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Studies in Moisture Relationships and Irrigation of Vegetables

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VICTOR N. LAMBETH

INTRODUCTION

The climate of Missouri is regarded as humid. Nevertheless, the distribution of rainfall is generally such that "drouths" of variable intensity occur during the growing season and many crop yields are severely limited by moisture deficiencies. Supplemental irrigation of vegetables under these conditions should be considered an essential cultural practice to "make the crop" in much the same way as the application of fertilizer, cultivation, or pest control. Only in this way can the calculated risks of moisture limitations in production be reduced to a satisfactory level consistent with other cultural practices and the economics involved. This objective has been adequately summarized by Mitchell (37) who states:

> "The general purpose of irrigation is not, as it is in the arid regions, to supply a normal deficiency in the annual rainfall of the locality; it is, rather to insure that sufficient moisture is always available when wanted, in order that maximum profits may be obtained from crops under intense cultivation."

Occasionally as in 1952, 1953, and 1954 drouths of very serious proportions occur in the so-called "humid states" when irrigation is absolutely essential to save the crop.

Studies of precipitation patterns in a localized area which cover an extended period of time have been helpful in estimating the long-range needs for irrigation. But excessive seasonal and localized variations in the distribution of rainfall, together with inadequate weather forecasting precludes any reasonable possibility of basing frequency and amounts for a specific crop on rainfall records alone. Such a guide may be insufficiently applicable in a humid area because the soil moisture reservoir—a function largely of the soil texture and extent of the plant's functional root system—is not usually known. Earlier investigations have demonstrated the fundamental objective in controlled irrigation is the maintenance throughout the season of an adequate moisture supply in the "effective rooting zone" of the plant. Knowledge of the reserves available in the root zone and the rate of depletion by the crop permits a more direct and satisfactory guide as to "when" and "how much" to apply. This approach also provides a better basis for managing the moisture reserves with greatest efficiency when the water supply is inadequate.

The development of practical, rapid methods for field measurement of available soil moisture has intensified investigations in (1) correlating crop response with soil moisture, (2) in determining rates of water utilization, and (3) in tracing relative moisture movement. To date, much of the research has been directed toward finding how wet to keep the soil, with relatively little consideration of the depth of effective rooting and how deep the soil should be wetted. Failure to consider this root-soil relationship may result in wasteful irrigation practices. Heavy irrigation frequently results in oxygen deficiencies for roots on heavy textured soils or excessive losses of water by deep percolation on sandy soils. On the other hand, shallow irrigations when subsoil moisture is low, will not provide an adequate supply of water for best crop development of deep rooted vegetables during advanced stages of development.

These investigations were conducted for the purpose of defining more precisely these relationships in order to arrive at a better basis for irrigation of vegetables in humid areas.

REVIEW OF LITERATURE

The Objectives of Irrigation in Humid Areas

Th annual rainfall in Missouri ranges from 35 to 50 inches per year. In Missouri, however, as in other humid states, the seasonal distribution of rainfall becomes the critical consideration with respect to irrigation needs. Rubey (42) states that one-fourth of the 78 years between 1870 and 1947 were very dry and often close enough together to cause an accumulation of crop losses. According to another survey, the average precipitation for the ten driest summers in 40 years for the entire state was 6 inches (54). This means that for one year out of every four there was 6 inches or less. Since it is known that many long season vegetables require about 18 inches of water per season for maximum development, and an average soil may store 5 or 6 inches of available water, it is obvious that supplemental irrigation of vegetables is required most years in Missouri.

The practical benefits of supplemental irrigation in promoting seed germination, in reducing injuries and losses to seedlings and transplants, in promoting the continuous growth necessary for higher quality products, in permitting double cropping, and in increasing yields are widely recognized. These are practical benefits resulting from the primary objective of supplemental irrigation in humid areas—that of maintaining at all times sufficient available moisture for efficient production.

With the recurrent drouths of long duration the past 4 years and the increased awareness of the need for water, the reasoning stated by Bradley and Pratt of New York (12) "Irrigate to Make a Crop, Not to Save It" is foremost in the grower's mind. With steadily increasing costs of production, the greater investments and the high risk involved with vegetables, this reasoning takes on still greater significance.

Factors Associated with Irrigation Requirements

Irrigation requirements depend upon such factors as climatic conditions, soil texture and depth, the root zones of the plant and the topography of the land. Climatic factors such as temperature, rainfall, relative humidity, and wind affect transpiration by plants and evaporation of water from the soil. Investigations (16 and 56) have shown that evaporation from the soil is confined to the top foot, whereas extraction of moisture from lower depths is largely due to transpiration losses. Since the soil reservoir makes a significant contribution to the total seasonal supply, and is so directly associated with transpirational losses by the plant, it deserves more than casual consideration in irrigation practice.

The amount of water retained by soils at field capacity varies considerably with texture. Since this water can be removed only by evaporation from the surface and by the plant roots, the reserve supply becomes an important consideration in determining the frequency and rates of application of irrigation water. Occasionally the water relationships of the soil, and consequently the rooting characteristics of the plant, are modified by hard-pan layers. Here excessive irrigation may cause a water-logged condition, a restricted root system, and a very limited reserve moisture supply.

There is much experimental evidence to indicate that in cases where no shallow free-water table exists, the capillary movement from moist to drier soil is very limited. In this respect, Bouyoucos (7) states:

> "From the standpoint of the plants, the rate of movement is more important than distance of movement. This is because the water requirements of plants are immediate, large and continuous. While in time, water may rise to considerable distances in the soil, the rate of rise is too slow to benefit the immediate and large demands of the plants for water. The conclusion is, therefore, that capillary movement of the water, especially from the deeper water tables, supplies little, if any, water to the growing plants during the short season of growth. Actually, the water that is the greatest determining factor in plant growth, is that which the soil is able to retain from rainfall and irrigation, or the available capillary water."

The amount of soil moisture available to plants depends upon the amount of water retained at field capacity, the amount of this moisture that the soil will release to the plant roots and the soil volume tapped by the roots.

However, more consideration should be given to methods that determine the available soil moisture supply continuously, at different depths in the root zone. Exposure of plant roots, even for a few hours, to soil that is at the permanent wilting percentage may seriously reduce their absorptive area.

Moisture Requirements of Vegetables and Water Loss

The amount of water required to produce a given crop will vary from area to area depending upon the temperature, light conditions, humidity, and the amount of wind. In this connection MacGillivary (35) states:

> "the water requirements of different plants vary; there are also differences between the water requirements of the same kind of plant growth in different climatic areas. Many plants use from 350 to 600 pounds of water to produce a pound of dry matter. Since these large amounts of water are supplied to the plant by the soil, it is convenient to consider the soil as a reservoir of water, which needs to be replenished periodically by rainfall or irrigation."

When considering the frequency of irrigation and the depth of soil wetting for a crop, it is helpful to know the approximate rate of water use for various stages of plant growth, especially during the critical summer months. For example, the frequency of irrigation will depend upon the rate of water use by the plants and the amount of readily available moisture that can be stored in the soil within the effective root zone of the crop. Similarly, the amount of water that should be applied at each irrigation depends upon the depth of rooting of the crop and the amount of water needed to wet each foot of soil to its field capacity. These values must be modified to take into account the effective precipitation.

Thus, Campbell in Mississippi (14) states that shallow rooted crops require 1.5 inches of water every week to 10 days; moderately deep rooted crops require somewhat more, 1.5 to 2 inches every week or 10 days; and deep rooted crops require 2 inches for the same period.

Loss of water from the soil occurs by evaporation from the land surface and by transpiration of the vegetative cover. This combined process is known as evapotranspiration.

Ashcroft and Taylor (1), after a two-year study of the water needs of alfalfa, barley, sugarbeets and Irish potatoes, reported a real possibility of calculating water needs from weather data. They stated that solar radiation and open tank evaporation appeared to show the greatest promise in determining evapotranspiration rates.

Blaney and Criddle (3) based their formula for evapotranspiration on the monthly temperature and monthly daytime hours. They also made use of a consumptive-use coefficient which was used to adjust for vegetative cover and stage of crop growth.

Thornthwaite (49, 50) based his formula on latitude and average temperature of the air. He calculated that at Raleigh, N. C., the average daily evapotranspiration for July was 0.21 inch.

Penman (40) developed a formula that could be used for plants that completely covered the soil and were well supplied with water. The formula was complicated and needed weather data obtainable only in a few areas.

Sanderson (43), working in Canada, reported that there was a close agreement between measured and computed rates of evapotranspiration. His study showed there was little difference between computations based on long term average temperatures and computations based on actual occurring temperatures.

Van Bavel and Wilson (55) stated that as a result of an irrigation experiment conducted at Raleigh, N. C., the dates of irrigation as determined by mercury tensiometers closely coincided with data computed from long term averages of evapotranspiration for which no correction was made for actual weather conditions.

Land and Carreker (32), working in Georgia, reported the following evapotranspiration rates:

Crop	*Date*	*Average Daily Rate*	*Date*	*Maximum Daily Rates*
Tomatoes	6/3-8/26	.187	7/16-24	.310
Beans	6/3-7/24	.185	7/18-24	.320
Corn	6/10-7/26	.220		.280
Cotton	6/9-8/26	.196	7/14-24	.310

Davis, Evans, and Hazen (21) made a number of observations in North Dakota to determine the water requirements of different crops. By the use of the consumptive use coefficient, these workers found the following water requirements: beans-9.62 inches; peas-10.98 inches; potatoes-19.75 inches and small truck crops 10.55 inches for the growing season. Likewise, Houston (25) in Nevada found the following moisture requirements during the growing season: potatoes 16.65 inches; Beans 13.6 inches; onions 18.4 inches.

Relationship Between Soil Moisture Level and Growth of Vegetables

From the foregoing discussion, it is apparent that the real objective of supplemental irrigation is to maintain at all times a "moist" soil throughout the so-called "effective root zone" of the plant. However, this terminology must be defined in terms of actual soil and plant characteristics.

Optimum Soil Moisture

Krimgold (30) states that the "effective root zone" is the zone containing the majority of the fine roots and root hairs plus an additional tributary zone through which moisture moves fast enough to keep up with the normal use of water by the plant. He also states that the optimum range of soil moisture for plant growth is 50 percent of field capacity for lighter soils and 70 percent of field capacity for heavier soils. He defines the practical optimum range as 50 percent of field capacity for light soils and 30 percent of field capacity for heavier soils.

During 1952 and 1953, Bradley and Pratt (12) applied irrigation water to onions and potatoes when the soil moisture dropped to 50, 25 and 5 percent of field capacity. Another plot was set up as a control (non-irrigated). The moisture level was determined by plaster of paris blocks and an electrical moisture meter. The yield differences between these crops at 50 percent and 25 percent available moisture were greater than the differences between the control (non-irrigated) plots and those irrigated when the available moisture dropped to 5 percent. From these results Bradley points out the value of timely irrigation (starting when about half the available soil moisture has been used) over the "emergency" type of irrigation.

Bowers, Benedict and Watts (9) irrigated All Gold sweet potatoes when the moisture level fell to 50 percent and 20 percent of available moisture. Other plots were unirrigated. In this study, the best results were obtained when 1 inch of irrigation water was applied when the soil had 50 percent available moisture.

Bloodworth, Maxwell, Ross and Cowley (4) conducted experiments with lettuce when the moisture level dropped to 75, 50, and 25 percent available moisture. The high moisture level produced more lettuce by weight, although the percentage of marketable heads was lower than in the medium and low moisture level plots. The percentage of cull heads and their weight did not change to a great extent among the moisture levels. They concluded that lettuce should be grown under conditions of medium to high soil moisture levels.

Lana and Peterson (31) reported that the highest sweet potato yield on a coarse sand in Iowa was obtained when the available soil moisture was kept at about 50 percent and a three to four day irrigation schedule was followed. MacGillivray (36), working with cantaloupes on a deep loam soil that was wetted to 6 feet before planting, reported that there was a significant increase in yields when additional water was applied during the growing season. However, there was no significant difference in yields between eight irrigation treatments which ranged from 2.8 to 17.8 inches of water. He concluded that there was a wide range over which water could be applied to a plant without either injuring or benefiting it. He further stated that maximum yields could be obtained from cantaloupes with properly spaced irrigations totaling 6 to 10 inches of water.

Taylor (46) found the greatest yield of Irish potatoes was obtained at 0.4 atmosphere of soil moisture tension. Wadleigh (60) stated that although soil moisture tension was about 0.1 atmosphere at field capacity and increased to about 15 atmospheres at the wilting point, soil moisture tension did not exceed 1 atmosphere in most soils until 50 to 75 percent of the available water was removed. As soil water was decreased, stresses resulting from increased concentration of salts in the soil solution were likely to be increased much more rapidly than stresses from physical forces. Thus, in saline soils, plants might suffer from the water being unavailable even though the soil appeared to be quite moist.

Root Growth and Depth of Rooting

Root growth in a permeable soil is dependent on several factors: sugars, hormones, and other constituents which are received from the shoot; water, minerals and oxygen which are obtained from the soil.

Below field capacity, capillary movement of water in a soil is so slow (2, 7) that the roots must continually be "searching" for water to supply the plant's moisture requirement. Shantz (45) observed that roots could not extend into dry soil. He found that elongation ceased but the roots remained turgid. Hunter and Kelley (27) and Volk (59) demonstrated that roots of corn plants were capable of penetrating several centimeters into dry soil that was below the wilting point when part of their roots were in moist soil. The roots extended slowly on a common front and raised the moisture content of the soil into which they penetrated.

Weaver and his co-workers (61-62) concluded from their investigations that changes in the lateral spread of roots, depth of penetration and branching are correlated with changes in the water content of the soil. They found that the root system could be varied by the application of water. Conrad and Veihmeyer (16) concluded from their studies that if the soil was wet deeply to the maximum extention of the root system early in the season, then irrigation during the summer had little influence on the extent or distribution of the roots. Furthermore, plants could not be made to keep their roots in the upper layers of soil if those at lower depths had an available supply of water and if no other adverse conditions for root development were present in the lower strata.

Veihmeyer and Hendrickson (58) reported that a compacted soil of a volume weight of 1.46 for some clays and 1.75 for sands would not allow roots to penetrate even though air and water were adequate.

Crist and Weaver (19) found that crops grown in soil of high fertility had roots that were shorter, more branched and more compact than those in similar but less fertile soil. Jean and Weaver (29) working on a fine sandy loam in Colorado concluded that crops with the most extensive root systems gave the greatest yield. There was a close correlation between the growth of underground and aerial plant parts. They believe root development often explains the reason for differences in crop yields that are otherwise obscure.

MacGillivray (36) found that cantaloupes in a deep permeable soil with a moisture content of field capacity to a depth of 6 feet, rooted to 6 feet whether they were irrigated or unirrigated. Other California studies showed that sweet potatoes rooted to 6 feet or beyond.

Corey and Blake (18) found that tomatoes extended their roots to 48 inches within eight weeks in a loamy sand and 36 inches in a loam, both of which were permeable soils.

