Water and Soil

Why these words and diagrams

Irrigation creates artificial conditions beneficial to man. It costs time and money and it involves risks of injury to soils and crops.

When a man irrigates, he brings soil and water together. Not all that happens in the process is apparent even to a careful observer. Research has developed knowledge far beyond that which you and I can learn by our own experience.

Taking advantage of that knowledge is an obligation of all who are entrusted with the use of water. Water is previous. It is an important limiting factor in our agricultural development. Water will probably be a major factor limiting the ultimate density of human populations. The amount of our good soil and climate we can use to produce food and fiber is limited by water supply. Good land not irrigated is not being fully used. Water wasted by poor irrigation is taken away from other land that needs it; furthermore, it likely harms soil and crops at the site of waste. Waste cheap water and you may have to use expensive water to irrigate land the wasted water could have irrigated.

Knowledge is the basis of good irrigation. Herein, we shall attempt to present in a few words and diagrams what a grower needs to know to irrigate effectively.

Basic principles

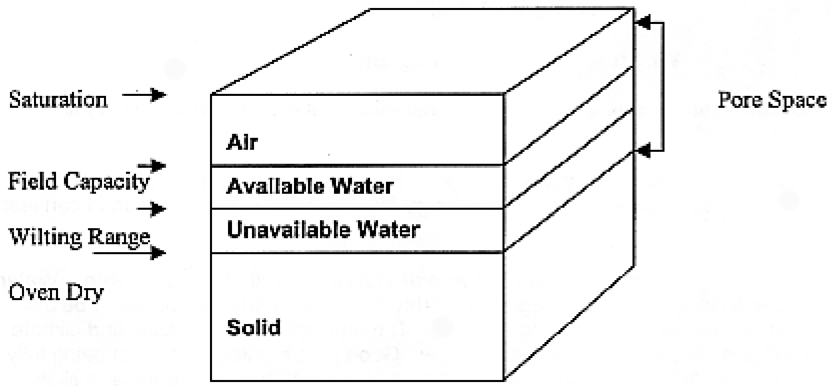
Soil and water form a combination that plants need. What happens when soil and water meet? Soil is partly solid particles and partly pore space between the soil particles. Water and air occupy this pore space. Dissolved in the water are solid materials of many kinds and gases of the atmosphere. When water and soil meet, water flows through the spaces between soil particles. Part of this flow is in response to gravity. The rest is the flow of water in thin films on surfaces of soil particles. This may be called capillary flow. Forces causing this flow are stronger than gravity. They readily move water horizontally and upward for limited distances. In a dry soil the space between particles is occupied by air. Water replaces part or all of the air. As soil dries, air replaces water.

Soil serves as a reservoir because of the slow movement of water at or below field capacity. For practical purposes, we may say that only roots can remove much water from soils below a surface layer of 6 to 8 inches. Near the surface the soil is dried by air and sunshine in a few days. In deep soils there is a slow downward drainage.

Soils are wetted to a point between field capacity and saturation during irrigation in which water stands or runs on the surface. Rapid movement of water in the soil takes place only when the soil contains moisture in excess of field capacity. This excess water is moved through the soil by gravity and capillary flow. In sand, gravity flow downward is rapid but capillary flow horizontally and upward in limited to a few inches. In clay, movement is slow, but water will move several times as far as in sand. Capillary flow is an important factor in determining distances between furrows. On a smaller scale, capillary flow moves water across small distances between root hairs in the soil.

Soil is about half solid material by volume; the rest is pore space occupied by air and water. Approximately one-half of the pore space of a recently irrigated and drained soil is occupied by water. Only about half of this water can be used by plants. Thus, about one-eighth of the soil volume contains moisture available for plant growth. The fraction is smaller for sand and larger for clay.

Penetration is the downward movement of water into and through a soil. The rate of penetration is determined by the sizes of pore spaces which are related to soil texture and structure. Rate of penetration has an important bearing on length of furrow or check, width of furrow or check, and size of stream to use. It is also a factor to consider in determining sizes and types of sprinklers and drip irrigation emitters.



The Soil Reservoir

Critical moisture levels describe soil as a reservoir

As a soil dries, the amount of pore space occupied by air increases, films of water covering soil particles become thinner, and plants have to suck harder to get water from the soil. As these changes take place, there are a few critical points along the way that can be approximately described and measured. Their measurement tells us something about a soil as a reservoir for water.

