RESPONSE OF APPLE (*MALUS SYLVESTRIS*) TO VARIOUS LEVELS OF SOIL MOISTURE

Thesis for the Degree of Ph. D.

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Stanley Joseph Gamble

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This is to certify that the

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RESPONSE OF APPLE (MALUS SYLVESTRIS)

TO VARIOUS LEVELS OF SOIL MOISTURE

presented by

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Major professor

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RESPONSE OF APPLE (_MALUS SYLVESTRIS_) TO VARIOUS LEVELS OF SOIL MOISTURE

By

Stanley Joseph Gamble

AN ABSTRACT OF A THESIS

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

DOCTOR OF PHILOSOPHY

Department of Horticulture

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ABSTRACT

RESPONSE OF APPLE (<u>MALUS</u> <u>SYLVESTRIS</u>) TO VARIOUS LEVELS OF SOIL MOISTURE

by Stanley Joseph Gamble

Response of 18-year-old apple trees to soil moisture level was studied for five years. Trees included three standard varieties on seedling rootstocks, spaced at 40 feet. The soil was described as Bellefontaine sandy loam, and was found to contain 8.9 percent water at field capacity and 1.0 percent water at the permanent wilting point. The soil had a density of 1.8 in the surface 18 inches and an available water storing capacity of 1.7 inches per foot of soil depth. Climatological conditions showed monthly averages during the growing season of 67° F. temperature, 6.3 inches of pan evaporation, and 3.0 inches of precipitation. Soil moisture treatments consisted of (treatment 70) allowing available soil moisture to fall to 70 percent (0.45 atmospheres tension) before being brought to field capacity: (treatment 40) allowing available soil moisture to be depleted to 40 percent (approximately 1.5 atmospheres tension) before being brought to field capacity: and (control) receiving only rainfall. Soil moisture was measured by an electrical resistance method at the major root zone depth of 18 inches, and was regulated by sprinkler irrigation. Effects of soil moisture level were studied by measuring yield and size of fruit, tree growth, leaf composition, and fruit

quality and composition. Available moisture in the control plots was reduced to near 20 percent for the first two years, to near 30 percent in the third year, and to 50 percent in the fourth year, and approached the permanent wilting percentage in 1962.

Total yield of McIntosh and Red Delicious fruit for the period of the experiment was not significantly increased by either irrigation practice. Total yield of Northern Spy was increased by either irrigation treatment, due to yield increases in the irrigated plots in the 1961 season. Irrigated McIntosh fruit was larger in 1962, but significantly smaller Northern Spy fruit was harvested from the high soil moisture plots in 1961. Fruit size was more closely related to total yield than to irrigation treatment. Terminal shoot growth was unaffected by soil moisture level, but trunk circumference increase was significantly correlated to soil moisture increase. There were no consistent effects of soil moisture level on leaf N, K, P, Ca, Mg, Mn, Fe, Cu, B, Zn, Mo, or Al.

Storage scald and ground color measurements on the fruit indicated no relationship to soil moisture. Brown core was significantly related to high soil moisture levels, but was reduced under CA storage conditions. Development of bitter pit in Northern Spy was not influenced by soil moisture.

In general, very slight response to the various soil moisture treatments was achieved. It is suggested that deep rooting habits of the apple tree, in addition to a relatively high soil moisture level in the control plots plus relatively low evapotranspiration rates, are probably responsible for the general ineffectiveness of the supplemental irrigation. It is further suggested that these results are applicable to other situations if certain data concerning soil characteristics, tree type and planting distance, and climatic conditions are known. Apparently, in comparable orchards on similar soils and under similar climatic conditions, soil moisture may not be a limiting factor in apple tree growth and productivity.

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CONTENTS

INTRODUCTION

Few fruits are produced commercially over as extensive an area as apples. In the United States thirty-five states produce apple commercially and of these Michigan now ranks third. Also, apple production has increased at a greater rate in Michigan than in any other state in recent years (10).

Michigan apple producing areas receive average annual precipitation ranging from 29 to 35 inches. Monthly averages during a growing season of May to October range from 3 to 4 inches (11). Much of this falls in small amounts which may be of limited benefit to apple trees, especially when grown under the prevailing sod system of soil management.

In recent years, sprinkler irrigation systems utilizing light weight portable aluminum pipe have made supplemental irrigation feasible in Michigan apple orchards. Also, either a surface or ground water supply is generally available, so grower interest in supplemental irrigation is increasing. However, little information is available as a basis upon which to recommend suitable irrigation practices to commercial apple growers. Whether or not normal precipitation in Michigan is adequate for optimum apple tree growth, production, and fruit quality is not known. Information is needed as to whether supplemental irrigation in Michigan will produce a response in apple tree growth and production.

The purpose of this investigation was to study the effects of various soil moisture levels on the apple tree, as measured by total yield and size of fruit, growth of tree, mineral composition of leaves, and pre- and post-harvest fruit quality and mineral composition of the fruit. By such measurements, an optimum range of soil moisture for apple trees might be determined.

REVIEW OF LITERATURE

The influence of soil moisture supply on tree growth and yield has been the subject of numerous investigations. Conclusions based on results of certain research are contradictory to generally accepted principles of soil moisture-plant response relationships, and the subject has remained somewhat controversial. Since soil moisture treatments were often based on irrigation intervals rather than upon percentage of available soil moisture, a comparison of results between certain of these experiments is rather difficult.

Much of the early work in the area of soil moisture requirements of deciduous fruit crops was done by Hendrickson and/or Veihmeyer in California. In 1927, Veihmeyer (34) used outdoor tanks to study water use and growth of young French prune trees. This was an historic experiment since it involved recognition of the fact that uniform soil moisture in the available range in an active root zone can be controlled in plant experiments only if the degree of moisture depletion is limited by bringing the entire root zone to field capacity. Data from the soil moisture treatments led to Veihmeyer's summary:

> "Studies of young trees grown in tanks under controlled conditions indicate that the use of water by these trees was not influenced by the amount of water in the soil above the wilting coefficient. Under comparable atmospheric conditions, the rate of moisture extraction by the

> roots of the trees was the same whether the moisture content of the soil above the wilting coefficient was high or low.
>
> Apparently the roots of these trees were able to obtain water as readily when the soil moisture had been reduced almost to the wilting coefficient as when the soil was filled with water to its maximum field capacity."
>
> "The results obtained from the controlled studies made with prune trees in tanks indicated that not only the use of water but the trees themselves were not affected by variations in amounts of soil moisture above the wilting coefficient. While these results apply only to these young prune trees, it appears that many of the current views regarding soil moisture relations of other plants may also be questioned."

Again, work published by the same authors in 1955 (38) indicated that water in the available range was equally available for evaporation, but there was insufficient evidence to indicate that this water was equally available for producing vegetative growth.

Veihmeyer and Hendrickson (35, 36, 37) made extensive tests to determine the most efficient methods for irrigation in California. On the basis of their observations on perennial fruit crops they have reported that moisture is equally available over the range from field capacity to near the permanent wilting percentage. They state (36) that studies with grape vines, peach, prune, apricot, apple and pear trees in field plots plus sunflowers in containers indicate that there is no single percentage of moisture above the permanent wilting point at which plants grow better than at another percentage and which therefore could be considered optimum for plant growth.

Hendrickson and Veihmeyer in 1929, 1934 and 1942 published reports (17, 18, 19, 20) concerning irrigation of fruit trees which contained such statements as:

> "The term readily available moisture is applied to the range between field capacity and the permanent wilting percentage since previous investigations by the authors have shown no difference in the rate of soil moisture extraction in this range."
>
> "Work at this station has indicated that the soil moisture above the permanent wilting percentage is readily available for use by plants."
>
> "Apparently, with the plants and soils studied, no one moisture content (within the available range) could be considered as optimum for plant growth."

Data concerning soil moisture extraction presented by these workers appears to be linear down to a point near the permanent wilting percentage, but this does not indicate that soil moisture is uniformly available for maintenance of plant turgor and growth over this linear extraction range. High moisture treatments usually produced the largest trees and highest yields of the largest fruits, but treatments providing a comparison between various degrees of moisture depletion through the available range were not described.

The irrigation procedures recommended by Veihmeyer and Hendrickson (35, 36, 37) were based on field tests on sandy soils and were well founded, but conclusions regarding relation of the growth rate to soil moisture in the available range were not in harmony with observations of other workers, especially with plants grown in containers. Considerable evidence is available to indicate that water is not equally available to plants over the entire range of available moisture.

Kenworthy (23) grew young apple trees in containers in a greenhouse study of the effect of soil moisture on tree growth. Tensiometers and wilting were used to indicate soil moisture conditions and treatments were spaced so that 20, 40, 60, 80 and 100 percent available soil moisture was used prior to irrigation. Significant growth decreases occurred when soil moisture was allowed to drop as low as 20 percent of available before irrigation.

Experiments reviewed to this point have emphasized the effects of soil moisture level on plant growth. However, since the fruit itself is the marketable product of the deciduous fruit trees, considerable emphasis has been placed by various workers on the measurement of fruit size and total yields as influenced by level of soil moisture.

Furr and Magness (13) reporting on the relation of soil moisture to stomatal activity and fruit growth of apples, stated that their investigations indicated that in apple orchards the trees could function at near a maximum level as long as the moisture content of the entire root zone was "appreciably" above the wilting percentage. They reported that as the permanent wilting percentage was approached, stomatal closing occurred earlier in the day, and growth rate of the fruit was reduced.

Work (39), in a report on the relation of soil moisture to pear tree wilting in Oregon, stated that soil moisture becomes less readily available to pear trees as the moisture in the adobe clay soil declined from field capacity toward the wilting percentage.

Work and Lewis (40), again working with pear trees in Oregon, reported that differential amounts of soil moisture within the available range exerted profound influence upon pear fruit size and consequent yield, and that during periods of relatively uniform weather conditions, moisture was lost from all soil depths at a decreasing rate as the moisture content decreased, beginning when from 50 to 60 percent of the available soil moisture was still present.

Additional data led Aldrich, Lewis and Work (1) later to publish:

> "With the heavy soil and climatic conditions at the Medford Station, whenever a reasonably large number of fruits are set, larger fruits will be produced by maintaining soil moisture high in the available range throughout the season, and particularly late in the season."

Their treatments were:

(1) Irrigated when available soil moisture dropped to 50 percent in top 3 feet of soil.
(2) Irrigated when soil moisture dropped to 10 to 20 percent.
(3) Same as (2) early, then (1) late.
(4) Same as (1) early, then (2) late.

For six years treatment 1 consistently produced larger fruits, and treatment 2 produced the smallest fruits, with size 26 percent smaller than treatment 1, and total yield 33 percent less than treatment 1. Neither treatment 3 or 4 was consistently better than the other.

Their data showed that the diminished rate of fruit growth due to the "dry" treatment was the result of a lowered rate of water accumulation and also a diminished rate of dry matter accumulation. Fruit growth was measured, and reduced rates of growth were observed when the average moisture content in the top 3 feet of soil was reduced below 50 percent available capacity.

The growth rate of apples in Maryland orchards (25) was reduced when the driest part of the root zone approached the permanent wilting percentage.

Claypool (17) found reduced apple fruit growth while the average soil moisture in the principal root zone was above the permanent wilting percentage.

Boynton and Savage (6) compared growth rates of apples at numerous locations in New York State during 1936 (a dry year) and 1937 (a wet year). In all reported cases, the rate of fruit growth was higher in the wet year, even though soil moisture was seldom depleted to the wilting percentage in any plot in either year.

