Chapter 11

Irrigation and Water Use[1]

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Peanuts have been irrigated on a limited basis for many years. However, in recent years the practice of irrigating peanuts has developed at a rapid pace. This has been brought about by drouths in the mid-fifties and sixties and the high cash value of the crop. The most rapid development has occurred in the southwest portion of the United States with recent interest being shown in the other peanut producing areas.

Prior to 1950 very little irrigation water was used on peanuts. The drouths of 1952, 1954, and 1956 coupled with the knowledge that adequate ground water was available resulted in an interest in irrigation. Also, the availability of money for loans from banks and federal agencies caused many producers to look into the practice. As a result, many irrigation systems were installed. Each year, more irrigation systems are being installed with the greatest increases being noted during the drier years.

Because of topography and soil structure, a majority of the peanuts are irrigated with a sprinkler system. This may vary in its sophistication from a hand to side-roll wheel move or a center pivot or self-propelled system. However, in New Mexico the entire crop is irrigated primarily by the furrow method.

In recent years new irrigation water sources have been the impounding of water in private reservoirs, federal lakes, and further development of known ground water

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sources. The future of peanut irrigation will depend on the price-cost relationship and the ability to further develop economic sources of water.

Water Use

Most of the water received for field crop production is lost by the process of evaporation. Surface water runoff and deep percolation represent a loss of approximately 10-15 percent of the precipitation water input. Under irrigated field conditions, the deep percolation and runoff losses can be managed by the grower and will not be discussed in this section.

The water requirement for a well-managed peanut production will be determined primarily by the evaporative loss. This loss is described by the term evapotranspiration (ET) owing to the difficulty of determining what portion of the water loss is evaporation from the soil surface or transpiration from the plant leaves. From the irrigation standpoint, it is of little importance as to whether the water was lost from the soil or directly from the leaves; thus the term evapotranspiration is a convenient notation. The maximum ET for a given crop at a specific time is limited by the atmospheric demand for water and is frequently called potential ET (6). It can be thought of as the ET rate that would prevail if the evaporation were taking place from a wet, bare soil.

The factors sustaining evaporation from a field are heat energy input and wind. The principal energy input comes directly from the sun in the form of solar radiation. The more nearly perpendicular the angle of solar radiation, the greater the energy input. This means that the more polar latitudes have less solar input than the more equatorial ones, thus giving a latitude effect. Also, the earth's angle to the sun varies from season to season as well as the exposure of a particular field in which the crop is grown. In the northern hemisphere, fields on southerly slopes have higher energy input than fields on northerly slopes. Solar radiation can cause in excess of 0.3 inch of evaporation per day where the sun is directly overhead (6).

Another source of energy causing evaporation is heated air blowing in from hot, dry regions. This is particularly significant in the southwestern regions of the United States and the plains states. This type of energy is referred to as advected sensible heat, since it is hot air blown in from another area. In the southwestern portions of the United States the amount of energy blown into a field can be almost as great as the amount of energy coming directly from the sun. On peak loss days, up to 0.5 inch of water per day can be lost from a field. Such a day might have temperatures near 100°F and winds in excess of 20 miles per hour.

Wind serves to carry water vapor away from a field as well as blow in sensible heat. Areas which do not have large inputs of advected energy such as the southeastern regions of the United States still find that wind causes water loss owing to the movement of water vapor from the field.

This information is summarized in Figure 1. Lines A and B show the relative effects of latitude, A being the more southerly. Lines C and D show the relative effects of advected energy, C being closer to desert areas. The total ET loss at any given location would be determined by the sum of the radiant energy component plus the advected. At the peak water use period of the season, as represented by Figure 1, approximately one half inch or more could evaporate under severe conditions. A typical potential ET value in the Southwest might look like line E (16). Recall that potential ET is the upper limit of water loss for a given area.

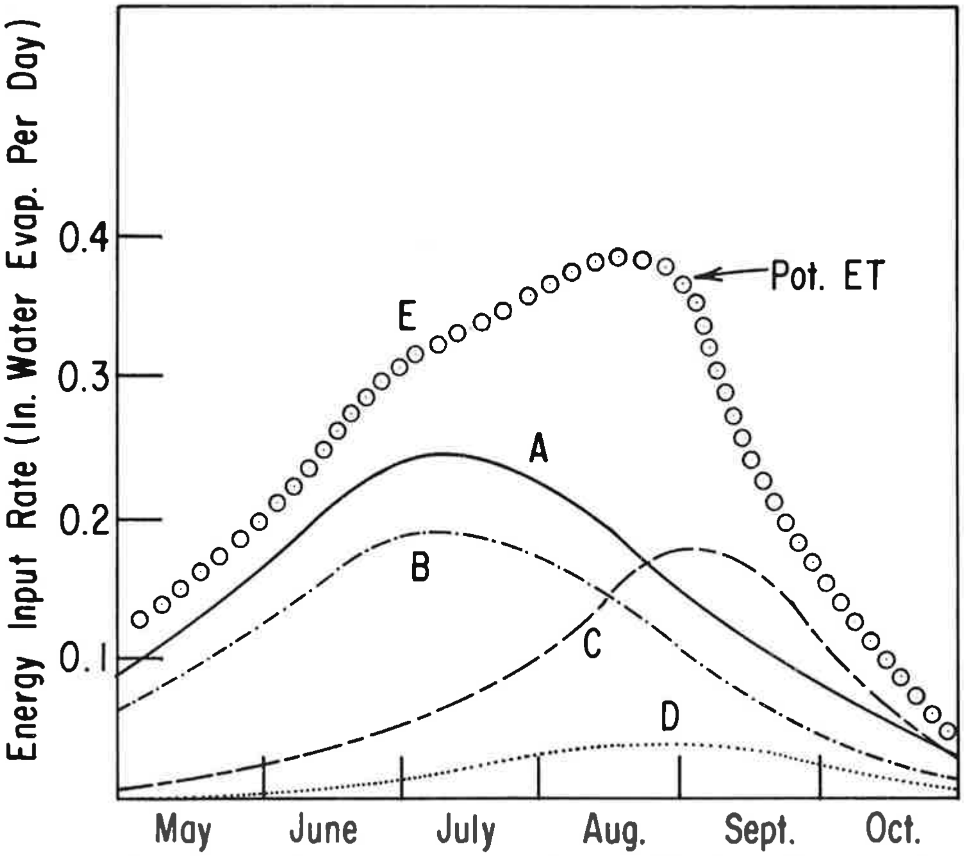

Figure 1. Annual inputs of energy causing evaporation to a field. A and B are solar input components at different latitudes; C and D are advective sensible heat input components in different regions; E and D are evapotranspiration in the southwestern United States area.

The amount of water actually lost will be equal to or less than the potential ET obviously. If the surface of the land is bare and the soil dry there will be little actual ET. If the land surface is vegetated and if the roots of the plants have access to free water below the soil surface, the ET rate may approach the potential ET value even when the soil surface is dry. Plants are very efficient at extracting water from the soil profile. Water use can be characterized throughout the growing season much as the potential ET is characterized in Figure 1.

Before looking at the seasonal use of water by the plants, consideration must be given to the characteristics which control the evaporation of water from a bare soil (4, 6). With a very wet soil surface and profile, the evaporation rate will equal the potential ET as indicated in Figure 2. Evaporation will proceed at this rate for a period of time until the soil-water content and soil-water conductivity are low. When this occurs, the evaporation rate decreases owing to the increasing difficulty to supply water to the evaporating surface. Water travels more readily through large pores in the liquid state than in the small pores and vapor state. The ET rate then drops rapidly to a very low level. The time for the evaporation rate to begin decreasing may vary from minutes to hours depending upon the texture of the soil and the distance to the water table. A sandy soil would give a trace more like the dashed line shown in the Figure 2.

