SPRINKLER IRRIGATION HANDBOOK

TENTH EDITION

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METHODS OF IRRIGATION

Irrigation is the artificial application of water to soil One purpose of irrigation is supplying moisture necessary for plant growth Irrigation can be controlled to ensure that plants have sufficient soil moisture for optimum growth during germination and development to maturity

In many areas of the world, irrigation is an absolute necessity if an economic crop is to be produced In other areas, the total annual precipitation is often more than is needed to produce an economic crop, but the distribution over a year is seldom ideal for plant growth

Water for the maintenance of plant growth may be applied in one of three ways subirrigation, surface irrigation overhead (or sprinkler) irrigation

SUBIRRIGATION

With subirrigation, water is applied below the ground surface rather than on it As moisture reaches the plant roots through capillary movement, an adequate supply of good-quality water must be available throughout the growing season The upward movement of high-saline water tends to accumulate salts in surface soil these salts hinder crop production

The soil must be nearly level and smooth, and there must be either a natural water table or a perched water table (created by a confining stratum) which may be maintained at some predetermined subsurface elevation.

The distribution system consists of a series of structures which will permit the water tables to be raised to a uniform depth below the ground surface over the entire area.

The use of subirrigation as described above will always be limited because there are few places where all of these conditions exist jointly.

In recent years perforated plastic hose has been buried under and around agricultural crops far the purpose of supplying irrigation water. At the present time this means of subirrigation has met with varying degrees of success and must still be considered in the experimental stage.

SURFACE IRRIGATION

Surface irrigation includes the general methods of flood, furrow, and corrugation irrigation.

There are three basic methods of *flood* irrigation: border strip; basin; contour border, with flooding and border ditch.

In flood irrigation, the water is permitted to cover the surface of the soil in a continuous sheet. Theoretically, the water should be standing at every point in the field just long enough to apply the amount of water needed to refill the root zone. But under practical field conditions, it is not possible to accomplish this. Some parts of the field receive too much water when others are provided with adequate amounts.

In furrow irrigation, water is applied in the furrows between rows of plants. As water runs down the row, part of it filters into the soil to refill the soil moisture reservoir. To accomplish this adequately requires considerable lateral moisture movement in the soil unless the furrows are close together. Since moisture must move laterally and upwards to wet the beds between the furrows, the soil salts move with it and tend to accumulate in the bed. This can be injurious to plant growth.

Furrow irrigation is characterized by relatively high annual labor costs for maintenance and operation; and this irrigation frequently requires extensive land preparation since natural land slopes are seldom ideal for surface irrigation.

In corrugation irrigation, water is applied in small furrows running down the slope from a head ditch.

The purpose of the furrows is not so much to carry the stream of water as to guide it Some overflowing of the furrows usually occurs. Heavy soils, when water floods the surface, tend to seal over and bake, thus limiting both plant growth and water infiltration Annual labor costs for corrugation irrigation are relatively high

SPRINKLER IRRIGATION

Sprinkler irrigation systems may be designed in several ways They may be permanent installations with buried main and lateral lines, semipermanent installations with fixed mainlines and portable laterals, and fully portable systems with portable mainlines and laterals

In all of these systems water is delivered through a mainline from the source of supply to the lateral lines It is discharged above the crop or soil surface through sprinkler heads on riser pipes attached to the laterals Each sprinkler head applies water to a circular area, the diameter of which is governed by the nozzle size and pressure For uniform coverage, the patterns are *overlapped* from 35% to 70%, depending on sprinkler type and wind conditions

Sprinkler irrigation systems, properly designed, installed. and operated, have many advantages Erosion can be controlled, and efficient irrigation is possible on land too steep for other methods Uniform application is possible on all kinds of soil On sandy soils that have high intake rates, or nonuniform soils with variable-intake rates, sprinkler irrigation distributes water more uniformly than any other method Water can be saved, more land can be irrigated with a designated amount of water, and drainage problems can be reduced

The amount of water applied can be controlled to meet the needs of the crop. Light applications can be made to seedlings or young plants, or for fertilizer and herbicide applications.

Land preparation is not required. Soils too shallow to be leveled properly for other methods can be irrigated safely with sprinklers. On deeper soils, the cost of land leveling can be eliminated or greatly reduced.

More land is available for cropping. Field ditches, levees, and borders are not needed. Sprinkler irrigation also decreases the weed problem, reduces wear on farm machinery, and simplifies tillage. Surface runoff of irrigation water is eliminated. Since with sprinkler irrigation small streams of water can be distributed over a large area, irrigation can be accomplished where there is insufficient water to irrigate efficiently with surface methods.

The time and amount of application of fertilizers can be controlled to meet the needs of the plant. Water-soluble fertilizers can be applied through the sprinklers. (See page 25 for fertilizer application.)

Labor costs are reduced notably on soil having a high water-intake rate and on land that is steep or rolling. Irrigation can be fitted into other farm operations as incidental work that is done once or twice a day. With solid or permanent systems, labor is negligible, and they lend themselves to automation for all water-application purposes.

Crop damage from frost and hear can be reduced or eliminated by the use of specially designed sprinkler systems. (See page 26 on frost protection and temperature control.)

Salt accumulation on the soil surface is reduced, as is the hazard to seed germination and plant growth from the accumulated salts.

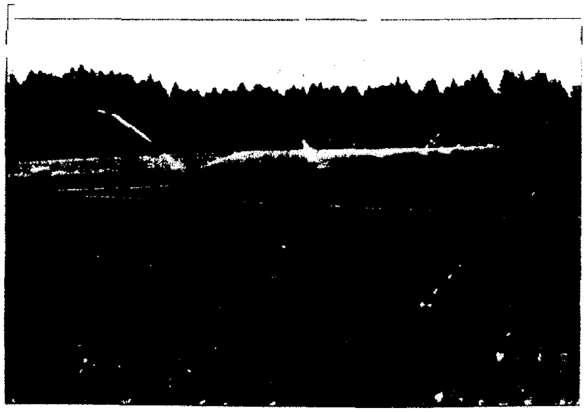
SECTION 2

TYPES OF SPRINKLER SYSTEMS

FULLY PORTABLE SYSTEMS

A fully portable system has portable mainlines, submains, laterals, and a portable pumping plant. It is designed to be moved from field to field or to different pump sites in the same field This type of system may be used on several different crops during one year and then consolidated during cold weather for frost protection where required.

A serniportable system is similar to a fully portable system except that the location of the water source and pumping plant are fixed Such a system may be used in more than one field where there is an extended mainline, but it may not be used on more



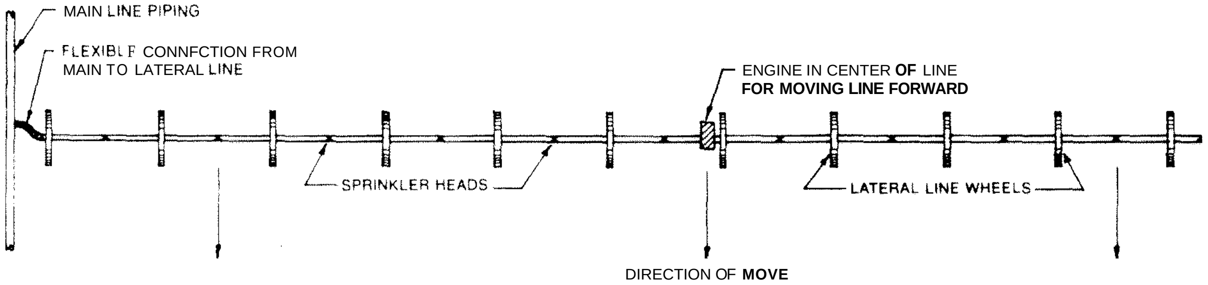
than one farm unless there are additional pumping plants

MECHANICALLY MOVED SYSTEMS

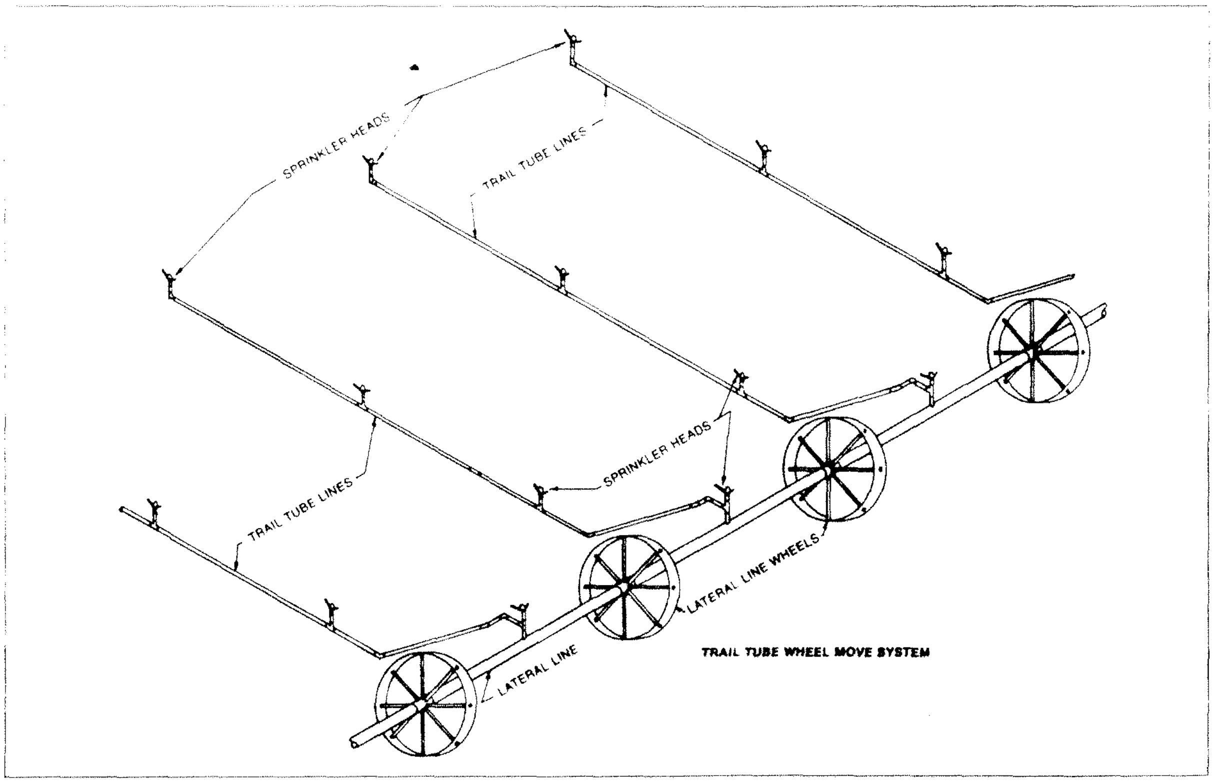
The increasing problems of high cost and scarcity of reliable labor have stimulated the rapid development of several mechanically moved irrigation systems These systems vary in the basic method of operation, degree of labor savings, cost per acre, and adaptability to certain crops, soils, terrain, and climatic conditions The various systems now available can be classed into three broad categories: side-roll wheel moves; center-pivot systems; and traveling sprinklers.

The side-roll ***wheel*** move is basically a lateral line of sprinklers suspended on a series of wheels. The unit, stationary during sprinkler operation, is then shut off while being moved, at right angles to the sprinkler-lateral axis, to each consecutive watering location.

The unit is mechanically moved by an engine mounted at the center of the line, or an outside power source at one end of the line.



WHEEL MOVE SYSTEM

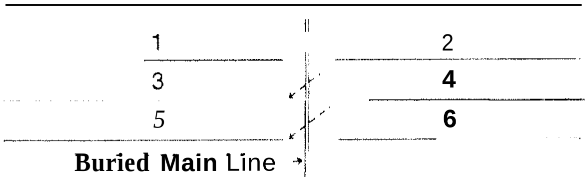


TRAIL TUBE WHEEL MOVE SYSTEM

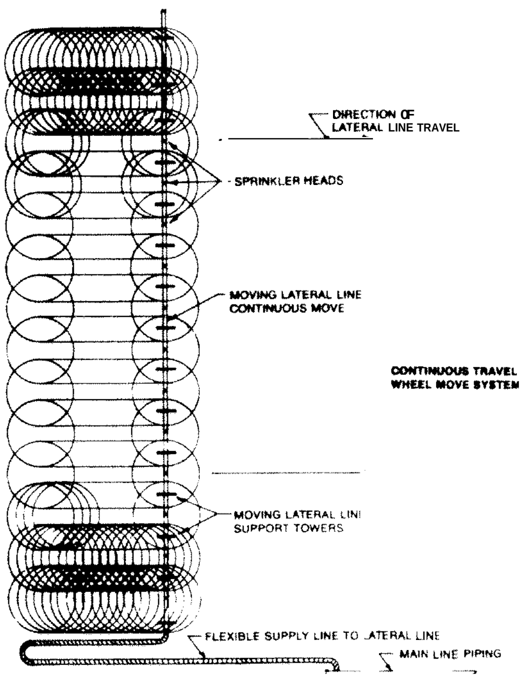
In one variation of the wheel move, trail tubes with sprinklers mounted on them are added The sprinklers on the trail tubes enable larger areas to be irrigated with each set and decrease the number of moves

A continuous-travel wheel move has recently been made possible with the development of a flexible hose that can be dragged by the unit The sprinklers remain in operation as the entire line moves continuously across the field

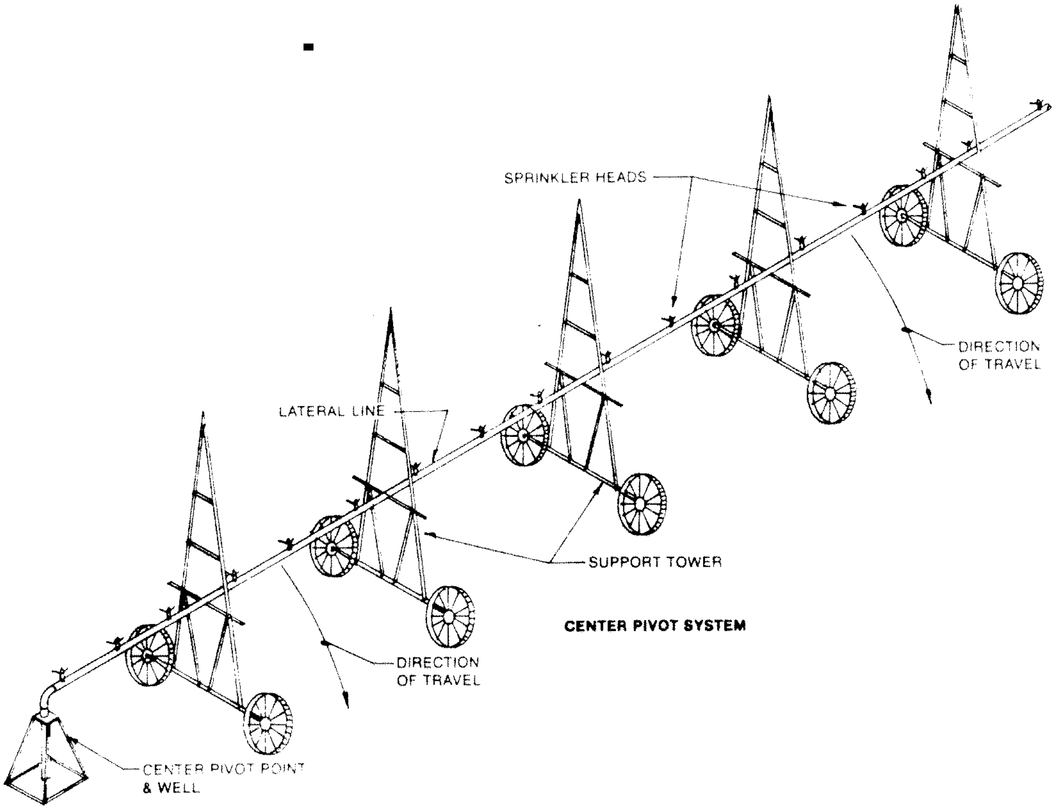
End tow systems are an aluminum lateral line mounted on either wheels or skids The line is towed with a tractor from one set to another across a main line, and may be moved laterally also The towed line may be connected to the main line from either end, thus requiring a buried main line at distances twice the length of the end tow line



The numbers on each line indicate the position of consecutive sets



CONTINUOUS TRAVEL WHEEL MOVE SYSTEM



CENTER PIVOT SYSTEM

The *center-pivot* system consists of a pipeline with various sized sprinkler heads spaced on it The pipeline is suspended above ground on individually powered tower units The system is self-propelled and continuously rotates around a pivot point at the center of the field

The traveling sprinkler consists of a single rain gun sprinkler (or boom-type sprinkler) mounted on a portable, wheeled unit The unit is initially positioned at one end of a travel path, connected to the end of 660 feet of flexible hose It is then selt-propelled up to 1320 feet before being stopped and repositioned in the adjacent travel path.

The continuous movement of all the self-propelled systems contributes to good uniformity of application It also maximizes the number of hours that the system can be used, reducing or even eliminating ‘ downtime” for making moves

All mechanically moved systems favorably affect the labor situation as it relates to portable sprinkler systems, either by changing the type of labor or reducing the amount of labor required Initial cost usually rises in proportion to the amount of labor eliminated, so that evaluation and comparison should include both initial and annual operating costs The unique qualities and advantages of each system should be considered when a system is selected for a special application

Future development of new systems and refinement of existing systems can be expected to progress at a rapid pace as the demand for economical, labor-saving methods continues to increase

SEMIPERMANENT SYSTEMS

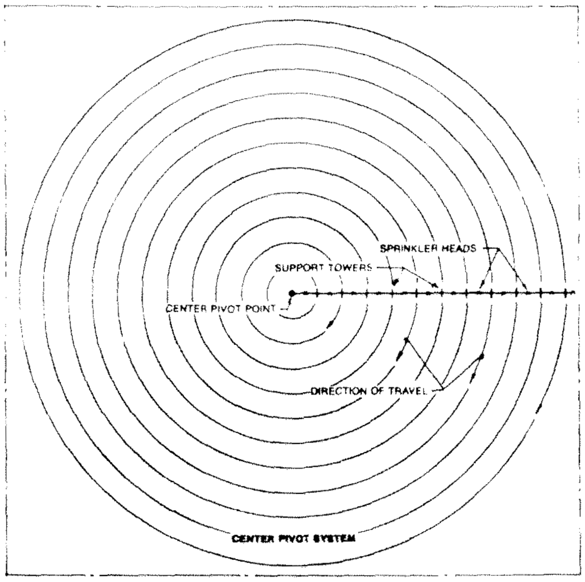
A semipermanent system has portable lateral lines, permanent mainlines and submains, and a stationary water source and pumping plant. The mainlines and submains are usually buried, with risers for valves located at convenient intervals.