Weaver and Bruner (63), working in a deep silt loam in Nebraska, found that tomato plants grown from seed developed taproots which penetrated 22 inches into the soil within three weeks. Transplanted tomatoes reached a depth of 2 feet within one month, 4 feet at two months, and 5 to 6 feet at maturity with a lateral spread of some 6 feet. The same investigators found that cantaloupes at Norman, Okla., rooted to a 4-foot depth at maturity on July 24, but that the bulk of the roots were in the top foot. Sweet potato plants rooted to 17 inches within 23 days, 41 inches a month later, and 69 inches by October 3. The "potatoes' were found in the surface 6 to 9 inches of soil.

Depth to Irrigate

The two guides to follow in determining how deep to wet the soil are the depth of rooting of the crop and the physical properties of the soil. They must be considered together in formulating an irrigation plan. The inherent rooting habits and the structure of the soil determine the depth to which a plant will root in a moist soil. It has been stated (33) that the ideal soil for root growth contains 50 percent solids and 50 percent pore space, with the pore space equally divided between water and air. Such a soil would allow for the escape of carbon dioxide and for the entrance of oxygen. To make this possible, there must be some large pores containing continuous air columns from the root zone to the soil surface.

The oxygen supply is frequently a limiting factor for root growth. Boynton and Reuther (11) working with fruit trees, found that the oxygen concentration in a sandy loam soil stayed at 20 percent oxygen at a depth of 3 feet, while in a heavy soil during the wet winter months, the oxygen concentration was near 1 percent. Trees did poorly on the heavy soil and while there were a few roots at this depth they were not long lived. Oskamp and Batjer (39) reported that the temporary depletion of oxygen during periods of high moisture resulted in death of apple tree roots. Boynton (10) reported that although old apple roots would remain alive or even grow slowly at oxygen concentrations between 5 to 10 percent, levels of 10 to 15 percent were needed for the initiation of new roots. Devilliers (23) noted that apple tree seedlings grew poorly when oxygen was decreased below 10 percent.

The supply of oxygen to roots may be depleted by filling soil with irrigation water, such as would occur if a permeable soil was underlain by a hardpan or a clay-pan. Cannon (15) found that raising the water-table even temporarily caused death of the deeper roots of some plant species. When the absorbing area of the root system had been reduced by lack of oxygen, the shoot adjusted itself by shedding some of its leaves and fruits, thereby reducing its transpiring area. Howard (26) found that the amount of shedding was often in direct proportion to the degree of injury to the root system.

Veihmeyer and Hendrickson (57) stated that an important objective in irrigating was to wet the soil only to the maximum depth to which the roots of a particular plant could be expected to penetrate. If no more water was applied until the available water in the soil was nearly exhausted, these roots would obtain sufficient oxygen to extend to their maximum depth. Root systems were most extensive in their tests when the moisture content approached a critical maximum from time to time but the soil was never water-logged.

Krimgold (30) suggested that irrigation practices in humid regions should take into consideration the "effective root zone." He maintained that the effective root zone would not be deeper than 3 feet for most vegetable crops and deeper irrigation would be unrealistic since 70 percent of the roots and 90 percent of the root hairs for most crops are found in the upper 18 to 20 inches.

Use of Instruments in Determining Soil Moisture

The most commonly used instruments at this time for determining soil moisture and the time to irrigate are tensiometers and gypsum moisture blocks.

Tensiometers have been found useful (48) for indicating the need for irrigation at tensions of less than 0.85 atmosphere. In many soils, 0.85 atmosphere indicates that 40 to 90 percent of the available moisture has been depleted. When the moisture content of a soil is to be kept high, the tensiometer is of most practical value. Several workers have reported difficulty in making tensiometers work satisfactorily.

Gypsum moisture blocks have been found to have a low sensitivity in the upper moisture range of less than one atmosphere, but better accuracy at higher tensions (48). Ashcroft and Taylor (1) found that while there was a variation within gypsum blocks that reduced accuracy below field sampling, variability of blocks was not as great as the variation in location. Also, since block data were much faster to take than direct soil sampling data, the number of samples could be increased thus reducing the location variability.

Bouyoucos (8) stated in regard to the theory of the Bouyoucos alternating current impedance meter and gypsum blocks, that when the blocks were firmly in contact with the soil, they, for all practical purposes, became a part of the soil and their moisture content tended to stay in equilibrium with their environment. The electrical resistance of the blocks varies with their moisture content. The meter measures soil water directly in the range from field capacity to the wilting point, or from 0.3 atmosphere to 20 atmospheres of pressure. Furthermore, according to the free energy concept, soils at any given electrical resistance level hold their water with the same force or tension. As a result, at a given resistance a sandy soil is just as wet as a clay soil and the percentage moisture for each can be read directly from the scale on the meter. Therefore, the meter and blocks could be used on any soil type without first calibrating the instrument to the soil.

In regard to excess salts in the soil, Bouyoucos (6) found salt effects were more pronounced in the higher moisture levels and were negligible at lower levels. At readings below 85 to 95 in heavier soils and 60 to 75 in sands, excess salts ceased to be an important factor. Around 2000 ppm salts were not a problem.

MATERIALS AND METHODS

The irrigation experiments were conducted at the Vegetable Field Station of the University of Missouri at Campbell, Mo., during the abnormally dry years of 1951-1954.

Climatic Characteristics of the Southeast Lowland Area

The following information has been condensed largely from "Climatic Summary of the United States," Section 55—Southeastern Missouri by the U.S.D.A. Weather Bureau (52).

The Southeast Missouri lowland area comprises less than 1/12 of the area of the state. It has the highest annual rainfall of any part of the state. Drouths are experienced occasionally. Serious drouths during the principal crop growing season occurred about eight times in the 61 year period, 1870-1930. The drouths of 1901 and 1930 were probably the most severe. Precipitation is most frequent in the spring and early summer, when it occurs on about 11 days a month on the average, and it is least frequent in September and October, when it occurs on about 8 days a month.

The summers are long and usually have several periods of high temperature, more often than not touching 100° F. or higher on one or more locations at stations of lower elevation. On a normal day in July, the temperature range is from a minimum of about 70° F. to a maximum of about 92° F.

Weather Data During Experiments

A United States Weather Bureau standard rain gauge and a self-recording hydrothermograph were placed near the growing crops to measure rainfall, temperature, and humidity. This was considered essential because of high local variation.

Soil Characteristics

The soil on which these investigations were conducted was a Lintonia fine sandy loam. According to the U.S.D.A. "Soil Survey of Dunklin County" (51), this soil as typically developed is a brown fine sandy loam or loamy fine sand underlain at about 15 to 30 inches by light-brown fine sandy loam or heavy fine sandy loam. Frequently, at about 30 inches, yellowish-brown heavy fine sandy loam to fine sandy clay is reached . Within a few inches, this passes into yellowish-brown, rather plastic, silty clay containing a small quantity of fine sand.

The textural and moisture characteristics of this soil as determined for different soil depths and locations are reported in the Results.

Determination of Available Soil Moisture

Because of the numerous determinations required and the necessity of reducing the local variabilities in sampling, it was desirable to employ gypsum moisture blocks and an electrical resistance meter. For the initial work the Bouyoucos equipment (Fig. 1) was used as it gives the percentage available moisture directly on most soils. For the last year's work (1954) the Delmhorst Moisture Detector and gypsum blocks were used and the meter readings calibrated against the available moisture as determined by difference in weight by oven drying.

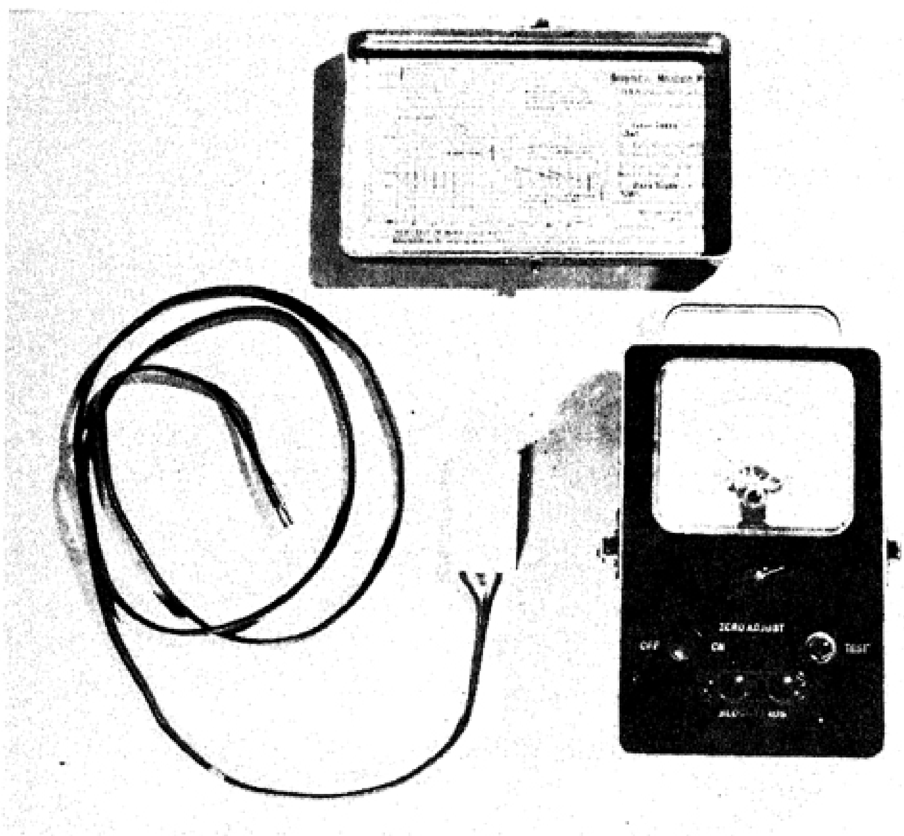


Figure 1. Bouyoucos Equipment

EXPERIMENTAL PROCEDURES AND RESULTS

Evaluation of Irrigation Treatments Based on Preceding Rainfall (1951)

In the initial stages of the investigation, it was desirable to determine more specifically the normal seasonal precipitation pattern of the area and to evaluate several irrigation treatments based upon previous rainfall for best crop response and irrigation efficiency.

Experiment Plan

Eight plots 200 feet long and 100 feet in width were layed out in a randomized arrangement to provide the following irrigation treatments:

Plot I: 1.5 inches each week minus the effective rainfall in the previous week.

Plot II: 0.5 inches when the previous week's rainfall was between 0.5 and 1.0 inches, and 1.0 inches when the previous week's rainfall was below 0.5 inches.

Plot III: 2.0 inches each two weeks minus irrigation and effective rainfall during the previous two weeks.

Plot IV: Non-irrigated (check plot).

Plot V: 1.0 inches each week minus effective rainfall in the previous week.

Plot VI: The balance of the amount of water required to bring the major part of the root zone to Field Capacity.

Plot VII: 3.0 inches each three weeks minus irrigation and effective rainfall during the three previous weeks.

Plot VIII: 1.0 inches whenever the available soil moisture dropped to 50% of field capacity as determined by gypsum soil blocks.

The available soil moisture was determined daily by the method of Bouyoucos (5) employing an electrical resistance meter and gypsum soil blocks. Triplicate sets of blocks were buried in each plot at depths of 6, 12, 18, 24, and 30 inches in the row. As a check, periodic determinations by difference in weight by oven drying were also made.

Top Crop bush beans, Flagship sweet corn, and Cubit cucumbers were planted in each treatment plot on June 6. All cultural operations except irrigation were consistent for all plots. Periodic harvests were made according to the demands of the crops and the products were graded to market standards.

Weather and Irrigation

The maximum temperature on most days ranged between the 80's and low 90's and the minimums between the 50's and low 60's. Neither the temperature nor the humidity was sufficiently high or low to be critical or to produce any noticeable detrimental effects on the plants.

Table 1 indicates that the precipitation for both June and July was above average.

TABLE 1 -- RAINFALL IN JUNE, JULY, AND AUGUST, 1951 AND AMOUNTS RECEIVED BY THE CROPS IN THOSE MONTHS

Month	Seasonal Average	1951 Total	Beans	S. Corn and Cucumbers
June	4.08"	11.00"	10.30"	10.30"
July	4.26	4.60	4.60	4.60
August	4.80	1.60	0.00	1.50
Total	13.14	17.20	14.90	16.40

There were, however, five dry periods during the 1951 season of sufficient duration to significantly affect crop growth:

May 20-June 2 .... 14 days
June 9-June 18 .... 10 days
July 10-July 22 .... 13 days
July 28-August 9 .... 13 days
August 11-August 31 .... 21 days

Since the three crops were planted on June 6 and harvested before August 15 the only "drouths" that could have affected them materially were

TABLE 2 -- WATER RECEIVED BY THE PLOTS THROUGH IRRIGATION AND RAINFALL (INCHES)

	Treatment Designation (Plots)							
	I	II	III	IV	V	VI	VII	VIII
June 13								
June 20								
June 27	0.9	0.5			0.5	0.4		
July 4								
July 11								
July 16								1.0
July 18	1.5	1.0	0.4		1.0	1.0		
July 25								
August 1	0.9	0.5			0.4	1.3		
August 3								1.0
August 8	1.5	1.0	1.4		1.0	1.5		
Irrigation for snap beans	2.4	1.5	0.4	0.0	1.5	1.4	0.0	1.0
Irrigation for cucumbers and sweet corn	4.8	3.0	1.8	0.0	2.9	4.2	0.0	2.0
Irrigation and rainfall for snap beans	17.3	16.4	15.3	14.9	16.4	16.3	14.9	15.9
Irrigation and rainfall for cucumbers and sweet corn	21.2	19.4	18.2	16.4	19.3	20.6	16.4	18.4

the July 10 to July 22 period for the snap beans and the periods July 10 to July 22 and July 28 to August 9 for the cucumbers and sweet corn.

The moisture determinations showed the available soil moisture dropped to approximately the permanent wilting percentage for all three crops during the July 10 to July 22 dry period and for the cucumbers and sweet corn during the July 22 to August 9 dry period. The critically low moisture supply was also confirmed by the plant symptoms—rolling of the sweet corn leaves, and drooping of cucumber and sunflower leaves.

Table 2 gives irrigation dates and amounts for the various treatments and the total amount of water received by each plot through irrigation and rainfall.

Results and Discussion

Green Beans (Top Crop)

As shown in Table 3, the treatments giving highest yields were I, II, VI and VIII which received from 1 to 1.5 inches of water during the July 10 to July 22 dry period. The available moisture in the unirrigated plot was very low for this period. Treatment III, although receiving 0.4 inch of irrigation water on July 18, gave a smaller increase in yield. Apparently, this application was insufficient to replenish the moisture in the root zone.

Plots IV and VII which were not irrigated, resulted in the lowest yields and the beans were delayed in maturity approximately 3 days. The low yield of Plot VII indicates too much risk in timing irrigations on the previous 3 weeks' precipitation. Based on this guide, Plot VII received no irrigation. Treatment Plot V was discarded because of water-logging.