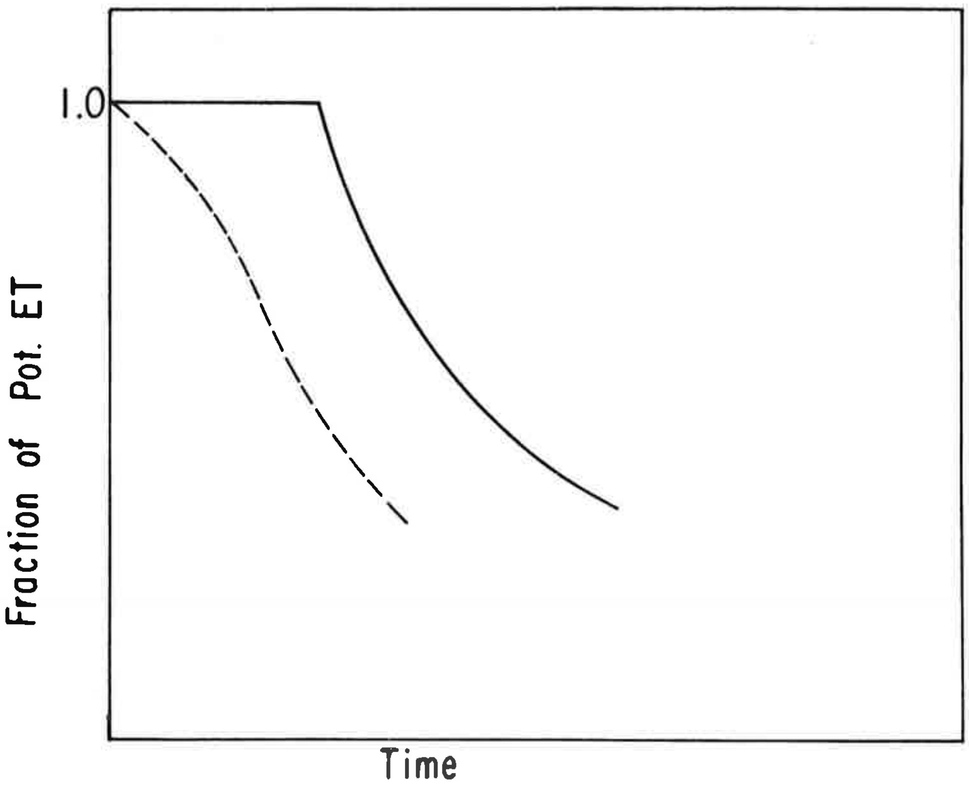

Figure 2. Evaporation rate from a bare soil. The solid line represents a fine-textured soil and the dashed line is a coarse-textured soil.

When considering a drying soil surface with small plants, one would expect a reduced rate of evaporation. The total ET rate would be rather small even if the plants had roots reaching down into the moist soil. As the plants grow and shade more of the ground they intercept more of the sun's radiation and consequently lose water at a greater rate. When plants are large and dense enough to cover the soil surface, the rate of water loss can approach that of the potential ET. ET could proceed at this rate with most of the water being supplied through the plants until the soil profile becomes depleted of water. At that time the plants would permanently wilt and ET would be very low.

To study the effect on an annual warm season crop such as peanuts, compare the factors just discussed with the information in Figures 1 and 2. For purposes of discussion, assume that the open circles in Figure 1 represent the potential ET for the region in question. The actual amount of ET will be conditioned by the environmental conditions relating to wind and energy input and by the amount of plant cover on the soil. The open circle curve is duplicated in Figure 3. In early spring, ET will be high only if frequent rains occur keeping the soil surface moist. When the soil is dry, the actual ET will be lower than the potential ET, such as shown on the graph in Figure 3. The period following plant emergence will result in only a slight increase in ET owing to the fact that the small plants do not intercept large quantity of energy. As the plants grow and intercept more energy the ET curve raises and may approach or reach the potential ET curve. From that point on, the ET may be equal to the potential ET. Depletion of soil moisture will cause the curve to drop below potential ET.

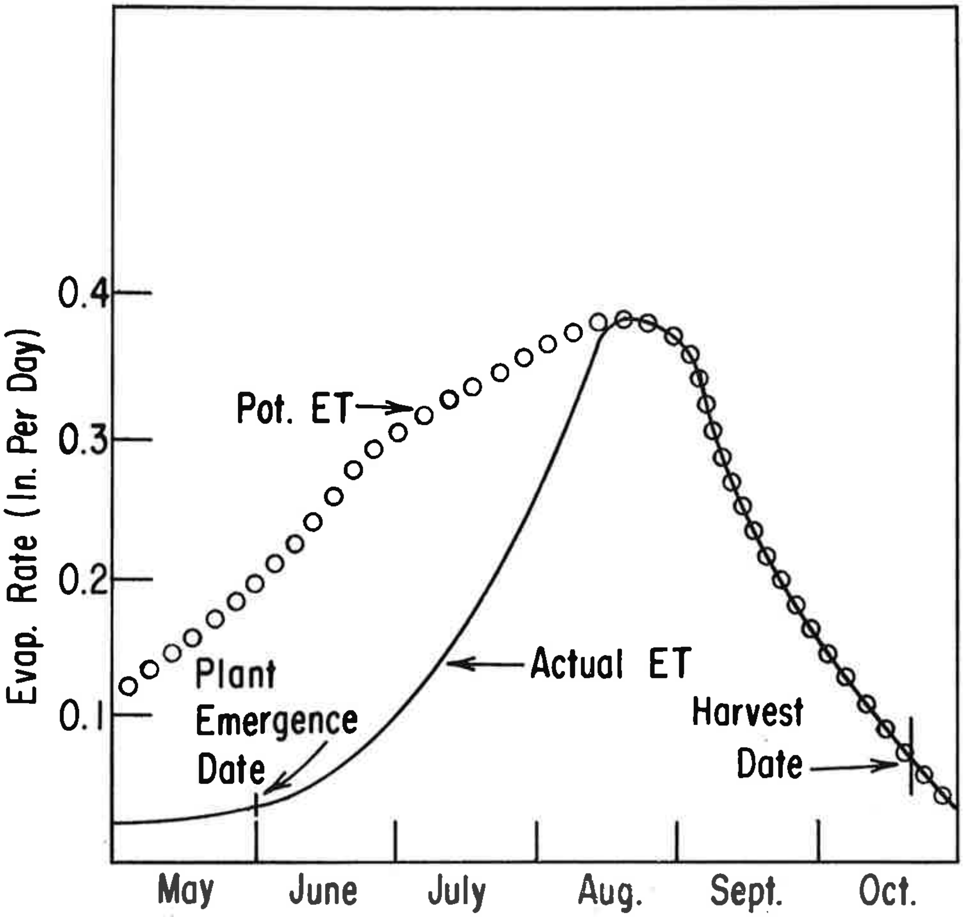

Figure 3. Comparison of a typical potential evapotranspiration and actual evapotranspiration in a southwestern United States peanut field.

The total seasonal amount of water lost will be proportional to the area under the lower curve in Figure 3. Note this is less than the potential amount of water lost. This might be typical of water use in the southwest United States peanut-growing area. Peanuts grown in the southeastern region of the United States would use water similar to the potential ET for that region.

The amount of water used by peanuts is determined by the potential ET during the crop-growing period and the degree of soil cover furnished by the plant. These factors have greater effect on the so-called crop water requirements than do the particular variety of crop being grown. Other crops planted on the same date as peanuts and having approximately the same growing season will consume about the same amount of water as peanuts.

In irrigated production, the maximum amount of water used during the season is proportional to the area under the potential ET curve between the time of plant emergence and harvest. If the grower irrigates sufficiently to maintain the soil surface at a high soil-water content, this is the amount of water that would be used and in the southwest peanut-growing area it could amount to over 40 inches of water. In actual practice it is more feasible to permit the soil to dry out at the surface between irrigations provided the plant does not suffer for water. At early stages of plant growth it may be necessary and desirable to keep the surface moist. This practice causes the ET to resemble the lower curve in Figure 3. The water evaporated from a well-watered peanut field may apporach 20 inches per season. In many parts of the irrigated southwest peanut area, much more water than this is applied and, as a result, losses by deep percolation and runoff occur.

Soil-Water Holding Capacity and Movement

The soil is generally looked upon as a reservoir for water storage. This concept, although appealing, is somewhat limited owing to the transient nature of water in the soil profile. The reservoir has holes in it in that some water may percolate down and out of the root zone owing to gravitational and other forces while simultaneously an additional amount of water is moving up and out of the profile as a result of evaporation at the soil surface. The conditions necessary for static equilibrium or no water movement in a natural-occurring field profile are unattainable under normal crop production practices. Therefore, an understanding of soil-water movement and the energy at which the water is held by the soil is essential for maximum water utilization and peanut production in irrigated regions.

