THE INFLUENCE OF IRRIGATION INTERVALS ON WATER USE EFFICIENCY MEASURED BY THE NEUTRON SCATTERING METHOD

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A study was carried out in the Beqa'a plain in 1964 to determine, yield, water use, and water use efficiency of potato, corn, and sugarbeet under different irrigation intervals. This objective was approached through soil moisture studies using the neutron scattering method.

The different intervals used were 1, 1.5, and 2 weeks for each of potato and corn; and ½, 1, 2, 3, and 4 weeks for sugarbeets. The root zone of each of these crops was brought to field capacity at each irrigation. Water use was determined by soil moisture determinations after and prior to every irrigation. Water use efficiency of potato, corn, and sugarbeet was arrived at by determining the yield under each treatment and expressing it as a function of the water used over the entire growing season by that treatment.

The average daily water use for each of the three crops was highest during the first week following irrigation and gradually decreased as the soil moisture tension increased. Between 50% and 60% of the water used was extracted from depths shallower than 40 cm. For potatoes the available level of moisture remained above 50% below the 30 cm depth in all treatments. Whereas for corn and sugarbeets only at depths, below 70 cm did the available moisture remain above 50%.

The yield of each crop was highest at the one week irrigation treatment; and the water use and water use efficiency of each of these crops were highest at the one week interval also. For potatoes the yield dropped from 3770 kg/D to 3210 kg/D to 2870 kg/D, as the irrigation interval increased from one week to 10-11 days to two weeks, respectively. The water use efficiency was 44.56, 38.21, and 42.08 kg/D/cm for the three respective treatments.

For corn the yield dropped from 1070, to 720, to 590 kg/D, as the irrigation interval increased from one week to 10-11 days to two weeks, respectively. The water use efficiency was 5.16, 3.69, and 4.13 kg/D/cm for the three respective treatments.

For sugarbeets the yield dropped from 8570, to 8530, to 7090, to 5910, to 4610 kg/D as the irrigation interval changed from one, to half, to two, to three, to four weeks, respectively. The water use efficiency was 54.48, 53.38, 44.40, 39.40, and 28.18 kg/D/cm for the five respective treatments.

The interruption in soil moisture determinations imposed by the periodic break-down of the neutron probe precluded the possibility of having statistically significant data for several observed trends. This as well as the anticipated use of data resulting from similar studies justify recommending, that the experiment be repeated, and further extended to cover more of the commonly grown crops of the area.

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I. INTRODUCTION

The basic purpose of irrigation is to supply plants with the water they require to obtain optimum yield and quality of a desired plant constituent. As Taylor (66) put it, "irrigation should take place while soil water potential is still high enough so that the soil can and does supply water fast enough to meet the local atmospheric demands without placing the plants under a stress that would reduce yield or quality of the harvested crop".

A knowledge of water use and water use efficiency of crops is of prime importance in the design of irrigation systems and the selection of cropping patterns. Determination of water use efficiency of corn, potatoes, and sugarbeets in semi-arid areas is of special interest because these crops are heavy water users and water is generally available in limited quantities. Much attention has been given to the problem of predicting rates of water use of crops under conditions where soil water supply is not a limiting factor. For a homogeneous, actively growing crop, it is usual to call this water use the potential transpiration rate. Less attention has been given to the question of what happens when the soil water supply limits evapotranspiration due to high soil moisture tension. Such information will prove of great value for establishing irrigation programs under conditions of deficient water supplies.

This study was planned as a basic step in a much wider program of water use studies aiming at optimizing yield under different or limited water supplies. The specific aim of this study was to determine the influence of varying soil moisture tension conditions on the rates of water use by corn, potatoes, and sugarbeets. Since varying irrigation intervals were used to produce these different soil moisture tension conditions, it was also possible to determine both the influence of varying irrigation intervals on yield as well as on water use efficiency.

It is hoped that through this and similar integrated studies a more precise knowledge of the influence of soil moisture tension could be gained which in turn would eventually lead to a more efficient use of existing water supplies.

II. REVIEW OF LITERATURE

Determination of Water Use and Water Use Efficiency of Crops

By definition (29), water use efficiency is the ratio between the weight of the crop produced and the weight of water used by the plant in evapotranspiration to produce it. It can be calculated by determining the total water used by a crop and the total amount of the dry matter produced.

Water use is commonly determined through soil moisture studies, growing crops in weighable tanks or lysimeters; it can be estimated by area wide studies of ground water fluctuations or area water inflow and outflow conditions, and by some rational and/or empirical methods. The following review will be mainly concerned with water use determination by soil moisture studies and problems associated with such work.

Soil Moisture Studies

These include direct and indirect methods. The direct method, also called gravimetric, requires drying a wet sample of the soil in an oven and expressing the loss in weight as a percentage of the dry weight of the soil (30). Although this method is the one against which all other determinations are checked (21), there are several drawbacks to it. First, it is tedious and time consuming. Second, repeated sampling from the same site are not possible, and in small plots, may modify soil conditions. Third, the result is expressed as a percentage of the weight of the soil and the apparent density has to be determined also before the results can be changed to a depth of water. Finally, where the subsoil is stony, this method fails entirely (54).

The indirect determination of soil moisture can be achieved through measuring some characteristic of the soil related to its moisture content. Some of the most common features that have been used are electrical conductivity (6, 8), moisture tension (1) and the existence of hydrogen atoms in the soil (26). Radioactive materials have been used for detecting the existence of hydrogen atoms in the soil and hence predicting the amount of water. This latter method was used in this study. It is the most recent and promising (26), and will be discussed below in greater detail.

This method is primarily based on two considerations:

First, hydrogen is practically the only element that will slow down fast moving neutrons. From the study of energy exchange during the collision between two nucleii of nearly equal mass, it can be concluded that hydrogen is more effective than other elements in slowing down fast moving neutrons. Not only does a neutron lose more energy when it collides with a hydrogen nucleus, but it has also a greater probability of striking such a nucleus (26).

Second, hydrogen in the soil is present almost entirely in the form of water (26).

The main features of this method are a scalar or neutron counting unit and a probe unit, while the former is a device that registers pulses, the latter contains both a source of fast neutrons and a detector of slow neutrons (54). The probe unit is lowered into a preinstalled metal tube, usually of aluminum or steel, to various depths. At underground levels, the fast neutrons are projected out into the soil in all directions. Some of them are slowed down by hydrogen nucleii and are deflected back to the detector where the pulse they produce is amplified and relayed to the counting unit. These pulses, which are registered by this unit are related to the soil moisture content of the soil.

It appears that a definite relationship exists between the soil moisture content and the counting rate of neutrons. Gardner and Kirkham (26) indicate that this relationship seems to be the same for all soils, including a sand and a clay, of varying specific gravities. This relationship is true, however, only if the moisture content is expressed in terms of unit volume of soil. Richards (54) indicates that only a single curve is needed for almost all types of soils. Mortier and Deboodt (46) however, found two different though close curves for clay and sand. McGuiness (45) reported that evaluation of soil moisture changes with the neutron method agreed closely with that obtained from lysimeters. From the above mentioned literature, it may be deduced that calibration of probe for specific soil is recommended.

The neutron scattering method is assumed to be temperature independent as long as the temperature is below 32°C. Davidson _et_ _al_., (14) found inaccurate probe readings when the temperature was above 32°C. Taylor (64) found a linear relationship between neutron counts and water content of the soil. This is in contrast with findings of Stolzy and Cahoon (60) and Stone _et al_. (61), who found a curvilinear relationship for a field calibration curve. Stolzy and Cahoon (60) reported that Harojeff and Javek in Australia obtained S-shaped curve in laboratory calibration.

The neutron scattering method is the most promising soil moisture method for determining evapotranspiration (26). It appears to be valid in a wide range of soil moisture - from ovendry to saturated soils - gives moisture content on volume basis, seems to be independent of temperature and compactness of soil, lends itself to insitu measurements and is by far less time consuming than the gravimetric method (26). Furthermore, the sampling error in this method is minimal (64).

Water Use and Water Use Efficiency of Potato, Corn, and Sugarbeet

Veihmeyer and Hendrickson (73) concluded from their own studies extending over many years and from the work of others that transpiration is independent of soil moisture as long as the moisture content of the soil in contact with the absorbing portion of the root is above the permanent wilting percentage. Kramer (40) found that plant growth is controlled directly by plant water stress and only indirectly by soil water stress. Plant water stress depends on the relative rates of water absorption and water loss rather than on soil water supply alone, hence it is not safe to assume that a given degree of soil water stress always will be accompanied by an equivalent degree of plant water stress because plants in moist soil are subjected to water stress when transpiration is rapid and plants in dry soil may be subjected to little water stress if transpiration is very low.

Doss *et al*. (18) found that the total amount of water used depends more upon the amount of available moisture in the soil than on plant species, and the rate of moisture use is increased as the amount of available moisture is increased.

Letey and Blank (43) concluded that at high soil moisture tensions there was greater reduction in vegetative plant growth when the environment caused high evapotranspiration than when the evapotranspiration was low. Transpiration diminished as soil moisture tension increased regardless of environment, but, under conditions of high evapotranspiration, the reduction in transpiration was relatively greater. Regardless of environment less water was used per unit dry weight produced when watering was delayed until higher soil moisture tensions.

Taylor (63) found that, using a single value representing the seasonal soil moisture regime, the mean soil moisture tension has been related to yields of alfalfa, sugarbeet, and potatoes showing that over the entire plant growth range of soil moisture, the yield is reduced as mean tension increases. This makes untenable the hypothesis that moisture is equally available to plants for growth throughout the entire plant growth range from field capacity to permanent wilting percentage.

Effect of Irrigation on Potatoes

Among cultural practices, rate and pattern of planting, fertilization and moisture regime have considerable effect on plant water use and water use efficiency. Stockton (59) has summarized all previous potato irrigation studies and suggested that irrigation should be done when the tension is in the range of 40 to 60 centibars. Irrigating at tensions above or below this range can be harmful to yield and quality. Irrigating when the soil moisture tension is below 40 centibars - probably because of poor aeration - can result in reduced yields. When the soil moisture tension reached 70 centibars, wilting was apparent and the plants were being stressed because of a soil moisture deficit. Fulton (24) found that one inch of water every seven days on light soils and 1.5 inches every ten days on heavier soils was a good irrigation plan, but additional irrigation was necessary if the available moisture fell to 50%.

Jones and Johnson (39) irrigated potatoes when soil moisture tension rose to 0.3, 0.6, 1.2, 2.4, and 4.8 atmospheres in the first foot of soil. Irrigation at 0.3 atmosphere tension gave a higher yield, both total and No. 1 potatoes, than irrigating at higher tensions. Irrigation at 0.3 produced 217.8 bushels per acre of No. 1 potato, while 32.2 bushels per acre were produced when irrigated at 4.8 atmospheres.

Singleton (57) concluded that maintaining a high moisture level (tension less than 0.8 atmospheres at 9 inch depth in the row) has produced greater yields than lower moisture levels (tension less than 4 atmospheres at the 9 inch depth in the row). Potatoes are also affected by periods of high tension during the time the tubers are forming and growing. High tension during this period caused a greater percentage of malformed tubers, which reduced the market grade of potato even more than it reduced the yield.

Corey and Meyers (13) used short, medium, and long frequencies corresponding to 1/3 and 2/3 depletion of available soil water within the top two feet of soil, and long frequencies in which plots were irrigated when there was a marked visible drought stress. The yield of U.S. No. 1's was significantly reduced from 195.2 cwt per acre to 106 cwt per acre in the long frequency irrigation treatment, although the total yield for all treatments was about the same.

Blake _et al._, (2) irrigated potatoes when the soil moisture tension reached values of 0.8, 1.2, and 2.5 atmospheres at the 9 inch depth. The yields were decreased as the tension was increased by 41.3% and 70.5% in two consecutive years, respectively. The data indicated that potato yields were equally good when soil moisture tension was 0.8 and 1.2 atmosphere before irrigation.

Timm and Flocker (67) found that tubers yield and quality in all soils were best when the soil moisture tension was near 0.5 atmospheres. At a lower tension (0.2 atm.) enlarged lenticels were more prevalent and at a higher tension (0.7 atm.) the yield and percent of U.S. No. 1 tubers diminished in severly compacted soil.

Box _et al._, (9) concluded that growth rates seem to be reduced, both in tops and tubers at relatively low stress. Very rapid cell enlargement, especially in the tubers apparently partially compensates for the slow down after stress is reduced by irrigation.

Specifying recommendations for potato irrigation is difficult, this is due to two reasons: First, to the apparent sensitivity of the crop during tuber formation to variations in the soil, water, temperature, fertility and other parameters. Second, due to lack of data on the specific water use of potato at different intervals, and lack of research on this subject.

Effect of Irrigation on Corn

Alessi and Powers (1) stated that forage and grain yield of corn were directly proportional to total available moisture in the soil during the growing season. According to Letey and Peters (42) corn yield and water use are closely related to reserve soil moisture conditions at the beginning of the growing season and to the soil moisture stress to which the plant is subjected during the growing season.

Robins and Domingo (55) showed that depletion to the wilting percentage by field corn at certain physiologic growth stages markedly depressed grain yields. Yield reductions due to the absence of available water after the fertilization period appeared to be related to the maturity of the grain. When the available water was removed following maturity, the depletion of the available soil moisture had no effect upon yield and did not influence the moisture content of the grain, cob, or stalk and had little influence upon the leaf moisture content.

Water use by corn was influenced markedly by the moisture treatments; when a severe deficit occurred during the fertilization period, water use was lowered by reduction of transpiration. Removal of the available water prior to maturity reduced water use whereas a similar removal following maturity had little effect. Fritschen and

Shaw (23) concluded that water use by corn is dependent upon corn development. This is probably true for other annual crops. Empirical methods of estimating evapotranspiration should be adjusted for crop development.

Vasquez (72) reported that there was no significant difference in production between frequent irrigation (where 20% of the available moisture had been depleted from the root zone) and intermediate irrigation (where 60% of moisture had been depleted); when irrigation was conducted throughout the growth season or until the hard dough stage.

Howe and Rhoades (36) reported that the yield of grain ranged from 69 bushels per acre without irrigation during the growing season to 153 bushels per acre where a low soil moisture tension was maintained throughout the season by adding 14.2 inches of water to the soil in six irrigations. In general, an increase in the number of irrigations was accompanied by a greater net input as irrigation water resulted in increased yields.

Van Bavel and Harris (71) showed that evaporation rates from corn show marked effects of the stage of growth. Briggs and Shantz (10) reported water use efficiency of 319 and 420, with an average of 370 grams of water per gram of oven dry matter, for several varieties of corn in Colorado. England (20) found a peak water use for corn of 6.55 in. per month during tasseling. Water use for corn was 29.49 in. during the day time and 2.65 in. at night, totalling 32.14 in. for the 8 month period. Van Bavel and Harris (71) reported an average seasonal evapotranspiration value of 5.05 mm per day in North Carolina, for a two year experiment. Maximum values were observed during pollination and were 8.24 mm per day. Sommer (58) for southern Alberta, Canada, reported an average water use of 15 inches for maximum yield during a 4 month growing season. This corresponds to 0.124 inches per day. Carlson _et_ _al_., (12) in a two year experiment in 1956 and 1957 obtained 659 and 772 pounds of dry matter per acre inch of water applied. Peters (51) found that the uptake of water and elongation of corn roots are decreased as the moisture tension increases, and that the uptake of water by corn roots is a function of the specific moisture content as well as the moisture tension.

Trunov (70) studied the effect of irrigation at soil moisture levels of 70% and 80% of the field capacity, and reported that the grain yield was improved by irrigation in both dry and wet years. At 80% soil moisture level the yield of grain was 600 kg per hectare higher than at 70% level.

