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Effectiveness of Evaporation from Ground and Foliage in Reducing Soil Moisture Depletion

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NAME AND ADDRESS

EFFECTIVENESS OF EVAPORATION FROM GROUND AND FOLIAGE IN REDUCING SOIL MOISTURE DEPLETION

by

Val D. Wynn

A thesis submitted in partial fulfillment
of the requirements for the degree

of

MASTER OF SCIENCE

in

Civil Engineering

UTAH STATE AGRICULTURAL COLLEGE
Logan, Utah

1954

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My sincere thanks to Dr. Vaughn E. Hansen for his suggestions and encouragement which led to the selection and completion of this project; to Dr. Orson W. Israelsen for his help in reviewing my report; and to all the members of my graduate committee for their help and suggestions.

Val D. Wynn

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INTRODUCTION

Purpose

Field irrigation efficiency is the percentage of the water delivered to the field that becomes available to the crop as soil moisture. The so-called "evaporation losses" from wetted ground and foliage are rather difficult to measure, but are estimated by Christiansen (3) to be between 15 and 30 percent. No doubt part of this may be termed as a "loss," but the other part may be incorrectly termed as such. Many authorities[1] claim that water must pass through the plant before being transpired into the atmosphere to be effectively used.

There are four predominant factors which are considered to affect the water application efficiency of sprinkler irrigation. They are:

1. Variation of individual sprinkler discharge along lateral lines.
2. Variation in water application within the sprinkler spacing area.
3. Loss of water by direct evaporation, either in the air or from plants before water reaches the soil.
4. Evaporation from the soil before the water is utilized by plants.

This experiment deals mainly with the last two factors influencing sprinkler irrigation efficiency. However, the results will not only be applicable to sprinkler irrigation, but also to rains, heavy dews, and to the water which evaporates from the ground surface following a surface irrigation. The loss of water by direct evaporation either in the air, from the plant, or from the soil is particularly important in sprinkler

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[1] No particular reference is given, but it is the consensus that direct water evaporation from the ground and foliage is of no value in reducing the soil moisture depletion.

irrigation where the irrigation generally consists of a light water application. The losses from these sources on a light application of perhaps two or three inches is a very considerable percentage of the total water applied, hence whether that water is actually lost or not makes the greatest difference when the unit application is small.

If positive results are obtained from the experiment--that is, if the evaporation is found to be effective in reducing the amount of water depleted from the soil--then field irrigation efficiency and the term effective rainfall, as they are used today, must be redefined or at least clarified. It may be possible that sprinkler irrigation and precipitation are more effective than has been recognized in the past.

Objectives

The specific objectives of the experiment were:

1. To determine the approximate extent to which direct evaporation from the ground and foliage is effective in reducing the amount of water that would otherwise have been removed from the soil.

2. To determine the effect of several factors which may influence the amount of evaporation from the ground and foliage. The main factors are (a) time rate of water application and (b) depth of water applied.

3. To make suggestions on the improvement of materials, procedure, and collection of data for an improved and more detailed study to follow.

REVIEW OF LITERATURE

Evaporation losses from wetted ground and foliage have long been considered serious. Irrigation by sprinkling has been thought to be of low efficiency because of high water losses from evaporation, and light rainfall has been considered ineffective because the moisture evaporates before entering the root zone of the soil to become available to plants as soil moisture.

Evaporation represents the movement of moisture in the form of vapor from the surface of soil particles or vegetation. Rates of evaporation depend mainly upon temperature, wind movement, vapor pressure gradient, and--probably the most important factor--evaporation opportunity.[1] Since all four elements are affected by the type and density of vegetation, any cultural or natural factors which alter vegetal characteristics will also affect the rate of evaporation.

Evaporation losses from the soil

Evaporation of water from a soil surface is so complicated that, as yet, a suitable expression of the several factors influencing it has not been found. Richards, et al. (15) discuss the factors affecting evaporation rate from the soil at the two extremes in the soil moisture range. When the soil surface is wet, evaporation is dependent on vapor pressure gradients and wind velocity in the air just above the surface, as well as

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1. Evaporation opportunity on a particular land area depends primarily on the amount of moisture available for evaporation and the manner in which it is exposed to evaporation. Thus conditions that affect moisture quantities and their exposure to the atmosphere also affect the evaporation opportunity.

the amount of radiant heat energy available. At the other extreme of soil moisture conditions, when the soil surface is very dry, the rate at which water may evaporate from the soil depends on the rate at which water moves from the lower layers into the evaporation zone[1] of the soil. For a coarse sand, the depth of the evaporation zone is about fourteen inches; for a clay, three to four feet (14).

The close dependence of evaporation upon the supply of available water is too often confused with the relation of evaporation to temperature (4, 10, 20). This error originates in the methods of determining evaporation by means of an evaporation pan with a free water surface and a plentiful supply of water (9); under such conditions water loss is closely related to temperature. Total evaporation losses are determined by the quantity of water that is available (evaporation opportunity).

The extent, variation, and rates of evaporation from the soil, as compared with evaporation from water surfaces, can be obtained only by observation. When the soil surface is moist, evaporation may be greater than from a free water surface because the soil, with its minute irregularities, presents a larger evaporating surface (19).

Studies by Blaney and Morin (2) at Carlsbad, New Mexico, show that evaporation from a U. S. Weather Bureau (Class A) pan was 92.64 inches, and from a water table two feet below the surface of the bare soil it was 31.87 inches, being a ratio between evaporation from the ground water and surface water evaporation of over 34 percent. Parshall (13) reported on a number of experiments made by himself and some made by others to determine the rates of evaporation from saturated soils and river sands. In one set of experiments he reported the ratio of evaporation from soils to

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1. The evaporation zone is the depth in the soil from which water may evaporate; it varies with all types of soil.

that from free water surface to range from 14 to 93 percent for water depths beneath the soil surface of one to 12 inches in various types of soil. In a later set of experiments he reported ratios ranging from four to 109 percent. These experiments show that determination of evaporation from soils is further complicated by considerable variation in soil types and conditions. These experiments also show that loss of soil moisture decreases as the depth from the surface of the soil to the available water increases.

Evaporation and transpiration do not reach to equal depths in most soils. According to Russel (17), unless the soil is loose in structure or cracked, water losses by evaporation are generally limited to the first foot of soil. Transpiration can generally dry out the soil to a greater depth as determined by the depth and extent of the roots. For example, during a prolonged drouth at Rothamsted (England), no water was lost from a bare plot below 18 inches; in a neighboring plot, however, a crop of barley had reduced the water content to a depth of 45 to 54 inches. It must be kept in mind, however, that comparisons between evaporation from a bare soil and transpiration serve merely to indicate the manner and magnitudes of water losses.

Interception and subsequent evaporation from vegetation

There is always interception of water by plants, either during rainfall or sprinkling, part or even all of which may be evaporated before reaching the soil. Clark (4) made several determinations of the maximum amount of water retained by plants; this interception capacity is usually less than 0.1 inch of water.

Musgrave and Norton (12) came to the following conclusions in their experiments:

> Actual measurements show that the amount which may be

> retained on the canopy of vegetation varies widely in accordance with the vigor and density of the vegal cover and also with the character of the storm. It is possible that agricultural crops seldom intercept more than 0.5 of an inch of water, and usually much less than this is held by plants above the surface of the ground. The amount of evaporation during a storm is relatively small.

The total interception throughout a storm consists of two parts: (a) that required to satisfy the surface storage of the vegetation, and (b) that which evaporates during the period of rainfall.

According to Linsley, <u>et al</u>. (10), interception by some types of cover amounts to a considerable portion of the annual rainfall. Since interception is essentially satisfied during the first part of a rain in most storms, and since most storms yield only small amounts of precipitation, interception by forest or other dense cover commonly amounts to 25 percent of the annual precipitation.

After the vegetation is saturated, the net interception would be expected to be zero if it were not for the fact that even during a storm there is considerable evaporation from the wet surface of the foliage. Therefore, the amount of water reaching the soil after interception storage has been satisfied, is rainfall minus evaporation. After the rain has ceased to fall, the vegetation still retains the interception storage, which is eventually returned to the atmosphere by direct evaporation. Musgrave, <u>et al</u>. (12) concluded that the amount of evaporation during a storm is relatively small.

Maximum interception by vegetation from either rain or sprinkling is about the same, but the conditions under which application is made are entirely different. According to Code, <u>et al</u>. (5), rain always occurs under cloud cover with temperatures less than maximum. Sprinkling often must be done during the day with temperatures of 100° F. or more. Nighttime sprinkling provides a close approximation to natural rain.

Lyon, *et al*. (11) say:

> Surface evaporation affects water that might otherwise be used readily by the crop, and thus the competition is direct and often disastrously keen. Moreover, evaporation losses frequently are at their maximum at the time that crop demands are greatest.

Evaporation from rainfall

Israelsen (8) says, "After light showers during the growing season the water lost by direct evaporation from the leaf surfaces and from the ground surface serves little, if any, useful purpose."

Barrett and Milligan (1) give the following definition of effective precipitation:

> Effective precipitation is the amount of precipitation assumed to reach below the evaporation depth in the soil, all of which becomes available to plant use or soil moisture increase in the root zone of the plant or as ground water storage. (It varies with the climate, the aerial growth of the plant, and its effect on rain interception, shading of the soil, and with the root habits, whether shallow and spreading or more local and deeply penetrating.)

In their report the maximum evaporation from any rain was estimated not to exceed 0.5 inch for alfalfa, pasture, grain, and native vegetation, and 0.3 inch for row crops. Moisture already in the evaporation zone of the soil was added to the measured rainfall for any storm. For example, if there were 0.2 inch of water in the evaporation zone of grain, and rainfall amounted to 0.4 inch, 0.1 inch of moisture would go to soil moisture storage (assuming 0.5 inch lost by evaporation).

Russell, *et al*. (18) made extensive studies at the Nebraska Agricultural Experiment Station concerning evaporation losses from precipitation. The following data show the magnitudes of evaporation losses in tests at Lincoln:

a. 16.31 inches per annum or 59 percent of the precipitation during four years of test with a corn, oats, wheat rotation by conventional tillage methods.

b. 10.82 inches per season, or 78 percent of the precipitation during four years of test with bare summer fallow by conventional tillage.

c. 11.21 inches, or 79 percent of the precipitation during a 211-day period in 1941. This test was conducted in cylinders and evaporation losses were determined by direct weighing.

d. 6.47 inches, or 75 percent of the precipitation during the period January 1 to May 3, 1945. This test also was conducted in cylinders.

e. 0.029 inches of loss per 24-hour day from snow as an average for fifteen tests in 1941, 1942, and 1945.

The evaporation from a bare soil at Rothamsted (England) lysimeters (7) averaged 14.7 inches annually and showed little variation from year to year in spite of a considerable range in precipitation. The average rainfall for the period of experimentation was 28.8 inches. On this basis, nearly 50 percent of the rain was lost as evaporation.

Rowe (16) carried on investigations at the California Forest and Range Experiment Station concerning the influence of forest-vegetation and land-use on evaporation-transpiration losses. These studies were carried on under conditions of heavy rainfall in the winter and very light rainfall in the summer. The interception losses due to direct evaporation from the vegetation were much lower than previously estimated:

> In moderately dense stands of chaperral, annual evaporation losses from interception have averaged only four to eight percent (1.5 to 2.0 inches) of the total precipitation. In a 60 to 80 year old, fully stocked stand of ponderosa pine the losses were somewhat greater but averaged less than 15 percent (7.5 to 9.0 inches) of the total annual precipitation.

As had been shown, the opinions of effective rainfall have a wide variance. Many farmers comment on how much better their crops look after a light storm, but the general thought is that any rainfall less than one-half inch is of little, if any, value.

Evaporation from sprinkling

There are certain losses that occur in sprinkling that must be taken into account. The principal losses are evaporation between the time the water leaves the nozzle and the time it reaches the ground or foliage, and evaporation from the wetted ground and foliage. Evaporation before the water reaches the ground or foliage has been shown by Christiansen (3) to be on the order of two percent providing the spray remains in the form of drops; this loss may be greater if the spray is broken up into a mist. Evaporation losses from the wetted crop is a much larger item; these losses vary considerably and are estimated to be between 15 and 30 percent. Christiansen (3) says:

> Since water is sometimes applied with sprinklers at rates as low as 0.10 inch per hour, an appreciable evaporation loss may occur during and immediately after an application. Even with application rates of 0.25 to 0.50 inch per hour, more than 10 percent of the water may evaporate as it is applied during the afternoon. The evaporation loss at night, however, is usually very low.