The physical character of a soil has a profound influence on the rate of water movement and quantity of water retained by the soil following a water application. Properties of particular importance are porosity, soil texture and pore size distribution. However, of more fundamental importance is the tenacity with which water is held in the soil by adsorptive and capillary forces. This tenacity is measured in terms of the potential energy of the water in the soil with respect to free water. As the water

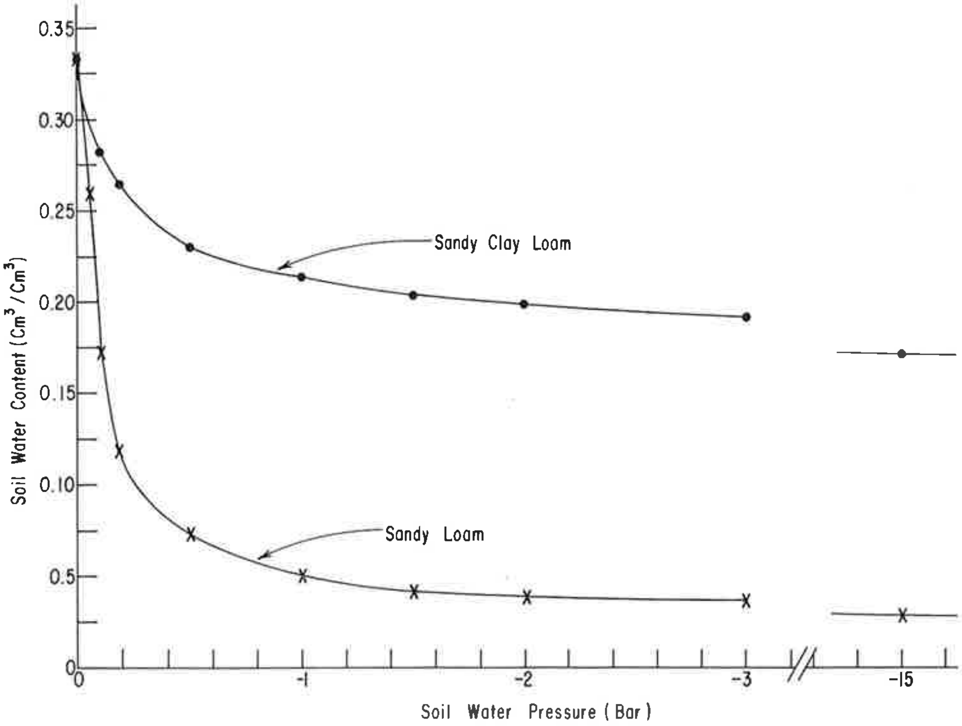

Figure 4. Soil-water content by volume versus soil-water pressure in bars for a sandy clay loam and sandy loam.

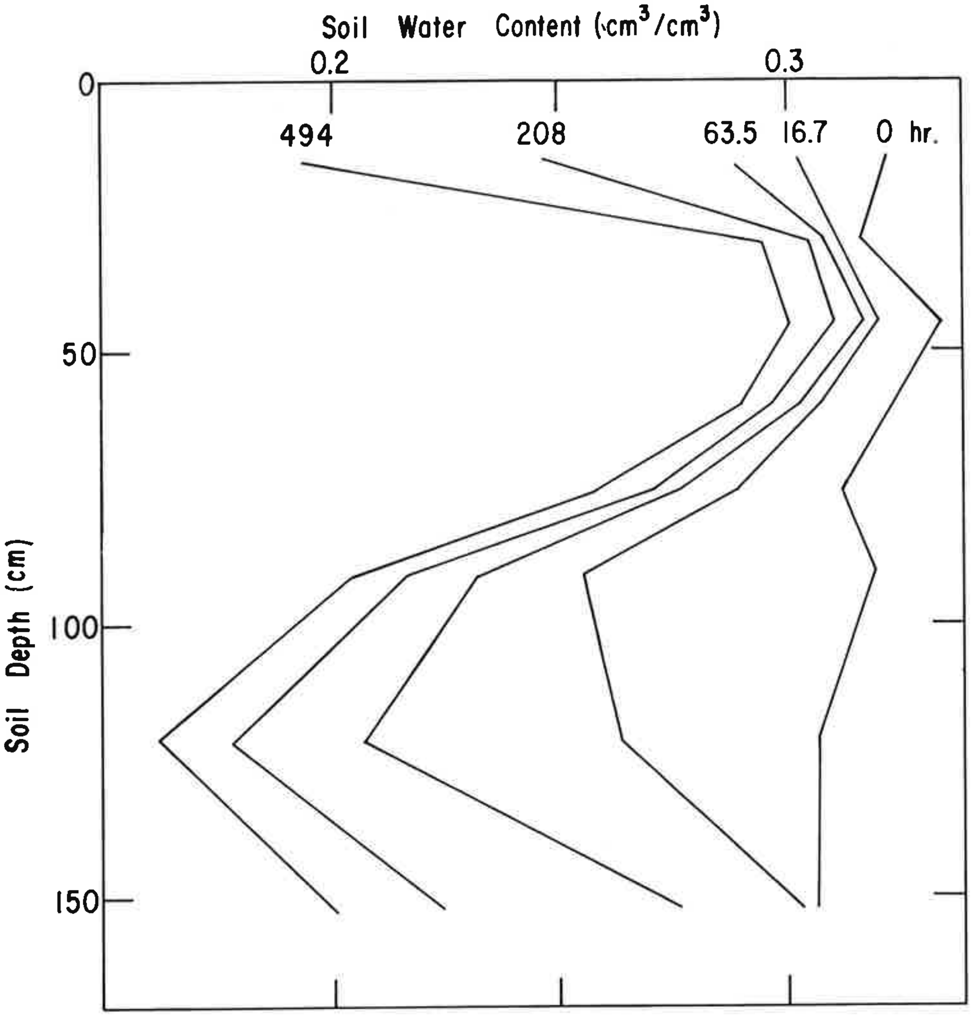

Figure 5. Soil-water content distribution within Cobb loamy sand for 0, 16.7, 63.5, 208, and 494 hours following the cessation of infiltration without evaporation from the soil surface (Davidson *et al.* 1969).

content decreases, the potential energy with which the remaining water is held decreases accordingly. Because the potential energy can be expressed as the energy of the soil water per unit volume, a pressure unit is frequently used. In unsaturated soils this quantity is negative and is often called the soil-water pressure. The terms soil-water tension and suction are commonly used to denote the negative of the soil-water pressure and thus avoid the negative sign. The tension is generally expressed in bars, atmospheres, or cm of water or mercury (hydraulic head).

The amount of water retained in a soil at a specific soil-water pressure is dependent upon the interconnection and size distribution of the pores within the soil. Soils with a high clay content frequently have a higher porosity than sandy soils, but sandy soils, in general, have a greater number of large pores than those soils composed of the smaller soil separates. The importance of pore size distribution and soil texture is clearly illustrated in Figure 4. The results in Figure 4 are of particular interest owing to the fact that the two soil textures appear in the same profile, but at different depths. The water content is expressed on a volume basis or as a fraction of the soil's bulk volume occupied by water. Note that the sandy loam loses more water than the sandy clay loam soil as the soil-water pressure is decreased (becomes more negative). This is of particular interest in that the water content at zero soil-water pressure is the same. That is to say, the saturated soil-water content of the two soil textures is the same.

Owing to the importance of pore size distribution in soil-water retention, it is imperative that only undisturbed samples of the field soil are used to establish a relationship between soil-water content and pressure. When the field structure is disturbed during sampling or in the laboratory, the pore size distribution characteristics are lost. The general result is that the soil-water content versus pressure relation shows a higher water holding ability at the greater soil-water pressures in the disturbed samples than actually exists in the field soil. This is illustrated in the work of Perrier and Evans (11) where the soil-water content pressure relation for disturbed and undisturbed soil samples are compared.

The soil-water content versus pressure relations shown in Figure 4 are smooth, continuous curves. There is no point on the curve that suggests that the water undergoes a significant change in its physical properties or state. Terms used for classifying soil water, such as gravitational, capillary and hygroscopic water are not identifiable. Also, attempts to establish the upper limit of the field soil-water content for growing plants with a specific soil-water pressure have not been successful in general.

The lower limit of available soil water is frequently called the permanent-wilting percentage. When the soil-water content drops below a certain value in a given soil, test plants growing in the soil sample become permanently wilted and do not recover when placed in a humid chamber overnight (17). Richards and Weaver (12) found the permanent wilting percentage for a wide variety of soils to correspond to a soil-water pressure of —15 bars (—15,000 cm of water). The usefulness and significance of the —15-bar soil-water content depends directly upon whether or not it corresponds to the permanent wilting soil-water content value observed under natural field conditions. Also, it should be noted (Figure 4) that a small change in soil-water content in the vicinity of —15 bars of soil-water pressure results in a large change in the potential energy of the water in the soil.

The upper limit of the field soil-water content for growing crops is generally referred to as "field capacity" (18). This value is intended to represent a specific soil-water content or pressure that develops two to four days after a rain or irrigation. For some medium-textured soils the —1/3-bar and for the more sandy soils the —1/10-bar soil-water pressure has been associated with field capacity. Figure 5 shows the soil-water content distribution in a field soil profile at various times following the cessation of irrigation in the absence of evaporation. The water content changes with time are the result of downward drainage owing to the gravitational force field. Note that no constant soil-water content develops after a period of time and that some depths are losing greater quantities of water than others over the same time interval. The sandy clay loam and sandy loam soils in Figure 4 are from the 45 and 122 cm depths, respectively.