The percentage marketable yield by weight was close under the various treatments. No significant effect of irrigation on the market quality of the pods was indicated. On the other hand, the great increases in the number of pods per plant indicate a very definite effect of irrigation on pod set. This confirms previous findings of other investigators.

Sweet Corn (Flagship)

As with the green beans, Treatments I, II, VI and VIII resulted in the largest yields of marketable ears. Again, these were the plots that received the most total irrigation water (2.0-4.8 inches) and received some of it through the dry periods of July 10 to July 22 and July 28 to Aug. 9 Treatment Plots IV and VII which did not receive irrigation during these periods, and Treatment III which received only 1.8 inches, produced very low yields. Treatment III did not receive sufficient water on July 18 and did not receive any during the July 28 to August 9 dry period.

As shown in Table 4, irrigation affected plant height, number of ears per stalk, average size of ears, and percentage of marketable ears. This confirms the findings of other investigators (34, 44).

TABLE 3 -- A SUMMARY OF RELATIVE GROWTH AND YIELDS OF TOP CROP BEANS WITH IRRIGATION TREATMENT.

	Plots						
	I	II	III	IV	VI	VII	VIII
Amount of Water Application (Inches)	2.4	1.5	0.4	0.0	1.4	0.0	1.0
Average Number of Pods Per Plant	8.68	9.30	6.84	5.74	8.80	5.85	8.83
% Increase	51.3	62.1	19.2		53.3	1.92	53.7
Average Weight of Plant (lb.)	0.194	0.220	0.178	0.153	0.226	0.158	0.223
Average Marketable Yield Per Plant (lb.)	0.058	0.062	0.045	0.034	0.058	0.035	0.060
Average Non-Marketable Yield Per Plant (lb.)	0.035	0.036	0.025	0.023	0.038	0.024	0.035
Total (lb.)	0.093	0.098	0.070	0.057	0.096	0.059	0.095
% Marketable Yield by Weight	62.4	63.5	63.7	59.4	60.5	58.7	63.0
% Increase in Marketable Yield	70.5	82.9	31.6		70.5	2.0	76.2
% Increase in Total Yield	62.2	71.1	22.6		67.3	2.1	66.0
Market Yield in lb./acre	2320	2480	1800	1360	2320	1400	2400

TABLE 4 -- A SUMMARY OF RELATIVE GROWTH AND YIELDS OF FLAGSHIP SWEET CORN WITH IRRIGATION TREATMENT.

	Plots						
	I	II	III	IV	VI	VII	VIII
Amount of Water Application (inches)	4.8	3.0	1.8	0.0	4.15	0.0	2.0
Average Height of Plant (ft. & in.)	7'8.5"	7'9"	6'9"	7'1"	7'7"	7'4"	7'10"
Average Marketable Ears Per Stalk	1.08	1.14	0.20	0.48	0.84	0.51	1.19
Average Non-Marketable Ears Per Stalk	0.06	0.06	0.53	0.48	0.25	0.49	0.05
Total Number of Ears Per Stalk	1.14	1.20	0.73	0.96	1.09	0.98	1.20
% Increase in Total	18.8	25.0	-24.0		13.5	2.08	30.2
% by Number of Market Ears	94.5	94.8	27.4	50.0	77.0	52.0	95.3
% Increase in Number of Market Ears	127	140	-58		77	7	150
Average Weight of Ear (lb.)	0.51	0.51	0.18	0.47	0.49	0.46	0.49
% Increase	7.6	7.6	-62.7		3.6	-2.1	4.0
Average Yield (Market & Non-Market) Per Plant (lb.)	0.58	0.61	0.13	0.46	0.54	0.46	0.62
Marketable Ears Per Acre	13,100	13,900	2,420	5,750	11,800	6,170	14,400

TABLE 5 -- YIELD OF CUBIT CUCUMBERS WITH VARIOUS IRRIGATION TREATMENTS

	Plots						
	I	II	III	IV	VI	VII	VIII
Amount of Water Application (inches)	4.8	3.0	1.8	0.0	4.15	0.0	2.0
Average Number of Market Cucumbers Per Plant	2.34	3.86	1.07	0.77	2.61	0.80	4.30
Average Number of Non-Market Cucumbers Per Plant	0.66	0.92	0.39	0.48	0.97	0.66	0.98
Total Number of Cucumbers Per Plant	3.00	4.78	1.46	1.25	3.58	1.46	5.28
% Increase in Total	141	282	17		187	17	324
% by Number of Marketable Cucumbers	78.1	81.0	73.2	61.6	73.0	54.7	81.7
% Increase in Marketable Cucumbers	205	403	39		240	4	460
Marketable Yield Per Plant (lb.)	1.80	3.14	0.89	0.52	2.13	0.60	3.53
% Increase by Weight of Market Yield	245	523	68		308	15	576

Cubit Cucumbers

As with the sweet corn and green beans, Treatments I, II, VI, and VIII gave the best yields, although those of Treatments I and VI were considerably lower than II and VIII. (See Table 5.) These treatments also gave a higher percentage marketable yield than treatments IV and VII which received no irrigation water. The unmarketable fruit in the unirrigated plots included a high percentage of nubbins.

Estimates of Consumptive Use

The method used in determining the consumptive use of the different crops under the climatic and soil conditions of these experiments was developed by Blaney and Criddle (3).

In Missouri, as in other humid regions of the country, little work has been done to determine water requirements of various crops. It was thus necessary to assume a consumptive-use coefficient for the purpose of these experiments. A preliminary estimation was then made of the consumptive use of the snap beans, sweet corn, and cucumbers during these experiments. This method of estimation of the consumptive use is shown in Tables 6 and 7.

As a check, another approximation of the consumptive-use needs of the three crops was made from Fig. 2 which shows the moisture level in the soil, rainfall, and irrigation for Plot VIII. This plot was irrigated 1 inch whenever the soil moisture meter read around 50 percent available moisture. The soil moisture curve gives the total amount of moisture (in inches of depth) for the top 15 inches of soil as determined by periodical soil sampling.

Fifteen inches of this soil at field capacity contained approximately 3 inches of total water. Since most of the roots were confined within a depth of 15 to 18 inches, any water beyond that required to wet to field capacity the top 15 inches of soil was considered excessive (lost through runoff and deep percolation). In addition, all precipitation below 0.25 inches was considered ineffective and thus discarded. The precipitation during June 29 and 30 was also discarded since that on June 28 was sufficient to replenish the soil moisture (bring it up to field capacity). The consumptive use estimated by this method compared favorably with that obtained by the Blaney and Criddle method (Tables 6 and 7). The following gives the estimated consumptive use of the three crops by analysis of rainfall, irrigation, and soil moisture for Plot VIII:

Snap Beans:

7.5 inches for a growing season of 7 weeks.

Cucumbers:

9.7 inches for a growing season of 9 weeks.

TABLE 6 -- OBSERVED MONTHLY TEMPERATURES AND PRECIPITATION AND CALCULATED CONSUMPTIVE-USE FACTORS FOR CAMPBELL, MISSOURI (LATITUDE 36° 29')*

	Mean Temp.	% daytime hours	Consumptive Use Factors	Average Precipitation	Growing Season and Crop					
					Beans June 7 - July 31		Sweet Corn June 6 - Aug. 15		Cucumbers June 6 - Aug. 15	
Month	(t)°F.	(p)	(f)	(r)	(f)	(r)	(f)	(r)	(f)	(r)
Jan.	35.2	6.95	2.44	5.51"						
Feb.	43.6	6.83	2.98	3.18						
Mar.	50.4	8.33	4.18	5.53						
Apr.	59.7	8.87	5.30	4.31						
May	68.0	9.85	6.69	4.34						
June	74.0	9.88	7.31	4.08	5.85	3.26	5.85	3.26	5.85	3.26
July	79.4	10.03	7.94	4.26	7.94	4.26	7.94	4.26	7.94	4.26
Aug.	76.8	9.43	7.23	4.80			3.61	2.40	3.61	2.40
Sept.	71.5	8.37	5.98	4.53						
Oct.	60.2	7.82	4.72	3.11						
Nov.	46.9	6.89	3.23	3.53						
Dec.	38.3	6.76	2.58	3.95						
Total		100.00	60.58	51.13	13.79	7.52	17.40	9.92	17.40	9.92

*Blaney, H. F. and Criddle, W. D. "Determining Water Requirements in Irrigated Areas From Climatological and Irrigation Data" U.S.D.A. Soil Conservation Service. August 1950. See footnote to Table 7.

TABLE 7 -- ESTIMATION OF CONSUMPTIVE USE AND IRRIGATION REQUIREMENT FOR BEANS, SWEET CORN AND CUCUMBERS, CAMPBELL, MISSOURI, AREA.

Crop	Growing Season	Consumptive-Use Factor (F)	Consumptive-Use Coefficient (Assumed) (K)	Consumptive-Use (U)	U-R	Field Irrigation efficiency (E)	Irrigation requirement (I)
Beans	June 6-July 31	13.79	0.65	8.95	1.43	80%	1.80
Sweet Corn	June 6-Aug. 15	17.40	0.75	13.00	3.08	75%	4.11
Cucumbers	June 6-Aug. 15	17.40	0.65	11.30	2.38	75%	3.18

u = kf = monthly consumptive use

k = monthly consumptive use coefficient

f = monthly consumptive as factor = t x p = mean monthly temperature x monthly percent of daytime hours

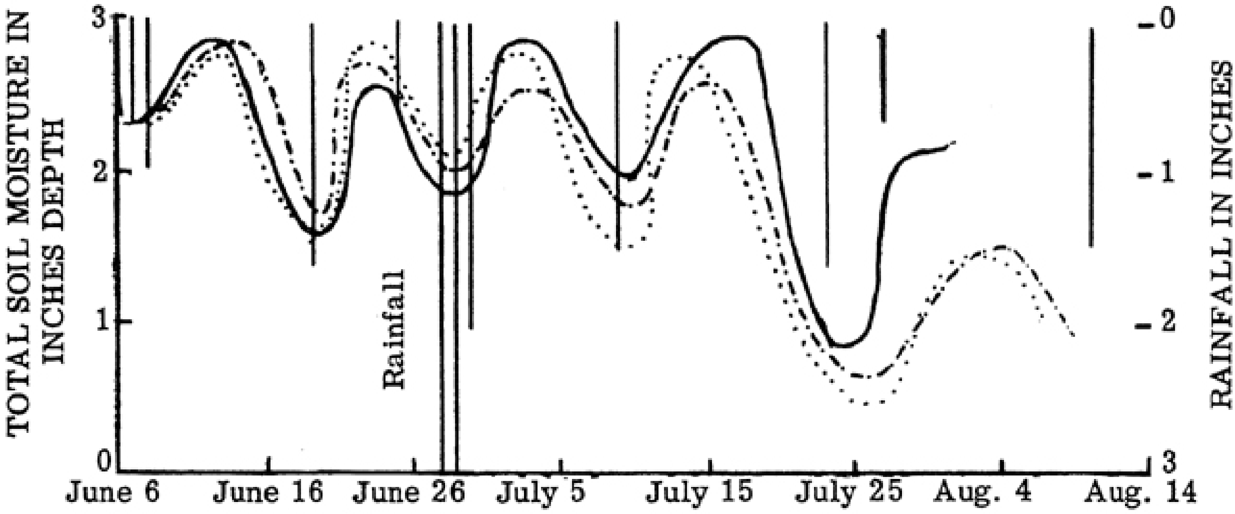
U = KF = consumptive use of growing or irrigation season

K = Empirical consumptive use coefficient determined experimentally (in above table assumed. Needs verification by research or by further analysis of existing temperature, humidity, evaporation, and infiltration data before being accepted for general use).

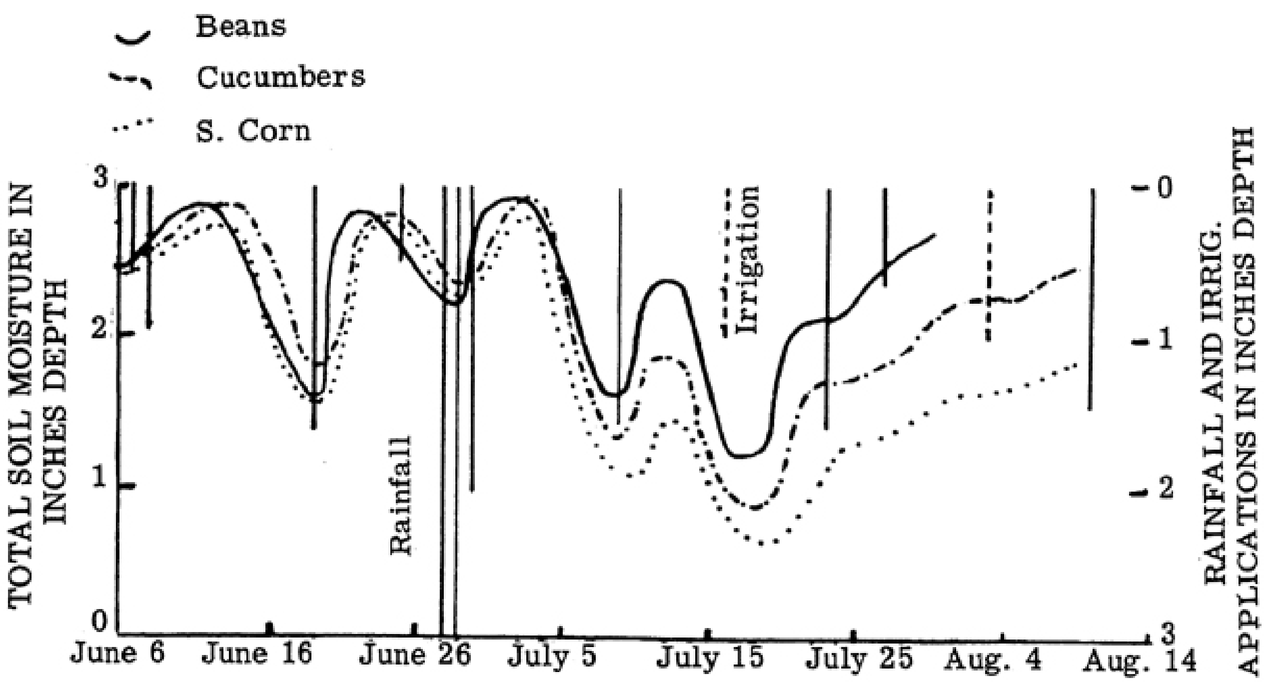
F = sum of monthly consumptive use factors, (f), for the growing or irrigation season

R = sum of monthly precipitation for growing or irrigation season

$I = \frac{U - R}{E}$ = Irrigation requirement at head of field



RAINFALL & AVERAGE TOTAL SOIL MOISTURE LEVEL IN TOP 15 " OF SOIL FOR PLOT IV (UNIRRIG.)



RAINFALL, WATER APPLICATION AND TOTAL MOISTURE LEVEL IN TOP 15" OF SOIL
PLOT VIII (IRRIG. AT ABOUT 50% AVAILABLE MOISTURE)

FIGURE 2

Sweet Corn:

11.2 inches for a growing season of 9 weeks.