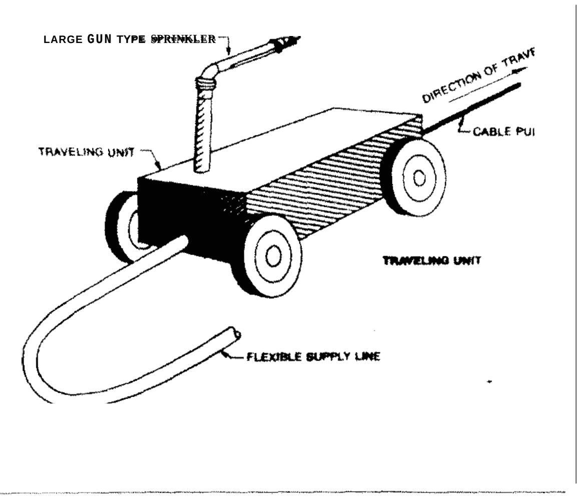
SOLID-SET SYSTEMS

A solid-set system has enough portable laterals to eliminate being moved. The laterals are positioned in the field early in the season and remain until the last irrigation before maturation of the crop. The mains and submains may be either buried or portable. These systems are used for crops requiring short, frequent irrigations (See following section.)

FULLY PERMANENT SYSTEMS

A fully permanent system consists of permanent mains, submains, and laterals, and a stationary water source and pumping plant. Mains, submains, and laterals are all buried Sprinklers are permanently located on each riser. Such a system is best suited to automation with moisture-sensing devices and/or irrigation controllers (For further information, see following section)





SECTION 3

SYSTEM LAYOUT CONSIDERATIONS

The initial cost and the labor required are both directly related to the portability of a sprinkler system The more portable a system, the lower the initial cost and the higher the labor requirements to operate it Conversely, the permanent system has the highest initial cost and lowest labor requirements Each person selecting a sprinkler system has his own set of circumstances and economic conditions to consider

The selection of a system is an economic compromise of these individual conditions. and no two may be exactly alike However, after the type of system has been selected, there is a basic common guideline to follow in developing the details of the system

The main factors affecting the detailed layout of a sprinkler system are listed below All available information should be collected prior to the design stage so as to be utilized in a system design

1 Availability of water, water quality, and source of power. (See Section 4.)
2. Soil factors. (See Section 5.)
3. Crop factors and uniformity required. (See Section 6.)
4. Purpose of the system and amount and frequency of water application. (See Section 7.)
5. Sprinkler spacing, nozzle size, and operating pressure. (See Section 8.)
6. Relative land elevations and pressure requirements. (*See* Section 9.)
7. Layout of main and lateral lines. (See Section 10.)
8. Sizing of main and lateral lines for proper operation. (See Section 10.)
9. Plans for proper operation of system. (See Section 11.)
10. Economic analysis of alternative system. (See Section 12.)

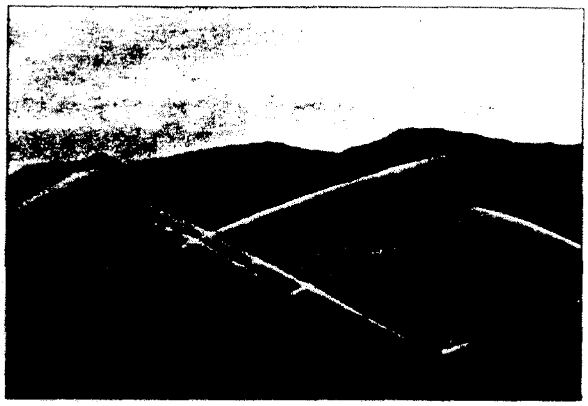
SECTION 4

WATER AVAILABILITY, QUALITY, AND SOURCE OF POWER

Quantity, quality, and location of water and power sources are all-important factors in planning a sprinkler system The quantity of water available and the scheduling of delivery (if the water comes from an irrigation district) may be the main factors determining the size of the system required Ideally, for sprinkler irrigation, continuous water delivery should be available in the quantity required to satisfy the crop requirements during the growing season If delivery is on a rotation basis, then the system must be of adequate size to irrigate the complete acreage in the time allotted. In addition, the rotation must be such that it coincides with the planned irrigation frequency. Because of difficulties encountered in ditch water deliveries, many farmers have drilled wells to assure a supply of water.

Low-quality waters with high salt content require special consideration in planning a system. Successful irrigation with high salt water for a prolonged period requires that enough water for leaching be applied periodically. This leaching may be done during each irrigation, or may be done in an annual


SOLID-SET SYSTEM


FULLY PERMANENT SYSTEM

irrigation Either way it must be considered in planning a sprinkler irrigation system Particularly in arid or semiarid climates, care must be exercised in the use of high salt waters on salt-sensitive crops Citrus, for instance, may be damaged by excessive salt accumulation in the leaves if sprayed in hot weather with water containing large amounts of sodium and chloride ions It may, in extreme cases, be necessary to sprinkle only at night In some cases, it is necessary to move sprinkler laterals downwind to wash accumulated salts from plant foliage. When other sources of water are available, high salt water may be mixed with water of better quality to reduce the average salt content.

Location of water source and power will affect the length and hence the size of mainlines required for a system. In most cases, a comparison of pipe cost, anticipated annual pumping cost, and local power costs will determine the most economical size and length of mainline where there is a choice of locations

SOIL FACTORS

The principal factors affecting the water-holding capacity of soils are texture, structure, and organic matter content

Water is held as a film, surrounding soil particles and in spaces between soil particles Water in the interstices is free to drain The adhesive forces of the soil particles hold the water film to the particles This means that the finer the texture, the greater the water-holding capacity due to greater adhesive force

The orientation of soil particles is termed structure If the particles of soil are very loosely arranged with a very high percentage of pore space, there is greater opportunity for each particle to hold its own film of water Therefore, within practical limits, the greater the percentage of pore space in a soil of a given texture, the greater will be the water-holding capacity

The effect of organic matter on water-holding capacity is direct, in that organic matter can hold several times its weight in water and indirect because of the effect of organic matter in improving soil structure and increasing the percentage of pore space

Field soils are classified from sands to clays and all gradations between The following tables show average moisture-holding figures

MOISTURE HOLDING **CAPACITY**
PER FOOT OF VARIOUS SOILS

Soil **Type**[1]	**Dry Soil**		Amount **Held In Soil at** Wilting Point[2]	Amount to **Add per** Irrigation[3]
	Inch **per** Ft	%	Inch **per** Ft	Inch **per** Ft
Light Sandy	125	20	025	1.00
Medium	2.25	25	0.56	**1.69**
Heavy	367	35	128	2 39

[1] **Average** for **group**
[2] **Moisture** not **available** for **plant use**
[3] **Moisture available** for **plant use**

There are three soil-moisture levels recognized in plant-soil-water relationships

1 Saturation – all soil pores full of water
2 Field capacity – moisture retained against gravity after soil drainage in a well-drained soil
3 Permanent wilting percentage – the soil moisture retained when plants wilt and do not regain turgidity at night

The moisture retained as the difference between field capacity and permanent wilting percentage is generally considered as available for plant use Some general relationships of soil moisture and soil texture are shown on page 33

The rate at which water will enter the soil surface is termed infiltration rate, usually expressed in units of inches per hour Coarse-textured soils (sandy and gravelly soils) will generally take water as rapidly as it is applied with a sprinkler system Fine-textured soils (fine silts and clays) take water more slowly, and the intake rate decreases with time Some heavy soils, which crack upon drying, take water very rapidly until the cracks close and then very slowly

CHECKING THE SOIL MOISTURE

Soil moisture should be checked both before and after irrigation Before irrigation, the check will determine whether or not the wilting point has been reached and whether or not moisture should be added. After each irrigation, the check will determine if the soil is wet to the bottom of the root zone A very simple method of checking moisture is the feel of the soil (See “Feel” Chart page **8)** The soil should compare to “**Fair**” on the chart when ready to irrigate, and should compare to “Excellent” at the bottom of the root zone **24** hours after irrigation These tests can be made with either a shovel or soil auger

THE “FEEL” CHART

Degree of Moisture	Feel	Amount of Moisture
Dry	Powder Dry	None
Low	Crumbly, will not hold together	25 percent or less (critical)
Fair	Somewhat crumbly, but will hold together	25 to 50 percent
Good	Forms ball; will stick slightly with pressure	50 *to* 75 percent
Excellent	Forms a ball and is pliable; sticks readily; a clear water sheen will come to the surface when ball is squeezed in the hand	75 to 100 percent
Too Wet	Can squeeze free water	Over field capacity

This check is absolutely necessary, especially when a system is first operated Only then can the operator determine whether he is getting sufficient moisture in the soil to the proper depth, and tell whether or not he is overirrigating

In addition to the visual/feel method of checking soil moisture, there are two types of instruments available to aid the agriculturist the tensiometer and the electrical resistance block

The *tensiometer* is a tightly closed tube filled with water One end inserted into the soil, is a hollow ceramic tip with a porous wall through which water can move slowly The other end, extending above ground, is a vacuum gauge that indicates water tension The tube has a stopper or cap that can be removed for filling the system with water

As soil dries, capillary action draws water out through the wall of the ceramic tip, creating a partial vacuum inside the tensiometer, which is read on the vacuum gauge This power of the soil (soil tension) to withdraw water from the ceramic tip increases continuously as a soil dries When a soil becomes wet again from irrigation or rain, soil suction is reduced, and water moves back into the tensiometer, thus lowering the vacuum reading on the gauge

Resistance blocks are made of various kinds of materials (gypsum, nylon, fiberglass, and plaster blocks with nylon and fiberglass) in which electrodes are mounted These units are similar in principle but different in detail In all cases, electrodes are surrounded by a porous material in contact with the soil Water is transferred both ways between soil and the porous material The resistance between the electrodes depends on the amount of water in the surrounding porous material This, in turn depends on: the relative affinity for moisture of the soil and porous material; the amount of moisture present; the rate of water transfer from one material to the other; and the electrical conductivity of the moisture or solution that is within the electrical influence of the electrodes.

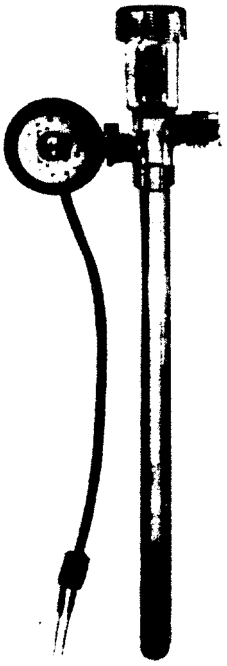
The electrodes are connected to a pair of wires, coated for moisture resistance, that are brought to the surface. The resistance is then read on a soil-moisture meter calibrated in ohms resistance or percent available moisture. Any number of blocks may be read with one meter.

All resistance blocks are sensitive to salts, but the plaster units are somewhat less sensitive than fiber units. This lesser sensitivity results from the presence of a saturated solution of calcium sulfate in the plaster block. When the soil solution is less concentrated than saturated calcium sulfate, it has only slight effect on the resistance of the units.

Within their working range (0 to 80 centibar), tensiometers are more accurate than resistance blocks. Tensiometers are direct reading, while resistance units must be calibrated to read either moisture tension or moisture content. Once calibrated, however, the resistance units operate over a much wider range of soil moistures.

Soil-moisture measuring devices should be located in various areas of the field that differ in soil texture and depth, kind of crop, or cover and slope.

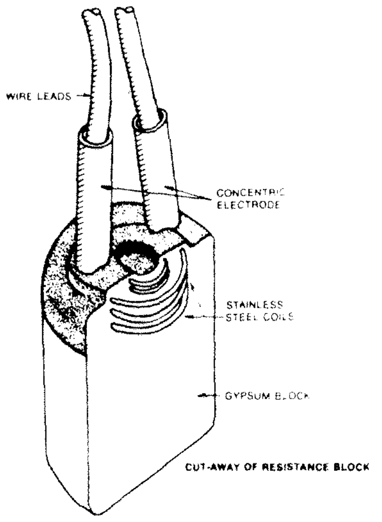
At each location, measuring devices at different depths may be needed. Usually, only one depth will



be needed for plants rooting less than 15 inches Two should be used for plants having active roots down to 4 feet For plants rooting deeper than 4 feet, it is desirable to have instruments at three different depths

A recommended procedure is to purchase a modest quantity of measuring devices initially Install them at two locations with different soil characteristics. After a trial period, it is easier to determine the total number needed Technical assistance may be obtained from any local agricultural extension office

The tensiometer tip or resistance block should be installed in the active root zone, in good contact with the soil Any mechanical soil-moisture measuring device measures moisture at a point or, at best, in a relatively small volume of soil rather than a large volume It is therefore important that the sensing portion be located where the plant roots will be active. With sprinkler irrigation, units should be placed where water is not blocked by intervening objects such as posts, tree trunks, branches, leaves, vines, etc.



CUT-AWAY OF RESISTANCE BLOCK

Tensiometers are subject to freezing damage and must be protected or removed in extremely cold weather. Draining the tube can protect the body, but water may still remain in the gauge, which is most susceptible to damage.

Both the tensiometers and the **leads** from the resistance units should be protected from field equipment. **Posts** or stakes are effective for this purpose.

Frequency of instrument reading will depend on the rate water is used **by** the crop as compared to the water-holding capacity in the root zone. More frequent readings give a better picture of the soil-moisture extraction and also a check for any malfunctioning instruments. A minimum of three readings should be made between irrigations, or if the irrigation cycle is fairly long, twice weekly.

The readings to be most useful should be recorded and plotted on a chart. In this way, moisture-loss history can be established, and some short-term predictions can be made. Plotting also shows whether irrigation is frequent and long enough to get the desired soil wetting for maximum plant growth. Units should be read at about the same time each day; this minimizes temperature variations. An early morning reading is desirable because moisture movement in plants and soil has virtually ceased at that time and a condition near equilibrium exists.

Variations in soil are almost always so great that soil will be the governing factor in both application rate and irrigation timing. The infiltration rate will have to be adjusted to the heaviest soil (lowest infiltration rate), and the timing will have to be adjusted to the lightest soil (lowest water-holding capacity).

CROP FACTORS

There are five main factors that affect plant growth Genetics, light, temperature, soil moisture, and availability of mineral nutrients Genetic factors would limit plant growth, even if the other factors could be kept at optimum The genetic constitution of a given plant variety or species sets definite limits on the development that plant is capable of However, **if** any of the environmental factors are above or below optimum, then they become the limiting or controlling factor in plant development.

For most agricultural operations, light intensity is determined by local climatic conditions Some crops, such as ornamentals, are altered by the use of artificial light, but the practice is limited.

Within given limits, the remaining factors can be altered to obtain the most desirable growing conditions. With proper cultural practices and application of water through sprinkler systems, critical temperatures can often be maintained at sufficiently high levels to avoid or minimize crop damage. Overhead sprinklers are used for some crops for frost protection. The overhead system utilizes a continuously forming layer of **ice to** prevent cold damage. The heat of fusion emitted upon the formation of ice maintains a temperature of about 31 degrees F as long as sufficient water is being applied. When water is not being applied, the ice temperature may drop below 31 degrees and damage the foliage it is intended to protect.

Maximum air temperatures can also be greatly reduced by the use of overhead sprinkling systems. Air-temperature reductions of 17 degrees F have been measured in the Central Valley of California, when the temperature was 95 degrees and the relative humidity 25%. Overhead irrigation during periods of extreme temperatures and low humidity will also reduce the moisture stress in a plant, prevent wilting, and thereby reduce blossom and fruit drop from many plants.

For some crops, the salt content of the water used for cooling is very critical. It is therefore urged that, if the water has over 120 parts per million of sodium or chloride, further advice be obtained from a competent authority prior to use for overhead cooling.

Growth of most land plants is restricted at both very high and very low levels of soil moisture. Extremely high moisture content adversely affects soil aeration and thereby usually restricts plant growth. It may also have an adverse effect on the behavior of soil micro-organisms such as the nitrifying bacteria.

Lack of soil moisture will result in excessive moisture stress in the plant. This stress causes a reduction in cell division and cell elongation and hence a reduction in plant growth. It may also cause the formation of an abscission layer and the dropping of leaves, fruit, and blooms. The uptake of plant nutrients from the soil is also restricted as soil-moisture stresses become excessive.

An adequate supply of plant nutrients is a prerequisite to maximum agricultural production. However, the supply of these nutrients alone is no guarantee of maximum production because one of the other factors may be limiting. The interaction of nutrients and available soil moisture is of particular importance. Most nutrients must enter the plant root in liquid form in conjunction with soil solution. Thus, as available soil moisture is reduced, so is the effectiveness of applied nutrients until water is added. On the other end of the soil-moisture scale, when the soil is saturated and oxygen content low, then nutrient uptake is practically stopped as plant growth ceases.

SECTION 7

FREQUENCY OF WATER APPLICATION

A single sprinkler system may be used for one or more purposes on a crop, or may be used on more than one crop in a year.

A system may be used for germination, irrigation, crop cooling, frost protection, or any combination of these. The total water requirement, pressure, and application rate must all be considered in relation to the multiple uses of a system. Each of the factors may vary greatly, depending on the system use considered.

The greatest water requirement at one time will be for frost protection, since at least half of the sprinklers should be running at one time. On the other hand, the application rate will probably be highest for irrigation, but only a portion of the sprinklers will then be running. Pressure requirements for frost protection and germination are higher than those required for irrigation or crop cooling. All the multiple uses of a system should be considered in the initial design of the system.

The required capacity of a sprinkler system depends upon the size of the area to be served; the purpose of the system; the depth of water to be applied; and the frequency with which the water must be applied to satisfy the peak demand.

The area over which the system is to apply water will be fixed unless the system is to be moved from one field to another. In that case, the system must be sufficient to cover the largest area adequately.

The depth of water to be applied during an irrigation will depend upon the effective rooting depth of the crop; the moisture-holding capacity of the soil; and the percentage of available moisture remaining in the soil at the time of irrigation. The above statement assumes that any required leaching would take place other than at irrigation, though a leaching requirement can be included and may increase the depth of application.

Irrigation frequency will depend upon the depth applied at each irrigation, and the peak water-use (evapotranspiration) requirements for the crop area. The system may only be used to its capacity for a short time each year; however, if adequate soil moisture is to be maintained, the system must be designed to apply water frequently enough to satisfy the peak moisture requirements of a crop for the local climatic conditions. (See Appendix for charts on rooting depths and peak water-use rates.)

To insure optimum growth with a maximum high-quality yield, it is critically essential to maintain a satisfactory balance between water absorption and water transpiration during plant growth. An optimum water content must remain in plant tissues at all times to assure proper functioning and development. This is the ideal situation seldom experienced under normal conditions in the field.