Saturation is a condition in which all pore spaces of a soil are filled with water. A soil remains saturated only if water is not allowed to drain from it. Roots of most plants cannot function or even remain alive for very long in saturated soil. They do not get enough oxygen.

Field capacity is the amount of water contained in a given soil after being thoroughly wetted and drained. This is the condition of soil in the field a day or so after an irrigation or rain. It is expressed in percentage of moisture by weight based on oven-dry soil or by a tensiometer reading. It is not a precise figure. It is influenced not only by the texture and structure of the soil, but also by the texture and structure and amount of water in adjacent soil. It is also influenced by vertical position in the soil. For example, if a column of soil of uniform texture and structure, and open to the air at both ends, were irrigated and allowed to drain for 72 hours, the water content would be higher near the bottom of the column than near the top. The soil at the very bottom of the column would be saturated. Water will drain from the bottom only when soil at the bottom is saturated. Bring the bottom of the column in good contact with a soil of much coarser texture and very little water will be withdrawn from the column. Bring the lower end of the soil column in good contact with dry soil of the same texture and structure and some water will be withdrawn from the column.

Field capacity is a characteristic not only of the soil but also of the soil and its environment. It is a useful concept - especially for people who design irrigation systems and people who make decisions regarding irrigation and people who irrigate.

Air-dry soil occurs only near the surface. The amount of moisture in a given soil in an air-dry condition varies with humidity and temperature.

Oven-dry soil is a condition produced by drying soil in an oven. It is used as a basis for expressing percent of moisture and other components because it is a constant figure, whereas the air-dry soil varies in weight as temperature and humidity change.

Available water is the water that roots can take from soil without wilting. It is the water which occurs in soil between field capacity and a soil moisture content at which plants wilt.

It is poor farming practice to require crop plants to use all of the available water in their root zones. At field capacity, it is easy for plants to take water from the soil. Extraction rates become slower as soil dries; but as wilting approaches, the forces required to remove water from the soil increase rapidly and plant growth is retarded before wilting occurs. This is partly because plant roots fail to thoroughly permeate the pore spaces of a soil within the root zone, they depend on water movement to the roots from soil between the roots. This movement becomes slower as the soil dries.

It may become too slow to keep plants from wilting even when measurements of soil moisture indicate moisture content is well above the wilting range.

Maximum production may require irrigating when only half to two-thirds of the available soil moisture has been extracted.

Useful available water for profitable crop production is less than the total available water. It is the amount of water that can be used by crop plants between the time of irrigating and when another irrigation is required to keep these plants functioning profitably. It varies with crops, weather, and stage of development of the crop, as well as with soil texture, soil structure, and soil salinity. It also varies with the judgment of the person deciding when to irrigate. Useful available water may be gone before the more readily observed symptoms of drought, such as wilting and dry appearing soil, develop.

Suction readings indicate availability of water

Suction (negative pressure) is a measurable force that pulls water into a relatively dry soil and tends to hold it there against the forces of gravity, against suction of roots, and against suction of nearby soil. Suction is measured in *centibars*. A centibar is one-hundredth the pressure of the atmosphere.

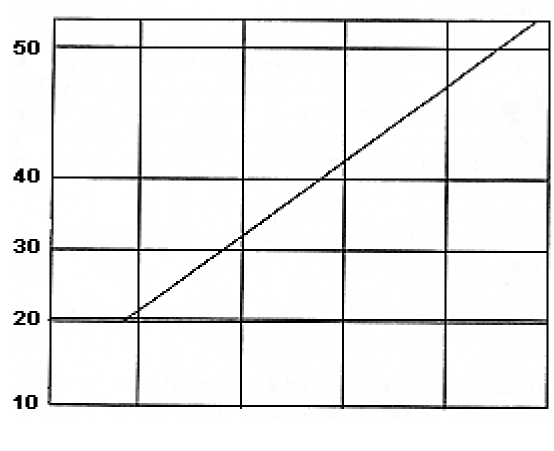
Suction is created in a soil whenever it is not saturated. Then the water in the soil is in a film surrounding soil particles. This film is thick in narrow angles formed by adjacent soil particles when soil is wet. The film becomes thinner as water in the soil is decreased. As the film becomes thinner, suction increases and water moves more slowly.

We are concerned about suction because to take water from a soil, plants have to develop more suction than is in the soil. We know that plants cannot get enough water to prevent wilting even at 100 percent humidity when suction in the soil is around 1500 centibars. In the field plants may wilt temporarily when soil suction is well below 1500 centibars and growth may be restricted at much lower soil suctions.