The evaporation losses from wetted ground and foliage are difficult to estimate or measure, and probably vary in different localities of sprinkler use and with each season of the year. In the western part of the United States it is commonly thought that at least one-half inch of water evaporates from the soil and crop during or after each sprinkler irrigation without being of any value. In the south-western United States, with its higher temperatures, the evaporation losses from each sprinkler irrigation are estimated to be as high as three-quarters of an inch of moisture. The evaporation during and after sprinkling could be serious and represent a great economic loss if the evaporation from soil and vegetation is a "true loss."

PROCEDURE

Gypsum (Bouyoucos) blocks[1]

Gypsum blocks were used as the principal instrument to measure the moisture content of the soil, from which any change in the moisture content could be detected. Gypsum blocks usually do not give an accurate account of the soil moisture content with soil moisture tensions of less than approximately 1.5 atmospheres. It was, of course, realized at the time this experiment was designed that gypsum blocks are insensitive to moisture changes in the wetter soil moisture range. However, this type of block was purposely placed where large daily water applications were to be made, because it was not known at the time how effective daily water applications would be in reducing the soil moisture depletion. It was discovered later in the season that these wetter sets could not be used to evaluate the evaporation effectiveness because of the wet condition of the soil and the resulting insensitivity of the blocks. Because of the deep percolation of water under wet soil conditions, the experiment was designed to disregard the moisture data obtained under wet soil conditions. Hence, where this occurred, it was not necessary to secure accurate moisture measurements.

Gypsum blocks are porous blocks made of plaster of paris. Inside of the block are embedded two electrodes with leads. Such a block, when buried in the soil, absorbs moisture from the soil and gives it up to the soil very readily so that its moisture content tends to be in equilibrium

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[1] The author made all of the gypsum blocks in the U.S.A.C. Soil Physics laboratory, using the procedure developed in that laboratory.

with the moisture content of the soil. The electrical resistance of the block varies with its moisture content, and in turn varies with the moisture content of the soil. Gypsum blocks are rather inexpensive to make and can be made in most laboratories.

Three hundred twenty-four (324) blocks were made for the experiment. There were 27 sets with 12 blocks per set.

The leads from the blocks were made of ordinary light-cord or "whipcord" and were of such length that when the blocks were buried to the desired depth in the ground, that portion of the leads above the ground was approximately 10 feet.

The electrodes to be placed inside the blocks were bared and given a lead coating;[1] these electrodes must be straight and parallel to each other when placed in the form. Every bag of gypsum varied in moisture content and required trial mixtures to insure consistency; each batch of gypsum must also be mixed with water for the same time period. The blocks were removed after being in the forms for approximately one hour.

The blocks were allowed to cure for at least two days before being tested. When testing the blocks, they were placed in tap water and allowed to become thoroughly saturated before being read with the resistance bridge. Blocks that did not fall within certain limits[2] were discarded; nearly 22 percent, or 70 of the original 324 blocks, were broken and remade.

The blocks were then sorted into 27 sets (12 blocks per set), placing blocks that had similar resistance readings in the same set. The 24 wires

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1. Approximately three inches of each wire was bared and dipped in molten lead. The electrodes were cut to the proper length before being placed in the form.
2. These limits were determined by the resistance reading produced by the majority of the blocks.

from the 12 leads (two wires per lead) of each set were then soldered to a 24-connector (male type) "Jones plug." The "Jones plugs" kept the wires from each set in the same order and also helped in reading the blocks, as will be described later.

Placing blocks and leads in the field

The experimental plots were located on the U.S.A.C. Agricultural Experiment Station's Greenville Farm. The soil type for the plots used in this study is classified as Millville silt loam. It is a deep soil, rather uniform in texture and well drained. Figure 1 (Appendix A) gives a view of the plots showing the corrugated metal shields, the crop, and a row of cans on plot 1. The general plot layout was as shown in Figure 2, and the detailed layout of sprinkling equipment and gypsum block arrangement in Figure 3.[1]

All sets of blocks were placed on a radius of the arc made by the sprinkler head (see Figures 2 and 3); the first set was placed 15 feet along the radius and the last set 45 feet from the sprinkler head. The sets were equally spaced between the 15 and 45-foot points.

The holes for the blocks were made with a four-inch soil auger to a depth of six feet. The blocks were placed in a horizontal position at six-inch intervals and the soil was replaced in the holes at approximately the same depth as removed. Tamping of the replaced soil was not necessary to obtain the desired soil density.

All leads were buried six inches below the soil surface for a distance of approximately 10 feet from the blocks. Three sets of leads were combined at a point for ease in reading, making a total of three reading points on each plot. A plastic bag was placed over each set of

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[1] Figure 3 does not completely show plot 2, but only sets 4 to 9.

three "Jones plugs" for their protection.

Sprinkling equipment

Figure 4 shows the type sprinkler head used and the corrugated metal shields. Figure 5 gives the arrangement of the pump, valves, and gauges.

Three different full-circle sprinklers[1] were used for water application. The distribution patterns and operating pressures are as shown in Figure 6. Corrugated metal was placed in a vertical position so that each full circle sprinkler would apply water to only one quadrant (their respective plot). Trenches were made to catch and drain the runoff from the metal shields.

Each sprinkler head was provided with a regulating valve and pressure gauge. By regulating the pressure with their respective valves, any or all of the sprinklers could be used simultaneously. The pipe and fittings used between the pump and sprinkler heads were one-inch in diameter.

The water supply was brought to the pump by a three-inch aluminum pipe. A waste-way from the pump was also provided to dispose of any excess water. The pump shown in Figure 5 was used mainly for "booster" purposes. At least 60 pounds per square inch pressure was needed to operate all three sprinklers at one time, and the small pump could produce only 30 p.s.i. pressure; when more than 30 p.s.i. pressure was required the additional pressure was received from one of the large pumps used for the irrigation of the farm.

Measurement of water application

For an accurate measure of water application, No. 2 fruit cans

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[1] RAIN BIRD sprinklers were used on all plots and were as follows:
Plot 1 - No. 40 Standard, 1/4 by 7/32;
Plot 2 - No. 40W, 3/16 by plug;
Plot 3 - No. 40 Standard, 13/64 by 5/32.

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(Figure 7) were used. Two rows of cans[1] --one row on each side and the same distance from the sprinkler heads as the nine sets of gypsum blocks--were used, making a total of 18 cans per plot. A funnel was soldered flush with the top of each can with a hole in the bottom so water could drain into the can and a hole in the top for removal of water. These cans were held on a stake with an elastic band and could be raised easily to keep the top of the can on the same level as the crop height.

Crop

The crop planted on all four plots was barley (Bonneville variety). Barley was chosen because of the lateness of the season. This crop matured with an expanding root zone throughout the summer and did not need to be disturbed during the growing season.

The barley was planted on June 15th in six-inch rows, using a one-row hand drill. No fertilizer of any kind was applied. Figures 9 and 10 show the barley as it was coming into head.

Reading the blocks

A Coleman resistance bridge was used for reading the blocks. This bridge was calibrated to read the soil moisture tension directly in atmospheres.

Two one-pole, 12-position switches[2] were connected to a 24-connector (female type) "Jones plug" to use in reading the blocks. It was then possible to connect the male type "Jones plug," which was on all 27 sets

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1. Two, rather than one, rows of cans were used on each plot for a better measure of application. The average depth of the water contained in each pair of cans gave an accurate measure of water applied. One row of cans could have been used if they had been placed directly over the blocks, but the crop, and hence the root system, would have been disturbed when measuring the water contained in the cans.
2. One two-pole, 12-position switch would have been better, but was not available.

of blocks to the female type "Jones plug," and by regulating the switch, read any desired block in each set. The switch and "Jones plugs" made only one connection necessary for reading each set of 12 blocks. Figure 8 shows the bridge and switch used in reading the blocks.

A form (Table 1[1] of Appendix B) was prepared for recording the block readings. Space was also provided for daily water application, other sprinkling data, weather data, and for the conversion and totals of block readings to inches of water contained in the root zone of the soil. One page was required for the reading of each plot.

<u>Determining daily water requirements</u>

The daily water requirements, or consumptive water use[2], was determined mainly from the plot[3] as shown in Figure 2. This experiment was conducted by Mr. U. A. Patil. Mr. Patil's plot contained 13 sets of gypsum blocks buried to a maximum depth of eight feet in six-inch intervals. Block readings were taken about every day and the daily average reading (atmospheres of tension) computed for each depth. From the daily average block readings the daily moisture depletion from the soil could be computed, which is the daily consumptive water use.

The daily consumptive use may vary by as much as 50 percent from day to day, depending mainly on several weather factors. The ratio of daily consumptive water use to daily evaporation from a water surface was, however, approximately a constant (Figure 11). This ratio at the

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[1] The form shown in Table 1 is a typical sheet used for collecting the data. The data sheets from all three plots are available in the Irrigation and Drainage Department at the U.S.A.C. in Logan, Utah.

[2] Consumptive water use is the total amount of water taken up by vegetation for transpiration or building of plant tissue plus the evaporation of soil moisture, or intercepted precipitation.

[3] Mr. Patil's plot was not given daily applications, but was irrigated only when the crop began to show a need for moisture.

beginning and end of the season was less than one-half[1] for all three comparisons. All curves in Figure 11 reached a maximum during mid-August, when the barley heads were filling out and developing most rapidly. These curves were used to estimate the consumptive water use for periods that Mr. Patil could not furnish the necessary data.

Three types of evaporation pans were provided near the experimental plots. They were:

1. A U. S. Weather Bureau Class A pan[2];
2. Fifty-five gallon metal barrel, painted aluminum color inside and out;
3. Fifty-five gallon metal barrel, painted black inside and out.

The two fifty-five gallon barrels used were of normal height and kept entirely above the ground surface. Each barrel was also screened across the top and provided with a stationary hook gauge, so that the water could be maintained approximately three inches from the top of the barrel. The barrels were essentially "Young" evaporation pans, set on top of the ground rather than being buried in the ground. They were set on top of the ground in order to secure a more consistent exposure condition and a condition which earlier observations indicated would be perhaps more representative of crop consumptive water use.

The basic data used for computing the three curves in Figure 11 were Mr. Patil's soil samples and block readings, and from soil samples and block readings after water application had been discontinued on the plots used in this experiment. A more detailed analysis of the results obtained from the three evaporation pans is to be presented by Mr. Patil

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[1] i.e., daily consumptive water use was less than one-half the daily evaporation from a water surface.

[2] There is an official U. S. Weather Bureau Station located at the farm where this experiment was conducted.

in his Masters' Thesis.

The author realizes that the normal consumptive water use-evaporation ratio may not produce smooth curves, as shown in Figure 11, but evaporation is the best index of the consumptive water use of all factors available.[1] The black barrel produced the smoothest curve of the three comparisons; its color gave the barrel greater sensitivity to temperature changes and was more representative of the plant leaf color than the other two evaporation measurement devices.

Application of water

An initial plot saturation, using perforated pipe, was made on July 2. Sprinkler application began July 3 and was discontinued on September 11. Water was applied on only one Sunday, and wind[2] would not permit application on several other days.

As shown in Figure 6, the sprinkler distribution patterns for each sprinkler differ somewhat from each other, with the greatest rate near the sprinkler head. The applications would vary[3] from approximately 25 percent to several hundred percent of the daily normal consumptive use. Each plot received approximately the same amount of water per day, but the time length of application of the water varied somewhat.[4]

As was previously stated, the consumptive water use may vary

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[1] Experiments have shown that solar radiation is slightly better than evaporation for determining the consumptive water, but this data was not available for the Logan area.

[2] Even a light breeze will distort a sprinkler distribution pattern so that uniformity cannot be obtained.

[3] Some sets on the same plot would receive less than the daily normal consumptive use and some even several hundred percent of the use, depending on their location with respect to the sprinklers. The experiment was purposely designed to make water applications greater than, and also lesser than, the normal consumptive water use because it was not known at the time how much water must be applied to result in no net soil moisture depletion with daily water applications being made.

[4] It may require two, three, or even five times as long to apply the same amount of water on one plot as on another.

considerably from day to day, and the exact percentages of the estimated use were not applied at all times. This situation could not easily be avoided because of the many factors that may influence the evaporation and consumptive water use.

A rather accurate measure of the applied water was accomplished by the use of the double row of cans on each plot. The water was poured from the cans into a graduated cylinder for measurement.

Careful observations were made to see that the soil and crop could handle the water as fast as it was being applied. No runoff was noticed on any of the plots except close to the metal shields, which was not within the area of measurement by the blocks.

Soil sampling

Throughout the summer, soil samples were taken for moisture content and apparent specific gravity determinations.

A "Uhland" type sampler was used for taking undisturbed soil samples for determining apparent specific gravity. The sampler would permit samples to be taken to a maximum depth of 54 inches. The soil from the sampler sleeve[1] was put into a paper bag and placed in the oven at 110° C. until dry; the sample was then weighed. The weight of the dry soil divided by the volume of the sleeve was the apparent specific gravity. Ten samples at each depth were taken throughout the growing season. Those values below 54 inches were obtained from data of other apparent specific gravity determinations made on the farm. The averages of these samples are shown in Figure 12.