An excessively high water content associated with high humidity and low sunlight will result in an unfavorably high plant-tissue water content at many stages of plant growth When this situation occurs in maturing crops, they become very succulent and frequently deteriorate rapidly after harvest during the marketing period Tomatoes will be soft, low in solids, often poor in color, and commonly show "blotchy ripening"

However, when the opposite occurs – little available moisture during periods of low humrdity, high temperature, and intense sunlight – plants will lose water more rapidly than they can absorb it When these conditions prevail during seedling emergence, young plants may be stunted or, in extreme cases, 'burned off' During bloom, a suboptimum water balance in the plant increases blossom drop in beans and tomatoes and perhaps in peppers, melons, and cotton

Plants wilt at midday during June and July when incoming radiation is highest and little increase in growth is realized. The resultant crops are tough or fibrous in some cases, strong or bitter flavored in others, and fruits show a marked reduction in size In tomatoes, for instance, the plant withdraws some of the water from the fruit for transpiration through its leaves, and the fruit tissue, particularly at the blossom end, will dry out and rot, with the fruit exhibiting "blossom-end rot".

In many irrigation studies on crop productivity, the influence of regulating the level of available soil moisture was investigated, with ***little*** reference to the many atmospheric environmental conditions that influence the water balance in the plant. These studiessuggest that soils maintained at or above **50** percent of' available water-holding capacity will satisfactorily supply the crop water requirement

Recently it has been found this **is** true only when the environmental factors **of** radiant energy, humidity, and air movement **do** not result in a higher rate of water **loss** by plants than they are able to withdraw from the soil water supply.

SECTION 8

SPRINKLER SELECTION AND SPACING

Selection of the correct sprinkler for a system will depend on spacing, pressure available nozzle size, crop characteristics, soil characteristics. climatic factors and the purchaser's personal preference The designer should be fully aware of the performance characteristics and limitations of each sprinkler considered

Spacing and nozzle size may be adjusted within some limitations on most systems, to give the required coverage for the range of pressures expected On some permanent systems in trees and vines, the sprinkler spacing is fixed by the tree or vine spacing because it is desirable to keep the sprinklers in the rows If a fixed pressure is available, the sprinklers may be selected on that basis A choice of pressures would increase the choice of sprinklers Wind will also have an effect on sprinkler selection and sprinkler spacing.

Sprinkler spacing on the line should be from 30 to 60 percent of the diameter of coverage, when the sprinkler lines are placed across the direction of the wind. The higher the average wind condition, the nearer the spacing on the line should approach 30 percent of the diameter. The spacing of the lines should not exceed 65 percent of the diameter of coverage. Some latitude is allowed by the rooting characteristics of the crop. In a shallow, sparsely rooted crop such as some vegetables, extreme care must be taken to obtain **a** high uniformity of application, while crops such as trees, vines, and alfalfa can tolerate a lower uniformity. (See Appendix for table of sprinkler spacings according to wind speed.)

SECTION 9

PRESSURE REQUIREMENTS

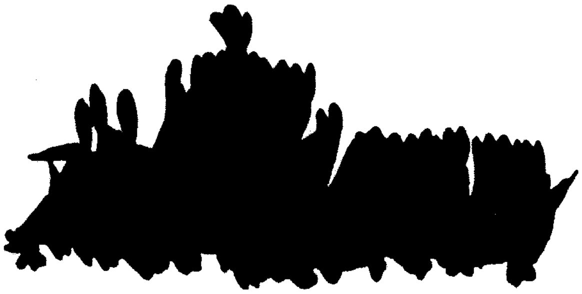
(Each sprinkler and nozzle size has a range of recommended operating pressures These may be found in the Rain Bird Agricultural Catalog, and should be adhered to)

Land elevations land slopes, and their relationship to the water source will have a direct bearing on the system design. They will affect the location of the mainline and laterals and the sizing of both to stay within recommended pressure variations. Differences in elevation of the sprinkler system can either increase or decrease available head or head **loss.** depending on land slope and direction of flow in the line.

The pressure at a point in a liquid is directly related to the height of the liquid above that point, allowing this vertical height or "head of liquid to be used as an indication of pressure Thus, pressures may be quoted in feet of head or pounds per square inch. The difference in head or pressure in a system due only to elevation **is** termed static head or static pressure Therefore, if the water in a mainline or lateral **is** running up hill, the change in elevation will be a head loss If the water in a line is running down hill, the change in elevation will be added to the available pressure The loss in pressure resulting from flow in a pipe and the roughness of the pipe is termed friction loss

A column of water 2.31 feet high produces a pressure of one pound per square inch. Thus, feet of water head may be converted **to** pounds per square inch, or vice versa, **by** use of the conversion factor 2.31. Feet of head are divided by 2.31 to obtain pounds per square inch.

LAYOUT OF LINES



Layout is often simple for a small, regularly shaped field but can be very complex for a large, irregular field In all cases, the factors previously mentioned will have an effect on the decisions to be made

The number of sprinklers operated at one time may vary from 2 per acre up to 35 per acre, depending on the time of year and the purpose of the system Water required per acre may vary from 5 gpm for irrigation in a moderate climate to 60 gpm for overhead frost protection The variation in the number of sprinklers operated at one time should be kept to a minimum In this way, it is possible to maintain a uniform load on the pumping plant For a portable system, the number of settings required for each lateral depends on the length of set and the number of days allowed for completion of one irrigation during the peak water-use season (Example if you have a 24-hour set and allow 14 days between irrigations then the number **of** sets for each lateral cannot exceed 14.) In a permanent or solid-set system, the laterals are all in place and may be used when the water is available or at the irrigator's discretion

Mainlines, or submains where used, should run up and down predominant slopes or along high ground such as a ridge whereas laterals may be run down both sides **If** it becomes necessary to run mainlines across the slope, the laterals should be split so that the pressure drop will be nearly equal on both sides In this case, the lateral on the uphill side will be shorter than that on the downhill side In either case, it is desirable to use a split lateral to reduce lateral size and minimize labor for hauling pipe back to the starting point in a portable system

The mainline should be sized so that the most economical balance between initial cost and pumping cost due to pressure drop is achieved For average power costs, if the pressure drop in the mainline exceeds 8 to 10 pounds per square inch, then it usually becomes more economical to go to the next larger size of pipe and reduce the energy required to pump against the added head

Pressure variation should be kept to a minimum to obtain a uniform distribution of water The maximum pressure drop from the first to the last sprinkler should not exceed 15 percent **of** the recommended operating pressure. If this criterion *is* adhered to, the variation in discharge from the first **to** last sprinkler will be less than **10** percent. **It** may become necessary in uneven terrain to install **pressure-or-***flow* regulating devices **to** meet these pressure variation criteria

Lateral ***lines,*** where possible, should be run across the predominant land slope **to** obtain split-line design and a **fairly** uniform head loss on both sides of the mainline This allows for equal lateral length on both sides of the mainline In addition, if the mainline is run uphill and the laterals across the slope the only pressure regulation points usually required are at the head of each lateral

Avoid running lateral lines uphill where possible When they must be used, it will be necessary to shorten them proportionally to the slope of the land Such a lateral is limited to that length in which the loss due to friction is equal to the difference between 15 percent of the operating pressure and the loss due to change in elevation For instance, if the difference in elevation is 10 percent of the operating pressure, then the friction loss will be limited to 5 percent and the length of lateral limited to that which will produce the 5 percent friction loss

Running lateral lines down slopes such as down both sides of a ridge from a mainline on top is often a distinct advantage, providing the slope is fairly uniform and not too steep When a lateral runs downhill, the difference in elevation between the two ends of the line becomes a gain in head rather than a loss This allows the laterals to be longer for a given size or of a smaller size than laid on level ground. If the slope of the land exceeds the loss in head due to friction, it may become necessary to install pressure-or-flow regulating devices in the line to avoid building up excess pressure and exceeding the pressure-variation limit.

Lateral lines should be located as nearly as possible at right angles to the prevailing wind direction. This allows for spacing the sprinklers closer together on the lateral, rather than the laterals closer together, and cuts down on the amount of pipe required Spacing of the laterals should follow the recommendations made under sprinkler selection ahd not exceed 65 percent of the diameter of coverage of the sprinkler used.

OPERATION OF SYSTEMS

The best prepared plans for a sprinkler system do little or nothing to achieve high production and efficient water use unless the components of the system are installed and operated as planned The installer, whether it be the designer, a professional installer, or the end user of the system should make every effort to follow the plans as drawn

The user of the system should be thoroughly familiar with the capabilities and limitations of the system to get the most efficient use from it A plan should be furnished to the user Such a plan should include a drawing of the design area, location of the water supply and pumping plant, locations of mainlines and laterals, and direction of movement of lateral lines (where it pertains), the length of lines required, and spacing of sprinklers. Operating characteristics of the sprinklers should be furnished and a recommendation made as to pressure, timing, and operation of the system

After all available information concerning soil, crop, water supply, purpose, and operating schedule has been obtained, the preliminary design work can be started

ECONOMIC ANALYSIS OF ALTERNATIVE SYSTEMS

Most irrigation systems are installed to make a profit for the owner Therefore, it is necessary to determine all of the costs of an irrigation system This total cost can be compared with the benefits received or the increase in income to determine what profit, if any, has been realized from the system

Often the only cost considered is the initial cost of the system This initial cost can be very misleading in fact, the initial cost is often less than one-third the total cost of irrigation

The following is a guide to figuring all the costs of an irrigation system The Capital Recovery Factor, as used here, combines depreciation and interest on investment into one number. Multiply the initial cost of equipment by this figure, and determine accurately how much the equipment costs per year. The following costs should be estimated:

FIXED COSTS—All costs including taxes and insurance where an initial outlay is made or a capital investment is extended. This should include annual depreciation charges and interest on capital investment.

Cost of getting water to farm —Water rights or shares in a water distribution system. Construction cost such as well, pumping plant. ponds, canals, pipelines, etc. Basic water charges per acre and annual

operational and maintenance charge, if applicable
Farm distribution system cost – Cost of pumping plant, mainline, laterals, etc Installation costs
Basic power charge if applicable
Taxes *and* insurance
ANNUAL OPERATION & MAINTENANCE COSTS
Labor of water distribution
Fuel or power costs
Maintenance such as ditch or leveling charges

TABLES TO HELP DETERMINE COSTS

ESTIMATED DEPRECIATION PERIOD FOR COMPONENTS OF AN IRRIGATION SYSTEM

Component	Depreciation Years
Well	25
Pump	15
Power Units	
Diesel	15
LP	12
Gasoline, Tractor Fuel	9
Air Cooled Gasoline	4
Electric	25
Power Mover	10
Concrete Structures	20
Concrete Pipelines	20
Wood Flumes	8
Pipe, Water-Works Class	40
Pipe, Steel, Coated, Underground	20
Pipe, Aluminum – Sprinkler Use	15
Pipe, Wood – Buried	20
Sprinkler Heads	8

ESTIMATED LABOR PER ACRE PER IRRIGATION

Type Move	Range Min.	Avg. Min.	Total Time Per Acre Per Irrigation Min. or Hrs.
Hand Move			
Move	20-40	30	
Return	6-10	8	**38 minutes or** 0.63 hours
Side Roll-Power			
Move	8-12	10	
Return	4-6	5	
Tractor End Tow			
Move	7-11	9	
Return	3-5	4	13 minutes or 0.22 hours

EXAMPLE OF COST COMPARISON OF VARIOUS TYPES OF SPRINKLER SYSTEMS

A 40-acre farm is to be sprinkler irrigated. Water source is a stream through the farm No charge for water. System is to be designed to cover the 40 acres in 10 days Irrigation season is 90 days Nine irrigations will be used for the season Labor available at $2 00 per hour

HAND MOVE SYSTEM – TWO MOVES PER DAY

System is moved twice per 24 hours Spacing is 40 feet x 60 feet. Precipitation rate is 0 34 inch per hour Total installed system cost is $3750, distributed as follows 5-inch and 4-inch aluminum main, $1600. Two 3-inch lateral lines, $800. 33 sprinklers, $150 Pump plant, $1200

CAPITAL RECOVERY FACTOR

Estimated Life Years	COMPOUND INTEREST RATE PERCENT									
	1	2	3	4	5	6	7	8	9	10
4		.2628	.2690	.2755	.2820	.2886	.2952	.3019	.3087	.3155
5	.2060	.2122	.2183	.2246	.2310	.2374	.2439	.2505	.2571	.2638
6	.1726	.1785	.1846	.1908	.1970	.2034	.2098	.2163	.2229	.2296
7	,1486	.1545	,1605	.1666	.1728	.1791	.1856	.1921	.1987	.2054
8	.1307	.1365	.1425	.1485	.1547	.1610	.1675	.1740	.1807	.1874
9	,1167	,1225	.1284	.1345	.1407	,1470	.1535	.1601	.1668	.1736
10	.1056	.1113	,1172	.1233	.1295	.1359	.1424	.1490	.1558	.1627
15	.0721	.0778	.0838	.0899	.0963	.1030	.1098	.1168	.1241	.1315
20	.0530	.0612	.0672	.0736	.0802	.0872	.0944	.1019	.1095	.1175
25	.0454	.0512	,0574	.0640	.0710	.0782	.0858	.0937	.1018	.1102
40	.0305	.0366	.0433	.0505	.0583	.0665	.0750	.0839	.0930	.1023

Electrical 15-hp centrifugal pump, 280 gpm at 140-foot TDH Brake horsepower required, 14 bhp

FIXED COSTS

Pump, $1200 Life 15 years
CRF 15 years at 5% = 0 0963
Cost per year = $1200 x CRF (0 0963) = $115.56

Aluminum Main, $1600. Life 15 years
CRF 15 years at 5% = 0 0963
Cost per year = $1600 x CRF (0 0963) = $154.08

Aluminum Lateral, $800 Life 15 years
CRF: 15 years at 5% = 0.0963
Cost per year = $800 x CRF (0 0963) = $ 77.04

Sprinklers, $150 Life 8 years.
CRF 8 years at 5% = 0 1547
Cost per year = $150 x CRF (0 1547) = $ 23 20

TOTAL .per year $369.88

(Insurance and taxes should be added to this)

OPERATING COSTS

Labor 0 63 hour per acre per irrigation time, 40 acres x 0 63 hour per acre per irrigation x 9 irrigations = 227 hours Cost per year = 227 x $2 00 per hour = $454 00

Power, 14 bhp 0 93 bhp per kw, 14 bhp x 0 93 bhp per kw = 13 kw per hour, 90 days x 24 hours per day = 2160 hours per season, 2160 hours x 13 kw per hour = 28080 kwh per season, 28080 kwh x 0 01 per kwh - $280 80 power cost

TOTAL COSTS

Total Fixed Costs	$ 369.88
Labor Costs	$ 454.00
Power Costs	$ 280.80
TOTAL COST per year for farm	$1104.68

COST PER ACRE PER YEAR $= \frac{\$1104\ 68}{40\ \text{acres}} = \$27\ 62$

HAND MOVE SYSTEM–ONE MOVE PER DAY

System is moved once per 24 hours. Spacing is 30 feet x 50 feet Precipitation rate is 0 18 inch per hour

Total installed system cost is $5318, distributed as follows 5-inch and 4-inch aluminum main, $1750 Five 2-inch lateral lines, $1634 110 sprinklers, $434 Pump plant, $1500

Electrical, 20-hp, centrifugal pump 315 gpm at 160-foot TDH. Brake horsepower required, 18 bhp

FIXED COSTS

Pump, $1500 Life 15 years
CRF 15 years at 5% = 0 0963
Cost per year = $1500 x CRF (0.0963) = $144 45

Aluminum Main, $1750 Life 15 years
CRF 15 years at 5% = 0 0963
Cost per year = $1750 x CRF (0.0963) = $168.53

Aluminum Lateral, $1634 Life. 15 years
CRF. 15 years at 5% = 0.0963
Cost per year = $1634 x CRF (0 0963) = $157.35

Sprinklers, $434 Life 8 years
CRF 8 years at 5% - 0 1547
Cost per year = $434 x CRF (0.1547) = $ 67.14

TOTAL...................................... per year $537.47

(Insurance and taxes should be added to this.)

OPERATING COSTS

Labor, 0.63 hour per acre per irrigation time, 40 acres x 0.63 hour per acre per irrigation x 9 irrigations = 227 hours. Cost per year = 227 hours x $2.00 per hour = $454.00.

Power, 18 bhp. 0.93 bhp per kw. 18 bhp x 0.93 bhp per kw = 17 kw per hour, 90 days x 24 hours per day = 2160 hours per season, 2160 hours x 17 kw per hour = 36720 kwh per season, 36720 kwh x 0.01 per kwh = $367.20 power cost.

TOTAL COSTS

Total Fixed Costs	$ 537.47
Labor **Costs**	**$ 454.00**
Power Costs	$ 367.20
TOTAL **COST** per year for farm	$1358.67

COST PER ACRE PER YEAR $= \frac{\$1358.67}{40\ \text{acres}} = \$33.97$

MECHANICAL MOVE SYSTEM–
TWO MOVES PER **DAY**

System is moved twice per 24 hours. Spacing is 40 feet x 60 feet. Precipitation rate is 0.34 inch per hour.

Total installed system cost is $5855, distributed as follows: 5-inch aluminum main, $1730. 4-inch lateral line with wheels, $2200. 33 sprinklers, $150. Power mover, $500. Mover engine, $75. Pump plant, $1200.

Electrical, 15-hp, centrifugal pump, 280 gpm at 140-foot TDH. Brake horsepower required, 14 bhp.

FIXED COSTS

Pump, $1200. Life: 15 years.
CRF: 15 years at 5% = 0.0963.
Cost per year = $1200 x CRF (0.0963) = $115.56

Aluminum Main, $1730. Life: 15 years.
CRF: 15 years at 5% = 0.0963.
Cost per year = $1730 x CRF (0.0963) = $166.00

Aluminum Lateral, $2200. Life: 15 years.
CRF: 15 years at 5% = 0.0963.
Cost per year = $2200 x CRF (0.0963) = $211.86

Sprinklers, $150. Life: 8 years.
CRF: 8 years at 5% = 0.1547.
Cost per year = $150 x CRF (0.1547) = $ 23.20

Mover, $500. Life: 10 years.
CRF: 10 years at 5% = 0.1204.
Cost per year = $500 x CRF (0.1204) = $ 60.20

Mover Engine, $75. Life: 4 years.
CRF: 4 years at 5% = 0.2820.
Cost per year = $75 x CRF (0.2820) = $ 21.15

TOTAL......................................per year $598.57

(Insurance and taxes should be added to this.)

OPERATING COSTS

Labor, 0.27 hour per acre per irrigation time; 40 acres x 0.27 hour per acre per irrigation x 9 irrigations = 97.2 hours. Cost per year = 97.2 hours x $2.00 per hour = $194.40 per year.