Figure 6 presents the soil-water pressure distribution in the Cobb loamy sand with time following the cessation of irrigation. Figures 5 and 6 are for the same drainage period. The soil-water pressure, regardless of soil texture, never decreases below —110 cm of water at any point in the profile after 494 hours of drainage, and at no time

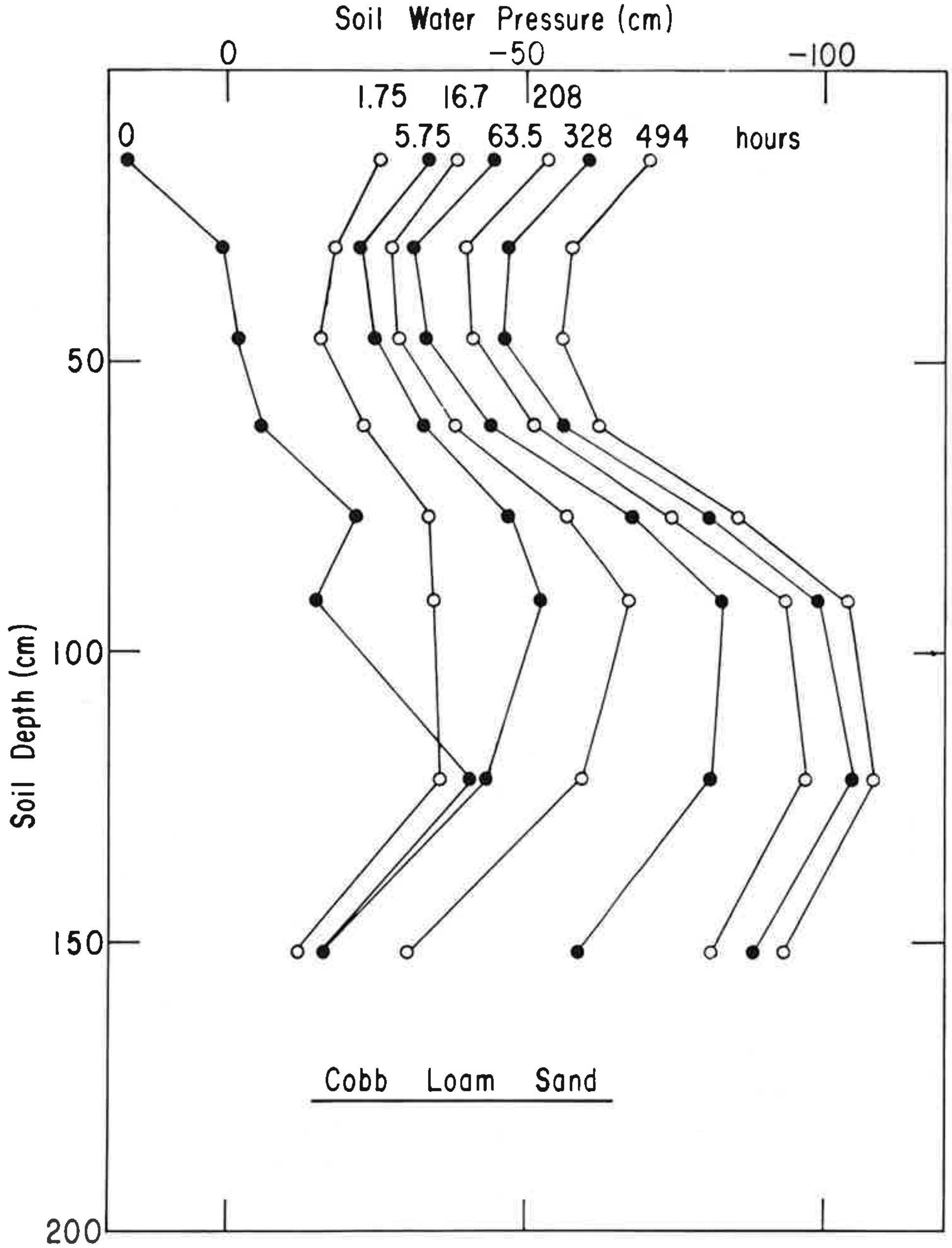

Figure 6. Soil-water pressure distribution with Cobb loamy sand during a 494-hour drainage period following the cessation in infiltration. (Davidson *et al.* 1969).

approaches the —1/3-bar soil-water pressure value frequently suggested for field capacity. Similar results with other soils were reported by Davidson *et al.* (3). Also, the time required to approach this value far exceeds the two to four day drainage period suggested earlier. Therefore, it would appear that in order to establish an upper limit soil-water content for plant growth, soil samples taken a few days after the cessation of infiltration would be beneficial and useful for determining the available soil-water content range.

The large change in soil-water content below the 75 cm soil depth in Figure 5 is unnecessary. The loss of this amount of water by deep percolation can be avoided by not adding sufficient irrigation water to wet the soil at these depths to their maximum water content. The measurement and use of the soil water flux or rate of water movement between the 130-150 cm soil depth would assist in minimizing the losses owing to deep percolation. The objective would be to hold the total soil-water potential energy at the two soil depths at about the same value for a downward soil-water flux of less than 0.5 mm/day.

In an irrigated region some drainage is necessary in order to prevent salt accumulation within the plant root zone. The amount of drainage required will depend upon the quality of the irrigation water and the sensitivity of peanuts to salt. The grower must strive to maintain a salt balance within the soil profile over an extended period of time. Because plant nutrients and pesticides also move, careful planning should be exercised when maximum drainage is allowed to occur.

Liquid flow is the primary mechanism by which water is relocated within the root zone. In the soil, water moves primarily in response to gravity and differences in soil-water pressure. These may not act in the same direction so the total potential energy (gravity plus water potential) must be determined for the water at each soil depth. For one dimensional (perpendicular to the soil surface) flow the following relation is used:

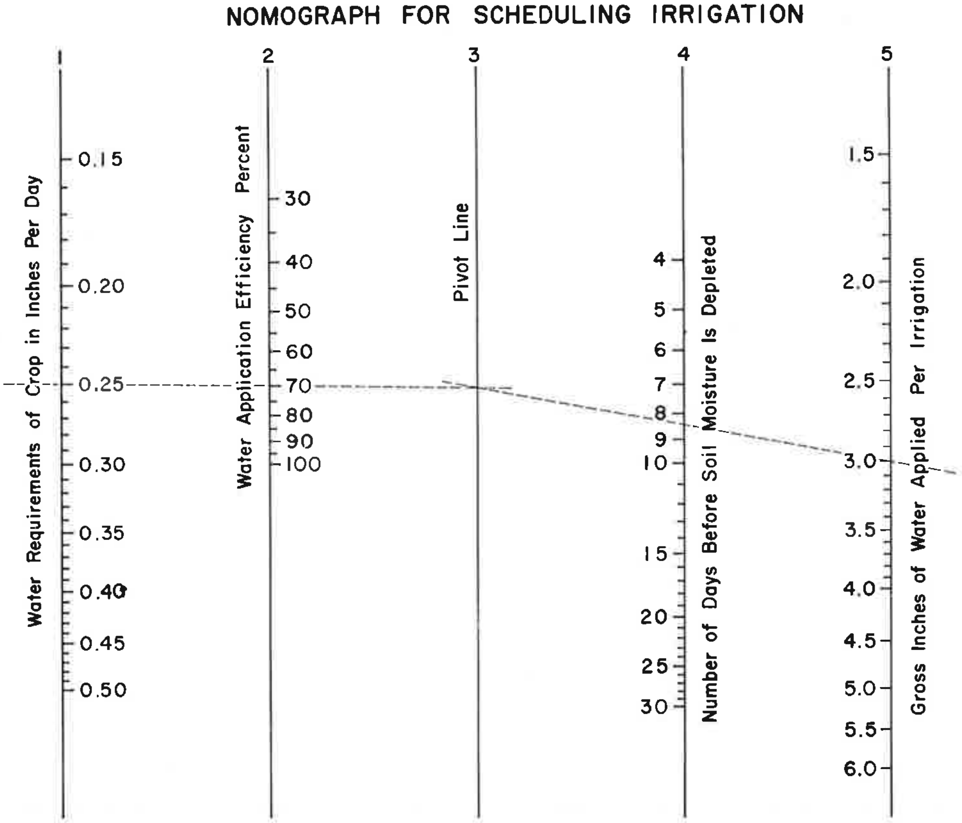

Figure 7. Nomograph for scheduling irrigations.

$$v = -K \frac{\Delta\Psi}{\Delta x} \quad (1)$$

where v is the volume of water crossing a unit area perpendicular to the flow in unit time, $\Delta\Psi$ is the difference in total soil water potential across the distance Δx, and K is the capillary conductivity. Water always moves from regions of high to regions of low total soil-water potential. This must be kept in mind and not the difference in soil-water content.

