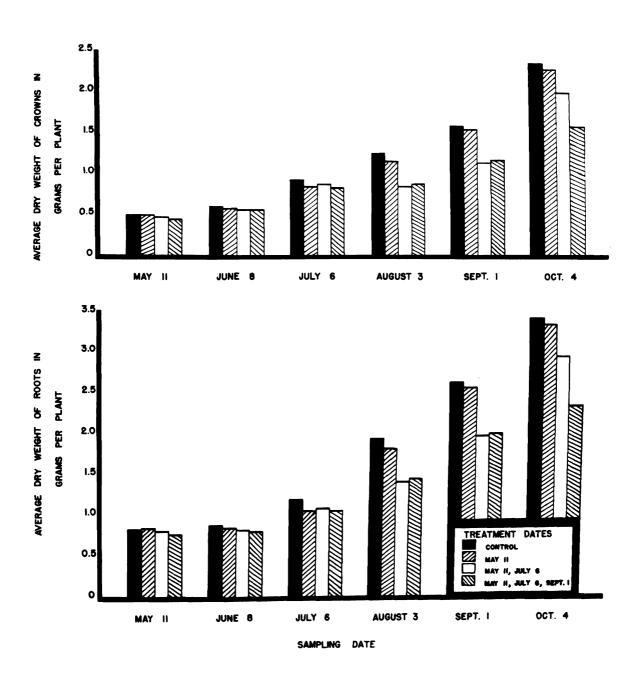


Figure 11. The effect of sprays, of the pentyl ester of 2,4-D at 0.5 pound per acre, on the growth of crowns and roots of Blakemore strawberry plants. Spray applications were made on May 11, July 6 and September 1.

The ordered array of treatment means of the dry weights in grams for roots and crowns of Blakemore strawberry plants sprayed with the pentyl ester of 2,4-D at the rate of 0.5 pound per acre. Table 4.

May 11	ונ	- Tuy	- B	#[6]		Sampling Dates	Dates			400	
treat-	1	1.000		t The		Tangus t	0	nendec	T JECT	- Jeconer -	- J9
ment:	mean	ment :	mean	ment:	mean :	ment:	meen :	ment:	mean :	ment :	mean
Roots											
 -	88	IV	•86	IV	1.17	ΙΛ	1.91	ΙΛ	2.63	IV	3.38
IV	.81	н	* 88	II	1.06	н	1.77	н	8.57	н	3.32
II	* 64.	II	ns •81	н	ns 1.03	III	1.43	III	1.99	Ħ	* 26° 2
	.77	III	90	III	1.04	II	an 1.39	II	ns 1.94	III	2.30
2. 2. 2. 2. 2. 2. 2. 2. 2. 2. 2. 2. 2. 2	at .03		•03		•05		•05		90•		90•
Crowns	;	į) 		•		
→	• 6	ΙΛ	•28	ΙΛ	.91	ΙΛ	1.23	IV	1.57	ΙΛ	2.33
IV	•49	н	.57	H	* 25	н	1.13	н	1.53	н	2.27
II	.47	II	na •56	н	* &	III	* 46 *	III	1.17	II	1.99
	•45	III	•56	III	ns -81	II	8a 88	II	1.14	III	1.57
200	at .02		80°		50.		0.3		0.03		90•
I SPI III SPI IV COY	Sprayed May Sprayed May Control	444	and July 6	. 6 and September 1	36r 1						

application value although

for the 0.66 greater which the me 0.82 greater plants

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May

applications. Damage to the leaves after the September application was much less than noted after the first two sprays.

Although each spray application produced a dwarfing effect in every instance, the plants recovered and the deformative effects disappeared within about two weeks after spraying.

By June 8, the mean dry weights of the crowns and roots for the Group IV plants, the controls, were 0.59 grams and 0.86 grams in that order. These weights were significantly greater than those for the other 3 groups of plants each of which received a spray on May 11. On this date for Group I the mean weight for the crowns was 0.57 gram and for the roots 0.82 gram, for Group II 0.56 gram and 0.81 gram, and for Group III 0.56 gram and 0.80 gram. Although these 3 groups of plants were smaller than the controls, as indicated by the mean weights of the crowns and roots, no significant differences in size were apparent between the 5 groups of plants which had each received a spray application on May 11.

The samples taken July 6 indicated that there was a significant increase in size of both crowns and roots in all plant groups as compared with those plants weighed June 8. The mean weight of the crowns of Group IV plants was 0.91 gram which was significantly greater than the 0.84 gram recerded for Group II, the 0.82 gram for Group I and the 0.81 gram for Group III plants. The mean weight of crowns for the Group III plants was significantly less than the mean weight of the crowns of the Group II plants. This difference may have been due to sampling error since the number of sprays

and kind of spray received by both groups were identical at the time the weights were determined. In August the average dry weights of the crowns and roots of the control plants were found to be 1.23 and 1.91 grams each.

The average dry weights of the Group I plants sprayed only on May 11 were considerably less than those of the controls; but, these plants were much larger, as indicated by mean dry weight, than the Group II and Group III plants each of which received sprays on May 11 and July 6. The mean weights of the crowns and roots of the Group I plants were 1.13 and 1.77 grams respectively. For the Group II plants these figures were 0.82 and 1.39 grams. The mean weight of crowns for the plants in Group III was 0.84 gram and for the roots 1.43 grams.

The mean weights of the crowns and roots of the Group IV, the control, on September 1 were still significantly greater than those of the Group I plants although the differences which were 0.04 gram for the crowns and 0.06 gram for the roots had lessened considerably. The mean weight of the crowns for the Group III plants was 0.40 gram less than the controls and for the Group II plants 0.43 gram less. The mean weight of the roots of the Group III plants was 0.64 gram less and of the Group II 0.69 gram less than the mean weight of the roots of the control plants.