Power 14 bhp 0 93 bhp per kw, 14 bhp x 0 93 bhp per kw 13 kw per hour, 90 days x 24 hours per day - 2160 hours per season 2160 hours x 13 kw per hour 28080 kwh per season, 28080 kwh x 0 01 kwh - $280 80 power cost per year

TOTAL COSTS

Total Fixed Costs		$ 598.57
Labor Costs		$ 194.40
Power Costs		$ 280.80
TOTAL COST	per year for farm	$1073.77

COST PER ACRE **PER YEAR** $= \frac{\$1073.77}{40 \text{ acres}} = \$26.84$

SOLID SEMIPERMANENT SYSTEM

Precipitation rate is 0.18 inch per hour

Total installed system cost is $23,864, distributed as follows 5-inch and 4-inch aluminum main, $1750 Fifty-two 2-inch lateral lines, $16,600 1,118 sprinklers $4314 Pump plant, $1200

Electrical, 15-hp, centrifugal pump, 280 gpm at 140-foot TDH Brake horsepower required, 14 bhp

FIXED COSTS

Pump $1200 Life 15 years
CRF 15 years at 5% = 0.0963
Cost per year = $1200 x CRF (0 0963) - $115 56

Aluminum Main, $1750 Life 15 years
CRF 15 years at 5% - 0 0963
Cost per year = $1750 x CRF (0 0963) - $168 53

Aluminum Lateral $16 600 Life 15 year.
CRF 15 years at 5% = 0 0963
Cost per year, $16,600 x CRF (0 0963) $1598 58

Sprinklers $4314 Life 8 years
CRF 8 years at 5% - 0 1547
Cost per year - $4314 x CRF (0 1547) $667 38

TOTAL per year $2550 05

(Insurance and taxes should be added to this)

OPERATING COSTS

Labor	Installation	20 hours
	Removal	20 hours
	Turning laterals on and off	45 hours
Total		85 hours

x $2.00 per hour = $170.00 per year

Power, **14** bhp. 0.93 bhp per kw, 14 bhp x 0.93 bhp per kw = 13 kw per hour, 90 days x 24 hours per day = 2160 hours per season, 2160 hours x 13 kw per hour = 28080 **kwh** per season, 28080 **kwh** x 0.01 **kwh** = $280.80 power cost per year.

TOTAL COSTS

Total Fixed Costs		$2550.05
Labor **Costs**		$ **170.00**
Power **Costs**		$ 280.80
TOTAL COST	**per** year **for** farm	$3000.08

COST **PER ACRE PER YEAR** $= \frac{\$3000.08}{40 \text{ acres}} = \$75.00$

CONCLUSIONS

Hand move system, two moves per day, costs $27 62 per acre per year If the value of the crop produced is increased $8000 per acre, hand move system, one move per day, costs $33 97 per acre per year It would be more convenient to make one move than two moves per day Lower precipitation rate is used on one move per day which results in better soil condition and increased crop yields in most cases

Wheel move, two moves per day, costs $26 **84** per acre per year It is more convenient to use than hand move Wheel move is not readily adaptable to all crops and all fields

Solid semipermanent system costs $75 00 per acre per year An increase in quality and quantity of production is possible in many crops This *is* due to excellent moisture control, light frequent irrigations and low precipitation rates These systems also may be used for frost and heat control

All the above is intended as *an* example only Specific systems will vary according to design, acreage irrigation season, crop, power, etc Cost calculation must be based on individual system design and conditions

SECTION 13

PERMANENT AND SOLID-SET SPRINKLER SYSTEMS

Permanent sprinkler systems are installed with buried mainlines and buried laterals, and only the risers and sprinklers are above ground and above crop

Solid-set sprinkler systems are of two basic types both are installed with either a portable aluminum surface mainline, or a buried mainline with aluminum laterals above ground.

Solid sets *in* annual crops are set in place after planting, with laterals spaced the same distance apart as portable-system laterals would be moved Solid-set laterals are left in place until harvest when they are removed for harvesting operations and then returned for the next crop or are transferred to another field on the same basis

In some cases, a solid-set system may be used as a portable system in the off-season for pre-irrigation, seed germination, or multiple other uses.

Solid sets in permanent *or* perennial crops are installed on the same basis as annual crops, except that they are never moved and are sometimes anchored above the crops for stability

Solid-set systems (used for grapes, caneberries, and pole beans) have the aluminum laterals anchored on top of the posts They are set on the ground for various tree and nut crops, with low-angle undertree sprinklers which are not moved

Solid sets are also used in what is called convertible solid sets In this application, a completely portable system is used for normal irrigation and then laid out and added to for frost protection

Example For undertree use, a portable irrigation system is designed for eight-day coverage with one lateral to move once a day for eight sets A pump is installed to furnish the necessary water

After the fall Irrigation is completed, an additional three lines are set in place For frost protection, sprinklers are placed at twice the spacing on the line as for irrigation, so that while there are four times the number of laterals, there are only twice the number of sprinklers Thus, twice the amount of water is required A second pump, or standby, is needed to turn into the system during the frost period

If a grower does not have this additional water available he then must sequence every other lateral alternately every two to three minutes to cover the entire acreage

Permanent systems are used in vineyards and caneberries with risers anchored to the top of the posts In overtree sprinkler crops the risers are either anchored to posts or to the tree itself In undertree sprinkler crops (citrus, fruit, or nuts), the sprinklers are generally six to twelve inches above the ground with the risers supported by the soil or by concrete blocks poured in the ground In permanent pasture, the sprinklers operate on quick-coupling valves and are moved from valve to valve or they are on permanent risers and protected from stock by 4 x 4 posts rock concrete pyramids, or sections of concrete pipe

Permanent systems are just coming into use for strawberries and for annual crops such as cotton sugar beets potatoes, and alfalfa The future will see a marked use of these systems

The size and *gallonage of sprinklers used* in permanent and solid-set sprinkler systems vary with crop, climatic areas, soils, and use

In citrus undertree systems, the gallonage will vary from 0 5 to 1 8 gpm Overtree systems will vary from 2 5 to 15 gprn, depending on soil type, tree spacing, and wind conditions

Undertree would use the Rain Bird models 14V LA or 20A, at 20 to 50 psi

Overtree would use Rain Bird models 14, 14V, 20, 20A (– 23 deg), 298, 30, 30E series, 14070, 14600, 70E or 70EW at 45 to 65 psi

In undertree systems for fruit and nut crops, the gallonage will vary from 1.0 to 5 gpm, depending on soil type, depth, and tree spacing. These systems would use Rain Bird models 14V, 14V LA, 14, 20, 20A, 298, or 298 LA at 45 to 60 psi.

In vegetable crops such as lettuce and potatoes, the gallonage will vary from 1.25 to 6.5 gpm, depending on climatic areas, soil type, and variety of use. These systems would use Rain Bird models 14, 14V, 20, 298, 30, or 30E series at 50 to 70 psi.

Irrigation is generally the primary use of permanent and solid-set systems. These systems allow much closer control of soil moisture than any type of portable system, thereby resulting in a more uniform growth of plant and product and a more uniform product maturity. However, these permanent and solid-set systems also can perform other functions.

LEACHING OF SALTS AND ALKALI

Alkali soils being brought into production and soils that have accumulated salts through the use of high salt-content water require leaching.

The very nature of permanent and solid-set systems lends them to the low application rates necessary in leaching The soil never becomes saturated and never seals, thereby allowing a continuous leaching process

Use of solid-set or permanent systems is becoming an accepted practice for vegetables in salt areas where salt leaching is done in conjunction with germination

FROST PROTECTION

Using both permanent and solid-set systems for frost protection of crops *is* becoming widespread in certain areas.

There are two types of application employed. overcrop for protection by ice encasement, undertree for protection by circulation of moist air.

The ice-encasement method requires roughly twice the water per acre as the undertree method but gives a greater degree of protection, and must be used where water cannot be circulated under the plants. Generally, the water requirements are 54 gpm per acre for overcrop application and 27 gpm per acre for undertree application.

CROP COOLING

Crop cooling with both permanent and solid-set systems is becoming widely accepted It provides a means of preventing plant stress during extended hot periods The manner of use depends mostly on the amount of water available for a given acreage. With unlimited water, a system may be operated as a full-coverage system With limited water, every second, third, or fourth tine may be operated. The object is to have moisture available for evaporation throughout the area

GERMINATION AND PLANT ESTABLISHMENT

This application is used primarily for vegetable plantings with the triple objective of uniform germination, salt leaching, and uniform early plant establishment and growth (Solid sets are more commonly used than permanent installations.) These objectives are becoming more important to the grower as the necessity for uniform product maturity grows with the increased use of mechanical harvesting equipment The solid-set systems may remain in place to harvest, but, generally, when the plants are well established, they are moved to a new area to establish another crop

EXAMPLE OF PERMANENT AND SOLID-SET SPRINKLER SYSTEMS

A 40-acre fruit-tree crop with tree spacing of 16 feet x 16 feet on the square, would use an overtree system

The mainline would be buried as in the previous example

The laterals are laid directly down the tree rows north-south or east-west

The trenching is between the trees but far enough from the trees so as not to disturb the major roots

The risers are offset from the laterals with a sublateral to the tree row, and the risers are either supported by posts or concrete blocks or anchored to the trees for support, extending above the tree tops. The laterals may also be in the center of the tree rows, with the risers placed in the row perpendicular to the lateral trench

The risers and sprinklers are set in every third row, or tree, for a 48-foot spacing along the lateral, and a lateral is laid in every third tree row for a 48-foot spacing between sprinklers The sprinklers can be either staggered or square as to location There is a 48-foot x 48-foot spacing in either case.

The sprinkler is a normal field sprinkler with a nozzle Size of 9/64-inch and a stream height of *6* to 7 feet at 60-psi nozzle pressure. The discharge of the sprinkler is 4 38 gpm, and the application rate is 0.182 acre inch per hour.

The sprinklers used are Rain Bird models 20A, 23 degree–20-29B-30 series and 14600 series

Wider sprinkler spacings would require larger capacity sprinklers. However, for best coverage, all sprinkler spacings must fall within the diameter of coverage capabilities of the given sprinkler.

A 40-acre potato field. The mainline is buried (or aluminum portable) along one side of the 40-acre block.

The laterals are laid down the rows. The risers are generally 24 inches high and must be stabilized by a foot on the coupler **or** a stake driven in the ground.

The sprinklers are spaced 30 feet apart on the lateral, and the sprinkler nozzle size *is* 3/32-inch and operates at a minimum **of** 50 psi.

The 3-inch-diameter laterals are set in place every 45 feet, providing a **30-foot x 45-foot** spacing, which **is** common in potatoes.

The sprinkler would discharge **1.8** gpm, and the application rate would be 0.129 acre inch per hour.

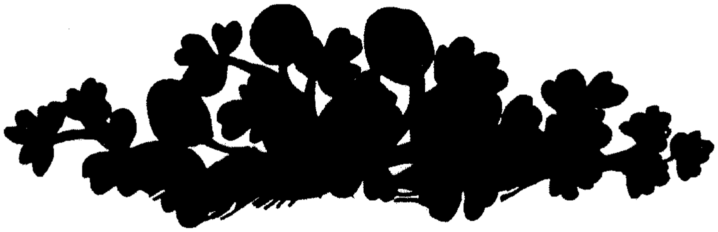
The sprinklers used are Rain Bird models 14 or 14V.

If the mainline were buried through the center of the field, the lateral size could be reduced to a 2-inch diameter.

While this example is common both in potatoes and vegetables, other sprinkler sizes and spacings are used.

Again, for best coverage, all sprinkler spacings must be within the diameter of coverage capabilities of the given sprinkler.

EXAMPLE OF SEMIPORTABLE SYSTEM DESIGN



Assume 40 acres of a certain crop in a square field, with a well in the center of the high end The well yields 500 gpm from a pumping level of 210 feet The available water is *of* such a quality that it may be used for overhead irrigation on most crops

Soil is a clay loam with a water-holding capacity of 2 0 inches per foot and a low infiltration rate such that it limits the water application rate to 0 14 inch per hour Assume this crop has an effective rooting depth of four feet and will be planted in rows 30 inches apart, solid planting The sprinkler system will be used for irrigation only and a pre-irrigation will take care of germination Since it will be used only for irrigation this will be figured as a semiportable system

Peak use rate of this crop has been established at 0 35 inch per day With 8 inches of available moisture in 4 feet of soil, irrigating when one-third the available moisture remains will give an irrigation frequency of 16 days It will require that 5 6 inches of water be applied at each irrigation Assume that this crop is grown in a semi-arid area and will require an irrigation efficiency of between 65 and 70 percent Thus, 8 3 inches of water must be applied at each irrigation With the infiltration rate at 0 14 inch per hour, this would require 60 hours of operation at each set Because 60 hours of operation would alternate morning and evening moving it would be better to cut back to a 48-hour set and irrigate more frequently If irrigation frequency is every 13 days for 48 hours, 6.5 inches of total water applied at 0 14 inch per hour would require 46 5 hours This would allow for an irrigation when approximately 57 percent of the available moisture had been removed and would allow 1½ hours to move the pipe every 48 hours

From the equation,

$$\frac{27154 \times I \times A}{H \times D \times 60} = \text{gpm}$$

the required flow rate to apply *6.5* inches of water every 13 days to 40 acres of land can be calculated.

27154 – Constant Multiplier for unit conversion to gpm.

I =	inches of water to be applied	(6.5)
A =	acres to be covered	(40)
H =	hours of operation per day	*(23.5)*
D =	days required to cover	(13)
60 =	minutes per hour	

Then,

$$\frac{27154 \times 6.5 \times 40}{23.5 \times 13 \times 60} = 385 \text{ gpm minimum}$$

From the performance tables in the Rain Bird Agricultural Catalog, the sprinkler, nozzle size, pressure, and spacing to accomplish the required irrigation can be selected The Rain Bird 20TNT with a $\frac{7}{64}$-inch nozzle operating at **40** psi will discharge 2 20 gpm at a diameter of 77 feet With a 30-foot x 50-foot spacing, this would put the sprinkler 39 percent of diameter on the line and *65* percent of diameter between lines Under a low wind condition, this should give a good uniformity, and the long 48-hour set will take advantage of changing wind conditions The application rate is calculated from

$$\frac{96.3 \times \text{gpm}}{\text{Area}} = \text{inches per hour}$$

where 96 3 = inches per square foot per hour
gpm = gallons per minute discharge per sprinkler
Area = spacing of sprinklers on lateral x spacing **of** lateral

Thus, the application rate would be

$$\frac{96.3 \times 2.20}{1500} = \mathbf{0.14} \text{ inch per hour}$$

If the well *is* located in the center of the high side, which is the ideal situation, with a slope of 0.3 feet per 100 feet away from the well, a mainline should be run down the center of the field with portable laterals at right angles to the main as shown in the following diagram.

With a split-line lateral design, the system will require 52 lateral settings 660 feet long. Each setting will require two days. Thus, nine laterals will be required to cover the area in 12 days, since the 48-hour set does not come out even with the number of lateral settings. Each lateral will require 22 sprinklers on a 30-foot spacing. The first sprinkler would be positioned 15 feet from the mainline and the last sprinkler 15 feet from the edge of the field. With 22 sprinklers on each lateral discharging 2.20 gpm, the total capacity of each lateral will be 48.4 gpm, and the total capacity of the system will be 415.6 gpm when all nine laterals are in operation. Since there will be laterals operating at several points along the mainline, the head-loss limitation of 15 percent of the operating pressure will apply to the loss in any one lateral. Where the operating pressure is 40 psi. the allowable head-loss is 6 psi.

When the Rain Bird Pipe Size Calculator is used, it is seen that for 22 sprinklers discharging 2.20 gpm, the head loss *in* 2-inch pipe would be 6 **psi.**

When the mainline size is chosen. the head loss must be kept below. 10 psi. The laterals will be rotated down one side of the main and back up the other. Thus, one lateral must be moved across each end of the field every 12 days for each irrigation. This will save the labor of moving two laterals the length of the mainline each irrigation.

The extreme mainline head-loss conditions will occur when all nine laterals are operating, and the last lateral is at the end of the main. When all laterals are operating, the flow rate will be 415.6 gpm. From the Rain Bird Friction **Loss** Calculator, mainline **loss** with 6-inch pipe would be 0.7 psi per 100 feet of line for 415.6 gpm. When the flow drops **to** 150 gpm, the head **loss** in 4-inch pipe is down 0.7 psi/100 feet. Since the land slope is 0.3 feet/100 feet, the total pressure gain in elevation is about 4 feet or 1.7 psi.

If the mainline **loss** is to be kept under 10 psi, it would be necessary to use 6-inch mainline. Since there will be a 5- or 6-pound head **loss** in the system, it would be desirable to operate with about 43 or 44 psi at the head of the mainline. This will allow for the loss in the system.

The power requirements for the system may be calculated with the Rain Bird slide rule. The flow will be 415.6 gpm for the nine laterals, with an operating head of 44 psi or 102 feet. In addition, there will be approximately 200 feet of lift in the well. The horsepower requirements for 415 gpm at 302 feet of head with a pump efficiency of 60 percent is 52 hp. The slight overload would allow the use of a 50-hp motor.

SECTION 15

EXAMPLE OF PERMANENT SYSTEM DESIGN

Assume 40 acres of almonds, on a 25-foot-square planting, located in a semi-arid area, where there might be frost when the trees are in early bloom Water comes from a canal on the high end of the land. which has an average slope of ½ percent Soil varies from clay to clay loam with a water-holding capacity of approximately 2.25 inches per foot between field capacity and permanent wilting percentage Application rate should be limited to 0.15 inch per hour to prevent runoff and erosion on the slope

The effective rooting depth is four feet The system will be used for both irrigation and undertree frost protection

Assume the water quality is good and that water delivery begins early enough **to** use the source of water for frost protection. The pumping plant will be located in the middle ot the upper end along the canal and must be of sufficient size to take care of frost protection as well as irrigation

Irrigation will begin when the soil moisture is 50-

percent depleted so there will be 4 5 inches for plant to utilize between irrigations

Trees with a deep-spreading root system, have an acceptable uniformity of application a little lower than a shallow-rooted crop With heavier soil, there will be more lateral movement of moisture than if the water were being applied to a sandy soil. For these reasons the uniformity of water application should be reasonable but not a major factor in the design of the system

During frost protection, one-half the sprinklers will be running at one time whether every other line is cycled or every other sprinkler on the line is plugged. Therefore the main lines must be sized with the flow for frost protection, and the laterals must be sized for irrigation.