For most moisture content samples, a two-inch soil auger was used. The samples were taken as near to the gypsum blocks as possible. A sample

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[1] Diameter - 4.90 cm., height - 7.64 cm., and volume of approximately 144 cu. cm.

of soil at each six-inch depth was removed from the auger and placed in a metal can. The samples were taken into the laboratory, weighed, and placed in an oven at 110° C. for at least 24 hours. The samples were again weighed, and the percent moisture, dry-weight basis, calculated.

By using the ordinary soil auger, it was possible to refill each sample hole with soil and not disturb the soil surface excessively and leave holes into which water would run. The soil from each hole was replaced at approximately the same depth as removed.

A "Veihmeyer-improved King Soil Tube" was used for taking moisture content samples after September 11. Samples were needed in the drier range (high soil moisture tension) and since no water was being applied, the holes left by the soil tube were of no consequence.

Differences in soil texture made a different curve (soil moisture content-soil moisture tension) necessary for each depth (Figure 13). A time shift[1] required two curves for the first six depths (36 inches) for an accurate analysis of the data. Strong winds during the last week of August prevented sprinkling on most days and the shift in the blocks occurred during this period. For the first six depths the upper curve of Figure 13 was used up to where this shift took place and the lower curve for the period after the shift. The same moisture content-tension curves for depths greater than 36 inches were used throughout the season. It was not necessary to analyze the data below five feet[2] in the soil profile, so curves for only ten depths were drawn.

A rating table was made for the conversion of gypsum block readings (atmospheres of tension) to depth of water (inches) contained in the soil.

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[1] i.e., block readings changed with time, for the same soil moisture content.

[2] The block readings below the five-foot depth in the soil profile remained approximately the same throughout the season.

The following equation was used for this conversion:

$$d = \frac{Pw \times As \times D}{100}$$

Where: Pw = the moisture percentage of the soil on the dry weight basis
As = the apparent specific gravity of the soil
D = the depth of soil being considered (inches)
d = the depth of water contained in the soil (inches)

The depth of soil (D) is nine inches for the first depth (six-inch depth) and six inches for the remaining nine depths (12-inch to 60-inch depths).

Analysis of data

The daily block readings were originally converted to equivalent inches of water contained at each soil depth in the first six feet of the soil profile; the soil moisture content-tension curves for each depth was assumed to be a straight line when plotting the moisture percentage as the ordinate against the logarithum of the soil moisture tension (atmospheres) as the abscissa. These curves were fitted to this condition statistically and no time shift in the curves was considered. The curves fit rather well in the mid-portion, but many points lay above the line at each end (wettest and driest regions of each curve).

A careful comparison of the daily totals (inches of water contained in the soil profile being considered) obtained by using the soil moisture content-tension curves, with the totals from the soil samples, revealed that the first set of curves was inaccurate in the wet and dry ranges and could not be used.

The soil moisture content-tension curves were again drawn, plotting the soil moisture content (percent) on the ordinate against the soil moisture tension (atmospheres) as the abscissa. There was considerable scatter in the points but this condition was thought unavoidable. The block readings were again converted to equivalent inches of water at each soil depth in the top five feet of the soil profile on a weekly, rather than a daily, basis. A comparison of the weekly totals with the soil sample totals showed that a time shift had occurred in the curves. The points of these curves were then dated, and the time shift in the blocks was very obvious. When considering the time shift the curves fit the points fairly well with little scatter. As is shown in Figure 13, two curves for the first six depths were needed to produce the desired accuracy.

From the new curves the block readings were converted to equivalent inches of water at each depth in the soil, on a weekly basis. Instead of computing the total moisture in the top five feet of the soil profile, the computed totals took into account only the moisture in the root zone of the soil. The depth of the root zone increased as the season progressed, and at any time was assumed to be approximately at the depth in the soil that the moisture was being depleted. The root zone depth was approximately two feet the first part of July, and increased to a maximum depth of five feet the latter part of August.

Each set of every plot was analyzed separately; the most important data are shown in Tables 2, 3, and 4 of Appendix B.

The total water depletion from the experimental area (Ue) is shown in column 5 of Appendix B, Tables 2, 3, and 4; it is the algebraic difference of column 4 and column 3. Column 4 is the total moisture applied during the time period and is the sum of the precipitation and water applied by the sprinklers. Column 3 is the change in the soil moisture content during the period.[1] Uc, the normal consumptive water use (column 6),

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[1] The change in the soil moisture content was the algebraic difference in the weekly totals of the moisture in the root zone of this soil.

was mainly determined from an adjacent plot (see section on determining daily water requirements). Column 7 is the ratio of the Ue to Uc, and column 8 is the percentage of the total soil moisture in the root zone and was determined from the following equation:

$$Ma = \frac{Aw - PW}{FC - PW} \times 100$$

Where: Ma = the percentage of the total moisture in the root zone that is available for plant use (includes that moisture in the evaporation zone of the soil).

Aw = the average depth of water (inches) in the root zone of the soil during the period being considered.

PW = the depth of water (inches) contained in the root zone of the soil at the permanent wilting point (15 atmospheres tension).

FC = the depth of water (inches) contained in the root zone of the soil at field capacity[1] (0.4 atmospheres tension).

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[1] The gypsum blocks are rather inaccurate in the soil moisture range of about 1.5 to 0.4 atmospheres tension. The soil moisture condition was considered to be "field capacity" at 0.4 atmospheres tension.

DISCUSSION OF RESULTS

The results obtained from this experiment definitely show that direct evaporation from the ground and foliage is effective in reducing the amount of moisture that would otherwise be removed from the soil by the plants.

Figures 14, 15, and 16 show the results obtained from plots 1, 2, and 3, respectively. The small number by each point of these figures is the set number on that particular plot. The results produced from plots 2 and 3 are almost identical in nature. The results from plot 1 were rather disappointing as all three plots received approximately the same treatment and no known bias was given to any one plot. A large portion of the points on Figure 14 are considerably lower than the points of Figures 15 and 16, indicating a small Ue, or that very little change in the moisture content of the soil occurred throughout the season. The points on Figure 14 have an erratic scatter, showing no particular pattern or trend. Sets 7, 8, and 9 tend to drift somewhat to the left, set 9 being farther to the left than sets 7 and 8; this drift was probably due to shifts in the blocks, causing them to indicate less water in the soil than actually existed.

The poor results obtained from plot 1 shown in Figure 14 are probably due to one or both of the following reasons:

1. The predominant slope of the ground on the experimental site was to the southwest (towards plot 1). The area around the pump was well saturated most of the time, and the water may have moved laterally toward the southwest, keeping sets 2 to 9 (set 1 got much drier than any other

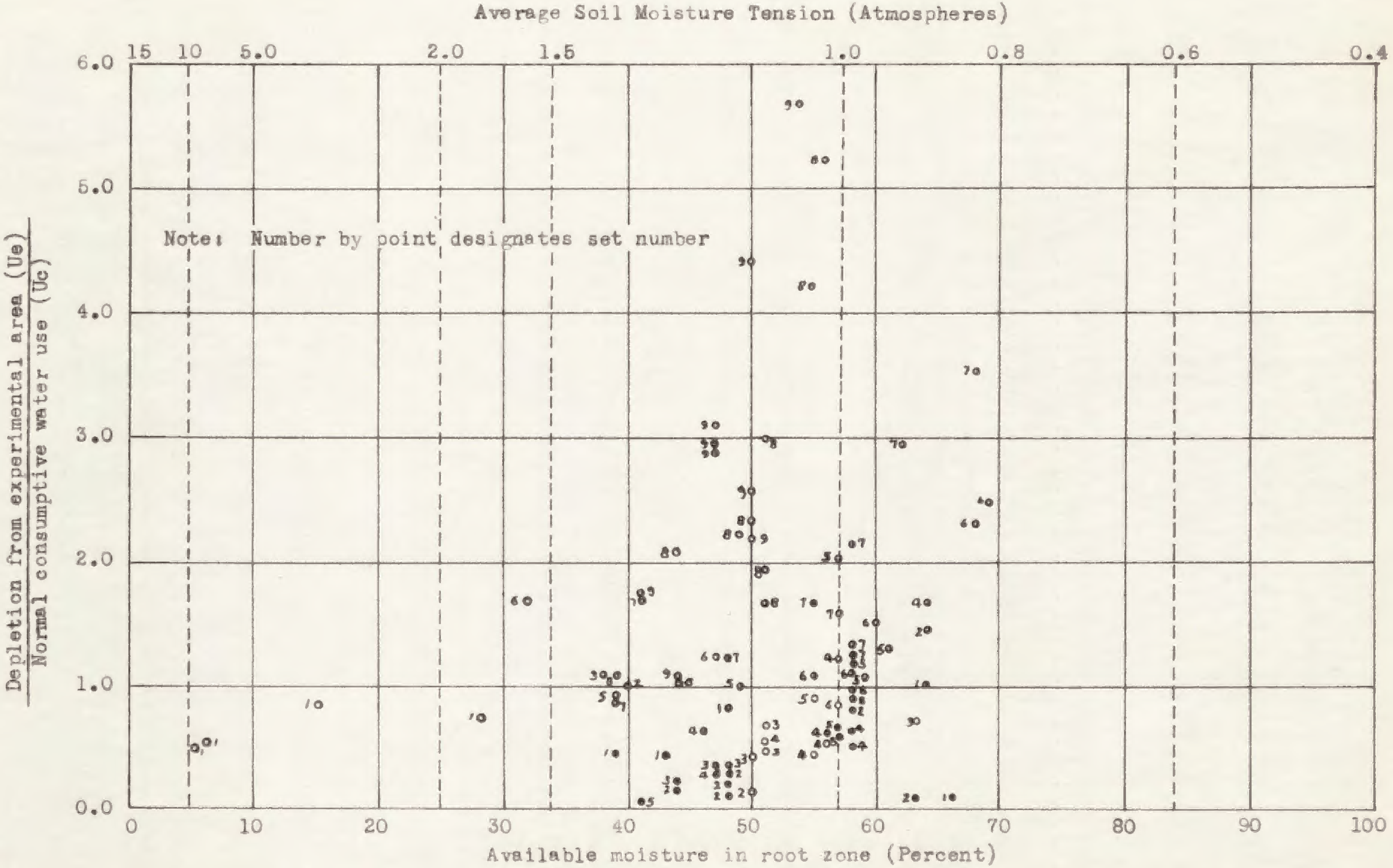

Figure 14. Ue/Uc in terms of available moisture and soil moisture tension (Plot 1).

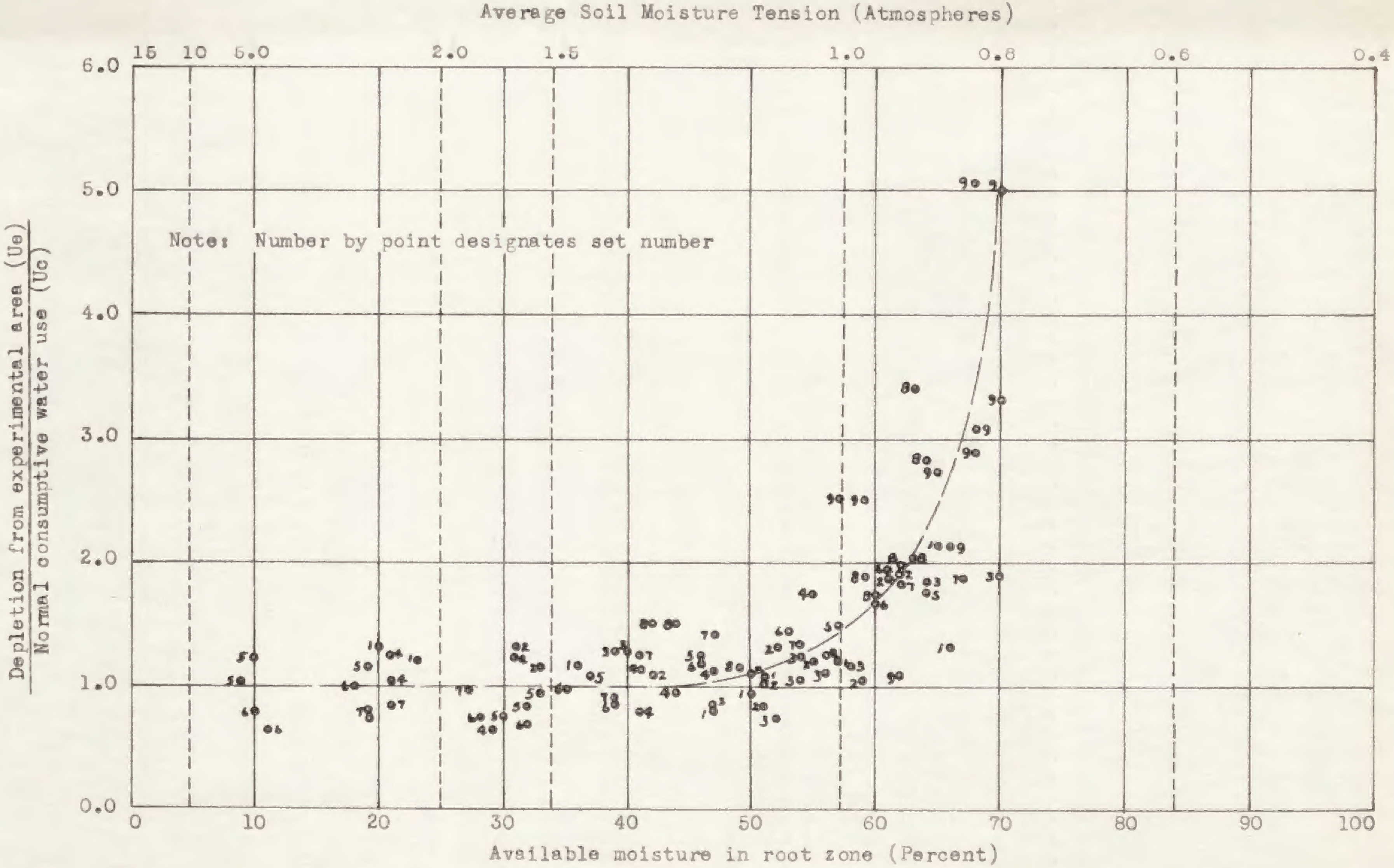

Figure 15. Ue/Uc in terms of available moisture and soil moisture tension (Plot 2).