Forshey (12) conducted tests in a New York (Hudson Valley) Golden Delicious apple orchard in 1957, a dry year. Treatment A, maintained above 50 percent available soil moisture, increased yields 75 percent over the check treatment which was below 25 percent available soil moisture for all but two weeks of the summer, although his data does not show how far below 25 percent. Treatments B and C in Forshey's tests, which were irrigated when the available soil moisture dropped to 37. 5 and 25 percent, respectively, did not yield significantly less fruit than did Treatment A, but all yielded significantly more fruit than the check plots. Also, the percentage of fruit larger than 3 inches in diameter from treatments A, B and C was significantly greater than from the check plot, but no one of these three treatments differed from another in effect on fruit size.

Apparently conflicting results are reported by Harley and Masure (16) working with apple trees in Washington. They stated:

> "With a given leaf area, Delicious apples continued to increase in volume in the 'dry' plots at about an equal rate with those on trees growing in soil maintained at approximately field capacity. After the wilting percentage was reached, however, the fruit growth rate decreased rapidly until water was applied."

These workers claimed that this was further evidence to the effect that varying the percentage of water in most soils is of minor importance in plant growth as long as the root zone is above the permanent wilting percentage.

Studies relating soil moisture to mineral composition of the plant have not been as widely reported as have been the effects on plant growth and fruit yield.

Nour (28), working with seedling plants of peach, apple, mustard, and strawberry, studied the effect of minimum moisture levels of 70, 40, and 10 percent of field capacity. The growth of all test plants was proportional to soil moisture, and phosphorus and potassium increased in leaf tissue with increasing moisture.

Benedict (2) reported that irrigation applications did not significantly affect the nitrogen composition of Jonathan apple leaves in comparison with no irrigation.

Mason (26) placed East Malling VII apple rootstocks in pots with half of them watered daily (wet treatment) and half allowed to dry to the incipient wilting point (dry treatment). The "wet" treatment reduced the concentration of nitrogen in the whole plant, increased phosphorus, potassium, and magnesium, and had no effect on calcium. In general, the effects of the treatments on mineral concentrations in the various parts were the same as on the whole plant.

Hibbard and Nour (21) found that regardless of the level of potassium supply, concentration of potassium in the leaves was reduced with a moisture stress. Moisture stress reduced leaf phosphorus, which was more affected by soil moisture stress than by the available phosphorus supply in the soil.

This relationship was not reported by Corgan (8) who found no effect of drought at any period of the year on the percent of phosphorus in the leaves of apple seedlings. He reported that the primary effect of moisture stress was a very large reduction in uptake of the cations calcium, potassium, and sodium.

Therefore, these reports concerning leaf composition could be summarized by stating that one worker found nitrogen content not affected by soil moisture stress and one report indicated a reduction in nitrogen on a whole plant basis. Phosphorus was reported by three workers to decrease with decreasing soil moisture, and to be unaffected by one. Four reports were in agreement by stating that potassium decreases with moisture stress. One report showed calcium decreasing with decreasing soil moisture, and one indicated no effect. Magnesium and sodium were reported to be reduced by moisture stress.

Some relatively early work concerning the effect of soil moisture on fruit quality was reported by Overly et al. in 1932 (29). In Washington, irrigation studies on Jonathan apples showed that the lightly irrigated plots produced the highest quality apples. Medium and heavily irrigated plots produced fruit with less red over color and a lower percentage of extra fancy grade. This fruit was of larger size, but was more readily bruised by handling and decayed more rapidly when stored at room temperature.

Ryall and Aldrich (31) found that Bartlett pears produced by trees on a continuously high level of soil moisture were lower in percent dry matter, less firm according to pressure tests, and higher in frequency of core breakdown than were fruits from trees at a lower level of soil moisture supply. These workers claimed that a moderate moisture stress during the latter part of the season was conducive to production of higher quality fruit.

Haller and Harding (15) stated that differences in soil moisture had no effect on the susceptibility of apples to decay, but irrigated apples were softer and showed greater breakdown after removal from storage than did non-irrigated fruit. However, they stated that the benefits from the greater yields and higher quality of the apples grown under ample soil moisture far outweighed the detriment of shorter storage life.

Mochizuki and Hanada (27) studied the effect of soil moisture on the growth and quality of apple fruits. They reported that the keeping quality of Jonathan apples grown in a relatively dry soil was greater than that of apples grown in a wet soil, since the cell size was decreased and the cell wall development increased. They stated that the nitrogen supply to the fruit was lower in the dry soil, and this reduced the rate of post-climacteric respiration.

EXPERIMENTAL PROCEDURE

For the purpose of studying soil moisture effects on the apple tree, experimental plots were established in 1957 in an 18-year-old planting of McIntosh, Red Delicious and Northern Spy varieties. All trees had been budded on seedling rootstocks, and were planted at a 40-foot spacing. The soil type was described as a Bellefontaine sandy loam and soil management practices consisted of a ladino clover-June grass sod, seeded in 1946 and mowed at intervals during the summer. Pruning had been done uniformly but lightly. Ammonium nitrate had been applied annually at the rate of five pounds per tree.

During the five years the experiment was conducted, uniform moderate pruning was done, and annual fertilizer applications consisted of ammonium nitrate at 6 pounds per tree on McIntosh and Delicious varieties, and 7 pounds per tree on Northern Spy in 1958, 1959 and 1960. In 1961 and 1962, 3 pounds of ammonium nitrate per tree was applied to all varieties. Trees within the plots varied in trunk circumference from 24 to 40 inches.

Soil moisture measurements were made by using gypsum blocks, as described by Bouyoucos and Mick (4, 5). Gypsum blocks were employed since they have been recommended by Kelley et al. (22) as being preferable for the range of soil moisture over which measurement were desired. Blocks were placed under the outer branches of each tree at a depth of

18 inches, since this depth represented an area of greatest root concentration (14). Insulated wire leads from the blocks were led underground to a stake near the tree trunk to avoid the possibility of damage by orchard machinery. Weekly soil moisture readings were taken, using a battery-powered meter (4) calibrated to read directly in percentage of available moisture. Water was applied by sprinkler irrigation.

The moisture retention characteristics of the soil were studied by removing samples of soil at various depths for measurement of field capacity, permanent wilting point, and soil density. Moisture release data were obtained by taking weekly readings on tensiometers placed adjacent to the gypsum blocks at nine locations. With these data, soil water tension at various levels of available soil moisture was calculated.

Soil moisture treatments, established in 1958, consisted of three moisture levels:

Treatment 70 - available soil moisture allowed to drop to 70 percent before being brought to field capacity.

Treatment 40 - available soil moisture allowed to drop to 40 percent before being brought to field capacity.

Control - received only normal precipitation. Available soil moisture level fluctuated as shown in Figures 1 through 5.

Each treatment was replicated three times, and each of the three varieties was represented by two trees in each replicate, involving a total of 54 trees. Border rows were left between rows of trees involved in the various moisture treatments.

Beginning in 1958, the following data were collected, on a per tree basis:

Total yield of fruit, recorded in number of bushels per tree. This figure usually included fruit from two separate pickings plus dropped fruit recovered from the ground.

Average size of fruit, recorded as average number of fruits per standard size bushel. Twenty-five percent of the total number of bushel crates harvested per tree were selected at random and the number of fruits per bushel was counted in each.

Since no difference in fruit size due to irrigation had been found through 1961, in 1962 12 fruits per treatment of each variety were selected and marked soon after petal-fall and their diameters were measured at weekly intervals until harvest, providing a record of fruit development throughout the season.

Tree growth was determined by making terminal growth measurements annually. Ten terminal shoots per tree were measured and marked in the autumn of 1958, and measurements were henceforth made annually on the same branches. Trunk circumference measurements were made after the second year and again after the fifth year, providing a measurement of trunk circumference increase over a three year period.

The nutritional status of the tree was measured by collecting leaf samples in mid-July of each year and making determinations of 12 elements on a dry weight basis. Nitrogen was determined by a modified Kjeldahl method, potassium was determined by flame spectrophotometer, and phosphorus, calcium, magnesium, manganese, iron, copper, boron, zinc, molybdenum, and aluminum were determined by photoelectric spectrometer.

Fruit quality was judged by placing samples of fruit from each tree in 32° F. refrigerated storage after the 1960 harvest. To determine if there was an interaction effect on fruit quality between soil moisture treatment and type of refrigerated storage, samples of McIntosh from each plot were placed in two types of controlled atmosphere (CA) environments in addition to the regular 32° F. storage. Regular CA storage conditions were a 32° F. temperature, 2 1/2 percent CO_2 during the first month, then 5 percent CO_2, with oxygen held at 3 percent. A second CA storage treatment consisted of a 38° F. temperature, with the same CO_2 and O_2 levels as listed for regular CA.

Again in 1962, since relatively large soil moisture differences were obtained between treatments, fruit from the McIntosh plots were placed in regular 32° F. storage. Prior to storage, samples from each storage lot were tested for flesh firmness with a Magness-Taylor pressure tester and for soluble solids with a Zeiss refractometer.

After removal from storage, the fruit was again tested for flesh firmness, soluble solids, and ground color (9), and observations were made on the following disorders, as described by Smock and Neubert (32): storage scald, brown core, internal breakdown, internal browning, CO_2 injury, and bitter pit.

Mineral composition of the fruit as influenced by soil moisture level was determined by analysis of fruit samples from the 1960 harvest. Wedge-shaped slices of fruit were collected for determinations of elements as previously described for leaf samples.

RESULTS

Analysis of variance was performed on all data presented. In the case of total fruit yields, a covariance adjustment was used as a significant relationship was evidenced between yield and tree size as indexed by trunk circumference.

Significance is indicated by ** at the 1% level, * at the 5% level, and *(10) at the 10% level.

Soil Characteristics

The Bellefontaine sandy loam had a soil layer of matted grass and leaf mold two inches thick over a brown loamy sand containing organic matter and averaging 10 inches in depth. The subsoil consisted of a slightly sticky mixture of reddish-brown clay, sand, and small gravel. This layer in turn, rested on a heterogenous mass of sand, gravel, boulders, and clay, containing a large amount of limestone gravel.

Undisturbed cores of soil at 6 inch (topsoil) and 18 inch (subsoil) depths were removed for determination of water-holding capacity. It was found impossible to remove soil cores at greater depths due to the coarse, gravelly subsoil. Cores from three separate locations in each of the three replicates were removed at both a 6-inch depth (actually from 4 to 8 inches) and at an 18-inch depth (from 16 to 20 inches). Thus, a total of 18 cores were removed and brought into the laboratory. Field capacity was determined by saturating the samples with distilled water, covering to eliminate evaporation, and allowing them to drain for 12 hours. Percent moisture on an oven dry basis was then determined. Bulk density (grams/cc of the undisturbed cores) was calculated by dividing the oven-dry weight by the total volume of the sample. Sunflowers were used to determine the permanent wilting percentage, as described by Veihmeyer and Hendrickson (36). The formula described by Richards and Wadleigh (30) and others for determination of the capacity of a soil for storing available water was employed:

$$R_{am} = \frac{FC - WP}{100} \times \frac{pb}{pw}$$

R_{am}: maximum available water ratio.

FC-WP: difference in percent water at field capacity and wilting point.

pb: bulk density of the soil, or mass per unit volume.

pw: bulk density of water.

A summary of the data obtained follows:

	% Water at F. C.	% Water at P. W. P.	Soil Density	R_{am}
6 inch depth				
Rep. 1	8.9	1.0	1.73	.137
Rep. 2	8.9	1.0	1.78	.140
Rep. 3	8.9	1.0	1.75	.138
18-inch depth				
Rep. 1	8.8	1.0	1.83	.143
Rep. 2	8.9	1.0	1.86	.147
Rep. 3	8.9	1.0	1.75	.145

Mean R_{am} values at 6 inches and at 18 inches are .138 and .145 respectively. This corresponds to an available water-holding capacity of slightly less than 1.7 inches per foot at the 6-inch depth, and slightly over 1.7 inches per foot at the 18-inch depth. The samples at the 6-inch depth represented the loamy sand topsoil containing organic matter, while the samples from the 18-inch depth represented the clay-sand-gravel subsoil.