Planning Irrigation Practice on the Basis of Rainfall Data

The consumptive use estimates suggest that each of the crops need about 1 inch of water per week (either from rainfall or irrigation). However, during the early spring, the water utilization by crops is not great because the plants are small, the temperature is low, and the length of day is short. It would therefore be safer to apply during this period 0.5 inch of water whenever the previous week's effective rainfall is less than 0.5 inch. In the latter part of summer and early part of fall, however, water requirements of crops are higher and the incidence of rains below 0.5 inch is greater, as seen in Table 8. Late in the season it would be safe to apply 1 inch of

TABLE 8 -- THE INCIDENCE (PERCENT BY FOUR WEEK INTERVALS) OF VARIABLE PRECIPITATION AT FOUR SOUTHEAST MISSOURI STATIONS*

Weeks (Mar. 1 to Sept. 12)	Precipitation (Inches) Less than 0.05	0.25-0.49	0.50-0.99	Less than 1.00	More than 1.00
First Four	28.4	15.0	24.6	68.0	31.2
Second Four	30.4	13.7	18.5	62.6	37.2
Third Four	33.0	11.0	19.6	63.6	36.4
Fourth Four	37.4	15.1	15.8	68.3	31.6
Fifth Four	47.5	14.4	16.5	78.4	21.7
Sixth Four	49.7	11.8	14.4	75.9	24.2
Seventh Four	45.3	12.0	16.7	74.0	26.0

*Composite for Caruthersville, Cairo, Sikeston and Poplar Bluff. The figures were obtained separately for each week and then calculated for four-week periods. Precipitation below 0.25 inches was considered ineffective. The figures in the table were derived from data provided by W. L. Decker, Climatologist at the University of Missouri.

water whenever rainfall during the previous week is less than 0.5 and 0.5 inch when the rainfall is between 0.5 and 1.0 inch.

In humid areas, there is always the possibility of excessive water due to irrigation followed by rainfall. To examine the possibility of such a condition, Table 9 was derived from Table 8. An accumulation in two weeks of more than 2.5 inches of water from irrigation and rainfall was considered excessive.

Table 9 applies particularly to Treatment II where 1.0 inch of water was applied whenever the rainfall in the previous week was below 0.5 inch and 0.5 inch whenever the rainfall was between 0.5 and 1.0 inch. Since Treatment II in this experiment showed very favorable results, an examination of the probability of excessive water received by the crops due to the accumulated effect of irrigation and rainfall would be helpful.

In *a* of Table 9, where rainfall in the week preceding irrigation is ineffective (below 0.25 inch), there is a 20 to 35 percent probability of hav-

TABLE 9 -- PROBABILITY OF EXCESSIVE SOIL MOISTURE RESULTING FROM THE COMBINED EFFECTS OF IRRIGATION AND RAINFALL

Irrigation plus rainfall in week preceding irrigation	(a) 1.0 inches				(b) 1.0-1.5 inches			
When rainfall in week following irrigation is	Less than 0.25 in.	0.25 -0.5	0.5-1.0 in.	More than 1 in.	Less than 0.25 in.	0.25-0.50 in.	0.50 -1.0 in.	More than 1.0 in.
Then accumulated rainfall and irrigation in the two weeks is	1.0	1-1.5	1.5-2.0	More than 2.0	1.5	1.5-2.0	2.0-2.5	More than 2.5
% Probability of securing this amount of water for the two week period (depending on month)	30-50	10-15	15-20	20-35	30-50	10-15	15-20	20-35

ing more than 1 inch of rainfall in the following week, making a total of more than 2.0 inches received by the crop in the 2 weeks (the week preceding and that following irrigation). The incidence of excessive water during the 2 weeks (more than 2.5 inches) would evidently be less. In *b*. where effective rainfall during the week prior to irrigation is below 1.0 inches, the percent probability of 2.0 to 2.5 inches of accumulated water during the 2 weeks is 15 to 20. The probability for more than 2.5 inches is 20 to 35 percent. This probability, as can be seen in Table 8, is highest in April and May and lowest from mid-June to mid-September. If the crops are planted in March, May, or early June, the probability of excessive water is lessened during this period by applying 0.5 inch of water only when the rainfall in the week prior to irrigation is less than 0.5 inch.

From these experiments, it was found that a dry period of more than 10 days could affect crop yield appreciably on Lintonia fine sandy loam. Therefore, any irrigation practice based on rainfall data of the 2 or 3 previous weeks is not advisable since the crop may not receive effective rainfall for more than 10 days. In addition, any practice based on the application of more water at lesser frequency than in Treatment II, would increase the risk of excessive water. This was the case with Plots III and VII during these experiments.

Effects of Prolonged Dry Periods on Different Stages of Plant Growth

Plantings of Top Crop green beans and Cubit cucumbers were made at weekly intervals and continued into a relatively long dry period during which each stage of plant growth was represented. After the dry period, all the plantings were irrigated sufficiently by furrow irrigation until maturity.

Table 10 shows that lowest yields of beans were produced by the 5th, 6th, and 7th plantings which were blooming and setting most during the dry period, July 10 to July 22. It thus seems that the time of blooming, fertilization, and setting is the stage most affected by a prolonged dry period. Other factors such as high temperature, wind velocity and low relative humidity have been found to cause an increase in blossom drop and thus affect the yield of beans (47). The fact that the percent marketability did not vary appreciably among these plantings suggests that once the plant has set, a deficiency of soil moisture for short periods does not affect the marketability of the pods. However, no conclusion can be drawn on the effect of longer dry periods.

Similarly, in the case of cucumbers, the time of blooming, fertilization and setting seems to be the stage most sensitive to deficiency of soil moisture. Undoubtedly, as with the beans, most, if not all, other stages were affected in some way and to a certain degree by a prolonged dry period. Unlike the beans, however, the percent marketability of the cucumbers was also appreciably affected by a prolonged deficiency of soil moisture as evidenced by a decrease of nearly 25 percent in the most seriously affected plantings. This reduction in percent marketability was largely accounted for by an increase in percentage of fruit showing constrictions.

TABLE 10 -- A COMPARISON OF THE EFFECT OF A PROLONGED DRY PERIOD ON DIFFERENT STAGES OF PLANT GROWTH

Bean Plantings	Planting Date	Age in Weeks on July 9	Harvest Date	Total Yield Per Plant (lb.)	Market Yield Per Plant (lb.)	% Market Yield
1	May 21	8	July 16	0.0862	0.570	66.1
2	May 28	7	July 23	0.0844	0.550	65.2
3	June 4	6	July 30	0.0843	0.551	65.5
4	June 11	5	Aug. 6	0.0845	0.547	64.7
5	June 18	4	Aug. 13	0.0793	0.513	64.8
6	June 25	3	Aug. 20	0.0751	0.482	64.2
7	July 2	2	Aug. 27	0.0772	0.493	63.9
Cucumber Plantings	**Planting Date**	**Age in Weeks on June 11**	**Harvest Date**	**Total Yield Per Plant (lb.)**	**Market Yield Per Plant (lb.)**	**% Market Yield**
1	April 16	8	July 2	3.32	2.88	86.7
2	April 23	7	July 9	3.24	2.79	86.2
3	April 30	6	July 16	3.30	2.81	85.3
4	May 7	5	July 23	1.46	1.15	78.9
5	May 14	4	July 30	1.34	1.05	78.5
6	May 21	3	Aug. 6	1.25	0.82	65.4
7	May 28	2	Aug. 13	1.63	1.01	62.1
8	June 4	1	Aug. 20	1.74	1.07	61.7

Evaluation of Soil Reservoir Moisture When Irrigating Deep-Rooted Vegetables (1952)

The investigations in 1951 suggested the desirability of evaluating the available moisture held in the soil reservoir when considering the amount and frequency of irrigation for deep-rooted vegetables. In this series, one treatment was included in which the available moisture was maintained above 45 percent of field capacity to a depth of 12 inches.

Replicated and randomized plots 40 feet by 50 feet were set up to provide variable irrigation treatments as follows:

A. Control, unirrigated.
B. Applied 1 inch of water when the available soil moisture was depleted to 45 percent of field capacity as determined by the Bouyoucos method.
C. Applied approximately 1 inch of water per week—0.5 inch when previous week's rainfall was 0.5-1.0 inch, 1.0 inch when previous week's rainfall was 0.0-0.5 inch.
D. Applied 1.5 inches of water per week (1½ inches —effective rainfall).

The gypsum moisture blocks were placed at the 6-inch and 12-inch depths in the row at two random locations in each treatment block. Readings were taken every other day and the average of the four blocks was used as a representative of the available moisture in the root zone. Any daily precipitation below 0.25 inches was considered ineffective and was disregarded in the determination of irrigation requirements.

Top Crop green beans and Cubit cucumbers were seeded on April 16, and Unit I Porto Rico sweet potatoes were transplanted on May 15. The period of harvest for the green beans was June 18 to August 6; for the cucumbers, June 23 to July 30; for the sweet potatoes, September 26. All treatment plots were irrigated on May 15 and again on June 10. After that date, water was applied according to treatments.

Weather Conditions

The growing season was characterized by a drouth of unusual duration and intensity. Although the total rainfall for the growing period was 9 inches the distribution was such that only approximately 1 inch of effective precipitation fell in the period May 25 to July 22 during which time the beans and cucumbers were flowering and fruiting heavily. The deficiency of soil moisture was also accompanied by very low atmospheric humidity, dessicating winds, and high temperatures.

Results and Discussion

Table 11 shows the effects of different amounts and frequencies of irrigation on yields.

TABLE 11 -- YIELD RESPONSE OF TOP CROP BEANS, CUBIT CUCUMBERS, AND UNIT I PORTO RICO SWEET POTATOES TO VARIABLE IRRIGATION, CAMPBELL, MO., 1952

Irrigation Treatment	Irrigation Water Applied			Effective Precipitation (inches)			Marketable Yields		
	Beans	Cucumbers	Sweet Potatoes	Beans	Cucumbers	Sweet Potatoes	Beans (lb./A)	Cucumbers (lb./A.)	Sweet Potato (Bu./A.)
A. Un-irrigated	None*	None*	None*	5.96	5.96	9.19	268	9,289	308
B. Available Moisture Above 45% of F. C.	5.0	5.0	7.0	5.96	5.96	9.19	2,149	16,503	462
C. 1 Inch Water Per Week	5.0	5.0	7.0	5.96	5.96	9.19	1,882	16,950	482
D. 1 1/2 Inches Water Per Week	7.0	7.0	9.5	5.96	5.96	9.19	3,714	17,938	536

*The 1-inch application to all crops and treatments on May 15 is not included. This application was necessary to germinate the seed and secure good plant stand of all three crops.

By far the most striking response shown by these data is between the irrigated versus unirrigated treatments. It should be noted that in treatments B and C, which received equivalent amounts of water but at different times, the yields did not differ significantly. The application of 1 ½ inches per week for a seasonal total of 9.5 inches, however, was most effective, apparently because it maintained a favorable moisture level to a greater soil depth.

The block readings indicated that the 1 inch per week treatment was not sufficient to maintain the available moisture above the 45 percent level in the upper 12 inches during extended periods of drouth. Even in the case of the deeper-rooted crops (cucumbers and sweet potatoes) where the depletion in this zone may not be as rapid due to the larger soil reservoir, it would appear that applications of 1 ½ inches per week or more are necessary on light soils such as Lintonia fine sandy loam during prolonged drouths and advanced stages of development.

This suggests further that better results might have been obtained with applications based upon the 45 percent moisture level had irrigation amounts been applied to maintain a favorable moisture level to greater soil depths.

Optimum Range of Soil Moisture for Irish Potatoes, Tomatoes, Sweet Potatoes (1953)

A study was made during the summer of 1953 to determine the optimum range of soil moisture for the production of three important vegetable crops—Irish potatoes, tomatoes, and sweet potatoes. Since this required frequent measurements of the available soil moisture throughout the season, it also permitted an estimate of the daily water use at different stages of plant development and under variable weather and soil conditions.

Experiment Plan

Treatment plots 50 feet by 200 feet were established to provide four irrigation treatments as follows:

Unirrigated
Available moisture maintained above 25 percent of field capacity (F.C.)
Available moisture maintained above 50 percent of field capacity (F.C.)
Available moisture maintained above 75 percent of field capacity (F.C.)

Plaster of Paris moisture blocks (Bouyoucos) were placed at 6, 12, 24, and 36-inch depths in the rows. Duplicate sets of blocks were established in each treatment plot and readings of the moisture were made three times weekly. The blocks at the 12-inch depth were used as the "guide" until August 7 at which time it was evident that large masses of fibrous roots had reached the 24-inch depth and were depleting the subsoil moisture. The blocks at the 24-inch depth were then used as the "guide" for the remainder of the season. When the available moisture by meter reading dropped to the minimum prescribed by the treatment, sufficient irrigation water was applied to bring the soil moisture to field capacity to the depth of the "guide" block.

Certified Rutgers tomato plants were transplanted on May 25 using a 4 x 3 foot spacing and periodic harvests made on approximately 250 plants in each treatment. Unit I Porto Rico plants were transplanted on May 15 using a 3.5 x 1 foot spacing. The roots were harvested on October 16 and yields of graded roots taken for six replications. Certified Northern-grown Red Pontiac Irish potatoes were planted on February 28 using a 3 x 1 foot spacing and weights of graded tubers taken on June 30. All crops received the recommended cultural treatment which was consistent among all irrigation plots.

Estimate of Average Daily Water Use for Different Periods of Plant Development

The available moisture, expressed as a percentage of field capacity averaged for a depth of 3 feet, was calculated at the beginning and the end of different periods of the plant's development. Care was exercised in choosing intervals of several days duration in which the moisture was slowly being depleted. The percentage differences (averaged) multiplied by 5.7 (inches of available moisture for this volume of soil at F.C.) gave a fairly reliable estimate of the total moisture used during a given period. Dividing by the number of days involved gave the approximate daily use of water.

