THE MEASUREMENT OF WATER USE EFFICIENCY OF CORN BY HYDRAULIC LYSIMETER

By

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WATER USE EFFICIENCY OF CORN

JALILI

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AN ABSTRACT OF THE THESIS OF

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Title: The measurement of corn water use efficiency by hydraulic lysimeter.

A study was carried out in the Beqa'a Plain in 1966 to determine water use and water use efficiency of corn under two irrigation treatments - an overirrigation and an underirrigation. This objective was approached through use of a hydraulic lysimeter and through soil moisture studies using the neutron scattering method. As a check on these methods, potential evaporation was calculated after Penman, while an evaporation pan provided a direct measure of evaporation.

The overirrigation consisted of adding 50 percent of the available water within the root zone whenever 42 percent was used. The underirrigation consisted of adding 50 percent of the available water whenever 70 percent was consumed. Water use efficiency of corn was arrived at by determining the yield under each treatment and expressing it as a ratio of the water applied to that treatment.

The total dry matter produced by the underirrigated corn was about 60 percent of that produced by the overirrigated corn while its water use was about 86 percent. Therefore, it is concluded that corn uses water more efficiently when adequately supplied with water than otherwise.

A comparison of the methods indicated a satisfactory performance of the lysimeter over 3 to 4 day periods; on daily basis, it was not adequately sensitive. The values obtained by the neutron probe fell short of the lysimeter values by about 50 percent. This discrepancy was attributed to faulty operation of the probe. Potential evaporation was in the same order of lysimeter values. Thus an underestimation of potential evaporation by the Penman equation is suspected.

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I. INTRODUCTION

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 in semi-arid areas is of special interest because corn is a heavy water user and water is generally available in limited quantities.

Several techniques may be employed for determining the water use of crops. Of these, lysimeters, periodic soil moisture determinations and basin-wide water balance studies are the most common. Of the several types of lysimeters used, hydraulic lysimeters have the advantages of being relatively inexpensive to construct and to maintain. Their use, however, is not yet widespread because their field testing has so far been restricted to few areas.

Water use by crops and the efficiency of such use is generally reported to be a function of the irrigation schedules followed in producing a particular crop. As such, it was deemed useful to carry out an investigation in which both the technical aspects of hydraulic lysimeters being investigated and the water use of corn under different irrigation schedules be determined. Because of time and material limitations only two irrigation treatments were studied. These represent the two extreme cases of over-irrigation and under-irrigation. Also because of financial limitations only two lysimeters could be built. Due to the mechanical implications of managing the irrigation of these lysimeters and the plots surrounding them, it was not possible to construct a statistically acceptable randomized design. However, since this study forms a part of an internationally coordinated program in which duplicate studies are carried out in various countries of Africa, Asia and Europe, an over all randomization would eventually be possible when all data obtained would be simultaneously analyzed. It is hoped that through this and similar studies a more precise knowledge of the water requirement of crops would be gained which would eventually lead to more efficient and productive irrigation projects.

II. REVIEW OF LITERATURE

Determination of Water Use and Water Use Efficiency of Crops

Water use efficiency is the ratio between the weight of the crop produced to the weight of water used 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. Of the two, the former is by far the more involved and the following review will be mainly concerned with water use determination and problems associated with such work.

Water use is commonly determined through soil moisture studies, by using weighable tanks or lysimeters and through basinwide studies of ground water fluctuations. Of these, the first two are the more common ones and will be reviewed below.

Soil moisture studies: These include direct and indirect methods. The direct method, also called gravimetric, requires drying a wet sample of the soil in the oven and expressing the loss in weight as a percentage of the dry weight of the soil (28). Although this method is the one against which all other determinations are checked (20), there are several drawbacks to it. First,,it is a tedious and time consuming method. Second, repeated samplings from the same site are not possible, and in small plots, it 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 (59).

The indirect determination of soil moisture can be achieved through measuring some characteristics of the soil related to its moisture content. Some of the features that have been used are electrical conductivity (10, 11), moisture tension (59) and the existence of hydrogen atoms in the soil (25). Radioactive materials have been used for detecting the existence of hydrogen atoms and measuring water in the soil. Since this method is the most recent and promising one, it 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 nuclei of nearly equal mass, it can be concluded that hydrogen is more effective than other elements in slowing neutrons. Not only does a neutron lose more energy when it strikes a hydrogen nucleus, but it has also a greater probability of striking such a nucleus. Second, hydrogen in the soil is present almost entirely in the form of water (25).

The main features of this method are a 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 (59). 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 nuclei and are deflected back to the detector where the pulse they produce is amplified and sent to the counting unit. The pulses registered by this unit are related to the 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 (25) indicate that this relationship seems to be the same for all soils, including a sand and a clay and varying specific gravity from 62.2 to 94.4 pounds per cubic foot. This relationship is true, however, only if the moisture content is expressed in terms of unit volume of soil. Richards (59) indicates that only a single curve is needed for almost all types of soils. Mortier and DeBoodt (49), however, found two different, though close, curves for clay and sand. McGuinness <u>et al</u>. (48) reported that evaluation of soil moisture changes with the neutron method agreed closely with that obtained from lysimeters.

This method is assumed to be temperature independent as long as the temperature is below 32°C. Hanbali (31) reports that Davidson <u>et al</u>. found inaccurate probe readings when the temperature was above 32°C. Taylor (66) found a linear relationship between neutron counts and water content of the soil. This is in contrast with findings of Stolzy and Cahoon (63) and Stone <u>et al</u>. (64), who found a curvilinear relationship for a field calibration curve. Stolzy and Cahoon (63) reported that Horonjeff and Javek in Australia obtained an S-shaped curve in a laboratory calibration.

The neutron scattering method is the most promising soil moisture method for determining evapotranspiration. It appears to be valid in a wide range of soil moistures from ovendry to saturated soil - 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 (25). Furthermore, the sampling error in this method is minimal (66).

Use of lysimeters: It is generally accepted that measurements of evapotranspiration by soil moisture studies is precise only for periods of several days because of sampling and instrumental errors in moisture determinations (69). For measurements of evapotranspiration on daily or hourly basis a continuously weighable lysimeter becomes the only alternative.

Lysimeters vary in shape, size, method of operation and cost of construction. However, they must all meet certain requirements before the data obtained from them can be reliable. These requirements as enumerated by Van Bavel (69) and Van Bavel and Meyer (70) are: (1) the soil must be returned to the tank in the same order as it was removed from the original profile; (2) the lysimeter must be surrounded by a large area of a growing crop to prevent an oasis effect; (3) the rim must be small; (4) to permit a normal rooting medium, the tank should be large and should be provided with drainage; (5) easy and accurate measurements must be provided, preferably by the use of an electrical recorder; (6) the installation must provide at least three replicates.

Based on the method of operation, lysimeters can be divided into two groups: mechanical and hydraulic.

Mechanical lysimeters: This group includes lysimeters that depend on scales or strain gages for indicating a change in weight. A strain gage design is proposed by Frost (23). A 12-foot diameter tank rests on three load cells spaced equidistant near the perimeter. The tank is filled with soil for growing the plants. The gross weight of the tank and soil is counter balanced by three weights each at the end of a steel beam resting on a sharp edged fulcrum located in a position which provides a 3.5 to 1 lever ratio. Changes of one to two pounds in the gross weight of the tank are read on a Baldwin-Lima-Hamilton type N strain indicator. The BLH U 1 load cells are of 500 pound capacity which is sufficient for measuring a maximum of 2" of precipitation or evaporation.

Hydraulic lysimeters: Lysimeters in this group are of two types; those using bolsters of some kind and those without. Included in the latter are floating lysimeters (75) and those that use a pressure cell as the weighing mechanism (8). The design put forth by Bloeman (8) consists of three circular steel pressure cells. There is a leak-proof pressure membrane at the upperside closed by a slack membrane. Into this pressure cell, oil can be pumped. When oil pressure increases, it will lift an upper plate which is supporting the container. Lifting is stopped when no electric contact remains between the lifted and the stationary parts of the cell. In this situation, the specific pressure in the cell is a direct indication of the weight of the container, since the area of the cell is constant and its capacity variable. This pressure can be read on the mercury manometer of the cell.

The design in which bolsters are used include small lysimeters of 10 to 20 kg capacity, primarily designed for green house purposes (37, 75) as well as large lysimeters that weigh 1 to 20 tons (15, 27, 70, 73). The large ones are of greater interest in field applications. They are provided with bolsters that are filled with water and support the tank of soil. Changes in weight of the tank are transferred through the bolsters to manometers. The bolsters can be butyl tubing (73), flexible bags (27) or steel containers (15).

General limitations to the operation of the lysimeters: There are several problems that are likely to limit the use of lysimeters unless they are accounted for. The first of these problems is the relation between cost and sensitivity. The automatic lysimeter proposed by Van Bavel and Meyer (70) has a sensitivity of 0.05 mm, but it is highly expensive. On the other hand the one proposed by Dagg (15) is sensitive to 0.5 mm but costs much less. Therefore, the problem is one of economics and depending on the funds available, the sensitivity may be established. The second problem is that most of the lysimeters using bolsters, especially those with rubber bolsters do not afford a constant area under the tank. Therefore, their calibration curve must be checked frequently (8). Another problem is wind and temperature effects. The more sensitive the lysimeter is the greater this problem becomes. Van Bavel and Meyer (70) suggest that three successive readings should be taken to reduce the wind effect. For temperature changes, Hanks and Shawcroft (32) propose installation of a dummy tube parallel to the active one and reading the difference between the two. Finally, if heavy fertilization is practiced, and if sufficient water is not applied to promote leaching, then eventual salt accumulation may become a serious problem (74).

Estimation of Water Use

Both direct and indirect methods of determining water use are laborious and costly. Consequently attempts have been made to correlate water use of crops with the climatic factors of the area in which they are growing. These emperical methods can be grouped into three categories.

In the first category there are formulae that take into consideration only a few common climatic factors. These include the formulae developed by Blaney and Criddle (5, 6, 7, 14), Lowry and Johnson (45), and Thornthwaite (67). Pruitt and Jensen (57) found a high correlation coefficient between evapotranspiration estimated by the Blaney-Criddle method and the actual one. Decker (16) used Thornthwaite's equation under Missouri climatic conditions and found that the equation offered very precise estimates of evapotranspiration over long periods but produced inaccurate estimates when shorter periods were used.

In the second category of relations are those in which "energy balance" and "heat budget" concepts are utilized. These equations are due to Penman (50), Tanner (65) and others. In these an attempt has been made to allocate incident net energy to the various processes in which it is consumed. Penman has incorporated an aerodynamic term in the energy balance. The resulting equation is a measure of the evaporative power of the air as well as its ability to dispose of the by-products of evaporation. The latter is necessary for continued evaporation.

Penman (54) found that the meteorological estimates of water use were in accepted agreement with the values obtained by soil sampling. Israelson and Hanson (41) reported that good correspondence between estimated and measured consumptive use values have been obtained. Penman's equation applies best under humid areas covered with vegetation. Van Bavel and Harris (72) consider Penman's method reasonably accurate for estimation of maximum evapotranspiration for long term seasonal values. For short term prediction the Penman's method is less accurate, tending to underestimate high values and over-estimate low ones. Decker (16) found that Penman's method estimated the average daily evapotranspiration with considerable precision where the soil moisture was maintained at or near field capacity. Gerber and Decker (26) found that accuracy of Penman's estimate of consumptive use depends on moisture content of the soil surface rather than the whole profile, being high for wet surfaces and low for dry ones. Hearn and Wood (36) studied the relationship between estimated evapotranspiration and evaporation as measured by an open pan. They found that from July to November (dry season), the measured evaporation exceeded Penman's estimate by a steadily increasing ratio. As this difference is closely correlated with the actual value of the Penman's estimate, correlation between Penman's estimate and Pan is good; from May to November the correlation for 10 day means gave a coefficient of determination of $r^2 = 0.9532$, $(n = 35)$.

