



AgEcon SEARCH
RESEARCH IN AGRICULTURAL & APPLIED ECONOMICS

The World's Largest Open Access Agricultural & Applied Economics Digital Library

This document is discoverable and free to researchers across the globe due to the work of AgEcon Search.

Help ensure our sustainability.

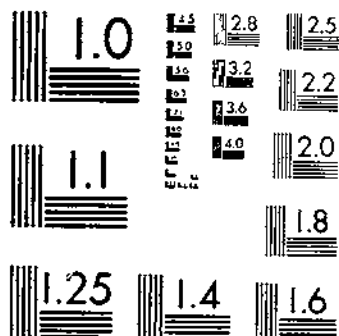
Give to AgEcon Search

AgEcon Search
<http://ageconsearch.umn.edu>
aesearch@umn.edu

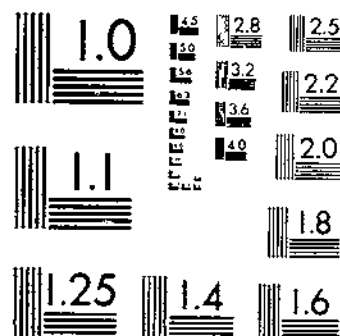
*Papers downloaded from **AgEcon Search** may be used for non-commercial purposes and personal study only. No other use, including posting to another Internet site, is permitted without permission from the copyright owner (not AgEcon Search), or as allowed under the provisions of Fair Use, U.S. Copyright Act, Title 17 U.S.C.*

TB 491 (1935) USDA TECHNICAL BULLETINS UPDATA
SOIL MOISTURE AND IRRIGATION INVESTIGATIONS IN EASTERN APPLE ORCHARDS
MAGNESS, J. R., DEGMAN, E. S., FURR, J. R. 1 OF 1

START



MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A



MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

UNITED STATES DEPARTMENT OF AGRICULTURE
WASHINGTON, D. C.

SOIL MOISTURE AND IRRIGATION INVESTIGATIONS IN EASTERN APPLE ORCHARDS¹

By J. R. MAGNESS, *principal pomologist*, E. S. DRUMAN, *assistant pomologist*,
and J. R. FURR, *assistant horticulturist*, *Division of Fruit and Vegetable
Crops and Diseases, Bureau of Plant Industry*

CONTENTS

	Page		Page
Introduction.....	1	Physiological effects of reduced moisture supply on apple trees—Continued.	
Outline of experimental work.....	3	Effect of moisture supply on sugar and starch content of bark, wood, and fruit.	28
Rainfall conditions during investigations.....	5	Discussion.....	29
Results of fruit-growth measurements.....	6	Moisture supply and functioning of apple trees.....	29
Yield and size of fruit.....	15	Soils for orchards.....	30
Results of 1-year irrigation experiments.....	17	The value of mulch in moisture conserva- tion.....	31
Orinnes Golden-Delicious plot, 1931.....	17	Moisture supply and regular bearing.....	31
Delicious plot, 1932.....	18	Relation of moisture supply to size and quality of fruit.....	32
Results in block C.....	20	When irrigation is feasible under eastern conditions.....	32
Effect of moisture supply on color develop- ment.....	21	Summary.....	35
Effect of moisture supply on fruit-bud forma- tion.....	23	Literature cited.....	36
Physiological effects of reduced moisture supply on apple trees.....	26		
Relation of moisture supply to stomatal behavior of apples.....	26		
Effect of moisture supply on leaf function.....	27		

INTRODUCTION

In the central and eastern parts of the United States most of the orchards are grown without irrigation, the trees depending upon natural rainfall and the water-holding capacity of the soil for moisture supply throughout the growing season. Under these conditions the amount of water available to the tree that can be held in the soil within the root zone of the tree is of extreme importance. Periods of from 1 to 2 months when very little rainfall occurs during the growing season are of relatively frequent occurrence. Unless the moisture-holding capacity of the soil is sufficient to carry trees

¹The writers wish to acknowledge the helpful advice and assistance of E. C. Auchter, principal horticulturist in charge, Division of Fruit and Vegetable Crops and Diseases, in planning and conducting these investigations. They wish particularly to express their appreciation to the American Fruit Growers, Inc., and to R. S. Dillon, both of Hancock, Md., who furnished the facilities of their orchards for these investigations. Without such facilities the investigations reported in this bulletin could not have been conducted.

through such periods, poor growth and development of fruit will result.

In the selection of locations for the orchards many factors in addition to soil must be considered. In many parts of the Eastern States the primary consideration has been to secure sites at sufficient elevations so that air drainage would be satisfactory and the frost hazard reduced. In many instances such elevated sites have relatively shallow soils with rock, shale, or hardpan within 2 or 3 feet of the surface. The root zone of trees in such soil is limited by the rock or hardpan, and the water-storage capacity of the soil is limited because of its shallowness.

On the other hand, orchards have sometimes been planted on relatively heavy soils with clay or similar impervious subsoils which afford poor drainage. During wet seasons the water table in such soils is likely to stand relatively near the surface, killing off the lower roots or preventing their penetration, and the root zone is confined to the upper soil layers. Trees on such soils will suffer also from water shortage during periods of prolonged drought because of the shallow-root system. The possible extent of the root system is therefore of great importance in determining the total amount of water that can be stored in the soil within reach of the roots.

Soils also vary greatly in their capacity to hold or store water. Several terms relative to the water-storage capacity of the soil should be familiar to the orchardist. The "field capacity" of the soil is the amount of water the soil will absorb against gravity, and this varies with the texture of the soil. The coarser the soil, in general, the lower the field capacity, while with finer textured soils, such as silt loams or clays, the field capacity or water-holding capacity is progressively greater.

Not all water in the soil is available for plant growth. All plants will wilt and are unable to take up additional moisture from the soil when there is still an appreciable amount remaining. The amount of moisture in the soil which is unavailable to the plant is termed the "wilting percentage." The work of Briggs and Shantz (3)², and of many other investigators since, have shown that this wilting percentage also varies with the texture of the soil, but it is substantially the same for all plants in the same soil. The amount of moisture remaining in the soil when plants wilt is generally greatest for the finer textured soils and least for the coarser, sandy-type soils.

The amount of moisture present in the soil above the wilting percentage is termed "available moisture" and represents that available for plant usage. The available water that can be stored in a soil also varies with the soil texture. In general, the greatest amount of available moisture can be stored in the finer soil types, such as silt loams to clay loams, while total possible available moisture becomes less as soils become progressively lighter. Consequently on thoroughly drained, fairly fine-textured or heavy soils the possible water storage per foot of depth of soil will be high, while on coarser textured, lighter soils it will be progressively lower.

The total quantity of water available for tree growth that an orchard soil will hold will therefore depend upon the texture of the soil and particularly upon the extent of the root system. Root

² Italic numbers in parentheses refer to Literature Cited, p. 36.

penetration in orchard soils in some regions may be as deep as 20 or more feet. Such soils, if of medium texture and if saturated to their field capacity during the winter months, will hold sufficient available water to carry the trees through a growing season even if little rain occurs. As the root zone is more and more limited either by hardpan, rock, or high-water table, the storage capacity of the soil becomes progressively less and the period during which trees can thrive without rainfall progressively decreases.

It is not possible to determine exactly the quantity of water that an apple tree requires to carry it through a certain period without impairment of its normal functioning. Water is lost almost entirely by evaporation or transpiration from the leaf system. The quantity of water that a tree will transpire per day varies with the foliage area of the tree and with the evaporating power of the air. When temperatures are high and humidities low, particularly if there is wind, trees require the maximum amount of water. On the other hand, during a day when the humidity is high and the temperature moderate, trees will use relatively little water.

Beginning in the spring of 1930, experiments were outlined to study the relation of moisture supply to production of apples under climatic conditions prevailing in the Middle Atlantic States. The purposes of this work were to determine how frequently trees on different soil types may suffer for lack of water, the effect of such water shortage on growth of tree, growth of fruit, color, quality, and yield of fruit, on fruit-bud formation, on the physiological functioning of the tree, and the value of irrigation in correcting these effects of deficient moisture supply.

OUTLINE OF EXPERIMENTAL WORK

As a basis for these investigations, plots were laid out under three soil conditions in a commercial apple orchard near Hancock, Md. Water for the experimental irrigation of these plots was available from a large spring and was delivered to the plots through a stationary spray pipe system. Water was applied to all irrigation plots by the overhead sprinkler system. Experiments outlined were as follows:

Block A.—These plots were laid out on a very shallow, eroded silt clay soil underlain with shale at a depth varying from nothing to 18 inches. The plots consisted of York Imperial and Wealthy trees alternating in each row. The soil was so shallow that tree growth and production had been limited. The trees were approximately 22 years of age at the start of the experiment but were not more than half the size of well-grown trees of that age. During dry seasons the fruit from these trees had been unmarketable because of small size. This plot represented an extreme condition of shallow soil for apple production, and the plots were designed to determine whether trees on such soil could be made satisfactorily productive through irrigation.

Two plots consisting of 16 trees each were laid out. Both of the plots were seeded to alfalfa, one irrigated and the other nonirrigated. Because of the limited water-storage capacity in the shallow soil, the need for water was so frequent on these plots that it was impracticable in these tests to keep the so-called "irrigated plot"

thoroughly watered. Growth condition and production have been improved by the water applications made, but not sufficiently to secure good commercial crops. Because of the extreme condition of these plots and the devitalized condition of the trees at the start, detailed records are not presented.

The evidence obtained would indicate that on such very shallow soils, irrigation at intervals of not more than 10 days would be required during drought periods to keep apple trees functioning at near capacity. Land of this type will seldom produce profitable fruit crops without irrigation, and installation of an irrigation system would be justified only if water could be applied very cheaply. Such soils must be considered as submarginal for apple growing in any region where droughts even of relatively short duration are likely to occur.

Block B.—The soil of these plots is a silt clay containing considerable fine rock underlain with shale at a depth of approximately 2 feet. The varieties were Rome Beauty and Oldenburg (Duchess) alternating in each row. The trees were about 22 years old at the start of the experiment but were below normal in size because of the rather shallow soil in which they were growing. Four plots consisting of 16 trees each (approximately half each of Rome Beauty and Oldenburg) with two buffer rows between plots were established. Two of these plots were given a heavy wheat-straw mulch in the spring of 1930, and additional mulch was applied in the spring of 1932. This mulch, about 8 inches deep, was sufficiently heavy to keep down all weed growth around the trees. One plot, termed "irrigated mulch", was watered as required to prevent moisture from becoming the limiting factor in tree functioning at any time during the growing season. The second plot, termed "nonirrigated mulch", received only natural rainfall.

The other two plots were thoroughly cultivated each spring and were allowed to grow up to grass and weeds after the spring cultivation. One of these plots, termed "cultivated irrigated", received irrigation at the same time as the irrigated mulch. The second plot, termed "nonirrigated cultivated", received only natural rainfall.

Block C.—Plots in block C were laid out in an orchard of York Imperial trees growing in a deep clay loam soil. These trees were approximately 22 years old at the start of the experiment and were extremely large for their age. Excavations 6 feet deep revealed some root distribution throughout that area. Additional penetration with soil tubes to 12 feet deep showed no hardpan within the 12-foot zone. It is not certain how much below 6 feet deep root penetration occurred.

Four plots were laid out in this orchard, two of which were maintained in grass mulch which was mowed at intervals during the summer. One of these plots received irrigation at intervals, the other received natural rainfall only.

The two additional plots were thoroughly cultivated in the spring and allowed to grow to grass and weeds following the spring cultivation. One of these plots also received irrigation, the other received only natural rainfall.

The plots in these three locations established in the spring of 1930 have now been carried through four growing seasons under

the same type of treatment, thus permitting a study of the cumulative effects of irrigation or of water shortage.

In addition to these, other plots were started in the springs of 1931 and 1932, respectively, each being carried through only one season. One of these additional plots started each spring was irrigated, and the other was nonirrigated. These plots were used for the purpose of studying the immediate response of trees from conditions of variable moisture supply without the hold-over effects of differential treatments during previous years. These additional plots will be described in connection with the presentation of data obtained from them.