Corn, being a heavy user of water, responds to change in the moisture regime to a great extent. Alessi and Power (1) stated that forage and grain yield of corn were directly proportional to total available soil moisture. According to Letey and Peters (42) corn yield and water use are closely related to reserve soil moisture conditions, at the beginning of the growing season and to the soil moisture stress to which the plant is subjected during the growing season. As far as the water use efficiency is concerned, the values fall in a wide range. This is due to differences in locations, cultural practices and the amount of water applied. Timmons _et_ _al_., (69) obtained water use efficiencies of 6 to 454 pounds per acre inch depending on the amount of water used which ranged from 7.8 in. to 15.5 in. Yao and Shaw (75) found a water use efficiency of 571 pounds per acre inch for 21 row spacing and 420 pounds per acre inch for 42 in. rows.

Effect of Irrigation on Sugarbeet

Hagan (29) reported, that Haddock reported, although sugarbeet crop is not considered highly sensitive to variations in soil moisture conditions wide differences in yield were obtained for different irrigation programs. It appears important that sugarbeet plants be kept growing vigorously early in the season.

Hagan (29) reported that Reeve and Kidder found that supplemental irrigation as applied to the sugarbeets caused excessive root rot during the summer. Harvest stands in the irrigated plots were reduced by as much as 25%. Moreover, early irrigation to get the beets up and off to a good start may be more important in normal years than late summer irrigations, because sugarbeets have the ability to draw moisture from the subsoil when no moisture is available in the surface area.

Owen (47) found that from an experiment in a small plot in which sugarbeet was protected from rain, the application of large amounts of water to keep the soil water stress to a minimum gave very large crop yields. Small frequent applications of water appeared to give higher yields than the same amount of water in one large application.

Larson and Johnston (41) concluded that when sugarbeet plants were allowed to remove 43, 75, and 95% of the available moisture in the root zone prior to irrigation, yields were 23.4, 22.0, and 16.9 tons per acre, respectively. Consumptive use of water for the growing season was 23.4, 22.5, and 19.0 inches, respectively.

Pruitt (52) reported that peak evapotranspiration rates at Davis, California, are near 0.3 inches per day with seasonal consumptive use exceeding 40 inches. Taylor and Haddock (65) reported that evapotranspiration rates at Logan, Utah also approached 0.3 inches per day; in Montana; Larson and Johnston (41) reported that seasonal consumptive use varied from 20 to 30 inches.

As far as the rates of water use are concerned, the values fall in a wide range. This is due to soil type, method of irrigation, and other factors in addition to potential evapotranspiration. They range from 20 to 50 inches for various beet producing areas in the U.S.A. (29).

III. MATERIALS AND METHODS

The field work for this study was carried out at the Agricultural Research and Education Center (A.R.E.C.) of the American University of Beirut, Lebanon, situated at an altitude of about 1000 meters and at 33^{0} 54" north of equator. Irrigation intervals were set at 7, 10-11, and 14 days for potatoes and corn; and 3-4, 7, 14, 21, and 28 days for sugarbeets. Water use and water use efficiency of each crop under the various irrigation intervals were arrived at by measuring the moisture content of the soil before and after each irrigation using the neutron scattering method and determining the yields obtained.

Field Procedure

The field work was carried out in 1964 with potatoes (Solanum tuberosum), maize (Zea mays), and sugarbeet (Beta vulgaris); and utilized an existing experimental setup (11). As such only the field and laboratory work related to the calibration of the neutron probe and the determination of the soil moisture content was carried out by the author. All other cultural operations and yield determinations were carried out by Bybordi (11). The experimental area had been surveyed and plots were laid out in such a way that a uniform application of water was possible. The treatments had been assigned at random to the different plots within each block. Each plot was a basin eight meters long and 3.75 meters wide. Crops were planted in rows 75 cm apart, separated by furrows which served for distributing the irrigation water. The soil was fertilized heavily and high plant populations were used in order to establish a relatively high yield potential.

Prior to starting the irrigation treatments, all crops were irrigated weekly by sprinklers until the plants were well established. The irrigation treatments indicated in Table 1 started on June 4,1964 and lasted 22 weeks for sugarbeets, while for potatoes and corn they started on May 28, and lasted for 14 and 18 weeks, respectively. The amount of water applied at each irrigation was not actually measured, however, enough water was applied to make sure that the entire depth of the root zone was brought to field capacity following each irrigation. At maturity the crops were harvested, graded and weighed. The average sugar content of the sugarbeets and the moisture content of the corn were determined.

Table 1. Irrigation schedule for the corn, potato, and sugarbeet.

Crop	Treatment	Irrigation interval (days)	Number of irrigations
Corn	C_1	7	17
	C_2	10 - 11	11
	C_3	14	8
Potato	P_1	7	13
	P_2	10 - 11	8
	P_3	14	6
Sugarbeet	S	3 - 4	34
	S_1	7	19
	S_3	14	9
	S_4	21	7
	S_5	28	5

The Neutron Probe

Soil moisture determinations were made by the neutron scattering method. Equipment manufactured by Troxler Electronic Laboratories of Raleigh, North Carolina were utilized. This consisted of a neutron probe and a scalar. The probe was Model 104 1.865" in diameter with radium - beryllium as a fast neutron source, and with a nominal activity level of three millicuries. The detector utilized boron trifloride (BF_3) enriched with B^{10} isotope which respond only to relatively slow neutrons. The scalar was 200B model with glow tubes indicators and barrery operated.

Moisture content on a volume basis was determined by taking neutron counts at the desired depths, comparing them to the neutron counts through the standard and then reading off the calibration curve. Readings at various depths were made by inserting the neutron probe into access tubes penetrating the root zone. These access tubes were made of two inches galvanized steel pipes closed at the lower end and placed vertically in the root zone by augering. While not in use each tube was capped to prevent the tube getting filled with water while irrigation was taking place.

Laboratory Calibration of the Probe

The probe was calibrated in the laboratory using soil brought from A.R.E.C. The purpose of this calibration was to compare its results with the general calibration curve supplied by the manufacturer.

A cylindrical asbestos-cement barrel, 61.5 cm in diameter and 71.5 cm high was filled with 665 pounds of air-dry soil. The initial moisture content, the field capacity and the apparent density of the soil were determined by the gravimetric method. An access steel tube closed at one end was inserted into the soil until its closed end was at 10 cm above the bottom of the barrel. The standard was measured by operating the scalar at 1350 volts and gain No.3. This was 10,389 counts per minute (c/m). Then the probe was inserted into the access tube and the counts were taken at 10 and 20 cm above the bottom of the container. At every measurement five counts were taken and the average was considered. The soil moisture content was increased by 4.33% on a volume basis, by adding 770 cc of water to each 5 cm layer of soil. The standard and average counts per minute at 10 and 20 cm above the bottom of the container were repeated for each moisture addition. Readings were taken up to a moisture content of 26.87%, and a further reading with the probe immersed in water.

Field Calibration of the Neutron Probe

To further compare the influences of specific soil types on the calibration curve of the neutron probe and more specifically to determine the difference between using disturbed and undisturbed soils for calibration; a field calibration at A.R.E.C. was carried out. A six meters long trench was dug to a depth of 120 cm in an alfalfa plot. Six access tubes 110 cm long were inserted 90 cm apart, and 60 cm away from the side of the trench. This arrangement was selected to facilitate taking soil samples for gravimetric determinations of both moisture and apparent bulk density at various depths immediately following probe readings. The initial moisture content, apparent density and counts per minute of the soil were determined at 40 and 80 cm depths. The plot was then flooded with water for eight hours and the moisture content, apparent density, and counts per minute were determined at 40 and 80 cm depths, after 24, 48, 96, and 144 hours. Each access tube was used for one set of readings only, as taking the gravimetric samples destroyed the homogeneous soil surrounding it, and it could not be used another time.

Field Soil Moisture Determinations

Access tubes were installed in the middle of each plot at 110 cm depth. Soil moisture determinations were made following irrigation, prior to irrigation, and as many times in the intervening interval as was practical. This is shown in Appendix A. Each treatment was replicated three times, except for the S and S_5 treatments of sugarbeet which were not replicated, as the original design of the experiment utilized for this study did not allow such replication. Thus a total of 29 access tubes were installed - nine in each of the corn and potato plots and 11 in the sugarbeets. Soil moisture readings were made at 110, 70, 50, 30 cm depths. The counts at each depth were taken twice and then their average compared to the average of the counts of the standard, which also were the average of two readings for each access tube. This required a total of approximately 3570 readings during the period of this study. Moisture content at each depth was read from the field calibration curve of the probe. Moisture use during each period was determined by obtaining the difference between the total moisture content of the soil profile within the root zone, for each two subsequent moisture determinations. The total moisture content of the soil profile was determined by multiplying the moisture content on volume basis by the thickness of the soil layer for which the reading was assumed indicative as shown in Appendix A (Tables 12, 13, and 14).

This being the first time the neutron scattering method was utilized in this country, many technical difficulties of both major and minor nature disrupted the continuity of taking readings during the period of this study. Furthermore, at certain times, although, seemingly in a working condition, the probe behaved erratically producing readings of doubtful nature. The time spent carrying the probe back and forth between the field and the electronic workshops in Beirut was nearly equal to that spent taking readings in the field.

IV. RESULTS AND DISCUSSION

This study was undertaken to determine the influence of soil moisture tension on the rates of water use of potato, corn, and sugarbeet, and to determine their water use efficiency under different irrigation intervals. A randomized block design was used. Water use was determined through soil moisture determination using a neutron probe which was calibrated using both disturbed soil samples and in the field. The determined rates of water use were further checked against the theoretical estimate of potential evapotranspiration by the Penman equation. Total yields of corn, potatoes, and sugarbeets for all irrigation treatments were obtained. Water use efficiency was then determined as a ratio between water used and the yield produced.

Soil and Water Analysis

The soil on which the study was carried out and the water used for irrigation were both analyzed in great detail by Bybordi (11). A summary of this work is given in Table 2. No duplication of such work was carried out in this study.

Soil Moisture Characteristics

The amounts of moisture held by the soil at different tensions were determined by the Richards pressure membrane method (53). Bybordi (11) reported that the soil moisture sorption curve , shown in

Table 2. Results of chemical analysis of the surface soil for the experimental plots and of the irrigation water.

Soil Analysis		Water Analysis	
pH (1:2.5)	8.2	Sodium	0.282 m.e./litre
Calcium carbonate, %	39.3	Calcium	0.705 "
Organic matter, %	1.29	Magnesium	0.833 "
Total nitrogen, %	0.131	Potasium	0.056 "
Cation exchange capacity, me/100 g	42.36	Sulphur	0.125 "
		Chlorine	0.318 "
Exchangeable cations (m.e./100 g)		Electrical conductivity	0.155 m mho/cm
Calcium	26.80		
Magnesium	13.34		
Potasium	1.02		
Sodium	1.20		
Soil Texture			
Sand, %	15.9		
Silt, %	40.1		
Clay, %	44.0		

Figure 1, depicts that the available water holding capacity of the soil was about 16% and that half of this moisture was held at a tension of 2.3 atmospheres or less.

Laboratory Calibration of the Neutron Probe

Table 3 and Figure 2 give the results of the laboratory calibration of the neutron probe using a disturbed soil sample. The calibration curve was constructed by plotting soil moisture content by volume as an abscissa and the corresponding ratio of the counts per minute at the set depth of soil to the counts through the standard as ordinate. The difference between laboratory calibration and the calibration by the manufacturer is discussed in the next section.

Table 3. Results of laboratory calibration of the neutron probe.

Average counts per minute (c/m)		Ratio c/m of sample c/m of standard	Moisture content, Pv% by volume
Sample	Standard		
1941.0	10,389	18.55%	9.55%
2882.0	10,451	27.57%	13.88%
3438.0	10,580	32.49%	18.21%
4733.0	10,537	44.92%	22.54%
5320.0	10,410	51.11%	26.87%
10923.0	10,578	103.27%	100.00%

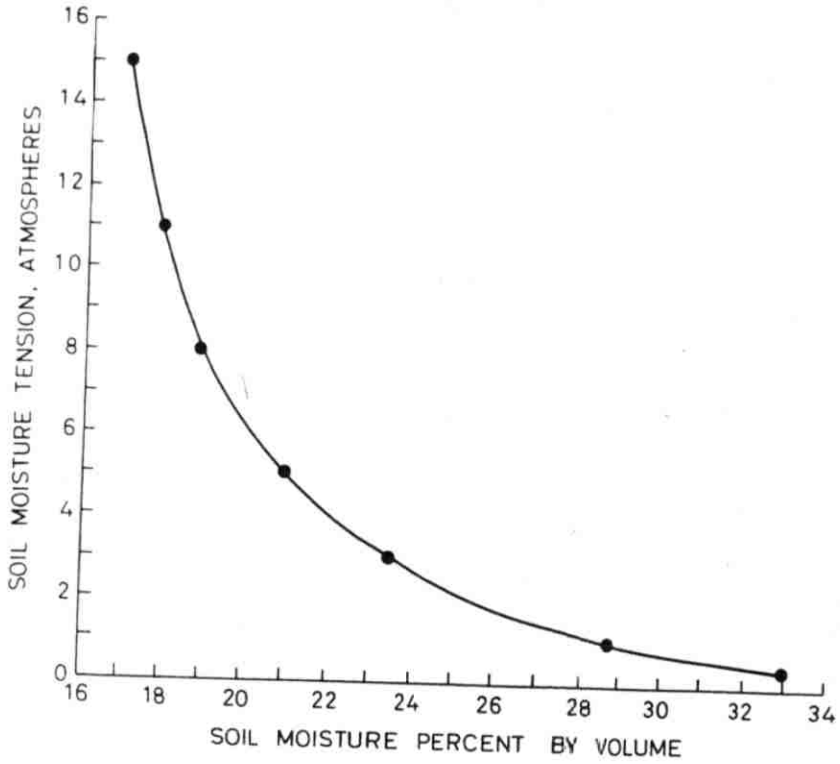

Figure 1. Relation between the soil moisture tension and the moisture content of the soil, in drying cycle (Bybordi, 11).

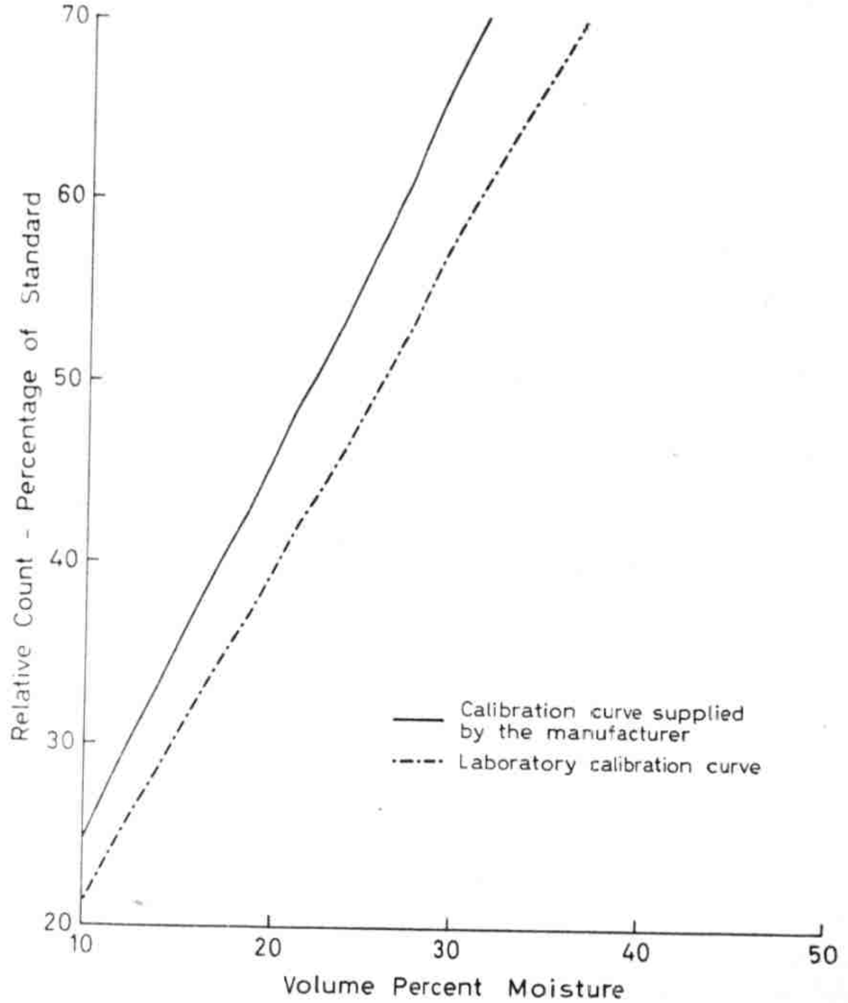

Figure 2. Laboratory calibration curve as compared to the calibration curve supplied by the manufacturer.