The capillary conductivity decreases with each reduction of the soil-water content. This is illustrated in Figure 6 where the soil-water content change decreases with time at each depth. This results from the decrease in capillary conductivity. Thus, the relation between water content and conductivity must be established before equation 1 can be used to describe unsaturated water flow. Once this is determined for each depth interval, the quantity of water lost owing to deep percolation and evaporation can be calculated and these measurements used to increase the efficient use of irrigation water. The use of tensiometers in the high soil-water pressure (0 to —800 cm of water) range has proven satisfactory for measuring the soil-water pressure.

Irrigation Frequency and Rate of Application

Irrigation scheduling is important in a peanut-growing area where wide differences exist between irrigated and dryland peanut production. Matlock *et al.* (9) found in their 1959 studies that four inches of irrigation water in August yielded 1000 pounds per acre more peanuts than treatments receiving no water. This is of particular interest in that 1959 was a wet year, since during the growing season 39 inches fell. In general, research in the southwestern portion of the United States has shown that for sandy soils the optimum irrigation program in peanuts appears to be two to three inches of water when this amount has been removed from the top 2.5 foot of soil. This means approximately a seven- to ten-day irrigation interval. Watering more frequently will maintain the soil wetter on the average, but a point is reached where returns are lowered. One Oklahoma study (9) shows that excessive amounts of water near harvest give an off flavor to the resultant peanut butter owing to the high number of immature nuts.

The nomograph in Figure 7 can be used to determine irrigation frequencies when daily water requirement for peanuts (ET), water application efficiency and desired gross application are known. For example: How often must a field be irrigated when the water requirements for peanuts is 0.25 inch per day, 70% of the water applied to the field is effectively stored in the crop root zone (water application efficiency), and a gross water application of 2.75 inches is desired.

Using a straight edge and the nomograph in Figure 7, draw a line through 0.25 on scale 1 and 70 on scale 2 such that it intersects scale 3 (pivot line). Now, connect 2.75 on scale 5 and the point of intersection located on scale 3. The value on scale 4 (7.6) represents the number of days between irrigations. When the evapotranspiration rate is 0.25 inches per day and the water application efficiency is 70%, a gross application of 2.75 inches of water will last about 7½ days. The nomograph can be used to determine how much water must be applied to carry a crop a given number of days; however, bear in mind that an application of more water does not result in more water being stored in the root zone of the peanut.

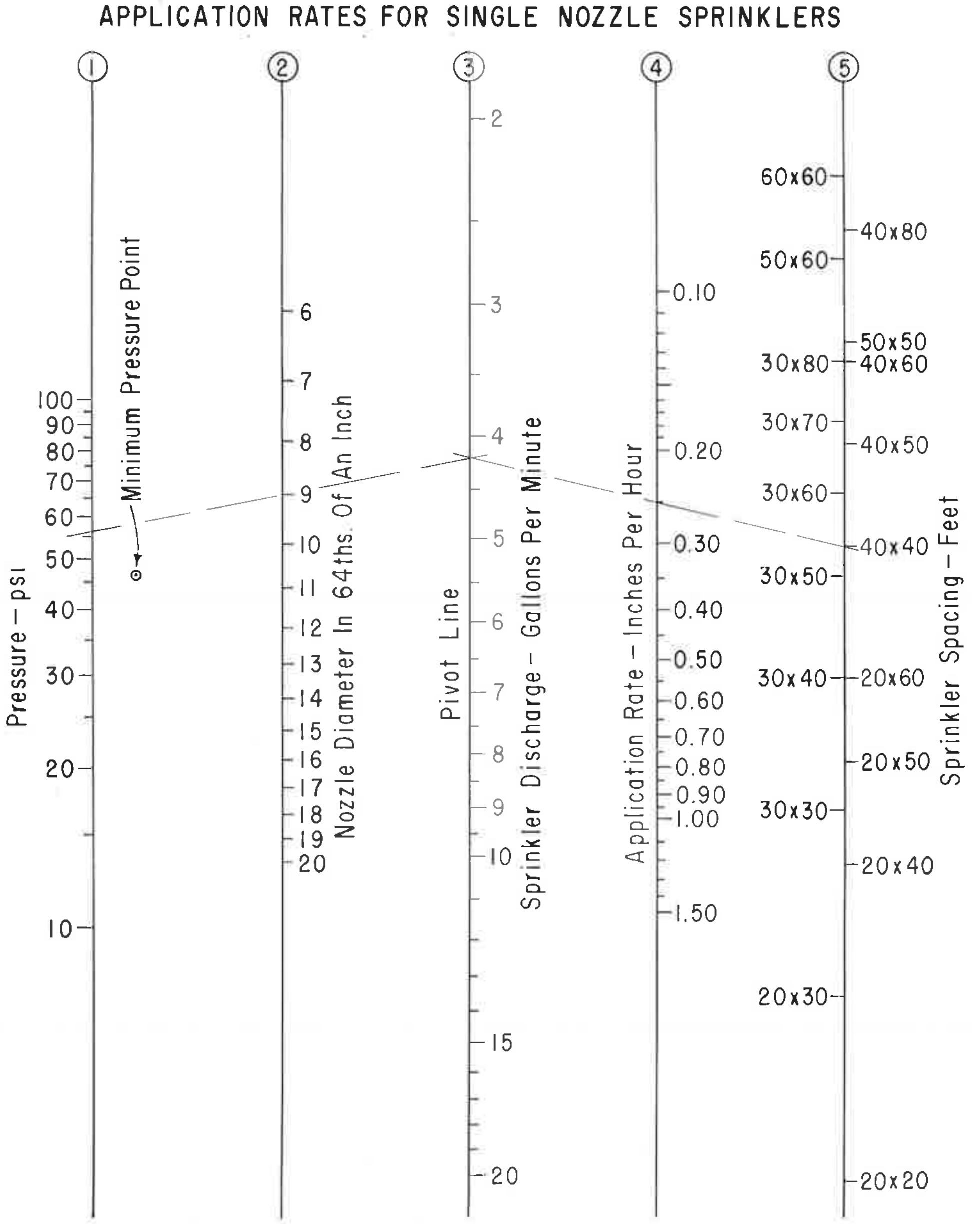

Figure 8. Nomograph for application rates for single nozzle sprinklers.

The irrigation method commonly used for sandy soils is sprinklers. A gross application of 2.75 inches will require nozzles which discharge 0.25 inch/hour for 11 hours, a convenient setting time interval. The application rate of a sprinkler irrigation system depends upon the gallons per minute discharged by each sprinkler head, the spacing of sprinkler heads along the lateral line and the distance the lateral line is moved between settings. Individual sprinkler discharges are determined by the combination of nozzle(s) diameter and nozzle pressure. A large diameter nozzle operating at a very low pressure may put out the same volume of water as either a small nozzle operating at high pressure or an intermediate size nozzle and pressure; however, there will be a considerable difference in the resulting distribution patterns. The final selection of nozzle size and pressure is a compromise between the poor distribution patterns produced by lower pressures and the high pumping costs associated with large pressures. The operating pressure selected should be the minimum that will produce an acceptable uniformity of application.

In the preceding example, it was determined that a sprinkler discharging 0.25 inch per hour would apply 2.75 inches of water in 11 hours. The nomograph in Figure 8 can be used to determine what combination of sprinkler capacity in gallons per minute and sprinkler spacing will provide desired rates of application. For example, using a sprinkler spacing of 40 by 40 feet, what sprinkler capacity will provide an application rate of 0.25 inch per hour? Using the nomograph in Figure 8, enter the desired spacing on scale 5 and connect the application rate (0.25in/hr) such that the line intercepts scale 3. Scale 3 indicates that 4.2 gallons per minute per sprinkler are required for this application rate. Once the required sprinkler discharge has been determined it is possible to select the combination of nozzle size and pressure by drawing a line through the point representing the desired discharge capacity on scale 3 and possible nozzle diameters on scale 2. The approximate pressure required will be indicated by the intersection with scale 1. Lines drawn on the nomograph indicate that an 8/64 inch diameter nozzle operating at 85 pounds per square inch pressure (psi), a 9/64 inch nozzle at 54 psi, and a 10/64 inch nozzle at 36 psi will all deliver 4.2 gpm. Note the "minimum pressure point" located to the right of scale 1. The nozzle diameter to select is the one whose line connecting it and its required pressure is the line just above this point. The 85 psi required with the 8/64 inch nozzle is excessive. The line connecting 10/64 inch diameter and 36 psi passes below the minimum pressure point. Therefore, we would select the 9/64 inch nozzle and 54 psi. Note that this nomograph is only for single nozzle sprinklers.

Early in the season the surface soil condition is obviously most important to crop growth. Water at the two-foot depth will do the plant little good if the surface is dry and the roots have penetrated only six inches. In such cases it may be necessary to apply a light irrigation to correct such early season conditions. It is also possible that a full irrigation late in the season, when the atmospheric water demand is low and harvest is imminent, could be detrimental to the crop. Irrigations after the period when the potential ET is markedly diminished from the peak should be applied with caution. A wet soil can cause severe problems at harvest.