On the final sampling date, October 4, the difference in the average dry weights of crown and roots between the Group IV plants or controls and the Group I plants which received a single spray on May 11 was not great. The mean weight for the crowns and roots of Group I were 2.33 and 3.38 grams respectively while the mean weights for the Group I plants were 2.27 grams for the crowns and 3.32 grams for the roots. This difference in weight was barely significant. Both groups of plants, however, were considerably larger than the remaining two groups of plants. A significant difference was now apparent between the average dry weights of the Group II plants sprayed on May 11 and July 6, and the Group III plants which received sprays May 11, July 6, and September 1. The latter plants were considerably smaller with a mean weight of 1.57 grams for the crowns and 2.30 grams for the roots as contrasted with comparable weights of 1.99 and 2.92 grams for the crowns and roots of the Group II plants.

The crown-root ratio showed a uniformly steady increase in all treatments for the first three sampling dates (Table 5). On July 6, the third sampling date, the crown-root ratios had increased significantly in all treatments including the controls. The ratios on this date were 0.79 for the plants each of Groups I and II and 0.78 for Groups III and IV. This suggests that the most rapid development of roots generally follows an earlier increase in weight of the crowns. The increase in the root system followed the increase in the crowns about a month. No effects of spray treatment on the crown-root ratios were evident at this time. On August 3, the fourth sampling date, an abrupt drop in the crown-root ratio was noted in all groups. There was a decrease of 0.15 in the crown-root

ester of 2,4-D on the The average dry weights The effects of various applications of the pentyl crown-root ratio of Blakemore strawberry plants. of crowns and roots are presented in Table 4. Table 5.

4 2 4 2 4 2 4 2 4 2 4 2 4 2 4 2 4 2 4 2			Sampl	Sampling Date				
	May 11	May 11 : June 8	July 6	: August	3 1 8	: July 6 : August 3 : September 1 : October 4	: Octo	er 4
May 11	09•	69•	e.79	•64		.60		68
May 11, July 6	•59	69.	•79	•59		• 59	•	. 68
May 11, July 6, Sept. 1	• 58	•70	•78	• 58		6 9	•	89
Control	•60	69•	•78	• 64		99	.70) <u>o</u> l
Total Date Means	2.37	2.17	3.14	2.46		2.38	2.74	4
L.S.D. 5% - 0.16								

ratio of the Group I plants, a decrease of 0.20 for Group III plants, a loss of 0.19 for the Group III plants and a value of 0.14 less for the Group IV plants than was obtained on July 6. These decreases in the crown-root ratio were significant only for the plants of Group II and III but barely missed significance in the other two groups. By September 1 the crown-root ratios were: for the plants of Group I 0.60, for Group II 0.59, for Group III 0.59, and for Group IV 0.60. A reduction of 0.04 was noted in the crown-root ratio for the plants each of Groups I and IV when compared to these same values of the same groups August 3. The crown-root ratios for the plants of Groups II and III remained the same as these obtained the previous month. The ratios of all the groups were now significantly less than at the beginning of the experiment on May 11.

During the period July 6 to September 1, the proportion of root to crown increased markedly in all groups regardless of treatment. The greatest development of adventitious or primary roots was observed during this interval, while much of the root growth during the prior months had been the origin and development of the secondary or "feeder" roots. Although the differences were not significant, the plants of Groups II and III both of which received a second pentyl ester spray on July 6 showed lower crown-root ratios on August 3 than the plants of the other two groups not receiving the sprays on this date. This would indicate the tendency of the sprays applied July 6 to check the growth of the leaves and crowns

proportionately greater than the growth of the roots. The roots increased in dry weight considerably, apparently at the expense of the above ground portions of the plant. The toxic effects of the sprays evidently affected the roots relatively less than the crowns, possibly for the most part indirectly, by reducing the growth of the leaves and crowns.

As indicated previously, there was only little or no decrease in crown-root ratios of the various groups of plants from August 3 to September 1. This would indicate that root formation had slowed somewhat during this period.

When the samples were taken October 4, the crown-root ratios of all the plant groups had again increased suggesting that proportionately the crowns had increased in dry weight at a more rapid rate than the roots. At this time the crown-root ratio of the three groups of plants receiving the pentyl sprays at different dates were identical at 0.68 and were only slightly less than the ratio of 0.70 for the controls. At no time in this experiment were significant differences in crown-root ratio found between any of the treatment groups, including the controls at the same sampling date. This would indicate that the sprays under the conditions of this experiment did not greatly effect the relative growth of the crowns and roots.

Experiment 3

The materials, ethyl, pentyl, and polyethylene glycol esters of 2,4-D at \frac{1}{2} pound, the amine salt of 2,4-D at l pound, and sesone at 2, 4, and 6 pounds per acre were applied to a spring planting of Blakemore strawberries. Spray applications of each material were made four weeks after planting, eight weeks after planting, and 16 weeks after planting.

Three-spray applications of the chemicals at the rates listed above were made also, with each material being applied at each of the three dates. This experiment was designed to compare the effect of various 2,4-D formulations and of sesone applied at several concentrations on the yield as affected by the number of runner plants produced.

A definite relationship between dates of spray treatment and the number of runner plants produced was noted (Table 6). These data show significant differences in runner plant set and also in yield between plants treated each at 4, 8, and 16 weeks after planting. The average number of runner plants in the control plots was 311 and these plants produced an average of 16 quarts.

All of the 2,4-D ester sprays caused a significant reduction in plant stand and in yield as a result of the spray application made May 13, four weeks after planting when compared with the controls.

The plants sprayed with the pentyl ester form and those sprayed with the polyethylene glycol ester produced significantly greater numbers of runner plants and significantly

A comparison of the effects of the time of application of single sprays of 2,4-D and sesone and of three-spray applications of these chemicals on the production of runner plants and yield of the Blakemore strawberry. These data are the average number of plants and the average yield in quarts per four 20-foot plots. Table 6.