Field Calibration of the Neutron Probe

Table 4 and Figure 3 give the results of the field calibration of the neutron probe. The same ordinates, as in the laboratory calibration curve, were used.

Table 4. Results of the field calibration of the neutron probe.

Average counts per minute		Ratio c/m of sample c/m of standard	Moisture content, Pv% by volume
Sample	Standard		
7339	10,905	67.3%	39.06
8030	12,323	65.2%	37.76
6900	12,600	54.76%	31.76
5685	11,154	50.90%	28.28
5588	12,648	44.20%	23.18

The difference between the calibration curve supplied by the manufacturer and the laboratory calibration curve was probably due to two special factors, over and beyond the difference that might result from the nature of the soil itself. First, the manufacturer used aluminium tubes while in the laboratory slightly rusted galvanized steel access tubes were used. Secondly, in the laboratory, the moisture content of the soil was increased by adding 770 cc of water to each 5 cm layer of soil, and the wet soil layer was compacted by hand. This resulted in some water pockets forming between the layers.

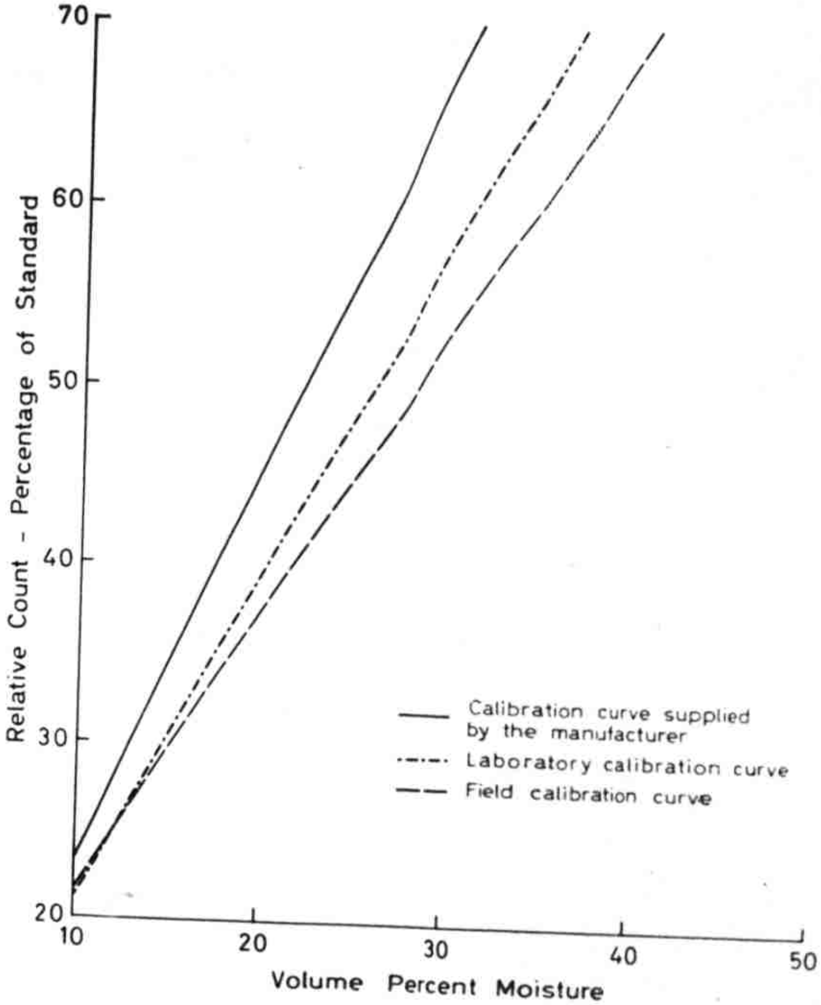

Figure 3. Field calibration curve as compared to the laboratory calibration curve and the calibration curve supplied by the manufacturer.

This factor might have also been a factor in the variation between the laboratory and field calibration curves. Beside this, there was another factor; the soil used in the laboratory was seived and stone free which might have changed some of its physical characteristics such as porosity, bulk density and water holding capacity. These modifying factors do not allow drawing any conclusion as to whether different soils require separate calibration curves as recommended by Mortier and Deboodt (46) and McGuiness (45) or whether one calibration is enough, as reported by Gardner and Kirkham (26), and Richards (54).

However, the differences between the calibration curves of the laboratory and of the field seem to justify the necessity for obtaining a calibration curve for each specific soil in the field. The field calibration curve as developed in Figure 3 was used for moisture determination throughout this study.

Yield, Water Use and Water Use Efficiency of Potatoes, Corn, and Sugarbeets

Yield

Potato: The yield of potatoes was decreased as the interval between irrigations was extended beyond one week as is shown in Table 5. Potato size and grade tended to decrease with increased soil moisture stress. This result is in conformity with the results of Jones and Johnson (39), Singleton (57), and Blake *et al.*, (2).

Table 5. Effect of irrigation interval on yield of potatoes (metric tons/hectare) and size of tubers.

	Irrigation interval, weeks		
	1	1½	2
Yield	37.7	32.1	28.7
7 cm[x]	36.8	34.8	28.9

[x] In length of largest dimensions, percent by weight.

<u>Corn:</u> The yield of corn was decreased, also, as the irrigation interval was increased. Moreover, increasing soil moisture tensions tended to delay maturity of corn, as shown in Table 6, by increasing the moisture content of the grain at harvest. This result is in agreement with the results of Alessi and Powers (1), Letey and Peters (42) and Robins and Domingo (55).

Table 6. Effect of irrigation interval on grain yield (metric tons/hectare) and moisture content of corn.

	Irrigation interval, weeks		
	1	1½	2
Yield	10.7	7.2	5.9
% moisture content	27.0	30.8	31.3

Sugarbeets: Like corn and potatoes, the yields of sugarbeets decreased as the interval between irrigations extended beyond one week as shown in Table 7. These results are in agreement with the results of Larson and Johnston (41), and Reeve and Kidder (29).

Table 7. Effect of irrigation interval on yield of sugarbeet (metric tons/hectare), and concentration of sucrose.

	Irrigation intervals, weeks				
	½	1	2	3	4
Yield	85.3	85.7	70.9	59.1	46.1
Sucrose, %	17.7	17.3	18.2	17.1	18.0

Water Use

Potato: Figures 4, 5, and 6 show soil moisture variation with time, at each of four depths for each of the three irrigation treatments of potato. Generally the soil moisture content throughout the root zone was uniform just after irrigation. With time the shallower depths lost more moisture than the deeper zones. However, it can be seen that in the P1 treatment the 50% available soil moisture level was never reached at all depths; indicating that at no time did the soil moisture tension exceed 2.3 atmospheres. In fact during most of the time it was closer to one atmosphere. In the P2 and P3 treatments the 50% level was reached only at the 30 cm depth.

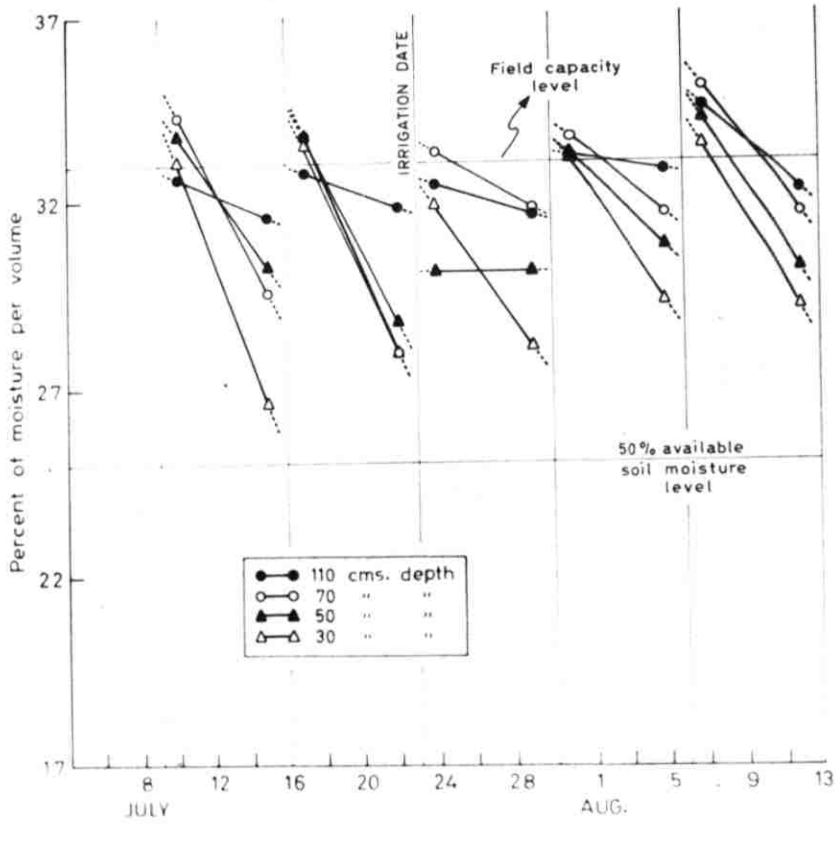

Figure 4. Effect of P_1 treatment (7 days irrigation interval) on soil moisture extraction by potato.

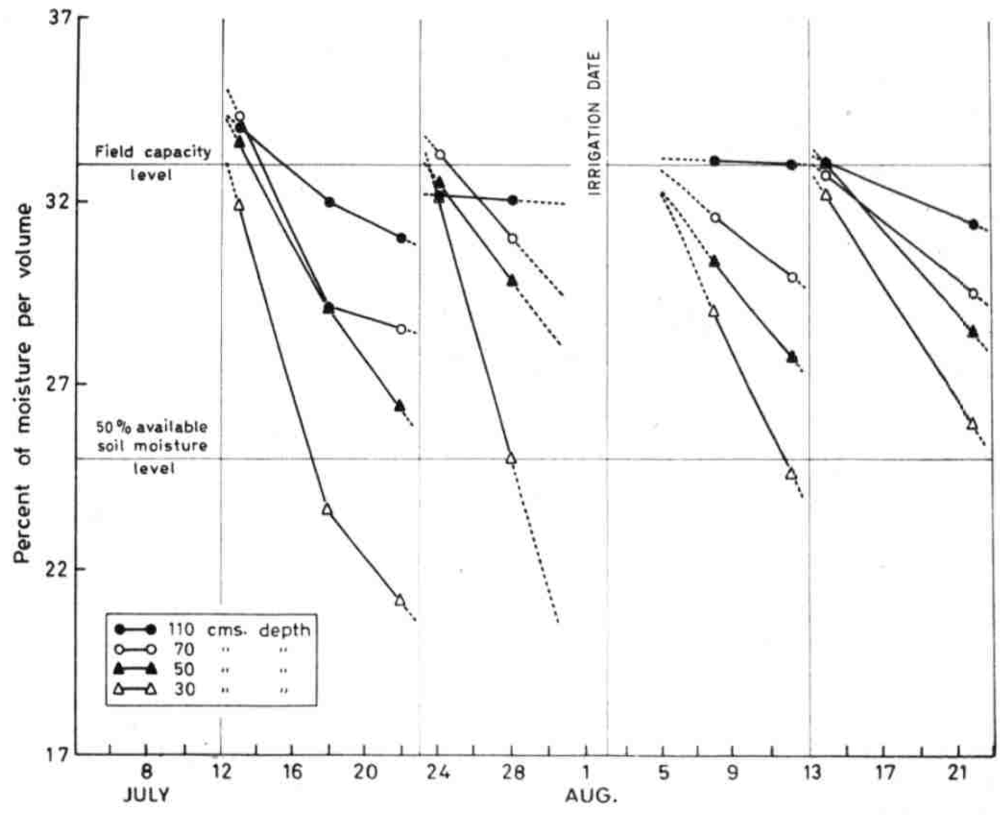

Figure 5. Effect of P_2 treatment (10-11 days irrigation interval) on soil moisture extraction by potato.

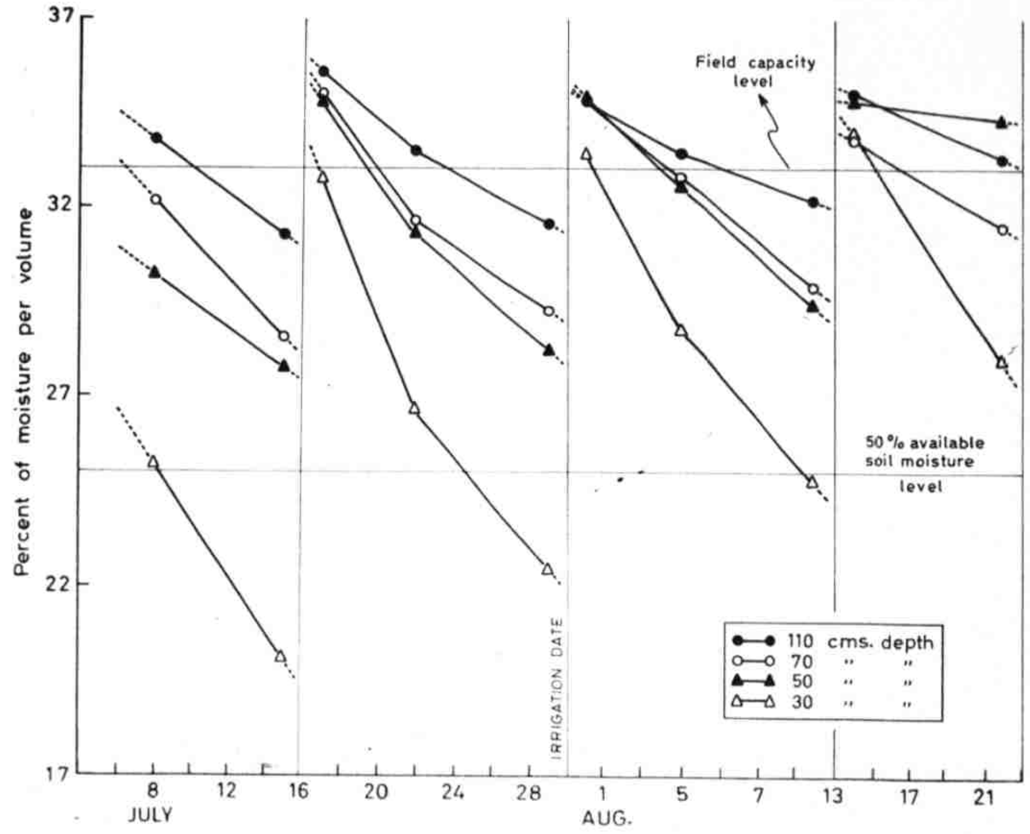

Figure 6. Effect of P3 treatment (14 days irrigation interval) on soil moisture extraction by potato.

Thus, although differing by as much as 100% in the length of the irrigation interval, the resulting variations in soil moisture tensions between the three treatments were not significant. Nevertheless, a tendency for a reduced rate of soil moisture extraction may be observed in Figure 6, beginning with the second week after irrigation; there is a break in the slope of the extraction lines and a gentle slope is apparent. This reduced rate of water use is further shown in Table 8 which gives the average daily use of water during the different segments of the irrigation interval. The average water use during the second week is lower than both average water use in the first week of P_3 and P_2 treatments, as well as P_1 treatment.