Hutchinsen et al. (40) stated that an annual crop, starting from a bare soil and progressing to full cover departs from Penman's model of complete cover. They suggested a factor of 0.3 at planting to a factor of 1.4 at full cover, should be applied to Penman's Eo (the estimated evaporation from a free water surface).

In the third category of estimates of water use is the use of evaporimeters such as atmometers and evaporation pans. Use of atmometers includes a correlation of difference in evaporation from black and white atmometers with measured evapotranspiration from crops (29). Correlation with evaporation pans have been proposed by Pruitt and Jensen (57) and by Bower (9). The basis for use of these devices is the assumption that they integrate the evaporative factors and through correlation give a reasonable estimate of evapotranspiration. According to Fritschen and Shaw (22) pan evaporation may be used to estimate evapotranspiration and irrigation requirements provided that a relationship between the crop to be irrigated and pan evaporation has been established for the area.

Limitations of indirect methods: These limitations fall into three categories (60): (a) with the exception of turbulent transfer and energy balance procedures, each of the methods depend upon emp rical relationships between factors employed and the basic energy transportation involved in evapotranspiration; (b) in all cases, except for turbulent transfer and energy balance methods, factors such as crop geometry, stage of development of the plant, rooting behavior, season of the year, etc. are composited by empirical correlation into one or more crop factors; (c) most of the procedures are best adapted to conservative situations and are either not applicable or difficult to apply in the more general cases of advected heat, which occur in Western United States and similar areas.

Halstead and Covey (30) found that no two of the emperical equations gave the same result. Thus, no more than one equation can be generally correct. According to these authors the observed discrepancies are a result of: (a) ignoring the size of the plots; (b) assuming a physical relation between temperature and evaporation; (c) relying on only one wind speed measurement; (d) and taking mean values instead of instantaneous ones.

Application of Penman's method and others is only possible when certain requirements are met. The crop should be a green crop, actively growing, of uniform height and never short of water (18).

Water Use and Water Use Efficiency of Corn

Effect of cultural practices: Among cultural practices, rate and pattern of planting, fertilization and moisture regime have considerable effect on corn water use and efficiency. Yao and Shaw (76) using 21, 32, and 42 inches as row spacing for corn found that there was less water used from a 21" row spacing than from 32" or 42". A higher rate of water use occurred with greater stand but increase in water use was smaller than increase in stand. Efficiency of water use, the authors report, was highest for 21" row and lowest for 42" rows. These two spacings corresponded to 28,000 and 14,000 plants per acre, respectively. Timmons *et al.* (68) report that evapotranspiration was not significantly affected by plant population at any stage of growth. They obtained highest water use efficiency in association with highest yield.

The effect of fertilization on corn water use and efficiency has been investigated by several workers. Carlson et al. (13) indicated that high N is essential for maximum efficiency in use of water. On dry land, however, little response has been noticed to N fertilizer (1).

Corn, being a heavy user of water, responds to change in the moisture regime to a great extent. Alessi and Powers (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.

Relation of evapotranspiration to corn development: Denmead and Shaw (17) indicated that after planting, the curve for the correlation between evapotranspiration/pan evaporation and time assumes a sigmoid shape as leaf area develops and more bare soil is shaded. At silking, leaf expansion is complete and the curve is flat for about two weeks. The ratio of evapotranspiration to pan evaporation is 0.81 at this stage. After silking and commencement of ear growth, evapotranspiration declines with growth. During this period some dying of the leaves is occurring and the lower leaves are starting to fire. The rapid decline in evapotranspiration could also suggest that physiological activity of the plant is declining. Fritschen and Shaw (22) report similar results and suggest empirical methods of estimating evapotranspiration must be adjusted for crop development.

Relation of evaporation to transpiration: Several investigators have tried to separate consumptive use into evaporation and transpiration. Harrold et al. (33) have achieved this objective by growing corn in a plastic covered lysimeter. According to these authors, evapotranspiration consists of roughly 2/3 evaporation and 1/3 transpiration. Fritschen and Shaw (21) using a similar technique found that transpiration was a small part of evapotranspiration before tasselling and after plants start to mature. In mid growing season transpiration was 73 percent of total water loss, which after adjustment for change in microclimate of the field would constitute 81 percent of total water loss. Peters and Russell (55) also used a comparable procedure to separate evaporation and transpiration. They believe evapotranspiration values can be split equally between the two.

Actual water use and efficiency of corn: Water use and efficiency of corn varies with locality and variety, everything else being the same. Briggs and Shantz (12) reported water use efficiency of 319 to 420, with an average of 370 grams of water per gram of oven dry matter, for several varieties of corn in Colorado. England (19) measured water use of several crops in lysimeters in North Carolina. For corn, he found a peak water use of 6.55" per month during tasselling. Water use for corn was 29.49" during the day time and 2.65" at night, totaling 32.14" for the 8 months period. Van Bavel and Harris (72) report 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. Sonmor (62) for Southern Alberta, Canada, reports an average water use of 15" for maximum yield during a 4 months growing season. This corresponds to 0.124" per day.

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. (68) obtained water use efficiencies of 6 to 454 pounds per acre inch depending on the amount of water used which ranged from 7.8" to 15.5". Yao and Shaw (76) found a water use efficiency of 571 pounds per acre inch for 21" row spacing and 420 pounds per acre inch for 42" rows. Carlson et al. (13) in a two year experiment in 1956 and 1957 obtained 659 and 772 pounds of dry matter per acre inch of water applied.

III. MATERIALS AND METHODS

The field work of this study was carried out at the Agricultural Research and Education Center (AREC) of the American University of Beirut. This center is located in the Beqa'a Plain, Lebanon, at an altitude of about 1000 m and at 33^{0} 54' north of the equator. The experiment consisted of building two hydraulic lysimeters and planting them as well as the surrounding area with corn. Daily rates of water use for two irrigation treatments were measured by the lysimeters and by soil moisture measurements using the neutron scattering method. These were compared with the theoretical value of evaporation obtained by Penman's equation and direct measurement of evaporation using the standard class A evaporation pan. Water use efficiency of corn under two irrigation treatments was arrived at by measuring the amounts of water applied and determining the yields obtained.

Hydraulic Lysimeter

A 2 x 2 x 2 m hydraulic lysimeter was built. This type of lysimeter consists of a tank resting on four bolsters filled with water and connected to a measuring column. Changes in the weight of the tank are reflected by change in the level of water in the measuring column. The bolsters and the tank are placed in a pit so that the top of the tank is level with the surface of the surrounding ground.

The tank is drained both by gravity and by tension. The water drained is led to a measuring device in an adjoining sump.

Construction: The pit and the sump were built using 20 cm concrete blocks and were connected together by a 24" concrete pipe (Fig. 1 and 2). The 2 x 2 x 2 m tank was built by welding 3 mm steel sheets with appropriate outlets and reinforcing flanges. The four bolsters, each 95 x 95 x 5 cm were built out of 1 mm steel and were provided with two outlets - a 3/4" to be used for introduction of anti-rust paint and a 1/2" for interconnecting the bolsters. Assuming the shape of the bolster affects both its strength and accuracy of response to variations in weight, several shapes were tested . A rectangular form (Fig. 3) was adopted as being the most satisfactory.

The bolsters were tested individually for leaks. Each was placed in a constraining frame to prevent its undue expansion and deformation, and was then subject to a pressure of 3 meters of water. Finally, the bolsters were covered with anti-rust paint both inside and outside.

A double drainage system was constructed. Rapid drainage was achieved by means of a 2" drain connected to the bottom of the tank and leading to the sump. Drainage under a tension of one meter was achieved by imbedding in the soil clay containers (local clay pitchers) filled with water and interconnected to a single tube leading to the sump also. A continuous tension of one meter was maintained on the clay pitchers which were in continuous contact with the soil moisture, and as such supplied a similar suction to the soil

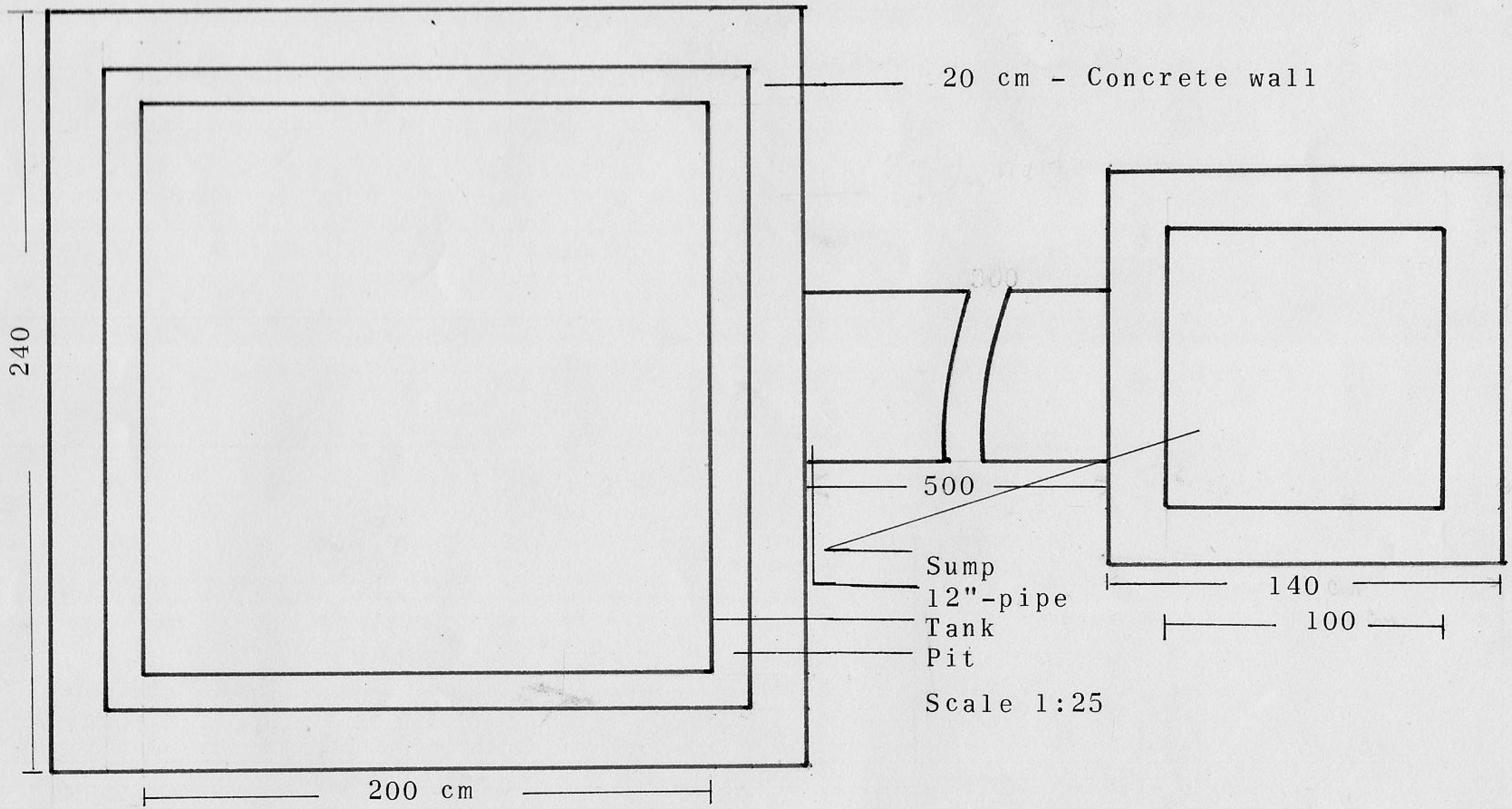

Figure 1. Plan of the pit and the sump.