	Rate	'			Time	er er	Treatment		Weeks at	after Plan	Planting	
	Per	'•• '		4	••		8			1	4.	8, 16
Materials	Acre (1bs.)		Plant Stand		Yield:	Plant Stand	: Yield		Plant : Stand :	Y1.01d		Y101d
Ethyl ester 2,4-D	Ď		179		14.57	122	11.82	N	217	15.55	9 4	4.89
Pentyl ester 2,4-D	ស្		195		14.82	116	12.05	ıΩ	232	15.72	55	5.17
Polyethylene glycol ester 2,4-D	ស្		205		15.15	148	13.12	N	249	16.17	69	6.47
Amine salt 2,4-D	1•0		254		15.97	243	15.83	ю	308	15.60	249	15.67
Sesone	8.0		308		16.57	306	15.77	7	316	16.15	288	16.13
Sesone	4.0		307		16,35	293	15.85	ιΩ	307	15.75	255	15.62
Sesone	0•9		304		15.95	998	14.25	ID.	287	15.65	199	13.42
Check	0.0		211		16.00							
L.S.D. Plant	Plant Stand 5% - 14.0	58	14.0]	11;	1% - 18	18.78	Yield 8	50	- 0.41;	- 0.41; 1% - 0.55	55	

higher yields than those plants sprayed with the ethyl ester of 2,4-D. The plots receiving the polyethylene glycol form produced an average of 205 runner plants and 15.15 quarts of berries as compared to the pentyl sprayed plots with an average of 195 plants and a berry yield of 14.82 quarts. The ethyl spray application resulted in an average plant stand of 179 runner plants and a yield of 14.57 quarts of berries. This is in agreement with the results of the greenhouse study in Experiment 2, where the low molecular weight ester forms Were found to be more phytotoxic than the esters of higher molecular weight. The 2,4-D amine spray applied at this date significantly reduced the plant stand without causing a decrease in yield when compared to the unsprayed control plots. Apparently the decrease in the number of plants was beneficial in that the competition between the roots of runner plants was lessened. The number of berries was reduced but the size of the berries was increased in these plots.

Plants sprayed with sesone four weeks after planting did not differ materially from the control plants in the number of rooted runner plants produced regardless of the application rate used. The average yield of 16.57 quarts from the plants sprayed with sesone at the rate of 2 pounds per acre was significantly higher than the controls, whereas, the production of the plants sprayed at the rate of 4 and 6 pounds was not greatly different from the control.

With the exception of the sesone spray at the rate of 2 pounds per acre, all sprays applied June 10, eight weeks after planting, resulted in a decrease in plant stand when compared with the plants sprayed May 13, four weeks after planting, and with the controls. An explanation of the general reduction of runner plants is that this treatment date coincided with the period of most active runner production.

Carlson (9) found that two applications of 2,4-D per acre inhibited 46 percent of the strawberry runners from forming on sprayed plants. The first spray was applied immediately after harvest. It was during this time that the greatest activity in runner initiation and formation was noted.

All of the plants receiving the 2,4-D ester sprays on June 10 showed a significant reduction in runner plants produced and in yield when compared to those plants treated May 13 with the same materials. The plants treated with the ethyl and pentyl esters of 2,4-D produced a significantly smaller number of runner plants than those plants sprayed with the polyethylene glycol ester, indicating the greater phytotoxicity of the low molecular weight esters. This was reflected also in the significantly lower yields obtained from the plants treated with either the ethyl or pentyl esters.

While the plants sprayed with the amine salt showed a decrease in plant stand and yield as compared with the plants sprayed May 13 with this material, the yield was not significantly different from the controls despite a nearly 22 percent reduction in runner plants. This is further indication of the relationship between plant stand and yield.

The spray applications of sesone at 2 pounds per acre

did not significantly alter the average number of runner plants produced when compared with the plants sprayed with this material at the same rate four weeks earlier on May 13. However, the plants treated with 4 pounds, produced an average of 293 runner plants which were significantly fewer than for the controls or for the plants sprayed with 4 pounds of sesone on May 13. Neither of the spray applications of sesone made at the 2 or 4 pounds per acre rate, 8 weeks after planting, reduced the yields the following spring when compared to the controls. The plots receiving an application of sesone at 6 pounds per acre showed an average reduction of 38 runner plants and of 1.70 quarts when compared with the plants treated four weeks earlier.

In those plots receiving the 2,4-D ester spray applications August 5, 16 weeks after planting, both the yield and plant stand were significantly higher than found for those plots treated with the same materials May 13 and June 10.

The average plant stand for the control plots was 311 plants which was significantly greater than for the plots receiving sprays. Also, a significant difference in the number of plants produced was observed between the plots sprayed with the different esters. The average number of runner plants for the plots treated with the ethyl form was 217, for the plots receiving the pentyl sprays 232 plants, and for the polyethylene glycol sprayed plots 249 plants. When compared with the controls, the yields were found to be reduced significantly only by application of the ethyl ester of 2,4-D.

These data continue to show the phytoxicity of the esters to be related to the molecular weight. The plants sprayed with the ethyl ester were significantly lower in runner plant production and yield than the plants sprayed with the polyethylene glycol ester. Plants sprayed with the pentyl ester had an average runner plant production of 232 plants and a yield of 15.72 quarts. These values were significantly less than the averages of 249 plants and 16.17 quarts obtained for the plants sprayed with the higher molecular weight material. the polyethylene glycol ester. It should be noted that the ester sprays, applied on August 5, although all inhibited runner plant production significantly, did not reduce the plant stand to the extent as did the materials applied May 13 and June 10. This increase in plant stand could be attributed to the fact that by August 5 the period of most active runner initiation was passed and thus the 2,4-D sprays were less effective on inhibiting runner plant production. The fact that the August 5 spray applications did not excessively inhibit runner plant production is shown by the average yields of the plants sprayed with the pentyl ester and those sprayed with the polyethylene glycol ester which were 15.72 quarts and 16.17 quarts. These yields were not significantly different from the average yield of the controls which was 16.00 quarts. The beneficial effects of greater plant spacing are reflected by these yields.