The average rate of water use ranged from 5.4 mm/day to 9.0 mm/day. The potential evapotranspiration rate as determined by Penman was around 7 mm/day. The possible explanation for this deviation is that for the period during which soil moisture was high, actual evapotranspiration was increased due to the Oasis effect which the Penman equation does not account for. As the soil moisture tension increased - which would be with the longer irrigation interval- the rate fell below that indicated by Penman, not withstanding the Oasis effect.

It is difficult to explain the variations between the different values of actual water use for the same treatment; three possible factors may have contributed collectively toward producing it.

1. Vertical water movement: Although moisture content readings were taken 24 hours after irrigation - on the assumption that by that time appreciable vertical movement had ceased - it is quite possible

Table 8. **Water** use by potatoes.

Irrigation treatment	Daily water use, mm/day					
	First week actual water use	Potential evapo-transpiration	1st half of 2nd week	Potential evapo-transpiration	2nd week	Potential evapo-transpiration
P_1	10.8	6.7				
P_1	11.4	7.0				
P_1	4.4	7.1				
P_1	5.4	7.2				
P_1	8.1	7.3				
Average	8.0	7.0				
P_2	12.9	7.2	5.7	7.0		
P_2	6.2	6.9	-			
P_2	8.0	7.1	-			
P_2	-		7.1	6.8		
Average	9.0	7.1	6.4	6.9		
P_3					5.1	7.1
P_3	9.3	7.0			4.9	7.1
P_3	7.2	7.1			6.4	6.7
P_3	4.6	6.9				
Average	7.0	7.0			5.4	7.0

that an appreciable amount of water was still moving through the profile. Since moisture determinations did not cover a depth that would allow the detection of this movement; it may be reasonable to attribute part of the variations in daily water use to this vertical movement. Moreover, this is further substantiated by the fact that soil moisture determination just after irrigation indicated a moisture level higher than the determined field capacity. To detect this vertical movement it would have been necessary either to take measurements down to the ground water table and then measure contributions to this water body, or if no ground water table is available, soil moisture determinations should have been taken to reach a soil layer not yet at field capacity.

2. Variation in advective heat: It is possible to assume that during the various intervals considered, different amounts of advective heat contributed to different rates of water use. The Penman equation does not consider this advective heat nor was it evaluated by any other means.

3. Improper functioning of the probe: This being the first year in which the probe was used, and as the result of the many malfunctionings that were repaired during the period of this study, it is not unreasonable to attribute a considerable part of this variation to errors in measurements.

Corn: Figures 7, 8, and 9 show soil moisture variation with time for the three irrigation treatments of corn. Again the same general trends exhibited by potatoes manifest themselves in these graphs. However, it can be seen that in the C_1 treatments the 50% available

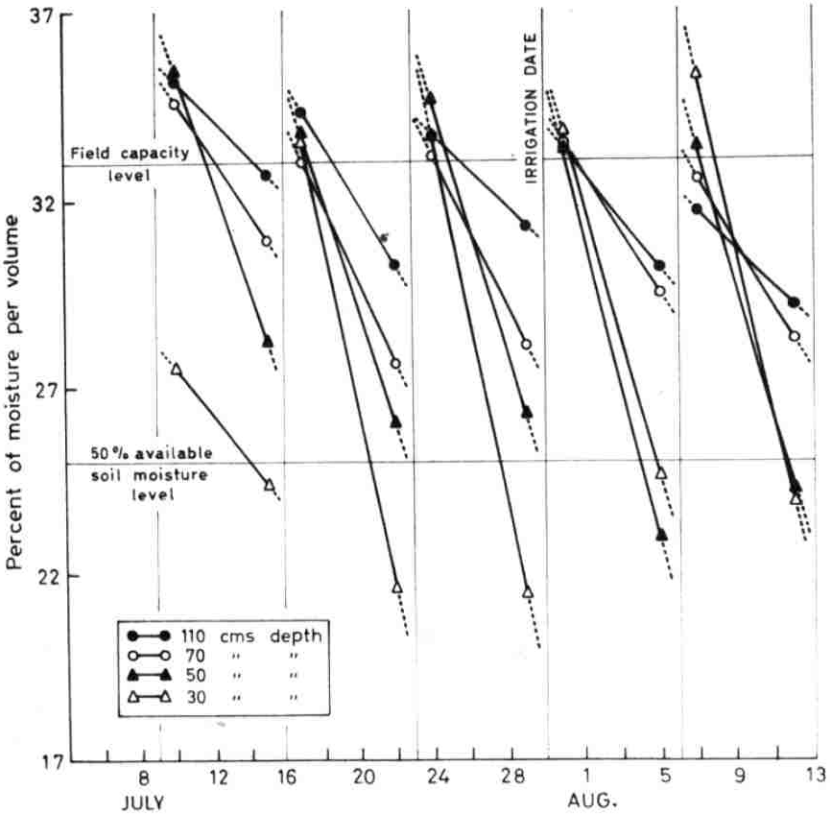

Figure 7. Effect of C_1 treatment (7 days irrigation interval) on soil moisture extraction by corn.

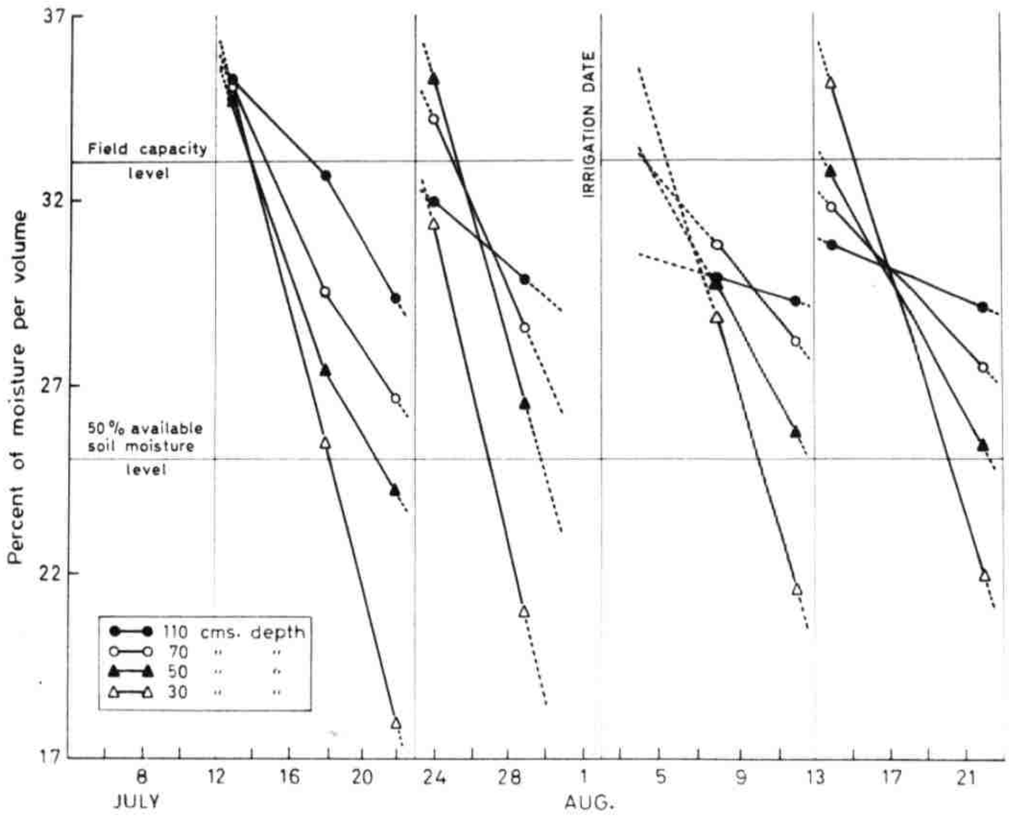

Figure 8. Effect of C_2 treatment (10-11 days irrigation interval) on soil moisture extraction by corn.

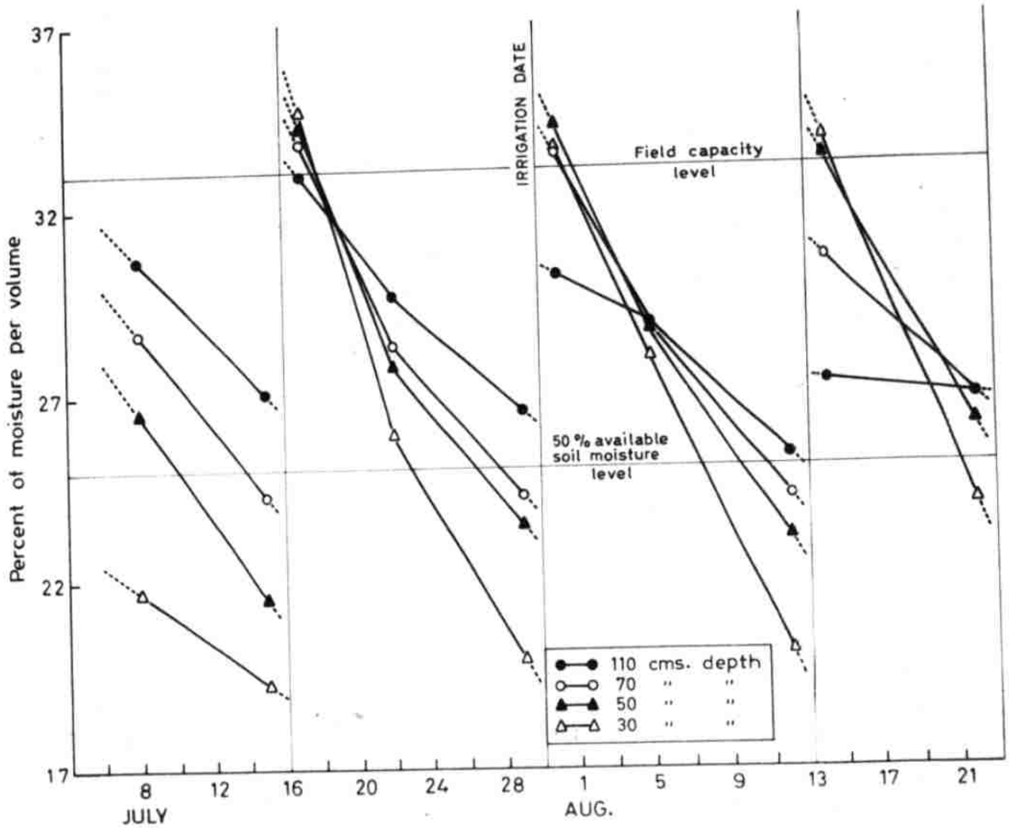

Figure 9. Effect of C_3 treatment (14 days irrigation interval) on soil moisture extraction by corn.

soil moisture level was reached at the 30 cm depth, and in the C_2 treatments at 50 cm depth, while in the C_3 treatment the 50% level was reached at the 70 cm depth. This indicates that corn generally extracted moisture from deeper depth than potatoes. The tendency for a reduced rate of soil moisture extraction, as the soil moisture tension increased, may also be observed in Figure 9. This reduced rate of water use is further shown in Table 9, which gives the average daily use of water during the different segments of the irrigation interval. The rates of water use during the second week are lower than both rates of water use in the first week of C_3 and C_2 as well as C_1 treatments.

The average rate of water use ranged from 7.7 mm/day to 14.8 mm/day. The potential rate as determined by the Penman equation was around 7 mm/day. This difference may be attributed to the same factors discussed under water use of potatoes.

<u>Sugarbeets</u>: Figures 10, 11, 12, 13, and 14 show soil moisture variation with time for the five treatments of sugarbeets. It can be seen that in the S and S_1 treatments the 50% available soil moisture level was never reached as in potatoes. During most of the time soil moisture tension in the S treatment was less than one atmosphere and in the S_1 treatment was around 1.5 atmospheres. In the S_3 and S_4 treatments the 50% level was reached at 30 cm depth, while in the S_5 treatment the 50% level was reached at 110 cm depth. A tendency for a reduced rate of soil moisture extraction, beginning the second week after irrigation, may be observed in Figures 13 and 14 and also in Table 10 which gives the average daily use of water during the different

Table 9. **Water use by corn.**

Irrigation treatment	Daily water use, mm/day					
	First week actual water use	Potential evapo-transpiration	1st half of 2nd week	Potential evapo-transpiration	2nd week	Potential evapo-transpiration
C_1	9.0	6.7				
C_1	18.0	7.0				
C_1	18.2	7.1				
C_1	13.6	7.2				
C_1	15.1	7.3				
Average	14.8	7.1				
C_2	15.4	7.2	13.7	7.0		
C_2	16.5	7.1				
C_2			12.6	6.8		
C_2	10.6	6.9				
Average	14.2	7.1	13.2	6.9		
C_3					6.3	6.7
C_3	14.9	7.0			7.7	7.0
C_3	10.3	7.1			9.2	7.1
C_3	8.3	6.9				
Average	11.5	7.0			7.7	6.9

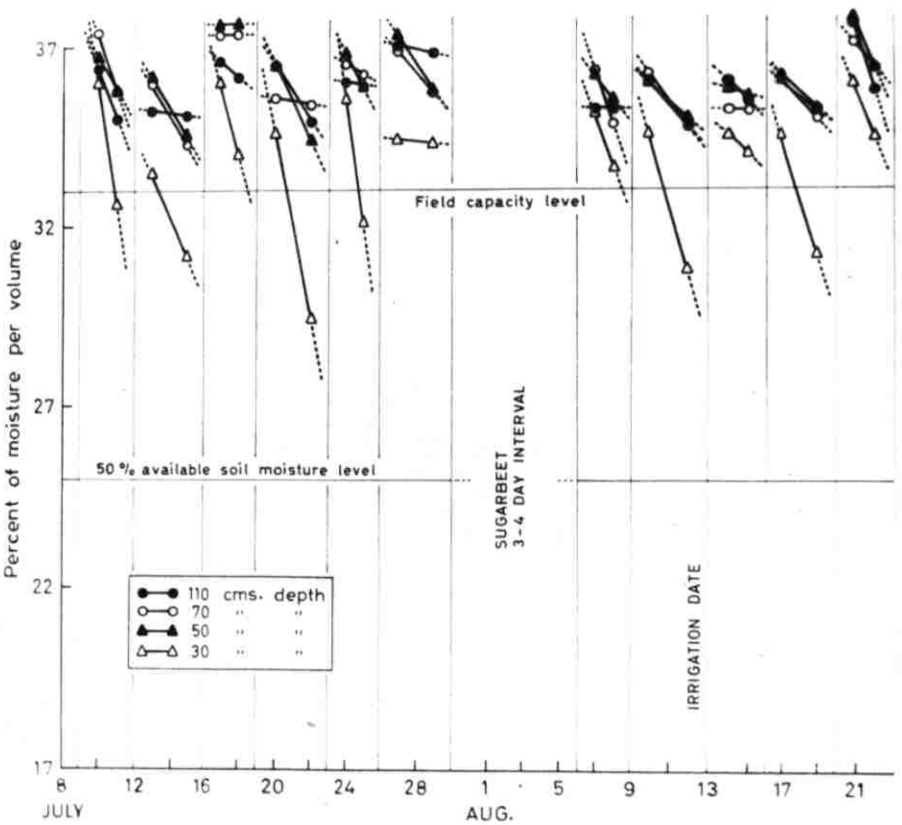

Figure 10. Effect of **S** treatment (3-4 days irrigation interval) on soil moisture extraction by sugarbeets.