Knowing soil suction can be more useful than knowing the amount of water in the soil. Suction readings tell us how hard plants have to suck to get water. We may decide that for profitable production a crop plant should not be required to develop more than 80 centibars of suction. Regular measurements of soil suction can be used to predict when suction will reach 80 centibars, then irrigating can be done at the least frequent intervals that will prevent suctions exceeding 80 centibars. This is only an example. For some crops, suction should not be allowed to exceed 40 centibars; for others it may safely exceed 80 centibars.

Suction readings can predict when to irrigate

The graph below illustrates how suction records can be plotted to predict when suction will reach 50 centibars.



Soils differ

Soil texture is determined by the size of individual soil particles. A particle may be sand, silt, or clay. The proportions of a soil which are sand, silt, and clay determine whether a soil is described as fine sand, fine sandy loam, loam, silt loam, clay loam, clay, etc. The word loam is used to describe soils that are mixtures of sand, silt, and clay in proportions favorable to good structure and desirable moisture-holding characteristics. The smaller the particles, the more water a soil will hold.

Soil structure is the arrangement of the soil particles. If the soil particles are arranged in groups, water and roots penetrate better than if the particles are dispersed because favorable structure provides larger pore spaces. Structure has little effect on water-holding capacity. It may have an important influence on the suitability of the soil as a medium for the growth and functioning of roots.

Soil in good structure allows water, air, and roots to pass through freely; it is easy to work because it is not as hard when dry, or as sticky when wet, as the same soil with poor structure.

Good structure often occurs in undisturbed soil. Cultivation may have a bad effect on structure. It appears to loosen and pulverize, but it tends to destroy soil aggregates. This leads to compaction. A compacted layer just below the cultivated soil is a common occurrence. Less noticeable is the bad effect on soil actually moved by cultivating.

Chemistry also affects structure. Excess sodium has a bad effect. Calcium has a good effect.

Unlike texture, structure is subject to change by cultivation and water quality.

Water quality may affect soils and plants

Water is not pure. As the relatively pure water of falling rain and melting snow makes its way off the hills and down the streambeds or through the underground channels, it picks up minerals of many kinds. Most of these minerals are salts. The salt best known to most of us is sodium chloride, or common table salt. Another commonly occurring salt is calcium sulfate (gypsum). Excesses of some salts can damage plants and/or soils.

Salts split into ions. When a molecule of a soluble salt dissolves in water, its component ions separate and behave independently. For example, the sodium chloride molecule is made up of one sodium ion (cation) and one chloride ion (anion). Cations are positively charged ions and anions are negatively charged ions. Because of these electrical charges, a solution of ions will conduct electricity. The more ionic charges there are in irrigation water, the higher will be its conductivity.

Electrical conductivity indicates salinity. A measurement of the electrical conductivity of a water is a good indicator of the salinity hazard of that water.

A *millimho* is a unit of conductivity useful in describing the salinity of irrigation water or of water extracted from a soil.

Ions accumulate in soil. In the usual water quality problem, we are not concerned about the effects of a single irrigation, but the effects of ions accumulating in the soil after many irrigations. With each irrigation ions are added to the soil. Between irrigations, water is removed by plant roots and by evaporation. Plant roots take up some ions, but leave most behind. Furthermore, much of the salt removed from the soil by plant roots is returned to the soil in plant residues. Evaporation of water from the soil surface leaves all ions in the soil where they remain as ions, increasing the concentration of the soil solution.

Possible problems related to water quality

Salinity

The risks of having soil salinity problems attributable to water quality are stated by U.C. Extension Laboratories as follows:

E.C.	
Below 0.5	Depending on soil texture, permeability problems may occur due to low salt content.
Below 0.75	Low salinity hazard - can be used for irrigation of most crops.
0.75 - 1.5	Medium salinity hazard - can be used for irrigation of moderately salt tolerant crops.
1.5 - 3.0	High salinity hazard - can be used for irrigation of highly salt tolerant crops.
Above 3.0	Very high salinity hazard - generally not suitable for continual use of irrigation except under most favorable conditions of soil, climate, salt tolerance of crop, and necessary leaching.

This interpretation of E.C. assumes that 10-20 percent of the total water applied passes through and below the root zone. In most cases, deep percolation losses due to inefficiency of normal irrigation practices will satisfy this leaching requirement for the usual crops of an area.

