GROWTH AND FRUITFULNESS OF THE BLAKEMORE STRAWBERRY ESPECIALLY IN RELATION TO PLANT THINNING

by

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INTRODUCTION

Strawberry production in the United States has increased rapidly within the last 25 years until it represents an annual 34 million dollar industry. From 1918 to 1941, the acreage of strawberries has increased from 94,120 to 211,110 acres, or an increase of 224 per cent. Accompanying this large increase in production area, numerous new varieties have been introduced by public and private agencies to meet the requirements of the expanding industry, especially in certain geographic localities. Varieties superior to those existing, were needed, which would be resistant to disease, drouth, and to high and low temperatures; which under adverse weather conditions would possess high dessert quality and be suitable for canning, freezing, or preserving.

Probably the most important new variety is the Blakemore, which was first planted commercially in 1929. This variety, an excellent preserving and shipping one, is particularly suited to the Eastern United States and has gained rapidly in favor until now, just 13 years later, it is the leading variety nationally, comprising over 25 per cent of the total acreage.

Although Blakemore is the leading variety, it has one decided fault in that it produces too many runner plants, which results in severe competition among plants for mineral nutrients and water, so that each plant is relatively small, with little chance of developing its fruit to marketable size.

To overcome this fault, a new practice of plant thinning or spacing was developed by research workers for the purpose of improving the size of the individual berries and the percentage of marketable fruit. By the term "plant thinning, or spacing" we mean the limiting of the number of runner plants in the matted row by some method of removal of excess runner plants during the growing season.

The introduction of any new agricultural practice, in general, aims to improve the quality of a given crop or to increase the production per acre of that crop with or without additional costs of production. Previous work on plant thinning has resulted in increased size of berries, as well as increased yields per acre, but involved considerable increase in production costs. The problem from this point on was to determine the most economical method of plant thinning from the standpoint of yields obtained of marketable berries, and further to determine the best method of plant thinning, regardless of cost of production. Another consideration was to determine the most desirable renewal system to employ following this plant thinning practice.

In addition, fundamental studies were needed on plant growth in relation to the various thinning practices, and to changes in environmental conditions. Therefore, the investigation reported here was conducted in an effort to determine: (1) the relationship of width of thinned, matted, and spaced rows to productiveness, (2) the influence of various renewal systems and width of row on berry production, (3) the effect of varying the time and rate of applications of nitrate of soda throughout the growing season on yield of fruit the following spring, (4) the seasonal development of the mother plant, and (5) the effect of differential percentages of soil moisture and aeration on plant development.

REVIEW OF LITERATURE

Plant Thinning and Spacing

Man has continuously modified cultural practices in order to obtain the highest yield possible of the most desirable product per unit of plant or land. The pomologist, by fruit thinning, limits the number of developing fruits per unit of leaf area, while the agronomist and olericulturist limit the number of plants per acre. The number of plants a soil will support, and the crop produced from it, is a measure of soil fertility. Soil fertility varies with moisture supply and the availability of nutrient elements in the soil. Thus, it is likely that the best spacing distances or the most desirable number of plants to the acre for one soil and locality may not be the most satisfactory for other localities under different climatic conditions.

Data from numerous experiments with field and vegetable crops show that within certain limits the greater the spacing given the individual plant the larger it may be expected to grow, and in turn the larger the per plant yield in foliage, fruit, and seeds. On the other hand, most of these investigations show that spacing which gives the largest yield per acre is much closer than the spacing which results in the maximum individual plant development.

Gillis (47), reported results of a 4-year investigation of distance of planting with snap beans, grown under various conditions with respect to soil and weather. Maximum yields were obtained with Refugee when spaced 2 inches in the row, while with Burpee Stringless Greenpod, a 1-1/3-inch spacing was best. Halsted (52), obtained largest yields of snap beans at a planting distance of 3 inches, his closest planting. Jordan's (72) results indicate a positive correlation between close spacing and the percentage of early yield. In investigations by Matthews (84), strains of Refugee and Burpee Stringless Greenpod snap beans, and Henderson's Bush lima beans were drilled in the row and later the plants were thinned to 3, 6, 9, and 12 inches apart with a 3-foot space between rows. He obtained larger total and early yields from the 3-inch spacing of both Refugee and Burpee snap beans and lima beans than from wider spacing.

Morrow and Hunt (86), in 1888 concluded that yields from field corn were practically the same from drill row and hill planting, as long as the number of plants per acre was kept constant. In 1891, Morrow (87) reported that thick planting rates reduced the average ear weight and increased the number of barren plants in field corn. Huelsen (67) has reported similar findings from recent planting rate studies with sweet corn in Illinois. Watson and Davis (113) in Puerto Rico, and Enzie (41) in New York, reported that close spacing gave highest yields but smaller ears. Working with sweet corn for canning in Maine, Bailey (9), found that as the plant feeding area was increased there was a marked tendency for the plant to produce more ears, heavier and larger ears, and more tillers.

There was some tendency for the higher percentage of usable ears to offset the loss in yield in the husk with increased plant spacing. Six inches to one foot between plants, planted in drill rows, appeared to be the most practical range to recommend under Maine conditions. Haber (50), working on the effect of numbers of plants per hill on yields of sweet corn for the cannery, found that the size or the weight of the ear decreased as the number of plants per hill increased; also the number of ears per stalk decreased as the number of plants per hill increased. He stated that the largest yields are generally obtained when there are four plants per hill; the greater the number of plants per hill, the greater the yield of fodder.

There is considerable diversity of opinion among sweet potato growers as to the optimum spacing of plants in the row from the standpoint of yield and quality. However, it is a generally accepted fact among growers on the Eastern Shore of Virginia that for rapid development of storage roots for early market the wider spacings, 20 to 24 inches, are most suitable. It has also been noted that wider spacing is productive of a large percentage of oversized roots if the harvest of early planting is delayed until October. Even with relatively close spacing it has been found that plants adjacent to vacant places in the row, due to irregular stands, produce a high percentage of "jumbos" which are frequently unmarketable.

Zimmerly (121), working with the Puerto Rico and Little Stem Jersey varieties of sweet potatoes, found that by progressively increasing the space from 10 to 24 inches between plants, an increase in the average weight of each root and, with one exception, an increase in the average number of roots to the plant resulted. The calculated yield on an acreage basis showed that the closest spacing, 10 inches between plants, gave the highest yield of marketable sweet potatoes and also the highest total yield. Claypool and Morris (30), from responses of potato plants to spacing and thinning, state: "The data indicate that it is possible to regulate the size and quality of potato tubers, within limits, by the spacing of hills, by the number of plants to the hill, or by a combination of both methods. It should be noted that the number of plants to the hill can be partially regulated by the number of eyes and the size of the seed piece." Whipple (116), in summarizing his experiment on thinning of potatoes reports that: "Thinning hills to a single stem improves the quality of the tubers both in size and uniformity of size. Under non-irrigated culture in Montana, thinning usually increases the yield of marketable tubers, but even under irrigated conditions close planting with thinning produces a much more desirable crop than wide spacing without thinning."

All of the literature reviewed on spacing of tomatoes shows that the highest yields per acre were produced on plots with closely spaced plants. Farish and Campbell (42), found this to be true and they report that size of marketable fruit was affected very little, if any, by spacing. Woods (119), in experiments covering a 4 year period, obtained the highest yields from Bonny Best plants spaced 12 inches apart in rows 3 feet apart, this being his closest spacing. The yield of individual plants was greatest at the widest spacing, but not sufficiently to offset the small number. Currence (35) states that: "... spacing as close as 1 by 4 feet increased yields uniformly for all the varieties tested and that fruit size may be reduced but the reduction in this test was not large enough to be considered statistically significant." Brosher (15), in a study in West Virginia of the influence on yields of two plants versus one tomato plant per stake, found the yield of early marketable fruit was 8.84 tons per acre from the double and 6.48 tons per acre from the single plants. The individual fruits produced from the rows containing the single plant per stake were slightly heavier than the fruits from the double plants, but not enough to compensate for the additional number of fruits produced by the pair of plants.

Working with dill, which is used in pickle manufacture, Seaton and Baten (100) found that on the basis of individual plant development, plants spaced 16 inches apart were significantly larger in all respects than those spaced 12, 8, or 4 inches apart. The 16-inch spacing produced more branches, more compound unbels, taller plants, larger primary umbels, larger stems, greater green and air-dry weight of entire plant, a higher percentage of seeds and heavier seeds, than the closer intervals. However, when the data were put on an acre basis the closer spacing of 4 inches, in every respect considered in these studies, was significantly more profitable for the grower. The authors suggested that even a closer spacing of plants than 4 inches may be highly desirable for maximum acre yield.

Jones (70), spaced California Early Red onions 3, 4, 6, 8, and 12 inches in rows 18 inches apart. In every case the plants that were set 3 inches apart in the row started to ripen first. As the space between the plants in the row was increased from 3 to 12 inches, there was a delay in the time of maturity, an increase in the size of the bulbs, and a decrease in yield per acre. Jones stated that: "... plants spaced three inches in the row do not grow too large for the average consumer; besides, they have a small neck which is well closed when ripe."

Using the Mary Washington variety of asparagus spaced at distances of 12, 18, 24, 30, and 36 inches in rows 7.5 feet apart, Hanna (53) found that although there was no significant difference in size of spear between different spacings, there was a difference in yield per acre and average number of spears per crown. A progressive decrease in yield per acre resulted as the spacings between plants increased, but a progressive increase in average number of spears per crown resulted as the spacing increased; however, this increase did not compensate for the smaller number of crowns per acre.

In general, the spacing work with vegetable plants shows that with the wide spacing each plant becomes larger, more productive, and the harvested edible parts are usually increased in size. With vegetable crops, the problem of plant spacing is one of setting the plant at a given distance or thinning plants after seedling germination. The strawberry differs from vegetable crops in that the distance of setting mother plants is not a factor but the development of runner plants determines the final plant stand.

Preliminary tests (36) with the Blakemore Strawberry demonstrated that the variety was very vigorous and an excessive runner-plant producer, with the result that plants tended to form and take root so thick in the row that there was subsequent crowding and competition for the available moisture and nutrient supply. It was noted that berries were small where plants were thick and crowded. To overcome this difficulty, plants were experimentally grown in individual hills with all runner plants removed. This method of culture resulted in the production of much larger berries, and these individual plants with all runners removed gave relatively high yields as well as fancy fruit. The hill system of culture, however, did not produce acre yields equal to the full acre yield possibilities or sufficient to compensate for the additional labor costs involved with this method. To improve this situation, plant thinning or spacing as a modification of the usual matted row system was developed for the specific purpose of improving size of fruit and marketable yield, particularly with varieties, such as Blakemore, that develop too many runner plants.

In some of the first work on Blakemore in North Carolina, reported in 1930 by Darrow and Dearing (36), each mother plant set 4 feet apart in rows 5 feet apart developed 375 runner plants on the average; thus, on an acre basis, approximately 800,000 plants per acre competed with one another under a 30-inch matted row system. In Maryland experiments, Schrader and Haut (98) reported the number of runner plants was calculated to be 600,000 per acre from plants set 22 inches apart in rows 42 inches apart, as a 30-inch matted row. In both of these experimental plots with such an overpopulation of the plants, the yield and size of fruit was very poor under the rather dry conditions which prevailed during the fruiting season. Even under the usual conditions of soil moisture and precipitation during the fruiting season in Maryland, only average yields of relatively small sized berries may be expected with the crowded matted-row of excessive plant-making varieties.

In results of spacing studies with the Fairfax, Dorsett, Howard 17, Catskill, and Blakemore varieties, Schrader and Haut (98) showed that both the 7-inch and 11-inch spacing of runner plants produced markedly superior yields over matted rows under several conditions of irrigation. The comparison of 7-inch and 11-inch spacing showed these treatments about equal except under very low moisture supply when the 11-inch spacing was superior. Increased yields with plant spacing under the conditions of this experiment were due largely to increased numbers of larger berries, that is, increased size of berry. Christopher and Shutak (28), in a preliminary study of the influence of spacing on yield, and later work by

Christopher (29) on the influence of spacing on yield and grade, found that runner plants spaced 6 to 7 inches apart produced the highest yields with both the Howard 17 and Dorsett varieties. Spacing procedure did not significantly influence size of berry. In a strawberry plant spacing study at Morgantown, West Virginia, from 1937 to 1939 inclusive, Childs (27) found that plants spaced 8 inches apart out-yielded the matted row with Blakemore, Catskill, Fairfax and Premier, but not with Gandy. Both a greater number of berries and an increased size of berry were noted in the spaced row, but the former was somewhat more important in influencing yield.

Nitrogen Application During the Growing Season

Plant thinning or applications of nitrate of soda during the growing season are designed to increase the size of the individual runner plants with subsequent increases in yield the following spring. By fertilizing the plants during the growing season and building up large top and root systems in this manner, it was thought that this would be a means of eliminating the thinning of runner plants.

From the standpoint of yield the application during the growing season of nitrogen fertilizers to strawberry plants has certainly given contradictory results. In some cases significant increases in yield have resulted, (81, 106), while in other cases equally significant decreases have been obtained, (49, 55, 75, 110, 115).

Under Long Island conditions, Hartman et al. (55), obtained no significant differential response from varying the time of application of nitrate of soda to strawberries in the year the plants were set. Van Meter (110), working in Massachusetts, applied nitrate of soda to Howard 17 plants at intervals from time of planting to October at the rate of 300 pounds per acre, and in general, there was little indication that summer and autumn nitrogen applications were in any way either significantly beneficial or injurious. In a test by Wentworth (115), no significant difference in yield was recorded regardless of season or size of the application, but, on the other hand, leaf area was increased by nitrate applications.

Greve (49), working on the same soil and location on which these investigations were conducted, applied nitrate of soda at three times throughout the growing season, at the rate of 150 pounds per acre at each application. Nitrogen fertilizer depressed all of the growth responses such as number of leaves, blossoms, and runner length per plant of Howard 17 strawberry plants. Plants grown without nitrogen fertilizer had a higher total carbohydrate total nitrogen ratio than plants receiving fertilizer, which, according to Greve, "... indicated that in the unfertilized plots the plants may have been in a more favorable condition for fruit bud formation, and consequently they produced a greater number of blossoms per plant."

Van Horn (109), working on the Eastern Shore of Maryland near Salisbury, in a study on time of fertilizer application, applied a 6-6-5 fertilizer at the rate of 800 pounds per acre to plants of the Blakemore variety on August 12 and September 11. Fertilizer, regardless of time of application, gave a definite response over the checks in increase in dry weight of roots and crowns. Comparing effects of fertilizer applied at two different dates, there were no noteworthy differences in crown and root increases.

Macoun (81), in Canada, reported increases in yield as high as 65 per cent were obtained from the applications of sodium nitrate. Applications of sodium nitrate made during the first fruiting season materially increased second year production. Taylor (106) also reported benefits from the application of nitrogenous fertilizers to strawberries in Alabama.

In a study made on the effects of applications of sodium nitrate on September 1 and April 1 at the rate of 400 pounds per application per acre on the dry weight of berries of five varieties of strawberries at Glen Dale, Maryland, for the June 2 and June 4 pickings when the soil moisture was high and dry matter of berries was low, Darrow (37) found no apparent effect from nitrogen. For the June 8 picking after sunny weather the average percentage dry matter for the nitrate berries was 8.08 and for the no-nitrate berries was 8.88 per cent. Darrow concluded that: "Heavy applications of nitrogen under conditions of ample but not excessive soil moisture seem to result in berries lower in dry weight than those grown without nitrogen. The average size of berries from the nitrogen plots was found to be considerably larger than those from non-nitrogen plots. Apparently, therefore, the increased water content of the 'nitrogen' berries is due to increased swelling."

Soil Moisture - Plant Relationships

A renewed interest has developed in the last few years as new developments showed the inadequacy of the older ideas concerning the water relations in plants. Work done previous to 1913 concerning the effects of soil moisture on growth and transpiration of plants is summarized in a paper by Briggs and Shantz (14). Practically all of these earlier workers found that there was an increase in growth with increasing soil moisture content over most of its range, although growth was somewhat reduced in soil that was nearly or completely saturated. Water requirement usually increased regularly with soil moisture content, but in a few cases very low values of soil moisture gave higher water requirements.

Briggs and Shantz (14) and Shantz (102) have raised the objection to much of the earlier work on the effects of different degrees of soil moisture on growth and transpiration in that it is impossible to maintain a mass of soil at a uniform low moisture level, because the small amounts of water added from time to time are insufficient to moisten the entire mass of soil.

Veihmeyer (112) has done a great deal of work relating to the penetration of water into soil,and has found that water applied to the surface of soil penetrates only to such a depth that the soil through which it passes is raised to its field capacity. Further penetration is exceedingly slow, and ordinarily is of little consequence to plants. If a plant growing in a container has reduced the soil moisture to the wilting point, the only way in which the water content of the entire mass of soil can be raised is to add enough water to bring all of the soil to its field capacity. Addition of less than this amount will leave unchanged the soil moisture of some of the soil in the bottom of the container. In such a case, the plant would be forced to grow in a smaller volume of soil than another plant in a similar container with higher average soil moisture.

In conducting studies of the effect of soil moisture on plants, Veihmeyer (112) recommends a way to avoid this difficulty of soil-water distribution by adding at each irrigation enough water to bring all the soil to its field capacity, but allowing different plants to reduce the moisture content to different degrees of dryness before again adding water. This procedure permits each plant to have water available throughout the entire soil mass, but the various plants would be working through different ranges of moisture. Using this method with prune trees, he has found that growth and rate of extraction of water from the soil are not appreciably affected over the range of soil moisture from field capacity to approximately the wilting percentage, results which are not at all in accordance with previous work.

Hendrickson and Veihmeyer (58, 59, 60, 61, 62, 63, 64, 65) experimenting in the field with prune, peach, pear, and walnut trees and grape vines, have obtained similar results, and have arrived at the conclusion (59) that "... trees either have readily available water or have not." Beckett, Blaney, and Taylor (10), working in citrus and avacado orchards, arrived at a similar conclusion.

Magness, Degman, and Furr (83), Furr and Magness (45), and Furr and Degman (46), have found that the behavior of stomata of apple trees may be affected when the moisture content of the whole root zone is apparently considerably above the wilting percentage, whereas with soils of medium or light texture at least part of the root zone is usually at or near the wilting percentage before variation in growth rate of the fruit can be detected.