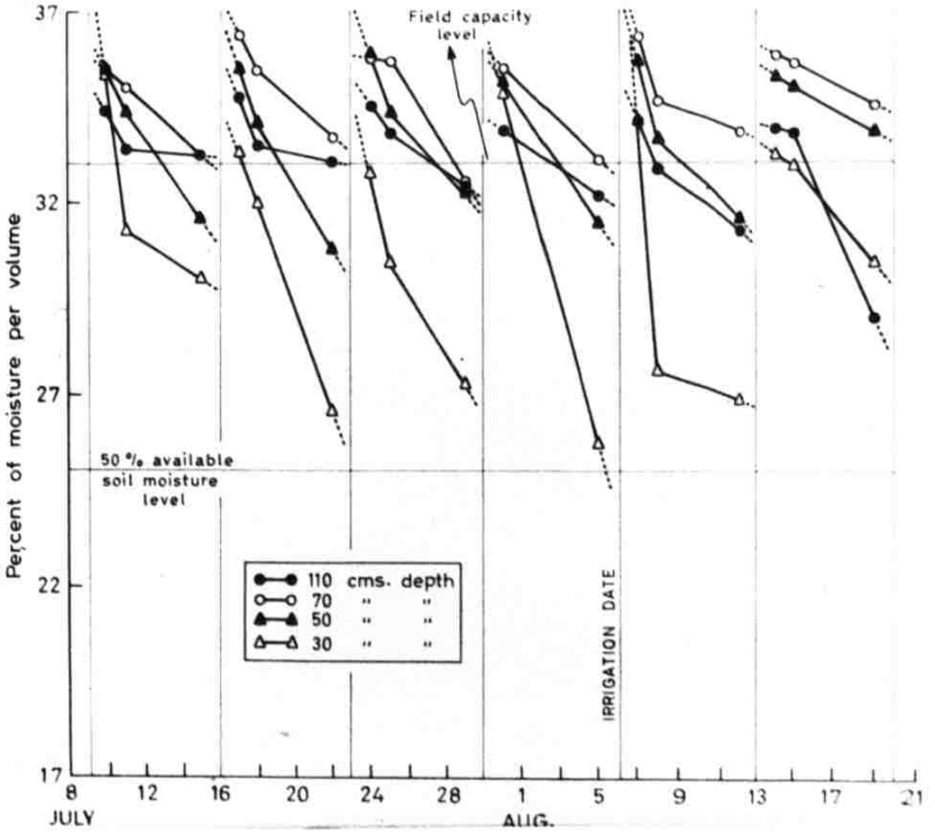

Figure 11. Effect of S_1 treatment (7 days irrigation interval) on soil moisture extraction by sugarbeets.

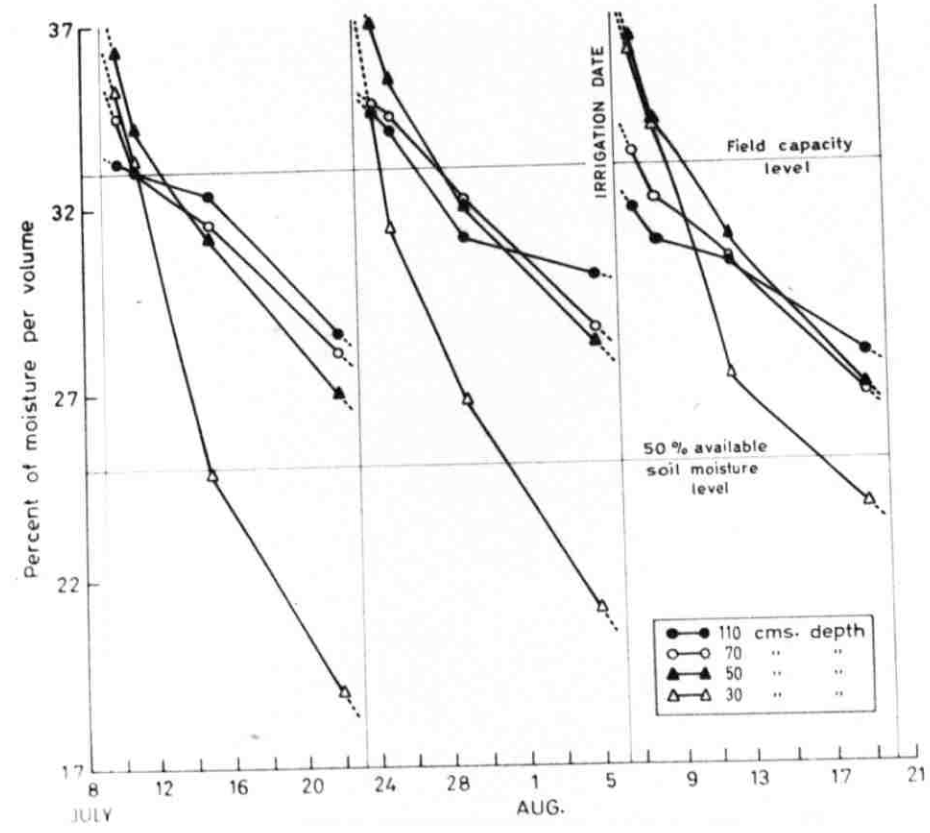

Figure 12. Effect of S3 treatment (14 days irrigation interval) on soil moisture extraction by sugarbeets.

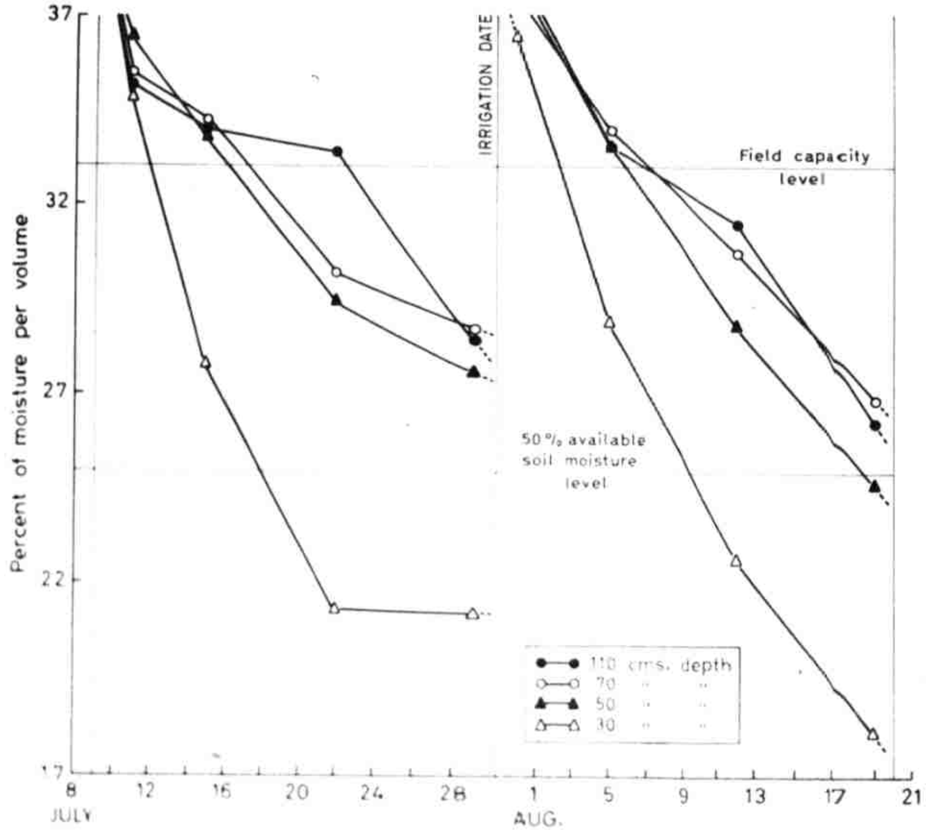

Figure 13. Effect of S_4 treatment (21 days irrigation interval) on soil moisture extraction by sugarbeets.

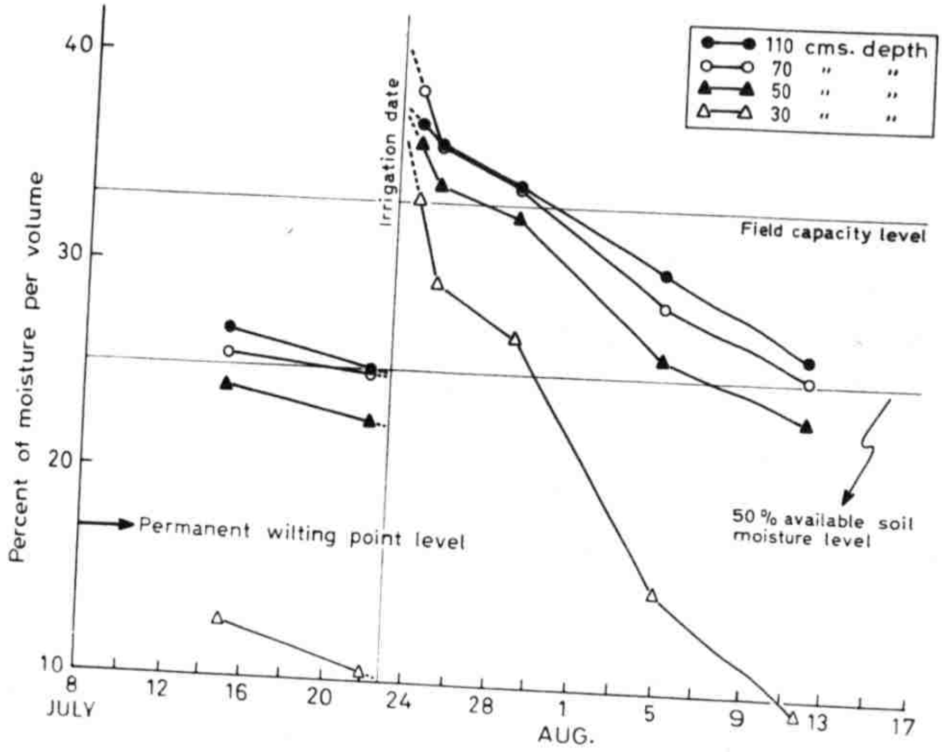

Figure 14. Effect of S5 treatment (28 days irrigation interval) on soil moisture extraction by sugarbeets.

Table 10. **Water use by sugarbeets**, mm/day.

Irrigation treatment	1st half of 1st week	Potential E.T.	1st week	Potential E.T.	2nd week	Potential E.T.	3rd week	Potential E.T.	4th week	Potential E.T.
S	26.2	6.1								
S	7.5	7.4								
S	9.5	6.9								
S	14.8	7.0								
S	15.1	7.3								
S	3.9	7.3								
S	12.5	9.2								
S	12.5	7.0								
S	3.9	8.0								
S	10.0	7.3								
S	16.5	6.6								
Average	12.0	7.3								
S_1	22.4	6.1	4.9	6.8						
S_1	15.4	6.9	8.0	7.1						
S_1	16.4	7.2	7.7	7.1						
S_1	39.3	9.2	3.6	6.8						
S_1	2.4	8.0	7.8	6.8						
Average	19.2	7.5	6.4	6.9						
S_3	17.2	6.1	11.6	6.8	7.6	7.1				
S_3	19.2	7.3	10.2	7.1	6.6	7.2				
S_3	19.4	9.2	9.8	6.8	5.6	6.8				
Average	18.6	7.5	10.5	6.9	6.6	7.0				
S_4	26.9	6.1	10.2	6.8	7.3	7.2	3.3	7.1		
S_4	-	-	12.6	7.2	6.8	7.1	7.2	6.8		
Average	26.9	6.1	11.4	7.0	7.1	7.2	5.3	7.0		
S_5									2.7	7.1
S_5	31.0	7.3	6.2	7.1	12.6	7.2	7.1	7.1	-	-
Average	31.0	7.3	6.2	7.1	12.6	7.2	7.1	7.1	2.7	7.1

sections of the irrigation interval. The rate of water use by sugarbeet started to decrease beginning with the second week after irrigation except for S5 treatment. The reason for this was that since most of the leaves had died during the latter part of the irrigation treatment where a new set of leaves had to be produced at the start of the new cycle before water could be used at a high rate. The actual rate of water use ranged from 2.7 mm/day to 3 1 mm/day. The potential evapotranspiration rate as determined by Penman was around 7.5 mm/day. The reasons for this variations are the same as given before for potato.

From the soil moisture determination for the three crops under study, there seemed to be a definite tendency for water use to decrease as the soil moisture tension increased. It is unfortunate that the malfunctioning of the probe did not allow taking enough readings to support statistically this tendency toward reduced water use exhibited by the available data. The implications of this reduction in use will be further discussed in the following sections.

From a study of the detailed data (Appendix A, Tables 12 to 23) that were used for constructing the water use figures and tables presented in this section, it became clear that most of the water use was from the shallower depths. In all three crops, between 50 and 60% of the water used in any interval was extracted from the top 40 cm. There was no significant difference between the various intervals - most of the water used always came out of the top soils.

Water Use Efficiency of Potato, Corn, and Sugarbeet

Water use efficiency is calculated as the ratio of yield of crop per dunum to the water used by that crop during the growing season. The total amount of water used by each of the crops under study was determined by taking the average daily water use as measured by the neutron probe and multiplying it by the number of days from the beginning of the treatment till harvest time. The amount of water used from planting time to the start of the irrigation of the treatments was considered to be one sixth (1/6) of the amount of water used during the treatment under one week irrigation interval. This was based on the length of the growing season, the date of commencing the treatment, the weather condition during these periods and the stage of growth of the crop. Total water use and efficiency are given in Table 11.

As shown in Table 11 the highest water use efficiency was achieved by following the P_1, C_1, and S_1 treatments. The P_2 and C_2 treatments, though giving higher yields than the P_3 and C_3 treatments, had a lower efficiency because of their relatively higher water consumption.

If these results can be considered indicative; it follows that, for corn, potatoes, and sugarbeets, when water supplies and labor are not limiting, weekly irrigation produces the greatest yield per unit of irrigation water applied. The total amounts of water used for both potatoes and sugarbeets in each of the treatments are very similar, indicating that no significant economy of water was achieved by

Table 11. Total amount of water use (in cm) used and water use efficiency of potato, corn, and sugarbeets.

Crop	Irrigation treatment	Water used during treatment	Water used before treatment	Total amount of water used	Yield in kg/D	Water use efficiency kg/D/cm
Potato	P_1	72.6	12.1	84.7	3770	44.56
"	P_2	72.0	12.1	84.1	3210	38.21
"	P_3	56.2	12.1	78.3	2870	42.08
Corn	C_1	177.6	29.6	207.2	1070	5.16
"	C_2	165.3	29.6	194.9	720	3.69
"	C_3	113.2	29.6	142.9	590	4.13
Sugarbeet	S	137.3	22.5	159.8	8530	53.38
"	S_1	134.8	22.5	157.3	8570	54.48
"	S_3	137.2	22.5	159.7	7090	44.40
"	S_4	122.4	22.5	144.9	5910	39.40
"	S_5	137.2	22.5	159.7	4610	28.18

following the longer interval. Although there was a tendency for reduced use during the latter part of the longer interval, this was not reflected in a reduced total water use. However, for corn, the C_3 treatment, required only 70% as much water as the C_1 did. However, the yield was only 60%.

From a practical point of view it seems that weekly irrigation is to be recommended, under the given soil and climatic conditions. Increasing the irrigation interval beyond one week has no advantage except reducing the cost of labor required for applying the water. It is very doubtful that this would make up for the reduced yields and lower water use efficiency.

If under the longer irrigation intervals, a higher efficiency would have been achieved, while a lower yield per unit area was produced, then it would have been reasonable to embark on a more detailed cost analysis to program the most profitable use of a deficient water supply. However, there were so many uncertainties in the data obtained during this first attempt, that it is reasonable to recommend repeating this work at least for another year to obtain more trustworthy results.

Table 11 gives an indication of the relative water use of the three crops under study. Applying the appropriate field efficiency figures the irrigation requirement of each of the crops may be determined . The data in Table 11 may be also used as a basis for selecting crops for a given rotation, if the corresponding costs of inputs and the value of the products are available. Generally, sugar-beets required about twice as much water as potatoes. As for corn, its water use was about 2.5 times that of potatoes or about one fourth more than sugarbeets. Of course more elaborate and detailed cost analysis should be carried out before any recommendations as to crop selection on the basis of water use can be made. However, this, and similar data on all crops considered for a given area would allow both selection for establishing a cropping pattern, as well as establishing the hydraulic modulus for the design of the required irrigation structures. Lack of such field data, throws an unjustified emphasis on empirical estimates that may result in grossly under or over designed projects.

V. SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

A study was undertaken in which a neutron probe was used to determine the water use and water use efficiency of potato, corn, and sugarbeet under different irrigation intervals. This study was conducted at the Agricultural Research and Educational Center of the American University of Beirut, in the Beqa'a plain, Lebanon, during 1964. Water use, as determined by the neutron probe following its field calibration, was compared with the potential evapotranspiration using Penman's equation.

The irrigation intervals used for each of potato and corn were 1, 1.5, and 2 weeks, while for sugarbeet ½, 1, 2, 3, and 4 weeks intervals were used. The amount of water applied at each irrigation was not actually measured, however, enough water was applied to make sure that the entire depth of the root zone was brought to field capacity.

Total water used by corn for the growing season amounted to 2072, 1949, and 1429 mm for the C_1, C_2, and C_3 treatments, respectively. The total yield produced under these different irrigation treatments was 1070, 720, and 590 kg/dunum, respectively. These resulted in water use efficiencies of 5.16, 3.69, and 4.13 kg/D/cm of the water used, respectively.

Total water used by potato for the entire growing season amounted to 847, 841, and 683 mm for the P_1, P_2, and P_3 irrigation treatments, respectively. The total yield produced by these treatments was 3770, 3210, and 2870 kg/dunum, respectively. These resulted in water use efficiency of 44.56, 38.21, and 42.08 kg/D/cm of the water used for the P_1, P_2 and P_3 treatments, respectively.

In sugarbeet the total amount of water used during the season amounted to 1598, 1573, 1597, 1449, and 1597 mm for the S, S_1, S_3, S_4, and S_5 treatments, respectively, and the total yield produced for the different irrigation treatments was 8530, 8570, 7090, 5910, and 4610 kg/dunum, respectively. These resulted in a water use efficiency of 53.38, 54.48, 44.40, 39.4, and 28.18 kg/D/cm of the water used, respectively.

One week irrigation intervals gave the highest yields on an area basis as well as the highest water use efficiencies for all crops under study. As the interval was increased the yields were seriously reduced, while the water use was only very slightly reduced.

The rate of water used by each crop was highest when the soil moisture tension was low. As the tension increased, the rate was reduced.

Water use was highest from the shallow root zones in general, although sugarbeets extracted moisture from greater depths than corn which in turn extracted from deeper layers than potatoes.

This was the first time a neutron probe was used for such soil moisture studies. Many technical difficulties prevented obtaining long uninterrupted field readings. Furthermore, it is suspected that appreciable vertical water movement, even later than 24 hours after irrigation, contributed to masking certain water use - soil moisture tension relations. It is recommended that this study be carried out for at least another year and the following suggestions be incorporated into the field work:

1. Two neutron probes be available, so that continuous data may be collected.
2. Actual measurement of irrigation water applied be made.
3. A lysimeter be incorporated into the field plots to check the contribution of vertical water movement to water use.
4. Daily probe readings be taken.
5. Incorporate open pan evaporation data with the climatic data to further check the Penman estimates.
6. Use a net radiometer for actual radiation measurements rather than an estimate based on cloud cover and theoretical incoming radiation.
7. Surround the experimental plot with a relatively extensive area of irrigated crops to reduce the oasis effect which might have influenced the results of this study.

It is further recommended that more of the commonly grown crops be included in similar studies of this nature.

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APPENDIX

Table 12. Water use by potatoes, F_1 treatment (7 days irrigation interval).

Irrigation date	Reading date	First 40 cm layer Soil moisture by volume, %				Water use/interval first 40 cm layer		Second 20 cm layer Soil moisture by volume, %				Water use/interval second 20 cm layer		Third 30 cm layer Soil moisture by volume,%				Water use/interval Third 30 cm layer		Last 30 cm layer Soil moisture by volume, %				Water use/interval Last 30 cm layer			Total water use	Number of days/ interval	Average daily water use, cm
		Sample number			Average of three samples	% by volume	cm	Sample number			Average of three samples	% by volume	cm	Sample number			Average of three samples	% by volume	cm	Sample number			Average of three samples	% by volume	cm	Total			
		1	2	3				1	2	3				1	2	3				1	2	3							
	July 10	33.6	32.4	33.3	33.1			36.0	33.1	32.3	33.80			33.8	31.8	32.4	34.33			33.6	34.0	30.2	32.60						
July 9						6.44	2.576^x					5.47	1.094					4.80	1.440					1.04	0.312	5.422	5.422	5	1.0844
	July 15	27.0	27.5	25.5	26.66			29.1	28.2	26.8	28.33			31.8	28.2	28.6	29.53			32.3	32.0	30.4	31.56						
	July 17	33.3	34.4	32.6	33.43			34.7	33.0	31.5	33.66			34.8	32.0	32.4	33.66			33.0	34.0	30.2	32.40						
July 16						5.53	2.765					4.90	0.980					5.76	1.728					0.84	0.252	5.725	5.725	5	1.1450
	July 22	27.6	28.4	27.8	27.90			29.8	28.7	27.8	28.76			32.4	28.4	28.0	27.90			32.4	32.5	29.8	31.56						
	July 24	31.3	31.9	32.5	31.90			33.2	32.8	31.6	30.10			34.5	33.0	32.4	33.30			33.2	35.1	30.0	32.76						
July 23						3.77	1.508					0.00	0.000					1.50	0.450					0.96	0.288	2.246	2.246	5	0.4492
	July 29	29.4	27.7	27.3	28.13			32.0	29.9	28.4	30.10			32.4	33.0	30.0	31.80			32.4	33.0	30.0	31.80						
	July 31	32.6	33.5	32.9	33.00			33.3	33.5	32.8	33.20			35.3	32.8	32.7	33.60			33.2	35.6	30.5	33.10						
July 30						3.74	1.496					2.50	0.500					2.07	0.621					0.37	0.101	2.718	2.718	5	0.5436
	Aug. 5	29.8	28.6	29.4	29.26			31.2	31.2	29.7	30.70			33.7	30.6	30.3	31.53			32.6	34.6	31.0	32.73						
	Aug. 7	33.2	33.0	34.0	33.40			34.5	34.0	33.8	34.10			34.8	34.2	34.4	34.86			33.4	37.4	32.5	34.43						
Aug. 6						4.27	1.708					3.97	0.794					2.93	0.879					2.27	0.681	4.062	4.062	5	0.8124
	Aug. 12	28.9	29.4	29.1	29.13			31.0	29.4	30.0	30.13			30.6	30.8	33.2	31.53			32.5	33.5	30.5	32.16						

x Water use % (volume basis) X depth of soil.

Table 13. Water use by potatoes, P_2 treatment (10-11 days irrigation interval).

Irrigation date	Reading date	First 40 cm layer Soil moisture by volume, %				Water use/interval first 40 cm layer		Second 20 cm layer Soil moisture by volume, %				Water use/interval second 20 cm layer	
		Sample number			Average of three samples	% by volume	cm	Sample number			Average of three samples	% by volume	cm
		1	2	3				1	2	3			
	July 13	30.0	31.2	34.5	31.90			32.8	33.0	35.0	33.6		
July 12						8.27	3.308					4.54	0.908
	July 18	24.0	26.5	20.4	23.63			29.4	27.2	30.6	29.06		
						2.47	0.988					2.66	0.532
	July 22	19.8	20.1	23.6	21.16			27.2	25.2	26.8	26.40		
	July 24	31.6	31.9	32.5	32.00			33.2	32.8	31.6	32.53		
July 23						6.94	2.776					2.67	0.534
	July 29	24.8	26.2	24.2	25.06			30.8	28.8	30.0	29.86		
	Aug. 8	27.7	31.3	28.0	29.00			30.5	29.8	31.0	30.43		
Aug. 2						4.47	1.788					2.63	0.526
	Aug. 12	24.8	25.3	23.8	24.63			28.4	26.6	28.4	27,80		
	Aug. 14	32.2	32.8	32.8	32.60			34.0	32.0	33.3	33.10		
Aug. 13						6.80	2.720					4.57	0.914
	Aug. 22	26.0	27.0	24.4	25.80			30.3	27.9	27.5	28.53		

Irrigation date	Reading date	Third 30 cm layer Soil moisture by volume, %				Water use/interval Third 30 cm layer		Last 30 cm layer Soil moisture by volume, %				Water use/interval Last 30 cm layer			Total water use	Number of days/ interval	Average daily water use, cm
		Sample number			Average of three samples	% by volume	cm	Sample number			Average of three samples	% by volume	cm	Total			
		1	2	3				1	2	3							
	July 13	34.4	32.2	34.3	34.30			37.6	30.0	34.6	34.06						
July 12						5.36	1.608					2.10	0.630	6.454	6.454	5	1.2908
	July 18	29.4	27.2	30.6	29.06			35.9	28.8	31.2	31.96						
						1.53	0.459					0.96	0.288	2.267	2.267	4	0.5668
	July 22	30.0	25.8	29.8	28.53			34.8	28.4	29.8	31.00						
	July 24	34.6	32.9	32.4	33.30			33.3	35.2	29.9	32.08						
July 23						2.27	0.681					0.02	0.006	3.997	3.997	5	0.7994
	July 29	32.4	29.4	31.3	31.03			36.6	29.2	32.0	32.06						
	Aug. 8	33.0	30.0	31.8	31.60			36.0	30.3	33.0	33.1						
Aug. 2						1.76	0.528					0.07	0.021	2.863	2.863	4	0.7158
	Aug. 12	32.2	27.7	30.0	29.96			35.8	29.1	31.2	33.03						
	Aug. 14	34.5	32.3	31.5	32.76			38.0	29.9	31.3	33.06						
Aug. 13						3.23	0.969					1.66	0.398	5.001	5.001	8	0.6251
	Aug. 22	31.8	27.6	29.2	29.53			36.0	28.2	30.0	31.4						

Table 14. Water use by potatoes, P_3 treatment (14 days irrigation interval).

Irrigation date	Reading date	First 40 cm layer Soil moisture by volume, %				Water use/interval first 40 cm layer		Second 20 cm layer Soil moisture by volume, %				Water use/interval second 20 cm layer		Third 30 cm layer Soil moisture by volume, %				Water use/interval Third 30 cm layer		Last 30 cm layer Soil moisture by volume, %				Water use/interval Last 30 cm layer			Total water use	Number of days/ interval	Average daily water use, cm
		Sample number			Average of three samples			Sample number			Average of three samples			Sample number			Average of three samples			Sample number			Average of three samples						
		1	2	3		% by volume	cm	1	2	3		% by volume	cm	1	2	3		% by volume	cm	1	2	3		% by volume	cm	Total			
	July 8	28.0	25.2	22.6	25.26			31.3	30.5	29.0	30.26			33.0	33.5	30.0	32.16			33.8	36.5	30.9	33.73						
July 2						5.30	2.120					2.46	0.492					3.63	1.089					2.50	0.750	4.451	4.451	7	0.6359
	July 15	20.6	19.1	20.2	19.96			27.9	28.3	27.2	27.8			30.0	28.4	27.2	28.53			30.9	34.4	28.4	31.23						
	July 17	32.2	32.8	32.5	32.50			34.4	34.4	35.5	34.76			34.9	34.8	35.3	35.00			35.3	37.2	34.2	35.56						
July 16						5.84	2.336					3.43	0.686					3.30	0.990					2.06	0.618	4.630	4.630	5	0.9260
	July 22	26.2	27.6	26.2	26.66			31.9	31.8	30.3	31.33			32.4	31.7	31.0	31.7			33.3	36.0	31.2	33.50						
						4.20	1.680					3.10	0.610					2.40	0.720					1.93	0.579	3.589	3.589	7	0.5127
	July 29	20.8	22.4	24.2	22.46			28.6	28.6	27.5	28.23			29.5	29.5	28.9	29.30			30.4	34.0	30.3	31.57						
	July 31	32.7	34.0	33.5	33.40			34.7	35.2	35.2	35.03			34.2	35.4	35.0	34.86			34.1	36.8	33.7	34.86						
						4.67	1.868					3.50	0.700					2.03	0.609					1.40	0.420	3.597	3.597	5	0.7194
July 30	Aug. 5	28.0	29.5	28.7	28.73			32.7	32.5	32.4	32.53			33.5	32.4	32.6	32.83			33.5	35.6	31.3	33.46						
						3.90	1.560					3.13	0.626					2.93	0.879					1.26	0.378	3.433	3.433	7	0.4904
	Aug. 12	23.2	25.6	25.7	24.83			28.4	29.4	30.4	29.40			28.7	30.3	30.7	29.90			30.2	35.1	31.3	32.20						
	Aug. 14	34.4	34.3	33.3	34.00			35.8	34.4	34.2	34.80			34.7	32.9	34.0	33.86			35.6	36.3	33.2	35.03						
Aug. 13						6.00	2.400					0.44	0.088					2.36	0.708					1.73	0.519	3.715	3.715	8	0.4644
	Aug. 22	26.4	28.0	29.6	28.00			29.8	31.3	32.0	34.36			30.4	31.9	32.2	31.50			31.9	34.8	33.2	33.30						

Table 15. Water use by corn, C_1 treatment (7 days irrigation interval).

Irrigation date	Reading date	First 40 cm layer Soil moisture by volume, % Sample number 1	2	3	Average of three samples	Water use/interval first 40 cm layer % by volume	cm	Second 20 cm layer Soil moisture by volume, % Sample number 1	2	3	Average of three samples	Water use/interval second 20 cm layer % by volume	cm	Third 30 cm layer Soil moisture by volume, % Sample number 1	2	3	Average of three samples	Water use/interval Third 30 cm layer % by volume	cm	Last 30 cm layer Soil moisture by volume, % Sample number 1	2	3	Average of three samples	Water use/interval Last 30 cm layer % by volume	cm	Total	Total water use	Number of days/ interval	Average daily water use, cm
	July 10	30.6	29.1	22.8	27.50			35.6	36.4	34.3	35.43			35.2	32.6	34.4	34.66			35.2	36.4	33.9	35.16						
July 9						3.04	1.216					7.10	1.42					3.73	1.119					2.53	0.759	4.514	4.514	5	0.9028
	July 15	24.2	27.2	22.0	24.46			27.6	30.0	26.5	28.33			31.0	32.6	29.2	30.93			31.4	35.8	30.7	32.63						
	July 17	35.0	33.4	32.3	33.56			34.4	32.4	34.5	33.76			34.4	32.6	32.0	33.00			33.5	35.8	32.8	34.33						
July 16						11.90	4.760					7.66	1.532					5.40	1.620					3.70	1.110	9.022	9.022	5	1.8044
	July 22	22.3	22.5	20.2	21.66			25.7	27.6	25.0	26.10			29.4	26.7	26.7	27.60			30.3	33.0	28.6	30.63						
	July 24	34.4	34.0	32.8	33.72			34.1	35.4	34.3	34.60			34.1	32.6	32.9	33.20			32.6	35.0	33.4	33.66						
July 23						12.23	4.892					8.27	1.654					5.10	1.530					3.40	1.020	9.096	9.096	5	1.8192
	July 29	21.5	22.0	21.0	21.50			24.6	28.4	25.1	26.33			29.0	27.4	27.9	28.10			29.6	32.4	28.8	30.26						
	July 31	33.1	34.4	33.4	33.83			33.5	34.4	32.0	33.30			32.3	35.2	33.0	33.50			28.8	34.4	32.9	32.33						
July 30						9.23	3.692					6.17	1.234					4.04	1.212					2.23	0.669	6.807	6.807	5	1.3614
	Aug. 5	24.0	26.7	23.1	24.60			25.3	30.0	26.1	27.13			28.8	30.8	29.8	29.46			29.0	33.2	28.1	30.10						
	Aug. 7	34.9	35.1	32.8	34.26			33.4	34.8	32.0	33.40			30.6	34.6	32.2	32.46			29.6	34.4	30.9	31.63						
Aug. 6						10.36	4.144					7.50	1.410					4.20	1.260					2.50	0.750	7.564	7.564	5	1.5128
	Aug. 12	23.2	25.5	23.0	23.90			24.4	28.5	24.8	25.90			27.6	30.0	27.2	28.26			27.8	32.2	27.4	29.13						

Table 16. Water use by corn, C_2 treatment (10-11 days irrigation interval).