- Electrical conductivity is an estimate of a concentration of soluble salts expressed as millimhos per centimeter.

Permeability

This type of problem can develop if the sodium adsorption ration (SAR) of a water is high. Such waters have a tendency to adversely affect the structure of soil by replacing calcium on the clay with sodium. Neither the total amount of sodium in the water nor the simple quantitative relationship between sodium and calcium ions is as reliable as sodium adsorption ration for indicating the adverse effect of sodium in an irrigation water on soil structure.

$$SAR^* = \frac{Na}{\sqrt{\frac{Ca + Mg}{2}}}$$ **Na, Ca, and Mg in me/1**

SAR is used to estimate the exchangeable sodium percentage (ESP) of a soil after long-term use of the water. The relationship between the SAR of the irrigation water and probable ESP of the soil, as well as interpretation, follows:

SAR	ESP	INTERPRETATION
Below 6	Below 10	No soil permeability problem expected due to sodium.
6 to 9	10 to 15	Possible permeability problems with fine-textured soils (Saturation percentage above 50).
Above 9	Above 15	Permeability problems likely on all mineral soils, with possible exceptions of very coarse-textured soils (Saturation percentage below 20).

Note: Permeability problems are more probable at a given SAR with waters of low salinity than at high salinity.

* - SAR can be adjusted to include effects of precipitation or dissolution of calcium in soils and related to CO_3+ HCO_3 concentrations by multiplying SAR by 1+(8.4-pHc).

pHc is a calculated pH value. Instructions for its calculation and a table of values for its calculation are in "Quality of Water for Irrigation" by Robert S. Ayres in Journal of the Irrigation and Drainage Division ADCE Volume 103, Number 1R2, Proc. Paper, June 1977, pp 135.154.

Sodium toxicity

The sodium toxicity hazard can be evaluated using SAR or adjusted SAR. When adjusted SAR is less than 3, there is no sodium toxicity hazard. Between adjusted SAR 3 and 9, the hazard increases and above adjusted SAR 9 severe problems can be expected.

Toxicity

Several ions in irrigation water may be toxic to plants. Examples are sodium, boron, lithium, and chloride ions. At least 16 elements, some of which are required as plant foods, have been listed as toxic to plants when present in amounts too small to affect salinity. However, it is unusual for any of these except boron to be a problem. Land irrigated with marginal waters with respect to toxic ions may be suitable only for crops tolerant to the toxic ion involved.

U.C. Agricultural Extension laboratories are using the following interpretation for boron content of irrigation water:

Boron	
Below 0.5 ppm	Satisfactory for all crops.
0.5 - 1.0 ppm	Satisfactory for most crops; sensitive crops may show injury (may show leaf injury but yields may not be affected).
1.0 - 2.0 ppm	Satisfactory for semi-tolerant crops. Sensitive crops are usually reduced in yield and vigor.
2.0 - 10.0 ppm	Only tolerant crops produce satisfactory yields.

There is no economically feasible method of removing boron from irrigation water. Similarly, there is at present no chemical or soil amendment which can economically be added to the soil to render the boron non-toxic. However, growers in some areas are learning to live with marginal boron and salinity conditions by:

1. Maintaining fertility levels slightly above the usual "optimum" and
2. By irrigating a little more frequently than "normal".

Sodium a triple threat

The sodium ion requires special attention because;

1. In concentrations sometimes developed, it is toxic to some plants
2. It is a major contributor to salinity, and
3. It may adversely affect soil structure by replacing calcium associated with clay in the soil.

When clay particles are loaded with calcium, they form groups or microscopic clods. Between these microscopic clods are spaces through which air, water, and roots move freely. When sodium replaces a certain amount of calcium on these clay particles, the microscopic clods fall apart. The clay particles are dispersed and drift into spaces between larger particles of soil. Filling these spaces blocks the passage of water, air, and roots. Sodium-affected clay particles make the soil sticky when wet and hard when dry.

Measuring water

Quantity

Acre-inch, the amount of water required to cover one acre of land one inch deep with water. This is 27,154 gallons of water. One inch of rain falling on one acre is equal to an application of one acre-inch of water on one acre.

Acre-foot, the amount of water required to cover one acre of land one foot deep with water. This is 325,850 gallons of water. One acre-foot equals 12 acre-inches. It weighs 2,700,000 pounds.

