An Irrigation Guide for Colorado

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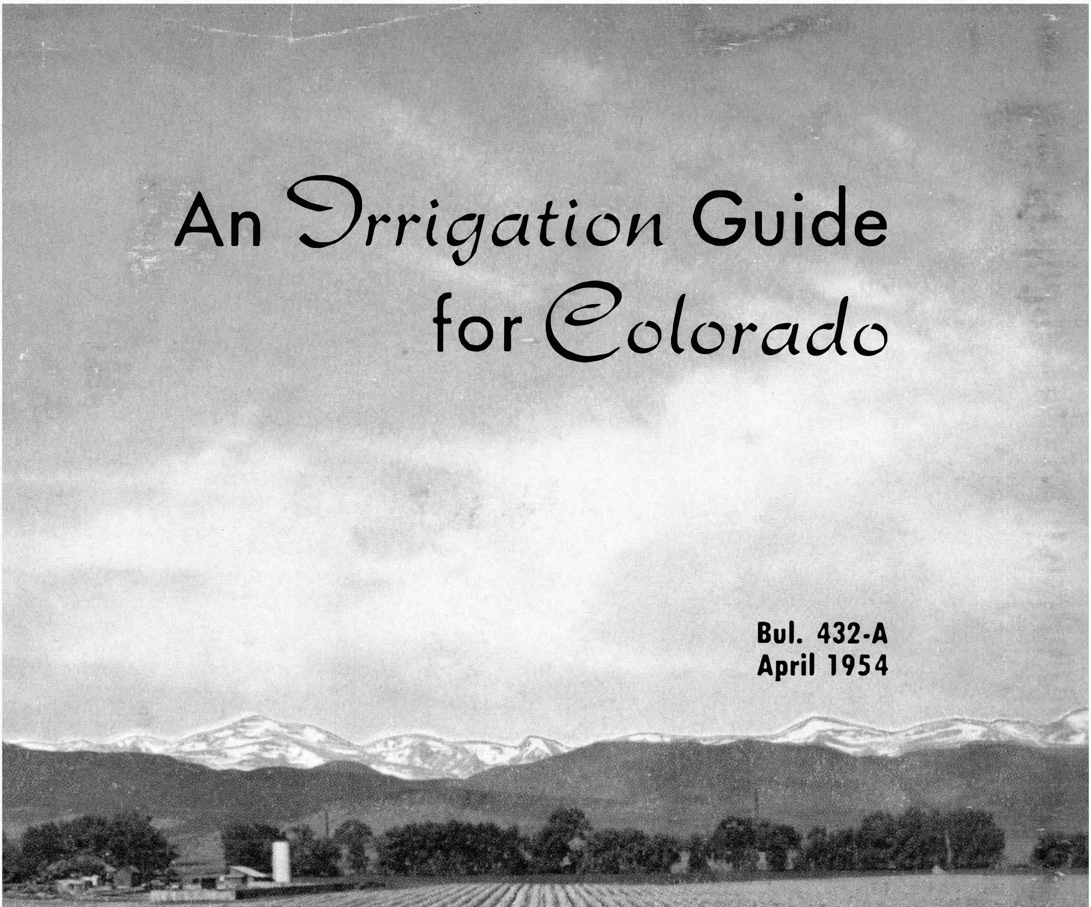

Agricultural Extension Service— Agricultural Experiment Station
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Fort Collins

Preface

In preparing this bulletin it has been assumed that the farm operator has a general knowledge and understanding of Colorado water law and administration. Also, that he has a working knowledge of the water rights in his immediate locality, the annual mean water supply available to him and the general pattern of its availability. This knowledge is necessary to plan adapted rotations and cropping systems. New farm operators who do not have such information and knowledge should contact the local water commissioner and canal officials and become thoroughly informed.

With few exceptions Colorado irrigation systems were built by private initiative and capital. Most irrigation systems are mutual companies owned and operated by the land owners they serve. This is to say that there is little uniformity of water rights or plans of operations. A few canals have abundant and constantly available supplies of water. Many canals are able to meet all reasonable demands in years of normal water supply. Others have very limited rights or none at all except during flood seasons.

There are also wide variations in the administration of water deliveries in the different irrigated valleys. Each river or stream is operated under the State constitution and general laws, but interstate compacts, treaties, and court decisions may impose regulations which have only local effect. Also, numerous local contracts and agreements may exist. All of these local peculiarities are sometimes referred to as "the law of the river."