Crop Response To Irrigation

Response factors of particular interest to the producer are those of yield and quality. These are the factors which determine the grower's financial return. There is no doubt of the profitability of irrigation in the areas where it is practiced. When a farmer makes the investment required for irrigation, it is essential that he modify all production practices to conform to the irrigation system. In many regions it is not uncommon to regard irrigation water as providing supplemental water to natural precipitation. This attitude is proper in regions of extremely limited water supply. In other areas, the peanut grower will be rewarded if he regards irrigation as the primary supply of water and rainfall as supplemental. In irrigated production, factors of variety, row spacing, plant spacing in the rows, fertilizer practices, and harvesting must be prescribed independently of dryland practices in the same region.

Crop response is conditioned by the particular region in which irrigation is practiced. Response appears to vary with the type of peanut grown and this varies across regions. For example Spanish bunch-type peanuts respond differently than runner types or intermediate types. Spanish bunch respond well to comparatively short growing seasons and are generally favored in the southwest peanut-growing area of the United States where irrigation is a common practice. The southeastern United States with its longer growing season and higher natural rainfall tends to favor the runner or intermediate types. Crop response, therefore, will differ between these areas.

Some detailed studies on peanut responses to irrigation in the southwest peanut-growing area have been made (9). Table 1 gives a comparison between irrigated and nonirrigated conditions which appear to be typical for the southwest (only two years are shown here). The effects of row spacing and plant spacing in the row were also studied. Note that increasing the plant population in the row from two plants per foot to eight plants per foot seldom increased the yield more than 200 pounds per acre. However, decreasing the row spacing from 40 to 15 inches provided increases of about 1000 pounds per acre in yield. Note also that an increase is evident in the nonirrigated part of the study. These results were obtained with Spanish bunch peanuts. In these studies the machinery problems were circumvented by hand harvesting the material, but the data do show the tendency for the Spanish peanuts to favor narrow-row spacings.

Studies in North Carolina (2) have shown intermediate-type peanuts to yield substantially higher when row-spacings were decreased from 36 inches. However, other independent studies seem to indicate that no benefit was obtained from reducing the row-spacings when some of the plants involved were runner type and some were intermediate. If yields are less than 3500 pounds per acre, the narrower spacing seems to increase yield. However, there is no doubt that several cultural and climatic factors are involved in ways that at present are not fully understood.

In extending the practices shown in Table 1 to field production, the spacings have to be modified to be compatible with existing machinery requirements. In fact, it is likely that cultural techniques will always be a compromise between optimum plant cultural characteristics and optimum management and machinery characteristics. For these reasons it is conceivable that the peanut grower may never be able to take full advantage of the narrow-row spacing indicated in Table 1.

Table 2 shows some information on the quality and value of peanuts as influenced by irrigation and row spacing. The results were taken from a 1967 study in Oklahoma (author's unpublished data). The yields expressed are lower than would be expected for most years, but the direction of differences is regarded as being valid and in general represents the resarch experience of several years. The peanuts studied were grown on fairly sandy soils and, in 1967, irrigations were confined to two inches per application at ten-day intervals. Note that the yield under narrow-row spacing appears to be greatly enhanced and the quality in general does not suffer due to the narrow-row spacing.

The 1967 growing season was characterized by a dry August and a wet September. This resulted in an increase in yield for the dryland case. The maturity was also affected. The dryland plants set late fruit as indicated by maturity being similar to irrigated and the low SMK. In spite of the lower maturity for narrow-row spacings, the net value of the crop was greatly increased by going from wide rows to narrow rows—nearly $100 per acre for the irrigated treatment. The fact that the narrow rows tended to show a low maturity could be handled by the grower by delaying harvest until the desired maturity prevailed. In this particular study all plants were harvested on the same date. Data obtained by J. W. Matlock (8) showed that plant spacing in the row and row width had very little effect on quality factors.

The potential for a greater return per acre with narrow-row spacing seems to be mainly a characteristic of Spanish peanuts produced in the southwest peanut area. There is little evidence for marked enhancement by narrow rows in other parts of the United States. Peanut quality does not appear to be affected as long as row spacings remain between 10 and 40 inches and plant spacing in the row is between two and eight plants per foot. Studies of water requirement as affected by row spacing show that the narrow rows require no more water than the wide rows.

It is not surprising that bunch peanuts tolerate and thrive under narrow spacings better than the runner types in that during the growing season the runner types cover most of the ground; this is true even for the wide-row spacings. This ground coverage makes better use of the sunlight and soil surface. The bunch types may fail to close the spacing between rows and thereby waste the sunlight and soil area for the wide configurations.

Quality of Irrigation Water

Two factors that must be considered in regard to irrigation planning are the quantity and the quality of water available. Either the quantity or quality of a new water source can limit its feasibility for irrigation purposes; therefore, both factors must be suitable.

Before any irrigation system can be designed, it is necessary to know the exact amount of water available. Wells, streams and even lakes and ponds may have varying quantities of water throughout the irrigation season. It is possible that well yields and stream flows may be lowest during periods of maximum irrigation water demands. Ponds and lakes are dependent upon rainfall and runoff for resupply and periods of below normal rainfall preceding the irrigation season can reduce the available water supply considerably. The quantity of water available influences the selection of the irrigation application method. Small water supplies are generally not suited to flood or gravity irrigation methods. Likewise, large water supplies are generally not ideally suited to sprinkler irrigation methods.

Irrigation water quality is determined by both the chemical composition and the concentration of dissolved salts in the water. The chemical composition and concentration of dissolved salts in water depends upon the solubility and chemical makeup of the minerals, soils, and rocks with which the water has come in contact as well as the length of time during which contact has occurred. Surface water supplies from ponds, lakes and rivers may contain dissolved salts from mines, oil fields, industrial and municipal wastes as well as the naturally occurring dissolved salts. When present in sufficient quantities, dissolved salts may have a detrimental effect on plants and/or soil.

Salts dissolved in water exist as individual constituents (ions) making up the salts rather than in the form of salt molecules. Substances normally determined analytically in irrigation water include the cations (positively charged ions) calcium, magnesium, and sodium; and the anions (negatively charged ions) chloride, sulfate, carbonate and bicarbonate. Boron concentration is also frequently of interest. Salts are left in the soil as waters evaporate from the soil surface. Usually the highest salt concentration is in the vicinity of the soil surface. Rain or irrigation water may redissolve these salts and move them downward through the soil profile leaving the soil surface relatively salt-free for a short period of time. However, further soil surface evaporation will cause salt accumulation to occur at the soil surface unless sufficient rain or irrigation water is received to leach the salts deep enough to prevent their return.

The use of soil water by plants contributes to the accumulation of salts in the soil in that the plant selects only those ions from the soil needed for growth. Ions such as sodium, sulfates, and chloride are taken up by the plant in small quantities and thus the major portion of them remain in the soil.

Research indicates the peanut is relatively sensitive to soil salinity. Using artificially salinized plots, Shalhevet, *et al.* (15) observed 50 percent nut yield when a soil salinity of 4,700 micromhos/centimeter was present. A maximum yield was obtained at salinity level of 3,200 micromhos/centimeter or less while a salinity level of about 6,500 micromhos/centimeter resulted in no peanut yield. The effect of salinity on yield was due to a reduction of both nut size and the number of pods per hill. Results of the study also indicate that for leaching to be effective, salts must be removed beyond the full rooting depth in the soil profile and not just from the main root zone.

There are several criteria for classifying irrigation waters. Two of the most widely used and important determinations are an estimate of total salt content, as measured by electrical conductivity, and the percent sodium in the water.

Figure 9 is a diagram that can be used to classify irrigation waters on the basis of their percent sodium and electrical conductivity (10). To establish the quality of an irrigation water, determine the percent sodium and electrical conductivity and locate this point on the diagram. The lines that curve down and across the chart in Figure 9 separating the water classes, represent calculated Sodium Adsorption Ratio (SAR) values. The SAR gives the approximate percentage of exchangeable sodium the soil will contain when it is in equilibrium with the irrigation water. The SAR values can be calculated with the following equation using the equivalents per million (milliequivalents per liter) of Ca, Mg and Na secured from an analysis of a water:

$$\text{SAR} = \frac{\text{Na}^{+}}{\sqrt{\dfrac{\text{Ca}^{++} + \text{Mg}^{++}}{2}}}$$

A soil containing more than 15 percent exchangeable sodium is considered an alkali soil.

The chart in Figure 9 is used as the primary basis for classifying irrigation waters; however, other factors also affect the suitability of water. In some regions boron or other elements may be present in sufficient amounts to be toxic to plants. Also, water in some areas may contain high concentrations of bicarbonate ions. When this occurs there is a tendency for the calcium and magnesium to precipitate as carbonates and thus increase the relative proportion of sodium ions present in the soil solution.