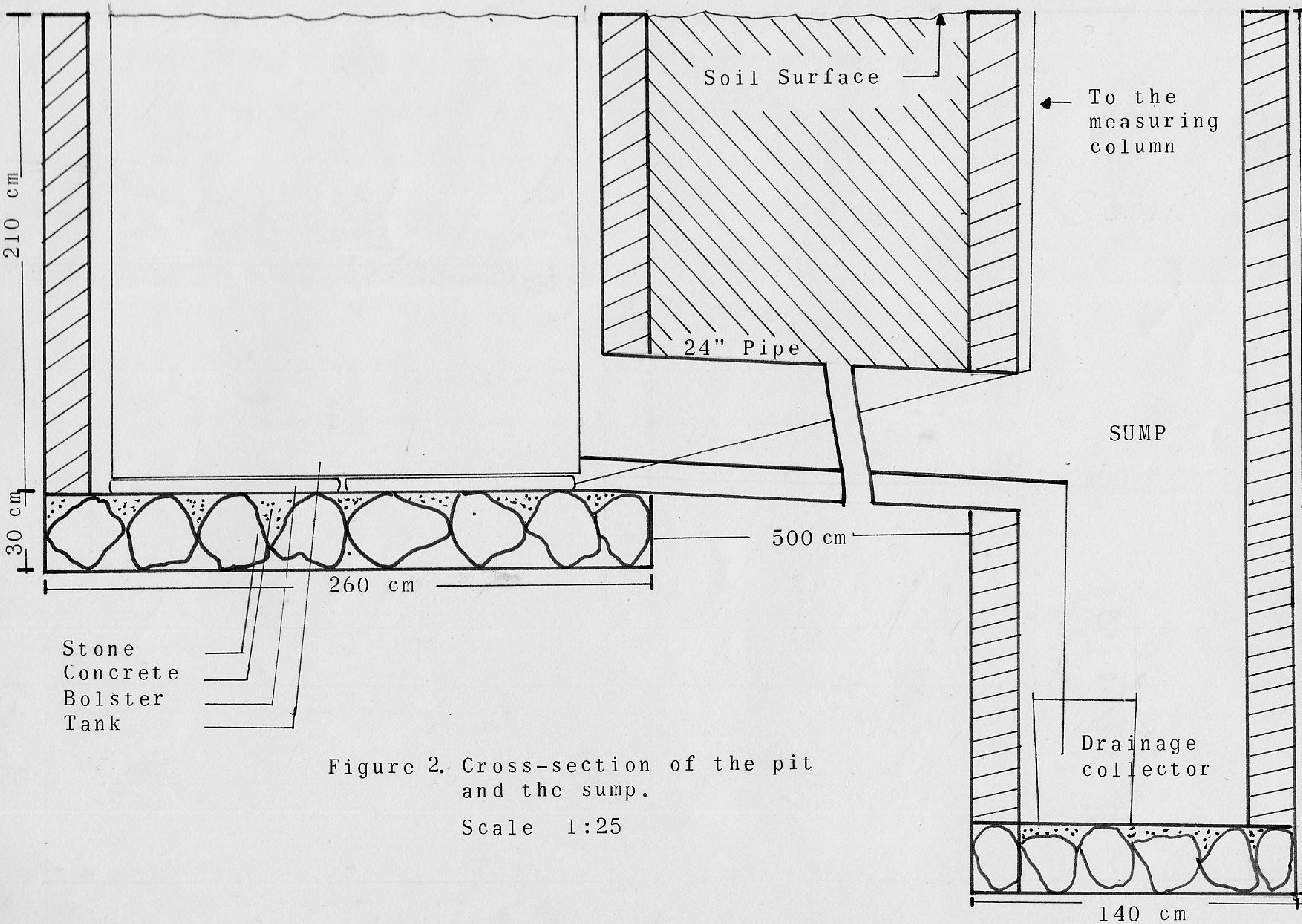

Figure 2. Cross-section of the pit and the sump.

Scale 1:25

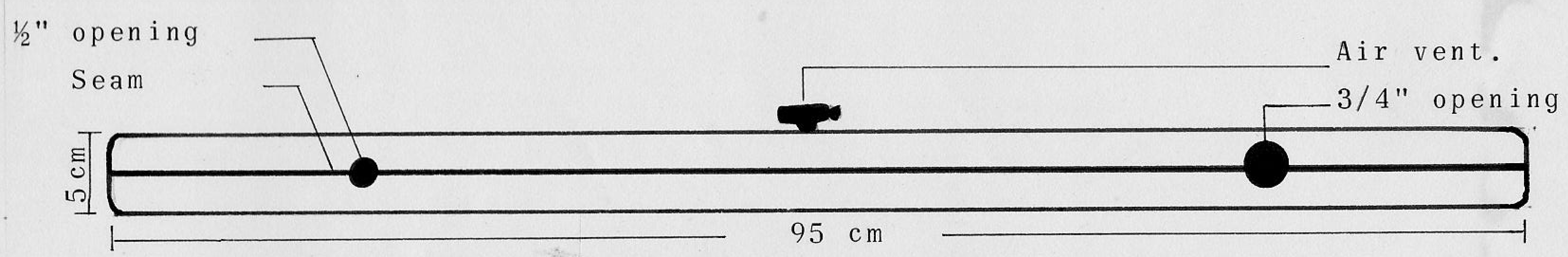

Figure 3. Side view of a bolster.

water. Originally gypsum candles were supposed to be used instead of clay pitchers. However, repeated trials failed to produce a suitable candle. All those produced rapidly dissolved under the flow of water and developed air leaks. The main characteristic of the drainage unit is to be permeable to water and not to air and to allow the passage of water at a rate that will drain a 1" storn in 24 hours.

Installation: The installation of the lysimeter consisted of filling the bolsters with water, placing the tank over them, assembling the drainage system and filling the tank with soil.

The bolsters were placed in the pit and were interconnected to a plastic tube which was passed through to the sump and connected to a measuring column. This consisted of a graduated plexiglass tube placed 150 cm above the ground level and laid at an angle of 45^o to increase its reading sensitivity. The bolsters were then filled with water, making sure no air was entrapped in the system, and covered by 5 cm thick boards to spread the weight of the tank which was to be placed over them.

The tank was first filled with sand to a depth of 5 cm. Three pairs of clay pitchers, interconnected to plastic tubes, filled with water and tightly stoppered were placed on the sand. The tubes were passed through to the sump where they were immersed in a container filled with water. This water level was one meter lower than that of the pitchers. The pitchers were then covered by another 5 cm of sand and the soil was placed in the tank. Time of filling the tank was spread over a week and every day the soil was wetted to obtain proper settlement. As the tank was filled the water level in the measuring column rose and by the time the tank was full, the water level was showing above the ground. Additional water was added to bring the water level within the range of the scale.

Calibration: The lysimeter was calibrated by loading the tank with preweighed concrete blocks. The change in the height of the water in the measuring column after each additional block was placed on the tank was recorded. This calibration process was repeated several times to obtain average readings. The calibration curve is shown in Figure 4.

Treatments and Land Preparations

Treatments: Two irrigation treatments were imposed on the corn. For both treatments the same amount of water was applied at each irrigation, but the interval between irrigations were different. The amount of water applied each time, Q, was determined by the following relation:

$$Q = 0.5\,(F.C. - PWP)\,Zr, \quad \text{where}$$

F.C.= the field capacity of the soil

PWP = permanent wilting percentage of the soil

Zr = depth of the root zone.

That is the irrigation dosage equalled one half of the available moisture in the root zone. For one treatment, the plot was irrigated whenever 42 percent of the available water of the root zone was used; since the water applied was 50 percent of the available water, this

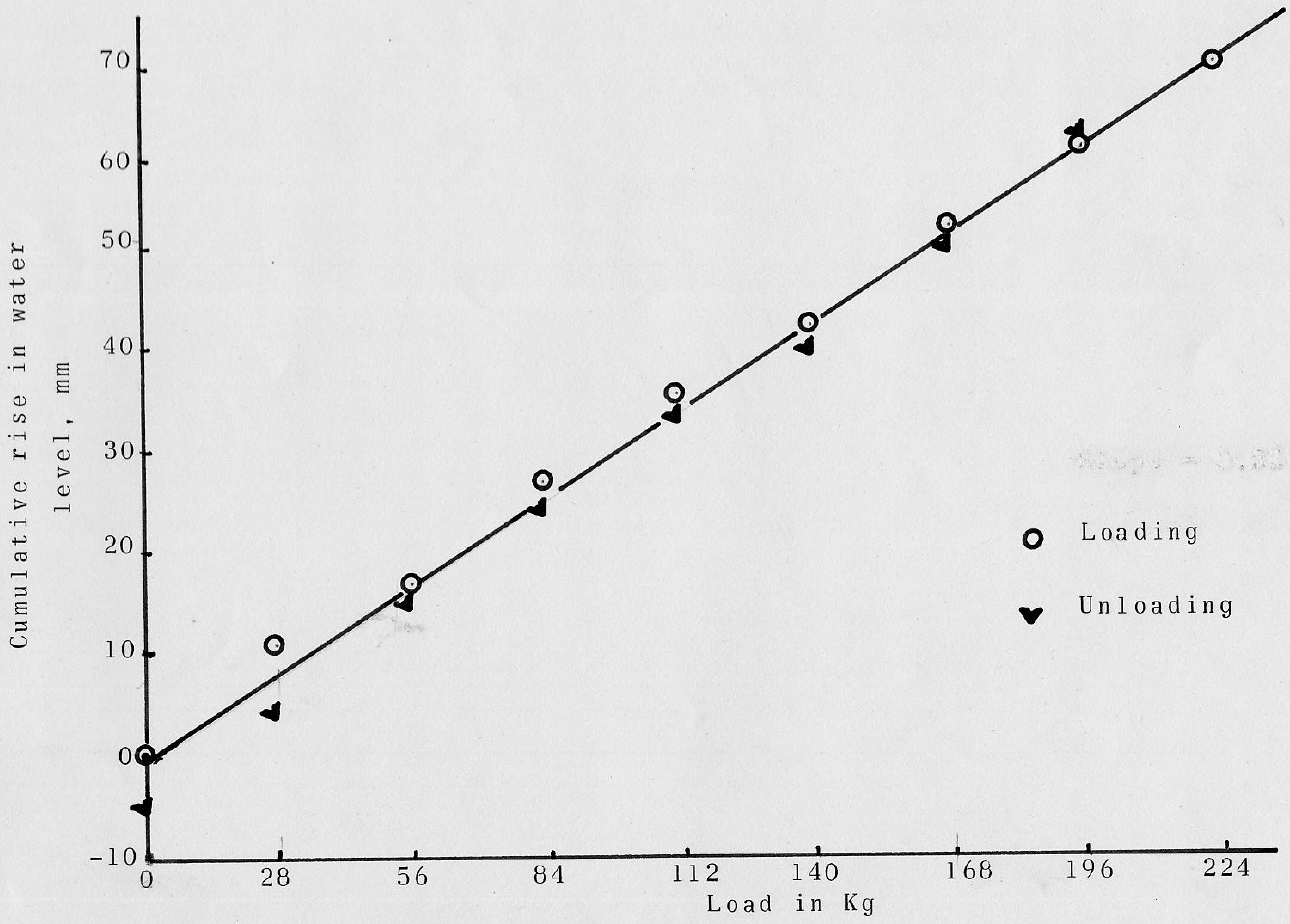

Figure 4. Lysimeter calibration curve

was an over-irrigation, and the plot that received it was designated as the "wet" plot. For the second treatment, the plot was irrigated whenever 71 percent of the available water in the root zone was used; this was under-irrigation and the plot that received it was designated as the "dry" plot. The irrigation date for each treatment was determined by one of the following:

1. $1.2 \sum_{n_1} E.T. = Q$, and

2. $0.7 \sum_{n_2} E.T. = Q$, where,

E.T. = the evapotranspiration as determined by the lysimeter

Q = 1/2 of the available water as defined above

n_1 & n_2 = the irrigation intervals in days for the wet and the dry irrigation treatments, respectively. That is, the daily water use as determined by the lysimeters for each treatment was recorded and whenever its accumulated total - since the last irrigation- equalled Q/1.2 or Q/0.7, it was time to irrigate the wet or dry plots, respectively.