An average of 308 runner plants was established in the plots receiving the amine salt sprays on August 5, which was

significantly greater than the 254 plants and 243 plants produced in the plots sprayed respectively May 13 and June 10 with the same material. In fact, there was no significant difference in the plant stand of the plots receiving the amine preparation 16 weeks after planting and the control, further indications that the period of most active runner initiation was past. Neither was the yield significantly different than that of the control, suggesting that the spray application of this material at this time affected neither the runner plant production nor yield.

The only significant differences observed in the plots receiving sesone were in the plots to which the 6 pound application was made. Both the yield and average plant stand of 287 plants and the average yield of 15.65 quarts were significantly higher than those of the plots receiving this material at the same rate eight weeks earlier. On June 10 the average plant stand was 266 plants and the yield was 14.25 quarts. Only significant differences in plant stand existed between the controls and the plots receiving sprays at the rate of 6 pounds of sesone on August 5. While the number of runner plants produced was barely significantly lower than the controls, there were no significant differences between yields.

When combination treatments consisting of sprays at each of the 3 dates were made with each material, all of the 2,4-D ester sprays drastically reduced the number of runner plants produced. The average number of runner plants produced in the plots sprayed with one of the three esters were for ethyl sprayed plots 46 plants, for those treated with the

pentyl ester 55 plants, and for those receiving polyethylene glycol sprays 69 plants. The yields of these plots were also much below that of all the others treated as well as the control plots. The average yield per 20-foot plots were 4.99 quarts for the plots treated with the ethyl ester, 5.17 quarts for the plots receiving sprays of the pentyl ester, and 6.47 quarts for the plots treated with the polyethylene glycol ester. There were significant differences apparent between the effects of the three esters on plant stand and yield. Plants treated with the polyethylene glycol ester sprays produced a significantly higher number of runner plants and yield than those plants receiving three-spray applications of the ethyl and pentyl esters.

significantly reduced the average plant stand from 311 runner plants to 249 when compared with the controls (Table 6).

However a like comparison indicated that the yields of the sprayed plots were not significantly lowered. There were no significant differences in plant stand between plots receiving the three-spray amine application and those sprayed with the amine formulation once each on May 13 and June 10. There were, however, significantly fewer plants produced than in those plots receiving the amine spray on August 5. It was interesting to note that none of the plots receiving the 2,4-D amine sprays differed significantly in yield from each other or from the controls. The plots producing the greatest number of runner plants had the lowest yield of all plots

treated with the amine sprays although as previously stated, these differences were not significant. It appears that the extra runner plants produced in these plants rather than increasing yields actually tended to decrease them slightly.

All of the three-spray treatments of sesone reduced significantly the number of runner plants formed when these plots were compared to the controls and the other plots receiving the sesone sprays (Table 6). These values were 288 plants for the plots receiving the three-spray applications at the rate of 2 pounds, 255 plants for those plots treated at the rate of 4 pounds, and 199 plants for the plots receiving the three-spray applications of sesone at the rate of 6 pounds per acre. Only those plots receiving 6 pounds of sesone were significantly lower in yield than the controls. Both the plots receiving the 2-pound and 4-pound rates of sesone, produced significantly less berries than the plots receiving the same concentration on May 13. The berries from the plots receiving three sprays of sesone at the 4-pound rate were larger than the berries from the control plots again emphasizing the chemical inhibition of runner plants which favorably affected plant spacing.

A comparison of averages for all treatments shows a close relationship between plant stand and yield (Table 7). The correlation of the number of runner plants with the yield was highly significant (r = 0.985) (Figure 12). Plants sprayed with the amine salt of 2,4-D produced fewer runner plants but had a higher average yield than those sprayed with

Table 7. A comparison of the effects of sesone and various formulations of 2,4-D used for weed control upon the runner plant production and subsequent yields of the Blakemore strawberry.

Chemical	:	Rate Per Acre (pounds)	:	Mean Plant Stand	:	Mean Yield (quarts)
Ethyl ester 2,4-D		•5		141.6		11.73
Pentyl ester 2,4-D		•5		149.9		11.94
Polyethylene glycol ester 2,4-D		•5		167.9		12.72
Amine salt 2,4-D		1.0		261.5		15.76
Sesone		2.0		304.5		16.13
Sesone		4.0		290.5		15.89
Sesone		6.0		264.0		14.81
Check		0.0		311.0		16.00
L.S.D. between	n tr	eatment av	verage 5% 1%	7.44 10.01		0.07 0.10

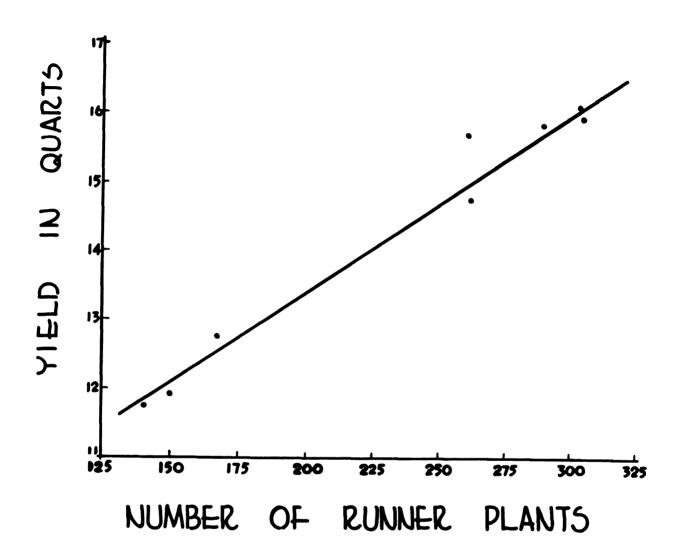


Figure 12. Regression of number of runner plants on the yield in quarts of Blakemore strawberry plants. These are averages for 20 foot plots.