If a water contains a large concentration of gypsum ($CaSO_4 \cdot 2H_2O$), a higher quantity of total salts can be tolerated in the water. Gypsum in the water tends to offset some of the detrimental effects of sodium. Irrigation waters which contain large quantities of sodium but have a low total salt content often may be improved

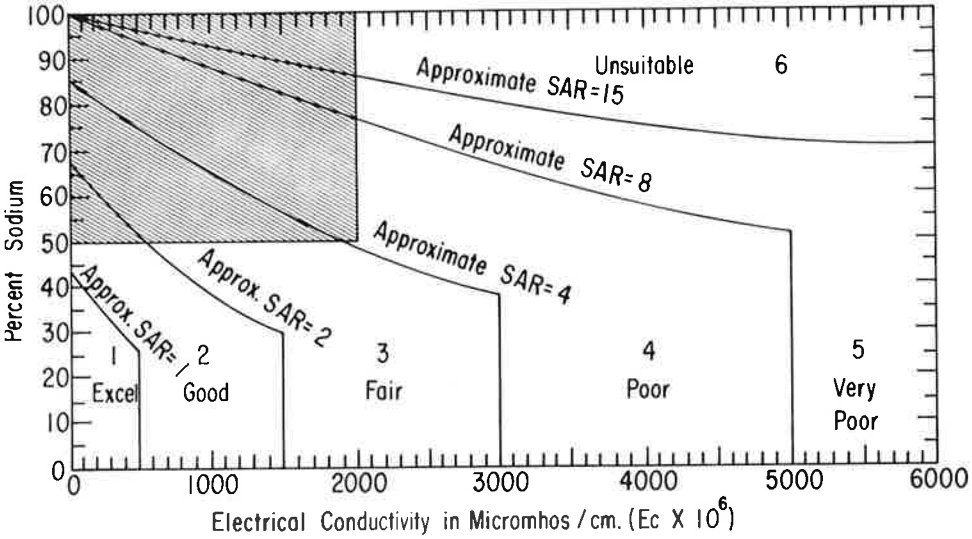

Figure 9. Diagram for classifying irrigation water.

in quality by the addition of gypsum to the soil. Also, methods are available for metering gypsum into the irrigation water.

Gypsum may be used to offset possible detrimental effects of high sodium content in Class 4, 5, and 6 waters if the electrical conductivity is below about 1500 to 2000 micromhos per cm. The sodium content should be about 50 percent or greater before considering the use of gypsum. The cross-hatched area in Figure 9 indicates the range of water quality which may be improved by the addition of gypsum. A further discussion of irrigation water quality is available in U. S. Department of Agriculture Handbook No. 60 (13).

Irrigation Methods

When selecting a method of irrigation, the factors tending to favor a sprinkler system are sandy soils, rolling topography, limited water supplies and high cash value crop. In most areas where peanuts are irrigated, all four of these factors apply and as a result most irrigated peanuts are grown under sprinkler systems.

The soils on which most peanuts are grown, together with their characteristic rooting zone, mean that small frequent applications of water will be used. Small but frequent applications result in more water being lost by evaporation and as a result a lower water efficiency. Also, small frequent applications result in higher labor costs when hand moved sprinkler systems are employed.

The limited water supply in many areas may restrict the acreage which can be irrigated. With a limited water supply, the system must be operated at a maximum percent of the available operating time to cover maximum number of acres adequately. With the recent advent of self-propelled or power moved sprinker systems, a means is available for operating the maximum number of available hours and at a lower labor requirement than is usually associated with irrigated peanuts. The cost of power moved or automated systems is high, but the conditions which prevail in many peanut irrigation locations support their use.

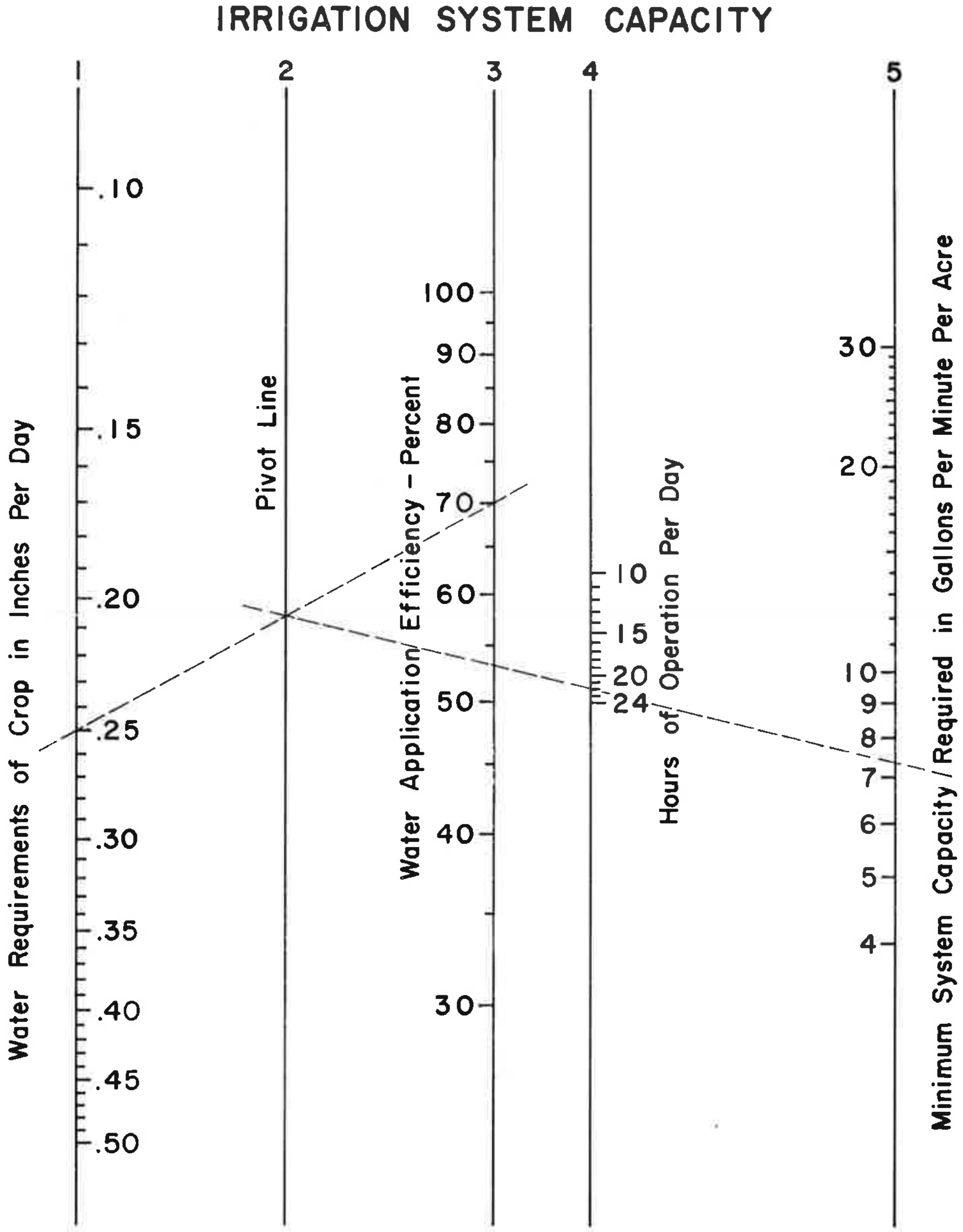

Figure 10. Nomograph for irrigation system capacity.

For example, if a system operating 22 hours per day will adequately irrigate 40 acres, a system operating 24 hours per day will adequately irrigate 43.6 acres. The system will justify an additional investment of about $3600 for each $100 per acre per year of net return, based only on the increased acreage. A $300 net per acre return would justify an additional investment of about $10,800 with no allowance considered for reduced labor expenses.

The selection of any system requires that the capacity be adequate to meet the needs of the crop during the period of highest water use. The lower cost of an in-adequate system is false economy. The required system capacity is dictated by the ET (daily crop water requirement), water application efficiency, and hours of system operation per day. System capacity in terms of gallons per minute per acre can be determined by the following equation:

$$\text{System capacity} = \frac{\text{CWR x } 27{,}154}{\text{WAE x HPD}}$$

where CWR is crop requirement (inches/day), 27,154 is gallons per acre-inch, WAE is water application efficiency (decimal fraction) and HPD is time of operation (hr/day).

For example: crop water requirement = 0.25 inch/day
water application efficiency = 70%
hours of operation per day = 22

$$\text{system capacity} = \frac{.25 \text{ x } 27{,}154}{.70 \text{ x } 22 \text{ x } 60} = 7.34 \text{ gallons per minute per acre}$$

It is also possible to solve system capacity problems using the nomograph in Figure 10. Lines drawn on the nomograph show the solution for the above example.