Weather Conditions

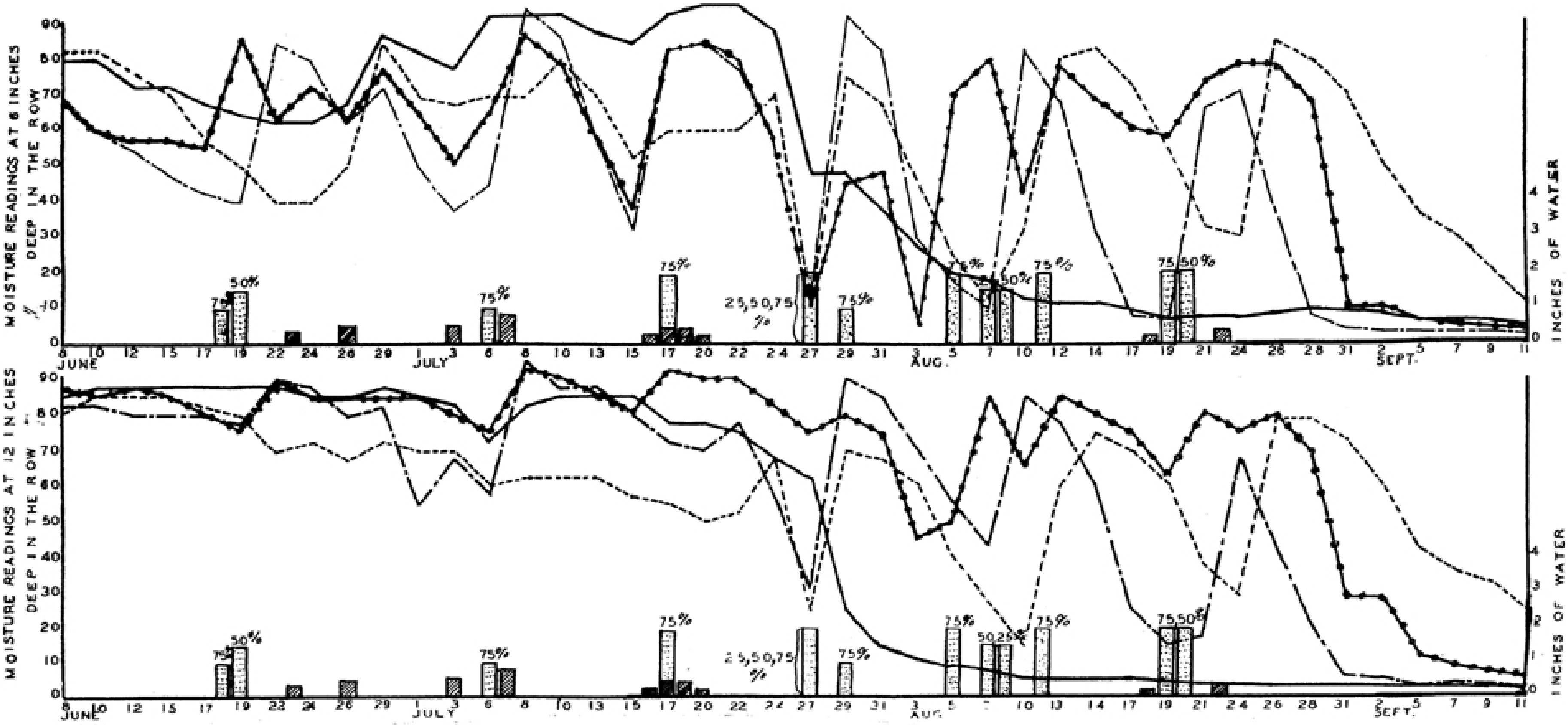
The total rainfall from June 8 until September 11 was 3.96 inches. There were five periods of a week or longer during which no rain fell:

Date	*Length dry period (days)*
June 8-22	16
June 26-July 3	7
July 8-16	8
July 20-Aug. 18	29
Aug. 22-Sept. 11	20

The temperature was unusually high in June and July. For example, there were nine days in June when the temperature was above 100° F. The average temperature for June was 80.4° F. This is only 0.4° less than the record high for June, established in 1952 (54, 22, 53). These unusually high day and night temperatures were unfavorable for the setting of tomato flowers and best development of Irish potato tubers.

The tomato yields according to irrigation treatment are given in Table 12. The dates and amounts of water applied, the rainfall and the moisture levels at various depths in the root zone are shown graphically in Figure 3.

TOMATO MOISTURE READINGS



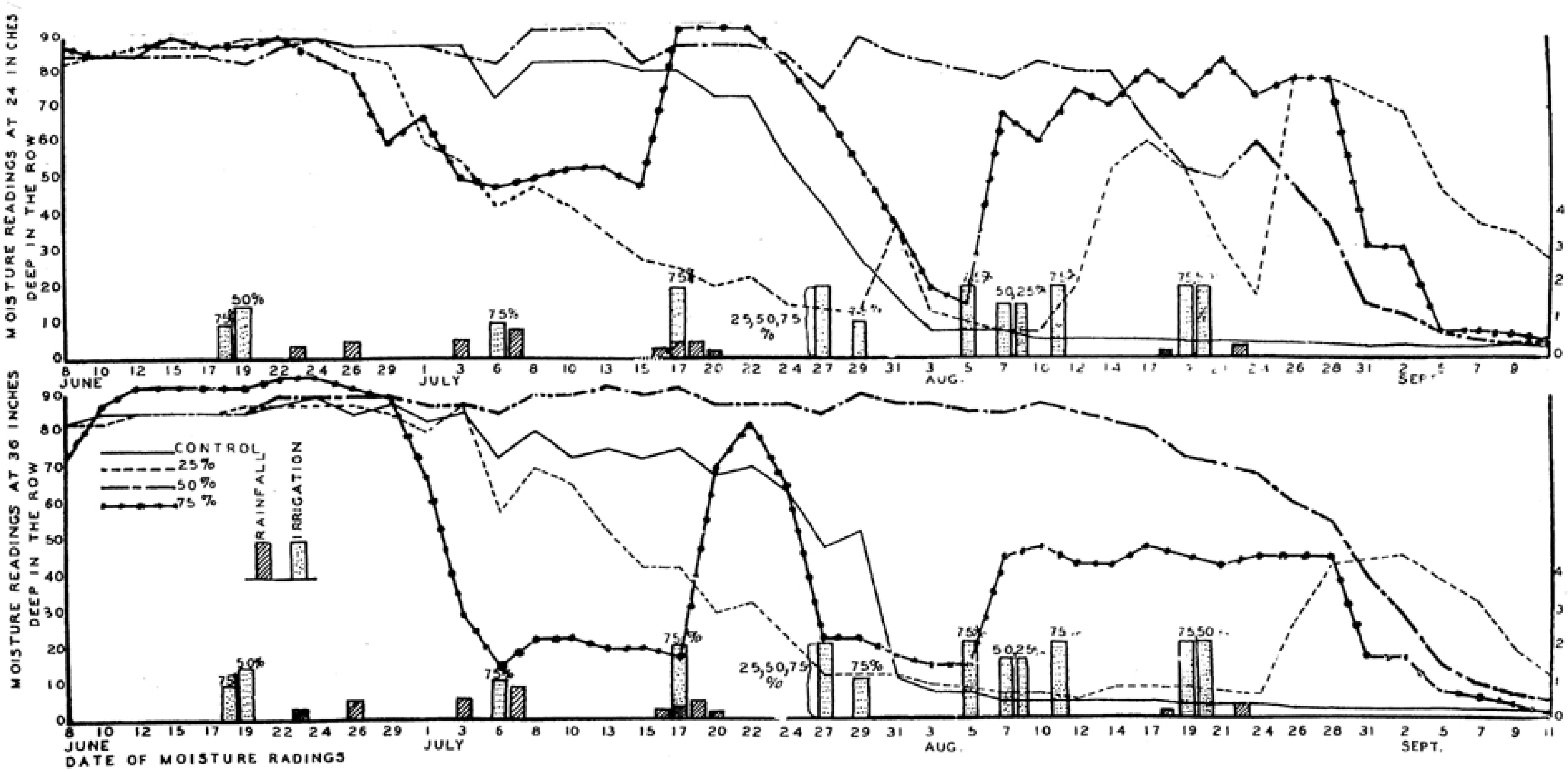

MOISTURE READINGS AT 24 INCHES DEEP IN THE ROW
MOISTURE READINGS AT 36 INCHES DEEP IN THE ROW
INCHES OF WATER
CONTROL
25%
50%
75%
RAINFALL
IRRIGATION
JUNE
JULY
AUG.
SEPT.
DATE OF MOISTURE RADINGS

FIGURE 3

TABLE 12 -- EFFECT OF MOISTURE LEVELS MAINTAINED BY IRRIGATION ON YIELD OF RUTGERS TOMATOES, CAMPBELL, MO., 1953.

Treatment	Total Irrigation Water Applied (inches)	Total Rainfall (inches)	Yield (Tons Per Acre) Marketable	Culls	% Increase over control
Unirrigated	none	3.96	3.2	1.3	
Available moisture maintained above					
25% of F. C.	3.5	3.96	11.6	1.8	265.6
50% of F. C.	7.0	3.96	12.0	1.9	275.0
75% of F. C.	12.5	3.96	15.0	1.9	368.7

As indicated by the 75 percent treatment, the tomatoes responded favorably to very heavy irrigation. While this may have been the result of the frequent applications maintaining a higher relative humidity and favoring better set it also stimulated heavier vine growth and abundant flowering late in the season.

Molenoar and Vincent (38) found that 20 inches of water produced larger fruits than 11 inches of water but the smaller number of fruits contributed to a lower yield per acre. The poorer set may have been due to an over-vegetative condition brought about by heavy irrigation on a nitrogen-rich soil since it has been established that high nitrates stimulate rank growth at the expense of initial flower setting. However, Corden (17) found that light irrigations were detrimental to fruit set. Thus, it appears that either extreme in moisture supply may interfere with proper flower set.

In this study, maintenance of the available soil moisture above 50 percent of field capacity was necessary for favorable vegetative reproductive balance. Since no actual flower counts were made, further investigation is needed to confirm the effect of moisture level on flower set.

As shown by the moisture curves, the available moisture in the root zone (to a depth of 3 feet) in the unirrigated plot was almost depleted by the last of July and the precipitation in August and the first part of September was insufficient to replace it.

Variation in the moisture level in the upper 2 feet followed the rainfall and irrigation applications closely, especially in the 75 and 50 percent treatments. Fluctuations were more violent in the 25 percent treatment due to the smaller moisture reservoir. It should be noted that where the moisture was maintained above 50 percent to a depth of 2 feet, the moisture at greater depths was never depleted to a point where root damage from drying would occur.

The amount of water used by the plant increased with vegetative growth and rapid development of the fruit (Table 13). Considerable daily variation occurred, too, dependent upon the rate of transpiration as affected by day temperatures and relative humidity of the air. The moisture level of the soil affected the rate of water use of the plant since more water was used at the higher moisture levels than at the lower moisture levels. This was probably due to a higher loss from evaporation as well as a higher transpiration loss. Considering an average water use of 0.166 inch per day for the season, more than 1 inch per week was necessary to maintain the moisture reservoir. This is also shown by dividing the total water received (irrigation plus rainfall) by the duration (weeks) of the experiment.

TABLE 13 -- ESTIMATED DAILY WATER USE FOR DIFFERENT PERIODS OF THE TOMATO PLANT'S DEVELOPMENT

Date	Amount Used Per Day in 75% Plots (inches)	Date	Amount Used Per Day in 50% Plots (inches)	Date	Amount Used Per Day in 25% Plots (inches)
6/8-17	0.048	6/8-19	0.090	6/8-24	0.1475
6/17-29	0.159	6/19-7/6	0.166	6/24-7/20	0.1960
6/29-7/6	0.319	7/6-27	0.100	7/20-8/24	0.1430
7/6-17	0.1175	7/27-8/24	0.180	8/24-9/11	0.0734
7/17-27	0.2465	8/24-9/11	0.196		
7/27-8/5	0.376				
8/5-28	0.2115				
8/28-9/11	0.242				
Average/day	0.222	Average/day	0.160	Average/day	0.115
Average number of inches of water used per day (all plots) = 0.166 in.					

Porto Rico Sweet Potatoes

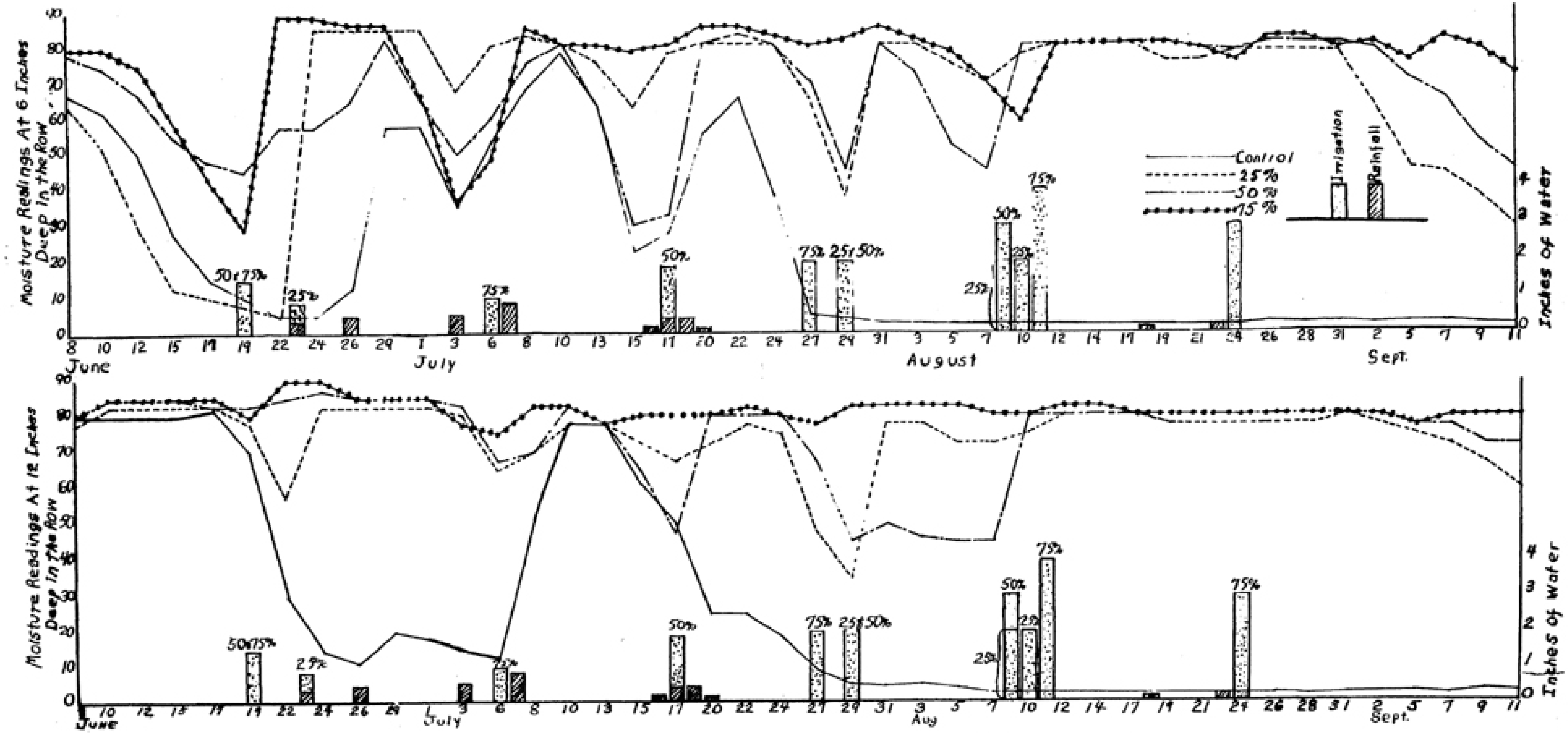
Table 14 shows that 6.5 inches of irrigation water increased the yield of sweet potatoes from 201 bushels to 280 bushels per acre —a 39 percent increase. Eight inches of irrigation water increased the yield 213 bushels per acre or 106 percent and 11.5 inches of irrigation water increased the yield 226 bushels per acre or 112 percent.