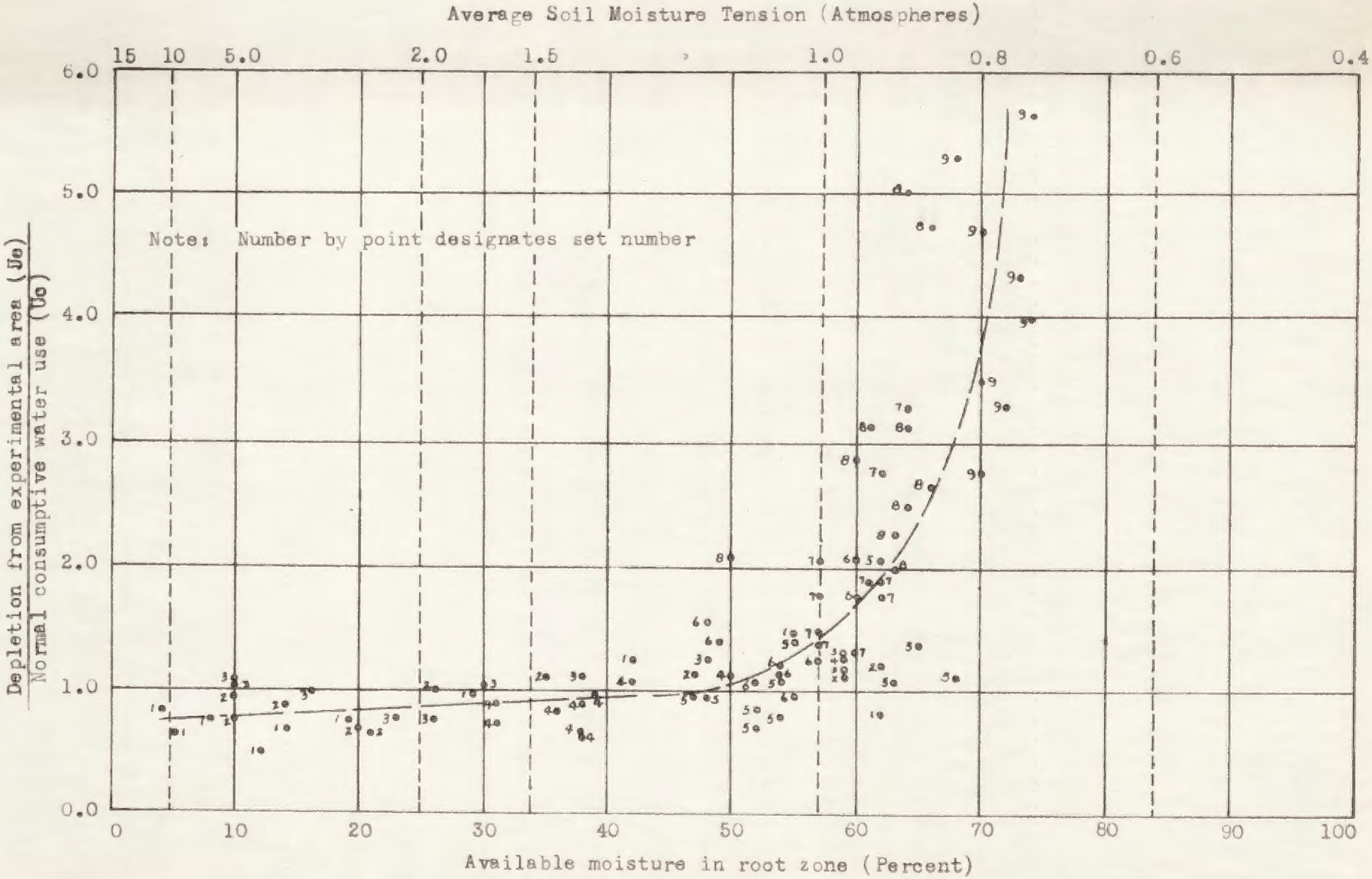

Figure 16. Ue/Uc in terms of available moisture and soil moisture tension (Plot 3).

set in this plot) fairly wet throughout the season. Since very little water was observed to move laterally on the surface of the ground in the vicinity of the blocks, the movement of water toward the southwest was in the form of soil moisture.

2. The application rate of the sprinkler head used on plot 1 decreased at a rapid rate from a maximum value at set 9 of one inch per hour to a rate of 0.08-inch per hour at set 1 (see Figure 6). This high application rate is the vicinity of set 9 together with the extensive variation in application rate between set 1 and set 9 would accelerate the lateral soil moisture movement to a greater degree than on either of the other plots.

The objective of this experiment is not necessarily to arrive at exact values on the effectiveness of direct evaporation in reducing the soil moisture depletion, but rather to determine whether or not it is effective, and to estimate the degree of effectiveness. Additional experiments designed on the basis of the results of this study will be necessary to determine more accurately the effectiveness. The curves in Figures 15 and 16 are approximations; no statistical analysis was undertaken to determine the best fit curve because the data did not seem to warrant this degree of apparent refinement.

The average line drawn for Figure 15 shows that the evaporation is approximately 100 percent effective[1] for the dryer conditions. The effectiveness begins to decrease when the available soil moisture is greater than 40 to 50 percent (approximately 1.3 to 1.0 atmospheres

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[1] When the ratio of Ue to Uc is one (1), the evaporation effectiveness is 100 percent; when the ratio of Ue to Uc is greater than one (1), the evaporation effectiveness is less than 100 percent; and when the ratio of Ue to Uc is less than one (1), the evaporation effectiveness is greater than 100 percent.

soil moisture tension) and continues to decrease as the available moisture increases.

The results from plot 3 (Figure 16) show that the evaporation effectiveness (in the drier range) is greater than 100 percent, and increases as the available soil moisture decreases. However, the errors inherent in the block calibration and the transposing of normal consumptive water use data from an adjacent plot to those plots involved in this study, make it unwise to claim effectiveness greater than 100 percent. The important observation is that effectiveness was essentially 100 percent. Conclusive proof was not afforded by the experiment to say that the evaporation effectiveness increases as the time required for water application decreases.

On all three plots, large daily applications were made, sometimes as much as one inch or more per day, on the sets closer to the sprinkler head. The reason for the low effectiveness is probably because of deep percolation; the soil in the wetter soil moisture range would probably lose most of these large daily applications through percolation to greater depths. The experiment was purposely designed to apply at some sets several hundred percent of the daily consumptive water use because it was not known at the time how much water would be required for normal plant growth and development when daily applications were being made.

Because of the excessive deep percolation in the vicinity of sets 7, 8, and 9, the data from this area cannot be used to evaluate the effectiveness. The observation that the surface evaporation is essentially 100 percent effective is based upon the data from sets 1 to 6, inclusive, where essentially no deep percolation occurred.

As was stated in the above discussion of the design of the experiment, the application per day was varied over the plot in order to bracket the daily application rate which would result in no net soil moisture depletion.

Now that the evaporation has been found to be highly effective, further studies can be conducted with a uniform water application,[1] which will produce a better control and permit a more accurate measurement of the evaporation effectiveness.

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[1] The term "uniform water application" should include at least the following variables: a. Uniform depth of application, b. uniform time rate of application, and c. uniform frequency of application.

SUGGESTED IMPROVEMENTS FOR FURTHER STUDY

There is no available information showing that an experiment similar to the one performed has ever been undertaken. Having performed the experiment, there are several suggestions that may be beneficial if this experiment should be repeated. The results of this experiment should make it possible for a better and more detailed study of the problem.

Placing and type of moisture unit

Probably the biggest change in procedure should be the placing and type of moisture units used. The first gypsum block of each set was placed six inches below the soil surface; considerable moisture depletion may occur from the first six inches of soil before any change could be detected by the gypsum block. This top block represented a nine-inch layer of the soil profile (six inches above the block and three inches below) while the remaining eleven blocks each represented six inches of soil profile. Blocks should be placed closer together in the evaporation zone of the soil (the first 12 to 18 inches). These blocks may be placed at two or three-inch intervals in this zone.

The type of block used may also be of importance. It is common knowledge that the gypsum block is insensitive in the wetter range of the soil (from field capacity to about 1.5 or 2.0 atmospheres of soil moisture tension). As the soil moisture tension increases, the gypsum block may give an accurate account of the soil moisture content. The gypsum from the block gradually dissolves and if left in the soil may eventually leave the electrodes bare. The gypsum block may give a consistent reading of the soil moisture content if the soil is either continuously wet or dry; the block reading for the same soil moisture content will shift with time if the moisture condition of the soil is allowed to vary (i.e., periods in which the soil is wet alternated with periods in which the soil is dry).

Although the nylon or fiber-glass units are more expensive, they may be used to a better advantage in the wetter range of the soil, and would probably give a better measurement of the soil moisture content in the range below two atmospheres tension. A combination of either the nylon or fiber-glass unit and the gypsum block could be used in the soil, using the gypsum block in the drier range and the other type block in the wetter range. In using both types of blocks, they may be used as a check on each other.

In this experiment the blocks were placed to a depth of six feet below the soil surface. In analyzing the results it proved to be unnecessary to go to that depth for this particular crop and soil. The root system of the crop used in the experiment should determine the approximate maximum depth in the soil to place the blocks.

Application of water

It should not be necessary to apply several hundred percent of the normal consumptive water use at some sets, decreasing the application rate until some sets on the same plot receive only a fraction of the daily use. Now that surface evaporation has been found to be highly effective in reducing the soil moisture depletion, water may be applied at a uniform application rate to as many sets[1] as desired to determine more accurately the limits and extent of the evaporation effectiveness.

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[1] Replications, if each set receives the same amount of water at the same application rate.

The variable of "time rate of application" should be given further study. This experiment did not definitely prove that the evaporation effectiveness increases as the time rate of application decreases, and should be carried out to a definite conclusion.

Reading the blocks

The blocks were read on most days throughout the growing season, and total amount of water contained in the soil profile for each day was computed for each set of blocks. Because of the many variables, these daily readings could not be accurately used in computing the evaporation effectiveness on a daily basis. Reading periods of from three to seven days would be sufficient for most purposes. Periods of one week were used in the final analysis of results for this experiment.

Determining consumptive water use

Determining the daily or even weekly consumptive water use presented some problem, and a better method for determining this use should be developed. At present, the best method for determining the consumptive use seems to be from taking soil samples. A "check plot" using the same crop could be provided from which soil samples can be taken at any time and the consumptive water use computed for the desired period.

Pumping equipment

The pressure pump used would create only 30 p.s.i. pressure, while about 60 p.s.i. pressure was required to operate all three sprinklers at the same time at their proper pressures. The pressure in excess of 30 p.s.i. was obtained from one of the large pumps used for irrigation on the farm. It is suggested that one pump be made available to furnish all of the pressure required.

Preventing splash

Splashing of water from the corrugated metal shields may easily be prevented; burlap or some other material may be placed on the shields which will permit the excess water to drain off without creating a splash.