All trees throughout all the plots have received each year from 8 to 10 pounds of nitrate of soda per tree, applied about the time of

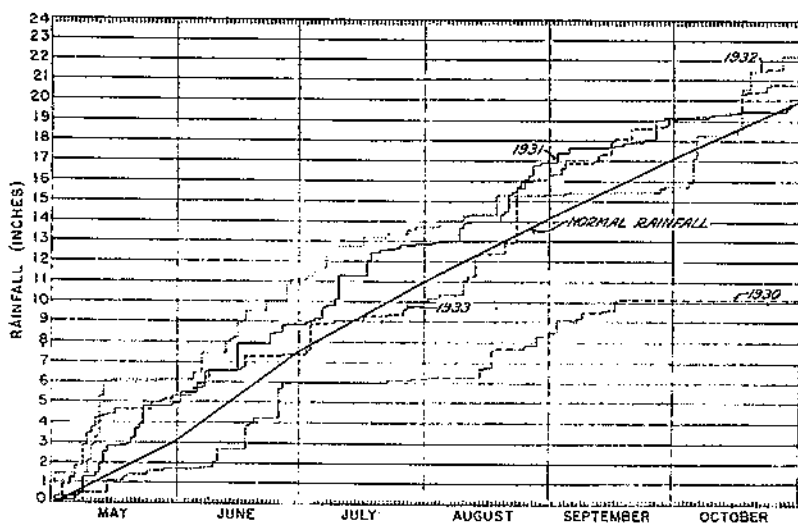


FIGURE 1.—Cumulative rainfall curves for the four growing seasons, 1930-33, inclusive. Data from May 1 to October 31, inclusive, obtained from United States Weather Bureau station at the orchard near Hancock, Md., where most of the experimental plots were located.

start of growth in the spring. The nitrate was distributed throughout the area from the trunk to slightly beyond the spread of the branches.

RAINFALL CONDITIONS DURING INVESTIGATIONS

Summaries of the rainfall during the growing season for each of the 4 years, together with the normal rainfall curve, are shown in figure 1. During the growing season of 1930 rainfall during May was approximately half of the normal. Rainfall during June was above average. From June 29 until August 14 practically no rainfall occurred. The weather during this period was extremely hot and dry. From August 14 to 18 approximately 11½ inches of rainfall occurred, with rainfall approaching normal until September 17. From that date until the end of the growing season no additional rainfall occurred. Rainfall from May 1 until October 30 totaled only 10.1 inches as compared with normal of 19.97 inches.

During the growing season of 1931 the total rainfall was slightly above average and was fairly well distributed. The periods of greatest moisture shortage that summer were during the first half of August and again during October.

In 1932 above-average rainfall occurred during May and June, but July rainfall was below normal. Following a 1-inch rain on August 19, no additional rains of as much as one-fourth inch occurred for a period of 45 days or until about the harvest season on late varieties. This prolonged late-season drought, following below-average rainfall in July and early August, resulted in extremely serious conditions in nonirrigated trees except those growing in deep soil.

During 1933 rainfall was fairly well distributed, but it was below normal during June and July. Only light rainfall occurred between July 4 and August 10, and during this period the trees on shallow soil suffered appreciably. Heavy rains occurred between August 10 and 25 followed by showery weather until the end of the growing season.

RESULTS OF FRUIT-GROWTH MEASUREMENTS

Throughout the experimental work, the rate of fruit growth on the various plots was determined by tagging representative apples in June of each season and measuring the growth in circumference of these fruits at intervals of 3 or 4 days throughout the growing season. Fifteen apples on each of at least three trees of each variety in each plot were used. Growth increments on a volume basis considering the fruit as a sphere have been calculated. The actual volume of the fruit is somewhat less than the volume of a sphere having the same circumference as the apples measured. The deviation of fruit volume from that of sphere volume is, however, consistent within a given variety, and in all cases comparisons of growth rate of fruit were made within the same variety. Results of growth measurements on the plots in block B for the 4 years, 1930-33, are shown in figures 2 to 5, inclusive.

The data obtained from the irrigated and nonirrigated plots in 1930 are shown in figure 2; also, the soil moisture is recorded as obtained by sampling at intervals throughout the season. The indicated points on the curves represent moisture determinations made on composite soil samples taken to a depth of 2 feet from at least 12 locations per plot. Samples during 1930 were taken with shovels, the soil was screened to remove fine rock, and moisture was determined by drying at 100° C. The wilting percentage of the soil in these plots, as determined by growing sunflowers in sealed cans of the soil, was about 6 percent. Field capacity of this soil, as shown by samples taken about 2 days after irrigations, averaged about 22 to 23 percent. Thus the soil in these plots held approximately 16 percent of available moisture, an excellent soil from the standpoint of its water-holding capacity.

In experimental work in a region having frequent summer rains it is impossible to obtain a completely accurate picture of the soil-moisture conditions throughout the growing season. The curves for moisture in figure 2 are based on the actual determinations made. Between determinations, the curves are hypothetical, being

based on rainfall and irrigation data. For example, a rainfall of 1 inch, coming on dry soil, does not wet the soil uniformly, but rather raises a portion of the soil to the field capacity while the remainder of the root zone is not affected. It is not possible to present this complete picture in the moisture curves. However, the approximate differences between the irrigated and the nonirrigated plots are clearly shown.

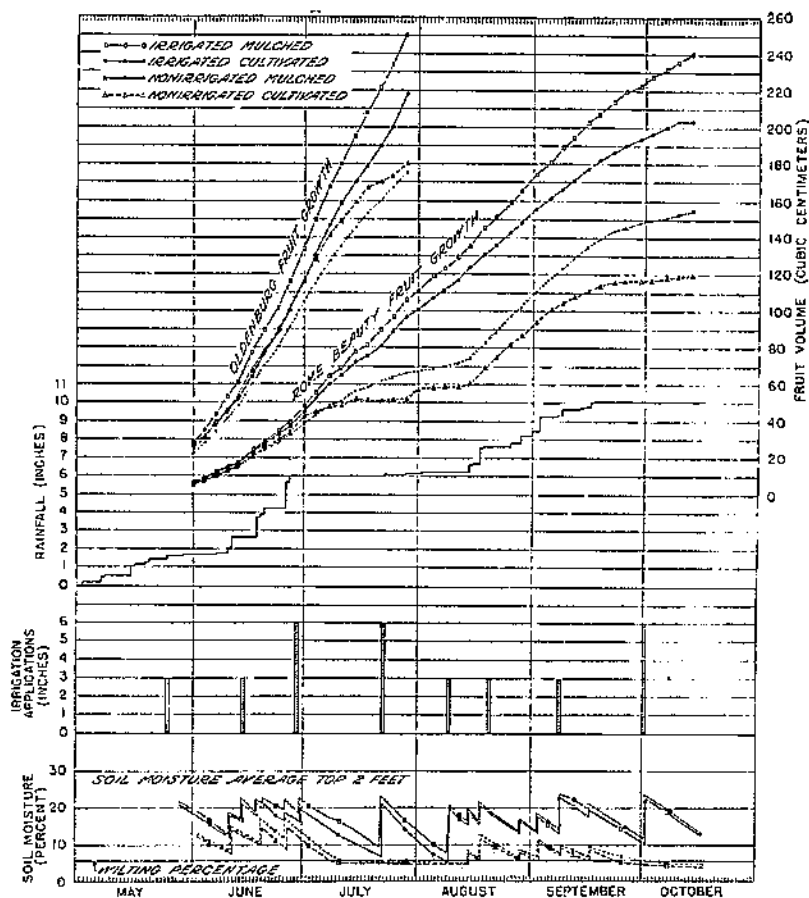


FIGURE 2.—Fruit growth, soil moisture, rainfall, and irrigation applications on Oldenburg and Rome Beauty plots, 1930.

The May rainfall during 1930 was limited. However, good rains occurred during June—a heavy rain on June 25, and a shower on June 26, totaling almost 2 inches. From June 26 to August 14 only three very light showers, totaling less than one-fourth of an inch, were recorded.

From the data in figure 2 it is apparent that by July 4 the fruit on the nonirrigated Rome Beauty trees in both the cultivated and mulched plots was growing at a much slower rate than that of the irrigated trees. The dry mulched Oldenburg apples were also growing at a slower rate than those on the irrigated mulched plot.

With the Oldenburg under cultivation, distinct differences in growth rate of the irrigated and nonirrigated fruit appeared by July 7. Thus within 9 to 12 days following the heavy rain on June 25 the fruit on all the dry plots was beginning to show reduced growth rate due to moisture shortage.

The Oldenburg apples in this experiment were picked on July 30. It was quite apparent prior to harvest, however, that as measured by fruit growth the Oldenburgs interplanted with the Rome Beauty trees were less seriously affected by the drought than were the latter. By July 30, fruit on the dry Rome Beauty trees was growing only

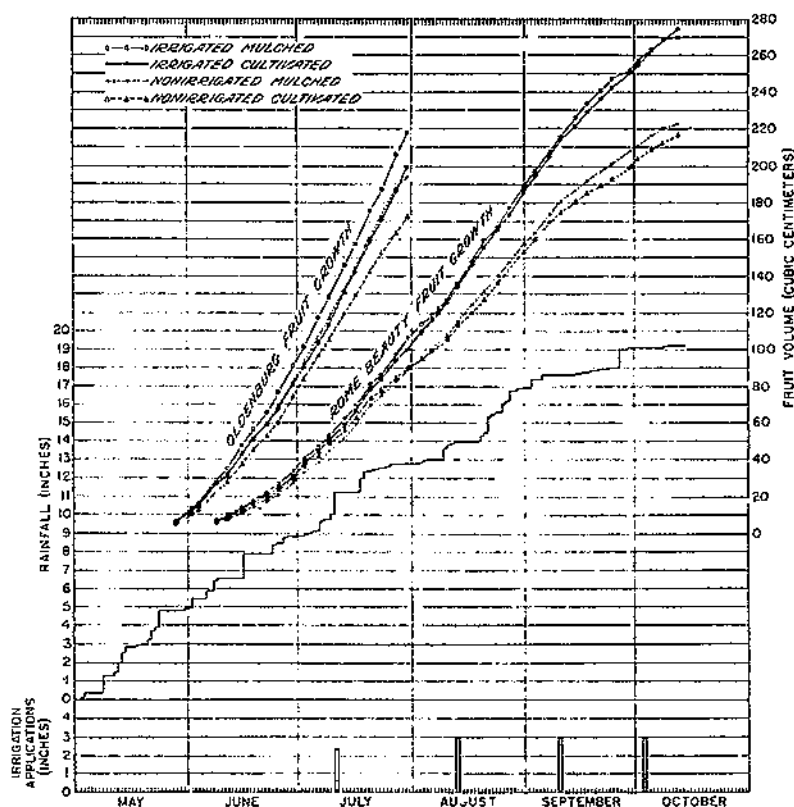


FIGURE 3.—Fruit growth, rainfall, and irrigation applications on Oldenburg and Rome Beauty plots, 1931.

approximately one-fourth as fast as on the irrigated trees, while the nonirrigated Oldenburg apples were growing at approximately half the rate of those on irrigated trees. Throughout the course of these experiments the Rome Beauty has apparently been somewhat more sensitive to moisture deficiency than has the Oldenburg.

During the period August 14 to 17 there was approximately 1½ inches of rainfall. Prior to this time the fruit on the nonirrigated Rome Beauty trees was making almost no growth, and the trees were approaching a permanently wilted condition. Following this rainfall and an interval of showery weather extending through the re-

mainder of the month the nonirrigated Rome Beauty apples grew almost as fast as those on the irrigated trees. Following a rain of approximately one-half inch on September 16 no further rain occurred until after the fruit was harvested on October 14. Within a few days the effects of this rain disappeared and the nonirrigated fruit was making little growth at the end of the season.