Very different results have been obtained by Lewis, Work, and Aldrich (76, 77), Work and Lewis (120), and by Aldrich and Work (2), with pears on a heavy clay soil. They found that the fruit growth rate was reduced whenever the soil moisture was lowered below 70 per cent of the available capacity.

An explanation of these apparently contradictory results has been advanced by Magness (82) and by Lewis, Work, and Aldrich (77). They suggest that, in those cases in which trees have suffered from water-shortage when the soil moisture was well above the wilting percentage, the trees were growing on heavy soils with slow capillary movement of water and poorly distributed root systems. As a result, the soil in immediate contact with the absorbing roots may be at or near the wilting percentage while the average, in masses large enough to be sampled, may be well above this point. On the other hand, experiments which have shown that soil moisture is equally available from the field capacity to about the wilting percentage have been with trees growing on moderate to light textured soils in which the root distribution is usually much more complete and capillary movement more rapid than in heavy soils. According to this hypothesis, in all cases of water-shortage the soil moisture in the immediate vicinity of the absorbing roots is at or near the wilting percentage, even though only a short distance away it may be well above this point. Failure of the tree to obtain water under these circumstances is presumed to be due to the relatively great spacing of the roots and slow capillary movement of water through the soil.

Of the voluminous number of experiments on horticultural crops reported in the literature on the relationship of soil moisture to the various growth processes, only a few investigations will be reviewed to illustrate the numerous phases studied. Degman, Furr, and Magness (39), working in the Western Maryland apple district, found that during a dry season irrigation does not directly increase fruit bud formation on trees bearing a heavy crop of fruit. With the Oldenburg variety there was no correlation between moisture supply and fruit bud formation, while with the Rome Beauty, the trees that became dry formed a greater number of fruit buds. With seriously devitalized trees which had suffered severely from drouth previously, and which did not carry any crop, irrigation tended to increase fruit bud formation.

Under various soil moistures (wet or dry), differential applications of sodium nitrate,and various degrees of thinning, Harley, Masure and Magness (54) found that soil moisture variations and nitrate of soda applications had no apparent direct effect on the time or extent of fruit bud formation. They stated that: "Sufficient soil moisture and nitrogen, of course, are important in maintaining good growth conditions, but within the limits used in these tests they do not appear to directly affect fruit bud formation."

Jones (71), working on Georgia Belle peaches in North Carolina, found that fruit borne on trees growing under distinctly different soil moisture conditions was correspondingly different in size, despite the fact that the leaf-to-fruit ratios were the same. Increase in moisture supply favored formation of fruit of increased size. He concluded that the minimum leaf area which favors the production of quality fruit varies markedly under different soil moisture treatments.

Heinicke and Childers (56), and later, Childers and Schneider (25), found, in a study of the influence of gradually reduced soil moisture content on carbon dioxide assimilation and transpiration, that gradual drying of the soil is accompanied by an appreciable reduction in the rate of transpiration and of photosynthesis. The influence was felt in transpiration some time before it became manifest in photosynthesis.

A reduction in the moisture content of the soil has been advanced as one of the principal reasons why apple trees fail to flourish when grown in sod. Working in Indiana, Oskamp (90) is firmly of the opinion that an increased moisture content of the soil played an important part in the better growth of trees under cultivation and mulch systems of management.

In the arid region of the Yakima Valley, the grade and yield of potato tubers can be controlled to a large degree by irrigation practice, as reported by Claypool and Morris (30). They stated that: "Application of water at regular intervals of from 7 to 10 days throughout the growing season which keeps the soil mass utilized constantly above a point of moisture deficiency or the wilting point, will result in the production of smooth, high quality tubers. Any irrigation treatment which at some time in the growing season results in a severe check in growth due to inadequate soil moisture will upon resumption of growth bring about the formation of second growth, knotty tubers."

Wiggin (117), using the Wilson auto-irrigator pot, studied the water relations of several commercial cut flower and pot plant crops under controlled moisture conditions. Using three degrees of soil moisture, namely, "wet soil," or soil near the maximum water holding capacity, "medium wet," or soil at a state considered ideal for cultivation, and "dry," or soil well above the wilting coefficient but far below what would be considered satisfactory for the proper growth of most crops, he found that as the moisture content of the soil decreased, a consistent decrease occurred in weight of plants, heights, diameter of flowers and stems, number of flowers, and number of flowering shoots.

It has long been a policy of commercial greenhouse men to "run plants dry," that is, withhold water in order to hasten their flowering. One of the best examples of this is the common practice of drying the soil of geranium plants to time their flowering and bring them into bloom for Memorial Day. The plants frequently wilt, but are not permitted to become sufficiently dry to lose their leaves. However, the experimental evidence presented by Reger (93) does not show this practice to give the anticipated results. Using three soil moisture levels, high, medium and low, he found that with Calendula, Larkspur, and Geranium plants low soil moisture conditions did not result in a more rapid flowering, but actually resulted in delayed flowering.

Tumanow (107), reported on work with sunflowers in small containers holding six kilograms of dry soil. The soil moisture of one set of plants (control) was maintained near 60 per cent of the maximum capacity of the soil, while that of another set was allowed to vary between this value and the wilting point. The experiment was continued throughout the life cycle, during which the test plants experienced sixteen wiltings. At the end of the series the control plants had about twice the dry weight of the others, but only 20 per cent greater water requirement.

Tumanow also grew bean plants to flowering in pots with a capacity of 3500 grams of dry soil. One set, (the control) was maintained at a moisture level of 60 per cent of the capacity of the soil, while the other two sets were started with moisture levels of 50 per cent and 40 per cent, but neither of the latter was given any additional water during the growing period. At the end of the series, the average soil moisture percentages of these last two groups were 24 per cent and 30 per cent respectively. The dry weights were 11.66 grams for the control set, 5.43 for the 50 per cent group, and 2.21 for the 40 per cent group, while the water requirements were 138, 108, and 86, respectively.

Soil Aeration

Cannon and Clements have reviewed the earlier literature on plant responses to soil aeration and they have extended our knowledge of that subject by a comprehensive set of experiments of their own (23, 32). The existing data indicate that the growth of most roots depends upon free soil oxygen (16, 91), although some roots can develop anaerobically (20). Roots under anaerobic conditions are characteristically devoid of root hairs (20, 22, 103), and consequently absorptive processes differ from those of typical roots (40, 44). However, even those roots with low soil oxygen requirements are readily injured by moderately high concentrations of soil carbon dioxide (18, 19, 43, 88). Relatively high oxygen tensions are needed to offset otherwise toxic carbon dioxide concentrations about the roots (21). Unfavorable composition of soil air manifests itself in reduced, slow-growing root systems, inadequate absorption, short-life, discolored foliage and delay or failure of reproductive processes (1, 11, 66). The symptomatic complex arising from impaired gas exchange of roots reflects a general reduction in rate and magnitude of normal absorption and growth processes.

The great bulk of existing evidence indicates that experimental manipulation of soil atmosphere provides an effective means of studying the role of root systems and their effect on the metabolism of the plant as a whole. It must be noted, however, that the preponderance of existing data deals chiefly with minimal oxygen requirements, carbon dioxide tolerance, and a general description of gross anatomical changes induced as critical concentrations of both gases are approached. The general character of the results of earlier workers suggests that root activity is influenced as markedly by modifications of soil air as by changes in supply of water and essential mineral nutrients.

In many investigations the roots have been found to be sensitive to change in soil oxygen and carbon dioxide (51, 88), and continued abnormal aeration has been found to induce marked changes in the structure of tops and roots (7, 68, 74), and to alter entirely the development of the root habit (17, 78). Such marked differences in root systems have been correlated with definite effect on tops, as for instance, good soil aeration generally results in a more vigorous appearance, larger, dark green leaves, and higher yield (3, 6, 7, 80, 105).

Other investigators have shown that proper root aeration is especially important in relation to the reproductive phase of growth, (1, 24), abundant soil oxygen being known to favor the setting and development of fruit. On the other hand, oxygen deficiency and carbon dioxide toxicity in the soil are known to induce premature abscission of reproductive structures (1).

Of interest are a few of the most recent investigations on aeration in relation to plant growth. Loehwing (79), working on the physiological aspects of the effect of continuous soil aeration on plant growth, found that aerated sunflowers and soy bean plants grown in sand and loam differed from unaerated controls in the following ways: (1) taller in size and heavier in weight as a result of early rapid growth; (2) larger in root system, more fibrous, and more highly branched; (3) more rapid nutrient absorption as shown by higher content of ash, calcium, potassium, and phosphorus per plant in terms of absolute weight of entire plants; (4) higher in total weight per plant of crude fiber, starch, total sugars, and nitrogen. The author concluded that moderate rates of continuous soil aeration with moist air increased size and growth rate of plants, but a very rapid rate of aeration had the opposite effect in that it desiccated the roots.

In supplying supplemental aeration by means of blowing air through sunken tiles and glass wool channels in the beds, Boicourt and Allen (12) reported that the total linear growth of hybrid tea roses was nearly double that of the growth in the same soil without aeration. They stated that "... although the oxygen difference of 1.5 per cent between the aerated soil and non-aerated soil treatments was small, it is possible that the rose is sensitive to slight differences in oxygen concentration and may have responded to this small increase."

Under controlled conditions in the greenhouse with apple trees growing in sealed containers with various oxygen and carbon dioxide percentages, Boynton (13) found that there was a very marked decrease in the formation of new rootlets from apple tree root systems as the oxygen level of the soil atmosphere was reduced much below 15 per cent, at least when the percentage of carbon dioxide increased to between 5 and 10 per cent so few rootlets were formed by the root system that the growth of the top of the tree was markedly reduced.

Childs (26) grew apple trees in soil with various concentrations of oxygen and carbon dioxide, maintained in the soil atmosphere either by varying the rate at which a stream of air was drawn through or by limiting gaseous diffusion. There was no appreciable depressing effect on plant growth as the oxygen concentration was decreased until there was slightly less than 12 per cent, when a distinct growth reduction was noted. A further gradual depression of growth was apparent as the oxygen concentration was decreased below this point but there was no other abrupt drop until a concentration of 1.5 to 2 per cent was reached. The concentration of carbon dioxide present, within the limits found in this study, had little effect on growth or on photosynthesis and transpiration. There may have been a slight depressing effect of high carbon dioxide concentrations, but this was so slight as to be negligible when compared to the effect of low oxygen concentration.

Knight (73) demonstrated the fundamental importance of aeration for root growth of alfalfa in artificial soil-sand mixture, and in undisturbed soil cores under greenhouse conditions. The results of an experiment by Heinike and Boynton (57) indicate that "... the gradual decline which often begins on a few limbs of one side of mature McIntosh trees grown under favorable soil conditions may be checked rather quickly by providing aeration close to the trunk of such trees. Within a few weeks after a tile covered with a foot or more of gravel was laid in early summer to within a few feet of the trunk, the leaves became normally green and the weak side of the tree could no longer be distinguished by poor leaf color from the healthy side."

MATERIALS AND METHODS

The Blakemore variety of strawberry was used in all of the investigations reported in this paper. This variety, the leading commercial variety in the United States as well as Maryland, was selected because it produces runner plants to excess, which results in an over-crowding of plants in the matted row. All plants used were obtained from the W. F. Allen Company, Salisbury, Maryland.

During the seasons of 1939 through 1942, investigations on cultural practices with strawberries were conducted in two localities on different soil types. The plots at the University of Maryland Campus consisted of a well-drained Sassafras sandy loam soil, while at the University Hopkins Farm, located seven miles northwest of the campus, the soil was a Sassafras fine silt loam.

Plant Thinning and Width of Row, 1940. This study, started in the spring of 1939 on the University Campus (figure 1), was designed to determine the most desirable width of row to attain highest yield, size, and quality of fruit, when the plants were thinned to a distance of 4 to 6 inches between plants. Each block, replicated five times, consisted of three 10-inch, three 20-inch, three 30-inch, and three 40-inch width rows randomized within the block. The thinning treatment was maintained on each of these widths, making a total of 15 rows per treatment.

Figure 1. Width of thinned row plots at the University Campus, September 1939. Left foreground, 40-inch width rows; right foreground, 10-inch width rows. The second block back is composed of 20-inch width rows on the left, 10-inch width rows in the center, and 30-inch width rows at the right.

On April 3, 1939, the land was prepared with an application of a 3-12-6 fertilizer, one week previous to planting, at the rate of 350 pounds per acre. In each block, on April 10, plants were set 18 inches apart in single rows 24 feet long. The roots of the plants, before setting in the field, were shortened to about 4 inches in length and all but one or two of the leaves removed. After planting, all blossoms were picked off as they appeared.

After the width of row was fully formed, a 10-inch aisle separated rows within treatments and also between rows of different treatments within the blocks. Thinning of runner plants was accomplished by a procedure which, it was thought, approached a commercially feasible method with or without machine power. Runners were allowed to root during July and August and about the middle of September the beds were raked cross-wise of the rows and the excess runners were pulled into the aisles where they were cut off with a circular edger back to the desired width of row. Following this procedure, the rows were inspected and occasionally additional plants were removed by hand in order that the desired density of stand remained. Since this year was not a good year for runner plant development, considerable difficulty was encountered in obtaining a uniform stand of plants to the outer limits of the wide 40-inch rows and in some cases the same difficulty was encountered with the 30-inch rows. The month of July was exceptionally dry, since only a little over an inch of rainfall occurred during this month. Consequently, the runner plants were slow to form and were unable to establish root systems until late summer.

Cultural operations, like those commercially practiced, were the same for all the rows throughout the season, and the plots were weeded by hand approximately every two weeks. About the middle of November, a 6-inch layer of rye straw mulch (figure 2), was applied to the plots and the following spring, April 3, it was raked into the aisles and amounts in excess were removed. After growth had started in the spring, the plants in each row were counted to determine the number of plants per square foot.

Harvesting began May 27, pickings being made approximately every two days until June 17, when the season ended. As soon as the berries were picked they were graded into U. S. No. 1's and culls, weighed, and then counted. The weights of the berries were converted to quarts by using the mean weights of several quarts of berries, selected at random at each picking.

As soon as harvesting was completed, 10 representative plants were selected and carefully dug from every row of each treatment within the 5 replicated plots, making a total of 150 plants per treatment. The roots were carefully washed free of soil and the plants were placed in a drying oven and dried at 70° C. Later the dry weights of roots, crowns, and leaves, as well as number of leaves per plant, were obtained.

Width of Row Studies on Thinned, Matted, and Spaced Rows, 1942. It was thought desirable to confirm the data obtained in 1940

Figure 2. All plots were mulched with a 6-inch layer of rye straw throughout the winter. December 1939.

on a different soil type, namely, a fine silt loam in the same Sassafras series located at the Hopkins Farm of the Maryland Agricultural Research Farm.

The ground was plowed on April 7, and a 5-10-5 fertilizer was applied at the rate of 400 pounds per acre and lime at the rate of a ton per acre. Each block, which was replicated five times, consisted of two rows each of the following widths: 10-inch thinned, 18-inch thinned, 24-inch thinned, 30-inch thinned, 10-inch matted, 24-inch matted (guard rows bounding the limits of each block), 30-inch matted, and 22-inch width rows with plants spaced 9 inches apart as recommended for the Blakemore variety by Darrow (36). On April 12, all plants were set 18 inches apart in single rows 16 feet 6 inches long. A 14-inch aisle separated rows within treatments and also between rows of different treatments within the plots (figure 3). Figure 4 shows the different widths of thinned, matted, and spaced rows with the comparative plant population under each treatment.

1941 was a particularly good year for runner plant development, and as early as the latter part of May considerable runners had emerged from the mother plants. By the middle of June it was necessary to space the runners in the rows calling for a 9-inch spacing, and by the first of July the stand of plants in these rows had reached the desired number, making it necessary to remove all runners which formed thereafter. Runner plants were spaced 9 inches apart, forming a row on each side of the mother plants (figure 4). In

Figure 3. Plots at the Hopkins Farm showing the different widths of thinned, matted, and spaced rows. June 1942.

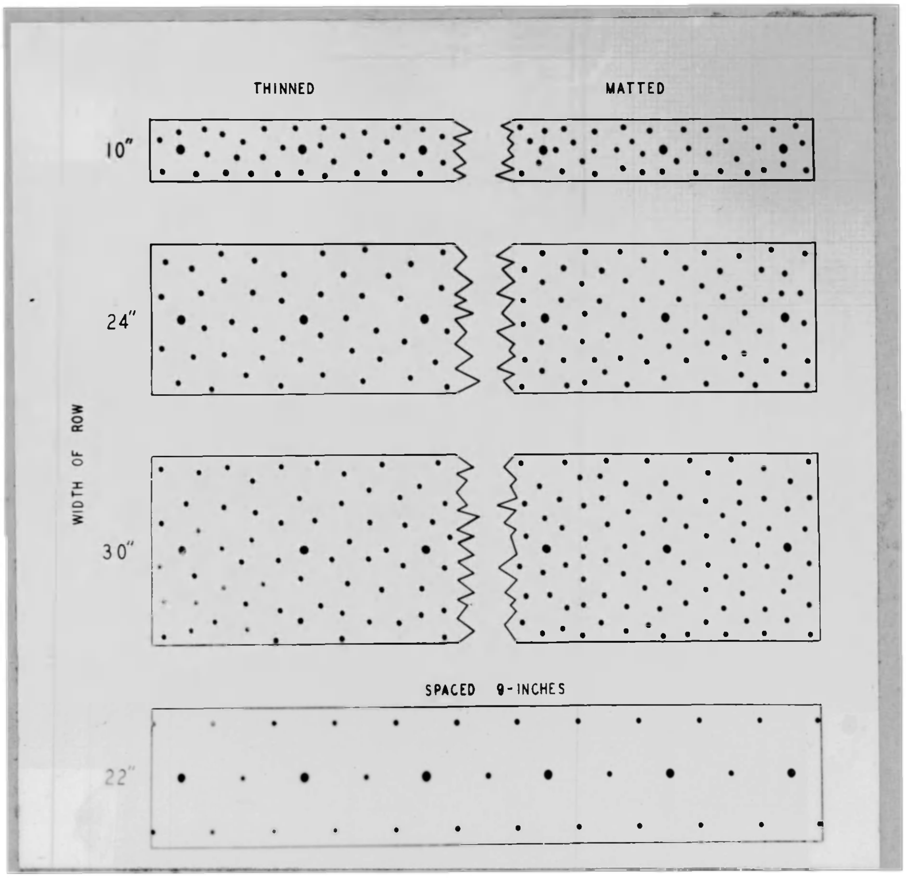

Figure 4. Different widths of thinned, matted, and spaced rows showing the comparative density of plants (based on actual plant counts). The large dots represent mother plants, while the small dots represent runner plants.

addition to the 14-inch aisle space, two inches were left on the outer sides of the runner plants to insure that there was no injury to the roots from cultivation operations.