Location of experimental plot with respect to wind

Since even a light wind may distort a sprinkler distribution pattern and make it almost impossible to make a uniform application, experimental studies should be conducted in an area in which the wind is at a minimum.

CONCLUSIONS

The following conclusions are based on and supported by the experimental work reported herein:

1. Direct evaporation from the ground and foliage has been found to be highly effective in reducing the soil moisture depletion. The evaporation effectiveness is approximately 100 percent in the drier soil moisture range but drops off rapidly when the available moisture is greater than 50 percent. The exact value of evaporation effectiveness at any soil moisture condition cannot be pin-pointed from the results of this experiment. Some results showed effectiveness of greater than 100 percent, but it is felt unwise to make this claim; the important observation is that the effectiveness is essentially 100 percent.

2. The wetter sets (sets 7, 8, and 9) could not be used to determine the evaporation effectiveness because of the excessive deep percolation at these sets; the daily water application to these sets was several times the normal daily consumptive water use. Very little deep percolation occurred in the vicinity of sets 1 to 6, which were used to reach the conclusion that surface evaporation was essentially 100 percent effective.

3. The experiment did not afford conclusive proof that the evaporation effectiveness is independent of the amount and frequency of application of water.

4. The research showed a tendency for an effectiveness of greater than 100 percent in the drier soil moisture range as the time required

for water application decreased and continued to increase as the available moisture decreases. Further study should be given to this variable.

5. Since evaporation has been found to be highly effective in reducing the soil moisture depletion, further studies should be conducted, using a uniform water application, to determine more accurately the extent and limits of the evaporation effectiveness.

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APPENDIX A

Figure 1. View of experimental area showing crop, shields and a row of cans on plot 1. Sprinkler is operating on plot 3 in the background.

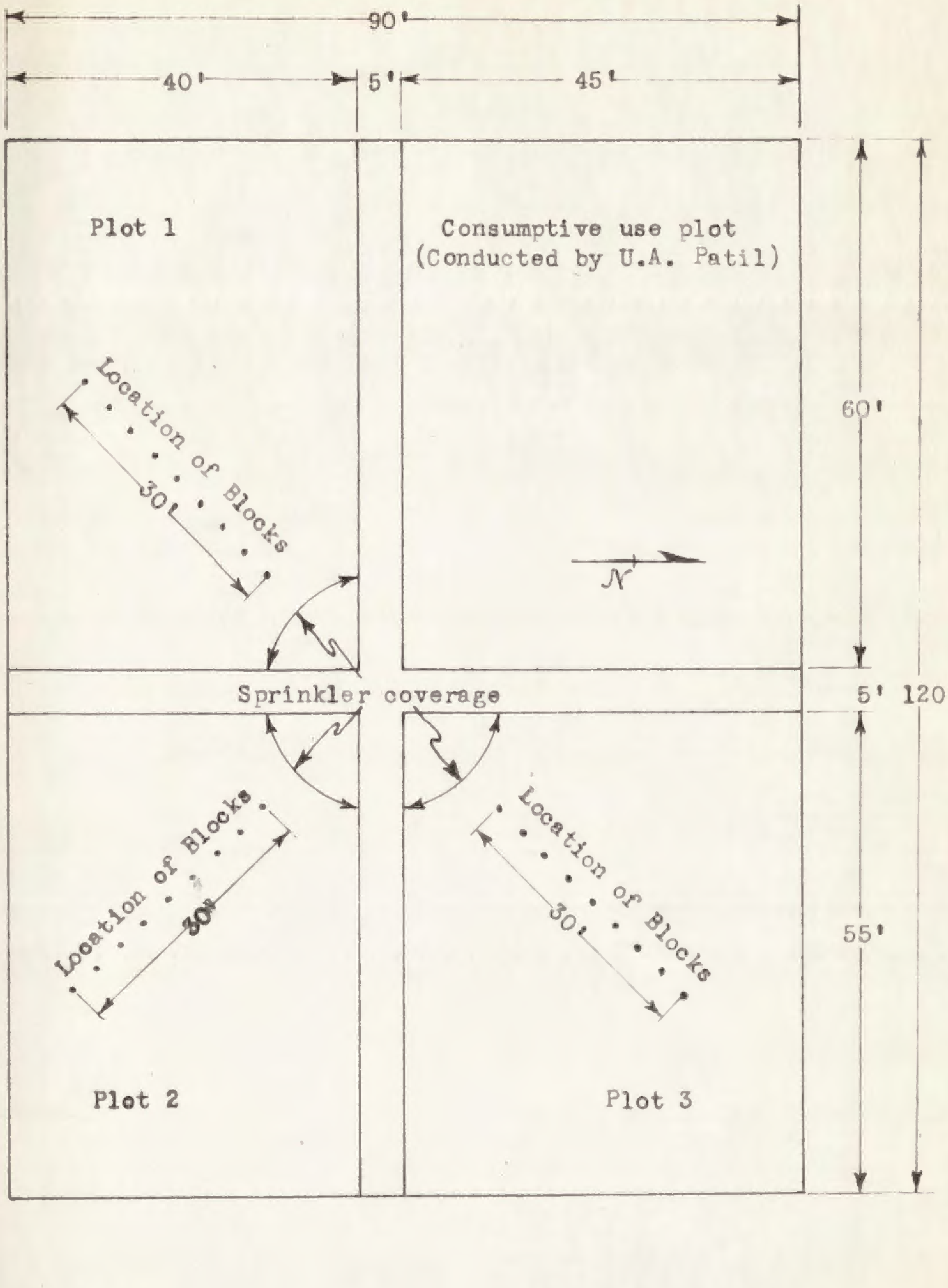

Figure 2. General plot layout.

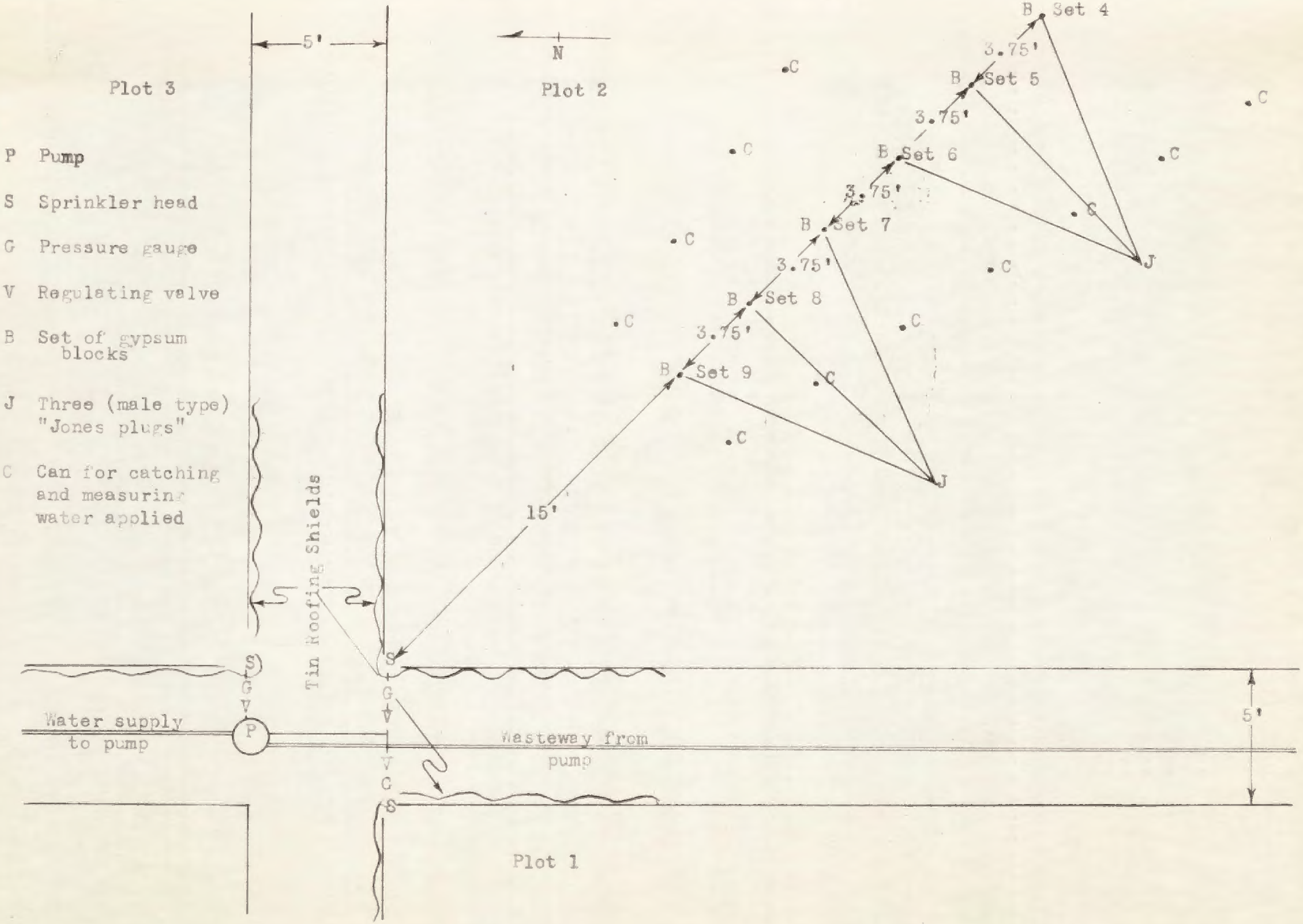

Figure 3. Detailed layout of sprinkling equipment and gypsum block arrangement.

Figure 4. "Rain Bird" full-circle sprinkler used for applying water to plots, with shields in the background.

Figure 5. Pump, valves and pressure guages. A valve and pressure guage was provided for the regulation of water application to each plot.

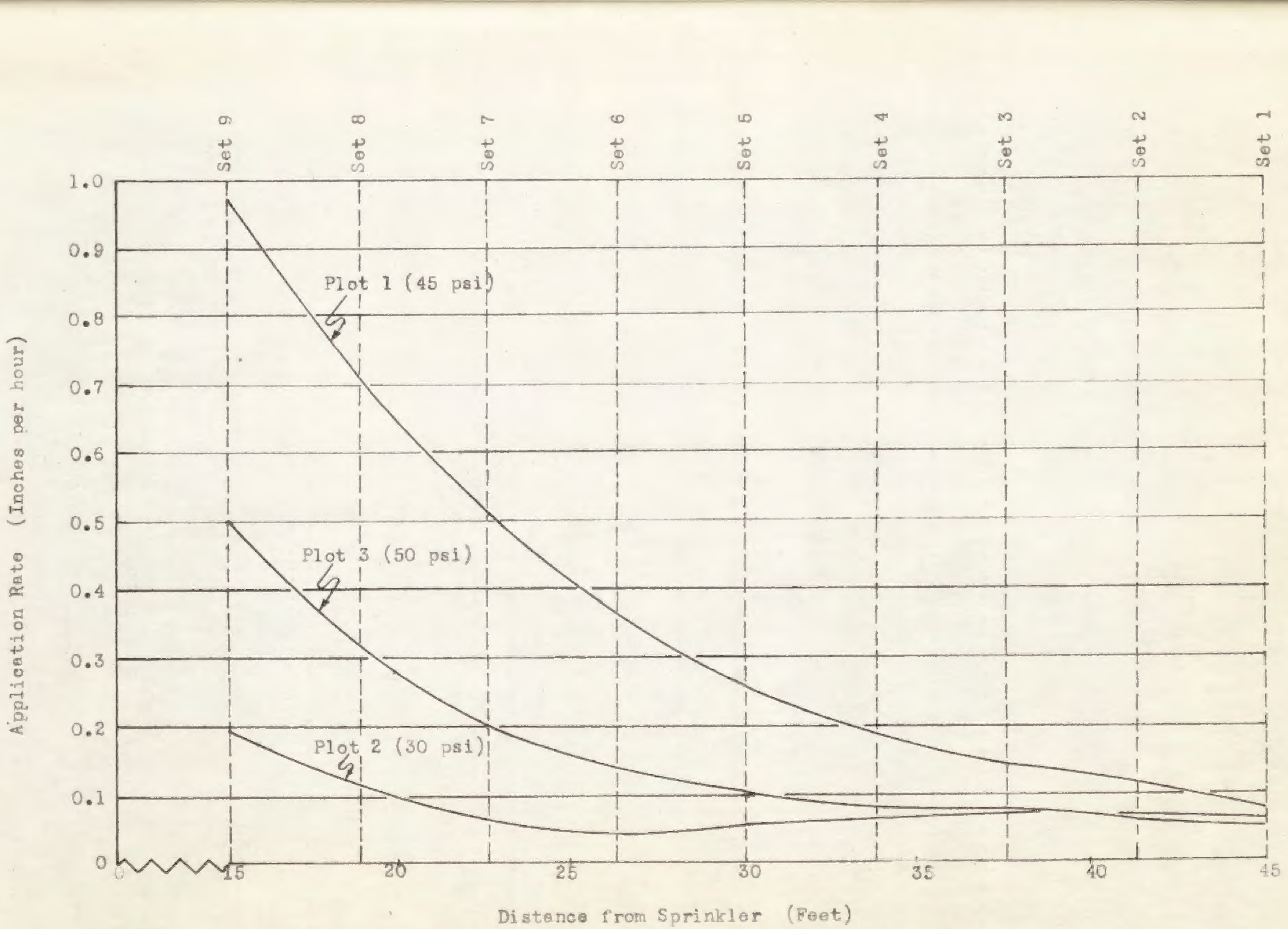

Figure 6. Sprinkler distribution patterns.