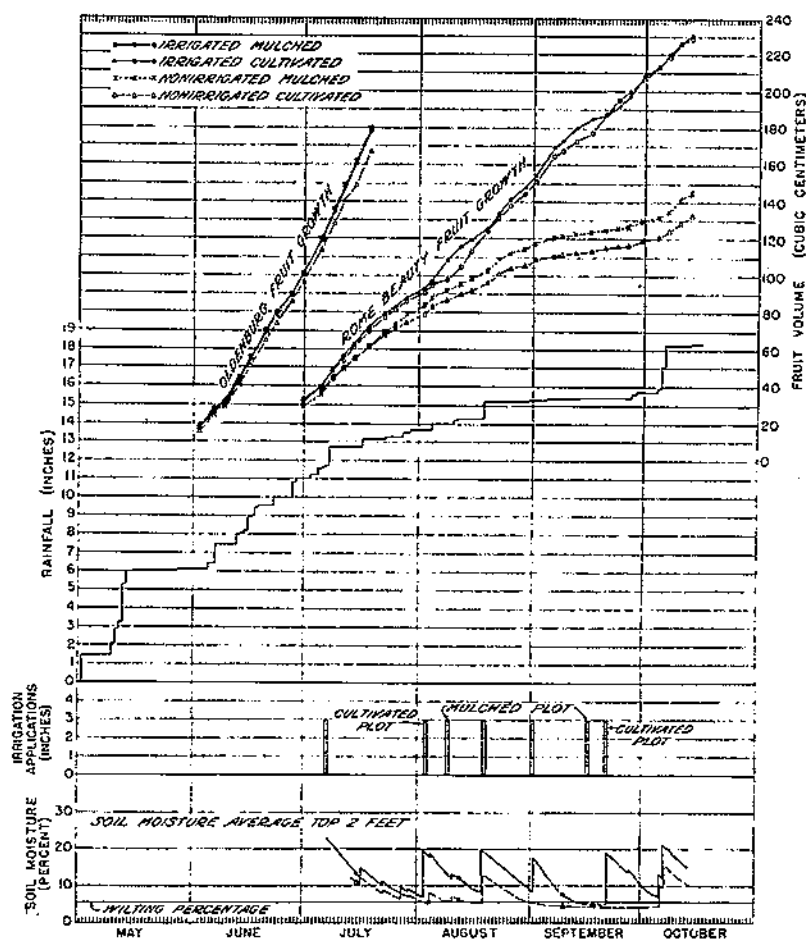


FIGURE 4.—Fruit growth, soil moisture on cultivated plots, rainfall, and irrigation applications on Oldenburg and Rome Beauty plots, 1932.

Typical Rome Beauty trees from the nonirrigated and irrigated cultivated plots on September 19 are shown in figures 6 and 7, respectively. The increased size of fruit and slightly denser foliage on the irrigated trees are evident from a close study of these illustrations.

Several points in the results for the 1930 season are particularly significant. According to the best records available on these heavily loaded trees, a reduction in the rate of fruit growth occurred while the average soil moisture in the root zone was somewhat above the

wilting percentage. Root concentration in these plots was very high in the surface foot, and it is practically certain that the soil moisture was down to approximately the wilting point in portions of this root zone before the growth rate was markedly affected by moisture supply.

A heavy irrigation of more than 5 inches of water was applied to the irrigated plots on July 21 and 22, 1930, which undoubtedly filled the soil to field capacity. No further irrigation was applied prior to the rain which started on August 14. A careful analysis of the

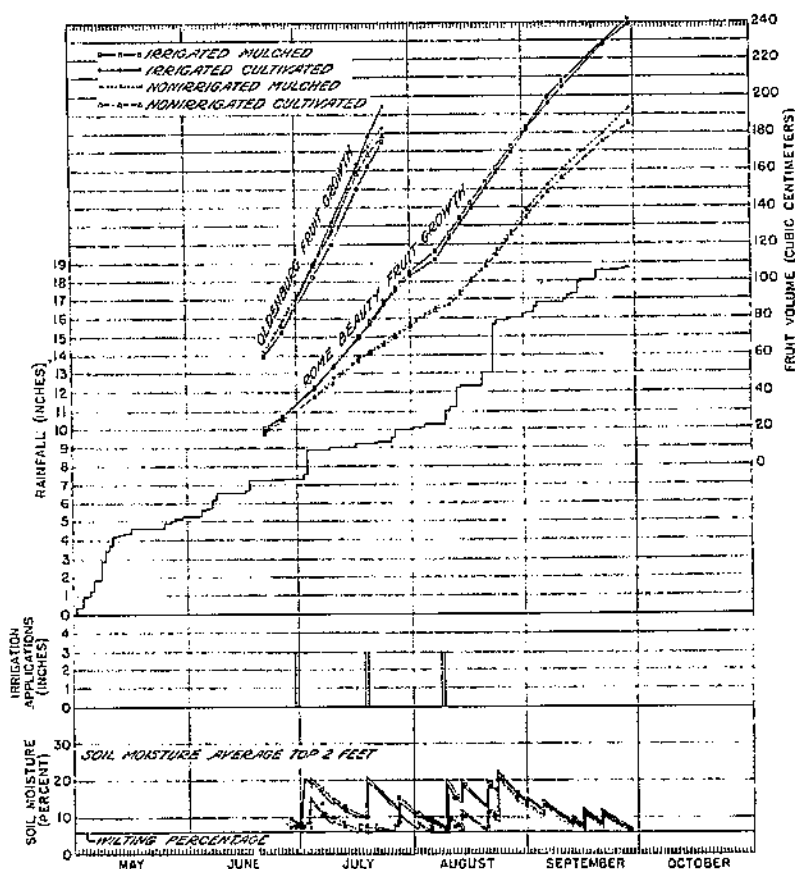


FIGURE 5.—Fruit growth, soil moisture, rainfall, and irrigation applications on Oldenburg and Rome Beauty plots, 1933.

growth curves of the irrigated fruit indicates that prior to August 14 the growth rate of this fruit had slowed down perceptibly. During this period temperatures were high, running over 100° F. during several of the days, with relatively low humidities. Under these rather extreme conditions the total water held by this soil was apparently only sufficient to carry the trees under optimum conditions for a period of approximately 25 days. Unless the soil moisture was at field capacity at the start of such a period of dry weather, the trees would suffer even earlier. Although such extremes of heat and



FIGURE 6.—Typical Rome Beauty tree from nonirrigated cultivated plot, photographed September 19, 1930.



FIGURE 7.—Typical Rome Beauty tree from irrigated cultivated plot, photographed September 19, 1939.

low humidity are rarely encountered in this section, these results with others obtained during the 4 years indicate that the water stored in these soils, 2 to 2½ feet deep, is only sufficient to carry the trees for a period of approximately 3 to 4 weeks. Since a period of drought is rarely encountered with soil moisture at field capacity at the start, reduction in growth rate of the fruit on trees on such soil is usually noticeable even during a relatively short period of dry weather.

By July 10 the soil moisture had reached the wilting percentage in the surface 2 feet of the nonirrigated plots and continued in that condition for a period of 35 days. Only a limited portion of the root zone could have been effective in absorbing water during that period. Oldenburg fruit on the nonirrigated plots between July 10 and picking date grew at approximately half the rate of the fruit on irrigated trees. The Rome Beauty apples on the nonirrigated mulched trees grew approximately one-third as fast as on the irrigated trees, whereas on the nonirrigated, cultivated trees growth was only about one-fifth of that on the irrigated trees. On a few individual trees, apparently in a permanently wilted condition, no fruit growth occurred during a part of this period. The results indicate that fruit growth will occur in apples until the tree is permanently wilted though the rate is greatly reduced as the moisture supply to the tree becomes very limited.

These plots have been carried through 3 successive years—1931-33. Growth data on the fruit taken each year in the manner indicated, together with the rainfall conditions and irrigation, are shown in figures 3, 4, and 5, respectively. Following the first season there was a distinct difference in growth condition of the trees during the spring of each year. Trees receiving irrigation during preceding years showed a more vigorous growth and a larger and more abundant foliage system. Consequently, following 1930, variation in size of fruit obtained each season, particularly with the Rome Beauty, can be attributed only in part to immediate differential moisture conditions that prevailed, and in part to the general vigor of the trees. This effect is shown particularly for 1931 in figure 3. During that year there was an excellent distribution of moisture throughout the season. There was a period of 3 weeks in late July and early August during which no heavy rains occurred, but light showers at frequent intervals kept the humidity high and reduced transpiration. There was, however, a rather definite decrease in growth rate of the Rome Beauty on the dry plots during early August which can be attributed to moisture shortage. Heavy rains occurred during late August and early September so that there was no time during that period when the nonirrigated trees approached the wilting percentage. Notwithstanding the fact that moisture was apparently available throughout the season with the exception of a short period in early August, there was a marked difference in the size of the fruit of the Rome Beauty and a slight difference in the size of the Oldenburg fruit at harvest time. These differences are probably due in considerable part to the better foliage on the more vigorous trees which had been irrigated during the previous season.

The results obtained in 1932 are shown in figure 4. The growing season of 1932 had above-average rainfall, as shown in figure 1, but distribution was very poor and trees on shallow soil suffered greatly.

Following heavy rains in May and June and a 1-inch rain on July 6 only light showers occurred until August 18. On that date a 1-inch rain fell, which was followed by a period of 46 days with no rain except very light sprinkles. The Rome Beauty in the dry plots showed a rather marked decrease in growth rate in early August, and in both the cultivated and the mulched plots the fruit growth was greatly reduced prior to the rain on August 18. The effects of that rain quickly disappeared, owing to the previously dry condition of the ground, and by September 1 growth of fruit on the dry plots had almost ceased. During September the fruit on the dry plots grew not over 20 percent as much as on the irrigated plots, and during the latter half of the month the trees were in a definitely wilted condition. Heavy rains occurring on October 5 resulted in fairly rapid growth of fruit in the dry plots during the last week of the growing season.

Notwithstanding the fact that 1932 had above-normal rainfall for the season, trees on shallow soil suffered under the conditions of this test even more seriously than in 1930. Nonirrigated trees in these experiments were definitely wilted during the last half of September and lost some foliage prior to the rains in October. Even under these extreme conditions, however, fruit growth was resumed at almost a normal rate when moisture again became available.

A full record of soil moisture throughout the season was not obtained in 1932. Curves based in part on actual moisture determinations, at points indicated, and in part on rainfall and irrigation data are shown in figure 4. Soil samples showed the moisture content of the surface 2 feet of the dry plots to be down to the wilting percentage on August 12. The 1-inch rain on August 18 restored available moisture for a few days and increased growth rate in the nonirrigated fruit. From August 28 to September 27, however, these plots were at or below the wilting percentage in the surface 2 feet and showed only very slow fruit growth.

On September 27 and 28 light rains occurred, totaling about 0.3 inch. Even these light rains increased growth rate in the dry plots for the 4-day period during which they occurred, as shown by the growth curves from September 27 to 30. While the effect of such light rains is quickly dissipated, the increased soil moisture, together with high humidity and decreased evaporation from the leaves, results in a temporarily increased fruit growth in trees suffering for moisture. As in 1930, appreciable decrease in the growth rate of fruit did not occur until the soil moisture approached within a few percent of the wilting point as an average condition. By that time a portion of the root zone probably had reached the wilting point.

The Oldenburg apples, harvested on July 18, 1932, showed no appreciable increase in size on the irrigated plots. Prior to the harvest date for this variety no period of moisture shortage occurred. Following good rainfall in 1931, all trees were in fairly good condition in the spring of 1932. The irrigated trees carried a somewhat heavier crop of fruit which attained equal size with that on the non-irrigated trees, perhaps because of the greater vigor of the irrigated trees.

Fruit-growth records for 1933 on these trees are shown in figure 5. During 1933 there was an unusually good distribution of moisture. Between July 3 and August 10, however, only a little over

1 inch of rain fell. During this period, growth of fruit on the dry plots was seriously reduced although showery weather and fairly high humidities resulted in a fruit-growth rate in the dry plots of Rome Beauty which was about two-thirds that in the irrigated plots. Following heavy rains in mid-August and showers throughout the remainder of the season, there was apparently no further period during which the nonirrigated trees showed indications of moisture shortage.

Following the extreme drought conditions of September 1932, the nonirrigated trees of Rome Beauty were much less vigorous in growth in the spring of 1933 and formed a smaller foliage system. Growth rate of the fruit on the nonirrigated Rome Beauty was somewhat less than on the irrigated trees in 1933, even when moisture was not a limiting factor, and notwithstanding the fact that the irrigated trees carried a heavier fruit crop (table 1). The Oldenburg trees, the crop of which was harvested prior to the drought period of 1932, were less seriously affected, and there was little difference in growth rate of fruit in 1933.