Moisture release characteristics of the soil were determined by placing tensiometers adjacent to nine of the gypsum blocks for two growing seasons. When plotted, data thus obtained showed the following relationships between soil water tension and percentage of available moisture. Values of one atmosphere and above were obtained by extrapolation.

Tension (atmospheres)	Available Moisture (percent)
0.1	92
0.2	82
0.3	77
0.4	71
0.5	67
0.6	62
0.7	59
0.8	56
1.0	50
1.5	40

The irrigation sprinklers, placed at a 30 by 40-foot spacing, delivered 8.8 gallons of water per minute per sprinkler, for an application rate of 0.70 inches per hour. Assuming that the surface three feet of soil held 5.1 inches of available water, when soil moisture dropped to 70 percent of available it was necessary to operate the irrigation system for two hours and twelve minutes. Thus, 1 1/2 inches of water were applied, the amount necessary to bring the surface three feet of soil to field capacity (treatment 70). When soil moisture was depleted to 40 percent of available (treatment 40), a water application time of slightly less than 4 1/2 hours duration was required. Since a slightly higher water-holding capacity of the soil had originally been estimated, the system was run either 2 1/2 hours for treatment 70 plots, or 5 hours for treatment 40 plots, resulting in wetting the soil to a depth of 3 1/2 feet whenever irrigation water was applied.

Seasonal Changes in Available Soil Moisture

Since precipitation contributed to soil moisture levels in all plots, wide fluctuations in moisture level necessarily occurred within all treatments.

Relatively extensive changes in soil moisture also occurred due to irrigation, since uniform soil moisture within the available range in an active root zone can be controlled only if the degree of moisture depletion is regulated by bringing the root zone to field capacity.

Soil moisture levels obtained for the various treatments during the course of this experiment are represented in Figures 1 through 5. Soil moisture and precipitation measurements were recorded at weekly intervals throughout the growing season. Soil moisture data is presented as the percentage remaining of the available moisture range. Dates and amounts of precipitation are indicated. Dates of irrigations are indicated, with amount of water applied calculated to bring the surface 3 1/2 feet of soil to field capacity.

Available Soil Moisture 1958-1963 (Figures 1-5)

Figure 1 indicates that although rainfall in 1958 was infrequent, timing and quantity were such that only one irrigation in each of treatments 70 and 40 was needed to maintain the desired moisture levels at an 18-inch depth. Irrigation equipment was not in working order until July 1, hence the soil moisture level in treatment 70 was lower than desirable prior to that date. Precipitation of less than 1/4 inch was not recorded. Note that the irrigated plots remained above 50 percent available moisture, and the control plots dropped below 20 percent only for a brief interval.

Figure 2 represents soil moisture levels for 1959 at 18 inches depth. Since no rainfall exceeding 1/4 inch was recorded from June 1 to late July, the available moisture level in the control plots fell rapidly to about 20 percent, where it remained during July. Rainfall of 1 1/2 inches was then apparently sufficient to reach the moisture blocks at the 18-inch depth. Two irrigations were sufficient to hold treatment 70 at a suitable level, and one irrigation was required for treatment 40.

Well distributed rainfall of sufficient quantity in 1960 (Figure 3) caused the control plots to remain above 40 percent available moisture except for brief periods. Two irrigations in each of treatments 70 and 40 held soil moisture at the 18-inch depth at the desired levels.

Figure 4 indicates that in 1961 treatments 70 and 40 required one irrigation each. Above normal rainfall after July 13 caused the control plots to remain above 50 percent available moisture throughout the entire growing season.

Relatively little rainfall in 1962 (Figure 5) allowed soil moisture in the control plots to be depleted to the lowest level of the five years studied. Available moisture in the control plots remained below 10 percent for about two weeks in late July. To maintain the desired moisture levels, four irrigations were necessary in treatment 70, and two were required in treatment 40.

Only in 1962, then, did soil moisture in the control plots drop to a comparatively low level, that is, near the wilting point at the 18-inch depth. In the years 1958 to 1961 available soil moisture remained above 20 percent, except for occasional very brief intervals.

Figure 1

Rainfall and percent of available soil moisture associated with irrigation treatments (1958).

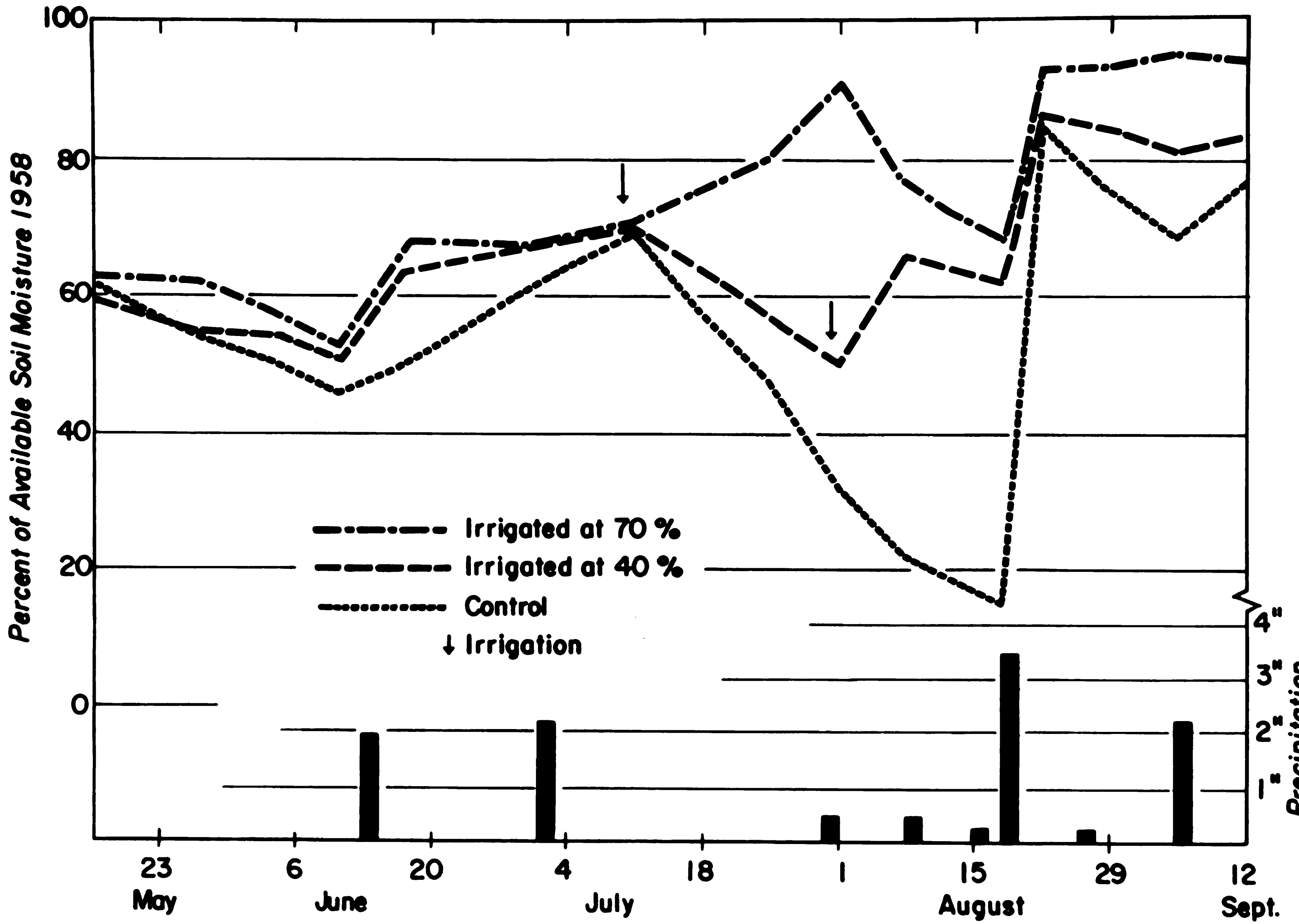

Percent of Available Soil Moisture 1958
100
80
60
40
20
0
Irrigated at 70 %
Irrigated at 40 %
Control
↓ Irrigation
4"
3"
2"
1"
Precipitation
23
May
6
June
20
4
July
18
1
15
August
29
12
Sept.

Figure 2

Rainfall and percent of available soil moisture associated with irrigation treatments (1959).