Figure 7. Cans used for catching water to measure application. A funnel was soldered flush with the top of each can to decrease evaporation losses. Also, note that the top of the can is kept on the same level as the crop height.

Figure 8. Coleman resistance bridge and switch used for reading the gypsum blocks. The bridge was calibrated to read blocks directly in atmospheres of tension.

Figure 9. Barley on plot 2 coming out in head. Foliage was heaviest in this region where the application was approximately equal to the normal consumptive water use.

Figure 10. Growth of crop was "stunted" close to the shields on plot 2 because of an excess application of water, resulting in a large amount of deep percolation. This decreased crop growth and density did not extend to region where gypsum blocks were buried.

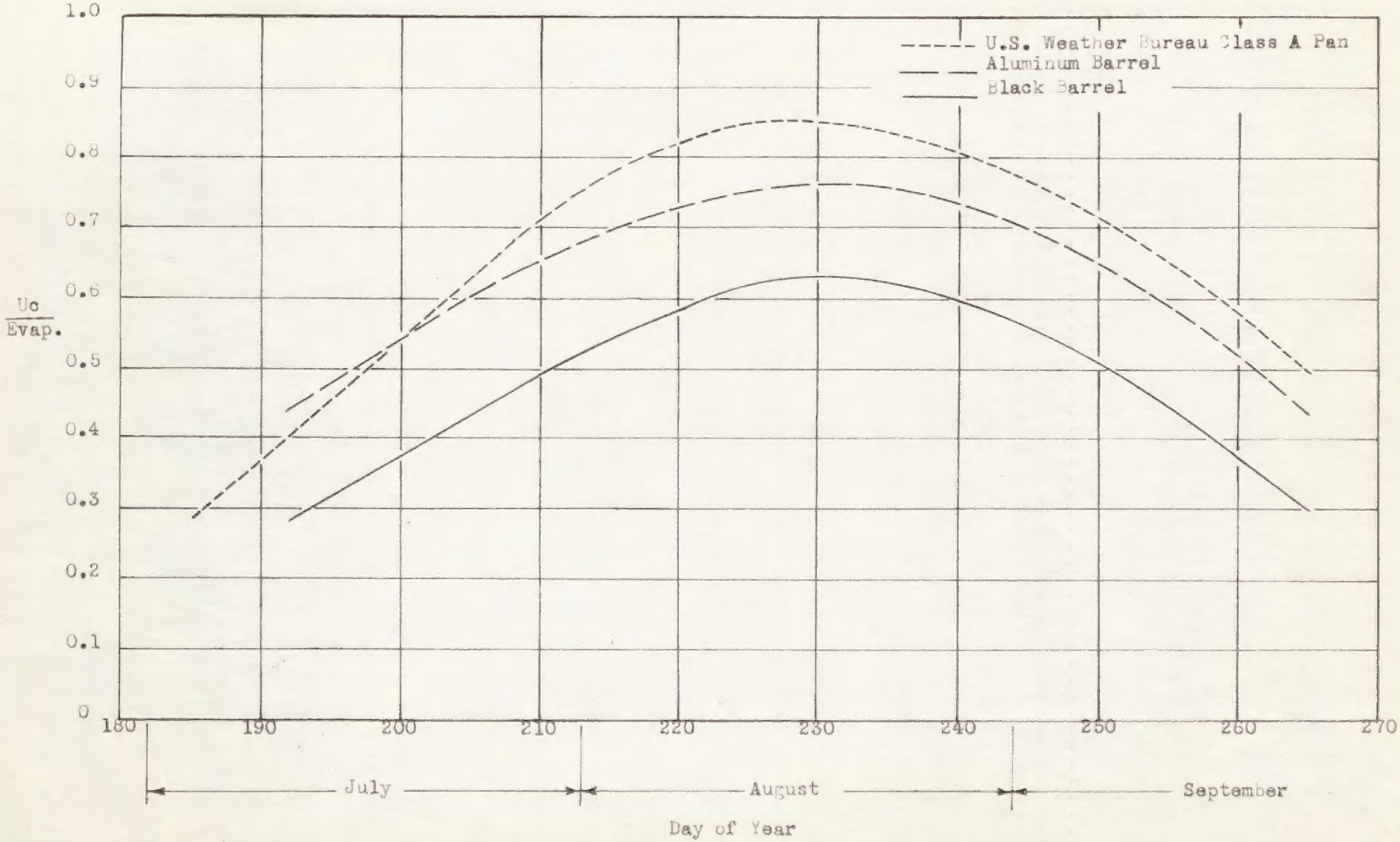

Figure 11. Consumptive water use-evaporation ratios for three types of evaporation pans.

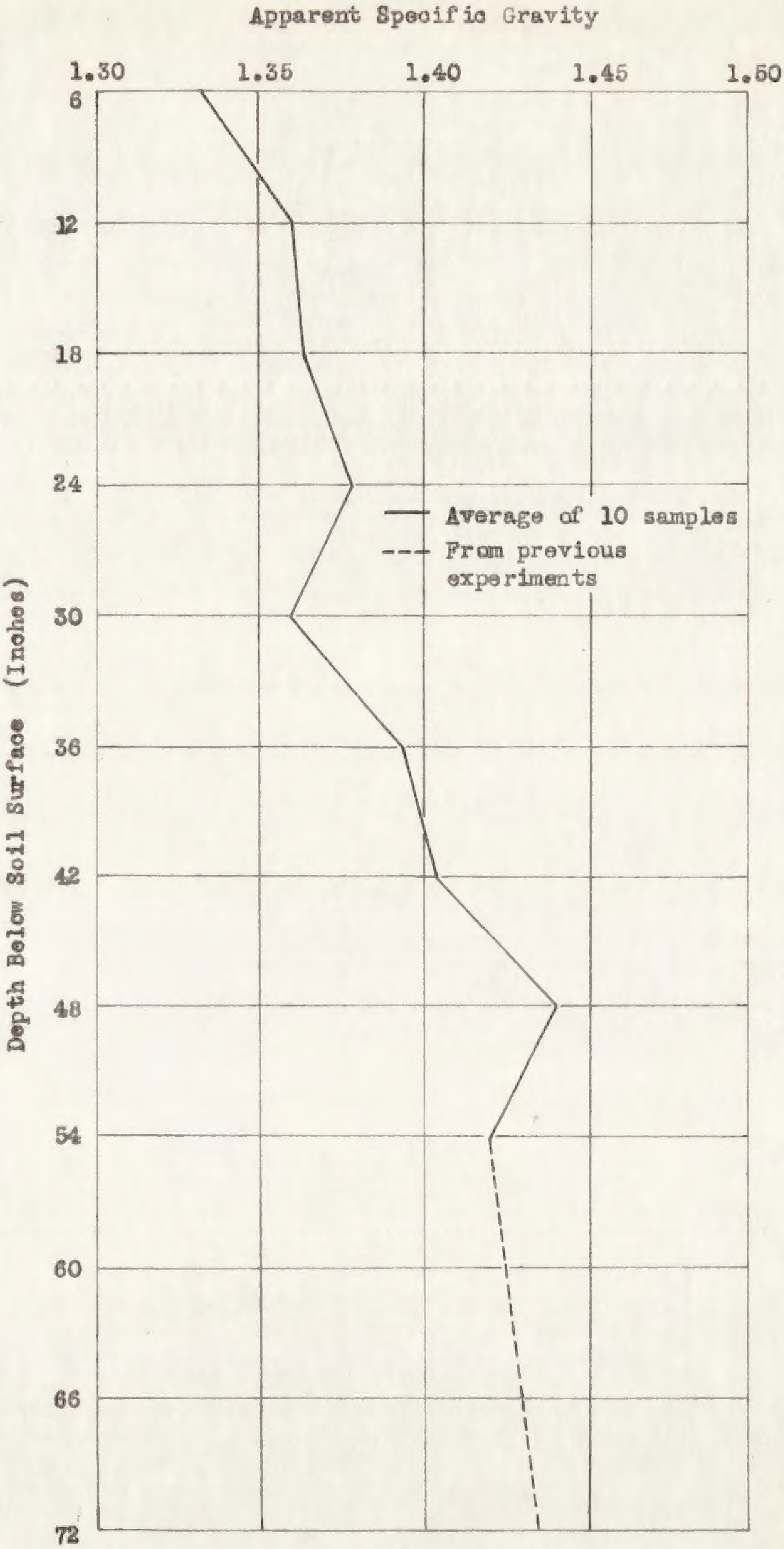

Figure 12. Average apparent specific gravity as a function of depth below the soil surface.

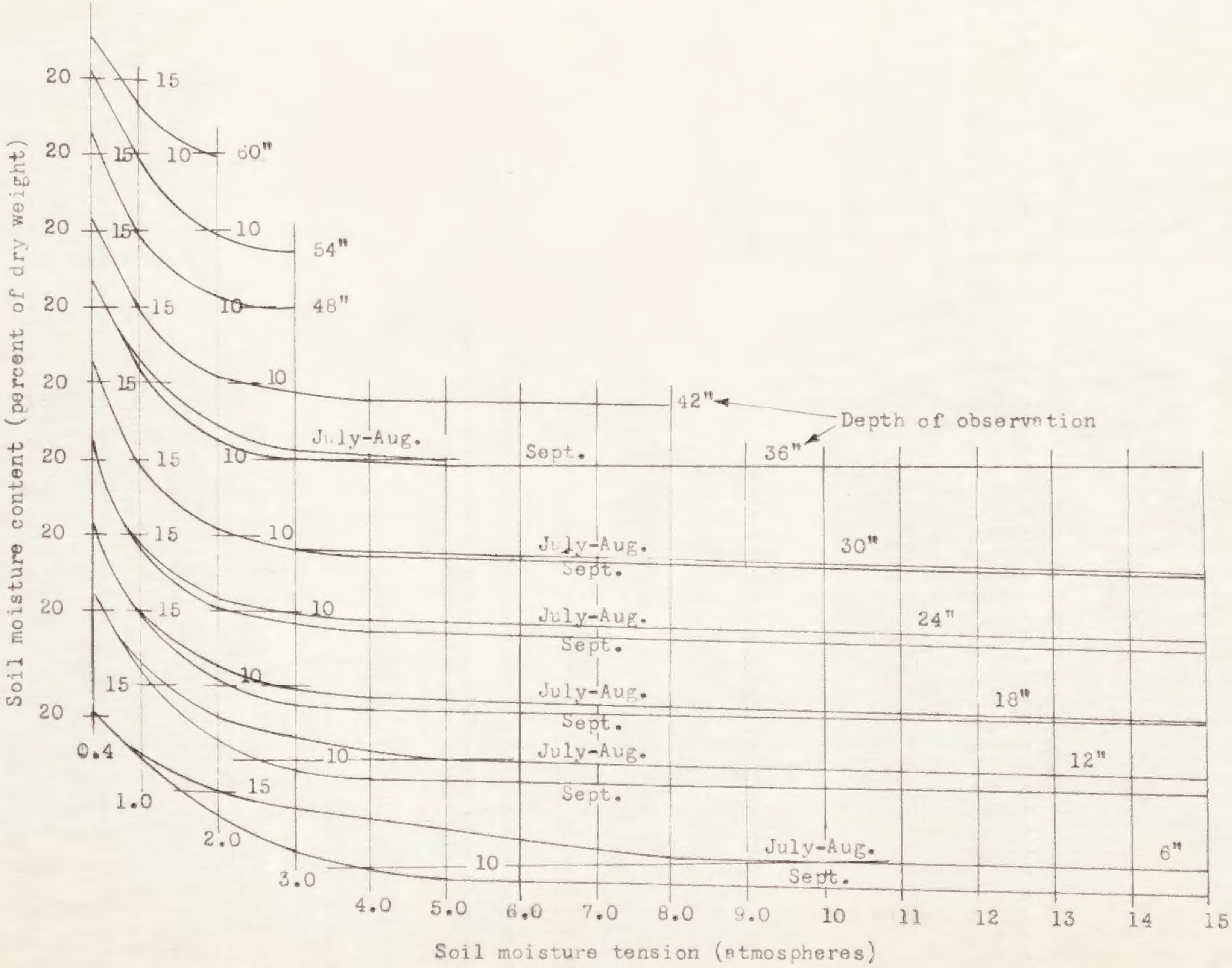

Figure 13. Relation between soil moisture content and soil moisture tension for gypsum blocks.