TABLE 1.—Average yield of fruit per tree and per 100-cm² cross-sectional area of trunks, and average number of fruits per bushel during 4 years of irrigation and mulching experiments, block B

Variety and treatment	Average yield per tree					Average yield per 100-cm ² cross-sectional area of trunk					Fruits per bushel			
	1930	1931	1932	1933	Total	1930	1931	1932	1933	Total	1930	1931	1932	1933
Rome Beauty:														
Cultivated nonirrigated	Bu. 5.9	Bu. 6.1	Bu. 5.0	Bu. 6.2	Bu. 22.3	Bu. 1.58	Bu. 1.58	Bu. 1.25	Bu. 1.57	Bu. 5.98	No. 210	No. 146	No. 188	No. 156
Cultivated irrigated	11.3	7.1	11.7	11.7	41.8	2.91	1.55	2.49	2.51	9.46	113	99	116	112
Mulched nonirrigated	6.8	9.7	7.2	7.4	31.1	1.59	2.06	1.32	1.59	6.56	164	130	155	126
Mulched irrigated	9.6	6.9	11.7	11.1	39.3	2.73	1.82	2.76	2.59	9.90	113	104	110	110
Oldenburg:														
Cultivated nonirrigated	5.7	6.8	3.7	4.1	20.3	2.01	2.13	1.04	1.12	6.30	183	133	119	140
Cultivated irrigated	7.5	4.5	6.3	3.6	21.9	2.74	1.41	1.86	.96	6.97	159	149	119	151
Mulched nonirrigated	6.4	6.5	6.1	5.3	24.3	2.04	1.92	1.29	1.12	6.37	168	137	116	151
Mulched irrigated	10.9	5.8	8.2	5.0	29.9	2.77	1.78	1.84	1.17	7.56	149	108	114	148

Although both the irrigated and nonirrigated trees in the mulched plots are in excellent vigor after 4 years of experimental treatment, the terminal growth is distinctly greater in the irrigated trees. Differences in the spring of 1934 would probably have been more pronounced had the growing season of 1933 been unusually dry.

YIELD AND SIZE OF FRUIT

The average yield of fruit per tree in bushels, the average yield per 100 cm² (15.5 square inches) cross-sectional area of the trunk of the trees, and the average number of fruits required to make a bushel for the four plots during the 4-year period are shown in table 1. Since there was some variation in size of individual trees, and since the yielding capacity of a tree is correlated with the size or trunk area of the tree, calculating yield data per unit of cross section of the trunk is believed to afford the most satisfactory basis of comparison.

From the data in table 1 it is apparent that the yield of the irrigated Rome Beauty trees per 100-cm² trunk area during the 4-year period has exceeded that of the nonirrigated trees by more than 54 percent. A comparison of these figures with the data on size of fruit (number of fruits per bushel) indicates that this increased yield was largely due to the increased size of the fruit each season on the irrigated trees as compared with those receiving similar cultural treatments but nonirrigated. The average size of the fruit on the irrigated cultivated trees was approximately 58 percent greater than that on the cultivated dry trees. Size of fruit on the mulched irrigated trees exceeded that on the nonirrigated mulched trees by approximately 32 percent. The average size of the fruit on the nonirrigated mulched trees was 21 percent larger than on the nonirrigated cultivated trees.

On the other hand, yield of fruit on the irrigated Oldenburg trees exceeded that on the nonirrigated trees in 1930, but the average of the 3 following years, 1931-33, inclusive, showed as high total yield per 100 cm² cross-sectional area of the trunk and almost as good average size on the nonirrigated as on the irrigated trees. Each year the Oldenburg crop was harvested no later than the last week in July. Only in 1930 did the trees suffer seriously from shortage of moisture prior to the time of harvest of the Oldenburgs, and this is reflected in the smaller size of fruit and smaller yields of Oldenburgs during that year. The Rome Beauty apples were not harvested until about October 10, thus showing the full effects of dry conditions through August and September.

The Rome Beauty trees showed on a 100-cm²-trunk-area basis a small but consistent increase in yield and size of fruit when mulched as compared with the similarly treated cultivated trees. This is believed to be due partly to slightly better moisture conditions under the mulched trees and partly to a slightly better growth condition because of abundant organic matter under these trees. The trees of the Oldenburg mulched and irrigated plot were more productive and the fruit averaged slightly larger than in the cultivated plot under irrigation. There was no significant difference between the dry cultivated plot and the dry mulched plot with the Oldenburg.

These results indicate that a variety requiring a long growing season, such as Rome Beauty, is much more likely to be benefited by irrigation than is a variety that ripens in midsummer, such as Oldenburg. Under the conditions of these tests the Oldenburg trees seemed to suffer slightly less than the Rome Beauty during drought periods when both varieties still carried their fruit. Since soil under eastern orchard conditions is likely to be saturated with moisture at the start of the growing season, varieties ripening in July or early August have a much better chance of reaching the fruit harvest season without suffering from shortage of moisture than do varieties that carry their fruit throughout the summer.

Results of tests with the Oldenburg indicate that these trees did not suffer greatly from drought conditions which prevailed after the crop was harvested. It has been observed repeatedly in these investigations that trees carrying very heavy crops of fruit suffer earlier and more severely than do trees carrying light crops or from which the fruit has been harvested. Similarly the benefits from

mulching have been more outstanding in the long-season Rome Beauty variety than in the early-ripening Oldenburg.

RESULTS OF 1-YEAR IRRIGATION EXPERIMENTS

GRIMES GOLDEN-DELICIOUS PLOT, 1931

During the summer of 1931 an additional series of plots for irrigation experiments was established in a block of Grimes Golden and Delicious trees in an orchard approximately 2 miles from that in which block B was located. These plots were established for the purpose of studying the effects of varying moisture conditions during the season of 1931 on trees that previously had not received differential moisture treatments. The trees were only about 12 years old but were relatively large for their age. Since the trees were planted only 22 feet apart, the roots occupied most of the available soil. The soil was $2\frac{1}{2}$ to 3 feet deep above shale and was relatively free of rock. It was a moderately heavy loam with a field capacity of about 20 percent and a wilting percentage between 9 and 10. The trees had only a moderate crop with an abundance of foliage in proportion to the crop carried. All plots were thoroughly cultivated in the spring.

These plots were laid out on July 20. Prior to that time, through May, June, and early July, there had been an abundant, well-distributed rainfall. On July 27 a heavy hailstorm injured the fruit and foliage, but the records obtained on growth rate of fruit in relation to moisture supply accurately represent conditions as they existed. Rainfall data were obtained at a point approximately 2 miles away and are not strictly accurate for these plots, as some local storms (including the hail of July 27) occurred in the vicinity of the plots that did not occur at the place where the records were taken. Rainfall, soil-moisture, and fruit-growth data for both varieties are shown in figure 8.

According to these data, samples from the nonirrigated plots on August 12 indicated that the soil-moisture supply in the surface 2 feet was within 3 percent of the wilting percentage. During the following week no rain occurred, although the weather was moderately cool. During this period the growth rate of the fruit on the nonirrigated trees of both varieties was about 25 percent below that on the trees receiving irrigation. During the period from August 19 until September 16, rainfall totaled 3.6 inches and was well distributed. No additional irrigations were applied until September 17. The nonirrigated plots from September 17 to 25 were within 4 percent of the wilting percentage, whereas the irrigated plots were near field capacity. The weather was moderately cool with a few very light showers. During this period the fruit on the nonirrigated plots grew at about 80 percent of the rate of that on the irrigated plots.

These results indicate that with an abundance of foliage and during moderately cool weather the growth rate of the fruit was not reduced as a result of moisture shortage until the average moisture content in the surface 2 feet approached less than 5 percent of the wilting percentage, with portions of the root zone probably reduced to that point. During the period from August 20 to Sep-

tember 10 the moisture content of the irrigated plots averaged from 4 to 6 percent higher than in the nonirrigated plots, but the growth rate of the fruit was practically the same. The soil-moisture data in this experiment are based on samples taken at 12 different points about each tree and present a very accurate picture of the moisture conditions. On these nonirrigated trees during the season of 1931 the growth rate of the fruit was slightly reduced between

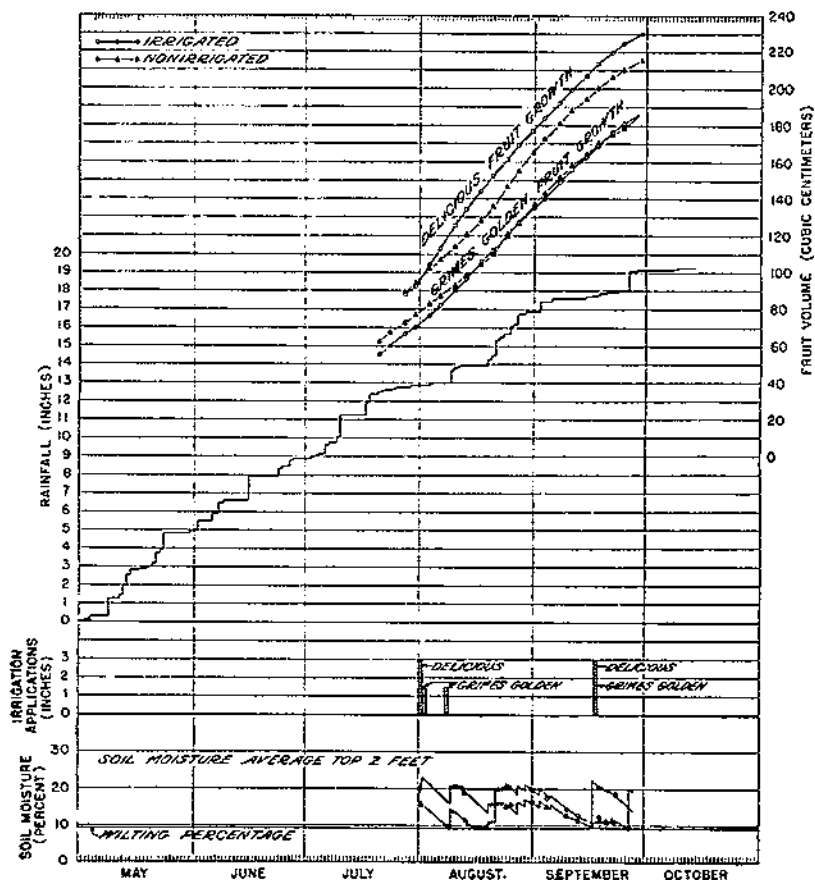


FIGURE 8.—Fruit-growth, soil-moisture, and rainfall record for Delicious and Grimes Golden apple plots irrigated for one season only, 1931.

August 1 and 17 and again between September 15 and 25, because of insufficient available water.

DELICIOUS PLOT, 1932

In early June 1932, a plot of Delicious trees which had not previously received differential treatment was laid out for moisture studies. These trees all carried a heavy crop, the nonirrigated plot carrying slightly more fruit on the average than the irrigated trees. Four representative trees were selected for detailed records, receiving only rainfall, and four other trees were irrigated as needed

through the season. These trees were about 18 years old, of fair size, and were growing in a stony, clay loam soil underlain with shale at a depth of approximately $2\frac{1}{2}$ feet. The shale beneath these trees was somewhat dense and impervious. The field capacity of this soil was about 26 percent and the wilting percentage between 11 and 12. The plots were all cultivated in the spring.