During the irrigation season there will be 4 5 inches of available water to be used between irrigations if water is applied when 50 percent of the available moisture is depleted A reasonable peak use rate in a semi-arid region is 0 3 inch per day Therefore, irrigation water must be applied every 15 days during the peak moisture-use season (4.5 inches/0 3 inch/day   15 days)

Since the system will already be available for frost protection irrigation can be done in a much shorter time The timing will depend on the most economical use of power and labor It may be desirable not to use some of the pumping facilities for irrigation due to standby charges or availablility of portable power sources This will depend upon each individual case and cannot be generalized For this example the calculations are based on irrigation every ten days leaving time between irrigations for cultural practices

The sprinkler spacing will be set by the tree spacing It is accepted practice to put a sprinkler in every row between every other tree and stagger the sprinklers as shown in the diagram

With 25-foot by 25-foot tree spacing, the sprinkler spacing will be *25* feet x 50 feet, staggered With this type of sprinkler arrangement, there are no blind spots behind the trees because the area in the row which does not have a sprinkler in it is covered by those on either side

Cultural practices are limited to the direction in which the sprinklers are in the tree row. Therefore, the preferred direction of travel should be a consideration in laying out the system

Since it is necessary to have adequate pressure for frost protection, the system should be laid out with sufficient capacity From the Rain Bird Agricultural Catalog, a 3/32-inch nozzle at 55 psi will apply water at 188 gpm If a straight-bore nozzle *is* used in a Rain Bird 14V, the diameter of coverage will be 70 feet If a 20-degree nozzle is used, the diameter of coverage will be 57 feet Some growers prefer to have the lower angle stream to keep the water lower in the trees Either would be sufficient for good irrigation

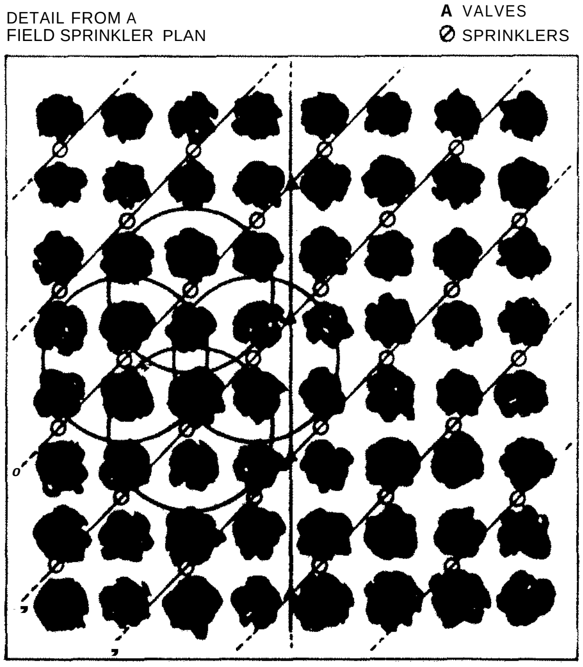
From the application-rate formula,

$$\text{inches per hour} = \frac{\text{gpm} \times 96.3}{\text{Area}}$$

Note that 1.88 gpm on a 25- by **50-foot** spacing gives an application rate of **0.145** inch per hour, which is under the allowable rate of 0.15 inch per hour This 0 145-inch-per-hour rate gives 3 46 inches gross, or about 2 78 inches net in 24 hours at an application efficiency of 80 percent. The higher application efficiency is applied undertree rather than overhead The **same** application rate gives 5.22 inches gross in 36 hours or **4.2** inches net with an 80-percent application efficiency Since the application will be for 4.5 inches every 15 days, it will be preferable to use a 36-hour set

The water supply is at the high side of the field, so the elevation change will be a gain in pressure of 0 5-foot per hundred feet of distance down the field Head-loss limitations of 15 percent of the operating pressure from first to last sprinkler should be adhered to

The most economical layout for a permanent system is laterals extending diagonally from the mainline instead of at right angles This allows a lateral every other row instead of a lateral every row, as would be required at right angles to the mainline As shown in the diagram below.



TYPICAL SYSTEM LAYOUT

NOTE **The size of both mainlines and laterals may be reduced by splitting the mainlines in a square field layout**

This will make the longest laterals about 478 feet and minimize the size of pipe required The sprinklers will be 35 4 feet apart on the line, and the lines 35 4 feet apart (instead of 25 feet apart, as would be the case if the laterals were run at right angles to the mainline)

There will be 34 8 sprinklers per acre, each of which will discharge 188 gpm Since the system will be irrigating 40 acres in ten days and running for 36 hours per set, the number of sets will be either six or seven Six sets would require nine days and seven sets, 10.5 days As the only difference for irrigation will be in pump size for summer use, six sets can be used and the irrigation completed in nine days This requires that 6 7 acres be irrigated at a time, and that 34.8 x 1.88 x 6.7 or 440 gpm be available for irrigation (For seven sets, the water required would have been 373 gpm)

The longest laterals will have 14 sprinklers, requiring 26 3 gpm per lateral The largest lateral will be 1½-inch pipe graduated down to ½-inch As the laterals become shorter, the size can be reduced to keep within the head-loss limits

As mentioned earlier, the sizing of the mainline will be determined by the total gallonage required for frost protection The most satisfactory application rate for undertree frost protection has been 0 06 to 0 07 inch per hour If every other sprinkler is plugged to obtain this rate, the gallonage required will be

$$\frac{34.8 \times 1.88 \times 40}{2}$$

or 1310 gpm. With the mainlines split, each main will start with 655 gpm and must be sized accordingly. It would be desirable to start with a 6-inch mainline and reduce it in size as the flow of water is reduced.

Note that the mainline losses for irrigation will be much smaller than for frost protection, while with every other sprinkler plugged, the lateral loss will be lower for frost protection than for irrigation.

The horsepower required for pumping will be quite different for irrigation and frost protection. If pump efficiency is 65 percent with pressure at the pump of 60 psi, 24 horsepower is required for irrigation. With the greater volume of water required for frost protection, 70 horsepower is required. It is evident that approximately 50 additional horsepower *is* required for frost protection.

The above example is for an undertree system, but it should be noted that with higher risers, it could just as well be used overhead in orchards or vineyards. If it were used for overhead frost protection, the mainlines would have to be enlarged to carry twice the flow because overhead frost protection requires an application rate of 0.12-0.14 inch per hour; for extreme conditions, even more gallonage.

SECTION
16

EXAMPLE OF HOSE-PULL SYSTEM

Hose-pull systems were originally innovated for use in citrus undertree irrigation, but are now being used more frequently in deciduous orchards and for some row crops It combines some of the features of a portable system with those of a permanent system The mains and sub-mains are buried with the riser attachment for the hose consisting of a flexible PVC section to a rigid pipe with a hose bib on top of the ground The line to the sprinklers is a flexible PVC hose that is cemented inside the sprinkler base or, in some cases, attached to the base with a female fitting The sprinkler bases are designed so that they may be installed in series with water flowing through one stand on to the next and so on The line is closed at the end with an end cap placed on the last base. sprinkler connections in the bases are usually either ⅜″ or ½′ NPT threads New plantings often receive their first irrigation from “spitters,” which are small stationary sprinklers having an opening on one side that may be directed to the base of the tree Spitters characteristically emit small amounts of water which satisfy the requirements of the young plants As the trees grow, the water requirements increase along with the size of the root systems. At this time, the spitters are replaced with small rotary sprinklers or impact sprinklers. Properly designed, a hose-pull system may be ultimately converted into a permanent system, since the buried mains and sub-mains are in existence and the buried laterals with risers may be added.

The soil is a clay loam, requiring a low application rate to prevent runoff. Irrigating alternate middles will allow for other cultural operations in the dry center. (When the trees are young, the sprinkler will throw part way into the next row, but as the skirts form, the water will seldom penetrate through the foliage.)

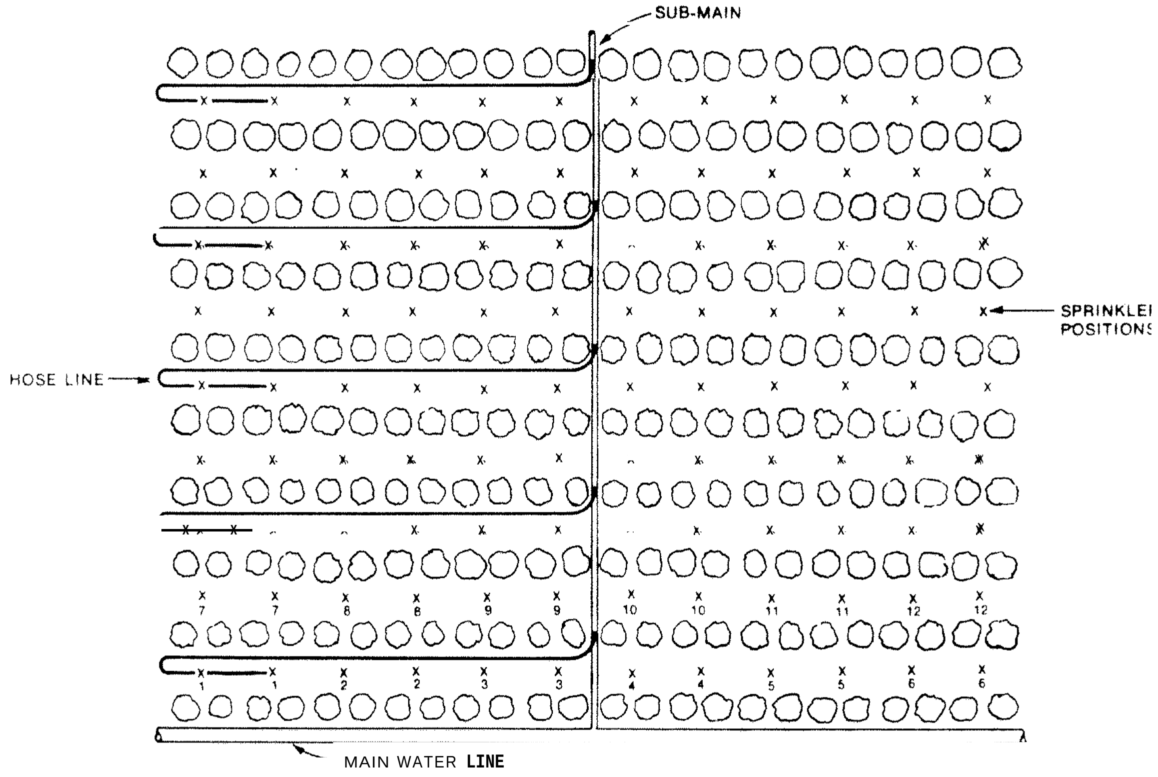
The trees are planted 12 feet in the row, and the rows are 20 feet apart. The effective rooting depth of an orange tree is about 4 feet; therefore, assume there is 4 inches of available moisture between irrigations. This will allow a safety margin on the heavy soil. The system will be used for irrigation only, and will be designed to cover every other center (between every other row) in six days. This is what Is commonly referred to as a 12-day system because both centers can be covered in 12 days. (A six-day system would have a hose in every tree row.)

A hose with two sprinklers spaced 24 feet apart will be installed on the submain in every other tree row. The sets will then be run as the numbers indicate in the diagram below.

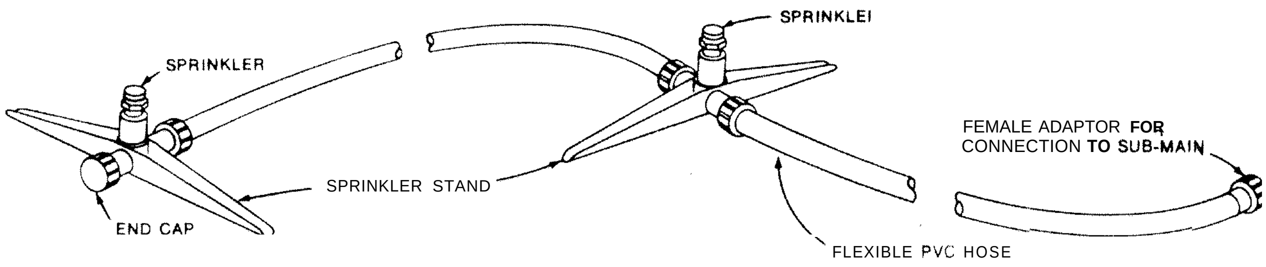
When a Rain Bird 14 V-LA-TNT with the 1/16-inch, 5-degree nozzle at 25 psi is used, 0.55 gpm per sprinkler will be discharged. On a 24-x 20-foot spacing. this gives an application rate of 0.11 inches per hour and will apply water to every tree during every 12-day irrigation cycle.

The attached diagram illustrates a 12-day hose-pull system. Two sprinklers are attached to each hose line. At the beginning of the irrigation, the sprinklers are positioned at the locations numbered "1." On the second day, they are repositioned to the locations numbered "2" and so forth until both rows have been covered by the end of the twelfth day. Since irrigation is taking place in only part of one row, cultural operations may be performed in the dry areas.

The length of hose between sprinklers may be any reasonable length to fit the tree spacing. If the trees were spaced extremely widely apart – walnuts would be an example – a single, larger sprinkler and base, such as Rain Bird 30, could be used with each hose.



12 DAY HOSE-PULL SYSTEM

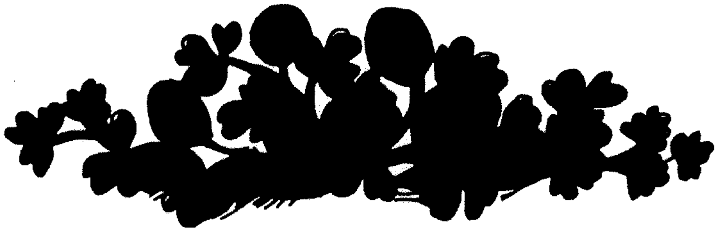


In this example, the land slopes are not steep enough to require pressure regulation, however, if the pressure differences exceeded the recommended 15 percent of the operating pressure, a flow regulator or flow disc could be inserted into the hose bibs

The sizing of mains and submains follows the same pattern as for other systems There are 17 hoses per submain, with two sprinklers per hose With 34 sprinklers on each of five submains, there is a total of 170 sprinklers At 0 58 gpm per sprinkler, the total flow rate is 98 6 gpm A 3-inch mainline could be used, being reduced as the gallonage decreased, as long as the overall head **loss** of 15 percent were not exceeded. The flow rate in the submains will be approximately 10 gpm each way from the mainline, so 1%-inch pipe would be used on the uphill side and 1-inch pipe on the downhill side. Again, the pipe size could be reduced as the gallonage **is** reduced. In the smaller pipe size, it *is* sometimes more reasonable to continue with one size, rather than spend the money on reducing fittings and labor to keep them straight and install them. This will depend on individual conditions and prices.

SECTION
17

SPRINKLER SYSTEM APPLICATIONS



Sprinkler irrigation has proven successful in the following types of installations

Agriculture

- Orchards (all types)
- Groves (all types)
- Hay
- Pasture
- Row crops (all types)
- Grain
- Vegetables
- Root crops
- Berries
- Cranberry bogs
- Green houses
- Lath houses
- Nurseries

Turf

- Golf courses
- Parks
- Cemeteries
- Athletic fields
- Public grounds
- Private lawns
- Race tracks
- Paddocks
- Airports

As mentioned earlier in this handbook agricultural sprinkler installations have more applications than surface irrigation Some of these specialized applications are discussed more fully below

CONTROL OF ALKALI

There are two types of alkali—white and black—found in what are termed alkali soils White alkali is composed of soluble salts and can be directly leached Black alkali is composed of insoluble sodium and potassium carbonates which must be chemically changed to soluble salts before leaching can take place The worst aspect of black alkali is its method of formation—the dissolving and dispersing of organic matter by carbonates—which defeats the purpose of organic matter

(This action also causes the black or dark brown color that gives black alkali its name) Sodium carbonate also disperses inorganic colloidal matter When organic and inorganic matter is dispersed, a Jellylike mass first forms and then becomes a structureless, impervious mass that is a soil-cementing agent Eventually, it prevents the percolation of water into the soil

The cure for white alkali is leaching with water and eliminating the source of the alkali, either by drain age, by improved irrigation practices, or both

The cure for black alkali is more involved and requires three steps: addition of gypsum and sulphur, leaching, and adding barnyard manure or planting green manure crops. The process is as follows. the sulphur becomes sulphuric acid and reacts with the calcium carbonate, and supplies soluble calcium in the form of calcium bicarbonate and calcium sulphate to replace the absorbed sodium Then the soil must be leached with water The addition of barnyard manure or green manure results in the formation of carbonic acid as the manure goes through the decomposition process from organic to humus, and forms soluble calcium bicarbonate The organic matter and resulting humus also improves the soil structure

Recommended application to reduce black alkali 1000 pounds each of gypsum and sulphur per acre Leach with water, and add barnyard manure or plant green manure crops

When alkali soils are leached the water-application rate should be slightly slower than the infiltration rate This permits the applied water to dissolve any soluble salts and percolate down through the soil Too fast an application disturbs the silt particles, causes them to cling together to seal off the soil from water and thereby defeat the purpose of the operation

APPLICATION OF FERTILIZERS

With the increasing use of sprinkler irrigation, there is a corresponding increase in the demand for liquid and soluble fertilizers that are applied through sprinkler systems

Application through sprinkler systems saves considerably in labor as both irrigation and fertilization are done in one operation The fertilizer, applied evenly throughout the area to be covered can be placed to any desired depth without danger of leaching With the fertilizer in solution or liquid form it is immediately available for plant use All of these factors combined produce a saving in both labor and fertilizer

Of the methods of introducing fertilizers into a system the best is through a fertilizer injector This is a sealed tank connected to the main line anywhere between the pump and the sprinkler lateral It can also be connected to a lateral on the first joint off the main line The injector is charged with the amount of fertilizer needed for the acreage covered, and the speed of application can be controlled as desired The injector can be shut off at any time while the system is operating if for any reason this is found necessary

After fertilizers are applied through a sprinkler system by any method, clear water must be flushed through the system for 20-30 minutes to wash all traces of the chemical out of the lines and off the growing plants

The proportion of 1 pound of liquid or soluble fertilizer to a flow of 10 gpm has been used without harmful results to any part of a system

QUANTITY OF FERTILIZER REQUIRED PER LATERAL SETTING

(Modified after Portland General Electric Company Agricultural Bulletin No. 52-3.)

Lateral length, ft	**No. of sprinklers, 40-ft. spacing**	**Area covered per 60-ft. setting, acres**	Quantity to apply **per** setting, for **rate of 100 lbs.** per acre, lbs.
160	4	0.22	22
200	5	0.28	28
240	6	0.33	33
280	7	0.39	39
320	8	0.44	44
360	9	0.50	50
400	10	0.55	55
440	11	0.61	61
480	12	0.66	66
520	13	0 72	72
560	14	0 78	78
600	15	0 83	83
640	16	0.89	89
680	17	0.95	95
720	18	1.00	100
760	19	1.05	105
800	20	110	110
840	21	1.16	116
880	22	1.21	121
920	23	1.27	127
960	24	1.32	132
1000	25	1.38	138

Example

An operator wishes to apply fertilizer at the rate of 300 pounds per acre He is operating 400 feet of lateral and moves it 60 feet along the main line at each setting How many pounds of fertilizer should he apply at each setting of the lateral?