TABLE 14 -- EFFECT OF MOISTURE LEVELS MAINTAINED BY IRRIGATION ON YIELD OF PORTO RICO SWEET POTATOES AT VEGETABLE EXPERIMENTAL FIELD, CAMPBELL, MO., 1953.

Treatment	Total Irrigation Water Applied (inches)	Total Rainfall (inches)	Yield Bu. Per Acre (55 lb.) U. S. No. 1	U. S. No. 2	Total	% Increase over control based on total
Control	None	3.96	109.5	91.6	201.1	0
Available moisture maintained above						
25% F. C.	6.5	3.96	151.9	128.5	280.4	39.43
50% F. C.	8.0	3.96	240.0	174.3	414.3	106.01
75% F. C.	11.5	3.96	226.0	201.7	427.7	112.68

Since there was no significant difference in total yield between the 75 and 50 percent treatments and a slightly lower percentage of No. 1 roots in the 75 percent treatment there was no advantage in maintaining a moisture level above 50 percent in the "effective root zone". Bowers, Benedict, and Watts (9) also obtained better results at 50 than at 20 percent. Thus it ap-

SWEET POTATO MOISTURE READINGS



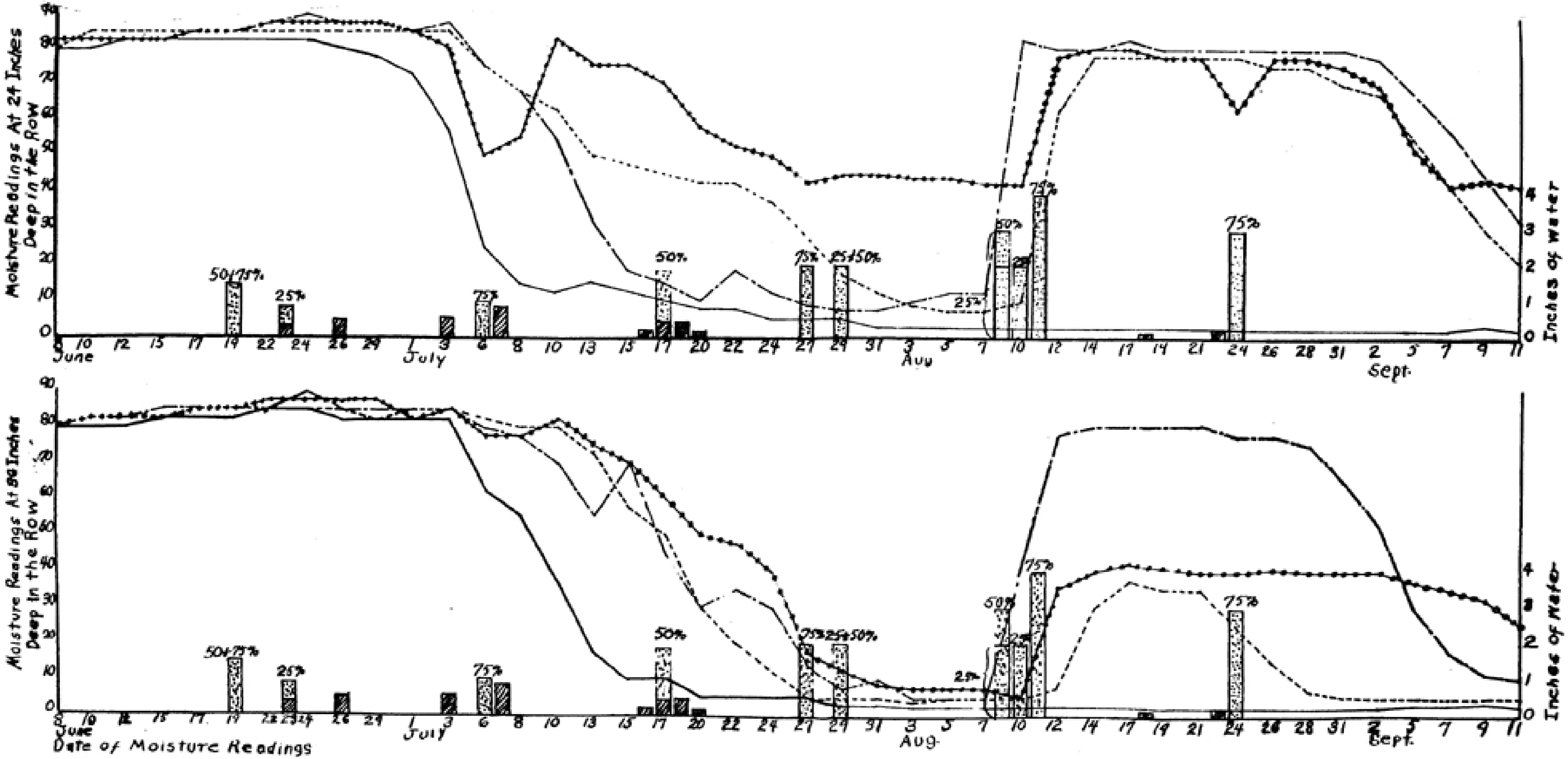

Moisture Readings At 24 Inches Deep in the Row
Inches of water
June
July
Aug
Sept.
Deep In the Row
Inches of Water
Date of Moisture Readings

FIGURE 4

pears irrigation should start when the moisture drops to about 50 percent. Although no statement was made as to the depth of block placement in their work, the 1 inch application was probably insufficient to wet the full depth of the root system.

The roots in the 75 percent treatment were stringy (long, narrow), apparently due to an over-vegetative condition of the vines.

The moisture readings graphically illustrated in Fig. 4 indicate the levels of available moisture at variable depths throughout the season for each irrigation treatment. The moisture in the unirrigated plot was almost depleted to a depth of 3 feet by the last of July, and the rainfall in August and the first part of September was insufficient to replace it.

As indicated in Table 15, the sweet potatoes showed generally about the same trends in daily water use as the tomatoes, although the daily average on all plots was 0.024 inch less for the sweet potatoes. There was also less variation in daily use between treatments.

TABLE 15 -- ESTIMATED DAILY WATER USE (INCHES) FOR DIFFERENT PERIODS OF THE SWEET POTATO PLANT'S DEVELOPMENT

Date	Amount Used Per Day in 75% Plot	Date	Amount Used Per Day in 50% Plot	Date	Amount Used Per Day in 25% Plot
6/8-19	0.0590	6/8-7/3	0.1255	6/8-7/3	0.044
6/14-7/6	0.1950	7/3-8/7	0.2410	7/3-8/7	0.143
7/6-8/10	0.1685	8/7-9/11	0.0760	8/7-8/11	0.206
8/10-9/11	0.3150				
Average/day	0.1785	Average/day	0.1460	Average/day	0.145

The average amount of water used per day (all plots) was 0.142 inches.

Red Pontiac Irish Potatoes

Because of the limited duration of drouth before maturity of the Irish potatoes the effects of irrigation were not as apparent as for the long-term crops (Table 16).

One inch of irrigation water increased the yield 29 bushels per acre (25 percent treatment). The additional 1.5 inches of irrigation water added to

TABLE 16 -- EFFECT OF MOISTURE LEVELS MAINTAINED BY IRRIGATION ON YIELD OF IRISH POTATOES, VEGETABLE EXPERIMENTAL FIELD, CAMPBELL, MO., 1953.

Treatment	Total Irrigation Water Applied (inches)	Total Rainfall (inches)	Yield Bu./A. No. 1	Yield Bu./A. No. 2	Yield Bu./A. Total	% Increase over Control based on total yield
Control	None	0.88	94.28	32.89	127.2	0.00
Available moisture maintained above						
25%	1.0	0.88	128.2	28.9	157.1	23.50
50%	2.5	0.88	178.2	38.6	216.8	70.44
75%	3.0	0.88	176.0	41.6	217.6	71.07

the 50 percent plot increased the yield an additional 59 bushels per acre but further application of 1.5 inches of water (75 percent plot) was not beneficial.

Although, as suggested by Hazen (24), the greatest need for water is when tuber growth is rapid, these results indicate late irrigations are also somewhat beneficial. Where a relatively constant moisture supply was maintained, there was little cracking and second growth.

The shallow-rootedness of the potato plant was readily shown by a comparison of the moisture curves at the four depths. The greatest fluctuations in moisture occurred at the 6-inch depth with very little change beyond the 12-inch depth. It is likely that the hard plow-sole layer confined most of the roots to the upper 6 to 8 inches.

As with the sweet potatoes there was no advantage in maintaining the moisture in the principal root zone above 50 percent of field capacity.

Response of Deep Rooted Vegetables to Depth of Wetting (1954)

A study was conducted during the summer of 1954 to determine the relationship of depth of soil wetting and response of two deep rooted vegetables—sweet potatoes and cantaloupes. It was also desirable to establish the approximate rate of water use by these crops at different stages in their development and at different soil moisture levels. This information, together with knowledge of the texture and moisture properties of the Lintonia soil was necessary to determine the amounts and frequency of application for best irrigation efficiency.

The electrical method of soil moisture measurement employing the use of gypsum soil blocks provided a satisfactory means of tracing moisture changes in the root zone, the depth of wetting, and rate of moisture depletion. Inasmuch as the Delmhorst moisture detector does not read the percentage available moisture directly on all soils, the meter readings were calibrated against the moisture percentages as determined by oven drying.

Experiment Plan

The moisture blocks were buried in the root zone, one each, at 1 foot, 2-foot, and 3-foot depths, three replications of blocks to each plot.

The irrigation treatments were:

Unirrigated.

Available Moisture maintained above 40 percent of F.C. —

—to depth of 1-2 feet.

—to depth of 2-3 feet.

—to depth of 3-4 feet.

When the averaged readings of the moisture blocks at a given depth indicated the moisture was 40 percent of field capacity, sufficient water was applied to wet the soil to that depth.

Purdue 44 cantaloupes were planted on April 15. The first irrigation was on July 7 and the last on August 8. The harvest period extended from July 31 to August 8.

Porto Rico and B4570 sweet potatoes were transplanted on May 5 and all treatments immediately irrigated to reduce losses in stand. The next irrigation (to irrigated plots only) was on June 30. Irrigation was discontinued on September 3. The B4570 variety was harvested on September 17 and the Porto Rico variety on October 10. The roots were graded according to the U. S. Standard grades.

Moisture Block Calibration

A representative sample of soil was taken from the sweet potato plot at depths of 0-1 foot, 1-2 feet, 2-2¾ feet and 2¾-3½ feet. The soil from each zone was partially dried, sifted through an eight-mesh screen and thoroughly mixed. Bouyoucos and Delmhorst moisture blocks were then embedded in soil from each zone and the meter readings over the entire moisture range plotted against the moisture percentage as determined by oven drying.

Three different techniques were used (13), two of which involved growing plants.

Field Capacity, Volume Weight, and Density Determinations

The soil characteristics were determined for both disturbed and undisturbed samples from the soil profile to compare their values. Standard laboratory techniques were used.

Evapotranspiration

Evapotranspiration, the amount of water evaporated from the soil and transpired by the plants during the season, was determined by two methods.

Method I

The first method entailed selecting periods from the soil moisture curves for the cantaloupes and sweet potatoes when the moisture blocks at the 1, 2 and 3-foot zones indicated the soil was below field capacity and on the drying cycle. Then by converting block readings to percentage moisture, the total inches of water used from the beginning of a period to the end of that period could be determined. The periods were short since they were sandwiched in between irrigations or rainfall.

Method II

Longer periods of time were selected for the second method. Evapotranspiration rates were determined by the following formula as described by Land and Carraker (32):

$$A = \frac{(B - C + (D + E) - F}{G}$$

Where A = evapotranspiration rate in inches per day
B = available soil moisture in inches at the beginning of the period
C = available soil moisture in inches at the end of the period
D = inches of rainfall during the period
E = inches of irrigation during the period
F = inches of runoff during the period
G = number of days in the period

In both methods it was assumed that the 12 inches of soil above a moisture block was at the same moisture percentage as that which the block indicated. No provision was made for the moisture transpired from below 3 feet.

Weather for the 1954 Season

The summer of 1954 was the hottest and the driest in Southeast Missouri since accurate weather records have been taken.

The severity of the drouth is apparent in the rainfall data, Table 17. No rain fell in June, only a small amount in July, and not until August 20 was there an effective rain.

TABLE 17 -- RAINFALL DURING THE SUMMER GROWING SEASON AT THE EXPERIMENTAL FIELD, CAMPBELL, MISSOURI, 1954

Date		Inches
July 5		.23
July 22		.40
Aug. 1		.25
Aug. 6		.33
Aug. 20		2.14
Sept. 7		.12
Sept. 21		2.40
	Total	5.87

TABLE 18 -- DATES AND AMOUNTS OF IRRIGATION FOR THE SWEET POTATO PLOTS

	Water (inches) per indicated plot		
Date	1-2 ft.	2-3 ft.	3-4 ft.
June 30	2.30	2.30	2.30
July 12	1.35	1.35	1.35
July 21	1.35	2.71	3.79
July 31	1.35		
Aug. 3		2.43	
Aug. 11			3.25
Aug. 14	2.03		
Aug. 16		2.71	
Aug. 18			2.03
Sept. 3	1.35	1.35	1.35
Total	9.73	12.85	14.07

During the period June 18 to September 16, there were only 11 days when the maximum daily temperature fell to 90° F. or below and then for not more than two consecutive days.

The dates of irrigation and amounts of water applied at each irrigation are shown in Table 18.

Six irrigations were applied at an average interval of 13 days. One irrigation could probably have been eliminated if it had been known that the rain on August 20 was to occur.

Results

Correlation Between Delmhorst Meter Readings and Available Moisture

The percentage of available soil moisture, which is indicated by Delmhorst meter readings, is shown in Figure 5 for each of the soil depths studied.