The field capacity and permanent wilting percentage of the soil were determined using one composite sample. Concurrently, a more detailed study of both of the soil characteristics using a large number of samples from the same plot was being carried out by a co-worker (2). These data along with the apparent density of the soil are given in Table 1.

Table 1. Average field capacity, permanent wilting percentage and apparent density of the soil at different depths. After Ali (2).

Depth, cm	Av. F.C. %	Av. PWP %	Av. app. density gm/cc
12.5	26.8	17.5	1.23
25	26.9	18.2	1.32
50	26.1	18.1	1.38
75	25.6	18.1	1.42
100	25.3	17.9	1.45

The depth of rooting was estimated as equal to the height of the shoot up to a height of 100 cm. However, later in the season a curvilinear relation was determined by actually measuring the depth of roots of several plants by excavating a trench. This relation which is shown in Figure 5 served as the basis for the root depth approximation for the later part of the season.

Land preparation: A 1.2 hectare plot was laid out and graded to a slope of 0.5 percent south-north and 1 percent east-west. This was divided into a northern and a southern block each with a lysimeter installed in the center and receiving the two treatments. A 12-meter strip running north to south across the field and containing the lysimeters was marked off as shown in Figure 6. Within this strip

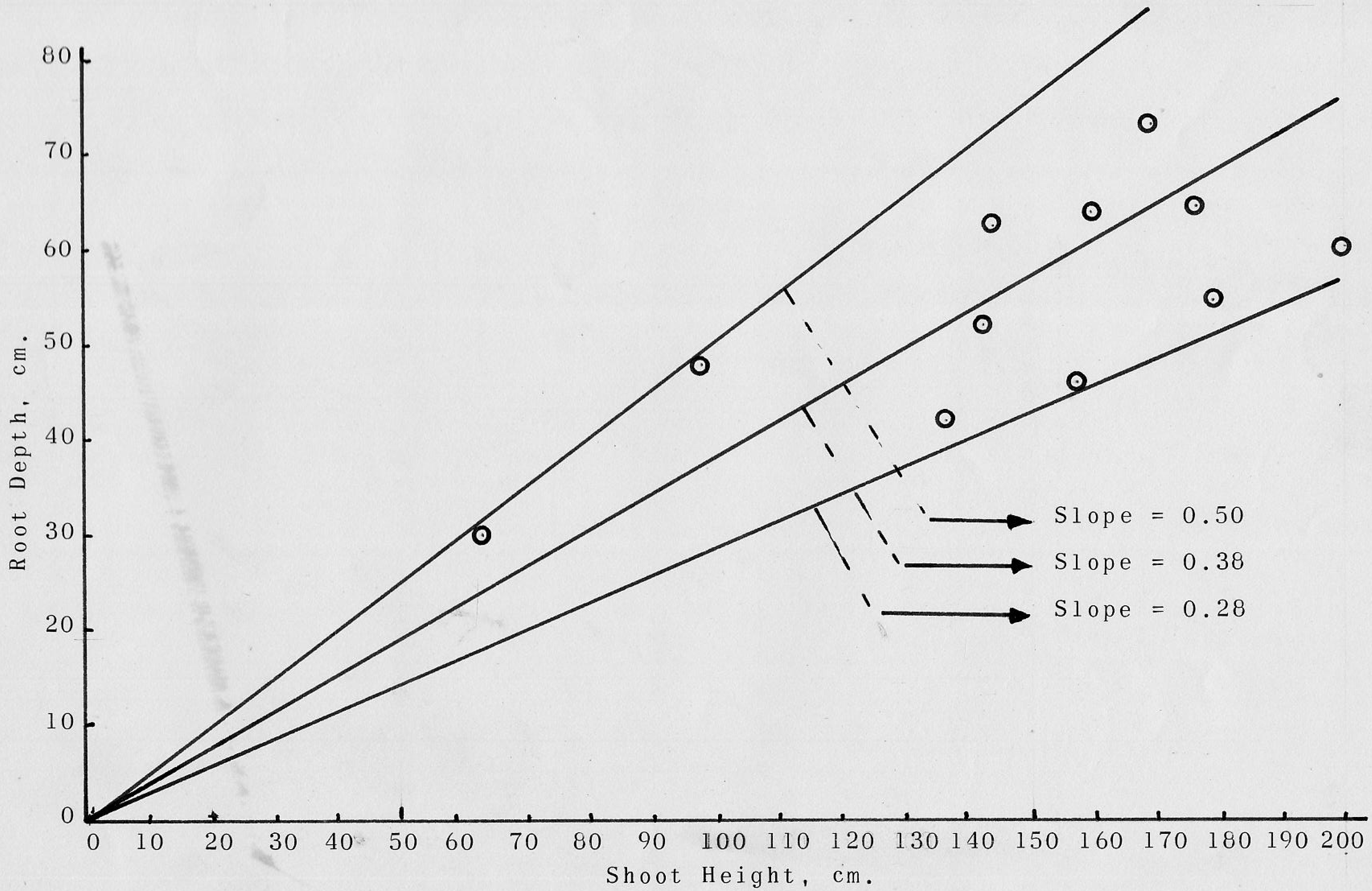

Figure 5. Root depth - shoot height relationship for corn

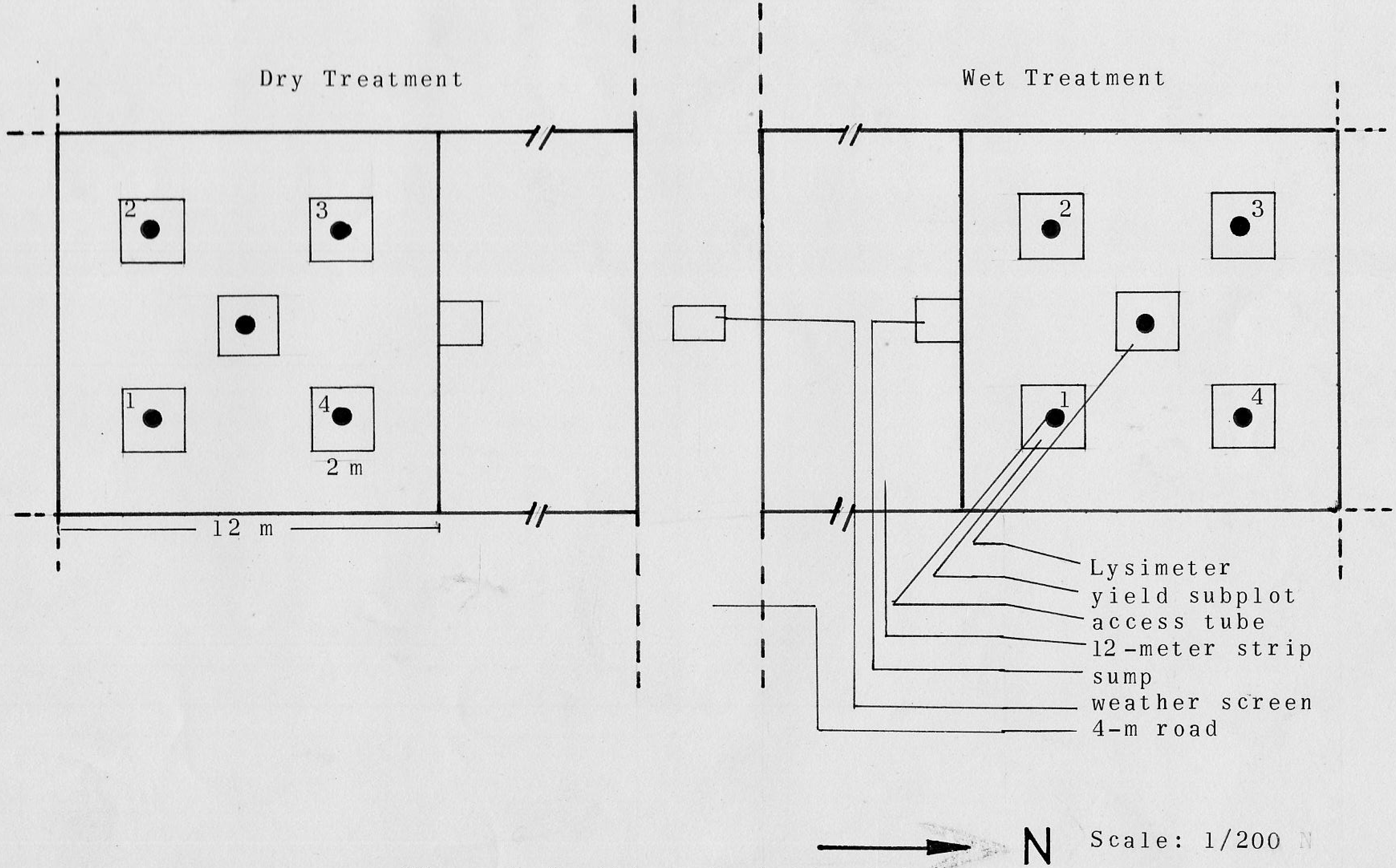

Figure 6. Position of yield subplots, lysimeter, and access tubes.

and around the lysimeters two 12 x 12 m plots were laid off. Within each of these plots four 2 x 2 m subplots, referred to as yield subplots, were marked off for yield determinations.

In the center of each yield subplot and of the lysimeter a neutron probe access tube was placed. Due to the stony nature of the subsoil, it was impossible to reach the 2 meter depth originally planned. The actual depths reached are shown in Table 2.

Table 2. Depth of neutron probe access tubes in different subplots.

Wet Plot		Dry Plot	
Location	Depth, cm	Location	Depth, cm
Lysimeter	180	Lysimeter	175
Subplot 1	134	Subplot 1	90
Subplot 2	144	Subplot 2	112
Subplot 3	136	Subplot 3	86
Subplot 4	143	Subplot 4	135

Cultural practices: Phosphorous and nitrogen fertilizers were applied to the whole field prior to planting. Phosphorous was applied in the form of normal superphosphate (18 percent P_2O_5) and nitrogen in the form of ammonium sulfate (20.6 percent N) at the rates of 200 kg P_2O_5 and 120 kg N per hectare. In addition, the treatment plots received another 80 kg of N per hectare as side dressing when plants were about 50 cm tall.