Depth		
Depth of water in inches =	Gallons per minute x hours / 450 x acres	
Depth of water in inches =	Cubic feet per second x hours / acres	
Depth of water in inches =	gpm per sprinkler x 96.3 / ft. between sprinklers x ft. between lines	(for 30 x 45 foot spacing)

Rate of flow

450 gallons per minute = 1 cubic foot per second
1 cubic foot per second = 1 acre-inch per hour
1 cubic foot per second = 2 acre-feet per day

They're all the same

1 acre-inch per hour
1 cubic foot per second
450 gallons per minute

Time required to apply water desired	
Hours =	450 x acres x depth in inches desired / Gallons per minute
Hours =	Acres x depth in inches desired / Cubic feet per second
Depth of water in inches = gpm per sprinkler x .0713	

Farming practices must be adjusted to water quality

Excess salts left in a soil by irrigation water must be removed. Where water quality is good and winter rains wet the soil to a depth well below the root zone, all is well. The small amount of salt left by the irrigation water is leached out. When irrigating with poorer quality water leaves a larger accumulation of salt in the soil, more leaching is necessary. The same poor quality irrigation water that caused the trouble can serve to wash excessive salts out of the soil. The soil solution is normally several times the concentration of water used to irrigate the soil. A soil may be more permeable to irrigation water than to rain water because ions in a saline water of low SAR are favorable to permeable soil structure.

Leaching may be accomplished either by putting on a small excess of water with each irrigation or by an occasional heavy irrigation, using two or three times the usual amount.

Water having a high SAR but not an excess of total dissolved salts can be improved by adding gypsum to the water or Gypsum reduces the sodium adsorption ratio. Competent agricultural laboratories can advise the amount of gypsum to use per acre foot of water. Some waters are a special problem because of a high amount of bicarbonate ion. In the soil some of the bicarbonate ion reacts with calcium to form calcium carbonate (lime). This raises the SAR of the soil solution and increases the gypsum requirement.

When irrigation water containing a high proportion of sodium is applied to porous, aggregated soil on which calcium is adsorbed, the sodium replaces the adsorbed calcium and causes the soil particles to rearrange so as to form small pores through which water moves slowly. This process is reversed when soluble calcium is applied to the soil and structure-building practices are employed.

Practical application of water

Irrigation is accomplished by several systems. These systems vary with crop, slope, soil type, locality, and tradition. Regardless of the system used, the aim is to supply sufficient water to the crop in order that it will give maximum growth and production. Too much water, however, can be harmful to crops and wasteful of a precious commodity. Time of irrigation, amount of water to apply, and the method of application to get uniform penetration require sound decisions for good irrigation.

Know where to irrigate

Rooting habits of plants vary considerably. Some are deep and some shallow rooted. Some cover wide areas and others are confined. To irrigate properly, you must know the rooting area of your plants. This is the critical area. It is from here the plant draws its moisture from the soil. Learn where the root zone of your crop is.

Water penetrating below the root zone is wasted unless it accomplished needed leaching.

Know when to irrigate

The time and amount of irrigation depends on the rate at which the crop uses water, the capacity of the soil for holding water, and the depth of rooting of the crop.

The rate that water is used by the crop depends on the type, vigor, age, the amount of ground shaded by the crop, and weather conditions. Their combined effects are best evaluated by observing soil moisture conditions.

Don't irrigate by the calendar. Irrigate by careful observation of your soil and plants.

Watch the plants

Plant symptoms of drought are easy to recognize in some crop plants. Some crops may safely be allowed to show drought symptoms for short periods. However, with the yield and quality required for profit today, plant symptoms of drought may only indicate that irrigating should have been done a week ago.

For several field and vegetable crops, a dark color of the foliage indicates that plants are having to suck hard to get water from the soil. Whether to allow this condition to develop or persist for short periods is a decision to be made by each farmer for each crop.

Examine the soil

The principal value of soil examination is the diagnosis of gross deviations from desirable conditions. Waterlogging and faulty irrigation that leaves part of the root zone un-irrigated can be discovered by soil examination. Soil examination will also reveal root penetration and the reaction of roots to unfavorable structure or moisture conditions.

A soil tube, a push tube, a soil auger, or a shovel may be the appropriate tool to use in examining the soil. For soil free of rocks and not too sandy or too dry, the push tube is the easiest to use. Several holes can be made with a push tube in the time and with the energy it takes to make one hole with any of the other tools. It can be used to good advantage before irrigating, while irrigating, and immediately after irrigating.