From the quantity column at the right side of the table, opposite a lateral length of 400 feet, 55 pounds of fertilizer must be applied per setting to obtain a rate of 100 lb/acre. **For** the desired 300 lb/acre multiply 55 by 3 Thus, 165 pounds is the quantity of fertilizer to apply at each setting of the lateral

Lateral moves other than 60 feet

To obtain the quantity required for lateral moves other than 60 feet, multiply the quantity figure in the previous table by a correction factor, as follows

Lateral Moves Along **Main, Ft.**	**Correction** Factor
30	0.500
40	0.667
50	0.835
80	1.330
100	1.667

Example

Assume that an operator is making 50-foot moves of the lateral along the main line He has 960 feet of lateral and wishes to apply fertilizer at a rate of 400 lb/acre

From the table, 60-foot moves on 960 feet of lateral require 132 pounds of fertilizer per setting Multiplying 132 by 0 835 (the correction factor for **50**-foot moves) gives 110 pounds per setting For 400 lb/acre, multiply 110 by **4,** giving **440** pounds as the quantity of fertilizer to be applied at each setting of the lateral

FROST CONTROL

Frost protection with sprinklers is being practiced in all parts of the country on all types of crops Row crops such as celery, tomatoes, corn, potatoes, and similar crops trellised and high-growing crops such as grapes blueberries and related crops – all are sprinkled overhead, at an application rate of approximately 0 12-inch per hour with relatively high pressure

Low-growing crops – cranberries and strawberries – can withstand heavier ice loads and can be protected by slush ice

Tree or orchard crops have been frost-protected with small-nozzle, low-angle, undertree sprinklers 7-degree, $^{7}/_{64}$- or $^{1}/_{8}$-inch, on spacings of 60 x 60 or 60 x 80 feet (depending on tree spacing) and with a nozzle pressure of 50-60 pounds

Frost protection for all crops requires a minimum application rate consistent with adequate coverage **A** rate of 0 12-inch per hour is generally accepted and has proven satisfactory, down to 25 degrees, beginning at 34 degrees Fahrenheit and continuing until all danger of frost is over and all ice is melted The latter is the critical period, and water must be applied continuously until all traces of ice have disappeared

There are two reasons for the low rate The first is to keep the ice load to a minimum and the second is to avoid applying too much water to the soil **As** frost protection may be required four or five nights in a row, high application rates could waterlog the soil, especially if the area has been pre-irrigated

Protection has been achieved with various row crops to 20 degrees Fahrenheit, orchards and nuts to 23 degrees Fahrenheit, grapes and blueberries to 18 degrees Fahrenheit using higher application rates

These are minimum temperatures actually experienced with complete protection The lowest temperature limit with complete protection is unknown at present, but field checks are becoming prevalent *on* an ever-expanding variety of crops

Frost protection by sprinklers is attributed **to** the following factors. When water changes to ice, heat is released, thereby raising the area temperature **Also,** the fog forms a blanket-like protection, which tends to hold the ground heat. When the temperature rises above the freezing point (and especially when the sun's heat hits the ice), heat is absorbed, and the ice melts. The heat **is** regained from the humidity in the air. If there were no moisture in the air, heat would be drawn from the product, resulting in cell breakdown and frost damage

SPACING OF SPRINKLERS FOR FROST CONTROL

Complete and continuous application ***of*** water is required, especially during the thawing periods. This requires the use of solid or permanent systems.

The system design will be determined by the primary use required by the customer, whether the system is for frost control and heat control and whether a normal irrigation program is **to** be incorporated.

Needless to say, a system designed only for undertree frost and heat protection does not need the high uniformity of application required of a normal irrigation system. Wider spacings can be used to achieve approximately 0.07-inch per hour, consistent with good coverage but not high uniformity.

COOLING CROPS

The value of sprinklers for cooling crops was mentioned briefly in the section on frost protection because the two systems are quite similar in design and operation. The one big difference is that water for cooling does not have to be applied continuously as in frost protection. One solid system in operation for grape cooling proved that an adequate temperature reduction could be maintained by **5**-minutes-on and 15-minutes-off alternation during a 6-hour cooling period. How much longer the water could remain off and still give adequate cooling is not known. Further experimentation is needed.

IMPORTANCE OF UPPER SOIL MOISTURE

The greatest advantage **of** the solid-set systems used **so** far for various crops is the ability to control the upper soil moisture, particularly keeping moisture in the upper one-third of the rooting area above the wilting point. The reason this control permits more growth and better quality of product is that the roots never stop feeding the plant Consequently there is no retardation of plant growth or the product on it due to lack of water in the high-use area It has been proven that water use from the upper one-third of the soil area is approximately 50 percent of the total plant water use

There is a difference in the amount of available water in different types of soil before the wilting point is reached So that roots will constantly grow and be constantly supplied with water, not more than 75 percent of the available water in a light soil should be used between waterings, and not more than 60 percent of the available water be used before returning moisture to a heavy soil

A solid-set system means higher initial cost A portable system may require only three ¼-mile laterals per 40 acres whereas a solid-set system will usually require 33 of these same laterals, if the spacing between is 50 feet This can mean as much as $700 per acre and when faced with this cost for sprinkler irrigation, the grower naturally wants to be able to raise the maximum crop with a maximum No 1 quality product Of course, growers who are willing to pay the extra initial price for solid systems are also willing to pay a little extra to hold their pipe to a size that assures as near uniform pressure as possible in all parts of the field For the design of any system, it is advisable to collate all basic information on soil type wind direction and velocity, and crop to be grown Rain Bird will then suggest the best possible set of sprinkler combinations that fit the particular job and result in the best uniformity of water application

Most semipermanent or solid systems laid out for a given crop can often also be used for another crop These can be used as completely portable systems after the initial crop is harvested For instance, a solid system can be taken out of potatoes at harvest time, and used to pre-irrigate a large area for grain, cotton, alfalfa, or some other crop, or be used to bring up a seeding on a crop

It is necessary therefore, to discuss with the grower the possibilities of additional use of his solid system before a design and particularly the pipe sizing is determined If the system is to be used only for solid sets, the designer may be able to specify much smaller pipe than would be required if the system were to be used later as a portable unit The importance of thorough discussion of all possible uses of a solid system prior to design cannot be stressed too strongly

To date, the most popular and seemingly the most successful design for solid systems is one which limits the length of the lateral to approximately 660 feet This requires division of a 40-acre field by a main line, with laterals in both directions, spacing the sprinklers 30 x 50 feet (i e , sprinklers 30 feet apart on the lateral, and laterals spaced every 50 feet throughout the field). The sprinkler most often used is the Rain Bird **30-W**, single nozzle ($^{9}/_{64}$-inch to $^{3}/_{16}$-inch) that uses a pressure of **45** to 50 pounds The size of the nozzle, of course, will be determined by the soil texture and the rate of application that should be used on a given area.

AERATION IRRIGATION

There is a new concept in sprinkler irrigation that the industry calls "aeration irrigation". This method is based on very low application rates, approximately one-half the normal intake rate of the soil, combined with **good** nozzle pressure. The application rates vary from 0.3-inch per hour on very light soils to 0.2-inch per hour on medium textured soils, and 0.10-inch to 0.15-inch per hour on heavy soils. The nozzle pressures range from 50 psi on nozzle sizes up to and including ⅛-inch; 55 psi on nozzle sizes $^{9}/_{64}$-inch to and including $^{3}/_{16}$-inch; then adding 5 psi for every $^{1}/_{32}$-inch increase in nozzle size. Generally, aeration irrigation requires twice as many laterals per given acreage with sets twice as long as previously considered normal. With deep-rooted crops like cotton, alfalfa, orchards, or nuts, 24-hour sets are being used in place of 12-hour sets. On shallow-rooted crops, the length of sets is usually doubled and the application rate cut in half. The results have more than offset the added equipment cost.

The labor situation is greatly improved. It takes no more labor to move, say six lines once per day than to move three lines twice per day. On a once-a-day move, the work is all done at one time, generally in the morning hours, rather than having to return after 12 hours to move pipe again, which usually means a 14 to 16 hour working day. Aeration irrigation has resulted in improved soil structure and elimination of soil compaction. These results have been produced with various crops and with all types of soil. The method has been particularly successful with extremely heavy soils and with the various soils in which orchard and nut crops are grown. (The latter are subjected to heavy machinery such as spray equipment when the soils are wet.) All of these soils have become very friable and almost sponge-like in texture and have retained these qualities.

Greater yields and more No. 1 quality products have also resulted from this new application method when it is combined with good irrigation practices. This means pre-irrigation to the bottom of the root zone or supplementing winter moisture. Also special attention must be given **to** the maintenance of soil moisture in the upper one-third of the root zone, keeping it above the wilting point at all times. The grower must check soil moisture either with recording instruments or by digging in the soil both before and after irrigation

Why has this new method of sprinkler irrigation produced these results? We in the sprinkler industry and the growers who have used this method believe it is because the low application rate combined with good pressure does not disturb any of the silt particles in the soil, and air and oxygen is never entirely excluded from the soil profile Air is actually taken into the soil with the irrigation water, hence the term ' aeration irrigation"

With a good supply of air and oxygen in the soil at all times, continuous interaction of soil bacteria, soil micro-organisms, earthworms, etc is established, producing a continuous exchange of gases in the soil

Through the action of the various soil organisms, there is a liberation of carbon dioxide, ammonia, nitrogen, and some mineral salts all of which tend to improve the soil and provide a better feeding area for the roots And, of course the movement of the gases makes the soil more friable, easier to work, and less prone *to* compaction

The soil air contains much less oxygen than the atmospheric air and considerably more carbon dioxide The large amount of carbon dioxide in the soil air causes an appreciable amount of the gas to be dissolved by the soil solution to form carbonic acid, a very weak acid. This carbonic acid is very important from the standpoint of availability of plant nutrients. Such compounds as tricalcium phosphate or calcium carbonate are practically insoluble in water but are soluble in weak acids.

There are many beneficial results from soil bacteria activity, all of which produce a healthy soil and a healthy environment for feeder roots This in turn makes for a healthier plant and better yields and quality product.

It is strongly believed that even further favorable results can come from aeration irrigation in the control **of** plant diseases and reduction of harmful insects.

The end results of aeration irrigation for all crops and on all **soil** types have been less overall operating costs, better soils, greater yields, and more No 1 quality products

All of these factors produce more net dollars per acre for the grower—a necessary consideration in the face of rising prices of everything that goes into a farming operation

SECTION
18

AUTOMATION OF SPRINKLER SYSTEMS

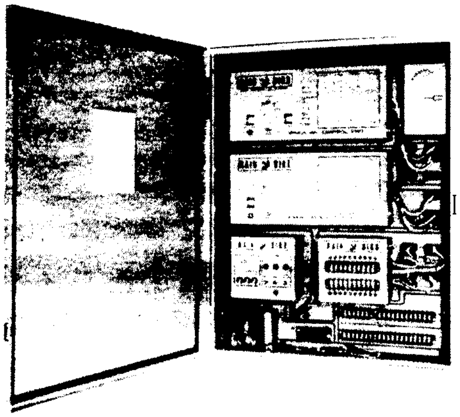
Automatic control of sprinklers started in large turf systems particularly on golf courses, where watering time is limited to the periods when no play is taking place The trend has been accelerated in recent years by the short supply and increasing cost of labor And the trend has been aided by the availability of much more dependable and versatile control equipment

The use of solid-set and permanent sprinkler systems for agriculture has led to different controller requirements Watering periods in agriculture are usually of fairly long duration from 12 to 36 hours And in addition to irrigation the controllers are being used for crop cooling and frost protection.

Once the decision to install a permanent or solid-set system has been made, the increased investment required for an automatic system is relatively small. The only changes required are: replacing the manual valves with electric or **hydraulic** valves; running wire or tubing to the valves; adding **a** controller of the appropriate design to do the required timing.

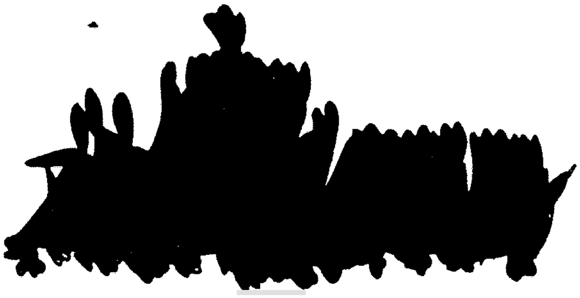
Automatic water application may be used for irrigation, crop cooling or frost protection, or for any combination of the three. Until very recently, control systems were operated solely on clock settings. A system could be programed to turn on at any selected time during the day, with a two-week selection of days provided on the more up-to-date controllers Several stations could be controlled sequentially with variable time setting for each station and provisions made for skipping some stations where desired

Later refinements of automated systems include the addition of external sensors to automatically protect the crop from environmental threats and to improve irrigation efficiencies. Controllers such as the Rain Bird **Agro-matic** System **AG-20** Rain Clox are designed for automatic irrigation programming and, in addition, may be activated by external sensors such as thermostats or anemometers to protect the crop from environmental threats. Provisions are made for rapid cycling or operating stations simultaneously for frost protection, crop cooling, or for wind erosion control on new plantings. Moisture sensing devices are used to irrigate on the basis of soil moisture. The controller is programmed to start at the desired time every day. If the soil moisture is sufficient, the electrical circuit of the controller is interrupted and irrigation will not start. When the amount of **moisture falls** below the desired level, a switch is closed which allows the controller to perform the irrigation upon the **next start signal from the clock.**



RAIN BIRD AGRO-MATIC SYSTEMS CONTROLLER

UNIFORMITY OF WATER APPLICATION



A very important criterion for judging sprinkler performance is uniformity of water application The measurement *of* uniformity is based on measurements of water caught in a series of equal-sized containers placed so that each represents an equal area of soil surface The containers are usually set right on the soil surface, but in a tall-growing crop, they must be put on stakes to prevent the foliage from interfering with distribution They may be equally spaced around a single sprinkler, across an area between two sprinklers on a lateral, or in the area between two laterals in a solid-set system

When a single sprinkler or lateral is used, the grid must be large enough to catch the extreme boundaries of the pattern even in windy conditions The water caught in each container is then measured and recorded on a table corresponding to the position of each container The patterns may then be overlapped for any desired spacing The application from all sprinklers affecting the net area must be included. The figures representing the accumulated catch at each point are then used in the evaluation of the uniformity of application.

The most commonly used expression for evaluating sprinkler patterns was developed by **J. E Christainsen**[1] This is designated the Uniformity Coefficient (Cu), and when expressed as a percentage is defined by the equation

$$cu - 100\left(1\ 0 \quad \frac{\Sigma x}{mn}\right)$$

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1 Christiansen J E *Irrigation **by** Sprinkling* Bul 670 U C 1942

where

Σ summation
X deviation of individual observations from the mean
m = mean or average value
n = number of observations

An absolutely uniform application is then represented by a uniformity coefficient of 100 percent and a less uniform application by some lower percentage

A sprinkler system may be designed to give very high Uniformity, but unless the crop has high value or the crop response to water applied is high, the system may be too costly to be practical

The Uniformity of water application with sprinklers is dependent on several variable factors The major factors ranked in approximate order of importance are as follows

1 The sprinkler selected
2 The sprinkler spacing (overlapped area)
3 The nozzle size and its operating pressure
4 Wind speed and direction

Sprinkler Model Sprinkler manufacturers should be able to help field-irrigation engineers select the sprinkler to be used for high uniformity this is based on distribution profiles for various nozzle and pressure combinations and uniformity figures for a variety of common spacings under a variety of wind conditions

Sprinkler Spacing The distance between sprinklers has an extreme effect on uniformity especially in areas where winds can be expected to exceed 5 mph In general, spacings should be closer across the wind for high-wind conditions (See Chapter 8, Sprinkler Selection and Spacing , and Table of Sprinkler Spacings in the Appendix)

Nozzle Size *and* Operating Pressure The effects of nozzle sizes and operating pressure on the sprinkler stream are closely linked It is important that the operating pressure be matched to the nozzle size If the nozzle is too small or the pressure too high, the sprinkler is “over forced ’ The stream breaks up into small droplets causing a decrease in sprinkler range and resulting in rapidly deteriorating uniformity in high winds If the nozzle is too large or the pressure too low, the sprinkler is “under forced” Breakup of the stream is limited, the droplet size is large and the stream cohesive, causing a typical “doughnut” pattern and resulting in poor uniformity throughout a range of winds Only when the nozzle-pressure combination is “balanced” can the best uniformity be obtained throughout a range of winds

Wind Uniformity is affected because wind increases the breakup of the sprinkler stream and blows the resulting droplets around Due to the difference in the mass of the drops wind will affect small droplets more than large ones A steady wind causes the upwind-sprinkler radius to be shortened and the downwind radius to be lengthened If the wind varies in speed and direction, an area getting little precipitation at one time may receive heavy precipitation the next because of changing wind conditions. Therefore, a gusty wind of variable direction actually may give a uniformity that is somewhat higher than a constant wind.

Uniformity of water application can be drastically affected by wind. **It is** the one major factor which cannot be controlled. However, an appropriate choice of spacing and other design parameters can minimize the adverse affect of wind on uniformity. For example, a Rain Bird model 30 TNT with a 5/32 x 3/32 – 7-degree nozzle combination operating at 60 psi will yield uniformity coefficients as indicated by this table:

	Coefficient of Unlformity	
Spacing	**2-mph** Wind	**9-mph** Wind
40 x 40 Rec	92%	84%
50 x 50 Rec	88%	63%
60 x 60 Rec	80%	31%

If it has been determined that 80 percent is the minimum uniformity acceptable, the table shows that any of the spacings may be used under low-wind conditions.