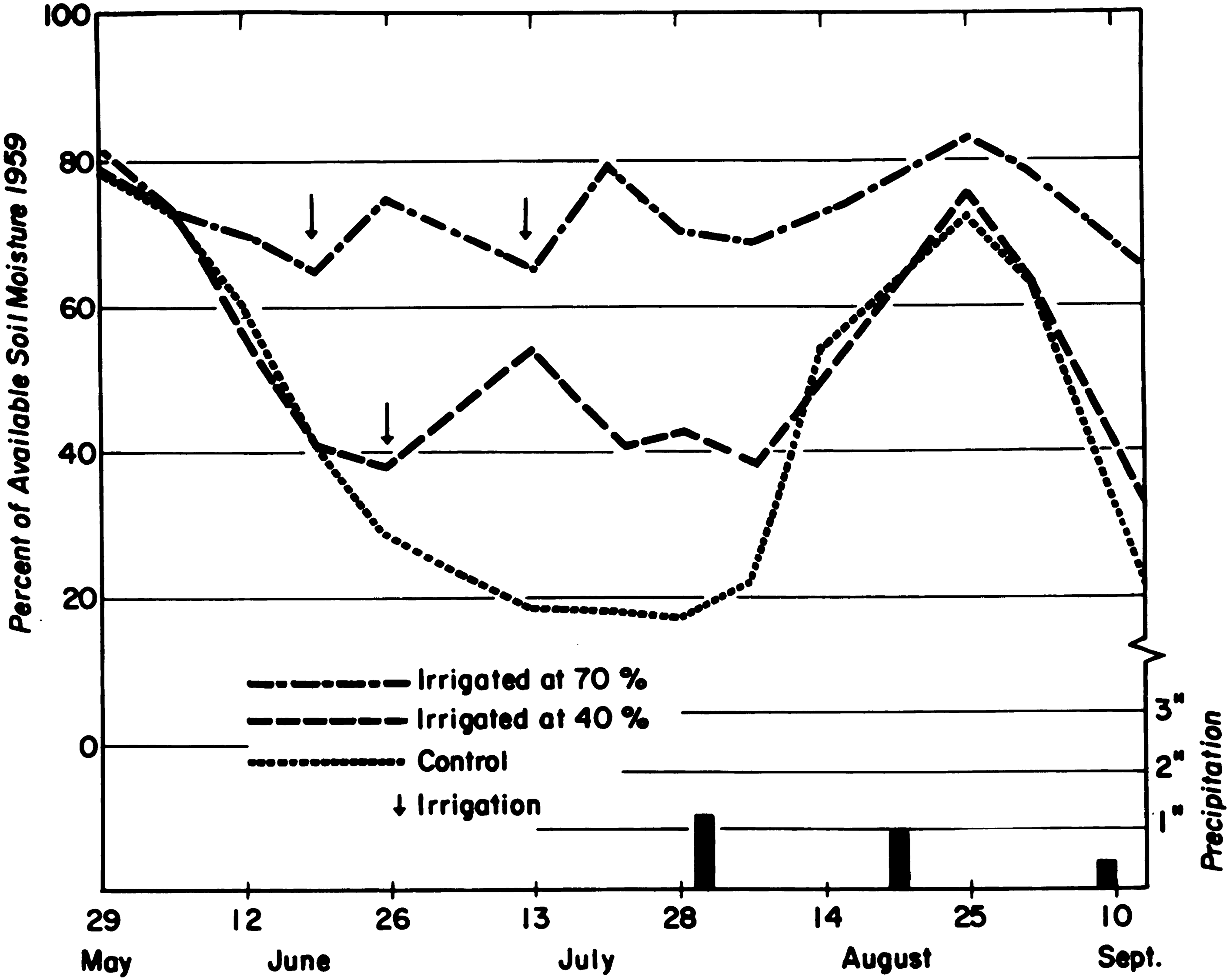
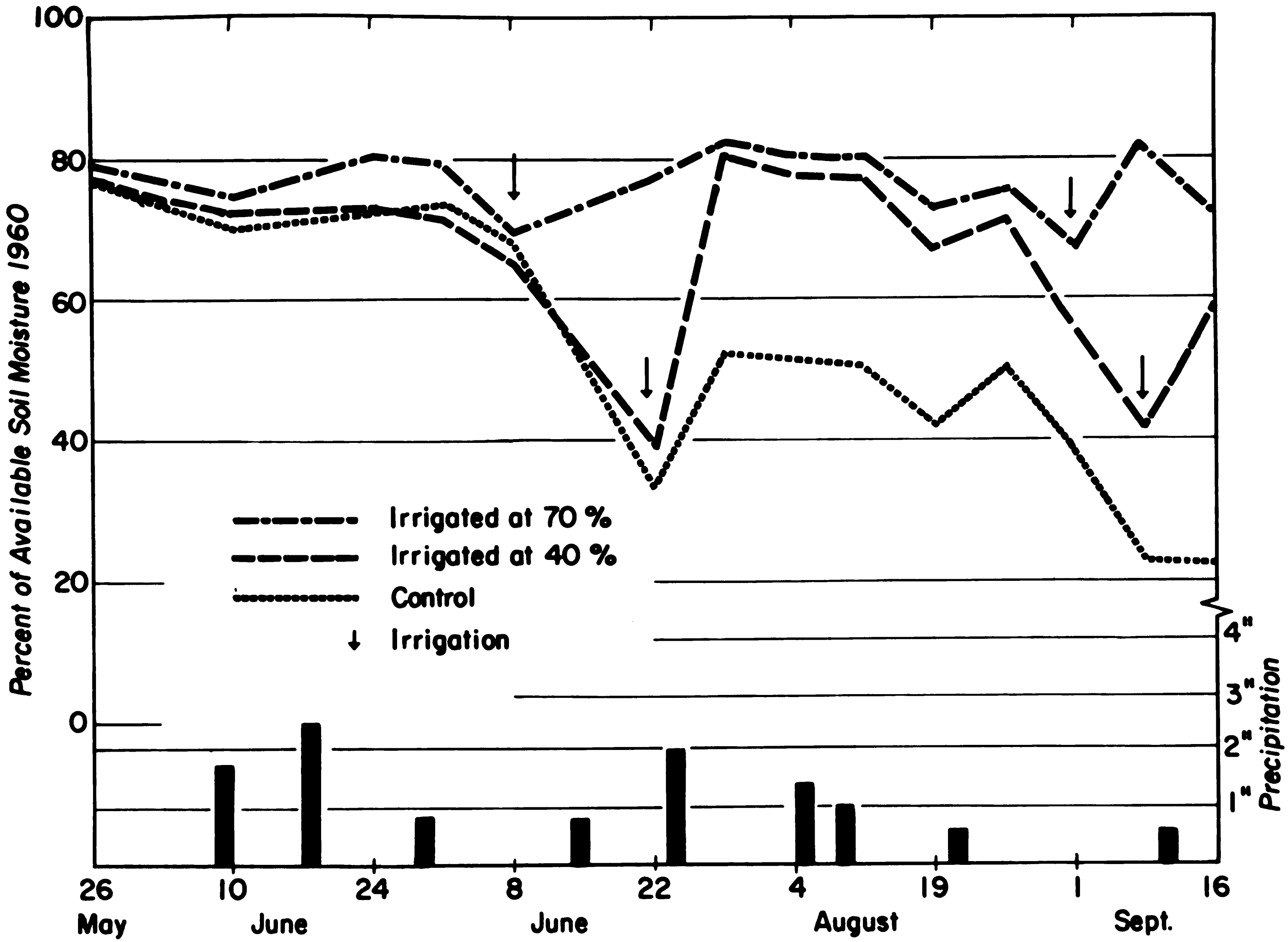

Percent of Available Soil Moisture 1959
100
80
60
40
20
0
Irrigated at 70 %
Irrigated at 40 %
Control
↓ Irrigation
3"
2"
1"
Precipitation
29
May
12
June
26
13
July
28
14
August
25
10
Sept.

Figure 3

Rainfall and percent of available moisture associated with irrigation treatments (1960).



Percent of Available Soil Moisture 1960
100
80
60
40
20
0
Irrigated at 70 %
Irrigated at 40 %
Control
Irrigation
4"
3"
2"
1"
Precipitation
26
May
10
June
24
8
June
22
4
August
19
1
Sept.
16

Figure 4

Rainfall and percent of available soil moisture associated with irrigation treatments (1961).

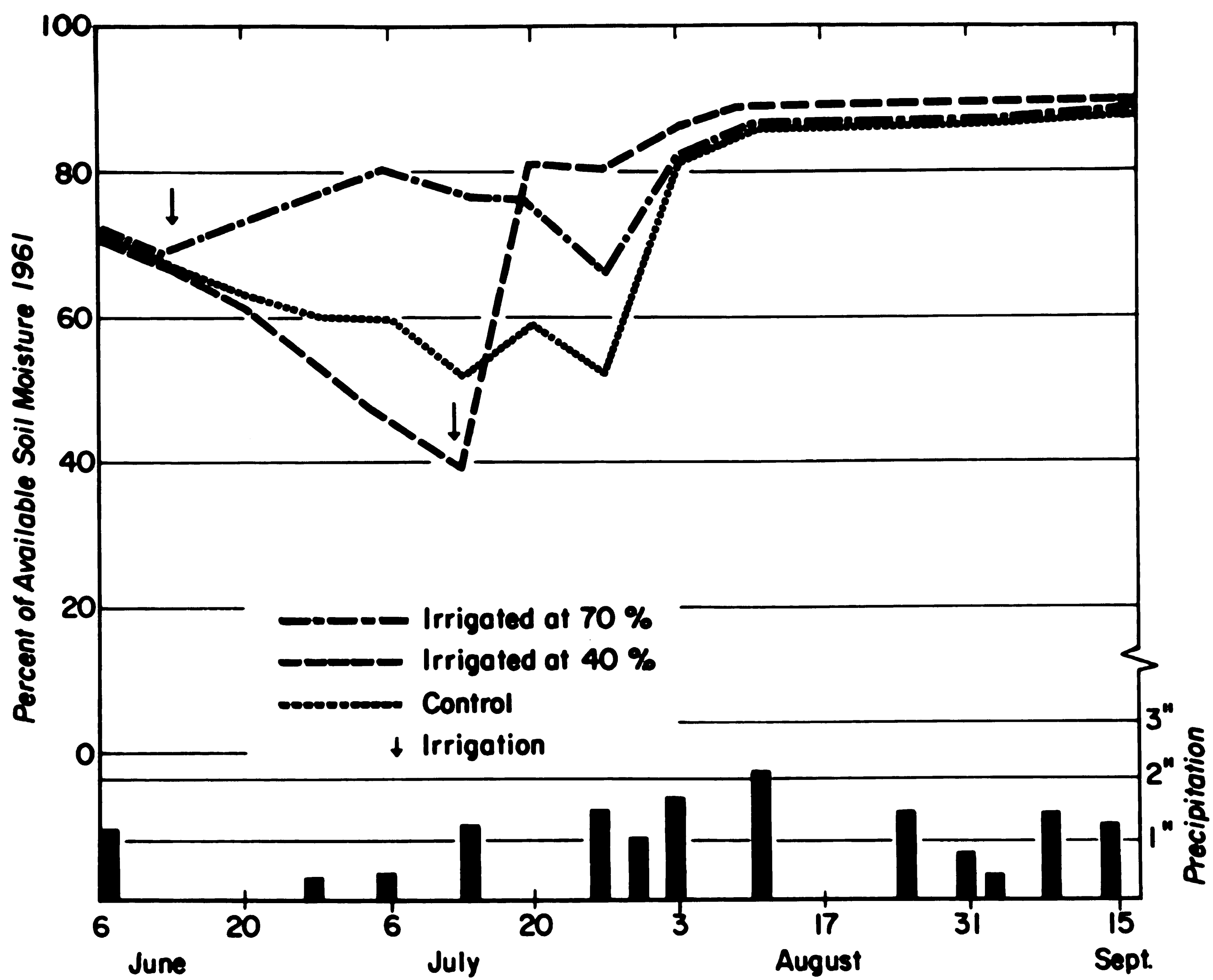
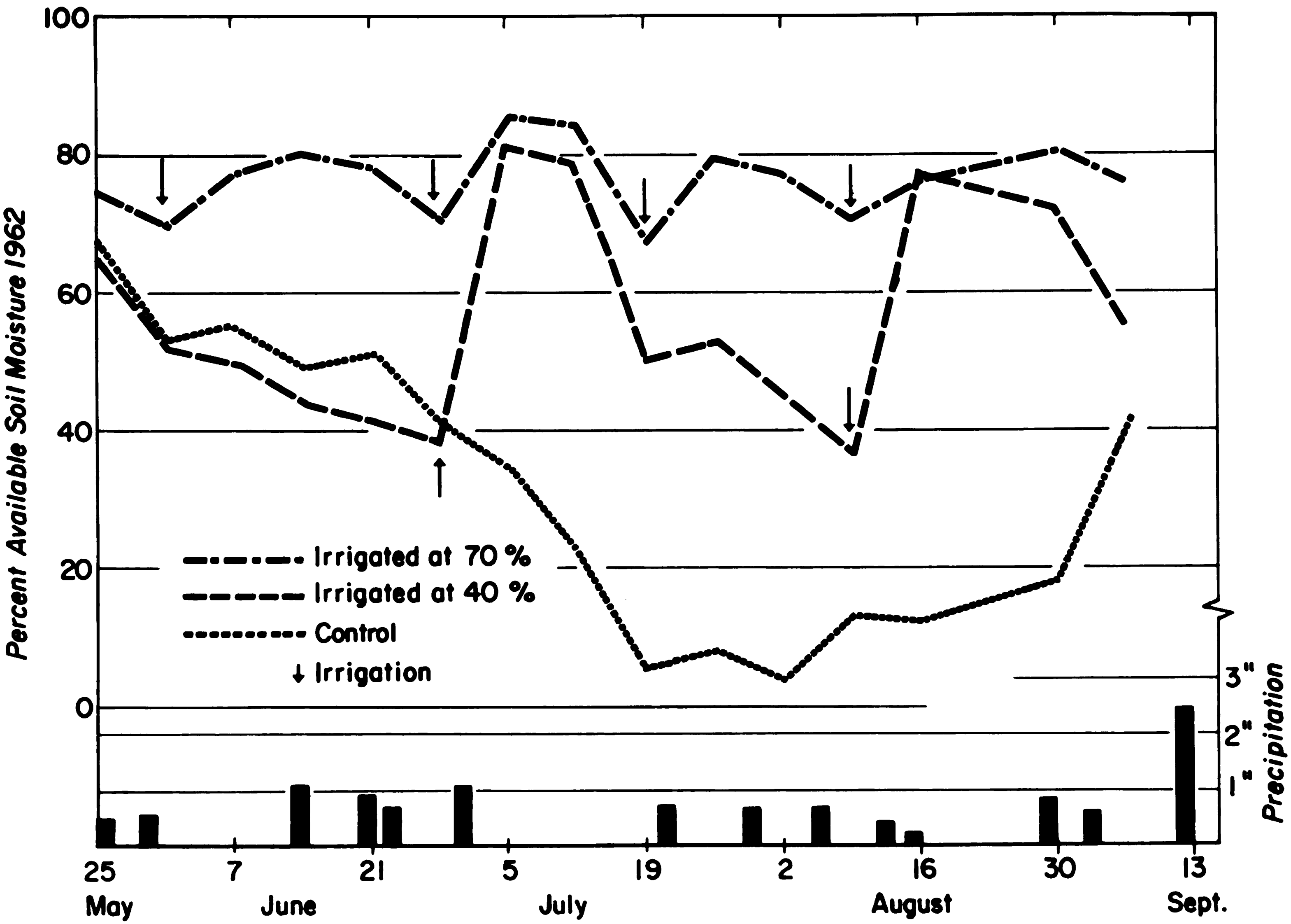

Percent of Available Soil Moisture 1961
100
80
60
40
20
0
Irrigated at 70 %
Irrigated at 40 %
Control
Irrigation
3"
2"
1"
Precipitation
6
20
6
20
3
17
31
15
June
July
August
Sept.