The fruit-growth data for these plots, also the rainfall data and a partial soil-moisture record, are shown in figure 9. Prior to about July 10, the growth rate of the fruit on the irrigated and nonirri-

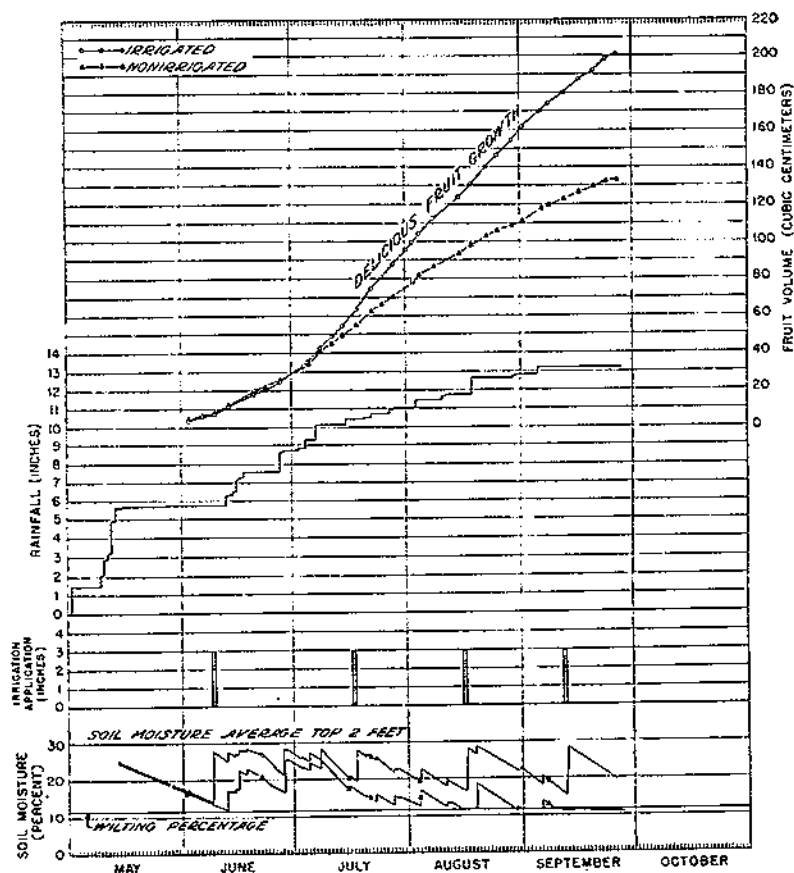


FIGURE 9.—Fruit growth, soil moisture, and rainfall record for Delicious apple plots irrigated for one season only, 1922.

gated trees was uniform. Following the 1-inch rain on July 7 only 3 inches of rain fell until the end of September or after the harvest period for this fruit. This limited rainfall was distributed through numerous light rains, as shown in figure 9. The fruit in the irrigated plots grew at practically a steady rate, which was much more rapid than that of the fruit on the trees in the nonirrigated plots. From August 1 until harvest the growth rate of the fruit from the irrigated trees was approximately double that of fruit from the nonirrigated.

Although the growth rate of fruit from the nonirrigated plot was much below that of the irrigated, a slow growth occurred throughout the whole period even though little rainfall occurred from August 18 until the end of September. There is a possibility that these nonirrigated trees obtained a little moisture from near the shale rock, as trees about this dry plot were given partial irrigation by the owner of the orchard. It would seem that unless this occurred the nonirrigated trees would have made progressively slower growth through September. Soil-moisture data indicate that by September 6 the moisture in the surface 2 feet had practically reached the wilting percentage, and it remained in that condition until harvest time. Throughout the whole season the moisture content of the irrigated plot did not approach close to the wilting percentage. The total yield of fruit at harvest averaged 18.9 bushels per tree for the irrigated plot and 14.3 bushels on the nonirrigated. The number of fruits per bushel averaged 111 from the irrigated and 156 from the nonirrigated plots.

RESULTS IN BLOCK C

Trees in block C, consisting of large York Imperial apples growing in heavy, deep soil, were in an alternate-bearing condition. (See p. 4 for detailed description.) During 1930 these trees bore practically no crop. In 1931, on the other hand, a heavy bloom and good set of fruit occurred and the crop was uniformly heavy over all plots. The trees in the irrigated plots had received irrigation as needed during 1930, but detailed records for that year are not shown because the trees were not bearing. Results on fruit growth and rainfall in 1931 are shown in figure 10.

These results indicate that in 1931 the growth rate of fruit on nonirrigated trees in this deep, fairly heavy soil slowed down slightly as compared with that of irrigated trees between August 5 and 18. The growth rate during this period was 20 to 25 percent slower in fruit on nonirrigated trees. Again between September 10 and time of harvest on October 8, the growth rate of the fruit on the nonirrigated trees was about 25 percent below that on the irrigated plots. On August 5, moisture in the surface 2 feet of the nonirrigated plots was within 2 to 3 percent of the wilting percentage when measurable difference in growth rate was occurring. The moisture record obtained on these trees was very incomplete but indicated a slowing down in growth rate when the surface foot, in which the greatest root population occurred, approached close to the wilting percentage.

In 1932 these trees carried a light crop of fruit, and detailed fruit-growth measurements were not made. In 1933 they bloomed heavily, but owing to frost and unfavorable weather conditions during the pollination period, very little fruit set. The fact that during 4 years this plot of trees bore only one heavy crop and one partial crop makes the moisture-relation studies less significant than they otherwise would be.

During both of the particularly dry years of 1930 and 1932 these trees were carrying very little fruit. In neither year did they suffer seriously from moisture shortage. At the end of 4 years there was very little difference in appearance or growth condition between the

trees that had been irrigated and those that received only rainfall. It is unfortunate, from the standpoint of these studies, that these trees did not carry a heavy crop during any particularly dry year. Observations on the trees, however, indicate that although the size of the fruit was reduced, the trees did not suffer seriously under the driest conditions that prevailed during the 4 years of these tests. Excavations indicated that these trees have roots at least 6 feet deep in a retentive clay soil though the main root population is in the surface 2 feet. Results of investigations by Aldrich and Work (1) on pears in very heavy soils at Medford, Oreg., indicate that on

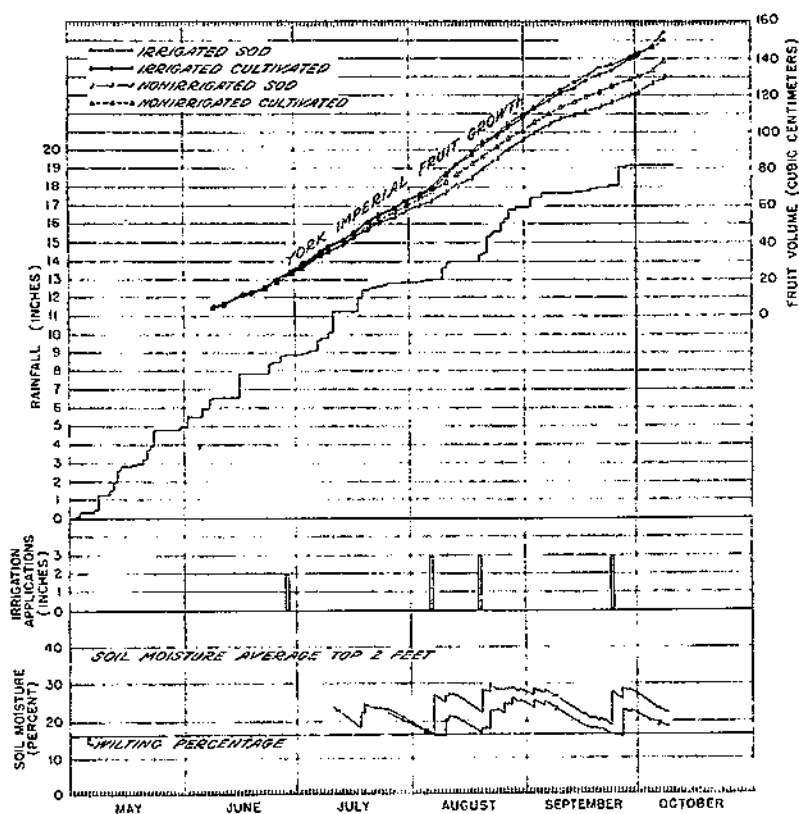


FIGURE 10.—Fruit growth, soil moisture, rainfall, and irrigation applications on experimental York Imperial plots, deep heavy soil, 1931.

such soils the growth rate of fruit decreases while the moisture content is still much above the wilting percentage. Results in 1931 indicate that, in the present tests, growth of fruit on these heavily loaded York Imperial trees was not reduced measurably until the moisture was fairly close to the wilting percentage in the surface 2 feet.

EFFECT OF MOISTURE SUPPLY ON COLOR DEVELOPMENT

Throughout the course of these experiments, records were made of the percentage of the fruit falling in various color classes at time of

harvest. Color records obtained on the Oldenburg and Rome Beauty plots in 1930 and 1931 have been reported in detail by Fletcher (5). His report indicates that in both 1930 and 1931 the color of the Oldenburg fruit at harvest time was slightly poorer on the plots that had been irrigated than on the corresponding nonirrigated plots.

Records showing the amount of the fruit surface which became red for three Rome Beauty crops and for the Delicious in 1932 are summarized in table 2. In the Rome Beauty apples the area of the red color was slightly greater on the fruit from the irrigated cultivated plot in 1930 than on the corresponding nonirrigated plot. There was no significant difference in color of the fruit from the irrigated and nonirrigated mulched plots. The quality of the color in that year was much superior on the fruit from the irrigated plots, being a bright sparkling red, whereas on the nonirrigated plots the color was dull bronze-red and much less attractive. In 1930 the color of the fruit from the mulched plots was distinctly better than that from the cultivated plots.

TABLE 2.—Effect of irrigation and cultural treatments on the proportion of fruit surface which became red

Variety, year, and treatment	Percentage of crop in color class					Average percentage of surface colored
	0-25	25-50	50-75	75-100	50-100	
<i>Rome Beauty, 1930.</i>						
Cultivated nonirrigated	24.7	39.4			35.9	44.6
Cultivated irrigated	25.9	26.1			48.0	48.0
Mulched nonirrigated	16.0	25.5			58.5	53.4
Mulched irrigated...	20.4	22.2			57.4	53.9
<i>Rome Beauty, 1931:</i>						
Cultivated nonirrigated	19.8	39.5			40.7	47.7
Cultivated irrigated	20.4	43.8			35.8	46.6
Mulched nonirrigated	16.9	40.5			42.6	48.0
Mulched irrigated...	42.8	33.5			23.7	35.6
<i>Rome Beauty, 1932:</i>						
Cultivated nonirrigated	22.5	33.5	22.3	21.2		47.9
Cultivated irrigated	22.1	31.7	22.2	25.0		50.4
Mulched nonirrigated	20.1	38.5	17.5	14.5		41.7
Mulched irrigated	23.7	28.7	19.6	20.5		40.1
<i>Delicious, 1932:</i>						
1-year plot -						
Nonirrigated	9.3	21.9	26.2	42.5		62.9
Irrigated	4.1	22.1	39.8	33.9		63.4

In 1931, a season of good rainfall and with moderately light crops on the trees, the area of the red color on the Rome Beauty fruit from the irrigated plots in each case averaged less than that on fruit from the corresponding nonirrigated plots. During that season there was not a marked difference in quality of color between fruit from the irrigated and the nonirrigated plots. The poorest color was on fruit from the mulched irrigated plots where the trees were very vigorous.

In 1932 the Rome Beauty, following three seasons of irrigation treatment, showed a slightly greater area of the fruit colored on the irrigated plots. The fruit on these plots was also very much brighter red and much more attractive in appearance. The nonirrigated trees were extremely dry during September, and the color of the fruit on these trees was dull and lifeless, even though the area of

the color was only slightly reduced. These results agree in general with those of Fletcher (5), also with color records reported by Overley, Overholser, and Haut (14) in Washington State, and with unpublished data which have been obtained by C. P. Harley and M. P. Masure at Wenatchee, Wash. During seasons of sufficient rainfall the application of additional irrigation water did not improve color but tended to decrease the area of the surface on the fruit that became red. On the other hand, during seasons when the fruit ripened with the moisture content of the soil at or very near the wilting percentage, the color development of the fruit was poor and dull as compared with that which received sufficient moisture. Apparently moisture available to the tree is essential to the highest color development, but excessive moisture in the soil is unfavorable and is likely to lead to poor color development.

Results were similar on the Delicious plots in 1932. The area of color was practically the same on fruit from the two plots, but the fruit from nonirrigated plots, which ripened with the trees suffering greatly for moisture, was dull and unattractive. Fruit from irrigated trees was a bright and clear red.