On April 29 and 30, the field was planted with corn (Zea mays, var. Asgrow 77). The row spacing was one meter in the 12 m strip and 75 cm in the rest of the field. This difference in spacing was necessitated by the fact that the field had to be planted at 75 cm, the available size of the planter, while the treatment plots needed wider spacing for ease of probe readings and passage through plants. In the 12 meter strip, three kernels were planted per hill which were thinned to one plant per hill later. The missing hills were planted with transplants taken from flats specially prepared for this purpose in the green house.

The whole field was sprinkle irrigated at frequent intervals receiving a total of 85 mm before the plots were subjected to the different irrigation treatments. Irrigation dosage to the subplots were measured by a flow meter using a rubber hose and were timed in accordance with the previously given relations. The rest of the field was irrigated by furrows using gated pipes on regular weekly basis.

May 20 and June 30 were considered approximate dates of germination and tasselling. The plants were harvested on September 15. The height of plants just before harvest were measured. All the ears from each plot were weighed. From each ear one row of seeds was removed for moisture determinations. Stalks were also collected, weighed and sampled for moisture determination.

<u>Auxiliary equipment:</u> Penman's equation was used to provide a check on the lysimeter readings. The following form of the equation suggested by McCulloch (47) was used.

$$Eo = \frac{H + Ea}{\Delta/\gamma + 1}$$

$$H = 0.95\ R_A\ (0.29\ \text{Cos}\ \phi + 0.52\ \frac{n}{N}) - \sigma\ Ta^4\ (0.56 + 0.09\ \sqrt{ed})\ (0.1 + 0.09\ \frac{n}{N})$$

$$Ea = 0.35\ (0.5 + \frac{U}{100})\ (e_a - e_d)$$

Where:

Eo = Evaporation from a free water surface

Δ = Slope of vapor pressure curve at mean air temperature (mm Hg/ ^{0}F)

γ = Psychrometric constant = 0.27

Ea = Value of Eo obtained by putting e_s-e_a in Penman's sink strength formula

H = Daily heat budget at the surface in mm H_2O/day

R_A = Theoretical radiation intensity at the surface in absence of an atmosphere, mm H_2o/day

ϕ = Latitude of the location

N = Possible duration of sunshine, hours

n = Actual duration of sunshine, hours

σ = Botlzman's constant = 2.01 X 10^{-9}

Ta = Mean air temperature in degrees Kelvin

e_a = Saturation vapor pressure at mean air temperature (mm Hg)

e_d = Saturation vapor pressure at dew point (mm Hg)

U = Mean horizontal wind speed at 2 meter height, miles/day.

To obtain the necessary data for the solution of the Penman equation a meteorological station was installed between the two lysimeters. The height of the shelter was continuously adjustable to correspond to the height of the plants. The station included a maximum thermometer, a minimum thermometer, a thermo-hygrograph and an aspirated hygrometer. At the height of two meters, an anemometer was installed to provide for wind speed determination. Adjacent to the experimental plot, another complete weather station served as a check and for supply of hours of sunshine. A standard class A evaporation pan was installed adjacent to the field on August 10. Soil moisture determinations were made using the neutron probe and the access tubes were placed in the plots and lysimeters. In addition, each treatment subplot was provided with four tensiometers to detect vertical water movement in the soil. Two of the 4 tensiometers were installed inside the lysimeters and the other two in one of the plots, at depths of 120 and 170 cms. The tensiometers were made of 1/2" copper tubes with prefabricated tensiometer cups and a mercury manometer.

Daily measurement and readings were made of all weather data, pan evaporation, manometer heights and soil moisture content.

During the course of the study two main problems were encountered. First, several failures in the operation of the neutron probe resulted in a discontinuity in the data. Second, in mid August the lysimeter in the wet treatment failed due to a leak developed in one of the joints of the bolster tubing system. From then on, rather than stop the experiment, water use of the wet plot was estimated. This estimation was based on the previously observed general relation between the wet lysimeter readings and soil moisture depletion as determined by the probe and the dry lysimeter readings during the first few days following an irrigation.

IV. RESULTS AND DISCUSSION

This study was undertaken to determine water use efficiency of corn under two different irrigation treatments - an over-irrigation and an under-irrigation. Water use was determined through hydraulic lysimeters and checked by soil moisture determination using the neutron scattering method. These were further checked against the theoretical estimate of potential evaporation by Penman's equation. Total dry matter of corn for the two treatments was obtained by sampling subplots. Water use efficiency was then determined as a ratio between water used and the dry matter produced.

Yield and Water Use Efficiency of Corn

Yields of corn under wet and dry irrigation treatments were obtained. In each case total grain and stover produced as well as 1000-kernel weight and plant height before harvest were determined. These data are presented in Table 3.

The plants under wet treatment produced more grain and stover and consequently higher dry matter than the plants under dry treatment. Moreover, taller plants and denser kernels were associated with the higher moisture regime.

In AREC, Haque (35) using 20,000 plants per acre obtained a grain yield of 538 kg per dunum while Hoque (38) using 16,000 plants per acre obtained 852 kg of grain per dunum. These figures compare

Table 3. Yield and plant characteristics of corn grown under wet and dry irrigation treatments, Beqa'a, 1966.

Treatment	Location	Grain kg/du 15% moist.	Stover kg/du air-dry	Total dry-matter kg/du	1000 Kr. wt., at 15% moist.	Average plant height, cm
WET	Lysimeter	597.5	405.8	1003.3	246.2	168.8
	Sub Plot 1	697.0	361.7	1058.7	280.8	175.6
	" " 2	616.0	375.2	991.2	234.6	176.8
	" " 3	828.0	461.8	1289.8	263.5	189.8
	" " 4	559.2	433.0	992.2	244.7	176.8
	Average	659.5	407.5	1067.0	254.0	177.6
DRY	Lysimeter	484.8	282.4	767.0	222.6	138.0
	Sub Plot 1	434.5	227.8	662.3	212.1	133.5
	" " 2	287.0	182.0	469.0	195.7	125.8
	" " 3	404.2	212.3	616.5	208.3	134.7
	" " 4	406.0	245.8	651.8	222.9	139.0
	Average	403.3	230.1	633.4	212.3	134.2

favorably with 659.5 kg of grain per dunum obtained from the wet treatment, but substantially exceed the yield of the dry treatment.

Significance of the difference between treatments as determined by paired t-test are given in Table 4. The subplots 1, 2, 3, 4 and the lysimeter of wet treatment were paired with corresponding plots of dry treatment.

Table 4. Significance of differences between wet and dry treatment plots as far as grain yield, stover yield, plant height and 1000 kernel weight are concerned, Beqa'a, 1966.

Item	t-value	p-value
Grain	4.59	0.02 - 0.01
Stover	7.78	0.01 - 0.001
Total dry matter	32.84	< 0.001
1000 Kernel weight	4.66	0.01 - 0.001
Plant height	9.86	< 0.001

It is seen that these differences include block differences since there has been no replication. It is hoped that future experiments may determine the true influence of such treatments.

Corn water use efficiency: Water use efficiency of corn was measured by calculating the total water use for the season and comparing it with the total dry matter produced. Total water use consisted of pretreatment irrigation, irrigation as treatment and the soil moisture change between the beginning and the end of the season. These are summarized in Table 5, and water use efficiency in Table 7. The treatment figures take into consideration the values of water draining out of the lysimeters. Subplots in each treatment received the same volume of water as the respective lysimeter. The details of irrigation are presented in Table 6.

Table 5. Water use of corn for the period May 1 to September 15, 1966.

	Treatment	
Water use, mm, as	Wet	Dry
Pretreatment, water applied by sprinklers from planting to the time of imposition of treatments.	85.0	85.0
Treatment, water applied during 10 irrigations of dry treatment and 15 irrigations of wet treatment.	509.0	327.4
Soil moisture, the difference between soil moisture at the beginning and at the end of the season.	100.8	182.3
Total	694.8	594.7

Table 6. Dates of irrigation and irrigation dosages for the wet and the dry treatments.

Wet treatment			Dry treatment		
Date		Water applied, mm	Date		Water applied, mm
June	20	12.76	June	22	12.76
	23	12.76			
				30	19.84
	27	19.84			
July	2	19.84	July	5	27.70
	5	27.70			
				12	39.94
	11	27.70			
	16	39.94		19	39.94
	22	53.65			
				28	27.70
	28	27.70			
Aug.	1	39.94	Aug.	2	39.94
	4	39.94			
				10	39.94
	8	39.94			
	16	39.94		19	39.94
	27	53.65			
Sept.	5	53.65	Sept.	27	39.94
Total		508.95			327.4

Table 7. Water use efficiency of corn under wet and dry irrigation treatments.

Treatment	Water use		Yield, dry matter		Water use efficiency		
	mm	Inches	Kg/du.	lbs/ acre	Kg/cm du.	lbs/ ac."	gm. water/ gm. dry matter
Wet	694.8	27.4	1067.0	9390.0	15.4	344.0	651.2
Dry	594.7	23.4	633.4	5574.0	10.7	238.0	938.3

As seen from Table 7, corn used water about 30 percent more efficiently when it was overirrigated than when it was under-irrigated. The same trend has been found by Timmons et al. (68) who found that with 11 to 15.5" of water, water use efficiency ranged between 190 and 454 pounds per acre inch, while with 7.8 to 14" of water use, water use efficiency dropped to 6 to 314 pounds per acre inch. Allison et al. (3) reported that most efficient water use was associated with higher yields. Yao and Shaw (76) attribute most efficient use of water to smaller between-row spacing.

The efficiencies found in this experiment were considerably lower than those found by Briggs and Shantz (12), Howe (39) and Carlson et al. (13). This may be due to two factors: (a) lower general yield in this case, and (b) wider row spacings which promotes evaporation.

Rates of Water Use

Lysimetric determination: Total water use for the period of June 23 to September 15 as measured by the lysimeters was 509.0 mm for the wet treatment and 327.4 mm for the dry treatment. Daily water use rates are given in Table 8. From these it is clear that water use rates on daily basis are too inconsistant to justify any generalizations. However, if water use is accumulated over the irrigation interval, as shown in Table 9, a more clear pattern will be formed. This is probably due to the nature of the bolsters used. Being of steel, they did not exhibit complete elasticity but rather cushioned, at least momentarily, some of the differential strain to which they were subjected. Perfectly elastic bolsters would instantly communicate change in pressure to the manometric column. However, if they were not so elastic, they might store part of the change to release it later at irregular levels.

The average daily rate of water use for the dry treatment ranged between 3.2 mm and 8.9 mm. Comparative figures for the wet treatment, excluding the unreliable figures of August 8 and on, are 3.6 and 11.4 mm. The highest rate of water use for both treatments occurred about three weeks after tasselling. During this period, the plants in the wet treatment were using water at an average rate of 7.9 mm per day and those of the dry treatment at an average rate of 5.6 mm per day. Fuehring et al. (24) reported that corn grown in the Beqa'a Plain used an average of 11.1 mm when it was weekly irrigated. However, when the irrigation interval was increased to 10 days and two weeks, the average daily water use dropped to 10.2 mm and 8.0 mm,

Table 8. Corn water use in mm, as determined by the wet and dry lysimeters for the period of July 23 to September 15, 1966.