Later in the season, after the runner plants had reached good size, certain localized areas of these spaced rows were stricken with what appeared to be some physiological disease which could not be identified by the author. Several persons familiar with pathological troubles of strawberries visited the plots and they, too, could not ascertain the cause of the disease. It was suggested that it might be caused by a combination of unsatisfactory moisture and aeration conditions and therefore, an experiment was set up in the greenhouse under controlled conditions which will be discussed later. The following spring, after growth had started, those plants were removed which were stunted or quite inferior in size and other respects to the other plants in the row. In computing acre yields for these rows, the average production per plant in a given row was determined and then this was put on a row basis as determined by the original number of plants in the row. From this average row production, the acre yields were computed as was done for other rows receiving different treatments. The author felt justified in this procedure, since the data obtained from all previous spacing work indicate that little, if any, different in unit yields can be expected between large spacing distances.

Thinning of the rows and cultural operations were practiced as mentioned for the previous season. On August 18, sodium nitrate was broadcast in the rows at the rate of 200 pounds per acre and a commercial 0-14-6 fertilizer was applied at the rate of 200 pounds per acre. The plots were covered with a 6-inch layer of rye straw mulch in November, and plant counts were made the following spring after growth had started. Harvesting began May 18 and ended June 2.

Six days previous to the first day of harvesting, approximately two inches of rain fell and during harvest an additional rainfall of one inch occurred. Since this soil has such a high moisture-holding capacity (37 per cent), and since the picking season was so short, it is assumed that moisture was never a limiting factor during the entire picking season.

After harvesting, a square foot area of plants was dug from certain rows not wanted for second-year fruiting studies. Plants were dug from at least one row of the 10-inch matted and 10-inch thinned in each of the five blocks. For the other treatments of different widths of row, plants were dug from one to four rows each, but in the case of those plants which were spaced 9 inches apart, only two plants per row were dug in each of the five blocks, since the plants in these rows were very uniform in size. The roots were washed free of soil and the plants were dried in an oven at 70° C. for several days, after which their dry weights were obtained.

Renewal of Thinned Rows of Various Widths, 1941. Many growers do not fruit their strawberry beds for more than one season, especially with those varieties which fruit heavily the first year and fail to give more than 50 per cent production the second year of fruiting. Fruiting only one season, following a year of preparation, naturally involves rather high costs of production which might be considerably reduced per unit of production if a method could be devised to greatly increase the yielding capacity the second year of fruiting.

Following the fruiting period in 1940, three renewal systems were devised for second-year fruiting studies, (figure 5). Three-row plots in the original block design made possible single row randomized renewal treatments with five block replications for each renewal treatment under the four different widths of row. The three renewal systems are described as follows:

(1) Conventional method.

The rows were "barred off" from each side, leaving only a middle strip of plants five inches wide (figure 6). From these remaining plants runners were allowed to form and fill out the rows to the various widths desired. The new plants in these rows were thinned, by the same method as outlined previously, to a distance of 4 to 6 inches between plants. This treatment was, therefore, a repetition of the treatment given all the rows in the experiment the previous year.

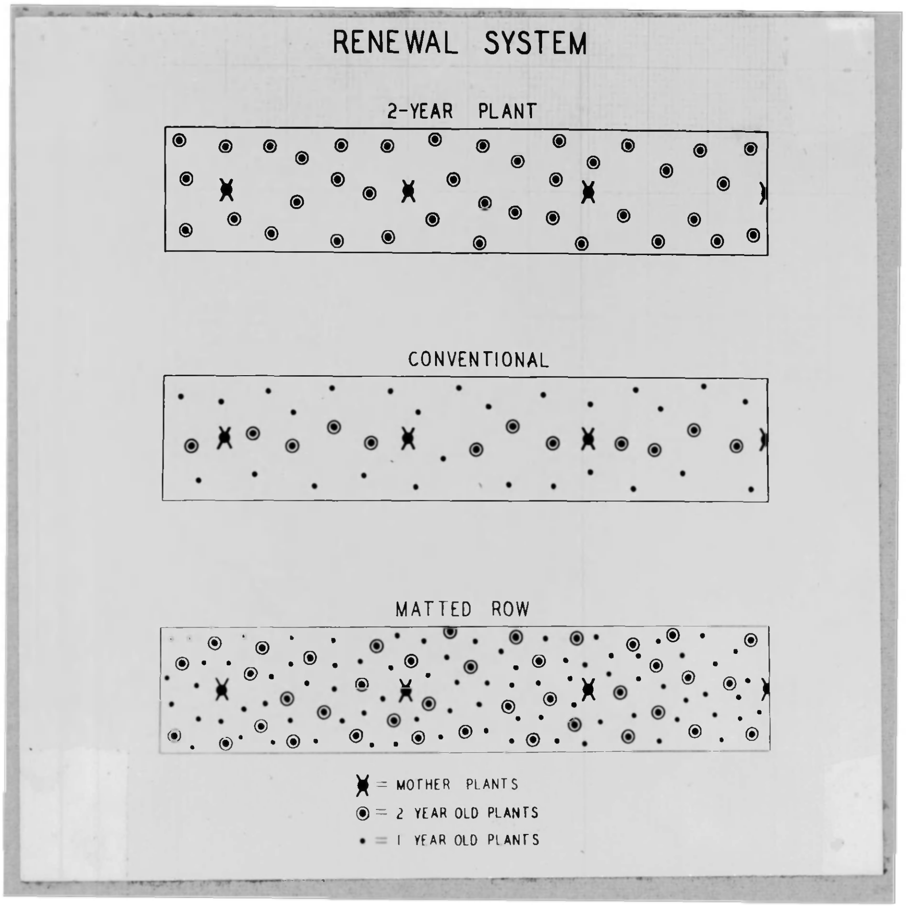

Figure 5. Showing the plant population and type of plants comprising the rows under three renewal systems. The two-year plant system had all runners removed; the conventional system consisted of "barring off" the rows to 5-inch widths, while the matted rows had no attention except to limit the width of row.

Figure 6. The conventional method of renewal consisted of "barring off" the rows to 5-inch widths and allowing new runners to fill out the row to the desired width, June 1940.

(2) Original plants fruited the second year.

This method consisted of removing all runners every two weeks throughout the season of runner formation, thus retaining the same plants which fruited in 1940 for fruiting again in 1941. Reference to this method throughout the manuscript will be designated as the two-year plant renewal system.

(3) Reversion to a matted row.

This system was accomplished merely by allowing the original thinned rows to revert to matted rows of similar widths. This type of renewal therefore consisted, at harvest time, of rows containing the original or two-year old plants interspersed with as many one-year old or new runner plants as took root within the designated widths of row. Figure 7 shows the response of the plots to the three renewal systems.

A commercial fertilizer of 5-10-5 analysis was applied to all blocks August 1, 1940, at the rate of 150 pounds per acre. Cultivation and mulching practices were employed, as was described in the 1939 experiments. After the start of growth the following spring, the plants were counted to determine the stand in each row.

The crop was threatened by drought so a portable overhead Skinner irrigation system was set up and each block was given an amount of water equivalent to 6 acre inches, approximately an inch every three days throughout the picking season. Harvesting began May 19, 1941 and pickings were made every other day until the season ended June 9. As soon as

Figure 7. 30-inch width rows with three systems of renewal the fall before second-year fruiting. Left, reversion to a matted row; center, conventional renewal; right, two-year plant renewal system. September 1940.

harvesting was completed, five separate square foot random samples of plants were dug for each renewal system from each width of row. The roots were carefully washed and the plants were dried in an oven at 70° C.

Differential Applications of Sodium Nitrate on Thinned and Matted Rows, 1939-1941. At the time the width of row and mother plant development studies were initiated in 1939, four blocks were set out to determine, with thinned and matted rows, the influence of varying the time and rate of application of sodium nitrate on fruit production of the Blakemore strawberry.

The rows were staked off 36 inches apart and 11 plants, approximately 18 inches apart, were set per row. Each row was allowed to fill out with runner plants to a 24-inch width, which left a 12-inch aisle separating all rows (figure 8). Half the rows were thinned the latter part of August by the method previously discussed, and cultivation operations were practiced throughout the season as is done commercially.

Each of the four blocks consisted of one row of each of the following randomized treatments (14 rows per block bounded on each side by guard rows):

Figure 8. Fertilizer plots at the University Campus. September 1939. These plots, composed of matted and thinned rows, received nitrate of soda at monthly intervals during the growing seasons of 1939 and 1940.

Treatment of Row	Fertilizer Application Dates
Matted) Thinned)	June 1, 1939
Matted) Thinned)	July 1, 1939
Matted) Thinned)	August 1, 1939
Matted) Thinned)	September 1, 1939
Matted) Thinned)	June 1 and July 1, 1939
Matted) Thinned)	June 1, July 1, and August 1, 1939
Matted) Thinned)	June 1, July 1, August 1, and September 1, 1939

Beginning June 1, 1939 and the first of each month thereafter, up to and including September 1, sodium nitrate was applied at the rate of 200 pounds per acre to the designated rows. Sodium nitrate was mixed with about a quart of sand, to insure uniform distribution of the nitrate, and this mixture was applied broadcast in the row.

These plots were likewise mulched, as in figure 2, with a 6-inch layer of rye straw over the winter, and harvesting operations were carried out as for the width of row studies.

Before the rows were renewed for second-year studies, 10 representative plants were selected and carefully dug from each row, making a total of 40 plants per treatment. The roots were washed free of soil and after the plants were dried in an oven at 70° C., dry weights of roots, crowns, and leaves were obtained.

Toward the end of June 1940, after plant samples had been dug, the rows in the fertilizer plots were "barred off" to 5-inch widths as is done commercially for second year fruiting. This practice consists of turning under the outer portions of the row, leaving only a strip of plants down the middle 5 inches wide. From the remaining plants, runner plants were allowed to form and fill out the row to the original 24-inch width. The first of September, the designated rows were again thinned to a distance of 4 to 6 inches between plants. In other words, after being renewed, these plots were exactly as they were the first year, that is, there was an equal number of matted and thinned rows receiving the differential fertilizer applications.

Since harvesting was not completed until June 17, the first fertilizer application date in 1940 was moved up to July 1, and those rows which had received fertilizer on June 1 the previous year were used as check rows. Straw mulch was again applied on November 18, and was removed the following spring. Harvesting began May 19 and ended June 9.

Mother Plant Development, 1939. The work of Van Horn, Schrader, and Haut (108) demonstrated the seasonal development of the runner plant, especially in relation to plant thinning and late summer or fall application of fertilizer. It was of special interest to learn the comparative seasonal development of the mother plant at the time it was giving rise to runner plants and on throughout the season, past the time of flower bud initiation.

On April 10, the same day that plants were set for the width of row experiment, 12 rows, each 15 feet long, were set with plants approximately 18 inches apart, making a total of 11 plants per row for a study of the seasonal development of the mother plant. Each plant in the row was numbered consecutively from 1 to 11, and a stake with the respective number on it was placed by the plant. Every two weeks, 12 plants, three from each plot, selected at random by drawing numbers from a hat, were carefully dug, washed, and the following data were taken: root length and starch content; crown diameter, length of crown with roots, and starch content; number of leaves open, number of leaves closed, starch content at basal and distal petiole positions; and the number of runners per plant. After the plants had dried in an oven at 70° C. for several days, dry weights of roots, crowns, and leaves were obtained.

Starch content was determined by making freehand sections of petioles, crowns, and roots and staining them with KI. The sections were then examined under the microscope and the starch content, which was merely observational, was given a value of from 0 to 10; 0 representing no starch present in the tissue and 10 representing the maximum quantity present.

Since 12 plants were taken at each sampling date, the original plot design did not contain enough plants to furnish samples after September 18. However, in order to determine what further development had taken place during October and November, 12 random plants were dug on November 30 from neighboring rows which had received the same treatment throughout the season.

Moisture and Aeration Studies, Experiment I. During the growing season of 1941, it was noted early in the season that the plants spaced 9 inches apart at the Hopkins Farm were slowing up in growth considerably, and as new leaves appeared they were greatly stunted and presented a rosette appearance. Recognizing that the soil type was a heavy silt loam, it was decided to set up an experiment in the greenhouse to determine if moisture or aeration might be the contributing factors responsible for this condition in the field.

100 plants were dug and placed in cold storage on November 19. Soil from the experimental strawberry plots was brought into the greenhouse and screened for use in 8-inch clay pots. The moisture holding capacity of this soil was determined to be 37 per cent, while the wilting coefficient, as determined by the sunflower method, was 7 per cent. A 3x3 factorial experiment, replicated 5 times, was set up using 3 moisture levels and 3 levels of aeration. The lower moisture level was 12 per cent, just 5 per cent above the wilting coefficient, while the upper level was 32 per cent, just 5 per cent below field capacity, and an intermediate level was 22 per cent of field capacity. The factorial design of the experiment, with five replications, enabled the following treatments: 5 pots with 12 per cent moisture with no aeration, 5 pots with 12 per cent moisture with aeration 3 minutes per day, 5 pots with 12 per cent moisture and aeration 3 minutes

every other day. The same aeration treatments were also applied to pots containing 22 and 32 per cent moisture.

A system of pot irrigation, devised by Grandfield (48), was used for maintaining the soil moisture distributed fairly uniformly throughout the soil. The equipment is illustrated in figure 9. It consisted of an 8-inch florists' clay pot with a hole in the bottom for a No. 6 rubber stopper. An irrigating coil to fit in each pot (figure 9) was made from ¼-inch copper tubing 4½ feet long. Before coiling, which was accomplished by wrapping the tubing around a thick glass vase of the proper size, two rows of holes approximately 1/64-inch in diameter were drilled at 1-inch intervals diametrically opposite for the length of the tube, except for the lower 4-inch portion, which passed through the rubber stopper and to which the watering hose was attached. Phonograph needles were used in a brace with a specially devised attachment which insured uniform penetration of the needle to obtain holes of the same diameter. The upper end of the copper tube was closed by collapsing the walls with a hammer. Water was forced into the pots by attaching a thick-walled rubber hose to the coil from a water faucet which had approximately 50 pounds pressure. Pieces of rubber tubing, about 1½ inches long with a ¼-inch bore, were sealed at one end and slipped over the protruding end of the coil at the end of each irrigation, so that there was no drainage from the pots. By using this technique no particles of soil were more than two inches from the source of water, and by using pressure, the

Figure 9. Equipment consisting of an 8-inch clay florists' pot and a copper coil used to insure uniform distribution of water throughout the soil mass. Similar to Grandfield's apparatus (48).

water was applied quickly and evenly distributed.

Aeration was accomplished by attaching to the coil a hose leading from a rotary air pump which delivered 0.80 cubic feet of air per minute at a pressure of 10 pounds per square inch (figure 10).

The pots, plus irrigating coils and stoppers, were weighed when dry and also after they had soaked in water over night. This was done in order to determine the exact amount of water which each pot was capable of taking up. Later the pots were filled with soil to within an inch of the top, weighed and the percentage of moisture in the air-dried soil was determined. The weight of the wet pot, coil and stopper, plant, and soil at the desired moisture percentage was painted on each pot with white enamel.

Forty-five uniform plants, as determined by fresh weight, were selected from the original 100, and all but one or two leaves were removed from each plant. They were set one to a pot on January 19, and watered thoroughly through the coil. All pots were watered uniformly from January 19 until February 1, when they were brought up to field capacity. No water was added thereafter until the soil moisture dropped below the desired percentage and from then on the pots were weighed each morning on Toledo platform scales (figure 11), and brought up to the designated weight to the nearest hundredth of a pound by watering through the coil. The soil moisture in a given pot never deviated more than 2 per cent from the desired percentage but, on the average, each pot lost about 1 per cent

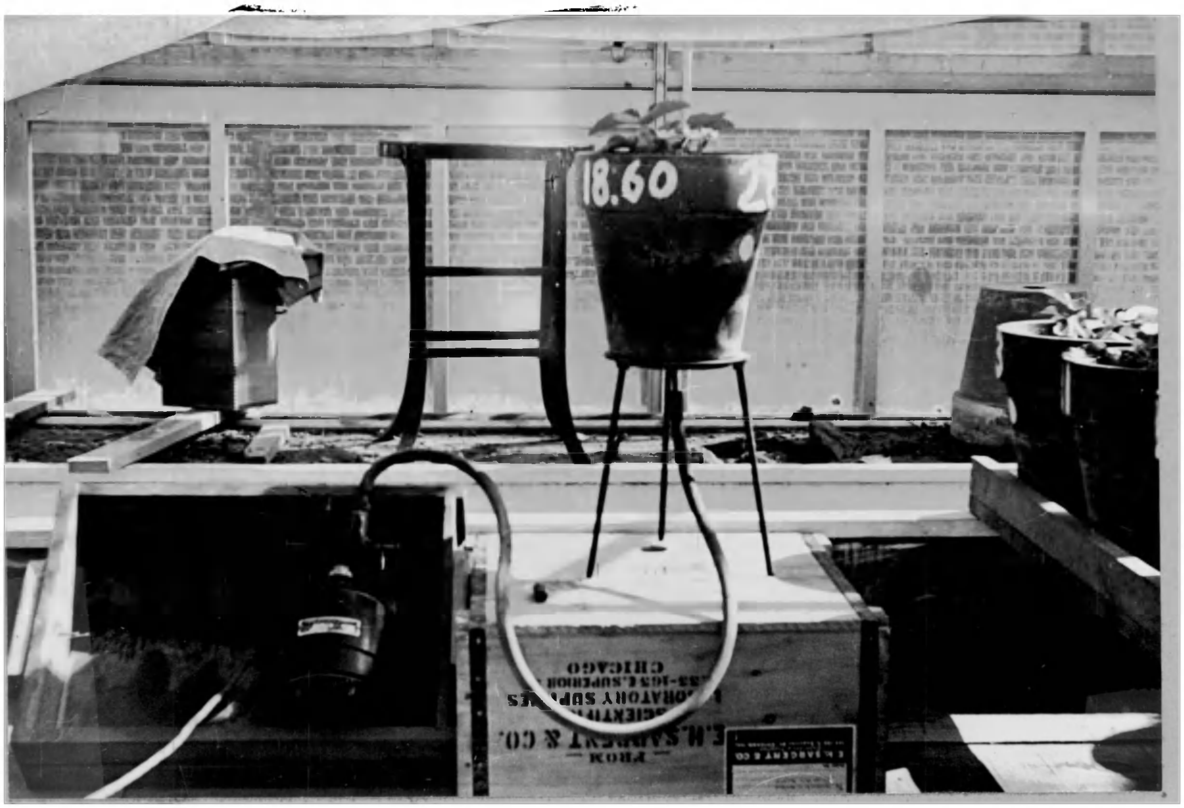

Figure 10. Showing method and equipment used in aerating the soil in pots containing one strawberry plant. The copper coil, also used for irrigation, has an open end protruding from the bottom of the pot where the rubber hose was attached. The air pump is apparent in the box at the left.