(Y = 0.02650X + 8.11) (r = .985)

6 pounds of sesone. Although the amine salt formulation sprays contained twice as much 2,4-D acid equivalent than did the ester formulation sprays, a comparison of the average plant stand showed that plots treated with the various ester formulations had a highly significantly reduction in plant stand when compared with plots treated with the amine formulation. The plants in the ester sprayed plots were considerably less productive than those plants in the plots treated with the amine formulation.

When only the single spray applications made 4, 8, or 16 weeks after planting were compared, an even closer relationship between plant stand and yield was observed (Table 8). The correlation of the number of runner plants with the yield was highly significant (r = 0.959) (Figure 13). The average plant stand of those plots sprayed with 6 pounds of sesone was greater than those sprayed with the amine salt of 2,4-D. The yield was lower. Berries produced on all the plots sprayed only once with 2,4-D were larger than those sprayed with sesone and those produced on the control plants, thus reflecting the effect of the inhibition of excessive runner plants by the 2,4-D treatments.

When comparing all of the ester spray treatments with respect to time of application, it was found that all of the spray treatments applied 16 weeks after planting or on August 5 had the least effect on runner plant stand and yield (Table 6). Further, the plots sprayed 8 weeks after planting on June 10 showed the greatest reduction in runner plant

Table 8. The effect of three applications of various 2,4-D formulations and of different concentrations of sesone on stand of runner plants and subsequent yield of Blakemore strawberries. The treatments of 2,4-D and sesone were made 4, 8 and 16 weeks after planting.

Chemical	: Rate : Per Acre : (pounds)	MeanPlantStand	: :	Mean Yield (quarts)
Ethyl ester 2,4-D	•5	172.6		13.98
Pentyl ester 2,4-D	•5	181.0		14.19
Polyethylene glycol ester 2,4-D	•5	200•6		14.81
Amine salt 2,4-D	1.0	268.3		15.80
Sesone	2.0	310.0		16.16
Sesone	4.0	302.3		15.98
Sesone	6.0	285.6		15.28
Check	0.0	311.0		16.00

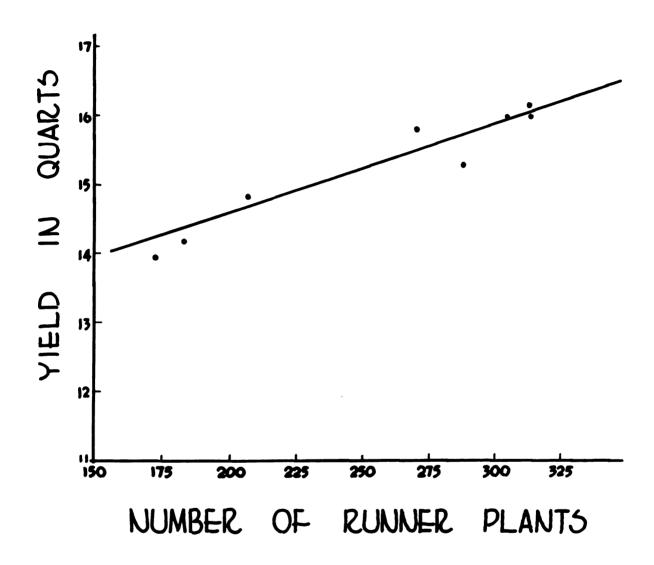


Figure 13. Regression of number of runner plants on the yield in quarts, of Blakemore strawberry plants. These values are averages of 20-foot plots.

(Y = 0.01383X + 11.77) (r = .959)

production and yield in all instances of any of the plots receiving only one spray. The plots sprayed 4 weeks after planting on May 13 were intermediate in their response to the ester sprays which is indicated by runner plant production and yield.

The differences between time of application were highly significant. It has been suggested earlier that the inhibition of strawberry runner plants was greatest if certain herbicides were applied when the initiation and development of runner plants was most rapid. This period of greatest runner plant activity would begin about the middle of May, reaching its peak about the third week in June and then gradually decreasing during the rest of the growing season. Therefore, time of application could be the explanation of the relative effect of the sprays applied May 13, June 10, and August 5 on runner plant production.

August 5 with the ethyl form of 2,4-D was barely significantly lower than for the control plants, while the plots receiving the pentyl or polyethylene glycol esters did not vary significantly in yield. The plots receiving the last two materials showed the beneficial effects of greater plant spacing by the greater size of the berries as compared with the control. Where the runner plant inhibition was excessive, as was true for all plots receiving the three-spray applications of each ester, a drastic decrease in yields resulted (Table 6).

The plants sprayed on different dates with the amine form

reflected the seasonal responses in runner plant production similarly to those plants receiving the ester sprays. The differences in runner plant production, however, were barely significant. Runner plant inhibition was greatest as a result of the June 10 spray, less severe in the plots sprayed May 13, and least in the plots sprayed August 5. The yields were not significantly different between plots treated on different dates, treated with different chemical formulations, and the controls. As stated previously, the yields from the plants receiving the three-spray treatment of the amine salt were not significantly lower than those of the controls.