Figure 5

Rainfall and percent of available soil moisture associated with irrigation treatments (1962).



Percent Available Soil Moisture 1962
100
80
60
40
20
0
Irrigated at 70 %
Irrigated at 40 %
Control
↓ Irrigation
3"
2"
1"
Precipitation
25
May
7
June
21
5
July
19
2
16
August
30
13
Sept.

Total Yield of Fruit

Table 1 illustrates the effect of soil moisture level on fruit yields for five years, with yields adjusted for tree size where applicable.

The average yields were not significantly different for the three treatments for McIntosh and Red Delicious. For Northern Spy, however, the differences were significant at odds of 9:1 with the irrigation treatments yielding more fruit than the control treatments.

Significant differences between treatments for each year were never above odds of 9:1. With Northern Spy such a difference occurred in 1961 when either irrigation treatment yielded more fruit than the control treatment. There were no instances of significant differences for McIntosh or Red Delicious yields during any year.

Data presented in Table 1 indicate that available soil moisture levels as low as 20 percent at an 18-inch depth for relatively brief periods did not reduce total yields. Even in 1962, when available moisture in the control plots fell to from 4 to 8 percent for a period of two weeks, yields were not reduced. Possibly such low moisture levels would have exerted a significant effect on yields were the trees not able to extract moisture from depths greater than the 18-inch level. Due to a lower concentration of roots at these greater depths, soil moisture is depleted at a slower rate, and

TABLE 1. --Effect of Level of Soil Moisture on Total Yield of Fruit (Bushels per Tree).

Variety	Year	Actual Yields			Adjusted Yields[1/]			Significance	Difference Required
		70	40	Control	70	40	Control		
McIntosh	1958	19.7	13.7	14.5	17.3	16.0	17.0	ns	
	1959	13.7	13.7	9.8	[2/]				
	1960	22.8	24.7	21.2	[2/]				
	1961	28.0	28.0	26.0	22.0	25.3	26.7	ns	
	1962	28.0	24.0	24.3	26.7	25.3	24.0	ns	
	Av.	21.6	20.0	18.6	20.3	21.0	20.7	ns	
Red Delicious	1958	6.7	5.1	6.4	5.7	5.3	7.3	ns	
	1959	28.2	27.8	22.8	28.3	29.0	27.3	ns	
	1960	10.7	10.0	9.7	10.7	11.0	11.7	ns	
	1961	12.5	10.5	9.5	[2/]				
	1962	21.0	18.0	18.0	20.3	18.3	17.0	ns	
	Av.	15.5	14.3	12.7					
Northern Spy	1958	30.2	27.2	37.0	31.7	33.3	33.0	ns	
	1959	8.8	8.5	6.3	[2/]				
	1960	28.2	25.5	35.8	24.7	31.0	25.3	ns	
	1961	17.0	14.3	12.3	17.3	18.0	6.7	*(10)	5.0
	1962	26.7	31.7	40.3	27.3	35.0	28.3	ns	
	Av.	22.2	21.4	26.3	23.3	25.3	17.3	*(10)	3.7

[1/] Yields adjusted for tree size (trunk circumference) when tree size significantly influenced yield.

[2/] No significant effect of tree size on yield.

therefore an ample moisture supply was undoubtedly available at depths of two and three feet or more.

Fruit Size

Table 2 presents the effect of soil moisture level on the size of the fruit.

Data for Red Delicious in 1959 and 1961 and Northern Spy in 1959 is missing due to fruit being removed from the orchard before a size measurement could be obtained. In 1962, Northern Spy was harvested in pallet boxes, which precluded obtaining a random sample of fruit for a size count. No fruit size record was obtained in 1958 on any variety.

Significant differences in fruit size for the three treatments occurred with McIntosh only in 1962. Both irrigation treatments produced larger fruit than the control. This situation was not evident in the three prior years. Probably the greater differences in soil moisture between the three treatments in 1962 than in other years contributed to these results.

Northern Spy showed significant differences at odds of 9:1 in 1961 with treatment 70 producing smaller fruit than treatment 40 or the control.

No differences in fruit size were shown for Red Delicious in either year that size records were obtained.

Figures 6, 7 and 8 are graphical presentations of fruit size measurements made by vernier caliper at weekly intervals from anthesis to commercial harvest date. Fruit diameter increase is depicted for McIntosh (Figure 6), Red Delicious (Figure 7), and Northern Spy (Figure 8) subjected to three different soil moisture levels during 1962. Each point at a weekly interval represents a mean of 12 fruits (4 each on 3 trees) within a soil moisture treatment and a variety. These figures represent data of 1962, when rather wide differences in soil moisture between the various treatments occurred. Although occasional relatively sharp increases in fruit size due to irrigation or precipitation may be observed, in general, growth of the fruit was a gradual, linear type.

Figure 6 indicates that at harvest, treatment 40 showed an 0. 3 cm. diameter increase over the control McIntosh, which averaged 6. 0 cm., or slightly under a commercially acceptable 2 1/2 inches diameter. Treatment 70 produced fruit measuring 0. 6 cm. greater in diameter than the control fruit. The relationship of fluctuations in fruit growth rate in treatment 40 and the control due to irrigation and rainfall may be noted.

Figure 7, showing Red Delicious fruit development in 1962, indicates that both irrigation treatments produced fruit measuring 0. 5 cm. larger in diameter than the control fruit. Although slight, some influence of rainfall and/or irrigation on fruit development may be seen.

Figure 8 presents fruit development data for Northern Spy in 1962. Treatment 40 produced fruit averaging 0. 5 cm. larger in diameter than the control fruit, and treatment 70 produced fruit averaging 1. 8 cm. larger than the control. Increased growth of treatment 70 fruit became apparent shortly after the first irrigation. The same relationship is seen for treatment 40. Much of the difference in size between fruit of treatment 70 and the other plots appeared relatively early in the growing season, prior to August 1. Various fluctuations in rate of fruit growth due to irrigation and precipitation may be noted.

Magness, Degman and Furr (25) found apple fruit growth to be linear from six to eight weeks following bloom to near harvest. Fruit growth data presented in Figures 6, 7 and 8 agree, in general, with this statement, although the growth curve could better be described as curvilinear, increasing in diameter more rapidly early in the season than later. Possibly measurement of fruit volume would show a different type of curve.

It may be noted that the greatest rate of fruit diameter increase occurred in all varieties prior to July 1. Fruit size data presented in these figures agree with fruit size (at harvest) data of Table 2, except for Northern Spy.

TABLE 2.--Effect of Level of Soil Moisture on Fruit Size (Number Fruits per Bushel).

Variety	Year	Treatment			Significance	Difference Required
		70	40	Control		
McIntosh	1959	131	139	144	ns	
	1960	178	176	191	ns	
	1961	159	161	161	ns	
	1962	208	199	228	**	17
Red	1960	124	127	132	ns	
Delicious	1962	169	177	187	ns	
Northern	1960	127	121	141	ns	
Spy	1961	125	107	106	*(10)	15

Figure 6

Fruit growth of McIntosh associated with rainfall and irrigation treatments (1962).

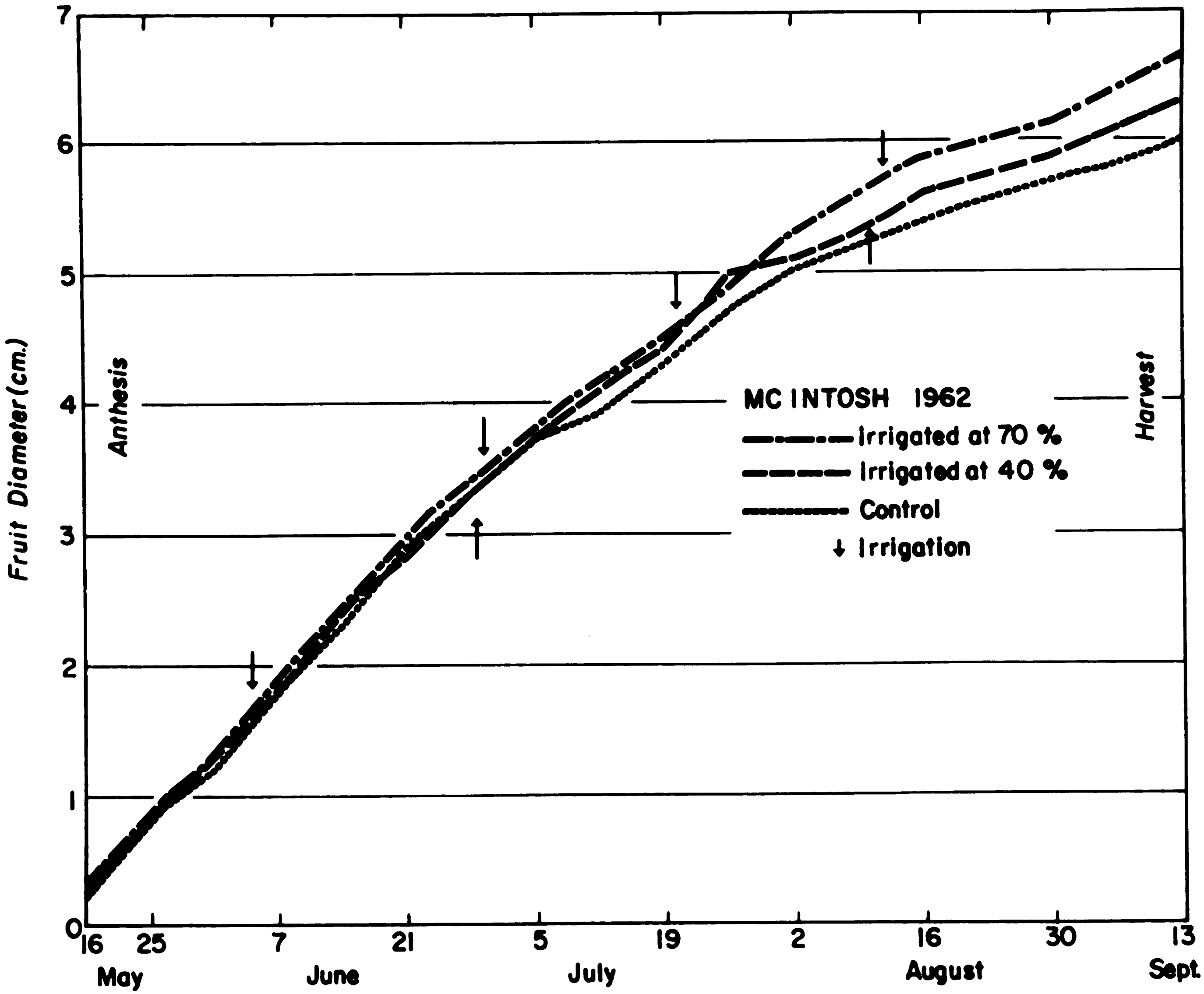

MC INTOSH 1962
Irrigated at 70 %
Irrigated at 40 %
Control
Irrigation
Anthesis
Harvest
Fruit Diameter (cm.)
0
1
2
3
4
5
6
7
16
25
May
7
21
June
5
19
July
2
16
30
August
13
Sept.