The water supply required will be the product of the system capacity expressed in gallons per minute per acre times the number of acres to be irrigated. In the above example it would require about 440 gpm to adequately irrigate 60 acres of peanuts when the evapotranspiration rate was 0.25 inches per day, the application efficiency was 0.70 and the system was operated 22 hours per day. Changing any one of these conditions will change the required system capacity.

Table 3 presents pertinent characteristics associated with various types of sprinkler irrigation equipment. Soil permeability, acreage, available labor and financial resources all affect final selection. Several of the self-propelled or water-propelled traveling sprinklers as well as the large capacity volume sprinklers require pressures in the range of 75 to 100 pounds per square inch (psi). A certain amount of pressure is necessary to properly operate any sprinkler system; however, it should be kept in mind that producing pressure costs money. For example, assume a grower can purchase either a self-propelled high capacity sprinkler or a side-roll power wheel move lateral system that will do an equally good job. The large capacity sprinkler requires 85 psi while the side-roll system requires 55 psi. What does it cost to create this additional 30 psi of pressure? One pound per square inch of pressure is the same as lifting the water a distance of 2.31 feet. An acre-foot of water weighs 1,357 tons or 2,714,000 pounds. One horsepower-hour is the equivalent of 1,980,000 foot-pounds per hour. Therefore, it requires 1.37 horsepower-hours to lift an acre-foot of water a distance of one foot at 100 percent pump efficiency. One psi equals 2.31 feet; thus, to pump one acre-foot of water against one psi with a 100 percent efficient pump will require 3.16 horsepower-hours. Using a pump efficiency of 65 percent, it would take 4.86 horsepower-hours to pump this acre-foot of water against one psi of pressure. If each horsepower-hour costs 1.75¢, each psi costs 8.5¢ (4.86 hp-hr x 1.75¢ = 8.5¢, 8.5¢ x 30 psi = $2.55). The additional psi pressure then costs an extra $2.55 for each acre-foot of water pumped.

Variation in pumping costs due to differences in required pressures should not be the sole reason for accepting or rejecting any sprinkler system. It may be that differences in initial cost or labor saved may more than offset the difference in cost of pumping.

More detailed information relative to the application and design of sprinkler irrigation systems can be obtained by referring to "Sprinkler Irrigation" (19). Detailed information on water well drilling, design, and development can be obtained from "Groundwater and Wells" (1).

Table 1. Yield as affected by row spacing and plant spacing in row.

	Row Spacing inches	Plants per foot of row	Yield (pounds) clean, dried nuts	
			1960	1961
Irrigated	15	2	4500	3000
	15	8	3200	2800
	40	2	2700	2000
	40	8	3100	1800
Non-Irrigated	15	2	1400	2000
	15	8	1500	2200
	40	2	1000	1300
	40	8	1200	1500

Table 2. Quality and value of peanuts as influenced by irrigation and population.

Treatment	Row Spacing	Rows Per 72″ Bed	Thousand Plants Per Acre	Fruit % Mature	%[1] SMK	%[2] OK	Yield (lbs/A)	Gross Value ($/A)	Net Value* (Gross-seed Cost) ($/A)
Dryland	6″	11	189	39	55	11	2230	197	142
	12″	5	105	49	56	9	1490	131	101
	24″	3	52	68	59	10	1100	106	91
	36″	2	39	83	62	8	990	91	80
Irrigated	6″	11	189	42	73	3	3210	369	314
	12″	5	83	49	73	3	2530	294	271
	24″	3	48	70	74	2	2080	242	228
	36″	2	33	56	76	1	1800	213	203

*Certified Seed Cost was 30¢/lb.
Seed Weight was 1100 seeds/lbs.
Number of seed was based on number of plants harvested.

[1] Sound Mature Kernels.

[2] Other Kernels.

Table 3. Comparison of sprinkler irrigation systems.

Type Irrigation System	Relative Investment Cost[1]	Relative Labor Required (%)[2]	Soil Limitations	Desirable Acreage	Pressure Required (psi)
Small to medium sprinklers-hand move	1.0	100	Adaptable to a wide range of soil types.	1 to 80	45-60
Giant sprinklers and lateral, hand-moved with wagon	1.2	75	Best suited for more permeable soils.	40 and up	75-90
Tractor-tow lateral	1.5	40	Adaptable to wide range of soil types.	20 and up	45-60
Traveling sprinkler unit self-propelled	1.7	30	Best suited to highly and permeable soils.	1 to 80+ per unit	75-90
Rotating boom winch-propelled	1.8	30	Best suited for more permeable soils.	20 to 80+ per unit	70-80
Center-pivot circular self-propelled	1.8	15	40 acre size adapted to a wide range of soil types. Larger sized best adapted for more permeable soils. Max. slopes 5-10%; requires square fields with no obstructions.	160 best but down to 40	75-90
Side roll power wheel move lateral	1.9	40	Adapted to a wide range of soil types.	20 to 40	45-60
Solid set	4.0 and up	20	Adaptable to a wide range of soil types.	1 and up	45-60

[1] Relative initial investment cost per acre for complete system including well, pump, power unit and sprinkler system for an optimum size acreage for each method compared to a hand move system.

[2] Relative overall labor required per acre per season to set up and operate the irrigation system.

LITERATURE CITED

1. Anonymous. Ground Water and Wells. Edward E. Johnson, Inc., Saint Paul, Minnesota.
2. Cox, F. R. and P. H. Reid. 1965. Interaction of Plant Population Factors and Level of Production on the Yield and Grade of Peanuts. *Agronomy Journal* 57(5):455-457.
3. Davidson, J. M., L. R. Stone, D. R. Nielsen and M. E. Larue. 1969. Field Measurement and Use of Soil-Water Properties. *Water Resources Research, December.* 5(6):1312-1321.
4. Evans, C. E. and E. R. Lemon. 1957. Conserving Soil Moisture. *Soil,* the 1957 Yearbook of Agriculture. U. S. Department of Agriculture, 340-359.
5. Goldberg, S. D., B. Gornat and D. Sadan. 1967. Relation Between Water Consumption of Peanuts and Class A Pan Evaporation During the Growing Season. *Soil Science* 104(4):-289-296.
6. Lemon, E. R. 1963. Energy and Water Balance of Plant Communities. *Environmental Control of Plant Growth.* Academic Press, N. Y., 1963. Chapter 5.
7. Mantell, A. and E. Goldin. 1964. The Influence of Irrigation Frequency and Intensity on the Yield and Quality of Peanuts (*Arachis hypogaea*). *Israel Journal of Agricultural Research* 14(4):203-210.
8. Matlock, J. W. 1961. Effect of Plant Population, Planting Date and Irrigation on the Yield and Grade of Two Peanut Varieties. Unpublished M. S. Thesis. Oklahoma State University Library, Stillwater, Oklahoma.
9. Matlock, R. S., J. E. Garton and J. F. Stone. 1961. Peanut Irrigation Studies in Oklahoma, 1956-1959. Oklahoma Agricultural Experiment Station, Bulletin B-580.
10. Palmer, P. G., R. B. Duffin and W. E. Baumann. 1968. Classification of Irrigation Water. Oklahoma State University Extension Fact Sheet No. 2401.
11. Perrier, E. R. and D. D. Evans. 1961. Soil Moisture Evaluation by Tensiometers. *Soil Sci. Soc. Amer. Proc.* 25:173-175.
12. Richards, L. A. and L. R. Weaver. 1943. Fifteen Atmosphere Percentage as Related to the Permanent Wilting Percentage, *Soil Sci.* 56:331-339.
13. Richards, L. A., ed., 1954. Diagnosis and Improvement of Saline and Alkali Soils. Agriculture Handbook No. 60, U. S. Department of Agriculture.
14. Schwab, D. 1970. Irrigation Water Measurement. Oklahoma State University Extension Fact Sheet No. 1502.
15. Shalhevet, J., P. Reiniger and D. Shimshi. 1968. Peanut Response to Uniform and Non-uniform Soil Salinity. Volcani Institute of Agricultural Research (N.U.I.A.). Bet Dagan, Israel, No. 1421E.
16. Suter, D. A. 1955. Consumptive Use of Water by Peanuts and Grain Sorghum in Oklahoma. Unpublished M. S. Thesis, Oklahoma State University, Stillwater, Oklahoma.
17. Veihmeyer, F. J. and A. H. Hendrickson. 1928. Soil Moisture at Permanent Wilting of Plants. *Plant Physiol.* 3:355-357.
18. Veihmeyer, F. J. and A. H. Hendrickson, 1949. Methods of Measuring Field Capacity and Permanent Wilting Percentage of Soils. *Soil Sci.* 68:75-84.
19. Woodward, G. O. 1959. Sprinkler Irrigation. Sprinkler Irrigation Association, 100 Vermont Ave., N. W., Suite 711, Washington, D. C. 20005.