Use tensiometers

A tensiometer is an instrument that tells how hard plants have to suck to get water from a soil. If plants have to suck too hard, they do not get enough water for the high rates of growth required for profitable crop production. A tensiometer with its porous cup placed in a representative portion of the root zone indicates the amount of suction in centibars required to remove water from the soil at the time of reading. A series of readings recorded over a week or more can be used to predict when critical suction readings will be reached.

Tensiometers function only at suctions less than 1 bar. On the tensiometer scale a bar is suction equivalent to one atmosphere of pressure. Tensiometers are useful in spite of this limitation because:

1. A large amount of the available water is removed from a soil at suctions within the range of tensiometers.
2. Profitable yields and quality of crop plants may require keeping soil moisture suction within the tensiometer range.
3. If it is desirable to allow soil moisture suction to exceed the highest reading of tensiometers, an advisable time interval between maximum tensiometer reading and irrigation may be established.

How much water?

Theoretically the amount of water to apply, except for leaching, is the amount necessary to wet the soil to field capacity throughout the root zone. In practice it may be modified by several things such as rate of water transmission in the soil, oxygen requirements of plant roots, air temperature, and extent that roots are able to deplete water from the soil at various depths before growth is affected. The deeper the soil, the smaller is the fraction of available water from each successive foot that can be depleted usefully. However, deeper soils permit a larger fraction of available water depletion from the shallower portions for plants having inherently deep and well-distributed root systems. Soils having limited penetration rates should not receive so much water at one irrigation that surface soil remains saturated more than a few hours in hot weather or the plant might asphyxiate for lack of oxygen."

Taking his statements of the paragraph above into consideration, Dr. Albert marsh, U.C. Extension Specialist, prepared the following table to show the approximate inches of water to apply when irrigation is needed for various soil textural groups and root depths.

	Inches of water to apply		
Root depth in feet	Sandy Soil	Loam soil	Clay soil
1	0.75	1.25	1.50

2	1.25	2.25	2.50
3	1.75	3.25	3.50
4	2.25	4.00	4.25
5	2.75	4.50	4.75

Figures in this table do not take into account the failure of irrigation systems to apply water uniformly. For example: the table suggests 2.25 inches of water for a crop on loam soil with a 2-foot rooting depth. If 2.25 inches are applied, parts of the field will get more than 2.25 inches and other parts will get less. The application of 2.5 to 3 inches may be necessary to apply at least 2.25 inches to 90% of the field.

Furrow and border irrigation

Furrow and border irrigation are two widely used methods of applying water to the soil. For uniform penetration, one important factor with each of these methods is the degree of slope on which water is applied. Another is the length of run. Slopes which are not uniform and runs that are too long present difficult problems to the irrigator. Careful observation will give the answers which will help toward correcting the problem. The following penetration profiles illustrate some of the problems and their solutions:

By observing the length of time it takes for water to reach the end of a run in a furrow or check on a uniform slope, an irrigator can determine whether the length of run or head of water is right for uniform penetration. A simple test can be conducted to make this determination: Drive stakes at 50 to 100 feet intervals along the length of your furrow or check. Turn in your usual head of water and record the time it takes the water to progress between stakes down the run. In orchards stakes are not necessary. Trees can be used as markers. If the time it takes the water to progress between successive stakes or trees increases at about the same rate from the beginning to the end of the run, the run is not too long and the head of water is correct. If, however, the time it takes the water to progress between stakes increases rapidly at some point in the run, the run is too long or the head of water is too small.

To correct the situation, first try a larger head of water. If this doesn't help, an additional head ditch or pipeline should be placed at or before the point where the time it takes the water to progress between markers increases more rapidly. In practice the additional ditch or pipeline would probably be placed in the middle of the field.

With border irrigation, the whole land area is irrigated. In furrow irrigation, whether or not the whole land area is wetted depends on the spacing of the furrows in any given soil.

To get complete coverage in a sandy and clay loam soil, the furrows would have to be closer in the sandy loam soil. Careful observation will show the best spacing for a given soil.

Wide or broad-base furrows have an advantage of better penetration control. In these, as in border checks, larger amounts of water can be flushed through to near the end of the run, then the stream cut down to get uniform penetration.

Irrigation by sprinklers

The use of sprinklers for irrigation is increasing. Equipment and technology are improving. Needs for taking advantage of the special results of sprinkling are also increasing.