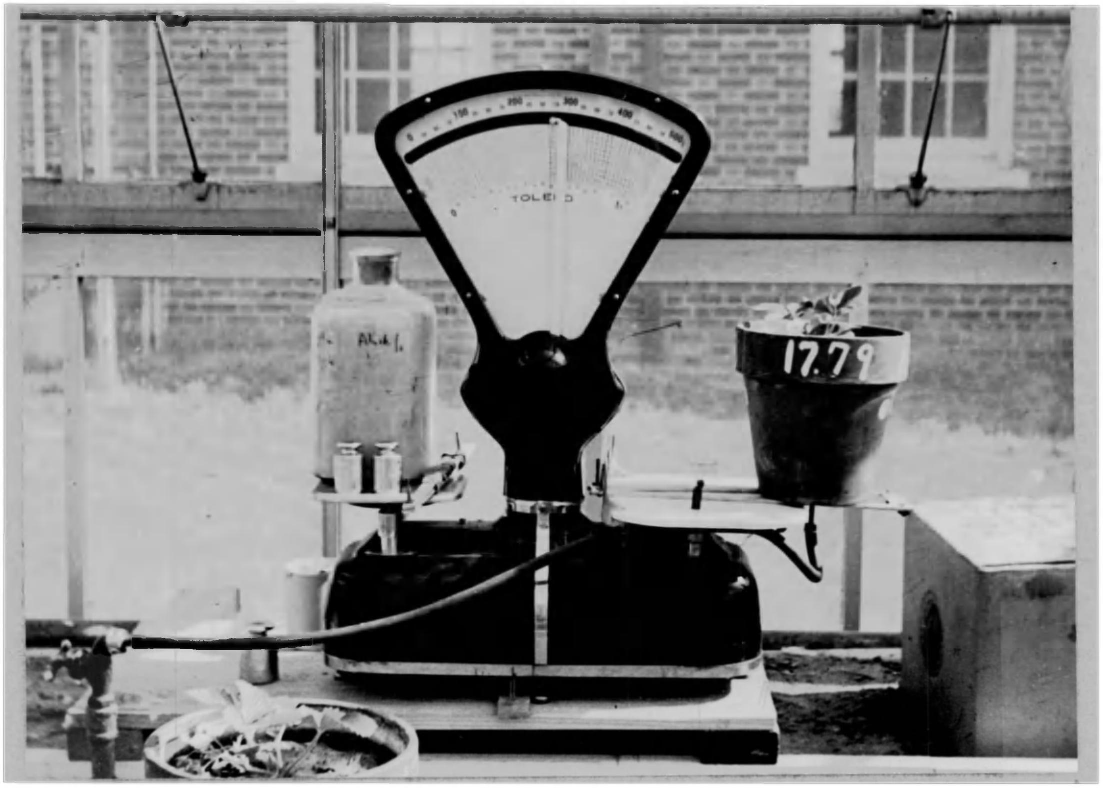

Figure 11. Method and equipment used in weighing and irrigating the pots. Jar at left, filled with sand and sealed, was used as a 15-pound counter-balance.

of its moisture daily. The aeration treatments were applied in the middle of the afternoon after the soil had taken up what moisture remained in the irrigating coil.

The date when each blossom unfolded was recorded and differences in leaf development were observed during the period of the experiment. On March 2 the plants were severely injured by sulfur fumes from a neighboring house, so the leaves were removed and their areas, fresh, and dry weights recorded. Leaf areas were measured with an instrument (figure 12) which Dr. G. M. Darrow of the U. S. Department of Agriculture had made especially for the purpose of measuring leaf areas of the Blakemore variety of strawberry. The roots and crowns were left in the pots and their individual treatments were continued in order to study rate of leaf regeneration; however, since several plants also appeared to have root injury, the experiment was terminated on March 18. The roots and crowns were carefully washed from the pots and their fresh weights and length of roots were recorded. The plants were dried in an oven at 70° C. and dry weights were later obtained.

<u>Moisture and Aeration Studies, Experiment II</u>. Since the results of Experiment I did show definite differential responses in leaf areas to the three moisture levels and an indication of some response from aeration at the 32 per cent moisture level, it was decided to repeat the experiment, using 9 pots held at 22 per cent moisture with no supplemental aeration to confirm the data obtained from moisture differences

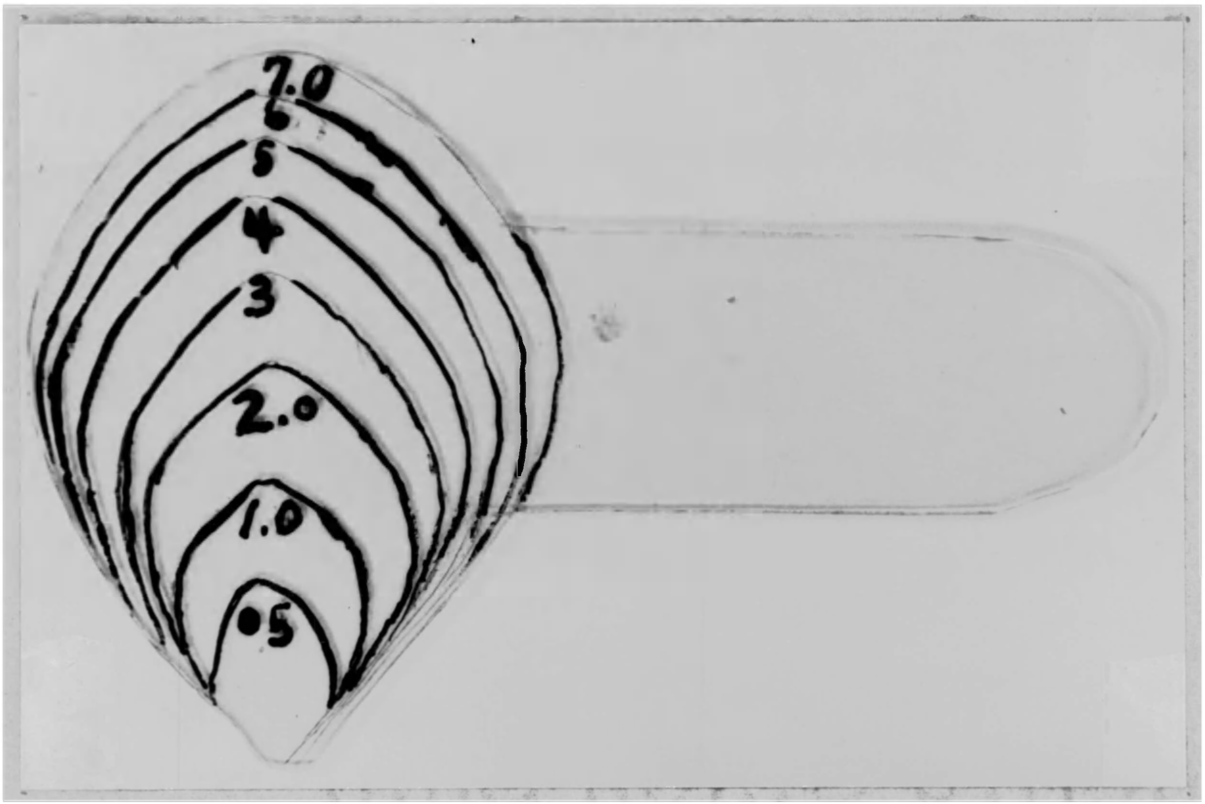

Figure 12. Leaf area measuring device which afforded the direct measurement in square inches. (Courtesy of G. M. Darrow, U. S. D. A., Beltsville, Md.).

in the first experiment, 9 pots held at 32 per cent moisture with no supplemental aeration, and 9 pots each of the following treatments at 32 per cent moisture: aeration 3 minutes a day, aeration 7½ minutes a day, and aeration 12 minutes a day.

The pH of the soil was raised to about 6.0 by adding hydrated lime, containing 11 per cent magnesium, to supplement the low magnesium content of the soil. 150 plants were dug from the experimental plots at the Hopkins Farm and from these, 45 were selected for uniformity in diameter and length of crowns. Since, in the preceding experiment, the plants were selected for uniformity mainly on the basis of fresh weight and the root response from the treatments could not be measured accurately due to variation in root number and length at the initiation of the experiment, it was decided to insure greater uniformity of the plant material by removing all but 15 comparable roots on each plant and to cut them back to 5¼ inches. The plants were set in the pots on March 30.

All plants were given the same amount of moisture for one week and on April 7, the differential treatments were started. On April 13, all blossoms were removed, and by April 17, runner formation had started. The date of runner emergence was recorded and when the individual runner had developed sufficiently to form leaves, it was removed, measured, weighed, and placed in a drying oven. The total leaf areas of each plant were taken every two weeks.

In addition to the rotary air pump, a piston type paint sprayer was used with an air displacement of 2-3/4 cubic feet of air per minute delivered at 10 pounds pressure. Two hoses were attached to the pump, which allowed three pots to be aerated at one operation. An individual pot was aerated with the rotary pump one day and the piston pump the next, thus insuring the same amount of air which was passed through a pot of a given treatment.

Runner emergence had ceased by May 23, so the plants were removed and their fresh and dry weights, leaf areas, number of leaves, and root lengths were obtained. At this time the roots were distributed rather uniformly throughout the soil mass (figure 13), except for a concentration of roots in the bottom of the pots (figure 14), especially in those pots which had soil at the 32 per cent moisture level.

Figure 13. Root distribution was rather uniform throughout the soil except for a concentration of roots in the bottom of the pots as shown in figure 14.

Figure 14. Root concentration in the lower two inches of the pot. This root mass is quite typical of those plants grown in soil at a 32 per cent moisture level.

RESULTS

Effect of Width of Row on Yield and Growth Response of Thinned, Spaced, and Matted Row Strawberry Plants

Width of row of Blakemore planting has resulted in marked differences in yielding capacities of the plants in the row and growth responses of the plants themselves which are reflected, likewise, in large differences in yield per acre.

In the season of 1940, on the basis of yield alone, (table 1), a decrease in width of row from the usual commercial width, resulted in increased yields on an acre basis. As the width of row decreased, a progressive increase in yield resulted as shown by an increase of 13 per cent for the 30-inch rows, 29 per cent for the 20-inch rows, and 49 per cent for the 10-inch rows. The differences in yields between successive treatments were found, by analysis of variance, to be highly significant. The 10-inch rows produced significantly higher total yields, as well as U. S. No. 1 berries, than the 20-inch, 30-inch, or 40-inch width rows. The percentage of U. S. No. 1 berries of the total yield was not modified to any great extent by differences in width of row.

Upon the determination of stand of plants, it was found that, with the method employed, some variation in spacing of plants resulted among plots; the average distance between plants being 4.3 inches in the 10-inch rows and progressively

[redacted]

Table 1. Relationship of Width of Thinned Row to Acre Yields of the Blakemore Strawberry, 1940.

Width of Thinned Row (Inches)	Total Yield Per Acre (Quarts)	Yield Per Acre, U. S. No. 1's (Quarts)	Per Cent U. S. No. 1's of Total Yield	Per Cent Yield Increase from 40-inch Row (U. S. No. 1's)	Number of U. S. No. 1 Berries Per Quart	Average Distance Between Plants (Inches)	Plants Per Acre
10	15,635	12,169	77	49	98	4.3	172,315
20	13,997	10,571	75	29	103	5.2	172,062
30	12,148	9,243	76	13	103	5.6	147,597
40	10,632	8,163	76	---	101	6.2	129,316

Difference Necessary for Significance:

1,476 1,392 - 1 per cent level

1,107 1,044 - 5 per cent level

[redacted]

increasing up to 6.2 inches on the 40-inch rows. This variation in distance among plots was due, primarily, to the difficulty in getting a sufficient density of runners to the outer limits of the wider rows as mentioned previously. However, the results of all previous spacing work indicate that little, if any, difference in unit yields can be expected between distances of 4 and 6 inches so that the yield data in table 1 were not affected by the variation in plant stand.

Although the plants in the 10-inch rows were closer together they outyielded, on a plant basis, the plants in the wider rows which had a greater distance between plants. This can be explained by the fact that the narrow rows were, very largely, composed of the earliest formed and established runner plants, whereas the wider rows contained a successively increasing percentage of late formed runner plants which have a much decreased fruiting capacity, as established by several workers. Also, the percentage of total plants receiving the benefits of the aisle border effect, as regards additional soil moisture and nutrients, becomes increasingly smaller as the width of row increases.

Table 2 presents the number of leaves per plant and the dry weights that were obtained from 10 random plants which were dug from each of the three rows of a given width per plot. These data offer additional explanation of the yield differences presented in table 1, in that as the width of row was increased, the dry weight of crowns, roots, and the

Table 2. Influence of Width of Thinned Row on Dry Weight of Roots, Crowns, Leaves, and Number of Leaves Per Plant, 1940. (Average of 150 Plants for Each Width, 10 Plants Dug at Random Soon After Fruiting from Each of 15 Rows).

Width of Thinned Row	Dry Weights in Grams				Number of Leaves
	Roots	Crowns	Leaves	Total	
10-inch	1.47	1.29	5.61	8.37	9.72
20-inch	1.38	1.21	5.51	8.10	9.60
30-inch	1.28	1.11	5.67	8.06	9.54
40-inch	1.23	1.08	5.90	8.21	9.14

number of leaves per plant tended to decrease. Weight of leaves, a variable material for measurement, remained relatively constant. As previously mentioned, this decrease in dry weight with an increase in row width is explained by the fact that the narrow rows are composed of a much higher percentage of early-formed and established runner plants which have been shown by various investigators to have an increased fruiting capacity over those runners which are formed later in the season. These early-formed runner plants are the first to become established and consequently build up root systems and tops over a longer period of time than runners which are formed later on in the season.

From the data in table 3, it is plainly evident that width of row in 1942 had no effect whatsoever upon production within a given treatment, contrary to the data obtained in 1940. The greatest difference in U. S. No. 1 yields between any of the different widths of thinned rows was 273 quarts which, by analysis of variance, does not even approach significance even at the 5 per cent level. The percentage of U. S. No. 1 berries of the total yield, size of berries, weight and number of berries produced per plant was in no way affected by width of row for a given treatment or cultural practice. However, it is of special interest to note that the thinned rows produced an average of 86.8 per cent U. S. No. 1 berries of the total yield while with the same treatment exactly but under different soil and environmental conditions, the plots in 1940 on the University Campus pro-

[redacted]

Table 3. Influence of Width of Thinned, Matted, and Spaced Rows on Size of Berries, Berries Produced Per Plant, and Production Per Acre of the Blakemore Strawberry, 1942.

Treatment and Width of Row	Total Yield (Acre Basis)	U. S. No. 1: Yield (Acre Basis)	Per Cent U. S. No. 1's of Total	Number of U. S. No. 1's Per Quart	Total Wt. Produced Per Plant (gms)	U. S. No. 1 Wt. Produced Per Plant (gms)	Number of Total Berries per Plant	Number of U. S. No. 1 Berries Per Plant	Plants Per Acre
10-inch Thinned	9,279	8,118	87.5	101	27.6	24.3	6.0	4.0	204,600
18-inch Thinned	9,339	8,049	86.2	103	28.1	24.3	6.3	4.1	203,458
24-inch Thinned	9,014	7,845	87.0	103	31.6	27.4	7.0	4.6	175,442
30-inch Thinned	9,283	8,028	86.5	101	27.8	24.0	6.0	3.9	206,294
Average	9,229	8,010	86.8	102	28.8	25.0	6.3	4.2	
10-inch Matted	8,170	6,732	82.4	109	20.6	16.8	5.3	3.0	241,560
24-inch Matted	8,020	6,750	84.2	107	18.3	15.5	4.4	2.7	267,340
30-inch Matted	7,877	6,600	83.8	113	16.5	13.8	4.2	2.5	294,294
Average	8,022	6,694	83.5	110	18.5	15.4	4.6	2.7	
Plants Spaced 9 Inches	12,478	10,727	85.9	105	131.9	113.0	29.4	19.4	58,080

Difference Necessary for Significance Between Types of Row (U. S. 1 Yield): 5% 457 Quarts; 1% 609 "

Difference Necessary for Significance Between Widths of Row (U. S. 1 Yield): 5% 560 "; 1% 747 "

[redacted]

duced only an average of 76 per cent U. S. No. 1 berries of the total yield. A similar relation holds true for the matted rows except that there is only a difference of 7.5 per cent. One big difference between the 1940 and 1942 seasons was that the 1940 picking season was exceptionally long, but both seasons were favorable as far as soil moisture was concerned.

Width of row had no effect on yields of the different widths of matted rows as the greatest average difference in U. S. No. 1 yields between any two widths was only 150 quarts. There was no difference in the percentage of U. S. No. 1 berries between the different width matted rows but the narrow rows produced larger berries than did the 30-inch width rows. As the width of matted row increased a progressive decrease in average weight and number of berries per plant resulted, which contrasts with lack of such a tendency with the thinned rows.

It might appear, from the data presented in table 1, on the number of plants per acre, that the increased yields from the 10-inch rows were due to the fact that there were more plants per acre in this type of row. However, there was practically no difference between the 10-inch and 20-inch rows in number of plants per acre, and yet the 10-inch rows produced over 15 per cent more U. S. No. 1 berries than did the 20-inch width rows. This increased production from the narrow rows is further substantiated in 1942 by comparing the yield and plants per acre for the matted rows in table 3.