		First 40 cm layer Soil moisture by volume, %				Water use/interval first 40 cm layer		Second 20 cm layer Soil moisture by volume, %				Water use/interval second 20 cm layer		Third 30 cm layer Soil moisture by volume, %				Water use/interval Third 30 cm layer		Last 30 cm layer Soil moisture by volume, %				Water use/interval Last 30 cm layer					
		Sample number						Sample number						Sample number						Sample number									
Irrigation date	Reading date	1	2	3	Average of three samples	% by volume	cm	1	2	3	Average of three samples	% by volume	cm	1	2	3	Average of three samples	% by volume	cm	1	2	3	Average of three samples	% by volume	cm	Total	Total water use	Number of days/ interval	Average daily water use, cm
	July 13	36.4	35.7	32.1	34.73			35.8	34.0	34.0	34.60			35.6	34.7	34.4	34.90			34.0	37.0	34.4	35.13						
July 12						9.27	3.708					7.20	1.440					5.40	1.520					3.50	1.050	7.718	7.718	5	1.5436
	July 18	27.6	25.4	23.4	25.46			30.0	27.0	25.2	27.40			30.2	29.6	28.7	29.50			31.3	34.2	32.4	32.63						
						7.63	3.052					3.24	0.648					2.90	0.870					3.33	0.999	5.569	5.569	4	1.3738
	July 22	17.3	18.5	17.7	17.83			26.2	23.8	22.5	24.16			27.3	26.5	26.0	26.60			28.6	32.5	26.8	29.30						
	July 24	32.9	30.1	30.8	31.26			36.0	35.9	33.8	35.23			33.6	35.2	33.5	34.10			29.9	33.1	32.6	31.86						
July 23						10.40	4.160					8.77	1.754					5.67	1.701					2.10	0.630	8.245	8.245	5	1.6490
	July 29	20.4	22.5	19.7	20.86			28.3	26.3	24.8	26.46			29.2	29.0	27.4	28.53			29.2	31.9	28.2	29.76						
	Aug. 8	28.2	29.3	-	28.75			30.5	30.7	27.7	29.63			29.5	32.4	30.2	30.70			28.1	33.1	28.2	29.80						
						7.25	3.000					4.00	0.800					2.57	0.771					0.60	0.180	5.051	5.051	4	1.2628
	Aug. 12	21.3	22.8	20.4	21.50			27.1	25.5	24.3	25.63			27.7	30.3	26.4	28.13			28.6	32.6	26.4	29.20						
	Aug. 14	36.0	35.3	33.7	35.00			34.9	30.0	33.2	32.70			32.0	30.3	32.8	31.70			28.7	32.9	30.0	30.53						
Aug. 13						13.07	5.228					7.37	1.474					4.30	1.290					1.57	0.471	8.463	8.463	8	1.0579
	Aug. 22	22.8	22.4	20.6	21.93			27.7	24.5	23.8	25.33			28.3	27.9	26.0	27.40			28.1	32.3	26.5	28.96						

Table 17. Water use by corn, C_3 treatment (14 days irrigation interval).

Irrigation date	Reading date	First 40 cm layer Soil moisture by volume, %				Water use/interval first 40 cm layer		Second 20 cm layer Soil moisture by volume, %				Water use/interval second 20 cm layer		Third 30 cm layer Soil moisture by volume, %				Water use/interval Third 30 cm layer		Last 30 cm layer Soil moisture by volume, %				Water use/interval Last 30 cm layer			Total water use	Number of days/ interval	Average daily water use, cm
		Sample number			Average of three samples			Sample number			Average of three samples			Sample number			Average of three samples			Sample number			Average of three samples						
		1	2	3		% by volume	cm	1	2	3		% by volume	cm	1	2	3		% by volume	cm	1	2	3		% by volume	cm	Total			
	July 8	23.8	19.8	21.6	21.73			26.4	26.8	26.4	26.53			28.7	28.7	28.5	28.63			30.9	30.5	30.6	30.66						
July 2						2.40	0.960					5.03	1.006					4.40	1.320					3.66	1.098	4.384	4.384	7	0.6263
	July 15	20.8	18.3	18.0	19.33			24.1	19.0	21.4	21.50			23.8	27.3	21.6	24.23			27.2	27.8	26.0	27.00						
	July 17	33.0	36.1	34.5	34.53			33.2	35.4	34.0	34.20			33.2	36.0	32.4	33.86			32.4	34.4	31.9	32.90						
						8.77	3.508					6.44	1.288					5.56	1.668					3.30	0.990	7.454	7.454	5	1.4908
July 16	July 22	26.0	27.2	24.4	25.86			28.9	28.2	26.2	27.76			27.7	30.6	26.6	28.30			30.0	30.6	28.2	29.60						
	July 24					5.96	2.384					4.26	0.852					4.10	1.230					3.07	0.921	5.387	5.387	7	0.7696
	July 29	20.9	21.0	17.8	19.90			24.8	24.4	21.3	23.50			25.0	26.2	21.4	24.20			26.8	26.6	26.2	26.53						
	July 31	35.2	33.0	32.4	33.53			34.6	35.5	32.5	34.20			32.0	35.8	32.4	33.40			27.0	33.8	30.1	30.3						
						5.60	2.240					5.54	1.108					4.60	1.380					1.40	0.42	5.148	5.148	5	1.0296
July 30	Aug. 5	28.2	27.6	26.0	27.93			29.2	30.3	26.5	28.66			28.4	31.4	26.6	28.80			28.2	31.5	27.0	28.90						
						7.87	3.148					5.56	1.112					3.54	1.062					3.64	1.092	6.414	6.414	7	0.9163
	Aug. 12	22.0	13.2	20.0	20.06			23.7	24.4	21.2	23.10			24.0	26.8	22.0	24.26			25.4	26.6	23.8	25.26						
	Aug. 14	35.6	33.3	32.3	33.73			33.8	34.6	31.3	33.23			30.1	31.2	30.2	30.50			26.2	27.2	28.2	27.20						
Aug. 13						9.80	3.920					7.17	1.434					3.87	1.161					0.44	0.132	6.647	6.647	8	0.8309
	Aug. 22	26.0	21.6	24.2	23.93			27.0	26.0	25.2	26.06			26.7	27.9	25.6	26.73			26.5	27.1	26.7	26.76						

Table 18. Water use by sugarbeets, S treatment (3-4 days irrigation interval).

Irrigation date	Reading date	First 40 cm layer, soil moisture by volume,%	Water use/ interval, first 40 cm layer		Second 20 cm layer, soil moisture by volume,%	Water use/ interval, second 20 cm layer		Third 30 cm layer, soil moisture by volume,%	Water use/ interval, third 30 cm layer		Last 30 cm layer, soil moisture by volume,%	Water use/ interval, last 30 cm layer			Total water use	Number of days/ interval	Average daily water use, cm
		Sample number 1	% by volume	cm	Sample number 1	% by volume	cm	Sample number 1	% by volume	cm	Sample number 1	% by volume	cm	Total			
	July 10	36.0			36.7			37.4			36.4						
July 9			3.6	1.44		0.9	0.18		1.6	0.48		1.4	0.52	2.62	2.62	1	2.620
	July 11	32.6			35.8			35.8			35.0						
	July 13	33.5			36.2			36.0			35.2						
July 12			2.3	0.92		1.7	0.34		0.7	0.21		0.1	0.03	1.50	1.50	2	0.750
	July 15	31.2			34.5			35.3			35.1						
	July 17	36.0			38.3			37.4			36.6						
July 16			2.0	0.80		0.0	0.00		0.0	0.00		0.5	0.15	0.95	0.95	1	0.950
	July 18	34.0			38.3			37.4			36.1						
	July 20	34.6			36.4			35.6			36.4						
July 19			5.1	2.04		2.0	0.40		0.2	0.06		1.5	0.45	2.95	2.95	2	1.475
	July 22	29.5			34.4			35.4			34.9						
	July 24	35.6			36.8			36.6			36.0						
July 23			3.0	1.20		0.8	0.16		0.4	0.12		0.1	0.03	1.51	1.51	1	1.510
	July 25	32.6			36.0			36.2			35.9						
	July 27	34.4			37.4			36.9			37.0						
July 26			0.1	0.04		1.6	0.32		1.2	0.36		0.2	0.06	0.78	0.78	2	0.390
	July 29	34.3			35.8			35.7			36.8						
	Aug. 7	35.1			36.2			36.3			35.2						
Aug. 6			1.5	0.60		0.7	0.14		1.7	0.51		0.0	0.00	1.25	1.25	1	1.250
	Aug. 8	33.6			35.5			34.8			35.2						
	Aug. 10	34.6			36.0			36.2			36.0						
Aug. 9			3.8	1.52		1.0	0.20		1.4	0.42		1.2	0.36	2.50	2.50	2	1.250
	Aug. 12	30.8			35.0			34.8			34.8						
	Aug. 14	34.5			35.8			35.2			36.0						
Aug. 13			0.5	0.20		0.2	0.04		0.0	0.00		0.5	0.15	0.39	0.39	1	0.390
	Aug. 15	34.0			35.6			35.2			35.5						
	Aug. 17	34.5			36.0			36.0			36.1						
Aug. 16			3.3	1.32		0.7	0.14		1.0	0.3		0.8	0.24	2.00	2.00	2	1.000
	Aug. 19	31.2			35.3			35.0			35.3						
	Aug. 21	35.9			37.8			37.0			37.6						
Aug. 20			1.5	0.60		1.5	0.30		0.7	0.21		1.8	0.54	1.65	1.65	1	1.650
	Aug. 22	34.4			36.3			36.3			35.8						

Table 19. Water use by sugarbeets, S_1 treatment (7 days irrigation interval).

Irrigation date	Reading date	First 40 cm layer Soil moisture by volume, %				Water use/interval first 40 cm layer		Second 20 cm layer Soil moisture by volume, %				Water use/interval second 20 cm layer		Third 30 cm layer Soil moisture by volume, %				Water use/interval Third 30 cm layer		Last 30 cm layer Soil moisture by volume, %				Water use/interval Last 30 cm layer		Total	Total water use	Number of days/interval	Average daily water use, cm
		Sample number			Average of three samples	% by volume	cm	Sample number			Average of three samples	% by volume	cm	Sample number			Average of three samples	% by volume	cm	Sample number			Average of three samples	% by volume	cm				
		1	2	3				1	2	3				1	2	3				1	2	3							
	July 10	34.4	35.6	35.8	35.26			34.6	36.0	35.6	35.40			34.8	36.1	35.5	35.46			34.8	31.0	37.2	34.33						
						4.03	1.612					1.04	0.208					0.50	0.150					0.90	0.270	2.240	2.24	1	2.24
July 9	July 11	28.9	33.6	31.2	31.23			33.6	34.2	35.3	34.36			35.0	34.6	35.3	34.96			33.8	30.2	36.3	33.43						
						2.23	0.892					2.83	0.566					1.76	0.528					0.17	0.051	1.967	1.967	4	0.4918
	July 15	24.8	27.6	24.6	29.00			30.4	32.0	32.2	31.53			32.0	33.6	34.0	33.20			34.0	29.5	36.3	33.26						
	July 17	31.9	34.6	33.4	33.30			35.8	35.3	36.4	35.83			37.5	35.3	36.3	36.36			35.3	31.0	37.8	34.70						
July 16						1.44	0.576					1.50	0.300					0.96	0.288					1.24	0.372	1.536	1.536	1	1.536
	July 18	33.0	31.8	30.8	31.86			34.6	33.6	34.8	34.33			37.2	33.8	35.2	35.40			34.4	30.0	36.0	33.46						
						5.33	2.132					2.10	0.420					1.77	0.531					0.46	0.138	3.221	3.221	4	0.8052
	July 22	27.5	27.3	24.8	26.53			32.6	33.0	31.1	32.23			32.8	33.1	35.0	33.63			33.3	29.3	36.4	33.00						
	July 24	32.5	33.7	31.9	32.70			36.6	34.6	35.2	35.46			37.4	34.4	35.3	35.70			35.6	30.6	37.4	34.53						
July 23						2.30	0.920					2.40	0.480					0.04	0.012					0.77	0.231	1.643	1.643	1	1.643
	July 25	26.0	32.3	32.9	30.40			32.9	32.3	34.0	33.06			36.0	34.2	34.8	35.66			35.7	29.4	36.2	33.76						
						3.10	1.240					2.23	0.446					3.16	0.948					1.30	0.390	3.064	3.064	4	0.7660
	July 29	28.1	28.2	25.6	27.30			30.1	31.5	30.9	30.83			32.7	31.8	33.0	32.50			34.0	28.1	35.3	32.46						
	July 31	32.2	34.4	37.8	34.80			35.2	34.2	36.0	35.13			36.0	33.8	36.6	35.46			35.3	29.5	36.8	33.86						
July 30						9.07	3.628					3.67	0.734					2.32	0.696					1.73	0.519	5.577	5.577	5	1.1154
	Aug. 5	24.8	26.0	26.4	25.73			31.0	31.4	32.0	31.46			32.9	32.7	33.8	33.14			34.0	28.0	34.4	32.13						
	Aug. 7	34.0	35.6	33.2	34.26			36.3	34.8	35.7	35.60			36.7	35.3	36.7	36.23			35.5	30.2	36.7	34.13						
Aug. 6						6.60	2.640					2.00	0.400					1.63	0.489					1.33	0.399	3.928	3.928	1	3.928
	Aug. 8	27.4	29.6	32.0	27.66			32.6	33.8	34.4	33.60			34.8	34.0	35.0	34.60			34.8	28.4	35.2	32.80						
						0.80	0.320					2.04	0.408					0.80	0.240					1.57	0.471	1.439	1.439	4	0.3598
	Aug. 12	24.6	29.2	26.8	26.86			30.3	32.0	32.4	31.56			33.2	33.4	34.8	33.80			30.6	28.0	35.1	31.23						
	Aug. 14	31.2	34.4	34.0	33.20			34.7	35.7	35.2	35.20			36.2	35.3	35.7	35.73			35.3	30.0	36.0	33.83						
Aug. 13						0.27	0.108					0.30	0.060					0.17	0.051					0.07	0.021	0.240	0.240	1	0.240
	Aug. 15	30.8	34.4	33.6	32.93			34.7	34.8	35.2	34.90			36.0	35.2	35.5	35.56			35.3	29.4	36.6	33.76						
						2.53	1.012					1.10	0.220					1.16	0.348					4.76	1.428	3.108	3.108	4	0.770
	Aug. 19	-	30.4	-	30.40			-	33.8	-	33.80			-	34.4	-	34.40			-	29.0	-	29.0						

Table 20. Water use by sugarbeets, S_3 treatment (14 days irrigation interval).