Advantages and limitations of sprinkling as compared to other methods of irrigation need to be well understood and carefully considered.

Advantages:

For land that is not leveled for furrow or border irrigation, sprinkler irrigation can reduce or eliminate the cost and disadvantages of land leveling.

Where the soil in the field is of variable texture, permeability, and water-holding capacity, sprinkling may facilitate adjusting irrigation to these variations.

Sprinkling facilitates frequent light applications of water to any kind of soil. This kind of irrigation may be especially important for germinating seed and establishing young plants.

Land too steep to be irrigated successfully by furrow or border method can be irrigated by sprinkling, provided water is applied at a low rate that will not cause run-off.

Leaching with sprinklers that apply water no faster than the soil will take it in will remove more salts per acre-foot of water applied than the more common method of applying water for leaching in basins.

Where it is important to control the depth of water penetration, this can be done more effectively with sprinklers than by furrow or other irrigation.

Limitations:

Uniformity of water application by sprinklers is never perfect and unless a sprinkler system is properly engineered and carefully operated, uniformity may be far from satisfactory.

On land leveled for furrow or border irrigation, sprinkling will probably be more expensive than these methods.

It is difficult to compensate for the effects of wind on a sprinkler system. This limits the number of hours per day when sprinkling can be done satisfactorily except in solid sets. Persistent or intermittent wind may make it necessary to temporarily modify spacing of sprinkler lines in order to compensate for wind effects.

Improperly selected or operated sprinkler systems can cause soil compaction, especially if droplets are large and the application rates high. Larger droplets may be attributed to low pressure.

Water losses from evaporation can be appreciable on warm, windy days. When the effects of wind and heat are taken into consideration, it may be necessary to sprinkle at night.

Water high in soluble salts can cause leaf burn and leaf drop by salt accumulation on the foliage of some plants. This damage is less when sprinkling is done at night when evaporation is slower.

Some crops may not justify the relatively high costs of sprinkler irrigation.

Details requiring attention

Each combination of sprinkler type and nozzle size is designed to operate best within a limited range of pressures and sprinkler spacings. Advisable combinations of pressures, nozzle sizes and spacings are found in literature published by sprinkler manufacturers.

The place to measure pressure is at the sprinkler. This can be done with a special gauge while the sprinklers are operating.

Sprinklers that do not turn at an even rate and those that are not in a nearly vertical position do not apply water uniformly all the way around.

Partly clogged nozzles reduce the amount of water discharged and disrupt the normal pattern of distribution.

Changes in the number of sprinklers operated from a booster pump require pressure adjustments.

Careless handling of sprinklers while they are being moved may bend the hammers or loosen the nozzles causing uneven distribution of water.

Uniform application of water cannot be expected from a sprinkler system made up of several sprinkler head types and several nozzle sizes.

Where it is essential to apply a precise amount of water, the rate of application must be known.

Because sprinkler irrigation is not perfectly uniform, extra water needs to be applied to assure a minimum of water application over a high percentage of the irrigated area. For example, if a 1-inch irrigation is desired, it may be necessary to apply 1.25 or 1.5 inches of water in order to obtain coverage of as much as 90% of the area with at least 1 inch of water.

Poor labor management or failure to use good mechanical aids will make costs of moving sprinklers unnecessarily high.

Large nozzles which permit wide spacings require high pressures and tend to apply water too fast.

For germinating a crop, a solid set system that can be turned on every day or two is required for the very best results.

When manufacturers instructions are followed closely, it may still be desirable to evaluate uniformity of water application by a carefully conducted test in which 40 or more cans are evenly spaced in an area bound by a sprinkler at each corner.

Sprinklers placed relatively close together with small nozzles and moderate pressure tend to give the best results when rate of application, uniformity of application, and cost of sprinkling are taken into consideration.

Drip irrigation

Drip irrigation applies water frequently at very low rates. Drip emitters of many kinds are designed to maintain an extremely small flow of water (1/4 to 5 gallons per hour) over a long period of time. For crops requiring a continuous line of wet soil under a row of closely spaced plants, porous tubes and perforated thin-walled tubes have an economic advantage over emitters.

Emission of water at low rates with low pressure is complicated by a tendency of the small apertures required to become clogged by fine particles of undissolved materials. For this reason, an effective filter system is essential to all kinds of drip irrigation.