As the width of row increased, a progressive increase in the number of plants per acre resulted, but the yields were the same. In other words, although there were 18 per cent less plants in the 10-inch rows than in the 30-inch rows, the yields per acre were the same for the different widths of row. It is interesting to note that with the method of thinning employed, the 24-inch width thinned rows in 1942 had approximately the same number of plants on an acre basis, as did the 10- and 20-inch thinned rows in 1940. These findings on the narrow rows further emphasize the importance of the early-formed runners, the greater proportion of early-formed runners in the narrow row, and the greater number of plants adjacent to the aisles which are influenced by border effect.

The rows which contained plants spaced 9 inches apart produced an average of 10,727 quarts of U. S. No. 1 berries per acre, an average of 25 and 37.5 per cent greater yields than were obtained from the average thinned and matted rows respectively. It is interesting to note that large yields, represented by number and weight of berries produced per plant, can be obtained per plant when the plants are widely spaced. On a per plant basis, in terms of weight or number of fruits, the plants which were spaced 9 inches apart yielded over four times as much U. S. No. 1 berries as those plants which were thinned to a distance of 4 to 6 inches between plants and over seven times as much as the matted row plants. This is primarily accounted for by the fact that each spaced plant had practically no competition for soil moisture and nutrients, established a root system early in the season, and had more nutrients per plant coming from the mother plant.

In every case, regardless of width of row, the thinned rows produced an average of 1,316 quarts per acre more than did the matted rows, which is significant at the 1 per cent level. Had it not been for the very favorable season, in regard to moisture, this difference would probably have been much greater. In every case the matted row berries were much smaller and the production per plant was considerably less than from either the thinned or spaced rows.

Table 4 presents the average dry weight of roots, crowns, leaves, and number of leaves per plant from the matted, thinned and spaced rows. Similar to the 1940 results with thinned rows, it is shown in table 4 that as the width of both thinned and matted rows increased a progressive decrease in dry weight of roots, crowns, and number of leaves per plant resulted with much more marked differences with the matted rows. Although 1942 was a favorable year for runner plant development, the dry weight data show that plants in the narrow rows were able to make larger roots and crowns and more leaves per plant than plants growing in the wider rows. The effect of high plant population in the row, which results in less moisture and mineral nutrients per plant, is demonstrated by a comparison of the average dry weights (33.38, 9.46, 4.78) and number of leaves (40.20,

[redacted]

Table 4. Effect of Width of Thinned, Matted, and Spaced Rows on Dry Weight, and Number of Leaves Per Plant, 1942. Size of Plant Sample Varied From 10 to 50 Plants.

Row Treatment	Dry Weight				Number of Leaves
	Roots	Crowns	Leaves	Total	
10-inch Thinned	1.25	1.67	7.18	10.10	12.14
18-inch Thinned	1.22	1.65	6.38	9.25	12.00
30-inch Thinned	1.21	1.21	6.65	9.07	11.53
Average	1.22	1.51	6.73	9.46	11.89
10-inch Matted	1.01	1.04	4.37	6.42	8.60
24-inch Matted	.80	.78	3.61	5.19	8.29
30-inch Matted	.57	.49	1.69	2.75	5.78
Average	.79	.77	3.22	4.78	7.55
22-inch Width, Plants Spaced 9 Inches	3.68	5.16	24.54	33.38	40.20

[redacted]

11.89, 7.55) of the plants from spaced, thinned, and matted rows respectively, (figures 15 and 16). The usual 30-inch matted rows produced plants with very low total dry weights of 2.75 grams which is less than 1/5 the weight of the thinned plants from the 30-inch thinned rows. The weight of thinned plants in 1940 was approximately the same as the weight of plants in 1942 with differences slightly in favor of 1942. Considering the various plant organs separately, the average dry weights for the 30-inch thinned row plants is at least twice that of the 30-inch matted row plants in every case. The average dry weight of roots from plants spaced 9 inches apart is 3 and 4½ times greater than the average weights of roots from thinned and matted rows respectively, while larger differences occurred between dry weights of crowns. Even greater differences were obtained for dry weight of leaves; the leaves from spaced plants being 3½ times greater than the thinned plants and approximately 8 times greater than leaves from matted row plants. Large differences between treatments were also present in the average number of leaves per plant.

Effect of Different Renewal Systems on Yield and Growth of Plants with Thinned Rows of Various Widths

In an attempt to devise better methods of renewal for thinned rows, in comparison with the conventional "barring off" used on matted rows, it was found that a marked improvement in yield the second season could be obtained with a

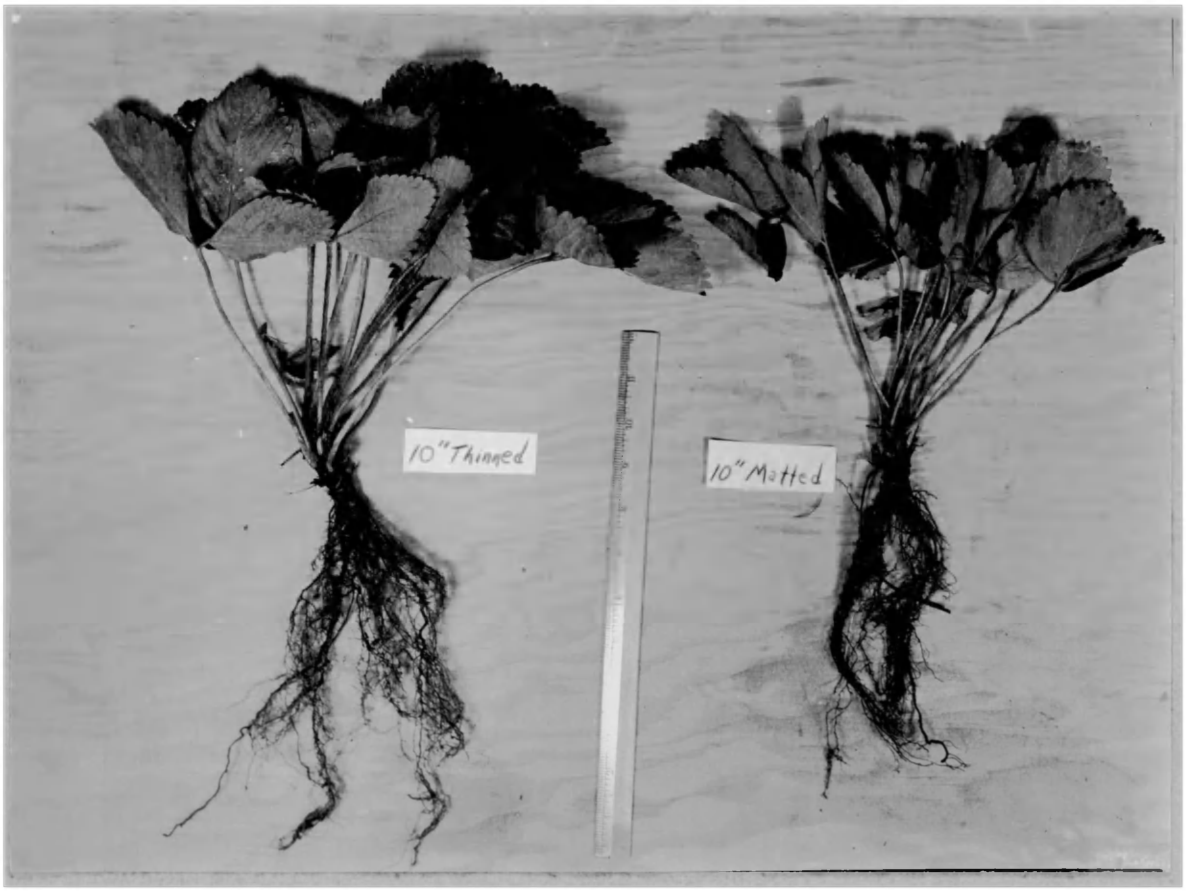

Figure 15. Comparison of plants from 10-inch width of thinned rows (average dry weight of 10.10 grams per plant) and plants from 10-inch width matted rows (average dry weight of 6.42 grams per plant).

Figure 16. A comparison of plants which were spaced 9 inches apart (average dry weight of 33.38 grams per plant) and plants from the 10-inch thinned rows (average dry weight of 10.10 grams per plant).

relatively economical method. The data presented in table 5 clearly show that with thinned rows of Blakemore, the removal of all runners, thereby fruiting only the original thinned plants during a second season, resulted in much greater yields than were obtained from either the conventional renewal practice of "barring off" the rows or by permitting the thinned rows to revert to a matted row condition. Increases in yield from this method approximated 66 and 81 per cent over the latter two methods respectively, and these differences in yield were highly significant as calculated by analysis of variance. The data further show that yields equally good to a conventional "barring off" were obtained from thinned rows when they were allowed to revert to a matted row the second year.

Regardless of the renewal system, as the width of row decreased a progressive increase in yield per acre resulted which is consistent with the results obtained during the first year of fruiting. This is especially evident with the two-year plant renewal system in which, without exception, the yield from the 10-inch width rows was highly significant over all other widths. With the conventional renewal method, there was no significant difference in yield between the 10- and 20-inch width nor between the 30- and 40-inch widths, but yields from the 10-inch width rows were significantly greater at the 5 per cent level than the 30- and 40-inch widths. The same holds true for the matted row renewal; the yields of the 10-inch rows being significantly

[redacted]

Table 5. Influence of Renewal System and Width of Row of the Blakemore Strawberry and the Percentage Yield Increase Over the 40-inch Rows, 1941.

Width of Row	Renewal System: Conventional	Renewal System: Matted Row	Renewal System: 2-year Plant	Per Cent Increase of 2-year Plant Renewal Over Conventional
	Yield of U. S. No. 1 Quarts Per Acre			
10-inch	6,910	6,336	11,476	66
20-inch	5,923	6,231	9,435	59
30-inch	5,399	4,836	8,720	62
40-inch	5,397	4,737	7,099	32
	Percentage Yield Increase Over 40-inch Rows			
10-inch	28	34	62	
20-inch	10	32	33	
30-inch	0	2	23	

[redacted]

greater at the 5 per cent level than the 30- and 40-inch rows. The differences are not as great, however, as were those obtained for the two-year plant renewal system.

The data in table 5, comparing yields on a percentage basis, more clearly illustrate that as the width of row decreases the yield per acre increases. Thus, with the two-year plant renewal system, progressive increases from the 40-inch width rows of 62, 33, 23 per cent occurred for the 10-, 20-, and 30-inch widths respectively. While these differences are not as great for the other two renewal systems, significantly greater yields were obtained on the narrower width rows regardless of the renewal system employed.

Decreases from first-year yields varied according to the renewal systems, but variations in width of row seemed to have no marked effect on the percentage decrease in yield from the first-year yields. The data in table 6 show that the rows composed of two-year plants yielded an average of only 8.8 per cent less during the second year of fruiting while the conventionally renewed and matted row systems produced an average of 40.7 and 44.7 less respectively the second year and the two latter decreases are commonly experienced in commercial growing of Blakemore.

The percentage of U. S. No. 1 berries of the total yield did not vary greatly on rows of different widths (table 7). However, there was a difference among renewal systems in that the matted row system produced approximately 13 per cent fewer marketable berries than did the other two renewal

[redacted]

Table 6. Comparative Decrease from First-year Yields (1940) of Various Second-year Renewal Systems Under Different Widths of Row, 1941.

Renewal System	Width of Row				Average
	10-inch	20-inch	30-inch	40-inch	
Conventional	43.3	44.0	41.6	33.9	40.7
Matted Row	48.0	41.1	47.7	42.0	44.7
2-year Plant	5.7	10.8	5.7	13.1	8.8

[redacted]

Table 7. Influence of Renewal System and Width of Row on the Percentage of U. S. No. 1's, and the Size of Berries as Measured by Number of U. S. 1's Per Quart, 1941.

Renewal System	Width of Row				Average
	10-inch	20-inch	30-inch	40-inch	
	U. S. No. 1's, Percentage of Total Yield				
Conventional	77	77	79	80	78
Matted Row	66	67	62	64	65
2-year Plant	78	77	77	78	78
	Number of U. S. 1's Per Quart				
Conventional	120	116	118	115	117
Matted Row	126	124	127	125	125
2-year Plant	112	116	115	117	115

systems. Relative to size of U. S. No. 1 berries, as shown by the number of berries per quart, the two-year plants produced berries slightly larger than those from the conventional renewal system while the berries from the matted rows were considerably smaller.

The effect of renewal system on time of fruit maturity, (figure 17), illustrates that the conventional renewal system produced berries earlier throughout the season than did the two-year plant renewal or matted row systems. This might be considered of importance since, on an acre basis, by May 30 the conventionally renewed rows had produced over 1000 quarts more of U. S. No. 1 berries than had the matted rows. Depending upon market conditions, this earliness factor might result in greater financial returns to the grower, but such returns might be more than offset by greater yields obtained by use of the two-year plant system.

The average fresh weight of berries produced per plant under the three renewal systems on each of the four widths of row is shown in figure 18. It will be noted that as the width of row increased a progressive decrease in production per plant resulted. This is particularly evident with the matted row renewal and the same holds true, but not in every case, for the conventional and two-year plant renewal systems. Plants under the two-year plant renewal system produced from 4 to 7 times the fresh weight of berries as did the matted row plants and about twice the fresh weight of berries as did those plants under the conventional renewal system.

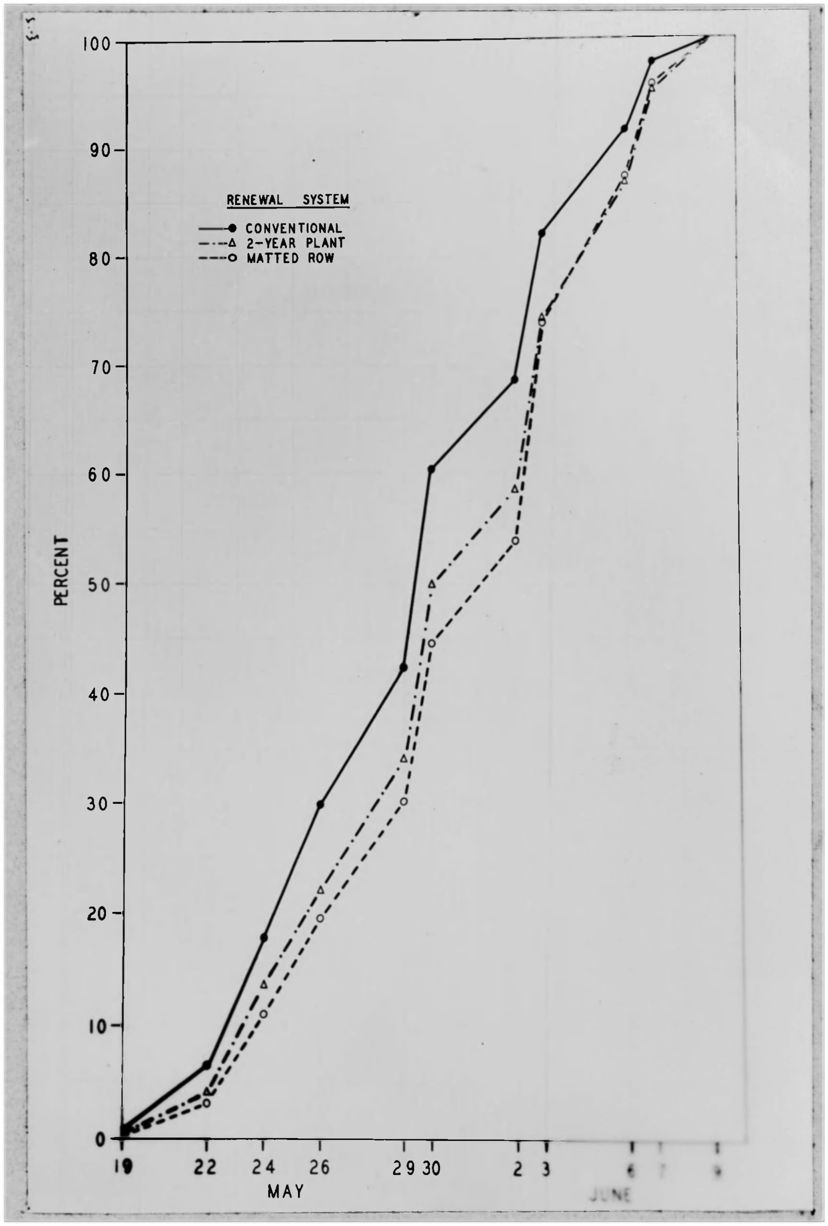

Figure 17. Effect of renewal system on time of fruit maturity, showing the accumulative percentages of fruit picked on a particular date (average of the four widths of row).

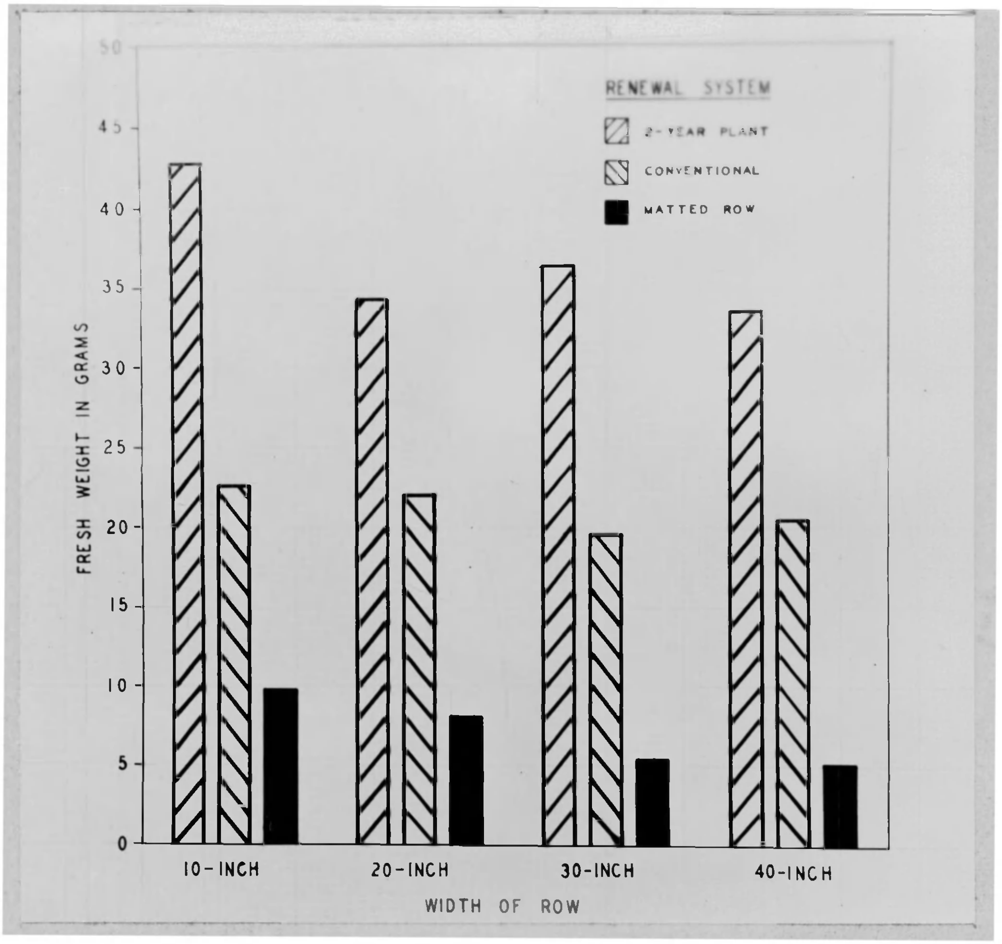

Figure 18. Influence of renewal system and width of row on the average fresh weight (grams) of berries produced per plant.