There were no significant differences in runner plant production between the plots receiving sesone at the 2 pound per acre rate on different dates. The plant stand was barely significantly reduced in the plots receiving 4 pounds of sesone on June 10 when compared with plots receiving the same material on the other two dates. This reduction in plant stand was not reflected in yield. The plants sprayed June 10 with 6 pounds of sesone produced a significantly lower number of runner plants and berries than the other plots receiving the same treatment in May or in August. The plots receiving three applications of 6 pounds of sesone at 4, 8, and 16 weeks after planting were greatly affected as evidenced by the average number of runner plants produced and the subsequent yields which were 199 plants and 13.42 quarts. Although sesone applied as single sprays at the rate of 6 pounds per acre reduced the plant stand significantly when

applied 8 weeks and 16 weeks after planting, the yields were reduced only by the treatment 8 weeks after planting, as previously reported. The accumulative effect of the three-spray treatment was apparently sufficient to reduce both runner plant stand and yield.

DISCUSSION

In the greenhouse transpiration studies, it was found that none of the chemicals, all members of the 2,4-D family, when applied at the rates normally used for weed control in strawberries, affected the transpiration rates of strawberry plants (Tables 1 and 2).

However, when the ethyl and butoxyethanol esters of 2,4-D were applied to the plants at the rate equivalent to 1.5 pounds per acre or three times the amount normally employed to control weeds in strawberry plantings, the transpiration rates were significantly lowered (Table 2). Similar results were obtained by Brown (4) working with bean plants. He found that 2,4-D sprays on bean leaves brought about a decrease in the transpiration rate during the three days immediately following treatment. Mitchell (45) reported a reduction of water loss from detached tops of kidney bean seedlings that had been treated while intact with chlorine-substituted phenoxy compounds.

The leaves of the strawberry plants sprayed with the high concentration equivalent to 1.5 pounds per acre of the ethyl and butoxyethanol esters of 2,4-D exhibited pronounced formative effects, curling severely after treatment. During this period, the affected leaves were quite crisp and brittle. A possible explanation for this condition is that the 2,4-D caused some of the stomates to close thus resulting in a definite increase in the turgor pressure of the

cells. Microscopic examination of strips of epidermis taken from treated leaves showed some stomatal closure. It has been reported by Ferri and Raclid (19) that the stomata of several species of plants closed at least partially following soil treatments with 2,4-D. Treatment of the leaves or the soil with 2,4-D was followed by partial stomatal closure according to Bradbury and Ennis (3). They suggested, on the basis of evidence obtained, that stomatal closure in treated leaves was a direct effect of the growth-regulator on the leaves rather than an indirect effect on the waterabsorbing mechanism of the roots.

It is realized that greenhouse conditions are considerably different from those encountered in the field. The lack of control of environmental conditions would make this type of study difficult in the field. However, there is no reason to believe that the results obtained in the greenhouse were materially different from what could be expected in the field.

When the effect of various 2,4-D ester formulations on the vegetative growth of strawberry plants was compared, a direct relationship between toxicity and length of the carbon chain of the alcohol was noted. The short chain esters were more phytotoxic than the esters of higher molecular weight. Evidence of this was the greater formative effects, increased hyponasty and petiolar curvature, as well as the decreased dry weight of the roots and shoots of the plants sprayed with the short chain esters (Table 3). It has been

suggested by Robbins, Craft and Raynor (49) that, when a long chain alcohol is used to formulate a 2,4-D ester, the high molecular weight of the alcohol might dilute the toxic group thus causing the compound to be less toxic than one formed from a short chain alcohol.

The increased phytotoxicity of the short chain esters may in part be due to the absorption of the volatile vapors through the stomata. It has been established that in general the greater the molecular weight of the ester, the lower the volatility. Marth and Mitchell (42) have reported the methyl ester of 2,4-D as being the most volatile of a number of ester formulations tested. They found also that the ethyl. butyl and isopropyl esters were more volatile than the esters of higher molecular weight. Mullison (46) exposed tomato. bean and cotton plants to esters of low molecular weight and observed that a number of them were sufficiently volatile to cause decided plant responses. He reported that as the number of carbon atoms in the aliphatic portion of the 2,4-D ester is increased the volatility decreases. He further observed that an alkanolamine salt and the sodium salt of 2,4-D were non-volatile, as determined by the responses of the exposed plants.

It was noted in these experiments that all of the esters used reduced the dry weight of the roots and shoots of the strawberry plants and that this reduction was greatest in those plants sprayed with the esters of low molecular weight. Further, on a percentage basis, the plants treated

with the short chain esters showed a greater reduction in the dry weight of the shoots as compared to the roots of the plants than those plants sprayed with the high molecular weight solutions (Table 3). It is possible that this differential effect on the dry weight of the shoots might have been due to either a physical or chemical difference in the ester. It has been reported by Frear (21) that esters of an aliphatic nature can penetrate the cuticle of plants readily but once inside the leaves, they do not enter the aqueous phase in any appreciable amount. He suggests such forms of 2,4-D to be effective in killing the leaves of plants, but that they are not translocated as well as the salts or esters formed from higher alcohols which are soluble in both water and lipoids.

When the pentyl ester of 2,4-D was applied to a first year planting of Blakemore plants at 3 different dates during the growing season, it was observed that each spray while decreasing the total dry weight of the plants did not equally affect the crown-root ratio (Tables 4 and 5). A rather uniform increase in crown-root ratios for the first 3 months indicated that the above ground portions of the plants were increasing faster than the roots. The spray applied in May did not alter this relationship. In August however, a definite drop in crown-root ratios was observed in all plots including the unsprayed controls. This suggests a continued growth of the root system following a decline in crown growth, and is in agreement with findings reported by

Mann (41) and Mann and Ball (40).