Irrigation date	Reading date	First 40 cm layer Soil moisture by volume, % Sample number 1	2	3	Average of three samples	Water use/interval first 40 cm layer % by volume	cm	Second 20 cm layer Soil moisture by volume, % Sample number 1	2	3	Average of three samples	Water use/interval second 20 cm layer % by volume	cm	Third 30 cm layer Soil moisture by volume, % Sample number 1	2	3	Average of three samples	Water use/interval Third 30 cm layer % by volume	cm	Last 30 cm layer Soil moisture by volume, % Sample number 1	2	3	Average of three samples	Water use/interval Last 30 cm layer % by volume	cm	Total	Total water use	Number of days/interval	Average daily water use, cm
	July 10	35.0	36.3	34.4	35.23			36.5	35.3	37.0	36.26			34.9	34.2	34.4	34.50			34.4	33.2	32.4	33.33						
						1.93	0.782					2.06	0.412					1.47	0.441					0.30	0.090	1.725	1.725	1	1.725
July 9	July 11	34.4	35.1	30.4	33.30			33.2	34.2	35.2	34.20			33.8	32.8	32.5	33.03			32.5	34.2	32.6	33.03						
						8.47	3.388					3.00	0.600					1.50	0.450					0.70	0.210	4.648	4.648	4	1.162
	July 15	24.2	24.1	26.2	24.83			30.6	32.2	30.8	31.20			31.5	32.7	30.4	31.53			30.4	33.6	32.0	32.33						
						5.83	2.332					4.17	0.834					3.53	1.059					3.77	1.131	5.356	5.356	7	0.7651
	July 22	16.2	16.8	24.0	19.00			25.5	27.8	27.8	27.03			27.4	29.6	27.0	28.00			27.0	31.2	27.5	28.56						
July 23	July 24	34.4	37.3	32.6	34.76			36.8	38.6	35.4	36.93			35.4	36.6	32.2	34.73			34.2	36.0	33.4	34.53						
						3.40	1.360					1.53	0.306					0.30	0.090					0.53	0.159	1.915	1.915	1	1.915
	July 25	32.0	30.2	31.9	31.36			34.6	37.0	34.6	35.40			34.6	36.3	32.4	34.43			33.8	35.7	32.5	34.00						
						4.60	1.840					3.44	0.688					2.33	0.699					2.87	0.861	4.088	4.088	4	1.022
	July 29	24.5	28.5	27.3	26.76			32.3	32.5	31.1	31.96			31.8	33.2	31.3	32.10			27.9	34.0	31.5	31.13						
						5.60	2.240					3.70	0.740					3.50	1.050					2.07	0.621	4.651	4.651	7	0.6644
	Aug. 5	20.7	20.0	22.8	21.16			27.4	29.4	28.0	28.26			27.6	30.2	28.0	28.60			28.2	31.2	27.8	29.06						
Aug. 6	Aug. 7	36.0	37.6	34.6	36.06			36.0	37.8	35.2	36.33			32.5	35.0	32.4	33.30			31.0	32.4	32.0	31.80						
						2.13	0.852					2.23	0.446					1.24	0.372					0.90	0.270	1.940	1.940	1	1.940
	Aug. 8	33.2	35.0	33.6	33.93			34.0	33.1	35.2	34.10			33.0	31.4	31.8	32.06			32.2	30.1	30.4	30.90						
						6.60	2.640					3.10	0.620					1.60	0.480					0.57	0.171	3.911	3.911	4	0.9778
	Aug. 12	27.5	26.5	28.0	27.33			31.0	31.8	30.2	31.00			29.7	31.2	30.5	30.46			30.4	31.2	29.4	30.33						
						3.53	1.312					4.00	0.800					3.56	1.068					2.53	0.759	3.939	3.939	7	0.5627
	Aug. 19	-	23.8	-	23.80			-	27.0	-	27.00			-	26.9	-	26.90			-	27.8	-	27.80						

Table 21. Water use by sugarbeets, S_4 treatment (21 days irrigation interval).

Irrigation date	Reading date	First 40 cm layer Soil moisture by volume, %				Water use/interval first 40 cm layer		Second 20 cm layer Soil moisture by volume, %				Water use/interval second 20 cm layer		Third 30 cm layer Soil moisture by volume, %				Water use/interval Third 30 cm layer		Last 30 cm layer Soil moisture by volume, %				Water use/interval Last 30 cm layer			Total water use	Number of days/ interval	Average daily water use, cm
		Sample number			Average of three samples	% by volume	cm	Sample number			Average of three samples	% by volume	cm	Sample number			Average of three samples	% by volume	cm	Sample number			Average of three samples	% by volume	cm	Total			
		1	2	3				1	2	3				1	2	3				1	2	3							
July 9	July 10	38.0	37.2	36.8	37.33			39.2	36.2	37.6	37.66			38.1	36.4	37.9	37.46			37.0	36.6	38.2	37.93						
						2.53	1.012					1.23	0.226					2.03	0.609					2.80	0.840	2.687	2.687	1	2.687
	July 11	34.0	32.4	38.0	34.80			36.7	35.0	37.6	36.43			36.8	34.5	35.0	35.43			34.4	34.0	37.0	35.13						
						7.04	2.816					2.70	0.540					1.33	0.399					1.13	0.339	4.094	4.094	4	1.0235
	July 15	24.5	28.6	30.2	27.76			34.5	32.7	34.0	33.73			35.0	32.7	34.6	34.10			34.4	32.0	35.6	34.00						
						6.43	2.572					4.27	0.854					3.97	1.191					0.60	0.180	4.797	4.797	7	0.6853
	July 22	17.0	21.8	25.2	21.33			30.8	28.2	29.4	29.46			32.6	28.4	29.4	30.13			33.8	33.8	32.6	33.40						
						0.13	0.052					1.86	0.372					1.43	0.429					4.97	1.491	2.344	2.344	7	0.3349
	July 29	20.0	23.4	20.2	21.20			28.8	26.5	27.5	27.60			30.3	28.3	27.5	28.70			30.3	26.2	28.8	28.43						
July 30	July 31	37.0	36.2	36.2	36.46			39.5	36.7	38.0	38.06			37.9	34.3	38.0	37.40			38.8	34.3	37.6	38.23						
						7.56	3.024					4.46	0.892					3.47	1.041					4.60	1.380	6.337	6.337	5	1.2674
	Aug. 5	29.6	27.1	30.0	28.90			36.0	31.0	33.8	33.60			35.8	31.6	34.4	33.93			36.4	30.7	33.8	33.63						
						6.24	2.496					4.80	0.960					3.23	0.969					2.23	0.669	5.094	5.094	7	0.7277
	Aug. 12	23.6	20.0	24.4	22.66			31.8	26.4	28.2	28.80			33.6	28.0	30.5	30.70			34.8	27.6	31.8	31.40						
						4.46	1.784					3.20	0.640					3.90	1.170					5.20	1.560	5.154	5.154	7	0.7220
	Aug. 19	-	18.2	-	18.20			-	25.6	-	25.60			-	26.8	-	26.80			-	26.2	-	26.20						

Table 22. Water use by sugarbeets, S_5 treatment (28 days irrigation interval).

Irrigation date	Reading date	First 40 cm layer, soil moisture by volume, %	Water use/ interval, first 40 cm layer		Second 20 cm layer, soil moisture by volume, %	Water use/ interval, second 20 cm layer		Third 30 cm layer, soil moisture by volume, %	Water use/ interval, third 30 cm layer		Last 30 cm layer, soil moisture by volume, %	Water use/ interval, last 30 cm layer					
		Sample number 1	% by volume	cm	Sample number 1	% by volume	cm	Sample number 1	% by Volume	cm	Sample number 1	% by volume	cm	Total	Total water use	Number of days/ interval	Average daily water use, cm
	July 15	12.6			24.0			25.5			26.8						
June 25			2.2	0.880		1.5	0.30		0.8	0.24		1.9	0.57	1.99	1.99	7	0.270
	July 22	10.4			22.5			24.7			24.9						
	July 24	33.2			36.0			38.5			36.9						
			3.9	1.56		2.0	0.40		2.7	0.81		1.1	0.33	3.10	3.10	1	3.100
July 23	July 25	29.3			34.0			35.8			35.8						
			2.5	1.00		1.5	0.30		1.9	0.57		2.0	0.60	2.47	2.47	4	0.6175
	July 29	26.8			32.5			33.9			33.8						
			12.0	4.80		6.5	1.30		5.4	1.62		3.8	1.14	8.86	8.86	7	1.2657
	Aug. 5	14.8			26.0			28.5			30.0						
			5.8	2.32		2.8	0.56		3.3	0.99		3.7	1.11	4.98	4.98	7	0.7114
	Aug. 12	9.0			23.2			25.2			26.3						

Calculations for potential evapotranspiration based on the Penman's equation utilized the following equations:-

$$H = 0.95\, R_a\, (0.24 + 0.52n/N - \sigma T_a^4\, (0.56 - 0.09\sqrt{e_d})\, (0.1 + 0.9n/N)$$

$E_a = 0.35\, (0.5 + v/160.9)\, (e_a - e_d)$ Where v is wind velocity in km/day.

From these:

$$\begin{aligned} E_o &= (\Delta H + E_a) / (\Delta + \gamma) \\ &= (\tfrac{\Delta}{\gamma} H + E_a) / (\tfrac{\Delta}{\gamma} + 1) \\ &= (\tfrac{\Delta}{\gamma} H + \tfrac{\Delta}{\gamma} \tfrac{E_a}{\Delta/\gamma}) / (\tfrac{\Delta}{\gamma} + 1) \\ &= \frac{\Delta/\gamma}{\frac{\Delta}{\gamma} + 1} \left(H + \frac{E_a}{\Delta/\gamma} \right) = \frac{G}{G+1} \left(H + \frac{E_a}{G}\right) \end{aligned}$$

Therefore,

$$E_o = J \left(H + \frac{E_a}{G}\right), \quad \text{where} \quad J = \frac{G}{G+1}$$

Therefore, E_o depends on J, H, and E_a/G.

This may be further broken down as follows:-

$$E_o = J\, (S - KL + RP)$$

Where

$$J = \frac{\Delta/\gamma}{\Delta/\gamma + 1}$$

$$S = 0.95\, R_a\, (0.24 + 0.52\, \frac{n}{N})$$

$$K = \sigma\, T_a^4\, (0.56 - 0.09\, \sqrt{e_d})$$

$$L = (0.1 + 0.9\, \frac{n}{N})$$

$$P = 0.35\,(0.5 + \frac{v}{160.4})$$

$$R = \frac{e_a - e_d}{\Delta/\gamma}$$

Tables for the above values for A.R.E.C. were prepared by M. Jalili in an unpublished study in 1967 and were used in the following table.

Table 23. Daily rate of potential evapotranspiration estimated by Penman equation[x].

	Air Temperature	Humidity	Sunshine	Wind vel.	J	S	R	P	L	K	Eo
July, 1964	20.0	31.0	12:15	254	0.680	10.68	5.6	0.72	0.86	5.18	6.97
	22.0	31.0	12:15	215	0.695	10.68	5.7	0.64	0.86	5.21	6.84
	21.0	47.0	12:15	162	0.690	10.68	4.3	0.52	0.86	4.40	6.30
	20.0	36.0	12:15	186	0.680	10.68	5.2	0.58	0.86	4.95	6.41
	21.0	36.0	11:45	414	0.686	10.39	5.2	1.07	0.83	4.90	8.15
	22.0	37.0	12:25	227	0.695	10.82	5.2	0.66	0.88	4.81	6.96
	24.0	19.0	12:30	482	0.720	10.82	6.8	1.22	0.88	5.86	10.07
	23.0	16.0	12:30	151	0.720	10.82	7.0	0.50	0.88	6.10	6.44
	22.0	39.0	12:30	151	0.700	10.82	5.0	0.50	0.88	4.70	6.43
	21.0	49.0	12:15	307	0.686	10.68	4.2	0.85	0.86	4.32	7.23
	20.0	31.0	12:40	137	0.684	10.91	5.6	0.47	0.89	5.18	6.11
	23.0	33.0	12:40	152	0.720	10.91	5.5	0.50	0.89	5.96	6.08
	24.0	34.0	12:35	132	0.720	10.86	5.5	0.46	0.89	4.88	6.52
	25.0	34.0	12:35	202	0.750	10.86	5.6	0.61	0.89	4.82	7.48
	25.0	16.0	12:30	203	0.750	10.77	7.1	0.61	0.89	6.10	7.25
	24.0	16.0	12:25	230	0.720	10.72	7.1	0.68	0.89	6.10	7.29
	23.0	30.0	11:30	229	0.714	10.21	5.8	0.68	0.83	5.14	7.06
	24.0	33.0	12:05	206	0.720	10.49	5.6	0.61	0.86	4.94	6.94
	24.0	31.0	12:30	269	0.720	10.77	5.8	0.76	0.89	5.05	7.68
	24.0	34.0	12:20	184	0.720	10.57	5.5	0.58	0.89	4.88	6.78
	25.0	32.0	12:30	156	0.740	10.77	5.7	0.51	0.89	4.94	6.86
	26.0	19.0	12:30	145	0.740	10.35	7.0	0.49	0.87	5.83	7.06
	26.0	32.0	12:15	146	0.740	10.51	5.9	0.49	0.88	4.90	6.73
	25.0	34.0	12:05	216	0.730	10.40	5.6	0.64	0.88	4.82	7.11
	22.0	44.0	12:15	307	0.704	10.50	4.6	0.82	0.88	4.47	7.28
	25.0	34.0	12:15	229	0.738	10.50	5.6	0.68	0.88	4.82	7.59
	24.0	36.0	12:00	138	0.720	10.35	5.3	0.48	0.87	4.76	6.30
	22.0	34.0	12:00	210	0.698	10.35	5.5	0.63	0.87	4.92	7.36
	26.0	35.0	12:00	203	0.742	10.35	5.6	0.61	0.87	4.70	7.17
	25.0	35.0	12:00	225	0.734	10.35	5.5	0.66	0.87	4.76	7.21
	24.0	40.0	12:00	225	0.720	10.35	5.0	0.66	0.87	4.54	6.98
Aug. 1964	23.0	40.0	11:45	294	0.714	10.10	5.0	0.81	0.87	4.60	7.25
	24.0	33.0	11:45	292	0.720	10.10	5.6	0.81	0.87	4.94	7.37
	23.0	32.0	11:45	296	0.720	10.10	5.6	0.82	0.87	5.02	7.43
	22.0	40.0	11:45	318	0.706	10.10	4.9	0.86	0.87	4.66	7.24
	23.0	45.0	12:10	200	0.716	10.33	4.6	0.61	0.90	4.36	6.60
	23.0	43.0	12:10	211	0.720	10.33	4.7	0.63	0.90	4.45	6.69
	24.0	28.0	11:55	173	0.724	10.18	6.1	0.56	0.87	5.23	6.55
	24.0	32.0	11:55	480	0.720	10.18	5.7	1.225	0.87	5.00	9.22
	23.0	34.0	11:55	211	0.720	10.18	5.5	0.63	0.87	4.88	6.76
	22.0	34.0	11:55	212	0.704	10.18	5.5	0.63	0.87	4.98	6.55
	22.0	40.0	12:00	211	0.702	9.98	4.9	0.63	0.91	4.66	6.20
	22.0	34.0	12:00	386	0.706	9.98	5.5	1.01	0.91	4.98	7.77
	22.0	43.0	11:45	286	0.697	10.10	4.7	0.79	0.87	4.52	6.89
	22.0	40.0	12:00	151	0.702	9.98	4.9	0.50	0.91	4.66	5.75
	24.0	33.0	11:45	352	0.720	10.10	5.6	0.94	0.87	4.94	7.96
	25.0	22.0	11:45	115	0.738	10.10	6.7	0.42	0.87	5.61	5.93
	25.0	19.0	11:45	115	0.738	11.45	6.9	0.42	0.87	5.84	6.84
	25.0	19.0	11:50	195	0.736	10.15	6.9	0.60	0.86	5.84	7.72
	24.0	18.0	11:50	219	0.720	10.15	6.9	0.65	0.86	5.94	6.86
	24.0	31.0	11:45	171	0.720	10.10	5.8	0.54	0.87	5.05	6.36
	24.0	33.0	11:50	172	0.728	10.15	5.6	0.54	0.86	4.94	7.22
	25.0	33.0	11:50	161	0.740	10.15	5.7	0.52	0.86	4.88	6.59
	25.0	33.0	11:50	134	0.732	10.15	5.7	0.47	0.86	4.88	6.32
	25.0	31.0	11:50	168	0.734	10.15	5.8	0.54	0.86	5.00	6.60
	26.0	32.0	12:00	207	0.740	9.98	5.8	0.62	0.91	4.90	6.76

[x] Eo = J(S-KL+PR).