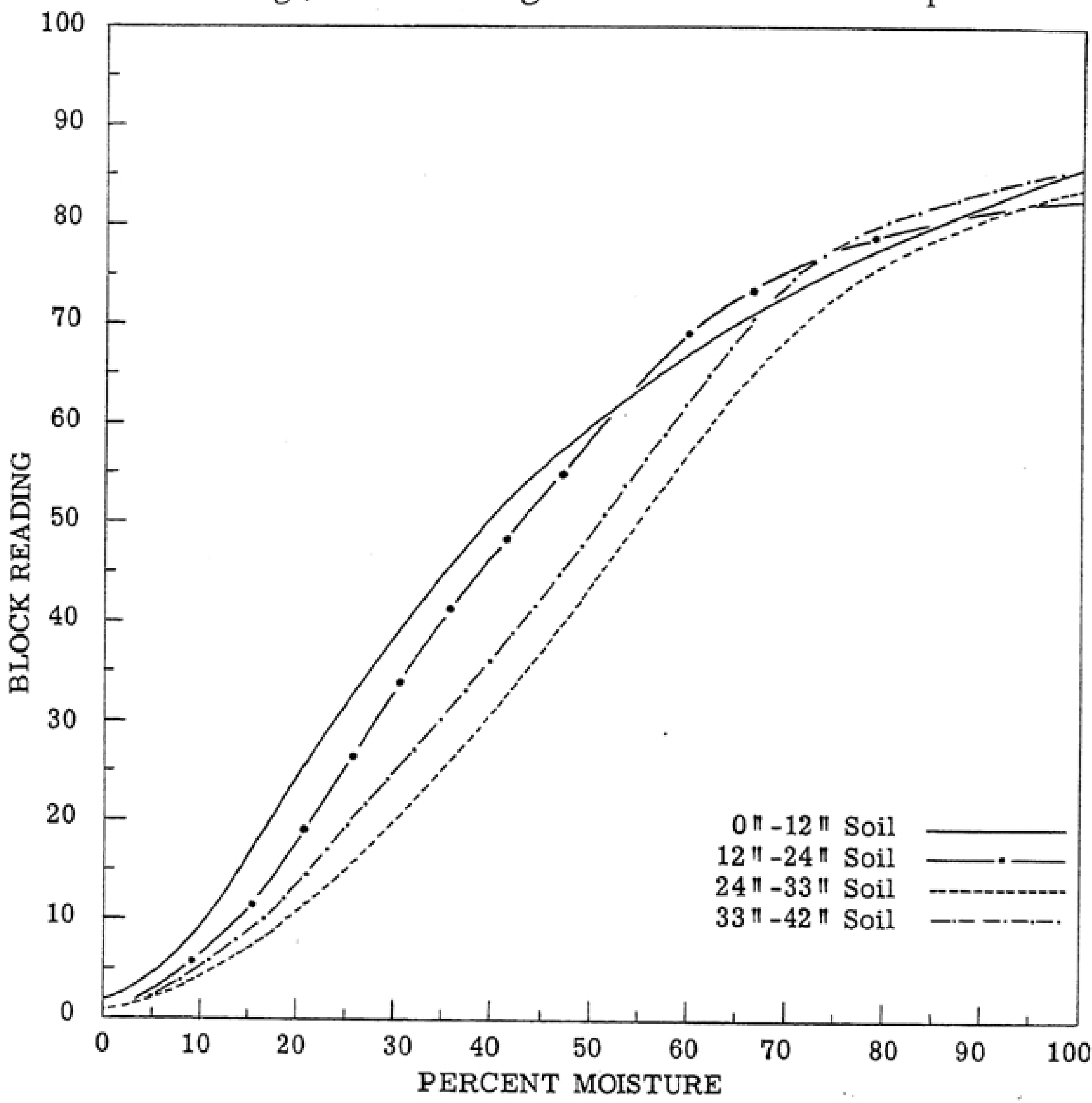


Figure 5 -- Correlation between Delmhorst meter readings and the percentage of available moisture in Lintonia fine sandy loam soil.

Delmhorst meter readings below 75 approximately indicate the percentage of available water in the soil. The heaviest soil, at 33 to 42 inches, most closely approximates this trend, and the 0 to 12-inch soil shows the most deviation from it. As a result, it follows that the Delmhorst meter readings were good enough for a practical irrigation study on this soil type without a calibration study being made.

The data in Figure 5 were used in the determination of the evapotranspiration rates reported for the cantaloupes and sweet potatoes.

Soil Texture and Moisture Characteristics

Table 19 gives the soil separates as determined by the beaker method and classified according to the Soil Conservation Service standards (28).

TABLE 19 -- PERCENTAGE OF SAND, SILT AND CLAY IN LINTONIA FINE SANDY LOAM, CAMPBELL, MISSOURI

Depth of Sample	Sand	Silt	Clay	SCS designation
Undisturbed soil samples				
6 in.	84.9	13.7	1.4	Loamy Sand
12 in.	63.0	30.7	6.3	Sandy Loam
18 in.	63.5	29.5	7.0	Sandy Loam
24 in.	63.4	30.5	6.1	Sandy Loam
30 in.	60.6	31.9	7.5	Sandy Loam
36 in.	19.6	64.4	16.0	Silt Loam
Disturbed soil samples				
0-12 in.	79.1	18.5	2.4	Sandy Loam
12-24 in.	63.8	31.0	5.2	Sandy Loam
24-33 in.	56.8	34.4	8.8	Sandy Loam
33-42 in.	37.6	48.5	13.9	Loam

Sand was determined as particles larger than 0.06 mm., silt between 0.06 to 0.002 mm., and clay less than 0.002 mm. The data for the undisturbed soil samples indicate that the surface 6 inches of the soil is of a more sandy nature than the remainder of the profile. The 12 to 30-inch portion is similar in texture throughout its depth. At 36 inches, considerable clay and silt are encountered. This silt layer evidently is thin as the disturbed soil samples at 33 to 42 inches are classified as a loam. Iron concretions and grey mottlings were encountered at about 33 inches. This extended through the maximum depth sampled.

As will be noted later, these textural characteristics can be associated with the aeration and water relationships, and likely affected the root development.

Soil and water data on Lintonia fine sandy loam are presented in Table 20. These figures show that at field capacity, there was only 9.08 percent of air space at the 36-inch depth. This indicates a waterlogged soil condition in which root growth may be inhibited (20).

Table 21 shows the relationship between field capacity, wilting percentage, and moisture block readings.

TABLE 20 -- DATA OBTAINED FROM SOIL SAMPLES TAKEN FROM LINTONIA FINE SANDY LOAM, CAMPBELL, MISSOURI

Soil Depth	Hygroscopic Moisture %	Density	Volume Weight	W. P. % by wt.	F. C. % by wt.	Solids, % by Volume	Water, % by Volume at F. C.	Air Space % at F. C.
Undisturbed soil samples								
6 in.	.2840	2.6346	1.51	3.51	8.39	57.31	12.67	30.02
12 in.	.4715	2.6243	1.58	4.87	11.02	60.21	17.41	22.38
18 in.	.4976	2.6346	1.42	4.98	11.15	53.90	15.83	30.27
24 in.	.5609	2.6362	1.44	6.38	12.85	54.62	18.50	26.88
30 in.	.7931	2.6307	1.48	8.83	15.76	56.12	23.32	20.56
36 in.	2.1620	2.6024	1.38	18.20	27.46	53.03	37.89	9.08
Disturbed soil samples								
0-12 in.		2.6295	1.58	3.81	8.91	60.09	14.08	25.83
12-24 in.		2.6317	1.52	5.67	12.05	57.76	18.32	23.92
24-33 in.		2.6334	1.47	7.59	14.18	55.82	20.84	23.34
33-42 in.		2.6166	1.21	13.94	22.16	46.24	26.82	26.94

TABLE 21 -- FIELD CAPACITY BY TWO METHODS, WILTING POINT AND METER READINGS AT EACH MOISTURE PERCENTAGE FOR THE DISTURBED SOIL SAMPLES

	Soil depth in inches			
	0-12	12-24	24-33	33-42
Field Capacity (Soil dried until a 1/4-3/8 in. crust formed)	8.91	12.05	14.18	22.16
Bouyoucos block readings	100	95	100	100
Delmhorst block readings	86	83	84	86
Field Capacity (Soil columns)	11.44	11.64	14.15	22.63
Bouyoucos block readings	80	75	87	95
Delmhorst block readings	77	75	80	85
Wilting Points	3.81	5.67	7.59	13.94
Bouyoucos block readings	0	0	0	0
Delmhorst block readings	2	1	1	1

The field capacities by the two methods were practically the same except for the top foot of soil. The 8.91 percent value is believed to be more nearly correct than 11.44 percent since a study of the soil separates in Table 17 reveals that a greater percentage of sand and a lesser percentage of silt and clay are contained in the upper foot of soil, compared to that in the second foot. Field capacities for the undisturbed soil samples in Table 18 at the same depth also more closely agree with 8.91 percent. Therefore, the values obtained by drying soil in front of a fan were used in preference to the soil columns for the calculations.

From these values calculations were made to determine the inches of available water contained in the top 3 feet of the profile (Table 22).

TABLE 22 -- INCHES OF AVAILABLE WATER AT FIELD CAPACITY AS DETERMINED FROM SOIL TAKEN FROM A LOCATION IN A SWEET POTATO PLOT

Soil depth	Inches of available water Undisturbed soil samples	Inches of available water Disturbed soil samples
0-1 ft.	1.03	0.97
1-2 ft.	1.11	1.16
2-3 ft.	1.29	1.17
Total	3.43	3.30

The values are similar for both the disturbed and undisturbed soil samples. The available water per foot slightly increased with soil depth. The values for the undisturbed soil samples were used in calculating the water relationships.

Response of B-4570 and Porto Rico Sweet Potatoes to Depth of Irrigation:

The sweet potato yields as related to irrigation treatments are shown in Table 23.

TABLE 23 -- YIELD OF SWEET POTATOES WHEN IRRIGATED TO VARYING DEPTHS, CAMPBELL, MISSOURI, 1954

Depth Soil Wetted Above 40% of F. C.	Yield in Bushels Per Acre and the Percent of the Total Represented by Each Grade						
	No. 1	%	No. 2	%	No. 3	%	Total (Bu.)
Porto Rico Variety, Harvested Oct. 10							
None	91.22	64.7	20.66	14.6	29.13	20.7	141.01
1-2 ft.	274.32	77.9	38.71	11.0	39.21	11.1	352.24
2-3 ft.	278.00	76.7	41.17	11.4	43.24	11.9	362.41
3-4 ft.	278.21	76.5	41.93	11.5	43.65	12.0	363.79
B-4570 Variety, Harvested Sept. 17							
None	30.26	36.2	22.85	27.3	30.56	36.5	83.67
1-2 ft.	273.25	73.7	52.96	14.3	44.48	12.0	370.69
2-3 ft.	261.45	79.7	33.44	10.2	33.13	10.1	328.02
3-4 ft.	223.02	77.5	35.40	12.3	29.50	10.2	287.92

By far the greatest response shown by both sweet potato varieties was by irrigated versus non-irrigated plots. There was no significant difference in yield of graded Porto Rico roots with depth of wetting beyond 2 feet. With the B4570 variety, however, yields decreased with deeper wetting. This apparent difference in response was attributed to irregular distribution of irrigation water and to unfavorable soil texture characteristics at approximately the 3-foot depth.

The B4570 plots were adjacent to the sprinkler laterals and received more water which penetrated to a greater soil depth. Furthermore, on August 20, 2.14 inches of precipitation was received shortly after the plots were irrigated. The block readings in the B4570 plot of the 2 to 3 and 3 to 4-foot treatments indicated the soil profile was saturated to or above field capacity to a depth of 3 feet until harvest on September 17.

Analysis of the data on texture indicated a very high silt and clay percentage and a low air space percentage (9.08) below 36 inches. The iron concretions and grey mottlings in this area also were evidence of low oxygen supply. It is suggested, therefore, that the lowered yield with the heavier irrigation rates was due to low oxygen supply to the roots. The Porto Rico variety receiving less water and having more time to reduce the moisture content by reason of later maturity, was able to size its roots under more favorable circumstances.

It is apparent from these results there was no advantage in maintaining the available moisture above 40 percent of field capacity to a depth greater than 2 feet, although roots penetrated to depths of 6 feet or more. Before irrigating deeper it should be established that subsoil conditions are favorable for good drainage and adequate aeration.

Estimates of Daily Water Use by Sweet Potatoes

The amount of water utilized from the irrigation, rainfall, and soil reservoir sources and the averaged daily use for the growing season are summarized in Table 24.

TABLE 24 -- SOURCES OF WATER AND THE AMOUNT USED BY SWEET POTATOES OVER THE SUMMER GROWING PERIOD

Variety	Depth Soil Wetted Above 40% of F. C.	Sources of Water				Avg. Daily Use
		Irrigation	Rainfall	Soil	Total	
Porto Rico	None	None	5.87	3.43	9.30	
(6/19-10/10)	1-2 ft.	9.73	5.87	1.72	17.32	.152
	2-3 ft.	12.85	5.87	2.04	20.76	.184
	3-4 ft.	14.07	5.87	0.81	20.75	.184
B-4570	None	None	3.47	3.43	6.90	
(6/19-9/15)	1-2 ft.	9.73	3.47	1.72	14.92	.166
	2-3 ft.	12.85	3.47	2.04	18.36	.204
	3-4 ft.	14.07	3.47	0.81	18.35	.204

The Porto Rico variety showed a smaller average daily water consumption than the B-4570 variety, possibly due to its longer growing period in the cooler days of September and October. The B-4570 variety had sized its roots in the hotter days of August and early September. Daily consumption of the unirrigated plot was not calculated because water use from below 3 feet was not known.

Moisture curves for the unirrigated plot are shown in Figure 6. These curves dramatically picture the extent of the summer drouth and the rapidity with which the available moisture in the top 3 feet of the soil profile was exhausted.

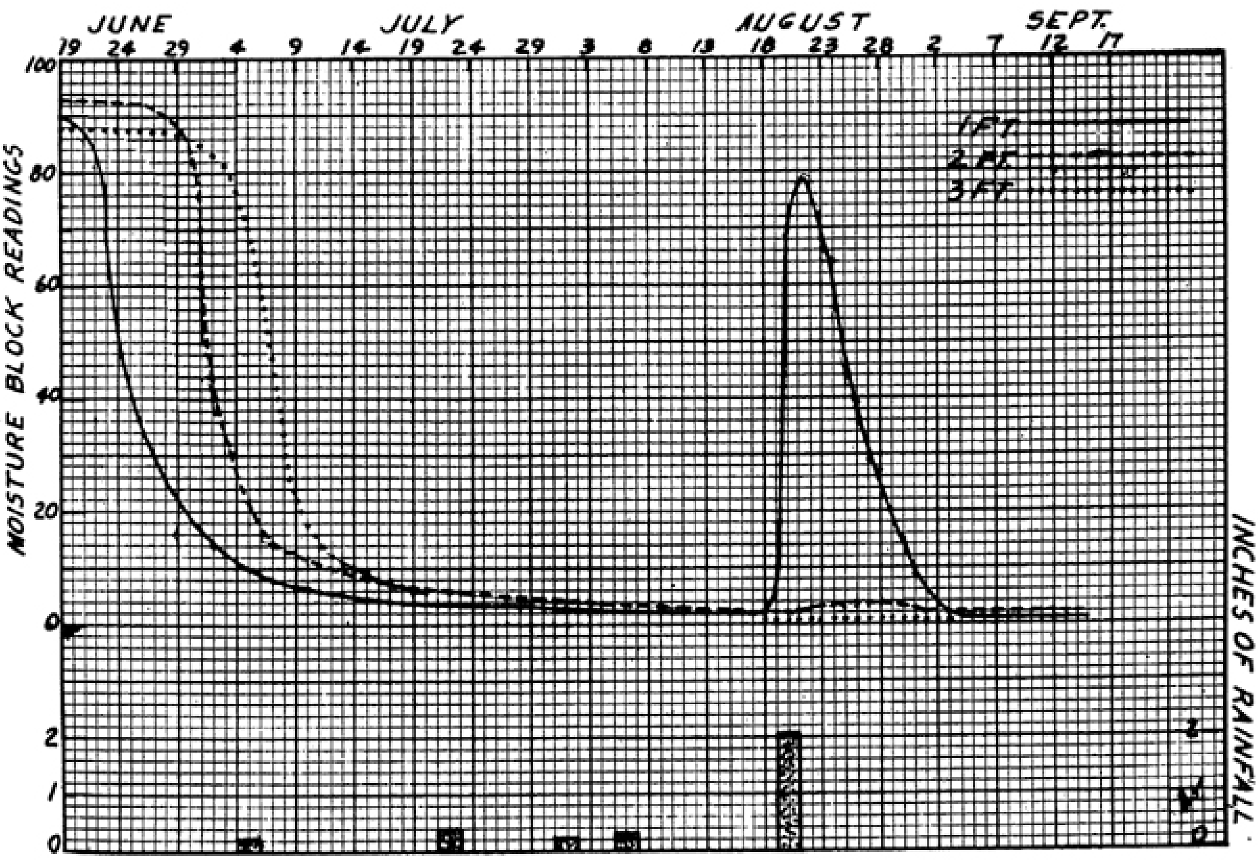


Figure 6. Soil moisture curves for the unirrigated sweet potato plot.