While all plants showed a definite drop in crown-root ratio in August, those plants receiving a pentyl ester apray application 4 weeks earlier in July had a lower crown-root ratio than the unsprayed plants. although this difference was not significant. This lower crown-root ratio observed in the sprayed plants in midsummer suggests that at this stage spray applications of the pentyl while decreasing the size of the crown and roots had a relatively greater effect on decreasing the size of the crown. This would seem to indicate that, while the action of the ester may have been systemic, the toxic effect was not uniform throughout the sprayed plants. Since each pentyl ester spray application appeared to inhibit leaf growth and development for 10 to 14 days, it is conceivable that some translocation of carbohydrates to the roots continued during this period. This may have accounted for the greater increase in dry weight of the roots. It was during this midsummer period that the most rapid development of the primary roots was observed. Prior to this time most of the root growth consisted of the initiation and development of the secondary roots. The pentyl ester applications evidently were more toxic to secondary roots than to the primary roots as injury and death to the former were observed frequently when there was no noticeable injury to the primary roots. Since the crowns were much larger in July and August than in May, translocation of the 2,4-D to the roots may have been slower.

By early October the crown-root ratio of all plots including those receiving a spray in September had risen significantly. There were no significant differences between the crown-root ratio of sprayed and unsprayed plants. Root formation had slowed somewhat and on a percentage basis the crowns were increasing in dry weight at a more rapid rate thus accounting for the higher ratios.

These findings emphasize a fact reported by others (9) (18) (32) (6) that the age of the plant and the stage of development of the tissues have a strong bearing on the effect of 2,4-D applications on strawberry plants. It has been shown (9) (18) that this material will inhibit runner production when applied prior to initiation of the runner buds. Spray applications during or following blossoming have inhibited flower and fruit production (9) (32).

In this study, spray applications of the pentyl ester reduced the dry weight of crowns and roots regardless of the date of application. Although some minor variations were observed, the pentyl ester sprays did not significantly change the proportion of crown to root, as shown by the crown-root ratios.

When various 2,4-D formulations and the compound sesone were compared to determine their effects on the number of runner plants produced and on yield of Blakemore plants, several relationships were observed.

Distinct differences were found regarding the influence of some of the materials on plant stand and yield (Tables 6,

and 8). The ester formulations used were of low, medium and high molecular weight and all were found to reduce plant stand and yield more than the amine salt containing twice as much 2,4-D acid equivalent. This difference in toxicity was verified by Robbins, Crafts and Raynor (49) who reported the toxicity of all the esters of 2,4-D on an acid equivalent basis as being nearly twice that of the acids and salts of the same material.

It is probable that the observed difference in phytotoxicity is due in part to differential absorption of the various materials by the sprayed portions of the plants. Ahlgren et al (1) thought the polarity of the herbicidal molecule to be closely related to the absorption phenomena. They reported the salts of 2,4-D to be polar while the ester forms were found to be nonpolar. Since the waxy cuticle of plant leaves and stems are nonpolar, the nonpolar herbicides tend to be absorbed more rapidly than the polar herbicides. The lipoid nature of the cuticle is widely recognized and Crafts (12) has pointed out that any material applied to a leaf surface may (a) remain on the outer surface, (b) penetrate into the cuticle and remain there in solution in the lipoids, or (c) penetrate into the cuticle and then dissociate and enter the aqueous phase of the epidermal cells and eventually reach the vascular system.

As previously stated, it has been found that the salts of 2,4-D penetrate the cuticle of the leaf with difficulty, but the portion that does penetrate into the leaves is

readily taken up by the aqueous phase of the cells. It has been mentioned also that esters of an aliphatic nature can penetrate the cuticle readily but once inside the leaves they do not enter the aqueous phase in any appreciable quantities, because of their nonpolar nature. This may partially explain the greater phytotoxicity of the shortchain esters.

It has been found by Robinson and Willard (50) that ester formulations of 2,4-D are safer to use as pre-emer-gence sprays than the amine salt formulations. They advance as reasons for this finding that the esters are not leached as readily as the amine salts but remain "fixed" in much greater concentrations in the first inch of the soil.

The chemical sesone has proven effective in killing germinating seeds of both grasses and broad-leaved weeds. This work suggests that the material may be applied to strawberry plantings at the 2- and 4-pound rates without seriously affecting plant stand and yield. Indications are that at 6 pounds per acre enough of the material may be absorbed by the roots to adversely affect plant production and yield when sprays are applied in early summer or when applications are made in the spring, early summer and late summer at this rate. Environmental factors doubtlessly influence the effectiveness of this chemical. In these studies the soil moisture was maintained at a near optimum level. Observations made on plantings where the soil moisture content was low at the time of application and for

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sometime afterward indicate that the toxicity of sesone to strawberry plants was of a low order (34). Further, the effectiveness of the material as a germinative toxicant against weed seeds was greatly decreased. Freed (22) reports that in the soil sesone is activated to 2, 4-dichlorophenoxyethanol, but whether it is activated to 2,4-D acid has not been definitely established. However, he suggests that chromatography of the soil constituents after treatment with sesone has given evidence that the ultimate active product may be 2,4-D acid. If this is true, the differential selectivity then would be dependent on the relative tolerance of the strawberry to the low concentrations of this chemical.

An intimate relationship was found between the time of application of the 2,4-D ester formulations, the sesone at 6 pounds and plant stand. All of the ester treatments and the 6 pound per acre application of sesone applied in early summer, June 10, resulted in a definite reduction in the number of runner plants produced. This date of application coincided with the period of most active runner formation which probably was responsible for the greater effects of these chemicals than when they were applied early in the spring or later in the summer. This agrees with reports by Denisen (17), Carlson (9), Hibbard and Hemphill (32).

A number of the spray chemical treatments, although reducing the plant stand significantly, did not uniformly reduce yield (Table 6). This failure of the yield to

reflect the plant stand could be due to a runner plant inhibition by some of the materials which resulted in less root competition within the rows and an increase in size of plants and berries.