Figure 7

Fruit growth of Red Delicious associated with rainfall and irrigation treatments (1962).

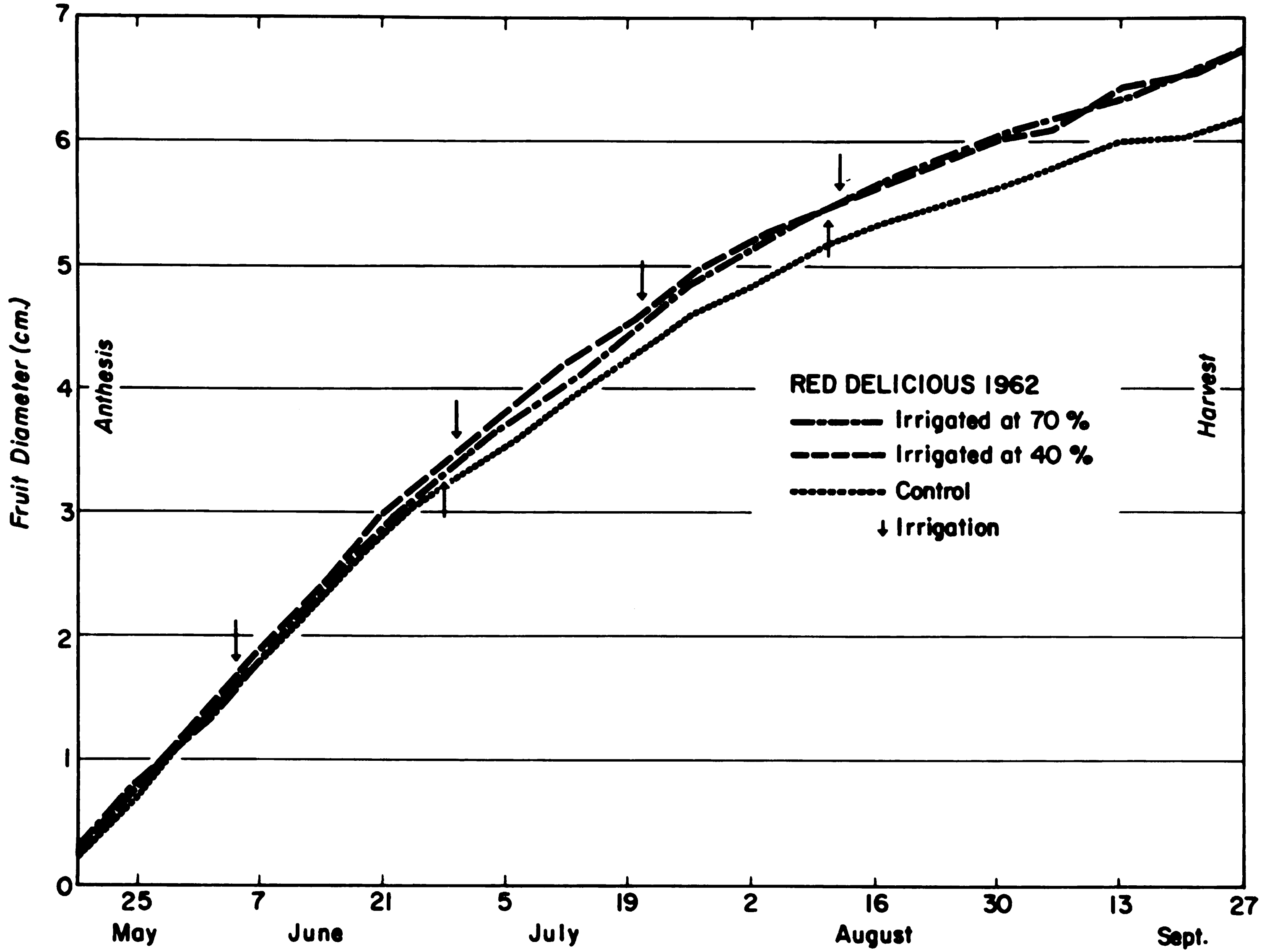
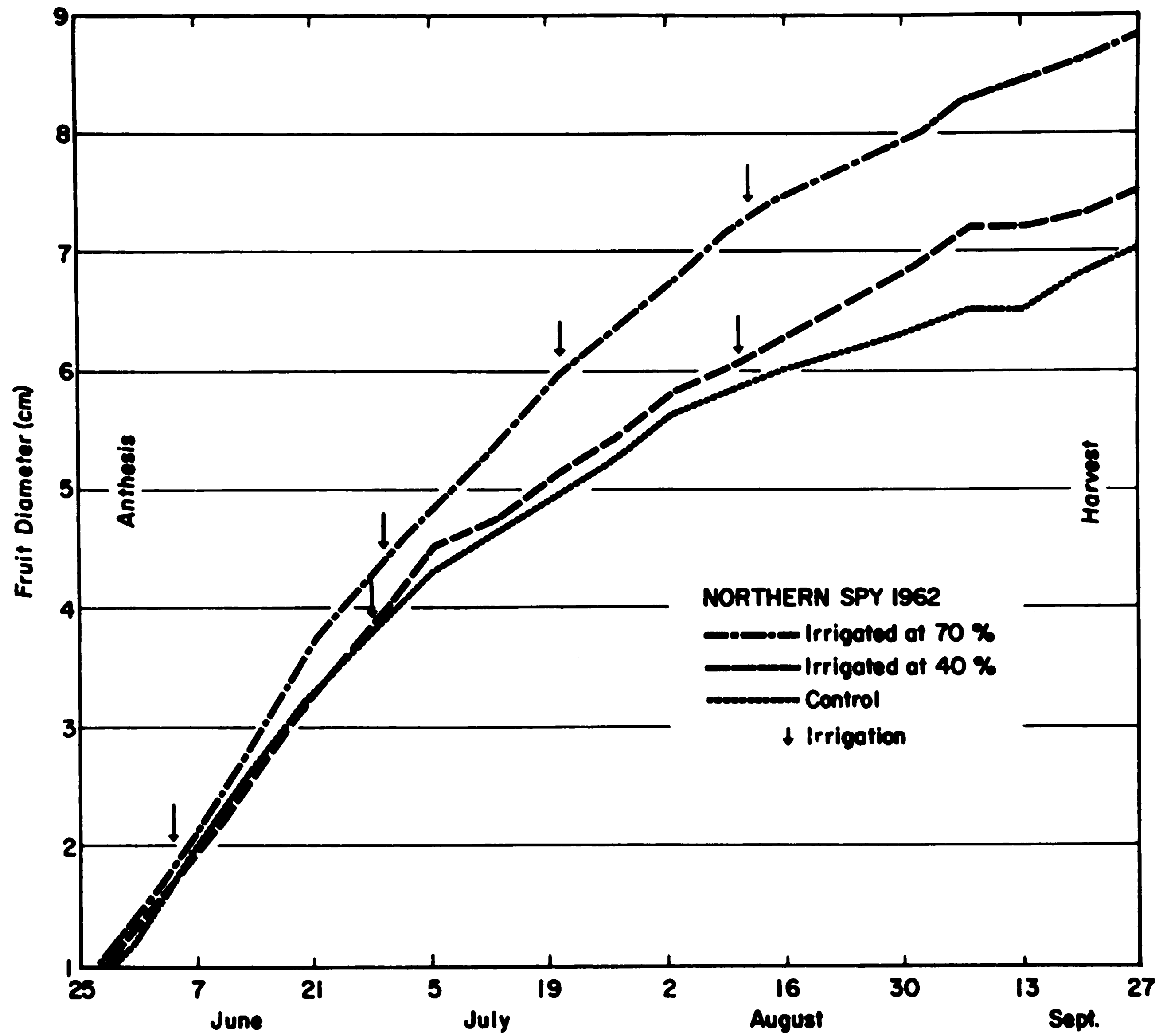

RED DELICIOUS 1962
Irrigated at 70 %
Irrigated at 40 %
Control
↓ Irrigation
Fruit Diameter (cm.)
Anthesis
Harvest
0
1
2
3
4
5
6
7
25
7
21
5
19
2
16
30
13
27
May
June
July
August
Sept.

Figure 8

Fruit growth of Northern Spy associated with rainfall and irrigation treatments (1962).



Fruit Diameter (cm)
9
8
7
6
5
4
3
2
1
25
7
21
5
19
2
16
30
13
27
June
July
August
Sept.
Anthesis
Harvest
NORTHERN SPY 1962
Irrigated at 70 %
Irrigated at 40 %
Control
Irrigation

Tree Growth

Terminal shoot growth (Table 3) was unaffected in all but one case by soil moisture level. With Northern Spy in 1959, treatment 70 showed significantly less growth than treatment 40 or the control, at odds of 9:1. This generally insignificant effect of soil moisture treatment upon terminal shoot growth may be explained by citing the growth habits of the apple tree. Generally, terminal shoot growth commences at time of bloom and progresses rapidly for about three to four weeks, when a terminal bud becomes visible. During the five years this experiment was conducted, shoot growth began in late May and terminal buds were usually visible by July 1, the trees averaging about 25 days of rapid shoot growth. During the month of June when this rapid flush of growth was occurring, available soil moisture never fell below 40 percent, except in 1959. Thus, soil moisture stress was apparently not great enough early in the season to exert a significant effect on shoot growth.

Trunk circumference increase (Table 4) for Red Delicious was not affected significantly by soil moisture level. With McIntosh, both irrigation treatments caused significant increases in trunk circumference, at odds of 9:1, over the control. With Northern Spy, treatment 40 showed greater trunk increase at odds of 19:1, than the control or treatment 70. Treatment 70 did not show a significant growth increase over the control. Apparently trunk circumference increase indicated greater response to soil

TABLE 3.--Effect of Level of Soil Moisture Level on Terminal Shoot Growth (Cm.).

Variety	Year	Treatment 70	40	Control	Significance	Difference Required
McIntosh	1958	36.7	36.0	36.3	ns	
	1959	29.0	32.7	26.3	ns	
	1960	21.3	18.7	18.7	ns	
	1961	19.7	18.7	17.7	ns	
	1962	9.7	10.0	9.7	ns	
	Total	115.3	114.7	108.0	ns	
Red Delicious	1958	29.0	28.7	28.0	ns	
	1959	26.3	27.3	25.7	ns	
	1960	27.0	29.0	25.0	ns	
	1961	31.0	29.0	28.7	ns	
	1962	23.0	22.7	18.7	ns	
	Total	135.3	135.7	125.3	ns	
Northern Spy	1958	28.7	29.3	28.0	ns	
	1959	21.0	23.7	24.0	* (10)	2.3
	1960	23.0	23.7	23.3	ns	
	1961	14.3	17.0	15.3	ns	
	1962	10.3	13.3	12.3	ns	
	Total	97.3	107.0	101.7	ns	

TABLE 4.--Effect of Level of Soil Moisture on Trunk Circumference Increase (Percent Increase 1959-1962).

Variety	Treatment 70	40	Control	Significance	Difference Required
McIntosh	12.8	12.3	11.0	*(10)	1.2
Red Delicious	10.2	9.5	8.7	ns	
Northern Spy	11.7	14.0	9.7	*	2.3

moisture level than terminal shoot growth. The significant increases in trunk growth due to soil moisture level presented in Table 4 are indicative of proliferation of conductive and associated tissues of the vascular cambium. Such tissues apparently were more responsive than shoot tissue to differences in soil moisture level, or else growth processes occurred for a greater portion of the growing season.

Leaf Mineral Composition

Leaf samples were collected in mid-July of each year from each tree. Table 5 represents means of the three varieties. No significant differences in amounts of potassium, calcium, magnesium, copper, or zinc were found in any year. Leaf nitrogen in 1959 showed higher levels, at odds of 9:1 in treatment 70 and the control, than in treatment 40. No differences in nitrogen due to soil moisture treatment were noted for the years 1958, 1960, 1961 or 1962.