Such differences in yield per plant can be definitely related to the size of plant produced under the various renewal systems.

Considering the matter of relative plant development as affected by renewal system and width of row, the data in table 8 show that the average dry weight per plant, under the two-year plant renewal system, was 9.4 grams, while with the conventional renewal method the average dry weight per plant was 5.7 grams. With all the runners removed from the two-year plants, large leaf areas, crowns, and root systems, as well as large food reserves, were built up. These factors are directly reflected in the large yields obtained the second year on rows in which the original plants again were fruited. In the matted rows, the two-year plants averaged 5.9 grams per plant, while the interspersed one-year plants averaged 1.1 grams. The failure of the two-year plants in the matted row system to develop and attain the size of those plants in the two-year plant renewal system is shown by the comparative dry weights per plant of 5.9 and 9.4 grams respectively, and indicates the adverse effect of new runner formation and increased competition for water and nutrients upon the development of those plants under matted row renewal during the second growing season. Moreover, there was a decrease in average dry weight from 7.7 grams per plant in the 10-inch row to 4.6 grams per plant in the 40-inch row, indicating that competition also increased as width of row increased. This is likewise indicated by the data presented

[redacted]

Table 8. Influence of Renewal System and Width of Row on the Average Dry Weight (Grams) Per Plant. (Average of Plants Taken from Five Random Samplings of One Square Foot Each). 1941

Renewal System	Width of Row				Average Dry Weight
	10-inch	20-inch	30-inch	40-inch	
Conventional, 1-year Thinned Plants	7.7	6.5	4.3	4.4	5.7
Matted Row,					
2-year Plants	7.7	5.5	5.7	4.6	5.9
1-year Plants	1.0	1.2	1.0	1.1	1.1
2-year Plant	10.1	9.0	8.9	9.7	9.4

[redacted]

for the thinned plants in the conventional renewal system where a decrease from 7.7 grams per plant in the 10-inch row to 4.4 grams per plant in the 40-inch row occurred. A comparison of the very low average dry weight of 1.1 grams per runner plant from the unthinned matted row renewal with the average dry weight of 5.7 grams per plant for those in the thinned conventional renewal system again illustrates the effect of plant competition upon the development of Blakemore runner plants.

Effects of Summer Applications of Sodium Nitrate on Fruit Production of Thinned and Matted Rows

Summer applications of nitrate of soda, as a top dressing in 1939 and 1940 at monthly intervals during the summer from June 1 to September 1, in an effort to influence growth and development of runner plants, proved to be of little value on this rather fertile type of soil.

The data presented in table 9 show that, regardless of the time or rate of application of sodium nitrate to either thinned or matted rows, no differences in yield which could be attributed to treatments were obtained from plants which had varying quantities of nitrate or which received the nitrate at different periods during the growing season. Not only were there no differences between yields, as a result of fertilizer treatments, but there were also no differences in yield as a result of plant thinning. On an acre basis, the average yield for all fertilizer treatments of the matted rows was similar to that obtained from the thinned rows. It

Table 9. Effect of Summer Application of Sodium Nitrate on Yields Per Acre, Per Cent U. S. No. 1's of the Total Yield, Number of Berries Per Plant, and Size of Berries, 1940.

Treatment	Date of Fertilizer Application							Average
	June 1	July 1	Aug. 1	Sept. 1	June 1 July 1	June 1 July 1 Aug. 1	June 1 July 1 Aug. 1 Sept. 1	
	U. S. No. 1 Yields Per Acre in Quarts							
Matted	11,964	11,461	11,374	12,390	11,597	11,635	10,832	11,608
Thinned	11,839	12,632	10,222	10,754	11,945	12,100	11,684	11,597
	Total Yields Per Acre in Quarts							
Matted	16,195	15,807	15,798	17,076	16,214	16,679	15,246	16,145
Thinned	15,546	16,243	13,416	14,249	15,846	15,972	15,565	15,262
	U. S. No. 1's of Total, Percent							
Matted	73.9	72.5	72.0	72.6	71.5	69.8	71.0	71.9
Thinned	76.2	77.8	76.2	75.5	75.4	75.8	75.1	76.0
	Total Number of Berries Per Plant							
Matted	6.6	7.4	6.6	6.7	6.8	7.4	7.2	6.9
Thinned	13.5	15.0	14.0	14.0	17.2	15.8	14.1	14.8
	Total Berries Per Quart							
Matted	143	152	150	151	151	153	151	150
Thinned	138	134	135	141	143	137	139	138
	U. S. No. 1 Berries Per Plant							
Matted	3.5	3.8	3.4	3.3	3.4	3.6	3.6	3.5
Thinned	7.8	8.7	8.2	7.9	8.6	9.0	7.6	8.3
	U. S. No. 1's Per Quart							
Matted	103	109	107	103	106	107	107	106
Thinned	105	101	104	105	103	103	100	103

should be pointed out that during the picking season very favorable conditions prevailed for ripening and sizing of all berries that were formed. The matted rows contained an average stand of 360 or 2.4 times as many plants as the thinned rows. However, the matted row plants, on a plant basis, yielded less than half of what the thinned row plants produced. The thinned rows produced an average of about 4 per cent more marketable berries than did the matted rows and the berries were also somewhat larger, as judged by number per quart.

The dry weight data in table 10, for plants receiving summer applications of sodium nitrate, show that there were no differences in number of leaves, or weight of plant which could be ascribed to nitrate treatments considering either matted or thinned rows. The average plant or plant part from any of the thinned row treatments was, in many cases, three times as large as the average matted row plant receiving the same treatment. The average dry weights and number of leaves per plant of all thinned row fertilizer treatments were practically double the same measurements for the matted row plants. This partially accounts for the large differences in yield presented, on a per plant basis, in table 9. Here too, as was mentioned previously, the thinned plants yielded, on a plant basis, over 100 per cent more total as well as U. S. No. 1 berries than did the matted row plants. In addition to the much larger dry weight of roots, crowns, and leaves of the thinned plants, the number of leaves per

[redacted]

Table 10. Effect of Summer Application of Sodium Nitrate on Dry Weight (Grams) of Plants in Thinned and Matted Rows, 1940. (Each Figure Represents an Average of 40 Plants Selected at Random in the 4 Replicates, 10 Plants to a Row. Plants Were Sampled in June Soon After Fruiting).

Plant Part	Fertilizer Application Date							Average
	June 1	July 1	Aug. 1	Sept. 1	June 1 July 1	June 1 July 1 Aug. 1	June 1 July 1 Aug. 1 Sept. 1	
				Matted Rows				
Roots	.63	.93	.95	.88	.70	.88	.78	.82
Crowns	.52	.70	.73	.73	.64	.75	.81	.70
Leaves	2.13	3.06	2.76	3.20	2.57	3.20	3.41	2.90
Total	3.28	4.69	4.44	4.81	3.91	4.83	5.01	4.42
Number of Leaves	4.72	6.47	5.35	6.45	5.55	6.45	7.22	6.03
				Thinned Rows				
Roots	1.34	1.54	1.35	1.28	1.22	1.33	1.26	1.33
Crowns	1.08	1.31	1.24	1.18	1.24	1.34	1.33	1.25
Leaves	6.03	6.03	7.13	6.87	6.72	7.11	7.02	6.70
Total	8.45	8.88	9.72	9.33	9.18	9.78	9.61	9.28
Number of Leaves	10.72	11.40	13.42	12.15	11.67	12.50	13.37	12.18

[redacted]

plant was double that of the matted row plants. Since it is the number of leaves and the leaf area per plant which is an important factor in determining the number of fruit buds formed, it is easy to see how these thinned plants produced an average of twice as many berries on a plant basis as did the matted row plants.

Again in 1941, as was the case in 1940, regardless of the time or rate of application of sodium nitrate to thinned and matted rows, no differences in yield could be ascribed to any treatment within a particular type row or even between the two types of row. In every respect the data obtained in 1941 (table 11) show practically the same trend as in 1940. It is interesting to note that the percentage of U. S. No. 1 berries of the total yield the second year was 6.9 per cent greater for the matted rows and 7.6 per cent greater for the thinned rows than in 1940. Since there was no difference in acre yields between the thinned and matted rows, it is only reasonable that there would be slight differences in percentage yield decrease the second year between the two types of rows. As anticipated, both the matted and thinned plants produced smaller, and fewer total, as well as U. S. No. 1 berries per plant the second year.

The dry weight data in table 12 again show the second year that there were no differences in size and weight of plant within a particular type of row, attributed to the time or rate of application of sodium nitrate. The average dry weights and number of leaves per plant of all thinned

[redacted]

Table 11. Effect of Summer Application of Sodium Nitrate on Yields Per Acre, Per Cent U. S. No. 1's of the Total Yield, Yield Decrease for Second Year Fruiting, Number of Berries Per Plant, and Size of Berries, 1941.

Treatment	Date of Fertilizer Application						Average
	Check	July 1	August 1	September 1	July 1 August 1	July 1, August 1, and September 1	
	U. S. No. 1 Yields Per Acre in Quarts						
Matted	7,415	9,186	8,528	9,322	9,022	8,673	8,691
Thinned	8,489	9,148	9,632	7,976	9,293	9,419	8,993
	Total Yields Per Acre in Quarts						
Matted	9,564	11,752	10,880	11,500	11,606	10,822	11,021
Thinned	10,309	11,219	11,393	9,428	11,055	11,122	10,754
	U. S. No. 1's of Total, Percent						
Matted	77.5	78.2	78.4	81.1	77.7	80.1	78.8
Thinned	82.3	81.5	84.5	84.5	84.1	84.7	83.6
	Decrease in Yield of U. S. No. 1's the Second Year, Percent						
Matted	38.1	19.9	25.1	24.8	22.3	25.5	25.9
Thinned	28.3	20.6	5.7	25.9	22.3	22.2	22.0
	Decrease in Total Yield the Second Year, Percent						
Matted	41.0	25.7	31.2	32.7	28.5	35.2	32.3
Thinned	33.7	31.0	15.1	33.9	30.3	30.4	29.0
	Number of U. S. No. 1 Berries Per Plant						
Matted	2.5	3.0	2.7	2.9	2.9	2.8	2.8
Thinned	6.4	6.8	7.1	6.0	6.7	6.9	6.7
	Number of U. S. 1's Per Quart						
Matted	116	112	111	110	114	111	112
Thinned	109	109	107	109	104	106	107
	Total Number of Berries Per Plant						
Matted	4.5	5.6	5.0	5.1	5.5	5.0	5.1
Thinned	10.4	11.2	11.1	9.3	10.4	10.8	10.5
	Total Berries Per Quart						
Matted	164	165	159	154	166	161	162
Thinned	146	145	141	144	137	141	142

[redacted]

Table 12. Effect of Summer Application of Sodium Nitrate on Dry Weight (Grams) of Plants in Thinned and Matted Rows, 1941. (Each Figure Represents an Average of Plants Taken from Four Random Samplings of One Square Foot Each. Plants Sampled in June Shortly After Fruiting).

Plant Part	Fertilizer Application Date						Average
	Check	July 1	Aug. 1	Sept. 1	July 1 Aug. 1	July 1 Aug. 1 Sept. 1	
				Matted Rows			
Roots	.58	.76	.81	.85	.72	.69	.74
Crowns	.51	.64	.72	.71	.64	.60	.64
Leaves	3.00	2.09	2.60	2.54	3.20	3.15	2.76
Total	4.09	3.49	4.13	4.10	4.56	4.44	4.14
Number of Leaves	4.64	5.49	5.00	6.30	5.25	5.80	5.41
				Thinned Rows			
Roots	1.28	1.49	1.40	1.25	1.18	1.30	1.32
Crowns	1.00	1.21	1.25	1.20	1.20	1.07	1.16
Leaves	6.08	6.00	6.83	6.98	6.50	7.04	6.57
Total	8.36	8.70	9.48	9.43	8.88	9.41	9.04
Number of Leaves	11.04	10.80	11.94	12.16	10.43	10.72	11.18

row fertilizer treatments were double the same measurements for the matted row plants.

Development of the Mother Plant in Relation to Runner Plant Formation

The seasonal development of roots, crowns, and leaves of mother plants from time of planting to the end of the growing season, show some interesting deviations from the normal growth curve which are considered in relation to runner plant development.

The data on root development, presented in table 13, show that there is a gradual increase of less than two centimeters in root length during the first month after planting. Presumably it requires about this length of time for the plant to become established in its new environment before starting rapid growth. This slow growth period was followed by rapid root elongation during a short period of a little over one week. During this period from May 27 to June 9, approximately 85 per cent of root length, not total root development, was made. This period of rapid root elongation was followed by a much slower rate which gradually continued throughout the growing season.

In regard to dry weight of roots, there was a gradual increase throughout the season until early fall when there was a rapid increase in dry weight (figure 19). The crowns made a gradual increase in diameter until, by November 30, they had reached an average diameter of over 2½ times the original size when the plants were set in the field.

Table 13. Mother Plant Development from April 10, (Planting Date) to November 30, as Expressed in Linear Measurements, Dry Weight, and Starch Content, 1939. (Each Figure Represents an Average of 12 Plants).

Sampling Date	Roots			Crowns				Leaves					Total Dry Weight (gms)	Number of Runners
	Length (cms)	Dry wt. (gms)	Starch	Diameter (cms)	Length with roots (cms)	Dry Weight (gms)	Starch	Number Open	Number Not Open	Dry Weight (gms)	Starch Basal	Starch Distal		
April 29	12.75	.48	——	.67	1.05	.33	——	3.47	.67	.32	——	——	1.13	——
May 12	13.95	.56	——	.90	.84	.38	.41	3.42	1.06	.50	——	——	1.44	——
May 27	14.35	.55	.24	.69	1.08	.43	1.00	6.55	1.24	1.29	3.00	2.00	2.27	.16
June 9	22.97	.74	1.70	.70	1.10	.45	3.45	6.40	1.45	2.67	2.87	1.75	3.86	2.05
June 23	24.24	.94	1.40	.75	1.29	.61	4.15	9.12	1.90	4.36	2.90	1.80	5.91	3.77
July 7	23.90	1.26	1.15	.75	1.06	.50	1.98	10.95	1.82	5.38	1.62	1.87	7.14	6.65
July 21	25.80	1.41	2.40	.94	1.53	.87	3.45	11.62	1.47	7.73	2.30	2.37	10.01	7.47
Aug. 4	24.90	1.42	1.80	1.24	1.37	.99	1.57	11.50	1.41	6.81	.74	.74	9.22	7.40
Aug. 18	25.29	1.32	2.50	1.16	1.42	.99	1.65	8.49	1.11	4.09	.68	.76	6.40	7.37
Sept. 1	27.00	1.40	4.70	1.28	1.35	1.14	1.87	9.00	1.16	3.70	.87	1.83	6.24	6.42
Sept. 18	26.70	1.17	3.90	1.00	1.25	.98	3.74	8.33	1.16	3.12	.91	.99	5.27	5.20
Nov. 30	26.66	3.19	9.58	1.84	3.61	2.39	3.08	14.58	1.41	4.90	.66	.75	10.48	8.21

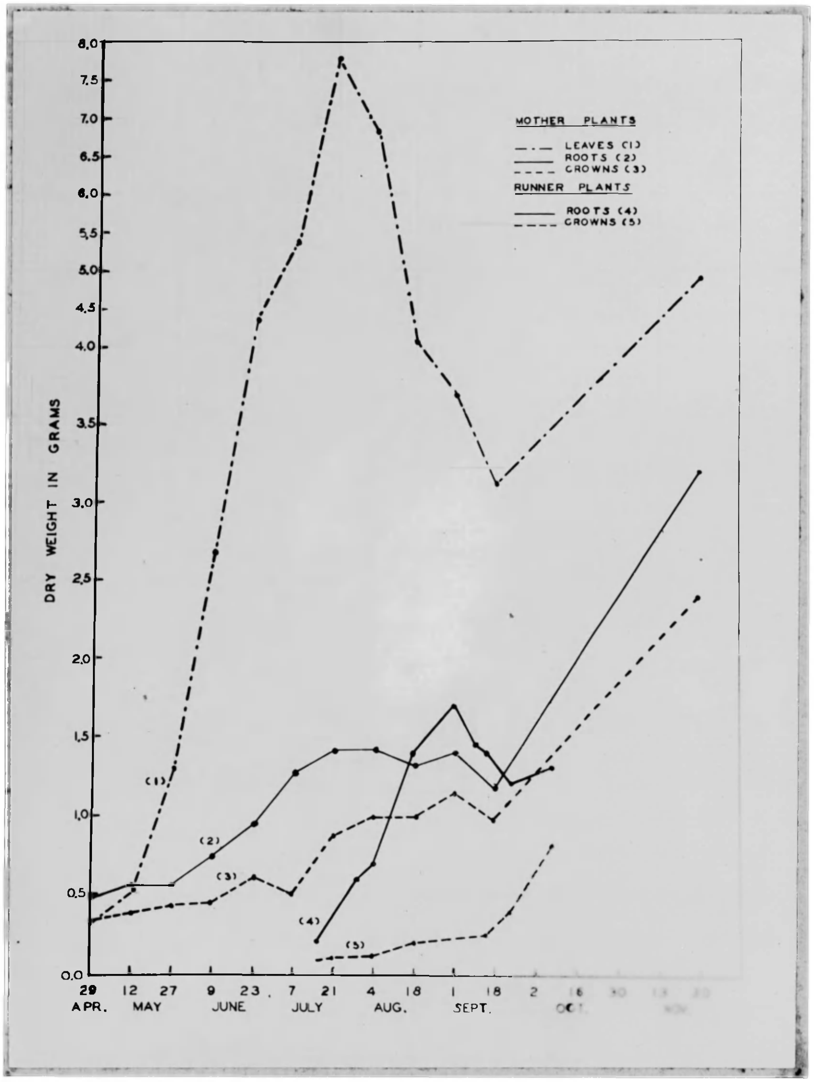

Figure 19. Seasonal development of roots, crowns, and leaves of mother plants and the comparative development of roots and crowns of runner plants in terms of dry weights in grams.