When 2,4-D is to be utilized as a herbicide to control established broad-leaved weeds in strawberry plantings, it appears that the use of an amine salt preparation at the rate of 1 pound per acre would be more feasible for spring or summer applications than any of the ester formulations tested at 0.5 pound per acre. On the other hand, it is indicated by this study that high molecular weight non-volatile esters can be applied in late summer or early fall with no resultant reduction in yield. The ester formulations are more effective against broad-leaved weeds than the amine salts. A beneficial runner plant inhibition may be obtained from the use of the 2,4-D sprays.

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SUMMARY AND CONCLUSIONS

- 1. Sesone and the amine salt, the ethyl, butyl, isopropyl and butoxyethanol esters of 2,4-D were tested on Blakemore strawberry plants growing in the greenhouse to determine their effect on the transpiration rate. Sesone was applied to the soil directly around the plants at a rate equivalent to 6 pounds per acre while the other materials were applied directly on the plants as sprays. The esters were used at rates equivalent to 0.5 and 1.5 pound per acre while the amine salt was used at a rate equivalent to 1 pound per acre.
- (a) The transpiration rate of the strawberry plants was not affected by the use of sesone applied at a rate equivalent to 6 pounds per acre, the amine salt of 2,4-D at a rate equivalent to 1 pound per acre, or to any of the ester formulations applied at a rate equivalent to 0.5 pound per acre.
- applied at a rate equivalent to 1.5 pounds per acre, there was a significant reduction in the transpiration rates of the treated plants. The use of these esters at this high concentration induced severe hyponasty of the leaves. This condition resulted in the closing of the stomata which in turn reduced the loss of water vapor.
 - 2. Five esters of varying molecular weight including

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the methyl, ethyl, butyl, butoxy ethanol and the propylene glycol butyl ether esters of 2,4-D were applied to Blakemore strawberry plants growing in the greenhouse at two different rates.

- (a) The dry weights of the shoots and roots of the plants treated at the rate of 1 milligram per plant were not significantly different from the unsprayed controls. There were significant differences in the dry weights of the plants sprayed with the different esters but no exact relationship between the molecular weight of the ester and dry weight of the shoots and roots were detected.
- (b) Spray applications of 4 milligrams per plant of the same materials resulted in significant reduction of the dry weights of the shoots and roots of all sprayed plants. Furthermore, this repressive effect on growth bore a definite relationship to the molecular weight of the ester, as the molecular weight increased the dwarfing effect decreased.
- 3. The pentyl ester of 2,4-D was used on plants growing in the field to study the effect of different dates on application of a representative ester formulation of 2,4-D upon the relative growth and development of strawberry crowns and roots. Late spring and late summer spray treatments while decreasing the total dry weight of the sprayed plants did not greatly affect the crown-root ratio. The most rapid period of root growth was observed in mid-summer following an earlier increase in crown growth. Although

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the differences were not significant the sprays applied in midsummer retarded root growth proportionately less than crown growth, indicating that the dwarfing effect was not as great in the roots. Apparently due to the larger size of crowns and leaves, less 2,4-D was translocated to the roots than earlier in the season when the plants were smaller. It is likely that after the spray was applied some translocation of carbohydrates continued from the leaves and crowns to the roots. Rapid development of the primary roots was observed during this period. The pentyl ester 2,4-D sprays were found to retard the growth and development of the secondary roots to a greater extent than the primary roots. The secondary roots were injured severely or killed when there was no noticeable injury to the primary roots.

- 4. Several related herbicides including the ethyl, pentyl and polyethylene glycol esters of 2,4-D, the amine salt of 2,4-D and sesone were applied under field conditions to spring planted Blakemore strawberry plants. Spray applications of each material were made in late spring, early summer and late summer. Three-spray treatments were made, with each material being applied at the times indicated previously. These materials were used to determine their effect on runner plant formation and subsequent yield.
- (a) All of the 2,4-D ester sprays applied at the rate of 0.5 pound per acre reduced significantly runner plant formation regardless of the time of application. The yields were reduced significantly also except for the plants

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sprayed with the pentyl ester or the polyethylene glycol ester form in later summer.

- (b) The amine salt of 2,4-D used at twice the actual acid rate used for the ester formulations resulted in a reduction of runner plants when a single spray application was made in late spring and in early summer and when a three-spray treatment was used. There was no significant reduction in yield in any of the amine sprayed treatments. These data indicate that the 2,4-D amine salt can be utilized at the rate of one pound per acre to control broad leaved weeds in strawberry plantings. These sprays also tend to reduce the number of runner plants produced, thus preventing overcrowding in the row. The size of the individual berries is considerably increased as a result.
- (c) The stand of plants was significantly reduced in the plots receiving the three-spray treatments of sesone at the rate each of 2 and 4 pounds. The yields were not reduced in any of the plots to which sesone was applied at these rates. Single applications of sesone at the 6 pounds rate in the early and late summer caused a reduction in plant production as did the three-spray treatments made each at the same rate. Yields were reduced except for the late spring and late summer treated plants in all plots sprayed with sesone at the rate of 6 pounds per acre. The results of this study indicate that applications of sesone at the rate of 2 to 4 pounds per acre may be made on strawberry plantings 2 or 3 times during the growing season

without seriously affecting plant stand and yield.

- (d) A comparison of the averages of all treatments showed a highly positive correlation (r = 0.959)
 between runner plant production and yield when plots
 receiving the single spray applications made at 4, 8 or 16
 weeks after planting were compared.
- (e) With respect to time of application, all of the forms of 2,4-D applied on June 10, eight weeks after planting, most severely reduced the number of runner plants. This date of application coincided with the period of most active runner plant initiation and formation, confirming the effectiveness of 2,4-D as a runner plant inhibitor.
- (f) Although several spray treatments including all of the amine salt applications and the pentyl and polyethylene glycol ester applications made on August 5 significantly reduced the plant stand, the yields were not significantly lowered. This suggests that the inhibition of runner plants resulted in greater plant spacing, thus reducing the root competition for water and soil nutrients. The berries of the treated plants were larger than those of the control plants.

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