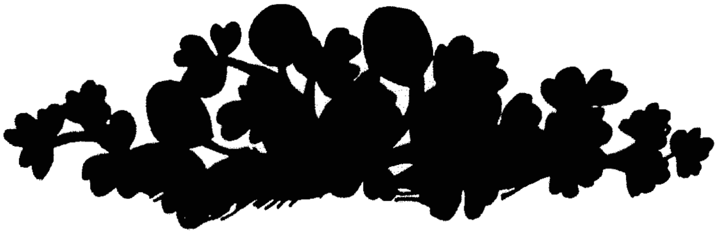
However, of the spacings mentioned, only the 40 x 40 spacing will still give a uniformity coefficient better than 80 percent in winds of 9 mph Therefore, if the sprinkler system is to be operated in an area of potential high winds, only the 40 x 40 spacing will guarantee an acceptable uniformity coefficient throughout the range of operating conditions

When sprinkler systems are evaluated by a comparison of uniformity figures, it is important to realize these uniformity figures are only accurate to within a few CU numbers This tolerance is required because of these factors

1 The method of testing uniformity
2 The way in which wind speed and direction vary during a test
3 The manner in which wind speed and direction are measured
4 Variations between individual sprinklers of the same model

Hundreds of tests on one model sprinkler were made under nearly identical conditions, from this, it was determined that the variation in CU is approximately ±3 CU numbers when uniformity is approximately 85 to 90 and approaches ±1½ CU numbers as uniformity approaches 95 This means that, for all practical purposes, uniformity coefficients of 83 and 85 are equivalent The wider variation in lower CU numbers arises from the conditions which give low uniformity These conditions are high winds, incorrect nozzle pressure combinations, and stretched spacings It is to be expected that uniformity under these conditions will fluctuate more in response to wind variation than if the wind were low and the spacing more favorable

EVAPORATION FACTORS



EVAPORATION LOSSES[1]

Sprinkler irrigation losses vary with the nozzle size, pressure and climate conditions Generally the losses are negligible at low temperatures and high humidities

If the spray is not very fine at low wind velocities, moderate temperatures, and humidities, the peak losses will be about 4 to 6 per cent and on hot, dry days 10 to 12 per cent No other losses should be included when determining the sprinkler irrigation efficiency on growing crops, especially those covering the soil In the case where bare soil is sprinkled, the losses for the spray should be doubled when determining the irrigation efficiency. Evaporation at the surface of bare soil has been found to be about equal to the spray losses during the sprinkler operation at application rates of 0.3 to. 0.4 inches per hour

The evapotranspiration loss per hour during sprinkling has been found to be less than between sprinkling periods, on crops that cover the ground. Therefore, this loss can be disregarded when sprinkler irrigating under these conditions.[2]

All sprinkler irrigation losses are very low at night and reach a maximum at two or three o'clock in the afternoon. If sprinkler irrigating for 24 hours a day, average losses are one-half (or less) of the peak losses or a total of 10 to 12 per cent on bare soil and 5 to 7 per cent on crops for hot, dry weather conditions. For moderate weather conditions the average total loss would be 5 to 10 per cent of the water applied to bare soil and 3 to 5 per cent on growing crops Under low airtemperatures and high humidities average losses are negligible at low wind velocities for all sprinkler irrigation and may approach 5 per cent at 10 to 15 miles per hour

INTERCEPTION AND SUBSEQUENT EVAPORATION OF WATER FROM PLANTS

When crops are sprinkled, part of the water is intercepted by the foliage and later evaporated without reaching the soil. Studies of rainfall interception by various investigators indicate that an appreciable amount may be caught by trees and other plants, especially when the rain occurs in small storms. The determination of rainfall reaching the soil under a vegetive cover is difficult, and results are not always consistent..

Furthermore, the interception is generally reported in per cent of rainfall, and therefore depends upon the intensity and duration of the storm. Clark[3] made determinations of the maximum interception capacity of many plants.

From his data it appears that few crops can retain 0.1 inch of water, although his attempts to measure interception by catching water in pans under the vegetation indicate much larger losses.

Interception of rainfall and that for water applied with sprinklers should differ principally in the amount that evaporates during the application. The evaporation rate while sprinkling may be high, whereas during a rain evaporation rates are generally very low. The presence of water on the foliage should temporarily reduce the rate of evaporation from the soil and the rate of transpiration from the leaves.

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[1] Reprinted from *Agricultural Engineering*, Vol 36, #8 Pages 526-528 August 1955 K E Frost/H C Schwalen University of Arizona

[2] Reprinted from *Transactions of the ASAE* 'Evapotranspiration During Sprinkler irrigation , Vol 3 No 1 Pages 18-20 24 1960

[3] Clark O R , Interception of Rainfall by Prairie Grasses Weeds and Certain Crop Plants Ecological Monograph- 10 243 77 April 1940

SPRINKLER IRRIGATION WITH HIGH SALT CONTENT WATERS

There are many areas that have irrigation water of high salt content. These areas pose special problems in irrigation practices and especially when using sprinkler irrigation

It is common practice when irrigating with sprinklers, to irrigate to the bottom of the root zone of the plant each irrigation However, when using a high salt content water, this practice must change, because each irrigation fills the soil to the bottom of the root zone, the plant uses the water and leaves the salt This is repeated several times each season, which results in an accumulation of salt in the soil. When carried on for several years the soil becomes very saline, and has a very detrimental effect on the plants, especially on citrus trees The result is less and smaller fruit, or produce and a gradual die-back of the feeder roots and then the death of the plant This generally shows up first in a yellowing of the leaves

To irrigate by sprinklers successfully with a high-salt-content water, it is absolutely necessary to leach the soil once a year and wash the past year's accumulation of salts below the bottom of the root zone

The leaching, of course, can be done at any time of the year However, it is generally done early in the spring when the weather is still cool, the plant water use is low, and there is time to leave the sprinklers in each location long enough *to* carry the salt well below the root zone

The time required to leach will vary from 1½ to 2½ times the normal set, depending on soil type and rate of application The main object is to remove the accumulated salts This must be thoroughly checked, after the first set, to determine the depth of water penetration. In light, sandy soils, this check should be made 24 hours after the water is shut off and in heavy soils, 36 to 48 hours after. These are the times usually required for the water to reach its ultimate depth. It is, of course, first necessary to determine the depth of the plant roots so as to determine the depth of water application necessary.

After this one deep irrigation, each successive irrigation during the year should be to the bottom of the root zone of the plant.

These high-salt-content waters, found in various areas throughout the world, are of general concern to crop growers.

One point to be remembered is that any leaching of the soil will leach out favorable salts and fertilizers as well as harmful salts It will, therefore, be necessary to add additional fertilizers, especially nitrates, after the yearly leaching. Additional care must be taken when sprinkling overhead with high-salt waters. As was mentioned earlier, waters high in sodium and chloride ions can be detrimental to plant growth. Extreme care must be taken when waters with a boron content of **1** ppm or over are sprinkled.

COOLING CROPS WITH SPRINKLERS

Water temperatures become extremely high for long periods, the benefits of cooling crops with sprinklers have definitely been proven.

Today, practically all crops raised in high temperature areas can be cooled successfully with sprinklers, including fruits and nuts, vegetables (especially potatoes), strawberries, pole beans. and caneberries.

Plants have a given capacity to draw water from the soil in order to transpire moisture into the atmosphere through the stomata (pores) of the leaves. The stomata also takes in carbon dioxide to manufacture carbohydrates, and emits oxygen. At high atmospheric temperatures (high 90's and up), the root system can no longer pump sufficient moisture and the stomata will close, with water movement in the plant stopping. If this condition continues beyond 4 to 5 hours each day for several days, the plant begins drawing moisture from the product it has formed with resulting cell breakdown, causing blossom and fruit drop. This fruit drop occurs when moisture is withdrawn from the fruit-supporting stem, causing cell breakdown with the stem drying and weakening, causing the fruit to drop. Blossom drop may occur from lack of moisture in the pistil, due to high temperatures or lack of soil moisture.

The important point is that, regardless of adequate soil moisture, damage will occur at high temperatures from heat stress.

MANY VARIATIONS

A cooling system has a number of variations of application, depending upon whether it is a manual system, a sequencing lateral system, or a block-sequencing system. Moreover, cooling takes less water than a frost protection system while at the same time providing good irrigation.

With some exception, **a** good cooling and irrigation system needs to be a permanent or solid set system. In such crops as cotton, sugar beets, and tomatoes, however, a low application 24-hour set portable system is satisfactory. With many small capacity sprinklers on lines with not too great a distance between laterals (usually not more than 300 feet) a drift of moisture carries humidity to all plants in the field assuming of course, that there is good pressure for good breakup

REDUCES TRANSPIRATION REQUIREMENTS

It was formerly thought that this water, drifting and cooling the plants, was completely lost to the crop However many tests, especially those made at the University of Arizona have proven that when adequate humidity is circulated throughout the crop area or over the crop area the transpiration rate is greatly reduced Therefore, the draw on the water reservoir in the soil is greatly reduced and that water which was supposedly lost to evaporative cooling is offset by the fact that much is saved by the reduction of transpiration during the irrigation period

It might be that even the tree crop systems on a portable basis undertree, where the same low application 24-hour set system is used, also gives a high degree of cooling in these various crops It must be remembered that in extremely high temperatures this type of cooling system gives limited results In other words, it does not give the ultimate result as a solid or permanent system

There are three general cooling systems in either the permanent or solid type

1 The Manually Operated System—If there is sufficient water, every fourth to sixth line is turned on when the temperature approaches 90" and is left until the temperature drops below 90" If these high temperatures are estimated to last three or four hours, the grower at the end of approximately two hours will alternate the operating lines so as to move the drift and also limit the water applied in one particular area

   As in the frost protection system the degree of cooling in high temperatures is in direct proportion to the amount of moisture that can be circulated throughout the crop area

2 Sequencing Laterals—Much more can be done with laterals when lines can be automatically sequenced through a controller by allowing laterals to sequence approximately every three minutes Very satisfactory results have been obtained by sequencing every six to eight lines and repeating until the temperature has dropped below 90". By sequencing in this manner, the entire moisture drift is never taken out of one particular area It keeps repeating by areas and thereby provides enough moisture to to alleviate the high transpiration requirements of the plant.

3. **The** Block System **of** Cooling—This is entirely different from either of the two systems previously mentioned. It must be remembered that when cooling by the block system, whether it is **2½**, **5,** or 10-acre blocks, once the water is shut off, all moisture circulation stops. Therefore, it is necessary to operate the system continuously for a minimum of 6-10 minutes to adequately wet the entire crop area, to completely cool the fruit and to return in not more than 30 minutes. In order to adequately cover by the block system, it is necessary to have one-sixth to one-fourth of the water available for any given acreage. This is in contrast to a system of sequencing laterals where up to one-eighth of the water is sufficient because drift is always moving throughout any given area. This does not occur in a block system of cooling.

COOLING TEMPERATURES

When cooling was first practised, very little was known about the necessity of turning a system on at any given temperature. In 1959 it was thought that 100" was a critical temperature. However, with the first system put in that year on 206 acres of grapes, operating in 112" to 115" atmospheric temperature and starting the system at 100" there was still considerable shattering of the young grapes On the next irrigation, the critical temperature was reduced to 90" and no further problems of shattering occurred. Thus, generally, throughout the West, 90" has been set as the critical temperature, not only for grapes, but for all crops

Work being done by some of our schools and **Ex**tension Service, seems to indicate that in some climatic areas, some crops should be cooled for a few hours and then be allowed to take the high temperatures for the remainder of the day. These tests indicate that the percentage of sugar holds at a more desirable level. Cooling until temperatures return to approximately 90" in some areas seems to drop the sugar content. Much more research needs to be done on all crops in all climatic areas.

Until more confirmed information is obtained, 90" will be considered the critical temerature for all crops.

Cooling systems will continue to be recommended to operate from 90" to a return to 90" with the exception, as stated above.

APPENDIX

All information in this handbook regarding soils, their classification, characteristics, water holding capacity, available moisture and infiltration rate; crops, as to feeder root depth, water use, etc.; climate, as to irrigation efficiency is general or for average conditions. This information is to be used only as a guide; local conditions must govern each individual design.

PLANT FEEDER ROOT DEPTHS*

Crop	Feeder Root Depth	Crop	Feeder Root Depth
ALFALFA	3 to 6 feet	NUTS	3 to 6 feet
BEANS	2 feet	**ONIONS**	1½ feet
BEETS	2 to 3 feet	ORCHARD	3 to 5 feet
BERRIES (Cane)	3 feet	PASTURE (Grasses Only)	1½ feet
CABBAGE	1½ to 2 feet	PASTURE (With Clover)	2 feet
CARROTS	1Y2 to 2 feet	PEANUTS	1½ feet
CORN	2½ feet	PEAS	2½ feet
COTTON	4 feet	POTATOES	2 feet
CUCUMBERS	1½ to 2 feet	SOY **BEANS**	2 feet
GRAIN	2 to 2Y2 feet	STRAWBERRIES	1 to 1½ feet
GRAIN, SORGHUM	2½ feet	SWEET POTATOES	3 feet
GRAPES	3 to 6 feet	TOBACCO	2Y2 feet
LETTUCE	1 foot	TOMATOES	1 to 2 feet
MELONS	2½ to 3 feet		

'Majority of Feeder Roots.

NET AMOUNT OF MOISTURE TO APPLY TO VARIOUS SOILS UNDER DIFFERENT MOISTURE RETENTION CONDITIONS

Soil Type	Root Zone Depth FEET	Field Cepacit INCHES	Amount Held at Wilting Point PERCENT	Amount Held at Wilting Point INCHES	Available Moisture Plant Use INCHES	Retained in the Soil at Irrigation 67%	Retained in the Soil at Irrigation 50%	Retained in the Soil at Irrigation 33%
LIGHT SANDY	1	1.25	20%	0.25	1.00	0.33	0.50	0.67
	1½	1.88		0.38	1.50	0.50	0.75	1.00
	2	2.50		0.50	2.00	0.66	1.00	1.33
	2Y2	3.13		0.63	2.50	0.83	1.25	1.67
	3	3.75		0.75	3.00	0.99	1.50	2.00
	4	5.00		1.00	4.00	1.32	2.00	2.66
MEDIUM	1	2.25	25%	0.56	1.69	0.57	0.85	1.13
	1½	3.38		0.85	2.53	0.84	1.26	1.70
	2	4.50		1.12	3.38	1.11	1.69	2.26
	2½	5.62		1.41	4.21	1.39	2.11	2.82
	3	6.75		[illegible]	5.06	1.67	2.53	3.38
	4	9.00			6.75	2.23	3.38	4.52
			35%	1.28				
HEAVY	1	3.67	35%	1.92	2.39	0.79	1.20	1.59
	1½	5.50		2.56	3.58	1.18	1.79	2.38
	2	7.34		3.20	4.78	1.58	2.39	3.25
	2½	9.17		[illegible]	5.97	1.87	2.98	3.97
	3	11.0		5.12	7.17	2.36	3.58	4.77
	4	14.68		5.12	9.56	3.15	4.78	6.37

NOTE For optimum yield of high vaiued shallow rooted crops maintain 67% available moisture
For lower valued deeper rooted crops maintain 50% available *moisture*
For low value deep rooted crops maintain 33% available moisture

MAXIMUM PRECIPITATION RATES TO USE ON LEVEL GROUND

Light sandy soils ....0.75″ to 0.5″ per hour
Medium textured soils ....0.5″ to 0.25" per hour
Heavy textured soils ......0.25″ to 0.10″ per hour

Allowable rates, increase with adequate cover, and decrease with land slopes and time.

MAXIMUM SPACING OF SPRINKLERS

Maximum spacing of sprinklers based on diameter of coverage of sprinkler used.

For water critical crops

Average Wind Speed	Spacing
Up to 7 M.P.H.	40% between sprinklers 65% between laterals
7 to 10 M.P.H.	40% between sprinklers 60% between laterals
above 10 M.P.W.	30% between sprinklers 50% between laterals

SLOPE PRECIPITATION TABLE

Slope	Precipitation Rate Reduction?
0- 5 per cent grade'	0 per cent
6- 8 per cent grade	20 per cent
9-12 per cent grade	40 per cent
13-20 per cent grade	60 per cent
over 20 per cent	75 per cent

[1] Grade drop in feet per 100 lineal feet
[2] Applied to proper soil type precipitation rate

EXAMPLE ON USE OF TABLES

An alfalfa crop is to be irrigated. The soil is medium type. Climate is hot. For convenience of labor two eleven hour sets per day will be used. Normal sprinkler spacing of 30' x 50' will be used.

From root depth chart alfalfa roots are three feet deep.

From net amount of moisture chart three feet depth in medium soil with 50% moisture retained at irrigation means 2.53 inches net must be applied per irrigation.

From peak moisture use chart alfalfa uses 0.30 inches per day in hot climate.

Irrigation interval is 2.53 inches net divided by 0.30 inch per day or 8.4 days.

From gross amount chart 2.53 inches net is 3.57 inches gross in a hot climate with 70% irrigation efficiency.

Required precipitation fate is determined by dividing 3.57 inches by 11 hours per set or 0.32 inch per hour.

From precipitation table on 30' x 5 0 spacing with a precipitation rate of 0.32 inch per hour a 5 g.p.m. sprinkler *is* required.

From maximum precipitation rate table for medium soils maximum rate is from 0.25 to 0.50 inch per hour.

From Rain Bird Sprinkler Catalog on a 30W TNT Rain Bird with $\frac{5}{32}$″ nozzle **4.98** g.p.m. is discharged at 50 p.s.i. with 90' diameter.

From spacing of sprinkler chart 60% of diameter may be used in winds up to 4 m.p.h. Diameter of 90' times 60% is 54'. This sprinkler on 30' x 50' spacing will give good coverage.

PEAK MOISTURE USE CHART

CROP	Cool Climate		Moderate Climate		Hot Climate		High Desert Climate3		Low Desert Climate3	
	Inches per day[1]	GPM per acre[2]	Inches per day	GPM per acre	Inches per day	GPM per acre	Inches per day	GPM per acre	Inches per day	GPM per acre
Alfalfa	.20	3.8	.25	4.7	.30	5.7	.35	6.6	.45	8.8
Cotton	.20	3.8	.25	4.7	.30	5.7	.35	6.6	.45	8.8
Pasture	.20	3.8	.25	4.7	.30	5.7	.35	6.6	.45	8.8
Grain	.15	2.8	.20	3.8	.22	4.2	.30	5.7	.40	7.6
Potatoes	.14	2.8	.20	3.8	.25	4.7	.30	5.7	.40	7.6
Beets	.20	3.8	.25	4.7	.30	5.7	.35	6.6	.45	8.8
Orchards and Groves	.20	3.8	.25	4.7	.30	5.7	.35	6.6	.45	8.8
Orchards and Groves • w/Cover	.25	4.7	.28	5.2	.35	6.6	.38	7.2	.45	8.8

'Acre inches Der acre Der day

'Continuous flow required per acre at 100% irrigatton efficiency Divide this value by estimated irrtgation efficiency

As of October, 1959, the above table of peak moisture use was checked with information obtained from various agricultural colleges, experimental stations and government agencies and was found to compare with the average of all recent data

'Source Extension Service, Industry and Growers 1964 1966

IRRIGATION FREQUENCY

Irrigation frequency or interval between irrigation is determined by dividing net moisture applied during irrigation by peak moisture use of the crop per day

GROSS AMOUNT OF MOISTURE TO APPLY TO OBTAIN DESIRED NET IN DIFFERENT CLIMATES"

Desired Net Inches	Cool Climate 80% Efficiency Gross inches	Moderate Climate 75% Efficiency Gross Inches	Hot Climate 70% Efficiency Gross Inches	High Desert Climate 65% Efficiency Gross inches	Low Desert Cilmate 60% Efficiency Gross inches
0.20	0.25	0.27	0.29	0.31	0.33
0.25	0.31	0.33	0.36	0.38	0.42
0.50	0.63	0.67	0.72	0.77	0.83
0.75	0.94	1.00	1.14	1.15	1.25
1.00	1.25	1.33	1.43	1.54	1.66
1.25	1.57	1.67	1.77	1.92	2.08
1.50	1.88	2.00	2.24	2.31	2.50
1.75	2.19	2.34	2.50	2.69	2.92
2.00	2.50	2.67	2.86	3.08	3.33
2.25	2.81	3.00	3.20	3.46	3.75
2.50	3.12	3.34	3.57	3.85	4.20
2.75	3.44	3.67	3.92	4.23	4.60
3.00	3.86	4.00	4.28	4.62	5.00
3.25	4.16	4.34	4.64	5.00	5.42
3.50	4.38	4.67	5.00	5.40	5.83
3.75	4.70	5.00	5.35	5.76	6.22
4.00	5.00	5.34	5.70	6.15	6.68
4.25	5.31	5.67	6.08	6.55	7.10
4.50	5.63	6.00	6.42	6.92	7.50
4.75	5.95	6.34	6.78	7.30	7.92
5.00	6.25	6.66	7.15	7.70	8.40

*Very law application rate systems can attain 80% efficiency in all climate areas

UNITS OF WATER MEASUREMENT

1 gallon = **231** cubic inches = **8.33** pounds

1 cubic foot = **7.48** gallons = **62.4** lbs.