Table 25 shows the daily water use for short periods as determined by Method I and Table 26 that for longer periods as determined by Method II.

TABLE 25 -- DAILY CONSUMPTION OF WATER (INCHES) BY SWEET POTATOES CALCULATED FOR SHORT PERIODS

	Soil Wetted 1-2 ft. Above 40% of F. C.	
Date	Porto Rico	B-4570
June 22-29	.103	.118
July 17-20	.287	.263
July 24-30	.163	.108
Aug. 7-13	.119	.153
Aug. 28-Sept. 2	.132	.138
Sept. 9-15	.075	.063
Average	.147	.141

TABLE 26 -- DAILY CONSUMPTION OF WATER (INCHES) BY SWEET POTATOES CALCULATED FOR PERIODS THAT INCLUDED BOTH RAINFALL AND IRRIGATIONS

	Soil Wetted 1-2 ft. above 40% of F. C.	
Date	Porto Rico	B-4570
June 19-June 29	.099	.126
June 29-July 10	.269	.269
July 10-July 20	.200	.178
July 20-July 30	.244	.228
July 30-Aug. 13	.149	.141
Aug. 13-Sept. 2	.185	.171
Sept. 2-Sept. 15	.123	.122
Average	.181	.176

A comparison of these tables reveals a difference in average daily water use of 0.035 inch. Since Table 25 covers periods when the soil moisture at a depth of 3 feet was below field capacity and on the drying cycle, it is logical that evapotranspiration rates would be less than those in Table 24 which included periods of irrigation and rainfall when soil water was held with less tension.

The period of greatest water consumption occurred during the month of July when temperatures were high, days long, humidity low, and the plants were developing rapidly. During this period, applications of approximately 2 inches every 10 days were necessary to supply the water needs in the plot giving the best yield.

Response of Purdue 44 Cantaloupes to Various Depths of Irrigation

The dates and amount of irrigation water applied in the various treatments are given in Table 27.

TABLE 27 -- DATE AND AMOUNT OF IRRIGATION FOR THE CANTALOUPE PLOTS

	Water (inches) per Indicated Plot		
Date	1-2 ft.	2-3 ft.	3-4 ft.
July 7	1.74	1.74	1.74
July 19	1.71	2.79	1.71
July 31	1.45		2.79
Aug. 5		2.66	
Aug. 17			3.29
Aug. 19	1.45	1.04	
Sept. 8	1.45	1.45	1.45
Total	7.80	9.68	10.98

Five irrigations were applied at an average interval of 12 days in July when the flowers were setting and melons were sizing. One irrigation could have been eliminated if it had been known it would rain on August 20. The melons in the 1 to 2-foot plot could have been produced with irrigations totaling 6.35 inches.

The total yield for irrigated melons was approximately double that of the unirrigated (Table 28), but within irrigation treatments, yields were not significantly different. The plot wetted above 40 percent of field capacity to a depth of 1 to 2 feet, produced slightly more melons but the melons were smaller than those produced by the two deeper irrigation treatments. The unirrigated plot matured several melons a few days before the irrigated plots.

TABLE 28 -- THE EFFECTS OF IRRIGATION TREATMENTS ON CANTALOUPE PRODUCTION, CAMPBELL, MISSOURI, 1954

Depth Soil Wetted Above 40% of F. C.	Yields of 8-95 ft. Rows for Each Treatment				
	Total (lb.) Production	Total Number of Melons	Average Weight (lb.)	Marketable Melons (lb.)	Crates per Acre (60 lb.)
None	1,414	929	1.52	664	106
1-2 ft.	2,791	1370	2.04	1920	306
2-3 ft.	2,995	1328	2.26	2000	318
3-4 ft.	2,781	1248	2.22	1842	293

Determinations of the soluble solids content of the melons, taken on random samples at the full slip stage, indicated lowered solids content as the depth of irrigation was increased. This apparent association was not definitely established, however, because of the difficulty of maintaining the same degree of maturity in the samples tested.

Estimates of Daily Water Use by Cantaloupes

The soil moisture readings in the root zone for the various irrigation treatments indicated that the 2.14-inch rainfall on August 20, coming shortly after irrigating, wet the soil profile to the 3-foot depth, but apparently had little effect on cantaloupe yields as the peak production had already passed.

The amount of water utilized from the various sources is summarized in Table 29.

TABLE 29 -- SOURCES OF WATER AND THE AVERAGE DAILY CONSUMPTION BY CANTALOUPES FOR THE PERIOD JUNE 19 TO SEPTEMBER 18, 1954

Depth Soil Wetted Above 40% of F. C.	Irrigation	Rainfall	Soil	Total	Average Daily Use
None	None	3.47	3.43	6.90	
1-2 ft.	7.80	3.47	1.78	13.05	.143
2-3 ft.	9.68	3.47	1.17	14.32	.157
3-4 ft.	10.98	3.47	1.17	15.62	.172

The average daily water use increased as the depth of irrigation was increased.

Table 30 gives the daily water use for short periods as determined by Method I and Table 31 gives that for longer periods as determined by Method II.

TABLE 30 -- DAILY CONSUMPTION OF WATER (INCHES) BY CANTALOUPES CALCULATED FOR SHORT PERIODS OF TIME

Date	Depth Soil Wetted Above 40% of F. C.			
	None	1-2 ft.	2-3 ft.	3-4 ft.
July 2-12	.079			
July 9-17		.224	.234	
July 14-17				.268
July 27-30		.162		
July 28-Aug. 4			.158	
July 21-29				.152
Aug. 6-16				.139
Aug. 12-18			.186	
Aug. 26-Sept. 3	.084			
Sept. 2-6			.102	

TABLE 31 -- DAILY CONSUMPTION OF WATER (INCHES) BY CANTALOUPES CALCULATED FOR PERIODS OF TIME THAT INCLUDED BOTH RAINFALL AND IRRIGATIONS

Date	Depth Soil Wetted Above 40% of F. C.			
	None	1-2 ft.	2-3 ft.	3-4 ft.
June 19-July 7	.113	.055	.082	.105
July 7-July 17	.097	.354	.319	.192
July 17-July 30		.151		.215
July 17-Aug. 4			.161	
July 30-Aug. 16		.132		.174
Aug. 4-Aug. 17			.164	
Aug. 17-Sept. 6	.101	.151	.131	.245
Sept. 6-Sept. 18		.133	.103	.115
Average		.163	.160	.174

The values for daily consumption are scattered because there were few periods when the profile was below field capacity at a 3-foot depth and on the drying cycle.

A comparison of Table 30 and Table 31 shows a similar trend. Evapotranspiration rates were the highest during July when the melons were sizing rapidly and vine growth was vigorous. During August when vine growth had slowed and fewer fruit were being produced, daily rates were reduced.

SUMMARY AND CONCLUSIONS

The experimental evidence appears to support an earlier contention that supplemental irrigation of vegetables in Missouri and most "humid" states is an essential cultural practice for consistently profitable production. Only in a relatively few cases would the yield and quality obtained without irrigation in these tests have proven profitable on a highly competitive market. Even during years of average or above average rainfall, such as 1951, irrigation proved profitable on vegetables maturing in late summer and fall.

Weather records for the southeastern Missouri lowland area covering a period of 20 years indicate drouths of long duration and serious proportions can generally be expected in 1 out of 4 years. However, in these studies, dry periods as short as 13 days were shown to have an adverse affect upon the yields of shallow rooted vegetables, especially those flowering and fruiting during periods of high water utilization.

Precipitation in the lowland area of southeastern Missouri was shown to be heaviest and most frequent during the spring and early summer months and lightest and least frequent in September and October. Therefore, there is a greater frequency of "drouths" during the latter stages of plant development when the rate of water utilization is greatest and the reserves of soil moisture are the lowest.

Guides as to "when" and "how much" irrigation water to apply based upon previous precipitation of the season did not prove entirely satisfactory. During the early part of the growing season when the soil reserves were high, the crop requirement low, and effective rains frequent, there was danger of over-irrigating. For this reason, the usual recommendation of applying 1 inch of water when the preceding week's rainfall did not total 1 inch, was modified to that of applying 0.5 inch when the previous week's rainfall was between 0.5 and 1.0 inch and 1 inch whenever it was below 0.5 inch. But these data also show that with this practice an accumulation in 2 weeks of more than 2.5 inches of water by rainfall and irrigation (an excessive amount early in the season) can be expected in about 20 to 35 percent of the weeks. This incidence is higher in April, May and June, because of higher average precipitation.

During the latter part of the season, under conditions of high temperature, low humidity, and advanced stages of plant development, the 1 inch per week application was inadequate to maintain a favorable soil moisture supply within the rooting zone during periods of extended drouth. At this time, 1.5 inches per week proved more satisfactory.

The risk of over-irrigating early in the season and under-irrigating late in the season from applications based upon the previous 2 to 3 weeks rainfall was found to be much too great. In these experiments, basing the amount and frequency of application upon the moisture available in the principal rooting zone of the soil profile proved to be a more direct and satisfactory guide.

Previous studies of the soil moisture-plant relationship where the irrigation applications were made according to the judgment of the grower indicated a high percentage were made "too late" and "too light." Studies of soil moisture availability and movement in the rooting zone suggests why this is frequently the case. The rate of water depletion at critical periods of soil supply and plant development is generally much greater than expected with the result that plant development is affected before the grower is aware of the need of irrigation water. For example, under conditions of high moisture utilization as during the months of July and August, the reserves of available moisture in Lintonia fine sandy loam may drop from a favorable level of 40 percent of field capacity to a point near the permanent wilting percentage within a period of 3 days. The soil moisture approach to irrigation—since it takes into account the soil's reserve, the plant's ability to forage, and the rate of depletion under existing crop and weather conditions —also contributes to more efficient budgeting of water by decreasing the tendency to over-irrigate during the early part of the season when the rainfall is heavier and the crop's requirement lower.

The electrical resistance methods of moisture measurement used in this study proved to be simple, quick, and practical for collecting information that has been difficult or impractical to obtain. By averaging the readings of several moisture blocks, randomly placed within the root zone within a uniform soil area, it was possible to determine the percentage of available moisture with enough accuracy to permit it to be used as a guide for irrigation applications. However it was found that the block readings indicated the moisture only within areas in close proximity to the blocks; therefore it seemed advisable to use 3 to 5 sets of blocks at each depth for representative sampling.

Since periodic readings could be made quickly without disturbing the soil or plant root system after the initial installation, this method was particularly valuable in studying relative moisture movement, as well as in charting moisture changes after rainfall or irrigation. By placing the blocks at different depths in the rooting zone, it was possible to estimate closely the size of the moisture reservoir and calculate when moisture would limit the proper functioning of the plant. Estimates of the approximate depth and extent of rooting could also be made as the season advanced.

The importance of recognizing soil properties, particularly texture, for proper irrigation practice was demonstrated on several occasions. Considerable variation in texture and moisture properties was found with location and depth in Lintonia fine sandy loam. On an averaged basis, the soil was found to contain approximately 1.9 inches of available water per foot of depth. The presence of a thin but compact silt and clay layer at the 36-inch depth slowed the percolation of moisture to greater depths and reduced the air space at field capacity at this level to 9 percent. This suggested that reduced yields of sweet potatoes under heavy irrigation treatment may have been due to an oxygen deficiency for the roots.

Although sweet potatoes and several other vegetable species were found to root to depths of 6 feet or more in this soil, there was no advantage in wetting the soil to depths greater than 2 feet. Deeper irrigations increased the likelihood of water-logging due to heavy rains following irrigation. This resulted in reduced yields when it occurred during "fruiting" stages of plant development. Furthermore, the saving of 2 to 4 inches of water could be important when the supply of irrigation water is restricted or where pumping costs are high. With the soil profile at field capacity at the start of the season, and the moisture maintained above 40 percent of field capacity in the upper 2 feet, the subsoil moisture at greater depths was not depleted to a critical level even during the extended drouths of 1953 and 1954.

The responses of some vegetables to irrigation was limited by high summer temperatures. Thus the proper sizing of Irish potato tubers in June and the flower set of tomatoes in July and August were suppressed by high temperatures. Vegetables directly seeded in June, July and August were found to require frequent light applications to maintain a moist condition in the upper 2 inches and to prevent excessive losses from drying by high transpiration rates.

Data on tomatoes suggest the value of maintaining the available moisture well above 25 percent of field capacity in the upper 12 to 15 inches of the rooting zone. A favorable response to the higher moisture levels was apparently associated with the effect of higher humidity favoring better fruit set, as well as increasing the fruit size. Daily water use by tomatoes reached the maximum of 0.376 inch. At this rate the available moisture in the rooting zone on Lintonia fine sandy loam would be depleted from field capacity to the 50 percent level in approximately 8 days. These data suggest irrigation to supplement rainfall and provide a good wetting at transplanting time, 1-inch applications at approximately two-week intervals during late May and June, and 1.5 to 1.75-inch applications at approximately 10-day intervals during July and August.

The water utilization rates for sweet potatoes were found to vary from less than 0.1 inch per day at approximately one month after transplanting to more than 0.25 inch during periods of rapid plant development, high temperatures, and low humidity. After the vines had completely covered the soil's surface, the evapotranspiration rates more closely corresponded with weather conditions than with the stage of development of the plant. The evapotranspiration rates of cantaloupes prior to June 15 were less than 0.1

inch per day. By July 15 during the period of maximum melon sizing, 0.35 inch daily rates were indicated. Under these conditions cantaloupes and sweet potatoes would not normally require irrigation until July, except for the transplant water given the sweet potatoes at setting time. This would hold true, providing the soil profile was at field capacity to the depth of 6 feet, before planting. During July and August, 1.75-inch irrigations at approximately 10-day intervals should furnish sufficient water for maximum yields. During the early part of September, the applications for sweet potatoes may be reduced and the plant allowed to deplete the soil reservoir in preparation for harvest.

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