Date		Water Use, mm Wet Lysimeter	Dry Lysimeter
June	23[x]	0.5	1.9
	24	8.1	6.9
	25	-	No readings
	26	13.4	0.8
	27[x]	4.2	2.5
	28	7.0	0.6
	29	3.2	0
	30[+]	5.6	0
July	1	-	No readings
	2	2.0	6.2
	3	6.4	1.9
	4	6.6	0
	5[x+]	7.6	No readings
	6	0.5	5.6
	7	7.6	10.0
	8	5.4	1.9
	9	3.5	1.4
	10	3.2	9.4
	11[x]	6.6	5.6
	12[+]	11.0	10.0
	13	6.6	5.0
	14	9.1	12.5
	15	4.5	2.5
	16[x]	4.8	6.2
	17	2.0	1.2
	18	10.4	8.5
	19[+]	9.1	6.2
	20	7.9	2.5
	21	8.2	14.8
	22[x]	8.5	6.2
	23	6.0	3.1
	24	15.1	14.4
	25	9.5	4.4
	26	1.6	6.2
	27	17.9	6.9
	28[x+]	1.6	1.9
	29	7.9	9.4
	30	10.4	8.8
	31	11.0	10.6
Aug.	1[x]	6.0	5.0
	2[+]	14.8	10.0
	3	13.5	4.4

Table 8 Cont'd.

Date		Water Use, mm Wet Lysimeter	Dry Lysimeter
Aug.	4^x	No readings	8.1
	5	9.9	5.6
	6	No readings	No readings
	7	17.5	19.4
	8^x	11.4	0
	9	17.0	14.4
	10$^+$	21.4	8.8
	11	7.6	9.4
	12	10.1	4.4
	13	2.0	6.9
	14	17.9	6.2
	15	28.1	9.1
	16^x	8.9	3.1
	17	0.8	6.9
	18	Wet lysimeter failed	17.3
	19$^+$	-	No readings
	20	-	8.1
	21	-	11.2
	22	-	5.0
	23	-	7.5
	24	-	6.2
	25	-	0
	26	-	7.5
	27^{x+}	-	9.1
	28	-	4.4
	29	-	8.8
	30	-	13.1
	31	-	0
Sept.	1	-	1.2
	2	-	0
	3	-	1.2
	4	-	10.0
	5^x	-	1.2

Table 8 Cont'd.

	Water Use, mm	
Date	Wet Lysimeter	Dry Lysimeter
Sept. 6	-	3.8
7	-	0
8	-	1.2
9	-	2.5
10	-	1.2
11	-	0
12	-	1.2
13	-	4.3
14	-	2.5

x Irrigation day of wet treatment.

+ Irrigation day of dry treatment.

Table 9. Corn water use in mm under wet and dry irrigation treatments as determined by lysimeter, neutron scattering method and potential evaporation as estimated by Penman's equation.

Wet treatment

Interval	Lysimeter		Neutron probe		Penman	
	Per interval	Av. daily	Per interval	Av. daily	Per interval	Av. daily
June 20-23	13.6	4.5	15.5	5.2	10.0	3.3
23-27	25.9	6.5	2.8	0.7	28.1	7.0
27- 2	17.8	3.6	18.2	3.6	34.7	6.9
July 2- 5	20.6	6.5	1.7	0.6	21.1	7.0
5-11	26.8	4.5	16.4	2.8	37.3	6.2
11-16	36.0	7.2	13.3	2.7	34.8	7.0
16-22	46.1	7.7	39.9	6.8	38.9	6.5
22-28	51.7	8.4	Probe out of order	-	40.4	6.7
28-1	29.3	7.3	-	-	18.5	4.6
Aug. 1-4	34.3	11.4	-	-	25.9	8.6
4-8	38.8	9.7	-	-	24.9	6.2
8-16	113.0	15.6	0.5	0.1	50.4	6.4
16-27	Wet Lysimeter failed		33.4	3.0	65.2	5.9
27- 5			28.1	3.1	43.6	4.9
Sept. 5-15	-		7.1	0.7	52.0	5.2

Dry treatment

Interval	Lysimeter		Neutron probe		Penman	
	Per interval	Av. daily	Per interval	Av. daily	Per interval	Av. daily
June 22-30	50.0	6.3	19.5	2.4	53.5	6.7
30- 5	35.5	6.9	14.4	2.9	35.2	7.0
July 5-12	43.9	6.3	21.5	3.1	44.6	6.4
12-19	42.1	6.0	25.2	3.6	46.6	6.7
19-28	60.4	6.7	Probe out of order	-	60.2	6.7
28- 2	43.8	8.5	-	-	31.6	6.3
Aug. 2-10	60.7	7.6	-	-	50.4	6.3
10-19	63.0	7.0	8.0	0.9	56.7	6.3
19-27	54.6	6.8	7.6	0.9	46.2	5.8
Sept. 27-15	56.7	3.2	4.3	0.2	95.6	5.0

respectively. These values represented the peak water use from July 2 to August 12. Atallah (4) reported average water use of 5.2 mm per day for the period of June 24 to August 19 and 7.1 mm per day for July 11 to September 5 on the AREC. These latter values are close to the average daily water use of corn under dry treatment which were 6.4 mm and 6.9 mm for the two periods, respectively. England (19), using weighing lysimeters found peak water use of 5.5 mm per day.

Water use by the neutron probe: Rates of water use as determined by the neutron probe are presented in Tables 9 and 10. Because of the failure in the operation of the neutron probe, the results are given only for the first and the last parts of the season. The values presented in Table 9 are averages of 5 readings in 5 sites in each treatment: the four yield subplots and the lysimeter. The daily water use of corn in the wet treatment is seen to be very irregular over the growing season. It ranges from 0.1 to 6.8 mm per day. In contrast to these values, water use in the dry treatment shows a more definite pattern. It increases during the first part of the growing season, reaches a maximum then decreases gradually. The range of values in this case is from 0.2 mm per day for the last two weeks of the season to 3.6 mm per day for the period following tasselling. The peak water use which might have been at three weeks after tasselling, as determined by the lysimeters, was not recorded due to the failure of the probe.

The total water use of corn for the period June 20 to July 22 was 107.8 mm for the wet treatment and 80.6 mm for the dry one. These

Table 10. Depth pattern of water use, percent volume as determined by the neutron probe, for the two treatments.

Wet treatment (Depth of soil layers, cm)

Interval	Location	0-30	30-60	60-90	90-120	120-145	145-170
June 20-23	Lysimeter	8.1	-0.1	-0.2	1.0	1.3	1.9
	Plots	1.1	0.5	0.8	0.2	1.3	-
23-27	L	0.6	0.4	0.3	-0.4	-0.2	2.5
	P	0.6	0.1	-0.1	0.3	-0.5	-
27- 2	L	1.9	1.7	-0.1	1.0	0.3	0.3
	P	2.4	1.0	1.0	1.1	1.0	-
July 2- 5	L	0.5	0	-0.5	-0.2	0.8	0.2
	P	0.3	0.2	0	0	-0.8	-
5-11	L	2.6	1.3	0.2	-0.9	-1.0	-1.1
	P	5.3	-0.2	0.9	-0.5	-1.1	-
11-16	L	2.2	0.1	-0.3	-0.8	1.0	0.3
	P	3.4	1.4	-0.4	-0.1	-0.6	-
16-22[x]	L	5.7	1.6	1.2	0.6	-0.1	0
	P	4.5	2.5	1.2	3.3	3.3	-
Aug. 8-16	L	3.4	0.5	-1.0	-1.2	-0.2	-0.8
	P	-1.2	0.4	-0.6	1.2	1.2	-
16-27	L	3.9	1.1	-1.3	0.8	0	0
	P	5.4	2.0	2.3	1.6	2.2	-
27- 5	L	5.9	1.2	3.4	-1.1	-0.4	0.1
	P	2.9	1.9	0.6	1.8	3.1	-
Sept. 5-15	L	2.5	0.5	-0.1	-0.9	-1.9	-1.2
	P	2.5	0.3	1.0	1.7	-2.6	-

Dry treatment (Depth of soil layers, cm)

Interval	Location	0-30	30-60	60-90	90-120	120-145	145-170
June 22-30	Lysimeter	1.4	0.5	-0.4	0.6	0.8	0.9
	Plots	3.3	3.8	0.3	2.0	1.8	-
30- 5	L	2.2	0.4	0.7	-0.6	0.4	-0.6
	P	2.2	1.0	1.4	0.8	0.6	-
July 5-12	L	2.2	0.3	1.1	0.6	0.2	0.4
	P	4.0	2.0	1.1	0.4	0.1	-
12-19	L	2.5	-0.5	0.7	-0.6	0	0.1
	P	5.5	2.5	1.6	0	-0.5	-
Aug. 10-19	L	1.9	-0.1	-1.3	0.4	0.5	-0.3
	P	3.6	0.5	-0.6	-0.4	-0.2	-
19-27	L	2.5	0.3	-1.3	0.9	0.7	-0.2
	P	2.3	1.0	-0.6	-0.3	-0.7	-
Sept.27-15	L	2.3	-0.5	1.1	-0.4	0.5	1.3
	P	0.2	-0.1	0.3	0.1	1.4	-

[x] From July 23 to August 8, the probe was out of order.

values are substantially lower than those of the lysimeters and those found by England (19), Van Bavel and Harris (71) and others who used different methods. These will be discussed later.

Potential evaporation by Penman's equation: Potential evaporation was estimated by Penman's equation. The accumulated values over the irrigation intervals as well as average daily values are presented in Table 9. Average daily values ranged from 3.3 to 8.6 mm over the intervals of the wet treatment and from 5.0 to 7.0 over the intervals of the dry one. Total potential evaporation was 525.8 mm for the period June 20 to September 15. This gavea an average daily figure of 6.0 mm for the whole season.

Evaporation by class A pan: Evaporation was measured by class A pan. Measurements were taken for the period August 23 to September 29. Measured evaporation along with Penman's potential evaporation are given in Table 11. Total pan evaporation for the period was 408.7 mm, an average of 8.9 mm per day. The measurements covered the latter part of the season and as such may underestimate the time average for the whole season.

Evaluation of methods: Comparisons among results obtained by different methods may be made by referring to Table 9.

Penman's equation versus evaporation pan: Penman's equation consistantly gave underestimates of evaporation as compared with the figures of the pan. The total by Penman was 282.3 mm for the period August 23 to September 29, with an average of 6.1 mm per day. Pan evaporation amounted to 408.7 mm for the same period with an average of 8.9 mm per day. This gives a ratio of pan to Penman of 1.4 and

Table 11. Daily evaporation and evaporation per 5-day intervals as determined by pan and as estimated by Penman, mm.

Date	Daily evaporation		Interval	Interval evaporation		Date	Daily evaporation		Interval	Interval Evaporation	
	Pan	Penman		Pan	Penman		Pan	Penman		Pan	Penman
Aug. 23	-	5.4				11	7.3	4.0			
24	12.2	5.3				12	8.1	4.6			
25	8.2	5.3				13	7.9	4.4			
26	11.9	5.4	23-26	32.3	21.4	14	7.6	4.6			
27	9.5	5.5				15	-	-	11-15	39.1	21.6
28	10.1	5.5				16	16.5[x]	8.1[x]			
29	10.7	5.7				17	6.1	4.3			
30	13.4	6.8				18	9.2	5.1			
31	7.9	5.2	27-31	51.6	28.7	19	8.2	4.7			
Sept. 1	10.4	5.0				20	6.1	4.5	16-20	37.8	22.6
2	11.6	5.2				21	-	4.4			
3	8.5	5.1				22	8.5	5.1			
4	10.4	5.1				23	7.8	5.3			
5	9.8	5.4	1-5	50.7	25.8	24	6.4	5.4			
6	9.5	5.4				25	7.3	4.5	21-25	38.0	24.7
7	11.0	4.9				26	5.9	4.1			
8	9.2	4.3				27	6.4	3.9			
9	9.5	5.0				28	6.4	3.8			
10	6.5	5.0	6-10	45.7	26.4	29	-	3.5	26-29	24.9	15.3
						Total	408.7	282.3			

[x] Includes values for September 15, too.