Some drip emitters and porous tubes have been tried underground. Few, if any, emitters function well underground. Furthermore, it is much easier to observe the performance of emitters when they are above ground. Porous tubes are suited to underground installations.

Drip irrigation appears to be best adapted to tree crops and grapes. Most drip systems apply water to only a small part of a field (for example, a small area around each tree) and maintain a relatively high moisture content in the irrigated soil.

In deciding to use drip irrigation rather than sprinkler, furrow or border irrigation, economics must be carefully considered. Two questions have to be answered:

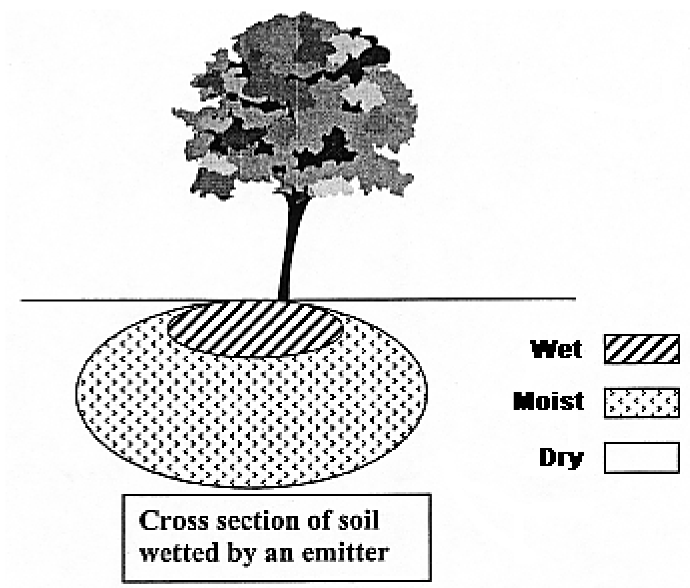
1. Will the improved results justify the cost?
2. Could the same advantages be realized at lower cost by improving the performance of the existing system?

As with other methods of irrigation, uniformity of water distribution of drip irrigation systems need to be evaluated. When uniformity is poor, it needs to be improved or compensated for by applying enough extra water so that a high percentage of plants receive the amount of water required.

Equations for evaluating emitter performance:	
Milliliters per 47.5 seconds x .02	= gallons per hour
$\frac{\text{Milliliters per minute}}{63}$	= gallons per hour

Drip irrigation provides more complete control over where, when and how much water is applied than does any other system. Relatively small amounts of water are lost by evaporation or percolation below the root zone. When the amount of water transpired from leaves of the crops since the previous irrigation is estimated, this amount of water can be applied by regulating the length of time the system is operated. Transpiration loss is well correlated with the amount of ground shaded by foliage and the rate of evaporation from a few water surfaces.

Drip irrigation is especially advantageous where other methods do not perform well - steep slopes, variable soil texture, persistent wind, expensive water, poor quality water, where furrows need to be kept dry.



Cross section of soil wetted by an emitter

Judging soil water depletion

Water depletion per foot depth of soil for major textures by feel and appearance

Soil water depletion can be judged approximately by feel and appearance. The accompanying table illustrates four levels of soil wetness that can be estimated for each major soil texture group. The figures placed by each level are the approximate quantities of water expressed as rainfall inches needed to restore one foot depth of soil to field capacity. The total amount of water needed at any irrigation would be the total of these values determined for each foot throughout the depth of the root zone.

Coarse	Inches	Medium	Inches	Fine	Inches
Dry, loose, crumbles.	1.0	Crumbly, powdery, barely maintains shape when squeezed.	1.5	Hard, firm, baked, cracked, too stiff to work or ribbon.	2.0

A fragile cast when squeezed.	0.6	May form a weak cast but still crumbly.	1.0	Pliable, forms a cast or ball, will ribbon but is crumbly. Slight finger stain.	1.4
Color darkened. Forms a weak ball when squeezed. Slight finger stain.	0.3	Color darkened, forms ball or cast. Works easily and smoothly, stains fingers, has slick feel.	0.5	Color darkened. Forms a good ball. Ribbons easily and has slick feel. Leaves finger stain.	0.7
Appears and feels moist. Forms cast or ball. Stains hand.	0.0	Color dark, has smooth mellow feel. Forms ball and will ribbon when squeezed. Leaves wet outline on hand.	0.0	Color darkened, appears moist, may feel sticky, ribbons easily, forms good ball and stains hand.	0.0