Leaf phosphorus in 1962 was higher in both irrigation treatments than in the control, at odds of 19:1. No differences in phosphorus were found for 1958, 1959, 1960 or 1961.

Leaf manganese showed more response to soil moisture level than other elements. In 1958, treatments 70 and the control showed lower leaf manganese, at odds of 99:1 than treatment 40. In 1959 trees of treatment 70 had lower manganese than treatment 40 or the control, at 9:1 odds.

TABLE 5.--Effect of Level of Soil Moisture on Leaf Mineral Composition.

Element	Year	Treatment 70	40	Control	Significance	Difference Required
% N[1/]	1959	2.47	2.38	2.48	*(10)	0.08
% P	1962	.191	.194	.173	*	0.015
Ppm Mn	1958	89	112	83	**	20
	1959	172	198	192	*(10)	20
	1961	162	179	195	*	21
	1962	190	211	207	*(10)	21
Ppm Fe	1958	177	215	199	*	27
Ppm B	1958	37.7	29.8	26.2	*(10)	2.7
Ppm Mo	1958	3.8	4.1	3.8	*	0.3
	1962	4.7	3.9	4.0	**	0.5
Ppm Al	1958	187	239	225	*	33
	1960	361	413	408	*(10)	44

1/ Only elements and years in which significant differences occurred are listed. No differences were found in any year for K, Ca, Mg, Cu or Zn.

Treatment 40 did not differ from the control. In 1961, treatment 70, but not treatment 40, was lower in leaf manganese than the control at 19:1 odds. Treatment 70 in 1962 showed lower leaf manganese than treatment 40, at 19:1 odds, but not lower than the control. No difference existed between treatment 40 and the control.

In 1958, leaf iron was lower in treatment 70 plots than in treatment 40, but not different from the control at 19:1 odds. Iron in treatment 40 and the control did not differ from each other.

Leaf boron in 1958 was lower in treatment 70 than in treatment 40, but not lower than the control, at odds of 9:1. No difference existed between the control and treatments 70 or 40.

Leaf molybdenum displayed inconsistent effects of soil moisture treatment. In 1958, treatment 70 and the control showed higher molybdenum content than treatment 40, at 19:1 odds. Treatment 70 showed no difference from the control. In 1962, treatment 70 showed higher molybdenum levels than treatment 40 or the control, which did not differ from each other, at highly significant odds of 99:1.

Aluminum in 1958 and 1962 showed lower levels in the treatment 70 plots than in treatment 40 or the control, which did not differ from each other. Odds were 19:1 in 1958 and 9:1 in 1960.

In general, leaf mineral composition showed no consistent effects of soil moisture level. Possibly soil moisture differences had not become great enough by the mid-July sampling date to exert definite influences on nutrient element accumulation. This may be illustrated by referring to Figures 1 through 5, where it may be noted that only in 1959 and 1962 were there any moderate differences in soil moisture between treatments prior to July 15. However, more differences in leaf composition occurred in 1958 than in any other year, and there were relatively small differences in soil moisture at the time of sampling. Therefore, it may be concluded that if soil moisture levels exert an influence on mineral accumulation in apple leaves, the moisture stress necessary to produce such effects must be greater than that achieved in these plots by mid-July.

Fruit Quality

Fruit quality as affected by soil moisture level was judged by measurements of soluble solids, flesh firmness, color, and development of certain storage disorders of economic importance to the Michigan apple industry.

Storage scald, a disorder affecting McIntosh, and to a lesser degree, Red Delicious, showed no significant relationship to soil moisture level. McIntosh ground color, an index of maturity, was not affected by soil moisture treatment. Bitter pit, a disorder affecting Northern Spy, and occasionally other varieties, also was not affected by soil moisture level.

Tables 6, 7 and 8 present other data pertaining to fruit quality. Brown core development (Table 6) was apparently related to soil moisture

TABLE 6.--Effect of Level of Soil Moisture on Brown Core Index.[1/]

Variety	Storage Conditions	Year	Treatment 70	40	Control	Significance	Difference Required
McIntosh	32° F. Reg. (a)[2/]	1960	60	34	35	ns	
	(b)		126	109	96	*	18
	32° F. CA (a)		22	22	21	ns	
	(b)		54	48	49	ns	
	38° F. CA (a)		16	21	23	ns	
	(b)		11	6	7	ns	
	32° F. Reg. (a)	1962	72	23	6	ns	
	(b)		92	85	44	**	29
Red Delicious	32° F. Reg. (a)	1960	0	0	0		
	(b)		3.0	1.9	2.5	ns	

[1/] Degree of brown core severity x frequency.

[2/] (a) At removal from storage.

(b) One week after removal.

stress in McIntosh. One week after removal from regular 32° F. storage, fruit from treatment 70 trees showed significantly more brown core than the control trees, at odds of 19:1 in 1960 and at odds of 99:1 in 1962. In 1962, fruit from treatment 40 also showed more brown core than did control fruit at 99:1 odds. In both years, no difference in brown core existed between treatments 70 and 40. Where McIntosh were stored under controlled atmosphere conditions, development of brown core was materially reduced, and significant differences due to soil moisture level did not occur. No differences in brown core development were found in Red Delicious.

Flesh firmness, as measured by a Magness-Taylor pressure tester, is presented in Table 7. No differences in flesh firmness were noted for any variety after storage. However, McIntosh fruit was tested in 1962 prior to storange, and it was noted that fruit from treatment 70 was softer than control fruit. Treatment 40 fruit was not different in firmness from either treatment 70 or the control. These data suggest that differences in flesh firmness due to soil moisture may occur at harvest, although the fruit may soften to a uniform degree during storage.

Data concerning the relationship of soluble solids to soil moisture level are presented in Table 8. Soluble solids in Red Delicious and Northern Spy were not affected by soil moisture, based on post-storage measurements made on 1960 season fruit. McIntosh of 1960 kept in regular 32° F. storage, or in the 38° F. controlled atmosphere conditions,

TABLE 7.--Effect of Level of Soil Moisture on Flesh Firmness.

Variety	Year	Storage Conditions	Treatment 70	40	Control	Significance	Difference Required
McIntosh	1960	32°F. Reg.	9.8	9.7	9.7	ns	
		32°F. CA	10.4	10.2	10.4	ns	
		32°F. CA	10.4	10.6	10.6	ns	
	1962	At harvest[1/]	16.8	17.4	18.4	*	1.1
		32°F. Reg.	22.5	22.5	23.1	ns	
Red Delicious	1960	32°F. Reg.	13.7	13.8	13.7	ns	
Northern Spy	1960	32°F. Reg.	12.1	11.9	11.8	ns	

1/ Differences between pressure tests at harvest and after storage are not significant, due to differences in methods of measurements.

TABLE 8. --Effect of Level of Soil Moisture on Percent Soluble Solids.

Variety	Year	Storage Conditions	Treatment 70	40	Control	Signi-ficance	Difference Required
McIntosh	1960	32°F. Reg.	11.0	11.4	11.3	ns	
		32°F. CA	10.9	11.2	11.6	* (10)	0.6
		38°F. CA	11.0	11.4	11.3	ns	
	1962	At harvest	11.5	11.9	13.0	*	1.0
		32°F. Reg.	11.2	11.4	12.3	*	0.5
Red Delicious	1960	32°F. Reg.	13.2	13.7	14.0	ns	
Northern Spy	1960	32°F. Reg.	12.1	11.7	12.0	ns	

failed to show differences in soluble solids upon removal from storage. However, the 1960 McIntosh, upon removal from 32° F. controlled atmosphere, showed less soluble solids in treatment 70 than in the control. Treatment 40 fruit showed no differences from the control. In 1962, McIntosh from either irrigated plot contained lower soluble solids than the control plot at harvest time and the same relationship held when the fruit was tested after removal from storage on May 1. These inverse relationships, of both flesh firmness and soluble solids, to soil moisture level could be explained on the basis of a larger fruit cell size caused by high soil moisture levels. Such cells would offer less resistance to penetration by the pressure tester, and the soluble cell contents may be diluted by an increased water supply.

Fruit Mineral Composition

The mineral composition of the fruit (Table 9) in general was not influenced by soil moisture treatment. Only magnesium and zinc showed significant effects of soil moisture, both increasing as soil moisture increased. Fruit of treatment 70 contained more magnesium, at odds of 9:1 than the control. Treatment 40 showed no significant difference in magnesium content from the control. Fruit from both treatments 70 and 40 contained more zinc than the control, at 19:1 odds. Although these differences were significant at the levels indicated, such slight differences in mineral content would probably be of no practical significance.

TABLE 9. --Effect of Level of Soil Moisture on Mineral Composition of Fruit (Dry Weight Basis) - 1960.[1/]

Element	Treatment			Significance	Difference Required
	70	40	Control		
% N	0. 27	0. 26	0. 25	ns	
% P	0. 082	0. 080	0. 076	ns	
% K	0. 70	0. 74	0. 76	ns	
% Ca	0. 116	0. 104	0. 116	ns	
% Mg	0. 060	0. 059	0. 058	*(10)	0. 002
Ppm Na	152	156	156	ns	
Ppm Mn	13	13	12	ns	
Ppm Fe	31	40	47	ns	
Ppm Cu	14. 7	12. 1	13. 8	ns	
Ppm B	17. 9	12. 1	13. 8	ns	
Ppm Zn	9	9	6	*	3
Ppm Mo	1. 06	1. 00	1. 00	ns	
Ppm Al	16	13	17	ns	

[1/] All values represent mean of three varieties.

DISCUSSION

The literature review presents what may seem an apparent disagreement among various workers concerning the availability to the plant of water in the so-called "available" range. Veihmeyer and/or Hendrickson (16, 17, 18, 19, 34, 35, 36, 37) published experimental results indicating that soil moisture was equally available to plants throughout the available range. Harley and Masure (15) reported essentially similar conclusions. Conversely, Aldrich, Lewis and Work (1, 38, 39) claimed that on the basis of their work, larger fruits would be produced by maintaining soil moisture high in the available range throughout the growing season, since soil moisture became less readily available as the moisture in the soil declined from field capacity toward the wilting percentage.

Baver (2) states that the amount of water required by a given crop will vary more with the type of soil than any other factor. Data is presented indicating that Chino clay, with its high specific surface, holds water rather tightly. About 1/10 atmosphere suction is necessary to remove any water from this soil. At 15 atmospheres tension, only 15. 7 inches of water from a total of 50 inches of water held per 100 inches of soil have been removed, or about 31 percent. At the other extreme, Hanford sand released 4. 1 inches of a total 11. 9 inches held; most of this was extracted before 0. 5

atmosphere suction had been applied. This data emphasizes that different soils not only hold different amount of water for plant use, but also hold this water with varying degrees of tenacity.

Richards and Wadleigh (30) present curves showing the percentage of available water remaining in various soils at different soil-moisture tensions. Experimental points are shown on the curve at the 1-atmosphere value; at this value it can be seen that the sandy soil retains only about 15 percent of the available water, as compared with 45 percent for the clay soil.

Vegetative growth of some plants decreases significantly as the soil moisture stress increases in the 1-atmosphere range (30), and response of economic significance may occur at tensions of 1.5 atmospheres or greater (33). Therefore, it may be understood why certain workers would claim that soil water was equally available to almost the wilting point, while others showed decreased growth when 40 percent of the soil moisture was yet available. Such was probably the case with Veihmeyer and Hendrickson, and Harley and Masure, working with sandy soils while Aldrich, Lewis and Work conducted their experiments on a clay adobe soil.