APPENDIX B

Table 1. Illustration of data sheet used for collection of data.

Data Sheet for Experiment Conducted on
U.S.A.C. Agricultural Experiment Station's Greenville Farm

Plot No. 3	Date August 6 1953
Pressure 50 psi	Observer Val Wynn
Time started 7:55	Precipitation None in.
Time stopped 10:25	Wind direction None
Time applied 150 min.	Cloud coverage Clear
Estimated use .29 in.	Time of reading 7:00

Set No.		1	2	3	4	5	6	7	8	9
Crop Ht. (In.)		20	21	21	22	21	20	19	18	18
Water Applied c.c.	can 1	24	32	38	42	50	54	64	104	204
	can 2	32	34	44	50	60	66	68	72	106
	Ave.	28	33	41	46	55	60	66	88	155
In.	Ave.	.14	.16	.20	.23	.28	.30	.33	.44	.78
		Block readings in atmospheres of tension & equivalent in. of water								
Gypsum Block Depth (Inches)	6	8.5 1.26	7.0 1.33	3.4 1.62	2.3 1.78	1.2 2.03	1.1 2.06	1.1 2.06	1.0 2.08	.7 2.25
	12	8.0 .75	4.6 .84	4.4 .85	2.4 1.00	1.1 1.27	1.4 1.17	1.1 1.27	1.0 1.32	1.0 1.32
	18	5.2 .71	2.7 .83	2.0 .91	2.0 .91	1.1 1.13	1.1 1.13	1.0 1.17	.9 1.24	.7 1.38
	24	4.1 .76	2.0 .90	1.8 .93	1.5 .98	1.2 1.11	1.0 1.27	1.1 1.20	.6 1.61	.5 1.71
	30	1.7 .88	1.3 .96	1.3 .96	1.3 .96	.8 1.34	1.0 1.16	.8 1.34	1.0 1.16	.6 1.50
	36	1.4 1.18	1.6 1.09	1.6 1.09	1.5 1.14	1.3 1.25	1.1 1.36	1.1 1.36	1.1 1.36	1.0 1.41
	42	1.2 1.12	1.2 1.12	1.4 .99	1.2 1.12	1.1 1.21	1.2 1.12	1.2 1.12	1.1 1.21	1.1 1.21
	48	1.3	1.2	1.5	1.3	1.7	1.1	1.2	1.0	1.4
	54	1.3	1.0	1.3	1.2	1.2	1.4	1.2	1.1	.9
	60	1.4	1.7	1.2	1.3	1.4	1.1	1.3	1.2	1.3
	66	1.2	1.3	1.3	1.4	.9	1.5	1.2	1.1	1.3
	72	1.3	1.3	1.2	1.5	1.2	1.3	1.1	1.5	1.7
Depth of water in root zone (in.)		6.66	7.07	7.32	7.89	9.34	9.27	9.52	9.98	10.78

REMARKS: Barley is starting to come into head. A few heads are visable.

Table 2. Analysis of data collected from Plot 1.

1 Location	2 Time Period	3 Change in Soil Moisture in Root Zone (in.)	4 Application plus Precipitation (in.)	5 Depletion from Experimental Area (Ue) Col. 4 - Col. 3 (in.)	6 Normal Consumptive Water Use (Uc) (in.)	7 Ue/Uc	8 Available Moisture in Root Zone (percent)
Plot 1 Set 1	Jul. 6-13	+.33	.42	.09	.74	.12	66
	13-20	-.67	.28	.95	.94	1.01	64
	20-27	-.77	.34	1.11	1.36	.82	48
	27-3	*			1.62		
	Aug. 3-10	-.18	.62	.80	1.83	.44	43
	10-17	-.40	.38	.78	1.65	.47	39
	17-24	-1.27	.50	1.77	2.22	.80	28
	24-31	-1.72	.03	1.75	1.98	.88	15
	31-7	-.37	.28	.65	1.12	.58	6
	Sept.7-12	-.12	.30	.42	.81	.52	5
Plot 1 Set 2	Jul. 6-13	+.48	.56	.08	.74	.11	63
	13-20	-.95	.42	1.37	.94	1.46	64
	20-27	-.70	.46	1.16	1.36	.85	58
	27-3	*			1.62	.12	48
	Aug. 3-10	+.09	.69	.60	1.83	.33	48
	10-17	+.20	.48	.28	1.65	.17	50
	17-24	+.10	.57	.47	2.22	.21	48
	24-31	-1.99	.04	2.03	1.98	1.02	40
	31-7	*			1.12		
	Sept.7-12	+.17	.32	.15	.81	.19	44
Plot 1 Set 3	Jul. 6-13	+.26	.82	.56	.74	.76	63
	13-20	-.54	.68	1.22	.94	1.30	58
	20-27	+.05	.70	.65	1.36	.48	51
	27-3	-.12	.96	1.08	1.62	.67	51
	Aug. 3-10	+.28	.99	.71	1.83	.39	48
	10-17	-.06	.66	.72	1.65	.44	50
	17-24	+.02	.86	.84	2.22	.38	47
	24-31	-2.18	.06	2.24	1.98	1.13	38
	31-7	*			1.12		
	Sept.7-12	+.25	.44	.19	.81	.23	44

* Data was of no value

Table 2. (Contd.)

1 Location	2 Time Period	3 Change in Soil Moisture in Root Zone (in.)	4 Application plus Precipitation (in.)	5 Depletion from Experimental Area (Ue) Col. 4 - Col. 3 (in.)	6 Normal Consumptive Water Use (Uc) (in.)	7 $\frac{Ue}{Uc}$	8 Available Moisture in Root Zone (percent)
Plot 1 Set 4	Jul. 6-13	-.22	1.02	1.24	.74	1.68	64
	13-20	-.24	.91	1.15	.94	1.22	57
	20-27	+.16	.91	.75	1.36	.55	56
	27-3	+.09	1.14	1.05	1.62	.65	58
	Aug. 3-10	+.11	1.30	1.19	1.83	.65	56
	10-17	+.09	.94	.85	1.65	.52	58
	17-24	+.03	1.07	1.04	2.22	.47	55
	24-31	-1.06	.08	1.14	1.98	.58	51
	31-7	-.19	.50	.69	1.12	.62	46
	Sept. 7-12	+.45	.60	.25	.81	.31	47
Plot 1 Set 5	Jul. 6-13	-.06	1.46	1.52	.74	2.05	57
	13-20	-.04	1.25	1.29	.94	1.37	61
	20-27	-.15	1.30	1.45	1.36	1.06	59
	27-3	-.04	1.52	1.56	1.62	.96	58
	Aug. 3-10	+.05	1.80	1.75	1.83	.96	55
	10-17	+.31	1.32	1.01	1.65	.61	57
	17-24	+.04	1.42	1.38	2.22	.62	57
	24-31	-1.91	.12	2.03	1.98	1.02	49
	31-7	-.39	.66	1.05	1.12	.94	39
	Sept. 7-12	+.70	.73	.03	.81	.04	41
Plot 1 Set 6	Jul. 6-13	+.06	1.90	1.84	.74	2.49	69
	13-20	-.35	1.84	2.19	.94	2.33	68
	20-27	-.30	1.88	2.18	1.36	1.53	60
	27-3	+.07	1.91	1.84	1.62	1.14	58
	Aug. 3-10	+.24	2.26	2.02	1.83	1.10	56
	10-17	+.15	1.78	1.63	1.65	.99	58
	17-24	+.29	2.22	1.93	2.22	.87	57
	24-31	-2.31	.18	2.49	1.98	1.26	47
	31-7	-.89	1.00	1.89	1.12	1.69	32
	Sept. 7-12	*			.81		

* Data was of no value

Table 2. (Contd.)

1 Location	2 Time Period	3 Change in Soil Moisture in Root Zone (in.)	4 Application plus Precipitation (in.)	5 Depletion from Experimental Area (Ue) Col. 4 - Col. 3 (in.)	6 Normal Consumptive Water Use (Uc) (in.)	7 Ue / Uc	8 Available Moisture in Root Zone (percent)
	Jul. 6-13	+.13	2.77	2.64	.74	3.57	68
	13-20	-.14	2.66	2.80	.94	2.98	62
	20-27	-.24	2.72	2.96	1.36	2.18	58
	27-3	+.02	2.62	2.60	1.62	1.60	57
Plot 1	Aug. 3-10	+.13	3.20	3.07	1.83	1.68	55
Set 7	10-17	+.31	2.44	2.13	1.65	1.29	58
	17-24	+.12	2.95	2.83	2.22	1.28	58
	24-31	-2.20	.25	2.45	1.98	1.24	48
	31-7	+.37	1.37	1.00	1.12	.89	39
	Sept. 7-12	+.09	1.48	1.39	.81	1.72	41
	Jul. 6-13	0	3.88	3.88	.74	5.24	56
	13-20	-.15	3.82	3.97	.94	4.22	55
	20-27	-.17	3.92	4.09	1.36	3.01	51
	27-3	+.02	3.70	3.68	1.62	2.37	50
Plot 1	Aug. 3-10	+.09	4.21	4.12	1.83	2.25	49
Set 8	10-17	+.15	3.44	3.29	1.65	1.99	51
	17-24	+.12	3.80	3.68	2.22	1.66	51
	24-31	-1.68	.35	2.03	1.98	1.02	44
	31-7	+.69	1.93	1.24	1.12	1.11	39
	Sept. 7-12	+.34	2.06	1.72	.81	2.12	44
	Jul. 6-13	-.06	5.46	5.52	.74	7.46	57
	13-20	+.05	5.40	5.35	.94	5.70	54
	20-27	+.44	5.56	6.00	1.36	4.41	50
	27-3	+.03	5.12	5.09	1.62	3.14	47
Plot 1	Aug. 3-10	+.12	5.55	5.43	1.83	2.96	47
Set 9	10-17	+.31	4.60	4.29	1.65	2.60	50
	17-24	+.06	4.96	4.90	2.22	2.21	50
	24-31	-1.69	.48	2.17	1.98	1.10	44
	31-7	+.88	2.85	1.97	1.12	1.76	41
	Sept. 7-12	+.30	2.71	2.41	.81	2.97	47

Table 3. Analysis of data collected from Plot 2.

1 Location	2 Time Period	3 Change in Soil Moisture in Root Zone (in.)	4 Application plus Precipitation (in.)	5 Depletion from Experimental Area (Ue) Col. 4 - Col. 3 (in.)	6 Normal Consumptive Water Use (Uc) (in.)	7 $\frac{Ue}{Uc}$	8 Available Moisture in Root Zone (percent)
Plot 2 Set 1	Jul. 6-13	+.31	1.30	.99	.74	1.34	66
	13-20	-.54	1.48	2.02	.94	2.15	65
	20-27	-.30	1.30	1.60	1.36	1.18	58
	27-3	+.05	2.04	1.99	1.62	1.23	56
	Aug. 3-10	-.20	1.74	1.94	1.83	1.06	51
	10-17	-.05	1.53	1.58	1.65	.96	50
	17-24	-.22	1.56	1.78	2.22	.80	47
	24-31	-2.10	.24	2.34	1.98	1.18	36
	31-7	-.55	.79	1.34	1.12	1.20	23
	Sept. 7-12	-.40	.67	1.07	.81	1.32	20
Plot 2 Set 2	Jul. 6-13	+.03	1.49	1.46	.74	1.97	62
	13-20	-.15	1.60	1.75	.94	1.86	61
	20-27	-.28	1.35	1.63	1.36	1.20	55
	27-3	-.12	2.00	2.12	1.62	1.31	52
	Aug. 3-10	-.02	2.04	2.06	1.83	1.12	50
	10-17	+.31	1.98	1.67	1.65	1.01	51
	17-24	-.09	1.80	1.89	2.22	.85	51
	24-31	-1.89	.30	2.19	1.98	1.10	42
	31-7	-.24	1.08	1.32	1.12	1.18	33
	Sept. 7-12	-.30	.79	1.09	.81	1.34	31
Plot 2 Set 3	Jul. 6-13	+.09	1.50	1.41	.74	1.91	70
	13-20	-.22	1.50	1.72	.94	1.83	64
	20-27	-.21	1.22	1.43	1.36	1.05	59
	27-3	-.18	1.62	1.80	1.62	1.11	56
	Aug. 3-10	0	1.86	1.86	1.83	1.02	54
	10-17	+.08	2.12	2.04	1.65	1.23	54
	17-24	+.10	1.82	1.72	2.22	.77	52
	24-31	-1.26	.36	1.62	1.98	.82	47
	31-7	-.06	1.38	1.44	1.12	1.29	40
	Sept. 7-12	-.13	.90	1.03	.81	1.28	39

Table 3. (Contd.)