Longitudinal elongation was practically negligible until late fall when, during a little over two months time, the length of crowns with roots more than doubled the original length. Dry weight of crowns followed practically the same rate of average increase as did the roots. Since the crowns and roots are the storage organs of the strawberry plant, such increases in dry weight during the latter part of the season are to be expected.

There was a rapid increase in dry weight of leaves until July 21, after which the new runner plants which had formed and which were not self-supporting, probably caused a heavy drain on the mother plant. After the runner plants had established their own roots and were more or less self-supporting, this drain on the mother plant ceased. In general, there was a gradual decline in starch content in the basal and distal portions of the leaf petioles throughout the growing season. Foliage development was practically complete by the middle of July and number of runners per plant shortly after. The total dry weight reached practically a maximum the middle of July and then decreased until sometime between September and November when an increase again took place until a maximum dry weight of 10.48 grams was obtained on November 30, the last sampling date.

In figure 19 plotted averages of mother plants show seasonal development in dry weight of leaves, crowns, and roots and also dry weights of roots and crowns of runner plants. Seasonal runner plant development was not included in these investigations but the data, which were obtained from the work of Van Horn, Schrader, and Haut (108), are presented for a basis of comparison between runner and mother plant development. These runner plants were grown on a Sassafras sandy loam soil under matted row conditions at Salisbury, Maryland. The mother plants from which these runner plants developed were set in the field the latter part of March while the mother plants grown at College Park were set the first of April and therefore, the two sets of data are quite comparable as to season of development.

Increases in dry weight of crowns of runner plants were gradual until the middle of September, when a rapid increase was started. Root development of the runner plant, on the other hand, was rapid from the time of initiation of runners until September 1 when, as the authors state: "This cessation in development of roots was probably associated with crowding of plants under matted row conditions." In addition, along about this time, probably the runner plants had attained sufficient size to become relatively independent of the mother plant. This is borne out by the fact that after the middle of September, at which time the runner plants ceased drawing on the mother plants for food supplies, the mother plants again resumed rather rapid growth rates of leaves, crowns, and roots.

The most striking feature presented in this graph is the time of initiation of runner plants. Only when the dry weight of leaves of the mother plant had reached about a maximum for the season, in this case about the middle of July, did the development of the runner plants begin. After the rapid development of the runner plant had ceased, the mother plant organs resumed growth and storage of carbohydrates.

In connection with these interrelations of runner and mother plant development, the application of any cultural practice which might change this picture is of great importance. Let us consider runner plant thinning for example. By plant thinning we remove sufficient plants to reduce competition for nutrients and moisture to a minimum for those plants remaining in the row. In addition to this, however, by thinning before early fall we also reduce the drain on the mother and first formed runner plants. The dry weight data of leaves, presented in figure 19, show that by November 30 they had not reached the maximum weight obtained earlier in the season. It is true that large quantities of carbohydrates were translocated from the leaves to the roots and crowns but, possibly had there not been such a drain om the mother plant, the dry weight of leaves would have surpassed the maximum attained earlier in the season.

Further studies on mother plant development under various conditions might bring out the importance of mother plant development in relation to earliness of runner formation and strong development of runner plants. Some lead in this regard is referred to later on in a report of the studies under greenhouse conditions.

Effect of Soil Moisture and Aeration on Growth of Blakemore Strawberry Plants

Controlling soil moisture at three levels and furnishing additional aeration to a Sassafras silt loam under pot culture conditions, emphasized the importance of the moisture factor and indicated that aeration is not an important factor except possibly near saturation levels. The strawberry plant apparently responds to variations in moisture levels between the wilting point and field capacity of this particular soil.

Table 14 presents the data showing the effect of 3 soil moisture and 3 aeration levels on the leaf area, area per leaf, and the average number of leaves per plant. As the soil moisture was increased, the total leaf area showed a progressive increase from an average of 23.17 square inches for those plants growing in soil at 12 per cent moisture up to 41.53 square inches for those plants in the same soil at 32 per cent moisture (figure 20). The average number of leaves per plant and the area per leaf practically, in every case, progressively increased as the soil moisture was increased. No significant plant response was obtained from the various aeration treatments at 12 and 22 per cent soil moisture levels but supplemental aeration 3 minutes daily or 3 minutes every other day at the 32 per cent soil moisture level resulted in significantly greater leaf areas per plant over those plants receiving no additional aeration.

[redacted]

Table 14. Effect of Various Moisture and Aeration Levels on Total Leaf Area, Average Area Per Leaf, and Number of Leaves Per Plant: Experiment I, Started January 19 and Ended March 18, 1942. (Area Expressed in Square Inches and Each Figure Represents an Average of 9 Plants).

Moisture Level	Degree of Aeration: Check — Total Leaf Area	Check — Number of Leaves	Check — Area Per Leaf	3 Min. Every Other Day — Total Leaf Area	3 Min. Every Other Day — Number of Leaves	3 Min. Every Other Day — Area Per Leaf	3 Min. Every Day — Total Leaf Area	3 Min. Every Day — Number of Leaves	3 Min. Every Day — Area Per Leaf	Average		
12%	22.08	8.8	2.51	25.32	9.2	2.75	22.17	8.8	2.52	23.17	8.93	2.59
22%	35.36	9.4	3.76	33.53	10.4	3.30	28.69	9.8	2.93	32.53	9.87	3.30
32%	37.79	10.4	3.63	38.45	10.4	3.70	48.36	10.6	4.56	41.53	10.47	3.96
Average	31.74	9.53	3.30	32.43	10.0	3.25	33.07	9.73	3.33			

Difference Necessary for Significance Between Interactions for Total Leaf Areas: 5% - 8.047; 1% - 10.837

Difference Necessary for Significance Between Means of Aeration and of Moisture for Total Leaf Area: 5% - 4.646; 1% - 6.257

[redacted]

Figure 20. Effect of various soil moisture percentages on plant development: left, 12 per cent soil moisture; right, 32 per cent soil moisture. Note the small size of plant on the left compared with the good growth on the right after 30 days of treatment at the two moisture levels.

However, even though these differences approach significance at the 1 per cent level, the author feels that they are mainly accounted for due to variation in plant size at the initiation of the experiment rather than to supplemental aeration because the second experiment with more rigid selection of plants showed no differences in response to supplemental aeration.

Figure 21 shows that earliness of blossoming is directly related to soil moisture in that plants growing at 12 per cent soil moisture started blooming first, followed in order by plants growing in 22 and 32 per cent soil moisture. By February 24, the plants growing in 12 per cent moisture had produced an average of 19 and 26 per cent more of their total blossoms than those plants growing in 22 and 32 per cent moisture respectively. All plants in the various treatments averaged approximately 7 blossoms per plant since the blossom buds had already been initiated in the field before they were dug for this experiment.

A new series of plants, as previously described, was designed to determine the effect of a much increased aeration at 32 per cent soil moisture in view of the fact that supplemental aeration at this soil moisture level gave significant responses in Experiment I.

Figure 22 presents graphically the development in leaf area in square inches measured approximately every two weeks and shows the effect of moisture and aeration on leaf development. For about the first 10 days all plants receiving

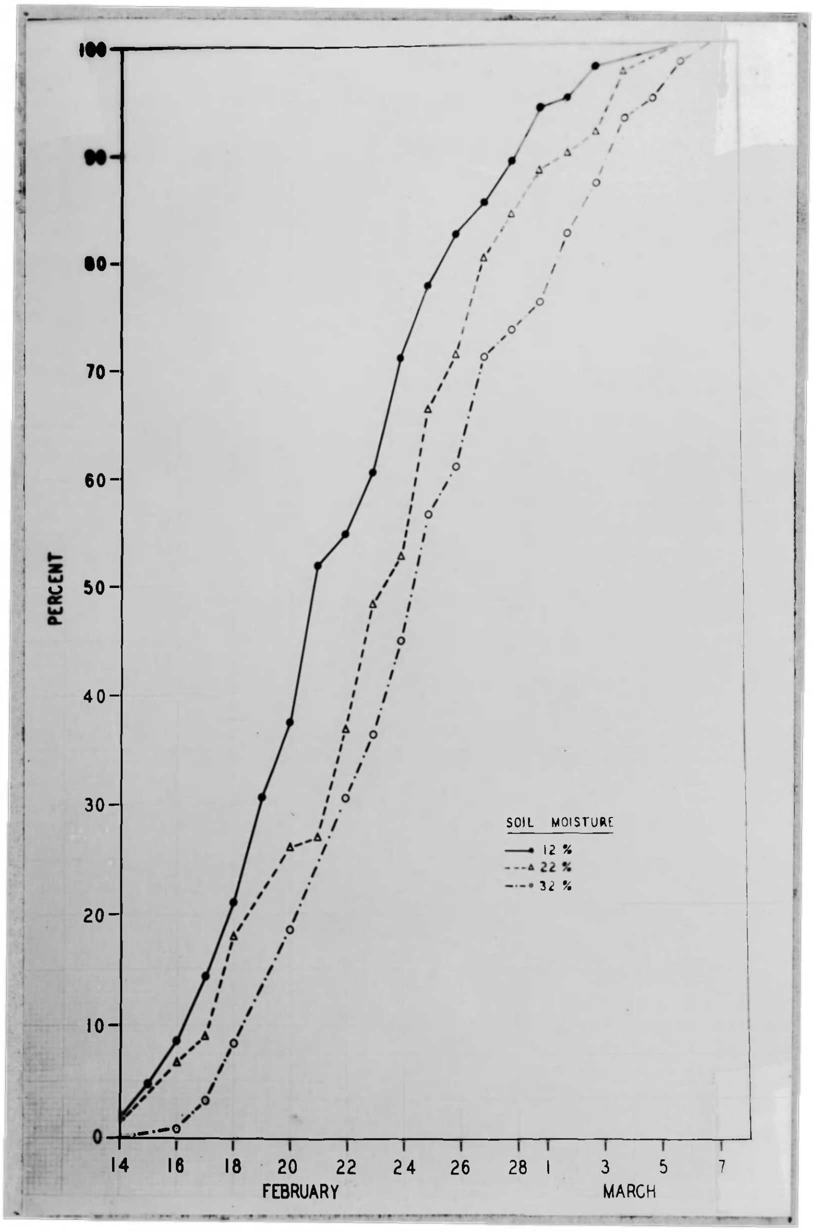

Figure 21. Effect of soil moisture on time of blossom unfolding showing the accumulative percentage of the blossoms opened on a particular date.

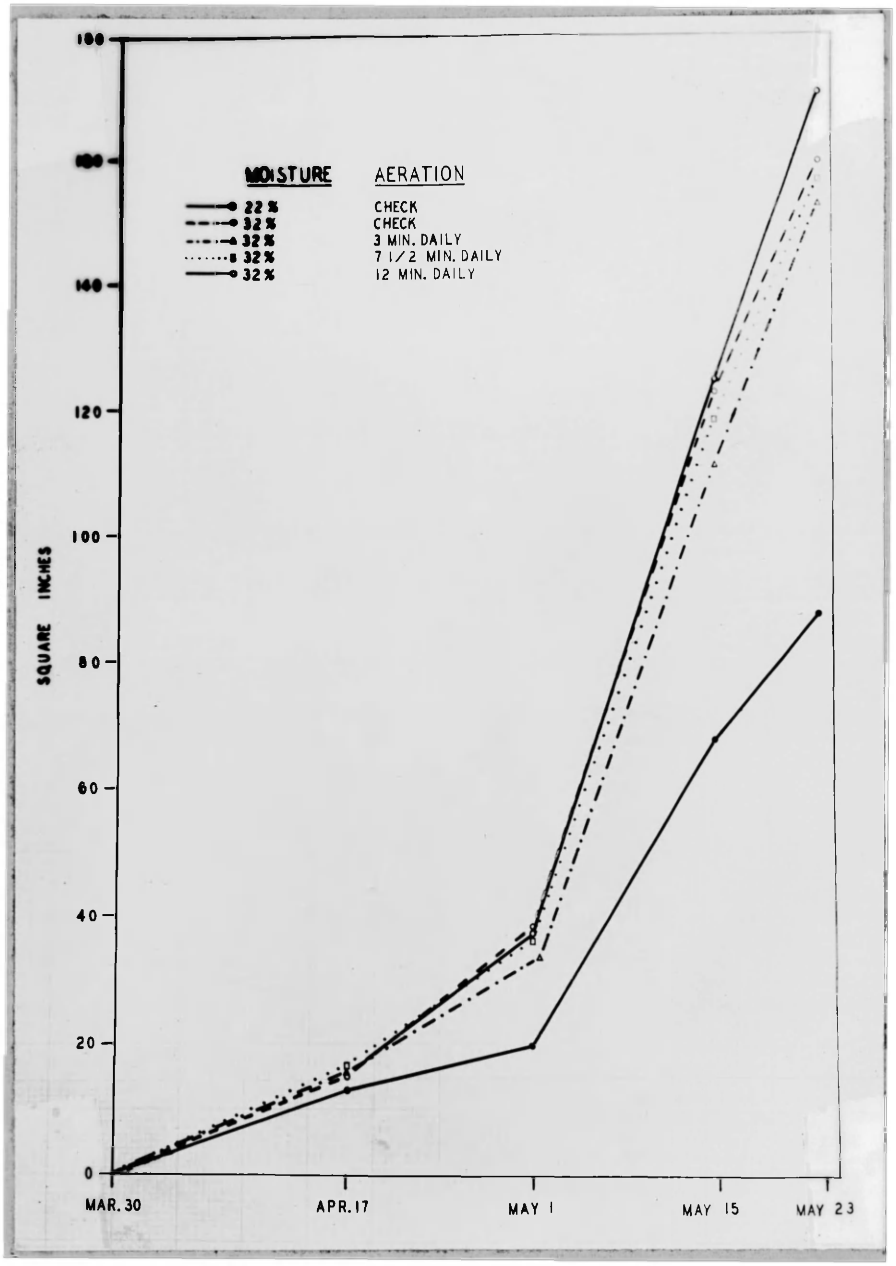

Figure 22. The effect of soil moisture and aeration on leaf area of Blakemore strawberry plants grown in pots, 1942.

the different treatments grew at about the same rate but by April 17 those plants receiving 32 per cent moisture had an average of about 3 square inches greater leaf area than plants receiving 22 per cent moisture. From April 17 to May 1, plants at the lower moisture level slowed up in their growth rates while plants at the higher moisture level increased their growth rates. From May 1 to May 15, plants of both moisture levels sharply increased their growth rates due probably to the fact that their root systems had become well established at this time. During the period of May 15 to May 23, the plants at the higher moisture level continued on at approximately the same growth rate while plants at the lower level began slowing up in growth rate indicating that their growth cycle was nearing the terminating point. In addition, the data show that under the conditions of this experiment aeration had no significant influence on plant development since the check plants at 32 per cent soil moisture had slightly greater leaf areas than those plants at the same moisture level which received additional aeration.

Table 15, in addition to the data which are presented graphically in figure 22, presents the average area per leaf as well as the average number of leaves per plant at two-week intervals throughout the course of the experiment. Seventeen days after the experiment was initiated all plants, even though they had received different treatments, had about the same number of leaves per plant and the

Table 15. Effect of Various Quantities of Moisture and Aeration on Leaf Area, Area Per Leaf, and Number of Leaves Per Plant. Experiment Started March 30 and Ended May 23, 1942. (Leaf Area in Square Inches).

Treatments		Leaf Area in Square Inches				Number of Leaves				Area Per Leaf			
Moisture	Aeration	Apr. 17	May 1	May 15	May 23	Apr. 17	May 1	May 15	May 23	Apr. 17	May 1	May 15	May 23
22%	Check	12.9	19.7	67.5	87.4	5.1	7.8	10.9	12.6	2.5	2.5	6.2	6.9
32%	Check	15.4	38.3	122.7	159.6	4.9	9.0	12.7	15.0	3.1	4.3	9.7	10.6
32%	3 min. daily	15.2	33.2	111.0	152.7	5.9	9.0	12.2	14.3	2.6	3.7	9.1	10.7
32%	7-1/2 min. daily	16.3	35.9	118.1	156.7	5.2	7.3	10.8	13.6	3.1	4.9	10.9	11.5
32%	12 min. daily	15.3	37.7	124.4	170.6	5.6	9.6	13.0	16.0	2.7	3.9	9.6	10.7
Average of 32% Moistures		15.5	36.3	119.1	159.9	5.4	8.7	12.2	14.7	2.9	4.2	9.8	10.9

average area per leaf was approximately the same. However, by May 1, plants growing in soil at 32 per cent soil moisture had, on the average, one more leaf per plant and the average area per leaf was 1.7 square inches greater. The difference in number of leaves per plant remained about the same until May 23, when the plants at the higher moisture level had an average of about 2 more leaves per plant than those plants at the lower moisture level. By May 15, plants at 32 per cent moisture had leaves averaging 3.6 square inches greater in area than did the plants at 22 per cent soil moisture. By May 23, this difference had reached 4 square inches or each individual leaf from the higher moisture plants averaged 37 per cent greater than leaves from plants at the lower moisture level.

Table 16 presents the dry and fresh weights of roots, crowns, leaves, and runners for the various moisture and aeration treatments. Considering both fresh and dry weight data for the various plant parts, it appears at first consideration, that with increased aeration there was a slight tendency for increased weight of plants. However, since the check plants at the 32 per cent moisture level were, in many cases, greater in weight than either of those groups of plants receiving aeration 3 or 7½ minutes daily, and since there were no significant differences statistically, additional aeration under the conditions of this experiment was considered to have no effect on plant growth (figure 23). On the other hand, moisture was the controlling factor.