There is no doubt that more energy is required to move water from soil to roots in a dry soil than in a moist soil. This may not immediately decrease transpiration or growth because as the diffusion pressure deficit of the soil increases, the osmotic pressure and diffusion pressure deficit of the plant may at first increase proportionately. There is, however, abundant data indicating that as the soil moisture decreases to the lower half of the available moisture range, growth and yield are often decreased before the permanent wilting point is reached.

Where soil is permeated thoroughly and uniformly by roots it is likely that plants can reduce the average moisture content much nearer the permanent wilting percentage without suffering from a water deficit than in heavy soils where root systems are inhibited in development and unevenly distributed. Kramer (24) states that the contradictory opinions concerning the availability of water held by various investigators results at least partly from differences in the soil types used, differences in opinion regarding what constitutes permanent wilting, and differences in interpretation of the data.

Probably the differences in soil moisture between the irrigated plots and the control, as described in Figures 1 through 5, were not generally sufficient to result in highly significant effects on yield or size of fruit, tree growth, leaf composition, or fruit quality and composition. Evidently such tensions as those existing in the driest year (1962), when available soil moisture dropped to about 5 percent, were not sufficient to cause responses in fruit yield (Table 1) although tree growth (Table 4) was affected. Certain other crops respond to soil moisture differences in a similar manner, i.e. soil moisture may affect vegetative growth without affecting yield of the marketable product. As an example, the vegetative growth of guayule was increased by soil moisture increases, while rubber production of guayule was decreased (30). If the marketable portion of the plant, or other portion utilized as the criterion of response, is of a highly vegetative type, favorable response to soil moisture increases in the available range may usually be observed. On the other hand, if the basis of measurement is a non-vegetative product, such as rubber, oil, starch, sugar or other elaborated carbohydrate or protein, or fruit containing large amounts of these substances, response to changes in soil moisture level have often not been detectable. Van Bavel (33) and others have shown that response of economic level to soil moisture tension may occur at tensions of about 1.5 atmospheres. Data presented in Figures 5 through 8 may illustrate such a response. It may be noticed in Figures 6, 7 and 8 that early in July, fruit in the control plots began to lag in size increase, compared to fruit in the irrigated plots. This relationship may be observed for each of the three varieties studied. By referring to soil moisture data for that year presented in Figure 5, it can be observed that in early July, soil moisture dropped below 40 percent of available. According to data on page 20 concerning the relationship of available soil moisture to atmospheres of tension, this point corresponds to slightly above 1.5 atmospheres. Hence, it may be inferred that this apparent retardation in the growth rate of the fruit may be due to soil moisture tensions exceeding 1.5 atmospheres. Only in 1962 did available soil moisture (Figure 5) fall below 40 percent (about 1.5 atmospheres tension) for an appreciable length of time. It may be observed in Table 2 that fruit size showed greater differences due to soil moisture level in 1962 than in other years.

The fact that soil moisture tension greater than 1.5 atmospheres in late June of 1959 did not influence vegetative shoot growth of the tree was probably due to shoot growth being practically completed by the time such tension occurred. In no other year did soil moisture tension exceed 1.5 atmospheres during this rapid period of shoot growth.

It has been pointed out by some researchers that the water needs of apple trees are greater during the period of rapid vegetative growth than at any other time. Although Figure 5 indicates that in 1962 approximately one inch of rainfall per week was not sufficient to maintain existing soil moisture levels during this period, rainfall and soil moisture data of the other years (Figures 1 through 4) does not aid in identifying such a period of higher water requirements. Rainfall in these years was either excessive or insufficient during the period of rapid vegetative growth.

Supplemental irrigation seemed to have less influence on yields of McIntosh and Red Delicious than on Northern Spy yields (Table 1). However, it may be noted in Table 1 that total yield of Northern Spy was influenced by increased yields in the irrigated plots in only one year, 1961.

Examination of the Northern Spy data indicate that possibly the choice of particular trees in establishing the plots had an influence on the yield response. In all cases the trees in the control plots were from three to nine inches greater in trunk circumference than were trees in the other plots. Therefore, the actual yield data of Table 1, presented as the average number of bushels of fruit per tree, does not represent the true effect of the irrigation treatments on fruit yield. However, analysis of covariance provided an adjustment of these average yields based on trunk circumference, since positive correlation existed between yield and trunk circumference. Significance related to differences in yield is based on the results of analysis of covariance and indicates that certain differences in yield due to soil moisture treatments do exist, after yields have been adjusted for tree size. Therefore, although the data showing higher actual yields of fruit in the control plots may be explained on the basis of larger trees in these plots, nevertheless the significance listed is based on adjusted yields and indicates that certain differences in yields may not be accounted for by differences in the size of the Northern Spy trees, and must be due to irrigation treatment.

Data presented in Table 2 concerning fruit size of Northern Spy in 1962 show fruit of treatment 40 and the control plots to be larger than fruit from treatment 70 trees. Figure 8 indicates that fruit from irrigated trees was larger than that from trees not irrigated. Such controversial data might be explained by recalling that the figures presented in Figure 8 represent fruit size on the lower accessible branches of the tree, while Table 2 represents size of fruit from all portions of the tree. Possibly irrigation water striking the lower branches of the tree may have resulted in increased size of the fruit on these lower branches, while fruit on upper branches was above the height reached by water from the sprinklers and was therefore not affected.

Undoubtedly, plant response to any given level of soil moisture is influenced by such factors as planting distance, depth of rooting, extent of root penetration and permeation in this zone, the texture of the soil, and evaporative capacity of the air. In the case of this experiment the trees were situated on a deep soil that was probably fully penetrated by roots giving a relatively large active root area compared to leaf area. Certainly the 40-foot spacing of the trees allowed tree roots an extensive area in which to range for moisture. Also the soil was relatively light, thus allowing rapid water movement. On such a soil a water deficit in the trees probably would not occur until the average soil moisture was depleted to nearly the permanent wilting point. And, since a minor fraction of the root system existed at depths of two, three and four feet or more, the available soil moisture at 18 inches might be reduced to near zero before effects of economic importance were measurable.

A summary of climatological data for the June through September growing season for the five years in which this experiment was conducted follows:

Year	Average Temperature	Average Monthly Pan Evaporation	Total Precipitation (June to Harvest)
1958	66	6.1	11.3
1959	70	6.3	2.4
1960	67	6.2	10.8
1961	67	5.7	14.4
1962	67	7.0	9.9

Temperature and pan evaporation data were taken from official U. S. Weather Bureau records, while precipitation data were collected at weekly intervals at the experiment site.

It may be noted that although the average temperature in 1961 and 1962 were identical, 1961 could be described as a season of relatively high rainfall, and relatively low evaporative conditions. 1962 showed the opposite conditions, that is, less total rainfall (that fell at frequent intervals, but in small amounts), and relatively high pan evaporation. Another relatively "dry" year occurred in 1959. However, yield data of Table 1 show that yields in the non-irrigated plots were not significantly lower in 1959 and 1962, and not higher in 1961. Therefore, in general, not only did supplemental irrigation fail to increase yields in two of three varieties, but climatological differences that affected soil moisture between years also did not influence yields. Weather Bureau data indicate that the years 1958 through 1962 were not abnormal in respect to temperature, evaporation, and precipitation, except for precipitation in 1959. Long term averages for this location show mean temperature for the months of June through September to be 68°F., pan evaporation for this period as 6.5 inches per month, and rainfall as an average of 3.0 inches per month. Therefore, it may be concluded that climatological conditions existing during these five years were fairly typical for the area.

Probably the relatively low evaporative power of the air under central Michigan conditions was a major factor in allowing continued growth of tree and fruit at available soil moisture levels below 20 percent. Climatological data indicate that during the five years in which this experiment was conducted, average temperature during the June through September growing season was 67° F., and pan evaporation during this same period averaged 6.3 inches per month. Under such conditions minor water deficits occuring in the leaves during the day may be compensated for at night.

It is of interest to note that of the irrigation experiments on apples reported by Hendrickson and Veihmeyer (20), no difference in size of the fruit as related to irrigation regime was found in two of the experiments. In the third, the larger fruit was found in the unirrigated plot. The latter experiment was carried out on a sandy loam soil, in an area having heavy winter rainfall, rather cool conditions during the growing season, and early morning fogs. On the unirrigated plot, the moisture content never reached the permanent wilting percentage below two feet of soil.

Leaf mineral composition data (Table 5) indicate that soil moisture levels within the range measured in this experiment exerted little effect upon the nutritional status of the trees. The literature review presents findings of various workers indicating that levels of the nutrients nitrogen, phosphorus, potassium, calcium and magnesium in apple leaves may be influenced by various degrees of soil moisture stress. Data presented in Table 5 do not support such previous findings. It is indicated that fertilizer programs should not be altered when supplemental irrigation is introduced in apple orchards.

On the basis of these findings it may be concluded that supplemental irrigation may not be profitable in orchards similar to the one herein described. The following conditions contributed to these results, and must necessarily be taken into account when determining if responses described herein might apply to other locations: (1) the type of tree studied, including rootstock, variety and planting distance: (2) the nature of the soil involved, including water storing and water release characteristics; and (3) climatological factors. If these conditions were known, it should be possible to predict response of apple trees to supplemental irrigation at locations other than the one studied. If the factors contributing to these results are similar, one may expect similar responses. Evidently in apple orchards located on soils having capacities of water storage and water release equal to, or greater than those in the orchard studied in similar climatic conditions and having trees of similar type, age, and spacing, supplemental irrigation may show only occasional significant effects. Possibly the use of systems of soil management, such as mulching, designed to collect precipitation and conserve soil moisture to the greatest extent possible, may be more profitable practice than investment in supplemental irrigation equipment. Of course, on lighter soils of lower water-holding capacity, and/or where planting distances are decreased as in "hedgerow" systems, the use of supplemental irrigation may prove valid.

SUMMARY

For the purpose of studying the effects of irrigation practices on apple trees under central Michigan conditions, experimental soil moisture plots including three commercially important varieties were established in 1957. Response of 54 18-year-old trees to soil moisture level was studied for five years. Soil moisture was measured by an electrical resistance method at an 18-inch depth, and was regulated by sprinkler irrigation. Treatments consisted of (1) allowing available soil moisture to fall to 70 percent before being brought to field capacity (treatment 70): (2) allowing available soil moisture to be depleted to 40 percent before being brought to field capacity (treatment 40); and (3) control (not irrigated).

Available moisture in the control plots was reduced to near 20 percent for the first two years, to near 30 percent in the third year, to 50 percent in the fourth year, and approached the permanent wilting percentage in 1962.

Effects of soil moisture level were studied by measuring yield and size of fruit, tree growth, leaf composition, and fruit quality and composition.

Total yield of fruit for the period of the experiment was not significantly increased by either irrigation practice. Occasionally, for certain years and certain varieties, differences occurred. Northern Spy seemed to respond more favorably to increased soil moisture than did Red Delicious and McIntosh. Irrigated McIntosh fruit was larger in 1962, but no difference was noted in

the size of fruit of the other varieties. Terminal shoot growth was unaffected by soil moisture level, but trunk circumference increase was significantly correlated to soil moisture increase. In certain years, leaf nitrogen and phosphorus increased as soil moisture increased, while manganese and iron decreased, and boron, molybdenum and aluminum showed variable effects. In other years these particular relationships failed to appear. Magnesium and zinc in the fruit were higher in the irrigated plots.

Storage scald and ground color measurements on the fruit indicated no relationship to soil moisture. Brown core was significantly related to high soil moisture levels, but was reduced under CA storage conditions. Development of bitter pit on Northern Spy was not influenced by soil moisture increase. Both flesh firmness and soluble solids measurements in McIntosh varied inversely with soil moisture, when tested at time of harvest.

In general, very slight response to the various soil moisture treatments was achieved. It is suggested that a relatively high soil moisture level in the control plots plus relatively low evapotranspiration rates may have contributed to these results. Apparently, in comparable orchards on similar soils and under similar climatic conditions, soil moisture may not be a limiting factor in tree growth and productivity.

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