1 Location	2 Time Period	3 Change in Soil Moisture in Root Zone (in.)	4 Application plus Precipitation (in.)	5 Depletion from Experimental Area (Ue) Col. 4 - Col. 3 (in.)	6 Normal Consumptive Water Use (Uc) (in.)	7 $\frac{Ue}{Uc}$	8 Available Moisture in Root Zone (percent)
Plot 2 Set 4	Jul. 6-13	-.07	1.38	1.45	.74	1.96	61
	13-20	-.31	1.35	1.66	.94	1.77	55
	20-27	-.44	1.10	1.54	1.36	1.13	47
	27-3	-.04	1.53	1.57	1.62	.97	44
	Aug. 3-10	-.41	1.68	2.09	1.83	1.14	41
	10-17	+.28	1.76	1.48	1.65	.90	41
	17-24	-.09	1.34	1.43	2.22	.64	29
	24-31	-1.95	.46	2.41	1.98	1.22	31
	31-7	-.18	1.20	1.38	1.12	1.23	21
	Sept.7-12	-.07	.78	.85	.81	1.05	21
Plot 2 Set 5	Jul. 6-13	-.11	1.20	1.31	.74	1.77	64
	13-20	-.25	1.15	1.40	.94	1.49	57
	20-27	-.68	.98	1.66	1.36	1.22	46
	27-3	-.41	1.33	1.74	1.62	1.07	37
	Aug. 3-10	-.32	1.43	1.75	1.83	.96	33
	10-17	+.26	1.67	1.41	1.65	.85	32
	17-24	-.63	1.09	1.72	2.22	.77	30
	24-31	-1.87	.40	2.27	1.98	1.15	19
	31-7	-1.25	1.10	1.35	1.12	1.21	10
	Sept.7-12	-.14	.68	.82	.81	1.01	9
Plot 2 Set 6	Jul. 6-13	-.12	1.12	1.24	.74	1.68	60
	13-20	-.37	.99	1.36	.94	1.45	53
	20-27	-.74	.88	1.62	1.36	1.19	46
	27-3	-.19	1.22	1.41	1.62	.87	39
	Aug. 3-10	-.59	1.22	1.81	1.83	.99	35
	10-17	+.11	1.26	1.15	1.65	.70	32
	17-24	-.69	.92	1.71	2.22	.77	28
	24-31	-1.68	.31	1.99	1.98	1.00	18
	31-7	-.16	.74	.90	1.12	.80	10
	Sept.7-12	-.08	.45	.53	.81	.65	11

Table 3. (Contd.)

1 Location	2 Time Period	3 Change in Soil Moisture in Root Zone (in.)	4 Application plus Precipitation (in.)	5 Depletion from Experimental Area (Ue) Col. 4 - Col. 3 (in.)	6 Normal Consumptive Water Use (Uc) (in.)	7 Ue / Uc	8 Available Moisture in Root Zone (percent)
Plot 2 Set 7	Jul. 6-13	+.12	1.50	1.38	.74	1.87	67
	13-20	-.23	1.50	1.73	.94	1.84	62
	20-27	-.60	1.26	1.86	1.36	1.37	54
	27-3	-.44	1.84	2.28	1.62	1.41	47
	Aug. 3-10	-.53	1.78	2.31	1.83	1.26	41
	10-17	+.18	1.69	1.51	1.65	.91	39
	17-24	-.48	1.28	1.76	2.22	.79	19
	24-31	-1.59	.37	1.96	1.98	.99	27
	31-7	-.02	.86	.88	1.12	.79	19
	Sept. 7-12	-.06	.63	.69	.81	.85	21
Plot 2 Set 8	Jul. 6-13	0	2.52	2.52	.74	3.40	63
	13-20	0	2.66	2.66	.94	2.83	64
	20-27	-.05	2.70	2.75	1.36	2.02	63
	27-3	-.17	3.00	3.17	1.62	1.96	62
	Aug. 3-10	-.06	3.08	3.14	1.83	1.71	60
	10-17	-.05	3.06	3.11	1.65	1.88	59
	17-24	+.04	2.70	2.66	2.22	1.20	57
	24-31	-1.73	.59	2.32	1.98	1.17	49
	31-7	-.12	1.80	1.68	1.12	1.50	42
	Sept. 7-12	-.08	1.30	1.22	.81	1.50	44
Plot 2 Set 9	Jul. 6-13	+.33	4.06	3.73	.74	5.04	68
	13-20	-.23	4.47	4.70	.94	5.00	70
	20-27	+.23	3.94	3.71	1.36	2.73	65
	27-3	+.14	5.12	4.98	1.62	3.07	68
	Aug. 3-10	+.24	5.42	5.28	1.83	2.88	68
	10-17	0	5.44	5.44	1.65	3.30	70
	17-24	+.02	4.82	4.80	2.22	2.16	66
	24-31	-1.12	1.01	2.13	1.98	1.07	62
	31-7	+.37	3.20	2.83	1.12	2.53	57
	Sept. 7-12	+.20	2.26	2.06	.81	2.54	59

Table 4. Analysis of data collected from Plot 3.

1 Location	2 Time Period	3 Change in Soil Moisture in Root Zone (in.)	4 Application plus Precipitation (in.)	5 Depletion from Experimental Area (Ue) Col. 4 - Col. 3 (in.)	6 Normal Consumptive Water Use (Uc) (in.)	7 $\frac{Ue}{Uc}$	8 Available Moisture in Root Zone (percent)
Plot 3 Set 1	Jul. 6-13	-.08	.52	.60	.74	.81	62
	13-20	-.52	.86	1.38	.94	1.47	55
	20-27	-1.11	.58	1.69	1.36	1.24	42
	27-3	-.72	.84	1.56	1.62	.96	29
	Aug. 3-10	-.60	.77	1.37	1.83	.75	19
	10-17	-.22	.92	1.14	1.65	.69	14
	17-24	-.49	.66	1.15	2.22	.52	12
	24-31	-.88	.68	1.56	1.98	.79	8
	31-7	-.21	.74	.95	1.12	.85	4
	Sept.7-12	-.05	.46	.51	.81	.63	5
Plot 3 Set 2	Jul. 6-13	-.26	.63	.89	.74	1.20	62
	13-20	-.31	.95	1.26	.94	1.13	59
	20-27	-.89	.70	1.59	1.36	1.17	47
	27-3	-.72	1.10	1.82	1.62	1.12	35
	Aug. 3-10	-.84	1.00	1.84	1.83	1.00	26
	10-17	+.10	1.15	1.05	1.65	.64	21
	17-24	-.64	.88	1.52	2.22	.68	20
	24-31	-1.02	.70	1.72	1.98	.87	14
	31-7	-.31	.78	1.09	1.12	.97	10
	Sept.7-12	-.10	.53	.63	.81	.78	10
Plot 3 Set 3	Jul. 6-13	-.26	.76	1.02	.74	1.38	65
	13-20	-.12	1.06	1.18	.94	1.26	59
	20-27	-.85	.82	1.67	1.36	1.23	48
	27-3	-.54	1.26	1.80	1.62	1.11	38
	Aug. 3-10	-.58	1.30	1.88	1.83	1.03	30
	10-17	-.02	1.28	1.30	1.65	.79	26
	17-24	-.59	1.16	1.75	2.22	.79	23
	24-31	-1.20	.76	1.96	1.98	.99	16
	31-7	-.33	.83	1.16	1.12	1.03	10
	Sept.7-12	-.24	.60	.84	.81	1.04	10

Table 4. (Contd.)

1 Location	2 Time Period	3 Change in Soil Moisture in Root Zone (in.)	4 Application plus Precipitation (in.)	5 Depletion from Experimental Area (Ue) Col. 4 - Col. 3 (in.)	6 Normal Consumptive Water Use (Uc) (in.)	7 $\frac{Ue}{Uc}$	8 Available Moisture in Root Zone (percent)
Plot 3 Set 4	Jul. 6-13	-.05	.88	.93	.74	1.26	59
	13-20	+.14	1.06	.92	.94	.98	39
	20-27	-.65	.88	1.53	1.36	1.12	50
	27-3	-.35	1.40	1.75	1.62	1.08	42
	Aug. 3-10	-.25	1.37	1.62	1.83	.89	38
	10-17	+.29	1.37	1.08	1.65	.65	38
	17-24	-.06	1.29	1.35	2.22	.61	38
	24-31	-.80	.84	1.64	1.98	.83	36
	31-7	-.14	.87	1.01	1.12	.90	31
	Sept.7-12	+.07	.67	.60	.81	.74	31
Plot 3 Set 5	Jul. 6-13	+.32	1.14	.82	.74	1.11	68
	13-20	-.59	1.34	1.93	.94	2.05	62
	20-27	-.26	1.18	1.44	1.36	1.06	63
	27-3	-.24	1.67	1.91	1.62	1.18	59
	Aug. 3-10	-.32	1.66	1.98	1.83	1.08	54
	10-17	+.34	1.66	1.32	1.65	.80	54
	17-24	+.06	1.64	1.58	2.22	.71	52
	24-31	-.50	1.14	1.64	1.98	.83	52
	31-7	0	1.06	1.06	1.12	.95	48
	Sept.7-12	+.03	.80	.77	.81	.95	47
Plot 3 Set 6	Jul. 6-13	+.18	1.50	1.32	.74	1.78	60
	13-20	-.11	1.84	1.95	.94	2.08	60
	20-27	-.11	1.56	1.67	1.36	1.23	57
	27-3	-.22	2.06	2.28	1.62	1.41	55
	Aug. 3-10	+.08	2.04	1.96	1.83	1.07	52
	10-17	+.34	2.18	1.84	1.65	1.11	54
	17-24	+.08	2.22	2.14	2.22	.96	55
	24-31	-.53	1.84	2.37	1.98	1.20	54
	31-7	-.05	1.51	1.56	1.12	1.39	49
	Sept.7-12	-.14	1.10	1.26	.81	1.53	48

Table 4. (Contd.)

1 Location	2 Time Period	3 Change in Soil Moisture in Root Zone (in.)	4 Application plus Precipitation (in.)	5 Depletion from Experimental Area (Ue) Col. 4 - Col. 3 (in.)	6 Normal Consumptive Water Use (Uc) (in.)	7 $\frac{Ue}{Uc}$	8 Available Moisture in Root Zone (percent)
Plot 3 Set 7	Jul. 6-13	+.20	2.24	2.04	.74	2.75	62
	13-20	-.20	2.88	3.08	.94	3.28	64
	20-27	-.04	2.36	2.40	1.36	1.76	62
	27-3	+.05	3.10	3.05	1.62	1.88	62
	Aug. 3-10	+.09	2.51	2.42	1.83	1.32	60
	10-17	+.12	3.19	3.07	1.65	1.86	61
	17-24	+.02	3.11	3.09	2.22	1.39	57
	24-31	-.31	2.64	2.95	1.98	1.49	57
	31-7	+.36	2.37	2.01	1.12	1.79	57
	Sept.7-12	-.05	1.62	1.67	.81	2.06	57
Plot 3 Set 8	Jul. 6-13	+.04	3.54	3.50	.74	4.73	66
	13-20	-.04	4.66	4.70	.94	5.00	64
	20-27	+.30	3.70	3.40	1.36	2.50	64
	27-3	-.15	4.15	4.30	1.62	2.65	66
	Aug. 3-10	+.09	3.92	3.83	1.83	2.09	50
	10-17	+.24	5.40	5.16	1.65	3.13	64
	17-24	-.10	4.91	5.01	2.22	2.26	63
	24-31	-.21	3.74	3.95	1.98	1.99	63
	31-7	-.09	3.46	3.55	1.12	3.16	61
	Sept.7-12	0	2.32	2.32	.81	2.86	60
Plot 3 Set 9	Jul. 6-13	+.05	5.39	5.34	.74	7.21	69
	13-20	+.34	7.29	6.95	.94	7.40	73
	20-27	-.06	5.82	5.88	1.36	4.31	73
	27-3	+.13	6.58	6.45	1.62	3.98	74
	Aug. 3-10	+.31	6.36	6.05	1.83	3.30	72
	10-17	+.04	9.33	9.29	1.65	5.63	74
	17-24	+.14	7.87	7.73	2.22	3.48	70
	24-31	-.25	5.25	5.50	1.98	2.78	70
	31-7	+.23	5.50	5.27	1.12	4.70	70
	Sept.7-12	-.27	4.02	4.29	.81	5.30	69