EFFECT OF MOISTURE SUPPLY ON FRUIT-BUD FORMATION

Throughout the course of these experiments, records were obtained each spring of the percentage of the growing points which formed blossoms and of the blossoms which set fruit. The total number of growing points and the total number of blossoms on from 6 to 8 branches $1\frac{1}{2}$ to 2 inches in diameter well distributed over the tree, and representative of the estimated average condition of the tree as a whole, were counted each season. Percentage of flowering was obtained by dividing the number of blossom clusters by the total number of growing points of the branches. Percentage of set was the percentage of clusters that set fruit.

The average percentage of fruit-bud formation and fruit set on the Rome Beauty and Oldenburg trees through three seasons is shown in table 3. These results indicate that the average bloom was heavier in the dry plots in the spring of 1931 than in the corresponding irrigated plots. These results, previously reported by the writers (4), indicated that if the trees suffer appreciably for water during the period of fruit-bud formation, increased fruit-bud formation is likely to result.

Following the heavier bloom there was a heavier crop of fruit on the nonirrigated than on the irrigated trees in 1931. No moisture shortage occurred in 1931 prior to late July. In the spring of 1932 a heavier bloom occurred on the irrigated than on the nonirrigated trees. In the spring of 1933 the nonirrigated trees on three of the plots carried a slightly heavier bloom, though the mulched irrigated Rome Beauty had slightly more bloom than the nonirrigated ones.

TABLE 3.—Average bloom and fruit-set record in irrigated and nonirrigated apple plots, 1931-33

Variety and treatment	Spring 1931		Spring 1932		Spring 1933	
	Bloom	Set	Bloom	Set	Bloom	Set
	Percent	Percent	Percent	Percent	Percent	Percent
Rome Beauty:						
Cultivated nonirrigated	31.4	40.5	45.6	53.0	30.8	43.4
Cultivated irrigated	23.1	40.9	61.6	45.9	29.4	48.4
Mulched nonirrigated	28.2	51.7	47.1	60.8	15.5	55.5
Mulched irrigated	14.0	55.0	58.2	39.4	17.0	49.9
Oldenburg:						
Cultivated nonirrigated	48.5	49.6	43.2	79.2	54.3	31.2
Cultivated irrigated	24.0	54.4	53.4	72.4	48.1	56.6
Mulched nonirrigated	39.8	47.7	32.6	81.6	69.8	22.6
Mulched irrigated	28.7	43.6	39.2	78.3	51.5	25.2

Throughout these experiments the amount of bloom has been correlated with the quantity of fruit carried on the trees the preceding season. Correlation curves have been prepared in which are charted the number of fruits carried on each tree per 100-cm² cross section of trunk during the preceding season and the percentage of fruit-bud formation following. Distribution curves for the irrigated and the nonirrigated trees, showing average behavior, will then indicate whether fruit-bud formation was affected by the treatment. In this analysis of the data, trees are grouped as irrigated or nonirrigated, without regard to cultural treatments. Such distribution curves for the 1932 and 1933 bloom are shown for Oldenburg in figure 11 and for Rome Beauty in figure 12. The close paralleling of the irrigated and nonirrigated curves for Oldenburg indicate no difference in fruit-bud formation due to irrigation in the summers of 1931 and 1932. With the Rome Beauty there is indication each year of slightly greater fruit-bud formation on the irrigated trees which is believed to be due to the greater vigor of these trees rather than to a direct immediate effect of added water in influencing fruit buds to form.

In neither 1931 nor 1932 did the trees in the nonirrigated plots show evidence of lack of sufficient water until late July (about July 20 in 1931 and Aug. 1 in 1932). In 1930, on the other hand, the growth rate of fruit was sharply reduced in the nonirrigated trees after July 1. The results of Magness, Fletcher, and Aldrich (10) indicate that in the section in which these investigations were conducted fruit-bud formation can be influenced in but very few buds after July 15, or 75 days after full bloom. Thus the formation of fruit buds could be influenced by lack of moisture only in 1930, as shown by the bloom records taken in the spring of 1931.

The block of Delicious trees irrigated for the first time in 1932 carried a heavy crop of fruit, as did the nonirrigated trees. In this experiment neither group of trees bloomed in the spring of 1933. The crop in each case was so heavy that fruit-bud formation did not occur, and this result was not affected by the differential irrigation treatments. In that experiment, also, the trees were not affected by reduced moisture supply until the season during which fruit-bud formation could be affected had passed.

The results obtained to date relative to the effects of moisture supply on fruit-bud formation are not conclusive. The data for 1930 indicate that if there is a shortage of moisture during the

period in which fruit-bud formation can be affected, such shortage will tend to increase fruit-bud formation. In the Shenandoah-Cumberland Valley, fruit-bud formation in most varieties is not affected by experimental treatments given later than July 15, and the proportion of the buds that are affected after July 1 is small. Consequently it is apparently only early summer drought that might appreciably affect fruit-bud formation.

Following the very dry July and early August of 1930 there was a fairly heavy bloom of apples the next spring throughout the Shenandoah-Cumberland Valley as a whole. There was an excessively heavy bloom of peaches, in which fruit the formation of flower buds can be influenced through August. These general observations

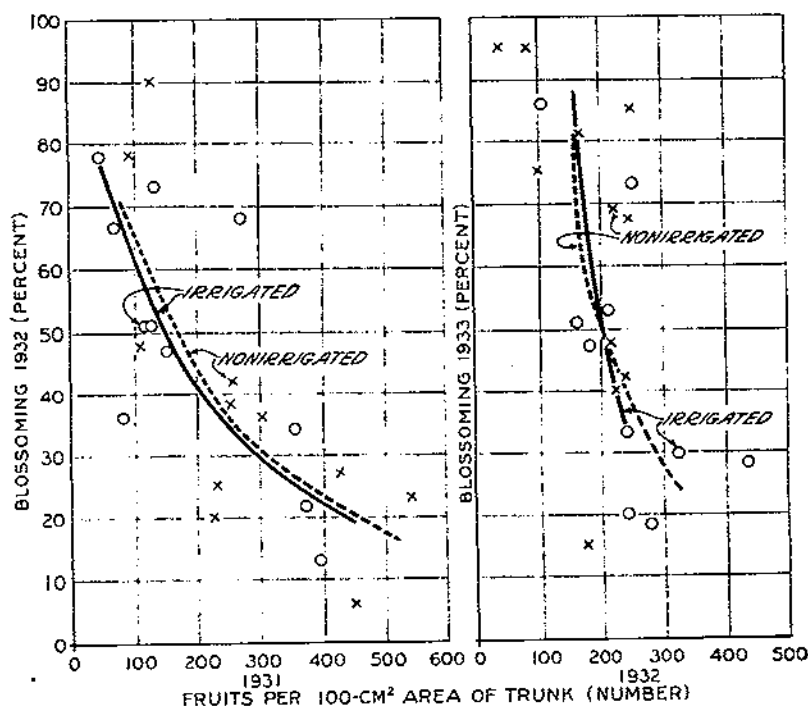


FIGURE 11.—Distribution curves for percentage of blossoming of Oldenburg apples, plotted against number of fruits borne per 100-cm² cross-sectional area of trunk during preceding season.

would tend to support the conclusion reported here that fruit-bud formation is increased under conditions of early summer moisture shortage. Similar results have been reported by Aldrich and Work (2) for pears in the Rogue River Valley of Oregon.

The most important factor in determining percentage of fruit-bud formation in these tests has been the number of fruits carried per tree in relation to the size of the tree or, more accurately, in relation to the foliage system of the tree. The maintenance of available moisture throughout the season through irrigation has not increased the tendency to form fruit buds. There is evidence from observations and limited experiments to indicate that periods of drought in early summer tend directly to increase the number of

fruit buds formed. The increased vigor and larger foliage systems on trees irrigated regularly apparently may result in greater fruit-bud formation when the crop of fruit being borne is only moderate.

PHYSIOLOGICAL EFFECTS OF REDUCED MOISTURE SUPPLY ON APPLE TREES

Throughout the course of this work, investigations have been conducted to determine the effect of shortage of moisture on the nutrition or physiological functioning of the trees. Several reports have

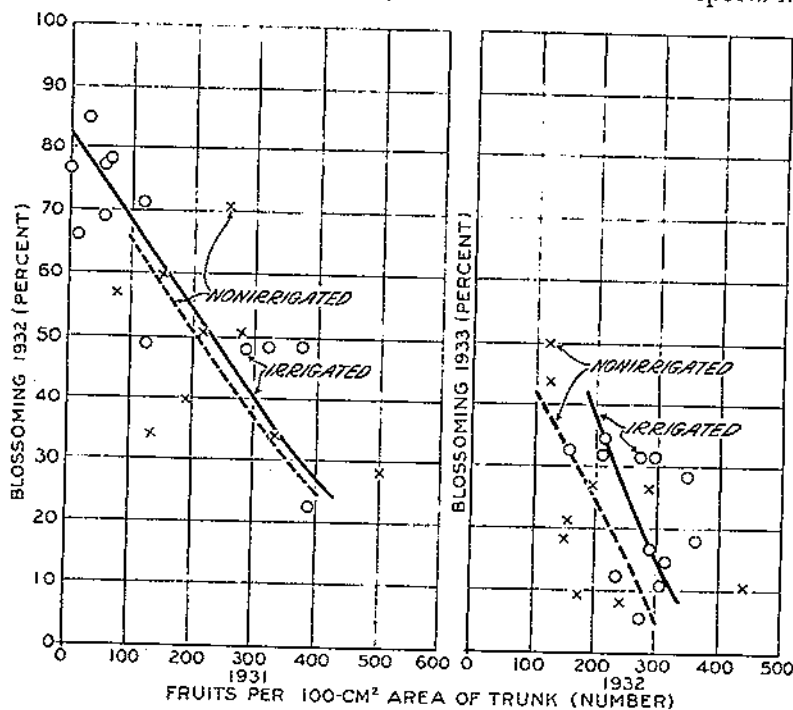


FIGURE 12.—Distribution curves for percentage of blossoming of Rome Beauty apples, plotted against number of fruits borne per 100-cm² cross-sectional area of trunk during preceding season.

been issued on various phases of these investigations, and detailed results previously published will not be included here. The following discussion summarizes the results obtained.

RELATION OF MOISTURE SUPPLY TO STOMATAL BEHAVIOR OF APPLES

Detailed results of a portion of these studies have been reported by Furr and Magness (7), and Furr and Degman (6). The stomata of apple leaves apparently are limited to the under surface. When moisture is available these stomata open in the morning, usually about the time the sun first strikes the leaves. With abundant moisture in the soil most of the stomata will open, the maximum number opening varying usually from 70 to 100 percent. The length of time these stomata remain open varies with the amount of available moisture in the soil and with the evaporating power of the air.

When the whole root zone is above the wilting percentage and humidity is high, most of the stomata will remain open throughout the day. On the other hand, with abundant soil moisture but with relatively high temperatures and low humidity, stomata may be completely closed before noon. With reduced moisture supply the period of stomatal opening under constant evaporating power of the air becomes correspondingly reduced. When the soil in most of the root zone of the trees reaches the wilting percentage, stomata may fail to open at all on the trees. With the soil at or near the wilting percentage but with the air nearly saturated during the early morning, the stomata will usually open for a short period but may be completely closed within an hour.

Previous results reported by Magness, Regeimbal, and Degman (12) indicate that the closing of the stomata in apple foliage is closely correlated with a decrease in moisture percentage in the leaf rather than with the accumulation of the products of photosynthesis. Apparently the stomata open under the stimulus of light, if the moisture content of the leaf is sufficiently high, and remain open until the moisture content is reduced to a certain point. The moisture content of the leaf rather than the accumulation of the products of photosynthesis seemed to be the important factor in determining the time of stomatal closing, under the conditions of these experiments.

EFFECT OF MOISTURE SUPPLY ON LEAF FUNCTION

It is extremely difficult, if not impossible, to determine accurately by leaf analyses the effect of reduced moisture supply and of earlier daily closing of the stomata on the quantity of carbohydrate materials formed in the leaf as a result of photosynthesis. These carbohydrates apparently move out of the apple leaf throughout the day as well as during the night. It seems logical to assume that this movement of carbohydrate materials from the leaf proceeds more rapidly when tissues are well supplied with moisture and when the water content of leaf and bark is high than when the water content in the conducting and storage tissues is reduced.