Penman to pan of 0.68. This is in sharp contradiction with the findings of Prashar and Singh (56) who reported a ratio of pan to Penman of 0.76.

The correlation coefficient between Penman's potential evaporation and the observed pan values was 0.81 (n = 46) which is significant at the one percent level of probability. This signifies the existance of a consistant factor diminishing the Penman's estimate. This will become more apparent in the next comparison.

Penman versus lysimeter: Corn water use under wet and dry treatments as determined by lysimeters and potential evaporation by Penman's equation are given in Table 9, and are graphically presented in Figures 7 and 8. For the dry lysimeter there is a fairly reasonable correlation between lysimetric values of water use and Penman's estimates of potential evaporation. The correlation coefficient in this case is 0.45 (n = 8). For the wet lysimeter, the correlation coefficient is -0.04 (n = 9). This lack of correlation together with the failure of the wet lysimeter at the end of the season, casts doubt on its operation throughout the season.

Total water use by corn under wet treatment for the period June 20 to August 16 was 453.9 mm by the lysimeter while Penman's gave 365.0 mm. These correspond to 8.0 mm per day and 6.4 mm per day, respectively. Total water use by corn for the dry treatment for the period of June 22 to September 15 was 510.7 by the lysimeter and 520.6 by Penman's equation. These correspond to 6.1 mm per day for both methods. This shows a definite trend of underestimation by the Penman equation which further substantiates that determined under

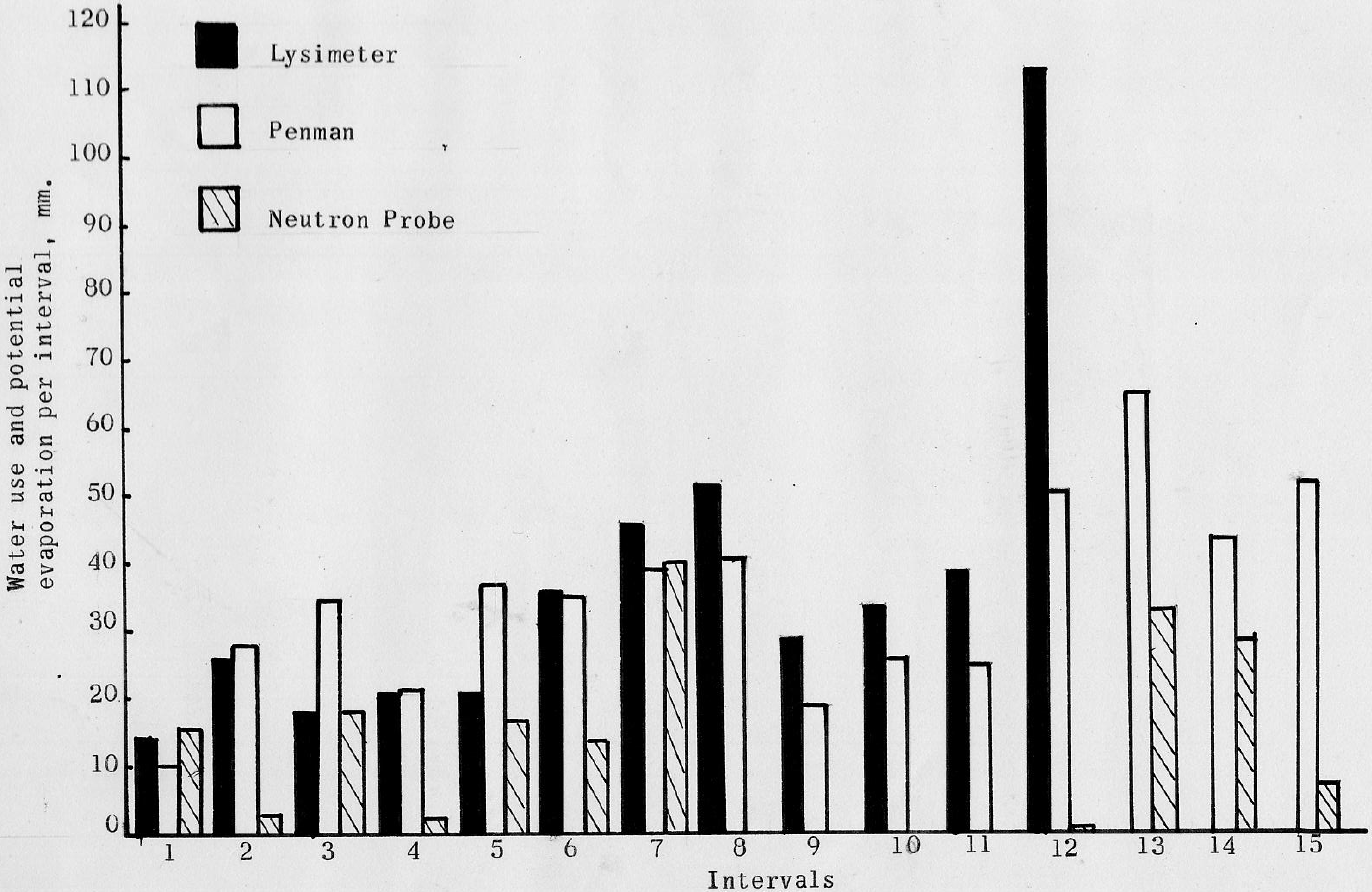

Figure 7. Comparison of corn water use by lysimeter and neutron probe and potential evaporation by Penman per irrigation interval (unequal intervals), wet treatment.

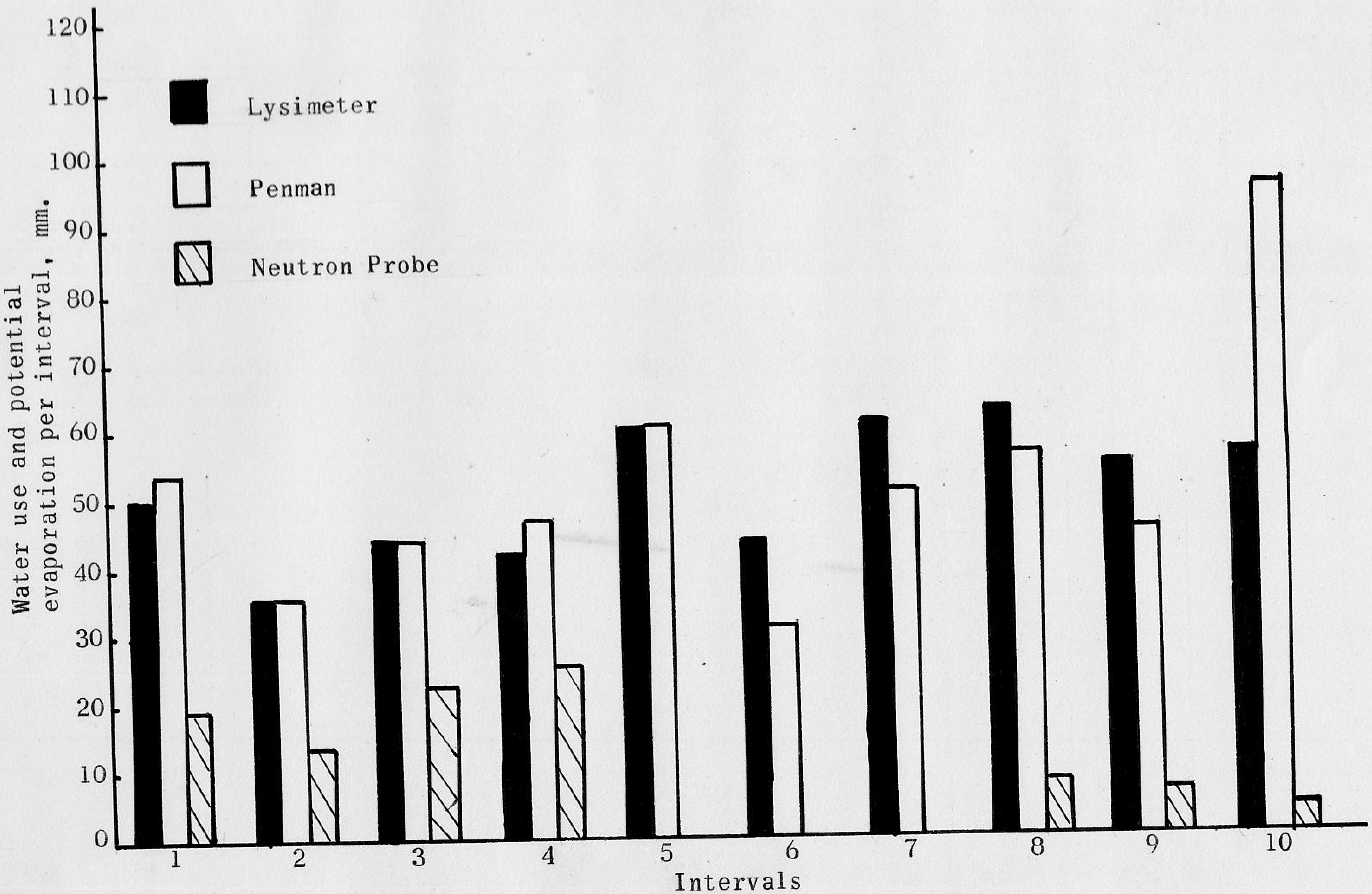

Figure 8. Comparison of corn water use by lysimeter and neutron probe and potential evaporation by Penman per irrigation interval (unequal intervals), dry treatment.

comparison with pan evaporation. Generally potential evaporation is higher than actual water use by most crops. However, when the leaf area is very large, it is conceivable to have a larger actual rate of water use. But since pan evaporation was also higher than the potential evaporation, even after applying a pan coefficient of 0.8 suggested by Linsley _et al._ (43), it seems reasonable to assume that due to some selected constants in the Penman equation an under-estimation is maintained. The correlation however, indicates the general soundness of the equation, but probable improper selection of constants. Considerable field work would be required to establish proper constants for this equations.

The correlation between lysimeter values on irrigation interval basis and Penman's estimate, though not significant, may still be an indication of the suitability of the lysimeter for determining water use.

Lysimeter versus Neutron Probe: The data available on the neutron probe were too few to justify calculation of a correlation coefficient. The correspondence between the lysimeter values for corn water use and those obtained by the neutron probe are illustrated in Figures 7 and 8. In general the neutron scattering method indicated the same trend of water use as the lysimeters but underestimated the absolute value. Total water use of the wet treatment for the period June 22 to July 22 was 107.8 mm by the neutron probe and 186.8 mm by the lysimeter. These correspond to an average daily use of 3.6 and 6.1 mm, respectively. For the dry treatment similar considerations gave 6.4 mm per day for the lysimeter and 3.0 mm per day for the probe.