[redacted]

Table 16. Effect of Moisture and Aeration on Dry and Fresh Weight of Plants: Experiment II. (Average of 9 Plants Per Treatment).

Plant Part	Moisture and Aeration Levels					Average of 32% Moisture Levels
	Check 22%	Check 32%	3 min. daily 32%	7-1/2 min. daily 32%	12 min. daily 32%	
			Dry Weight (Grams)			
Leaves	4.16	8.33	7.52	8.11	8.61	8.14
Crowns	1.18	1.45	1.40	1.44	1.55	1.46
Roots	2.40	3.76	3.65	3.82	4.03	3.81
Runners	.75	1.49	1.39	1.57	1.61	1.46
Total	8.49	15.03	13.96	14.94	15.80	14.93
			Fresh Weight (Grams)			
Leaves	16.22	32.38	30.55	32.02	34.83	32.44
Roots and Crowns	25.25	38.25	39.41	44.02	44.52	41.55
Runners	4.10	8.89	8.39	8.98	9.70	8.99
Total	45.57	79.52	78.35	85.02	89.05	82.98

Difference Necessary for Significance Between Total Dry Weights: 5% level 3.066
1% level 4.168

[redacted]

Figure 23. Comparative leaf areas of plants receiving different quantities of air. Left, plant received 12 minutes of additional aeration daily; right, plant received $3\frac{1}{2}$ minutes additional aeration daily. No differences in leaf area were obtained as a result of supplemental aeration.

Even though the soil moisture at the 22 per cent level was 15 per cent above the wilting point and never deviated more than 1 per cent from this level, those plants growing in that soil were only slightly more than half as large as plants growing in soil at 32 per cent soil moisture, (figures 24 and 25). The dry weight of roots of those plants growing in 32 per cent soil moisture was 37 per cent greater than the roots from plants growing in 22 per cent soil moisture (figure 26), while leaves, crowns and runners were 51, 19, and 50 per cent greater respectively.

As shown in table 17, aeration seemed to produce little, if any, effect upon runner production as determined by the time to form the first node with leaves. There is some indication that with increased aeration there was a tendency for earlier development of runners. However, since there is no definite trend of runner production and no difference in total number of runners produced with the various degrees of aeration, no differences can be definitely ascribed to additional aeration. Moisture, on the other hand, did have a definite effect on runner growth and number of runners produced. Plants growing in 22 per cent soil moisture by May 10 had produced only 2 runners, while plants growing in 32 per cent soil moisture had produced an average of 15.6 runners. At the end of the experiment, the high moisture plants had produced an average of 51 runners with a linear length of 69.21 inches, while the lower moisture plants had produced only 25 runners with a linear length of 48.25

Figures 24 and 25. Comparative sizes of plants growing in soil at different percentages of soil moisture. Left, plant growing in 22 per cent soil moisture; right, plant growing in soil at 32 per cent soil moisture.

[redacted]

Table 17. Effect of Moisture and Aeration on Runner Production. (Runners Were Removed When Leaves Began to Appear on the First Runner Node).

Treatments		Accumulative Number of Runners Based on Nine Plants Per Treatment																
Moisture	Aeration	Apr. 28	Apr. 30	May 3	May 5	May 7	May 8	May 10	May 12	May 13	May 14	May 15	May 17	May 19	May 20	May 23	Total	Total Linear Length (in.)
22%	Check							2	5		6	10	15		18	25	25	48.25
32%	Check			1	4	6	9	15	17		19	29	32	36	39	50	50	68.12
32%	3 min. daily			2	4	6	8	13	18		21	30	35	38	40	48	48	66.40
32%	7-1/2 min. daily	1		5	11	15	18	21	26	28	29	34	42	44	46	52	52	64.89
32%	12 min. daily		1	4		6	10	14	18	21	24	27	38	40	43	54	54	77.46
Average of 32% Moistures		.25	.25	3	5.7	8.2	12.2	15.6	19.7	21.0	23.2	30.0	36.7	39.5	42.0	51	51	69.21

[redacted]

inches. Runners produced on plants at the lower moisture level were very small in diameter, considerably tough in texture, and were red in color, while runners produced by plants at the higher moisture level were much larger in diameter, more tender in texture, and were of a normal green color.

Figure 26. Comparative sizes of root systems of representative plants growing in 32 and 22 per cent soil moisture.

DISCUSSION

The results of these investigations show that the Blakemore strawberry responded markedly, as measured by growth and fruiting behavior, to changes in cultural and environmental conditions, particularly in relation to modification of the normal plant population of this variety. These growth and fruiting responses can be readily understood when the interrelation of such factors as earliness of runner plant formation, mother plant development, runner plant development, and soil moisture are considered.

Any cultural practice or change in environmental conditions which promote the early formation of runner plants, provided the conditions during the remainder of the growing season are favorable, favors the development of plants with large leaf areas and root systems which are associated with the production of large yields.

The investigations of Richey and Schilletter in Iowa (94) showed that the length of time for runner formation is dependent upon environmental conditions. As was found in the investigations here reported, conducted in the greenhouse, soil moisture appears to be the main factor determining time of runner formation. It is also apparent that mother plant development, as determined by soil moisture and other factors, may play no small part in relation to runner plant development. In the Iowa study, on the average number of days intervening from the time of setting the mother plants to the time of rooting of the first plant on each of the runner series, it was found that during a dry season the difference in time for the formation of the first runner plant on the five series became progressively greater from the first to the fifth series. Even after careful selection of plants for their apparent similarity, there was an average interval of 30 days between the formation of the first plant on the first runner series and the formation of the first plant on the fifth runner series. In other words, the plants of the first runner series had an average of 30 days more to develop root systems and tops before fruit bud formation than the plants of the fifth runner series. These authors reported that during a favorable growing season, a period of only 13 days was required between the time of formation of the first plant on the first runner series and the formation of the first plant on the fifth runner series.

Runner plants which are formed early in the season have a comparatively long time to develop and generally speaking, the longer the time they have to grow during the summer and fall, the more highly productive they are the following spring. Since the number of leaves per plant, just previous to and during the time of flower bud formation, starting early in September, has been found to be closely correlated with the number of flower buds formed, one can see how important it would be to obtain early-formed and established runner plants. The work of Sproat and Darrow (104), on the effect of leaf area on production, showed that, as the authors state, ". . . the possible crop is determined by the leaf area during the previous fall. The larger the leaf area during the fall when fruit buds are formed, the larger the crop the following spring." Morrow and Darrow (85) presented data to show that there is an increase in the number of flowers per plant for each increase in size of plant as measured by number of leaves on November 15. Since the extent of flower-bud formation and the number of fruit buds are entirely determined in the fall under usual conditions in Maryland, the possible crop is determined then.

Following runner plant formation, runner plant development during the growing season can be divided into two critical periods, which were found, in this study, to be interrelated with mother plant development. First, the development of the runner plant throughout the summer and, secondly, further growth and development following the first initiation of fruit-buds in the fall. Previous to the first period, the mother plants are increasing their root systems, enlarging the crowns, and developing new leaf area at a rapid rate. Shortly before the leaf area of the mother plant has reached a maximum, runner plants start to develop and are entirely dependent upon the mother plant for mineral nutrients and water until sufficient root systems and leaf areas are made to enable them to be independent of the mother plant. If during this period, adverse environmental conditions exist, such as low soil moisture, runner plant development is seriously retarded as was shown in the investigation under greenhouse conditions. After the runner plants have become more or less self-supporting, they enter into another period which can be altered seriously by environmental conditions. If the cultural practice has been one of growing the plants in matted rows, the plants cease further development in early fall, but if the plants have been thinned or spaced, they continue to develop at about the same rate until frost. This was shown by Van Horn, Schrader, and Haut (108) who, with both matted and thinned rows, reported that early runner plants developed dry weight of roots at a rapid linear rate during the growing season, except that plants from matted rows ceased this rapid development in early fall compared with continued development of thinned plants. Rapid crown development occurred in the fall after an earlier slow, steady rate of dry matter increase. They stated that: "The continued fall development of plants in thinned rows possibly has significance in the excellent fruiting behavior of such plants in the following spring compared with matted row plants." Thus, with this knowledge of growth relationships, the importance of cultural and environmental conditions during mother plant development, runner formation, and runner development can easily be seen in relation to the growth and fruiting behavior of the Blakemore strawberry.

Soil moisture is probably the most important factor in the growth of the strawberry plant other than basic soil fertility, so that soil moisture, as shown by the results obtained in the greenhouse investigation reported here, can be termed the limiting factor in strawberry plant growth. This work showed that on a heavy or fine-textured soil, a readily available moisture supply over and above average soil moisture levels, was definitely needed for good, vigorous mother plant development and subsequent runner plant production and development. Conversely, from the results with aeration, this first known work on the effects of supplemental aeration on the development of the strawberry plant has shown that the strawberry is not likely to be restricted in its growth and development due to unfavorable soil atmospheric conditions in the soils on which strawberries are commonly grown. The soil used, a fine Sassafras silt loam, for these aeration studies would probably, in most cases, be considered heavy for strawberries but this bears out the conclusion that the strawberry is probably, under the majority of cases (barring poor drainage), not restricted in growth by limited soil aeration but rather to lack of moisture. Under field conditions, one can readily see how a dry growing season would result in poor mother plant development, a small number of weak runner plants, and subsequent low yields the following spring. However, the importance of a high soil moisture level during the plant growing season has not been recognized. Moisture could not only be the limiting factor during the growing season but it can also seriously curtail plant growth and fruit production during the fruiting season, as has been shown under Maryland conditions (98).

How, then, can the grower apply this knowledge of strawberry plant growth and soil moisture requirements in order to insure good plant development during the growing season with consequent high yields the following spring? As a result of the extensive field studies, the answer to this question lies in plant thinning or spacing in combination with a narrow width row. By plant thinning or spacing we adjust the density or the number of plants in the row and thereby reduce competition between plants for mineral nutrients and moisture. This factor alone greatly increases the size and productiveness of the individual plant and when the width of row is kept narrow still greater possibilities are afforded. By keeping the width of row narrow, together with plant thinning, we not only reduce competition among plants for mineral nutrients and water but we increase the proportion of early-formed and established runner plants which have a high fruiting capacity. Cutting off all runners beyond the narrow width of row desired also greatly reduces the drain on the mother and the first-formed runner plants. In addition to these greatly desirable features, the proportion of plants in the row next to the aisle is increased, which affords a greater soil area per plant from which to draw moisture and nutrients. Therefore, by plant thinning or spacing, using the narrow row, it is possible for the strawberry grower to greatly increase production over even the usual thinned row method. In addition, in unfavorable seasons, this method insures full stands of plants, not possible with wide rows in such seasons. As described later, the narrow thinned row also offers advantages from the standpoint of renewal for second-year fruiting.

The increases in yield and growth responses obtained from thinning or spacing of Blakemore plants corroborates the findings of all previous investigations of this nature. Excellent responses in increased yield and size of berries have been obtained by plant thinning in practically all of the investigations reported. An exception to the general rule, that thinning results in increased yields, was found in the 1940 and 1941 seasons when yields from both matted rows and thinned rows were exceptionally high, approaching maximum yields obtained from the best of irrigation practices. It is probable, that when conditions are very favorable for maximum growth of plants in matted rows which results in high yields, that plant thinning merely increases yield per plant to maintain about the same very high level of yield. However, plant thinning did result in some increased size of berries which might offset the cost of thinning. The removal of excess runner plants presents a problem in labor cost if such work is to be done by hand. Now, by a few simple modifications of the cultural practices followed for years, the grower can, without much additional labor costs, thin his plant beds and maintain narrow rows in order to insure comparatively high yields. Recognizing the importance of fall development of runner plants (108), plant thinning can be delayed until early fall, when the beds should be raked cross-wise of the rows, as practiced in these investigations, at very little additional cost. Disc attachments can be placed on the cultivator to cut off runners raked into the aisles.

Plant thinning offers two possibilities of renewal which give comparatively high yields the second year of fruiting. After fruiting, the thinned rows may be allowed to revert to matted rows or all runners may be removed so that only the original thinned plants are left for fruiting. The latter practice, from the standpoint of yields, is much more desirable but involves higher labor costs, such costs probably being more than offset by the increased yields; yields nearly equal to first season yields. It seems reasonable that the removal of all runners at the time of weeding operations would not greatly increase the labor costs of this type of renewal over the conventional method now being used by most growers.

In conjunction with the question of renewalfor second-year fruiting, the narrow width row offers possibilities of even further reducing the time and labor involved in renewing strawberry beds. An ideal renewal system would be one in which there would be very little hand labor involved, and which would be comparatively easy and simple for the grower to adopt, and mainly, one which would insure comparatively high yields the second year. In addition to the renewal practices reported in these investigations, some modifications were devised for further consideration. In the case of the narrow 10-inch width rows with a 14-inch aisle, it is possible to take out every other row and allow this 10-inch row to extend to a 32-inch width for second-year fruiting. Another alternative is to allow two 10-inch width rows to grow together or fill up the aisle space between adjacent rows for second-year fruiting. This would be a cheap and simple method for the grower providing the yields were favorable.

Comparing the two seasons of work on response to width of row, as reported in these investigations, the results appear to be contradictory. During the fruiting season of 1940, as the width of row decreased a progressive increase in yield per acre resulted, while in 1942, all of the different widths of row yielded the same on an acre basis. Let us consider the cause of this difference in fruiting behavior. In the summer of 1939, during which new runner plants were developing to fill out the rows to the desired width of row, unfavorable conditions prevailed for runner plant formation and development and consequently the beds were not formed until late in the season. The mother plants were slow to initiate runners and consequently the newly formed plants had a comparatively short growing period. As the width of row progressively increased, the percentage of late formed runner plants increased. Since runner plants which are formed late in the season have only a short growing period before frost, they do not have enough time to develop large root systems and build up sufficient leaf areas to be very productive the following fruiting season.

On the other hand, the summer and fall preceding the 1942 fruiting season was an exceptionally good period for runner plant formation and development. In fact, by the middle of July, even the wide 30-inch rows had the desired density of runner plants. Since this was such a good season for rapid runner plant development, there was not a great deal of difference in the time between the formation of the first and the last runner plants and consequently, the wide rows contained practically the same age plants as did the narrow rows and therefore had about the same time to develop roots and tops throughout the remainder of the growing season. Even though there were no differences in acre yields between the different widths of row, in reality, the 10-inch rows produced approximately 1½ times as much as did the 30-inch rows, due to the fact that about 41 per cent of the total area was covered by the 10-inch rows while about 68 per cent of the total area was covered by the 30-inch rows.

In both seasons, the plots were on soils high in fertility, as evidenced by good growth and high yields, in fact, also by lack of response to nitrogen applications during the summers of 1939 and 1940.

Applications of nitrogen fertilizer during the growing season because of its effect on vegetative vigor with many plants on soils low in fertility, might greatly affect the size of the plant and the potential development of fruit buds. Strawberries growing in soils of low fertility, it would seem, would greatly benefit from applications of nitrate of soda during the growing season, in that it would aid in the production of large leaf areas and subsequent development of more flower buds. However, on soils high in fertility such as the soil used in these investigations, it would seem logical that no response should be expected from nitrate of soda applications, as was found in these investigations.

SUMMARY AND CONCLUSIONS

This investigation was undertaken in an attempt to determine the interrelationship of various environmental or cultural factors and the growth and yield of the Blakemore strawberry. The investigation included the following problems: (1) the relationship of width of thinned, matted, and spaced rows to productiveness; (2) the influence of various renewal systems and width of row on berry production; (3) the effect of varying the time and rate of application of nitrate of soda throughout the growing season on yield of fruit the following spring; (4) the seasonal development of the mother plant; (5) the effect of differential percentages of soil moisture and aeration on plant development.

From the study, covering the period from 1939 to 1942, the following conclusions were drawn:

1. In a fruiting season preceded by a summer and fall unfavorable for runner plant formation which is not uncommon in Maryland, as the width of row decreased a progressive increase in yield per acre resulted.

2. On the other hand, in a fruiting season preceded by a summer and fall favorable for runner plant formation, no difference in yield was obtained between the different widths of thinned or matted rows, but yields from any one width of thinned row averaged over a 1000 quarts per acre more than

yields from the same width matted rows.

3. Greater yields from a thinning practice can be obtained when the width of row is kept sufficiently narrow to insure a high proportion of early formed runner plants. Such is the case, it is believed, with a 10-inch width row, where the width of row to be maintained is formed early in the season from early formed runner plants, thereby obtaining a much higher percentage of plants with a high fruiting capacity.

4. With Blakemore strawberries grown under a previously fruited, thinned row system, significantly greater yields were obtained from the renewal system by which all runners were removed and the original plants fruited the second year than from either the conventional renewal system or reversion to the matted row.

5. Compared with first-year yields, fruiting the original plants the second year resulted in only a small reduction in yield of approximately 8 per cent, whereas with the other two renewal systems, decreases of approximately 40 per cent occurred.

6. It is indicated that when thinned rows are allowed to revert to a matted row condition for second-year fruiting, yields equal to a conventional "barring-off" may be obtained.

7. Greater yields per acre were obtained from the 10-inch width rows with progressively lower yields from the 20-, 30-, and 40-inch width rows regardless of the renewal system employed.

8. Under the conditions of this experiment, nitrate of soda applied to thinned and matted rows had no beneficial or detrimental effects on fruit production regardless of the time or rate of application.

9. Studies on the seasonal development of the mother plant showed that there was a gradual increase in dry weight of the various plant organs up until the time of runner plant formation when a sharp decline in the dry weight of leaves occurred. This dry weight decline in leaves, and to some extent in roots and crowns, of the mother plants continued until the runner plants were well established and practically self-supporting after which, the mother plants again increased in dry weight until late fall.

10. The results of greenhouse investigations, under controlled conditions, on the effect of different levels of available soil moisture and aeration on growth of strawberry plants, showed that as the percentage of available soil moisture increased, a progressive increase resulted in leaf area, number of leaves per plant, dry and fresh weight per plant, and number of runners per plant.

11. Earliness of blooming was directly related to the percentage of available soil moisture since plants growing in 12 per cent moisture started blooming first, followed in order by plants receiving 22 and 32 per cent moisture.

12. Aeration, under the conditions of this experiment, seemed to have no influence on either root or top growth.

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Especially in Relation to Plant Thinning

Thesis and Abstract Approved: ______________________
Professor in charge of thesis

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