Investigations previously reported (12) have indicated that the content of both starch and sugar is slightly higher throughout the day in leaves of trees well supplied with moisture than in leaves of trees in which the moisture supply is so limited that the growth rate of the fruit is being measurably reduced. The greater photosynthetic activity of leaves well supplied with moisture is also indicated by the fact that trees and fruit supplied with an abundance of moisture throughout the season show a much higher total content of carbohydrates late in the summer than do similar fruit and trees that have suffered seriously for lack of water. These results indicate that one basic physiological effect of reduced moisture supply is reduced total carbohydrate formation in the leaves of the trees.

While it has not been demonstrated experimentally, it is believed that the carbon dioxide enters the leaf largely through the stomata and that the closing of the stomata under conditions of reduced moisture supply greatly diminishes the amount of carbon dioxide which enters the leaf. Since carbon dioxide and water are the two raw materials from which carbohydrates are manufactured in leaves, reduction of the amount of carbon dioxide that enters the leaf is

probably the basic factor in the reduced photosynthetic activity. The moisture supply of the leaf is also reduced to an appreciable extent, in some tests being approximately 5 to 7 percent higher at the time of stomatal opening than at the time of stomatal closing. There is so much water present in the leaf, even at the time of stomatal closing, however, that it seems doubtful if deficiency of water is a direct factor in the reduced photosynthetic activity of the foliage under conditions of moderate water shortage.

A reduced period of stomatal opening is the first measurable effect of reduced moisture supply to the tree. Slight variations in the period during which the stomata remain open, due to reduced moisture supply, can be detected much earlier than changes in growth rate of the fruit can be measured. Results of these investigations indicate that the variation in time of stomatal opening is perhaps the most sensitive criterion of any change in the condition of the tree due to moisture variation. By following stomatal behavior throughout the day, variations in behavior can be detected when the moisture content of the whole root zone is apparently considerably above the wilting percentage, whereas at least a portion of the root zone on soils of medium or light texture apparently is usually at or near the wilting percentage before variations in the growth rate of fruit can be measured.

Rather limited data obtained to date (12) indicate that the leaves and bark are the organs of the tree which show greatest fluctuation in water supply throughout the day. Moisture content of the leaves may be reduced as much as 6 percent between sunrise and midafternoon, and the moisture content of the bark on branches less than 6 years of age may be reduced in approximately the same proportion. There is little daily fluctuation in the moisture content of the younger wood.

The moisture content of apple foliage did not continue to decrease after the stomata were closed except in leaves in a definitely wilted condition. When the trees were definitely wilted, moisture content of the foliage showed a slow decrease throughout the day even though the stomata were closed or were open for only a few minutes in the early morning.

EFFECT OF MOISTURE SUPPLY ON SUGAR AND STARCH CONTENT OF BARK, WOOD, AND FRUIT

On September 15, 1932, samples of bark, wood, and fruit from the irrigated and nonirrigated Delicious trees were taken. These trees, differentially handled for the first time during the growing season of 1932, had shown differences in fruit-growth rate beginning about July 8 (fig. 9). From that date through to time of sampling on September 15, or for a period of more than 2 months, decreased fruit-growth rate had occurred on the nonirrigated trees although at no time had they been in a definitely wilted condition. On September 15 the sugar content of the bark of the dry trees was from 14 to 19 percent higher than that of the bark of the irrigated trees. The sugar content of the bark was approximately five times as high as the sugar content of the wood.

On the same date the starch content of the bark of the irrigated trees was more than 30 percent higher than that of the nonirrigated

trees, with about the same differential in the starch content of the wood.

These results indicate that under conditions of reduced moisture supply to the trees the sugar content is relatively high while the starch content is reduced. Under conditions of abundant moisture supply the carbohydrate accumulates largely in the form of starch.

The percentage of starch in the wood of branches under 1 inch in diameter was practically the same as that of the bark from the same branches. Since the weight of wood in a large tree far exceeds the weight of bark, it is apparent that the total quantity of starch in these trees far exceeded the total quantity of sugar both in the irrigated and the nonirrigated trees. Since the starch content of the irrigated trees in both wood and bark averaged more than 30 percent higher than in the nonirrigated trees, it was apparent that the total amount of carbohydrate in these trees was much higher than in those that had suffered for moisture during the season.

The sugar content of the fruit averaged approximately 10 percent higher in that from nonirrigated trees which were suffering because of moisture shortage, while the starch content of the fruit from irrigated and nonirrigated trees was not consistently different. On this date, however, the average size of the fruit from irrigated trees was almost 50 percent greater than that from nonirrigated trees. Thus it is apparent that far more total carbohydrate had gone into the building of the fruit from irrigated than from nonirrigated trees. These data indicate that much more total carbohydrate had been built during the season in the irrigated than in the nonirrigated trees.

While more experimental data are needed on this point, results obtained indicate that the sugar content of bark and wood is higher in trees suffering for moisture, while the starch content and total carbohydrate is reduced under these conditions in proportion as leaf function is reduced. The fact that sugar concentration in trees growing under conditions of seriously reduced moisture supply is higher than in trees abundantly supplied with moisture may be of significance in the apparent increased fruit-bud formation which occurs under conditions of limited moisture supply if that reduction in moisture takes place during the period when fruit-bud formation can be influenced.

Analyses for total nitrogen in trees well supplied with moisture and those growing under conditions of moisture shortage have not shown a consistent difference in nitrogen content either on a wet-weight or dry-weight basis.

DISCUSSION

MOISTURE SUPPLY AND FUNCTIONING OF APPLE TREES

Results secured in these investigations indicate that apple trees are not measurably reduced in function, and growth rate of fruit is not measurably reduced so long as the moisture content of practically the whole root zone is above the wilting percentage. These results are in general agreement with the findings of Hendrickson and Veihmeyer (8, 9), working with peaches and other fruits in California. In the present investigations, however, there was wide variation in root distribution so that the moisture in a portion of

the root zone might be reduced while much of the root system still had moisture available. Under these conditions, the degree of reduction in tree function seemed to depend on environmental conditions. During cool moist weather fruit growth was almost normal, even when the moisture in most of the root zone was reduced to the wilting percentage. On the other hand, during hot dry weather fruit-growth rate and the period of stomatal opening were markedly reduced if any considerable portion of the root zone reached the wilting point.

SOILS FOR ORCHARDS

Results secured in these investigations indicate that under conditions in the Middle Atlantic States, mature apple orchards, growing in soils 2 to 2½ feet deep and of good water-holding capacity, will exhaust their water to the extent that the fruit-growth rate is reduced within a period of 25 days during the summer. This holds true even if the soil is wet to the full field capacity at the start of the period. It rarely happens under natural rainfall conditions that a soil even of this depth is wet to full field capacity during the summer months. This would occur only if as much as 3 to 4 inches of rain had fallen and been absorbed by the soil within a very short period.

Under actual conditions as they existed during the 4 years, the growth rate of fruit on trees bearing a full crop generally was reduced following not more than 2 weeks of midsummer weather without rainfall. It is significant that during each of the past 4 years the growth rate of fruit on trees in such soils was reduced at some time during the growing season due to shortage of moisture, notwithstanding the fact that in 3 of the 4 years the total rainfall for the growing season was above average. In 2 of the 4 years the fruit hardly reached marketable size and was of poor quality because of lack of moisture.

These results indicate that under the conditions prevailing in the Middle Atlantic States and States westward having similar length of season and temperatures it is extremely hazardous to attempt to grow orchards on soils as shallow as 2 feet, even though they are retentive of moisture, of good fertility, and well drained. It would seem that the economic limit for orchard soils of good water-holding capacity, where orchards in that region are to be grown without irrigation, would be not less than 3 feet of good soil.

In regions farther north where the total length of the growing season is reduced and where the mean temperatures of the growing season are also lower, the hazard of moisture shortage decreases correspondingly. On the other hand, to the southward with even a longer growing season and higher seasonal temperatures, deeper soils and soils of better water-holding capacity are required to assure that the orchards will not suffer unduly from soil-moisture deficiencies. Except in the extreme north the planting of orchards on soils in which the root zone is limited, either by rock or by impervious and poorly drained subsoil, to less than 3 to 4 feet deep, should be considered as hazardous. Unless the soil is of good water-holding capacity with at least 10 to 12 percent of available moisture between

the field capacity and the wilting percentage, even more than 4 feet of depth would be required to assure fairly dependable moisture conditions.

THE VALUE OF MULCH IN MOISTURE CONSERVATION

Throughout these tests, plots heavily mulched with wheat straw with and without irrigation were compared with plots cultivated in the spring and then allowed to grow up to weeds with and without irrigation. A study of the results shown in figures 2 to 5 indicates that Rome Beauty apples were somewhat larger each season on the nonirrigated mulched plot than on the nonirrigated cultivated plot, and Oldenburg apples from the mulched plot were larger most of the years. It is not possible to say how much of this result can be attributed to difference in moisture and how much to increased organic matter. In these tests, trees in the nonirrigated mulched plot did not suffer for water quite so quickly as those in the cultivated plot owing to three factors: (1) The mulch was sufficiently heavy to keep down all weed growth to beyond the spread of the branches of the trees and transpiration from weeds did not occur as in the cultivated plot. (2) The mulch apparently reduced somewhat the surface evaporation of moisture from the soil. (3) The mulch completely prevented run-off of water during heavy rains and resulted in the soil taking up all moisture that fell. It is probable that under some orchard conditions, particularly on slopes or hilltops, the last effect is the most important of the three, since summer rains frequently come as heavy downpours of short duration. Under these conditions such a mulch insures the penetration of the water where it falls.

On the other hand, during periods of prolonged drought, non-irrigated trees growing under heavy mulch in soil only 2 to 2½ feet deep, suffered very severely from lack of moisture. The size of Rome Beauty fruit on the mulched nonirrigated trees was always smaller than that of the fruit from the irrigated trees either on the cultivated or mulched plots. When the trees growing under mulch exhaust the available water from the soil they suffer apparently as severely as nonmulched trees. While the condition of the Rome Beauty trees under mulch was fairly satisfactory on such shallow soils, they did not approach the condition of those where moisture was applied directly. There was less difference with Oldenburg where the fruit generally was harvested before a serious shortage of moisture occurred.

MOISTURE SUPPLY AND REGULAR BEARING

Irrigation under the conditions of these tests did not correct the tendency of trees to bear biennially. The York Imperial in block C remained biennial under irrigation. In 1932 the Delicious trees carrying a heavy crop failed to form fruit buds for the following year, either under irrigation or nonirrigation. Rome Beauty trees carrying a heavy crop in 1930 formed fewer fruit buds for the following year under irrigation than when the trees suffered for moisture during July. The direct effect of abundant moisture supply seems to be to decrease rather than to increase fruit-bud formation.

On the other hand, the trees that did not suffer for moisture during 4 years are more vigorous and thrifty than those that suffered

from time to time. With these more vigorous trees it seems certain that regular production can be secured more easily than with trees in low vigor.

RELATION OF MOISTURE SUPPLY TO SIZE AND QUALITY OF FRUIT

In these tests the greatest benefit from having sufficient moisture throughout the growing season was in increasing the size of the fruit and, during seasons of drought, in greatly improving the color at harvest time. Since a market premium is usually paid for the larger sized and better colored fruits there were great gains in total marketable fruit and in market value per bushel under irrigation on the more shallow types of soil under the conditions of these tests. Yields of marketable fruit of late-maturing varieties were approximately doubled during the dry seasons and were appreciably increased in 3 of the 4 years during which these tests were run. These results apply only to the fairly shallow soils. With increasing depth of soil and increasing water-storage capacity at the beginning of the growing season, progressively decreasing benefits from irrigation could be expected under eastern conditions.

These investigations have emphasized particularly the desirability of selecting orchard soils where the root zone is deep and has good water-holding capacity. Where orchards are established on moderately shallow soils, irrigation will greatly benefit the yield and market quality of fruit during many seasons. With extremely shallow soils averaging not over a foot in depth under the conditions of these tests, irrigation to maintain sufficient moisture must be so frequent that the feasibility of attempting to operate such orchards either with or without irrigation is very doubtful.

WHEN IRRIGATION IS FEASIBLE UNDER EASTERN CONDITIONS

A practical question with many orchardists in the Eastern States is whether they should consider equipping their orchards for irrigation. Several factors must be considered in connection with this question.