This underestimation could have been explained on the basis of the calibration curve of the probe. This curve was obtained in the laboratory using a disturbed soil sample. However, it was subsequently used by Fuehring et al. (24) and their determinations do not support this explanation. Furthermore, the variations in daily readings between similar plots indicates the possibility of a faulty mechanical behavior of the probe or the scaler. This was masked by averaging the individual readings. The only sure test would be to compare the readings obtained by using this probe to those obtained by using another set under similar conditions. This, however, was not possible since only one such piece of equipment was available.

General comparison: For an overall comparison of the methods, the cumulative water use as determined by the lysimeter and the neutron probe and potential evaporation by Penman's equation are shown in Figures 9 and 10. Cumulative plotting helps remove short term variations. From these figures, there seems to be a satisfactory correspondence between the lysimeter and Penman's estimate. However, the increasing slope of the curve for the wet lysimeter in Figure 9 gives another hint to its improper operation.

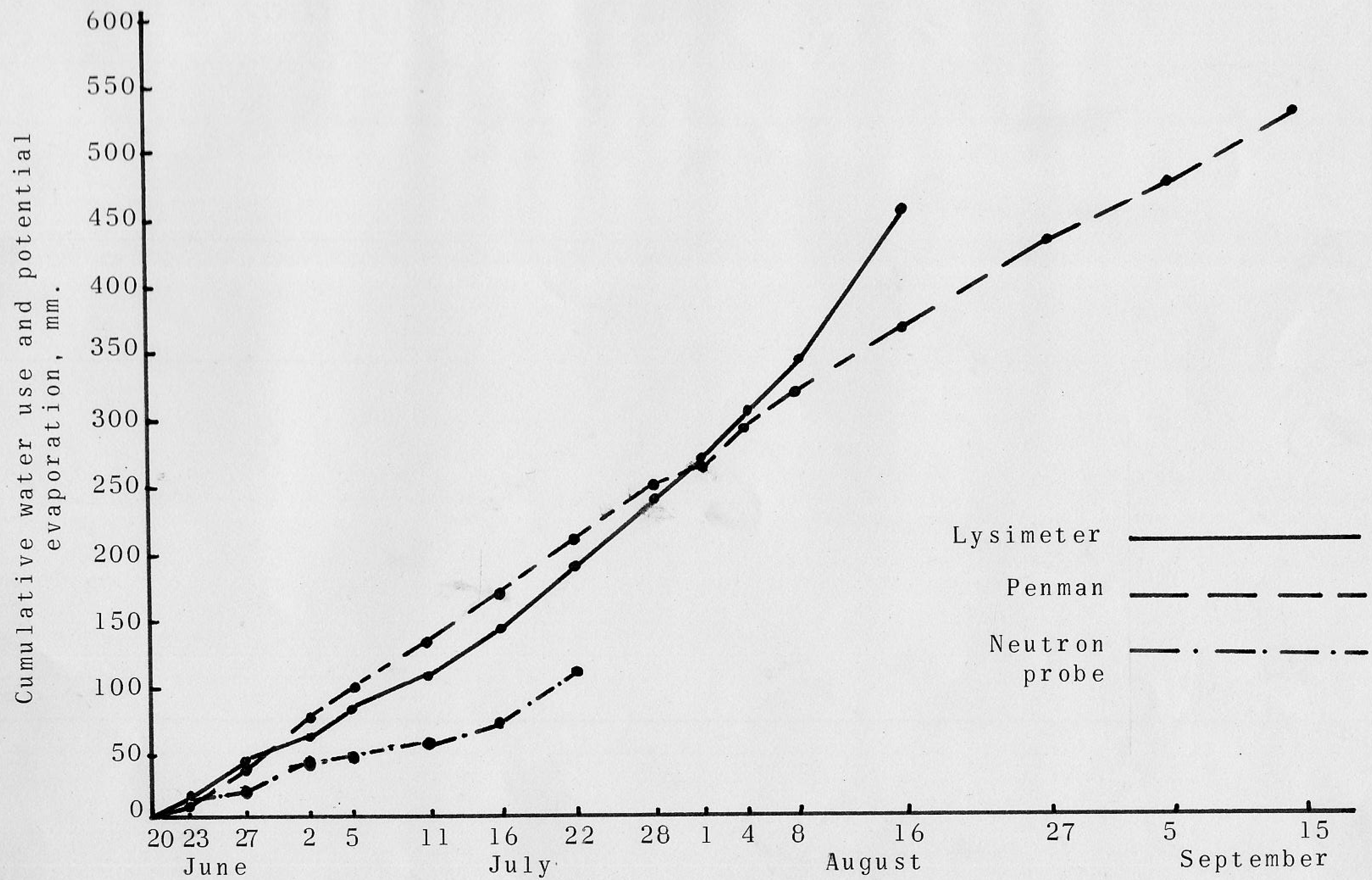

Figure 9. Cumulative water use by lysimeter and neutron probe, and potential evaporation by Penman, wet treatment.

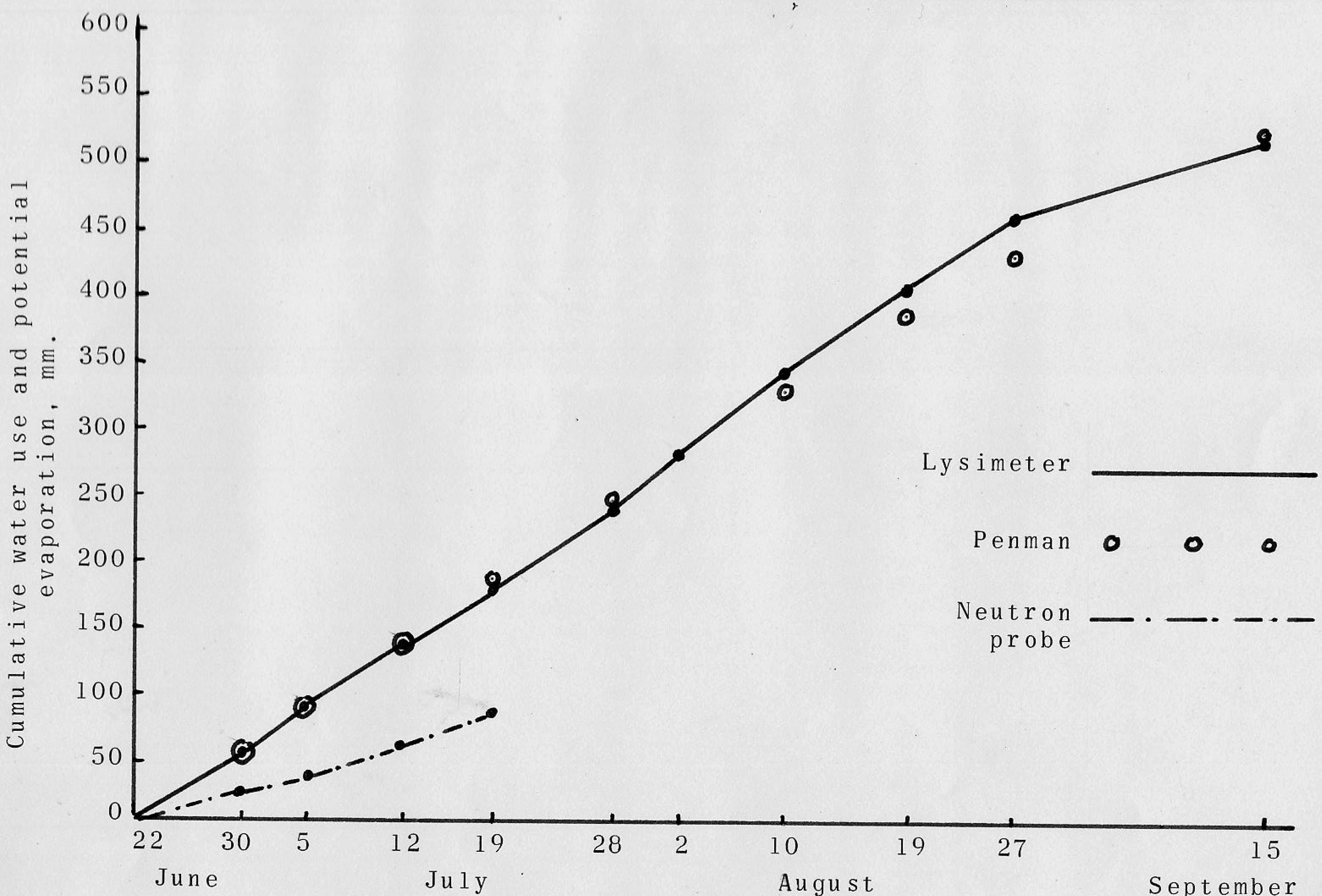

Figure 10. Cumulative water use by lysimeter and neutron probe, and potential evaporation by Penman, dry treatment.

V. SUMMARY AND CONCLUSIONS

A study was undertaken in which a hydraulic lysimeter was used to determine the water use efficiency of corn under two irrigation treatments - an overirrigation and an underirrigation. This study was conducted at the Agricultural Research and Education Center of the American University of Beirut, in the Beqa'a Plain, Lebanon, during 1966. Water use as determined by the hydraulic lysimeter was checked by soil moisture determinations using the neutron scattering method. These were compared with the theoretical estimates of potential evaporation (P.E.) using Penman's equation.

Two hydraulic lysimeters were built during 1965. This type of lysimeter consists of a tank which rests on 4 steel bolsters that are filled with water and connected to a single manometer. Any change in the weight of the tank, which is a measure of evapotranspiration is reflected in the water level of the manometer.

Corn was planted in the lysimeters and in the 12 dunum area surrounding them in the spring of 1966. The two irrigation treatments imposed on the corn were an overirrigation and an underirrigation, both had similar dosages of water, but different irrigation intervals. The overirrigation, "wet" treatment, consisted of applying 50 percent of the available water within the root zone whenever about 40 percent was used. The underirrigation, "dry" treatment, consisted of adding 50 percent of the available water whenever 70 percent was consumed.

Total water use for the season amounted to 694.8 mm for the wet treatment and 594.7 mm for the dry one. The total dry matter produced by corn under the two treatments were 1067.0 kg/du and 633.4 kg/du, respectively. These resulted in a water use efficiency of 1.5 and 1.1 kg/m^3 or 651.2 and 938.3 grams of water used for the production of one gram of dry matter for the overirrigated and underirrigated corn, respectively.

The performance of the lysimeter was compared with the values of P.E. by Penman's equation and soil moisture changes using the neutron probe. Lysimetric values followed the P.E. closely. For the period of June 22 to September 15, the lysimeter indicated a total water use of 510.7 mm for the underirrigated corn while P.E. was 520.6 mm. For the overirrigated corn the corresponding figures were 453.9 and 365.0 mm, respectively, for the period of June 20 to August 18. Since P.E. is generally considered to be higher than actual water use by many crops, it was assumed that Penman's equation was underestimating the P.E. This was confirmed when P.E. was compared to actual evaporation from a class A pan. The pan on the average was 1.8 times higher than P.E., while a factor of 1.2 is more widely used.

The neutron probe underestimated the lysimeter values. Its values on the average were 50 percent lower than those of the lysimeters. This underestimation was attributed to the faulty operation of the probe.

From the results obtained, the following conclusions may be drawn. First, corn was about 1.4 times more efficient in using water when it received an adequate supply of it than when water was limited. Second, hydraulic lysimeter may be used satisfactorily for water use determinations over 3 to 4 day periods. However, this type of lysimeter is not sensitive enough for daily measurements. Third, Penman's equation should be modified for the conditions of Beqa'a . Finally, due to the malfunctioning of the probe, the results obtained by the neutron probe are not conclusive.

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