1 acre foot = amount of water required to cover one acre one *foot* deep
= **43,560** cubic feet
= **325,850** gallons
= **12** acre inches

1 acre inch = amount of water required to cover one acre 1 inch deep
= **27,154** gallons

1 gallon per min. = **0.00223** cubic feet per second

1 miner's in. = **11.25** gal. per min. @ **40** in. per sec. ft.
= 9.0 gal. per min. @ **50** in. per sec. ft.

1 cubic ft. per sec. (sec. ft.) = 7.48 gal. per second
= **448.8** gal. per minute (commonly used as 450 gpm)
= **646,272** gal. per day (**24** hours)
= **1.983** acre feet per day (**24** hours)
= **40** miner's inches, legal in some states
= **38.4** miner's inches in Colorado
= **50** miner's inches, legal in some states

REQUIRED PRECIPITATION RATE

Precipitation rate in inches per hour is determined by dividing gross moisture in inches **by** number of hours per set.

TABLE OF PRECIPITATION, INCHES PER HOUR

Spacing Foot	Gallons per Minute from each Sprinkle																	
	1	2	3	4	5	6	8	10	12	15	18	20	25	30	35	40	45	50
20 x 20	24	48	.72	.96	1.20	1.44	1.92											
20 x 30	16	32	.48	.64	.80	.96	1.28	1.60	1.93									
20 x 40	12	24	.36	.48	.60	.72	.96	1.20	1.45	1.81	2.17							
20 x 50	10	20	.30	.40	.50	.60	.80	1.00	1.20	1.50	1.80	2.00						
20 x 60	08	16	.24	.32	.40	.48	.64	.80	.96	1.20	1.44	1.60	2.00					
25 x 25	15	30	.46	.61	.77	.92	1.23	1.54	1.85	2.31								
30 x 30	11	21	.32	.43	.54	.64	.86	1.07	1.28	1.61	1.93	2.14						
30 x 40		16	.24	.32	.40	.48	.64	.80	.96	1.20	1.45	1.61	2.01	.40				
30 x 50		13	.19	.25	.32	.38	.51	.64	.76	.96	1.15	1.28	1.60	.92				
30 x 60		11	.16	.21	27	.32	43	.53	.64	.80	.96	1.07	1.54	.61	1.87	2 14		
40 x 40		12	.18	24	.30	.36	.48	.60	.72	.90	1.08	1.20	1.50	.80	2.10	2.40		
40 x 50		10	.14	19	.24	.29	.38	.48	.58	.72	.86	.96	1.20	.44	1.68	1.92	2.16	
40 x 60			.12	16	.20	.24	.32	.40	.48	.60	.72	.80	1.00	.20	1.40	1.60	1.80	2.00
40 x 80			.09	12	.15	.18	.24	.30	.36	.45	.54	.60	.75	.90	1.05	1.20	1.35	1.50
50 x 50			...	15	.19	.23	.31	.39	.46	.58	.69	.77	.96	.15	1.35	1.54	1.73	1.92
50 x 60			.10	13	.16	.19	.26	.32	.39	.48	.58	.64	.80	.96	1.12	1.28	1.44	1.60
50 x 70				11	14	17	.22	.28	.33	.41	.49	.55	.69	.82	.96	1.10	1.24	1.37
60 x 60				11	.13	.16	.21	.27	.32	.40	.48	.53	.67	.80	.93	1.07	1.20	1.34
60 x 70					.11	.14	.18	.23	.27	.34	.41	.46	.57	.69	.80	.92	1.03	1.15
60 x 80					.10	.12	.16	.20	.24	.30	.36	.40	.50	.60	.70	.80	.90	1.00
70 x 70					10	12	.16	.20	.24	.29	.35	.39	.49	.59	.69	.79	.88	.98
70 x 80						10	.14	.17	.21	.26	.31	.34	.43	.52	.60	.69	.77	.86
70 x 90							.12	.15	.18	.23	.28	.30	.37	.46	.53	.61	.69	.76
60x80							.12	.15	.18	.23	.27	.30	.38	.45	.53	.60	.68	.75
80 x 90							.?1	.13	.16	.20	.24	.27	.33	.40	.47	.53	.60	.67
80 x 100							.10	.12	.14	.18	.22	.24	.30	.36	.42	.48	.54	.60
100 x 100								.10	12	.14	.17	.19	.24	.29	.34	.39	.43	.48

PUMP HORSEPOWER CONVERSION

One brake horsepower, electric = 1.25 continuous horsepower for diesel— L.P. gas or natural gas engines: 1.45 continuous horsepower for water cooled gasoline engines: 1.6 continuous horsepower for air cooled gasoline engines.

Do not **use** over 70% of rated horsepower for continuous operating horsepower *of* any type engine.

A rule of thumb for fuel consumption for gasoline or diesel engines is 1 pint per horsepower per hour.

When engines are used at high elevations some power is lost due to thinner air. 3% per 1000 feet is lost, starting **at** 3000 ***feet.*** **Below** 3000 feet no deduction is necessary.

HYDRAULIC FORMULAS FOR SPRINKLERS

DISCHARGE FROM NOZZLES

$$G.P.M. = \sqrt{P} \times D^2 \times 29.82 \times C$$

$$D - \sqrt{\frac{G.P.M.}{C \times \sqrt{P} \times 29.82}} \qquad P = \left[\frac{G.P.M.}{C \times D^2 \times 29.82}\right]^2$$

G.P.M. = Gallons Per Minute
D = Diameter of nozzle in inches
P = Pressure in pounds per square inch
C = Coefficient of discharge

LOSS OF PRESSURE THROUGH SPRINKLER AND NOZZLE

$$L = P - (C \times P) \qquad C = \frac{P - L}{P}$$

L = Lost pressure
P = Gage Pressure
C = Coefficient of discharge

PRECIPITATION

$$Pr = \frac{G.P.M. \times 96.3}{A} \qquad G.P.M. = \frac{Pr. \times A}{96.3}$$

Pr. = Precipitation in inches per hour
A = Area or Distance between sprinklers on line x distance between lines
G.P.M. = Gallons per minute per sprinkler

96.3 = inches per **sq. ft.** per hour
Derived as follows
One gallon = 231 cu. inches—144 **sq.** in. per **sq.** ft.

$$\frac{231}{144} = 1.604 \text{ inches per sq. ft. per gallon per min}$$

1.604 **x** 60 min. = 96.3 inches per **sq.** ft. per hour

VELOCITY

$$V = \sqrt{\frac{P}{.00674}} \qquad P = .00674 \times V^2 \qquad V = \frac{G.P.M}{2.45 \times D^2}$$

V = Velocity in feet per second
P = Pressure in lbs
D = Dia. of pipe or nozzle in inches

POWER FORMULA

1 H.P. = 550 foot pounds per second
= 746 watts or 0.746 **KW**
= **1** second foot of water falling 8.8'

$$\text{Water H.P.} = \frac{\text{Second foot of water x head in feet}}{8.8}$$

$$= \frac{\text{Gal. per min. of water x head in feet}}{3960}$$

$$\text{Brake H.P.} = \frac{\text{Water M.P.}}{\text{Eff. of Pump}}$$

1 kilowatt **(kw)** = 1000 watts
= 1.341 H.P.
= 737.5 foot pounds per second

NOTES

A column of water **1** foot high equals **.4331** pounds pressure.
1 pound pressure equals a column of water 2.309 feet high.
1 acre equals 43,560 square feet.
1 acre inch equals **27,154** gallons.
1 cubic foot equals 7.48 gallons.
The height **of** an equilateral triangle is **.866** times its base.
The discharge of a nozzle is in proportion to the square of its diameter and the square root of the pressure.
For greatest economy a pipe system should be **so** designed that the annual cost of power lost **by** pipe friction equals 40% of annual fixed cost of pipe.

AREA COVERED WITH VARIOUS LATERAL MOVES

Distance of Move (Feet)	Lateral Length (Feet)	Acres Covered
20	2640	1.21
20	1320	0.60
20	660	[illegible]
20	330	0.15
40	2640	2.42
40	1320	1.21
40	660	0 60
40	330	030
50	2640	302
50	1320	151
50	660	0 76
50	330	0.38
60	2640	3.64
60	1320	1.82
60	660	0.91
60	330	0.46
80	2640	4.84
80	1320	2.42
80		
100	2640	
100	1320	0.60
100	660	1.51 6.04
100	330	0.76 3.02

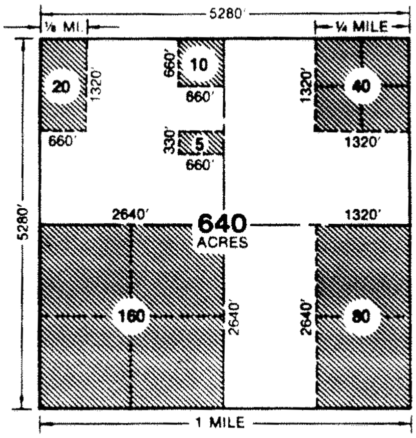
LOSS OF HEAD IN FEET PER 100 FEET OF ALUMINUM PIPE

(K_S = .34 for 2″ pipe, K_S = .33 for 3″ pipe, K_S = .32 for other sizes)

G.P.M.	C.F.S.	2" O.D. .05″ wall	3″ O.D. .05″ wall	4″ O.D. .063″ wall	5″ O.D. .063″ wall	6"O.D. .063″ wall	7″ O.D. .078″ wall	8"O.D. .094″ wall
5	.01	.07						
10	.02	.32	.04					
20	.04	1.20	.15	.04				
30	.07	2.58	.32	.08				
40	.09	4.49	.56	.13	.04			
50	.11	6.85	.85	.20	.07	.03		
60	.13	9.67	1.21	.28	.09	.04		
70	.16	12.95	1.61	.38	.12	.05		
80	.18	16.70	2.06	.49	.16	.06	.03	
90	.20	20.80	2.58	.60	.20	.08	.04	
100	.22	25.40	3.18	.74	.24	.10	.05	.03
120	.27		4.51	1.06	.34	.14	.07	.04
140	.31		6.00	1.41	.46	.19	.09	.05
160	.36		7.76	1.82	.59	.24	.11	.06
180	.40		9.67	2.27	.73	.30	.14	.07
200	.45		11.83	2.78	.89	.36	.17	.09
220	.49		14.12	3.31	1.07	.44	.20	.11
240	.54		16.72	3.91	1.27	.52	.24	.13
260	.58		19.42	4.56	1.47	.60	.28	.15
280	.62		22.40	5.26	1.71	.69	.33	.17
300	.67		25.45	5.98	1.93	.79	.37	.19
350	.78			8.03	2.59	1.05	.50	.26
400	.89			10.36	3.33	1.35	.64	.33
450	1.00			12.90	4.15	1.69	.80	.41
500	1.12			15.73	5.07	2.06	.97	.50
550	1.23			19.12	6.16	2.50	1.18	.62
600	1.34			22.46	7.24	2.94	1.38	.72
650	1.45			26.10	8.42	3.41	1.62	.84
700	1.56				9.68	3.92	1.86	.97
750	1.67				11.05	4.46	2.11	1.10
800	1.79				12.48	5.03	2.38	1.24
850	1.90				13.95	5.64	2.67	1.39
900	2.01				15.65	6.35	2.98	1.56
950	2.12				17.35	7.02	3.32	1.73
1000	2.23				19.10	7.72	3.64	1.90
1100	2.46				22.85	9.22	4.37	2.27
1200	2.68				26.95	10.88	5.16	2.68
1300	2.90					12.62	5.96	3.10
1400	3.12					14.65	6.90	3.60
1500	3.34					16.67	7.87	4.07
1600	3.57					18.80	8.89	4.62
1700	3.79					20.95	9.95	5.16
1800	4.01					23.60	11.15	5.79
1900	4.24						12.35	6.42
2000	4.46						13.65	7.10

Table based on Scobey's Formula

LAND MEASUREMENTS
(U.S. Government Land Survey)



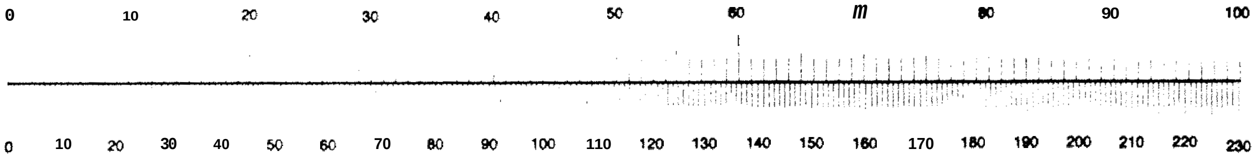
STANDARD SECTION OF LAND

Table of Measurements

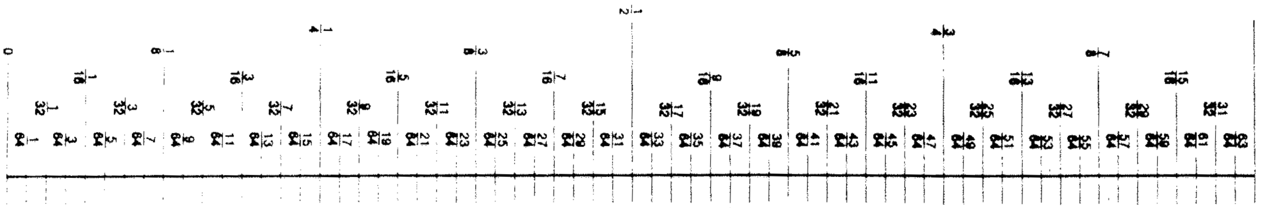
Mile	Chains	Rods	Feet
⅛	10	40	660
¼	20	80	1320
½	40	160	2640
1	80	320	5280

CHARTS OF EQUIVALENTS

PRESSURE IN POUNDS PER SQUARE INCH



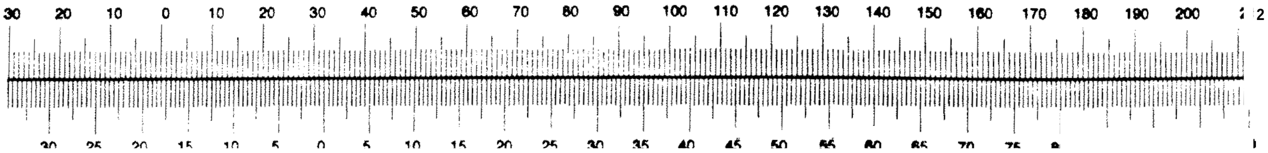
HEAD IN FEET



DECIMAL EQUIVALENTS TO FRACTIONS

F = 9/5 × C + 32°

TEMPERATURE FAHRENHEIT



TEMPERATURE CENTEGRADE

C = 5/9 × (F − 32°)

CONVERSION OF UNITS OF FLOW

Cubic Feet per Second	Gals. per Minute	Mill. Gals. per Day	Miner's inches			Acre In. per Hour	Acre Ft. per 24 Hrs.
			Aruona Calif. Montana Nevada Oregon	Idaho Kansas Nebraska New Mex. No. Dakota So. Dakota Utah	Colorado		
1	448.8	0.646	40	50	38.4	0.992	1.983
0.00223	1	0.001440	0.089	0.1114	0.0856	0.0022	0.00442
1.547	694.4	1	61.89	77.36	59.44	1.535	3.07
0.025	11.25	0.0162	1	1.25	0.960	0.0248	0.0496
0.020	9.00	0.01296	0.80	1	0.768	0.0198	0.0397
0.026	11.69	0.0168	1.042	1.302	1	0.0258	0.0516
1.01	452.42	0.651	40.32	50.40	38.71	1	2.00
.504	226.3	0.3258	20.17	25.21	19.36	0.5	1

METRIC SYSTEM CONVERSIONS

Measures of Length

10 millimeters (mm) = 1 centimeter = 0.3937 in.
10 centimeters (cm) = 1 decimeter = 3.937 in.
10 decimeters (dm) = 1 meter = 39.37 in.
10 meters (m) = 1 decameter = 393.7 in.
10 decameters (dkm) = 1 hectometer = 328 ft. 1 in.
10 hectometers (hm) = 1 kilometer = 0.62137 mi.
10 kilometers (km) = 1 myriameter (mym) = 6.2137 mi.

Measures of Capacity

The standard unit of capacity is the liter, equal to 1 cubic decimeter or 0.9081 dry quart or 1.0567 liquid quarts.

10 milliliters (ml) = 1 centiliter = 0.338 fl. oz.
10 centiliters (cl) = 1 deciliter = 6.1025 cu. in.
10 deciliters (dl) = 1 liter = 0.9081 dry qt.
10 liters (l) = 1 decaliter = 0.284 bu. or 2.64 gal.
10 decaliters (dkl) = 1 hectoliter = 2.838 bu. or 26.418 gal.
10 hectoliters (hl) = 1 kiloliter (kl) = 35.315 cu. ft. or 264.18 gal.

Land Measures

1 sq. meter (m^2) = 1 centiare = 1550 sq. in.
100 centiares (ca) or 100 m^2 = 1 are = 119.6 sq. yd.
100 ares (a) or 10,000 m^2 = 1 hectare (ha) = 2.471 acres
1 sq. kilometer (km^2) = 1,000,000 sq. meters = .3861 sq. mi.

Metric Equivalents of Common Units

inch = 2.54 cm
foot = 0.3048 m
yard = 0.9144 m
rod = 5.029 m
mile = 1.6093 km
sq. inch = 6.452 cm^2
sq. foot = 0.0929 m^2
sq. yard = 0.8361 m^2
acre = 0.4047 ha
sq. Mile = 259 ha or 2.590 km^2

cu. inch = 16.387 cm^3
cu. foot = 0.0283 m3
cu. yard = 0.7646 m3
liquid qt. = 0.9463 l
dry qt. = 1.1012 l
gallon = 3.7853 l
bushel = 35.238 l
oz. av. = 28.3495 g
lb. av. = 0.4536 kg
oz. troy = 31.1035 g
lb. troy = 0.3732 kg

RAIN BIRD

Rain Bird Sprinkler Mfg Corp., Glendora. California 91740

Printed in U S A

A-2071/10M 1171

[redacted]