There is enough good orchard land in the Eastern States which is sufficiently deep and retentive of moisture to produce the needed fruit crops of the country without irrigation. It seems doubtful if new orchards should be planted where irrigation is necessary unless unusual conditions of water availability prevail.

On the other hand, many orchards are now established on soils where moisture supply will frequently be a limiting factor in fruit production. With such orchards, if planted to good varieties and on good locations, irrigation is worthy of consideration if a dependable water supply is available. The main considerations should be the quantity of water available and the cost of distributing it in the orchard. Irrigation systems depending upon small streams for water supply are frequently unsatisfactory, since such streams may be dry or nearly dry during periods of extreme drought when irrigation is most needed. The expense of installing an irrigation system is warranted only in case the water supply is completely dependable.

QUANTITY OF WATER REQUIRED

In the Eastern States water requirement of the orchards is generally lower than under the arid conditions of the West, since with higher humidities the evaporating power of the air is generally lower. Also, it is only rarely that prolonged periods with a complete absence of light showers occur. In view of results obtained in these investigations it seems probable that 4 acre-inches of water per month would be required to maintain the trees at maximum functioning if no rainfall occurred. Such maximum usage would occur so seldom, however, that it seems doubtful if the orchardist would be justified in providing for the application of this quantity of water unless it could be done at fairly reasonable expense. On the other hand, 2 acre-inches of water, or approximately 54,000 gallons, would represent the minimum application per acre per month which might be considered as satisfactory in a supplementary irrigation system.

TYPES OF IRRIGATION

Various methods of applying irrigation water to orchards are in use in different parts of the United States. The method of delivering and handling the water on each individual orchard is a different problem and will not be discussed here. Throughout the course of these investigations the sprinkler method of application, where the water is pumped through pipes to sprinklers set on the tops of standpipes 12 to 14 feet high, has been used. Each of these standpipes, equipped with a sprinkler at the top, throws the water over an area of approximately 50 feet in diameter. Under this method the leaves and fruit of the trees are kept soaked for periods of 10 to 24 hours whenever an irrigation is given.

The sprinkler irrigation systems are satisfactory for orchards from the standpoint of distributing water on rough or broken land. On the other hand, wetting of the foliage and fruit has resulted in some increase in fungous diseases. The orchards in which these tests were conducted are clean and thoroughly sprayed, and the disease factor was not serious under these conditions. Although detailed records were not taken, it was evident that there was a slight increase in scab infection in the plots irrigated with sprinklers. These results are in line with those obtained in Washington (13).

Fletcher (5) reporting in part on the same tests that are reported here, found apparently somewhat poorer color on the sprinkler-irrigated plots than on similar plots irrigated in furrows in which the fruit and foliage were not wet. These results also are similar to those obtained in Washington.

These factors indicate the desirability, particularly in the Eastern States, of applying the water directly on the ground, where possible, rather than through sprinklers. Furrow irrigation is very satisfactory in orchards that are not too steep and in which the soil is not too open or porous. In orchards too steep or with the soil too open for furrow irrigation, application of water through such devices as perforated hose is fairly satisfactory. The sprinkler system is very satisfactory from the standpoint of good distribution and

ease of handling, but it requires a fairly expensive installation to distribute the water. The best method of handling the water on individual orchards can be determined only by a thorough study of the particular condition in each orchard.

WHEN WATER SHOULD BE APPLIED

One of the most difficult problems in connection with irrigation is to determine when water should be applied in the orchard. Too frequent or too heavy irrigations may result in water-logging of the soil, particularly if it is poorly drained, as well as in unnecessary expense in the application of the water. If irrigation is delayed too long and growth rate of fruit is seriously retarded as a result of lack of moisture, fruit size at the end of the season will be reduced in proportion.

The keeping of accurate records of rainfall is valuable in determining when irrigation should be applied under eastern conditions, where summer rainfall is generally rather frequent. The experienced grower can judge fairly well how long the soil in various parts of the orchard will carry the trees following a thorough irrigation, if he considers the amount of rainfall that has occurred.

A very valuable index is the wilting of relatively shallow-growing plants in the orchard. When shallow-growing vegetation becomes wilted, and particularly if it remains so during the cooler parts of the day, it is an indication that the soil in the root zone of those plants is at or near the wilting percentage. After that condition is reached it will not be long until the trees also begin to suffer unless moisture is applied.

The present studies, as well as others (11) reported from Washington, indicate that under ideal conditions the late varieties of apples grow at an approximately steady rate on a volume basis from late June through until near harvest time. One of the best indexes as to when the trees are suffering for water is the reduction in the growth rate of fruit. This can be followed rather accurately by tagging certain fruits and measuring their circumferences at intervals and plotting their increase in size on a volume basis. While this practice would be somewhat unusual in commercial orchard management, it could be done with a limited amount of time and might be very helpful to the orchardist who is starting in to practice irrigation, as it gives an excellent index as to when his particular trees need additional moisture. If the same apples are measured from week to week, or preferably at least twice a week, measurements on a large number of individual apples are not needed to determine the growth condition of the fruit as a whole.

Orchards on deep soils of poor water-holding capacity, or on shallow soils even with excellent water-holding capacity, will suffer greatly because of moisture shortage under such rainfall conditions as have prevailed during many years in the eastern part of the United States. Moisture-conservation measures such as mulching to prevent run-off and to keep down competing vegetative growth, or cultivation, which eliminates the competition of other plants, are helpful in maintaining orchards under these conditions. Under severe drought conditions, however, the actual application of water through irrigation is the only means of obtaining optimum fruit

growth and quality. Apple trees carrying little fruit will stand drought conditions well, but with heavy crops on the trees the immediate as well as later effects on the tree are serious.

SUMMARY

Investigations have been conducted through four growing seasons, 1930-33, inclusive, to determine the soil-moisture conditions and tree response in irrigated and nonirrigated plots in apple orchards in western Maryland.

During 3 of the 4 seasons, total rainfall from May 1 to October 31 was above normal, yet in each season apple trees in rather shallow shale soil showed reduced fruit-growth rate due to moisture shortage at some time during the season.

The growth of apples measured on a volume basis proceeds at very nearly a uniform rate from a period some 6 to 8 weeks following bloom until near harvest time, if all conditions are favorable.

The growth rate of the fruit of trees growing in moderate textured silt loam or silt clay soils is generally not measurably reduced because of moisture shortage until at least the driest parts of the root zone approach the wilting percentage.

When ample moisture is restored following a period of reduced growth rate due to moisture shortage, growth of fruit is resumed at apparently normal rate, provided the drought has not been so severe as to cause serious loss of foliage.

The size of the fruit at the end of the season will be reduced in proportion to the length and duration of the drought. Following even a short period of reduced growth rate, the ultimate size of the fruit will be reduced accordingly.

During the 4 years of these tests the yield of Rome Beauty was increased more than 50 percent because of increased size of fruit, due to irrigation. Oldenburg, on the other hand, when harvested in late July, showed little increase in yield or size of fruit due to irrigation.

The color of the fruit is dull and lifeless when the ripening season occurs while trees are suffering from lack of moisture. Moderate available moisture during the late-growing season has given maximum color, both in brightness and in area. Excessive moisture tended to reduce the amount of color.

When moisture shortage occurs not later than early July, fruit-bud formation appears to be increased. Water shortage during the period from late July until fall apparently has no effect on fruit-bud formation.

The first measurable effect of reduced moisture supply on the functioning of apple trees is an earlier closing of the stomata. This occurs prior to a reduction in the growth rate of fruit.

Leaf function apparently is reduced under conditions of insufficient moisture supply, and the total carbohydrate materials in the trees are less than under conditions of ample moisture.

The sugar content of bark and wood of the trees is markedly higher following a period of serious moisture shortage than it is in trees well supplied with moisture. The starch content is much lower in the trees suffering from deficient moisture.

The effects of soil-management practices on soil moisture and the value of irrigation under eastern orchard conditions are discussed.

LITERATURE CITED

- (1) ALDRICH, W. W., and WORK, A.
1933. PRELIMINARY REPORT OF PEAR TREE RESPONSES TO VARIATIONS IN AVAILABLE SOIL MOISTURE IN CLAY ABOVE SOIL. Amer. Soc. Hort. Sci. Proc. (1932) 29: 181-187, illus.
- (2) ——— and WORK, A.
1934. EFFECTS OF LEAF-FRUIT RATIO AND OF AVAILABLE SOIL MOISTURE IN HEAVY CLAY SOIL UPON AMOUNT OF BLOOM OF PEAR TREES. Amer. Soc. Hort. Sci. Proc. 31 (sup. vol.) 57-74, illus.
- (3) BRIGGS, L. J., and SHANTZ, H. L.
1912. THE WILTING COEFFICIENT FOR DIFFERENT PLANTS AND ITS INDIRECT DETERMINATION. U. S. Dept. Agr., Bur. Plant Indus. Bull. 230, 83 pp., illus.
- (4) DEGMAN, E. S., FURR, J. R., and MAGNESS, J. R.
1933. RELATION OF MOISTURE SUPPLY TO FRUIT-BUD FORMATION IN APPLES. Amer. Soc. Hort. Sci. Proc. (1932) 29: 198-201, illus.
- (5) FLETCHER, L. A.
1933. A STUDY OF THE FACTORS INFLUENCING RED COLOR ON APPLES. Md. Agr. Expt. Sta. Bull. 358, 119 pp., illus.
- (6) FURR, J. R., and DEGMAN, E. S.
1932. RELATION OF MOISTURE SUPPLY TO STOMATAL BEHAVIOR OF THE APPLE. Amer. Soc. Hort. Sci. Proc. (1931) 28: 547-551, illus.
- (7) ——— and MAGNESS, J. R.
1931. PRELIMINARY REPORT ON RELATION OF SOIL MOISTURE TO STOMATAL ACTIVITY AND FRUIT GROWTH OF APPLES. Amer. Soc. Hort. Sci. Proc. (1930) 27: 212-218, illus.
- (8) HENDRICKSON, A. H., and VEITHMEYER, F. J.
1929. IRRIGATION EXPERIMENTS WITH PEACHES IN CALIFORNIA. II. CANNING QUALITY OF IRRIGATED PEACHES. Calif. Agr. Expt. Sta. Bull. 479, 63 pp., illus.
- (9) ——— and VEITHMEYER, F. J.
1930. SOME FACTS CONCERNING SOIL MOISTURE OF INTEREST TO HORTICULTURISTS. Amer. Soc. Hort. Sci. Proc. (1929) 26: 105-108.
- (10) MAGNESS, J. R., FLETCHER, L. A., and ALDRICH, W. W.
1934. TIME DURING WHICH FRUIT-BUD FORMATION IN APPLES MAY BE INFLUENCED IN THE SHENANDOAH-CUMBERLAND FRUIT DISTRICTS. Amer. Soc. Hort. Sci. Proc. (1933) 30: 313-318.
- (11) ———, OVERLEY, F. L., and LUCE, W. A.
1931. RELATION OF FOLIAGE TO FRUIT SIZE AND QUALITY IN APPLES AND PEARS. Wash. Agr. Expt. Sta. Bull. 249, 26 pp., illus.
- (12) ———, REDEMBAL, L. O., and DEGMAN, E. S.
1933. ACCUMULATION OF CARBOHYDRATES IN APPLE FOLIAGE, BARK, AND WOOD AS INFLUENCED BY MOISTURE SUPPLY. Amer. Soc. Hort. Sci. Proc. (1932) 29: 246-252, illus.
- (13) OVERLEY, F. L., OVERHOLSER, E. L., GARVER, H. L., VANDECAYEVE, S. C., SPULER, A., and MORRIS, O. M.
1932. IRRIGATION OF ORCHARDS BY SPRINKLING. Wash. Agr. Expt. Sta. Bull. 268, 50 pp., illus.
- (14) ———, OVERHOLSER, E. L., and HAFT, I. C.
1932. THE RELATION OF SOIL MOISTURE AND SPRAY APPLICATIONS TO STOMATAL BEHAVIOR AND GROWTH OF JONATHAN APPLES. Amer. Soc. Hort. Sci. Proc. (1931) 28: 543-546, illus.

END