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Acknowledgments

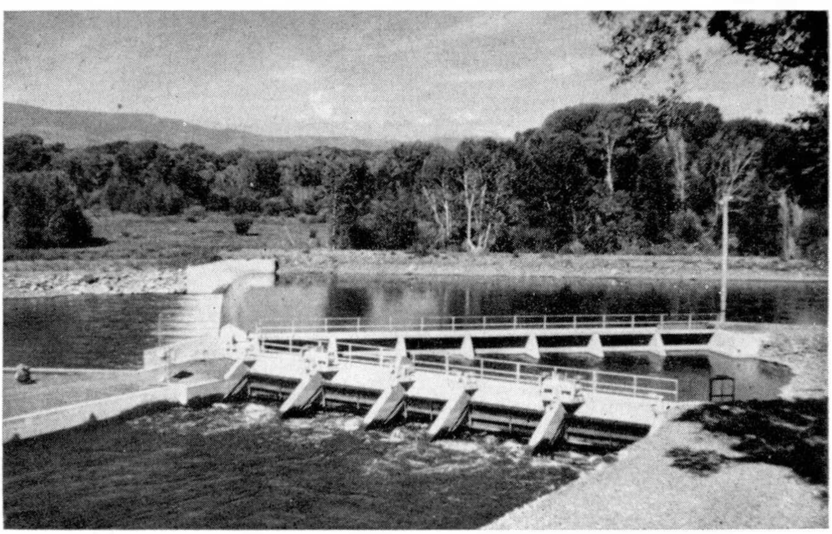
The author is deeply indebted to all those who have contributed to the preparation of this bulletin. In this group deserving special mention are C. M. Drage, Extension Service Horticulturist, Ferris M. Green, Superintendent Western Slope Agricultural Branch Station, Dr. Robert S. Whitney, Professor of Agronomy, and C. H. Diebold, Survey Supervisor, Soil Conservation Service, Albuquerque, New Mexico. Appreciation is also acknowledged for the assistance of all those who have read and criticized the original manuscript.

An *Irrigation* Guide for *Colorado*

[1]A. J. HAMMAN and W. E. CODE

MOST IRRIGATION WATER is diverted direct from natural streams. According to the 1950 census of agriculture, there were 7,709 diversion dams, 1,182 reservoirs, 1,371 flowing wells, 4,988 pumped wells, and 9,158 organized irrigation enterprises in use in Colorado. There is no uniform size of share used among these ditch and canal organizations. Many irrigation systems use units of measurement which are not standard. Ownership of water certificates or canal company shares neither guarantees nor implies that any specified quantity of water will be available at any time or during a season. Farmers with backgrounds of experience under their respective canal systems, have developed cropping and rotation patterns to fit their normal water supplies.

The total annual water supply may not be as important as the pattern of availability. Most important is a supply to meet crop needs at critical periods of germination and development.



One of the larger canal diversions in Colorado. Automatic electrically controlled head gates of the Rio Grande Canal, mutually owned and operated, Del Norte, Colorado.

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The availability pattern is an important factor in selecting kinds and varieties of crops and in determining comparative acreages of each and, in some instances, the planting dates. In some areas time and quantity of application often depend more on availability of water than on scientific determination of crop needs or the wishes and convenience of the canal management or the farm operator.

Generally speaking, plentiful water supplies during spring and early summer followed by short supplies in late summer indicates need for comparatively large acreages of early maturing crops and less of those which require late irrigation.

There are other important items which should be pointed out to the new irrigator. Irrigation agriculture is carried on in Colorado at elevations of 3,400 feet up to mountain meadows at 8,000 feet and above. This means that Colorado irrigators, as a group, must consider a wide range of seasonal and climatic conditions. There is also a very complicated variety of soil conditions. The successful irrigation farmer fits his operations and practices into his particular situation. This bulletin can describe only the general practices.

Income from Colorado's irrigated lands could be approximately doubled if all the participating farmers could and would apply the most practical and proved cultural and irrigation practices now available to them.

Some areas have greatly benefited by mutual agreements which permit consolidation or partial consolidation of water decrees. There are other areas within the State which could be greatly benefited if the water rights were pooled and the distribution systems consolidated.

Soil and Water Relationships

The character of the soil is probably the one greatest factor in determining the most suitable irrigation practice. Texture, structure, and porosity determine the water-absorbing, retaining, and transmitting capacity of a soil. All of these properties vary between wide limits. The rate of movement of water into and through a soil is extremely important in both irrigation and drainage. Without some knowledge of this factor the irrigation farmer cannot determine the proper length of run or duration of an application, the quantity of water to turn into furrows or the distance between drains.

Water-absorbing and retaining capacities of top soil can usually be greatly improved by the addition of humus or organic matter. A soil in a high state of organic fertility will usually absorb water faster and retain more water than will soil where the humus content is low. High organic content can mean a faster rate of water application and longer intervals between irrigations, a saving in labor costs, and a higher production potential.

The above conditions, together with the type of crop and the depth of its root zone, are among the determining factors in selecting the method of applying water, frequency of application, and the amount of water to apply at one time. As deep-rooting crops develop the deeper the root zone to be wet and the more water required.

There are three common ways of expressing the amount of water held in a soil: percentage of dry weight of soil, percentage by volume, and depth of water held per foot of soil. The third method is the most common and useful when measurements are expressed in inches of water per foot or other given depths of soil.

Other common terms with which the irrigator should be familiar are, field water capacity, wilting point, and available capacity. By field water capacity, is meant the amount of water held by the soil after the downward movement of percolating water has ceased. It is usually expressed in inches of water in the root zone. This movement generally stops 1 to 3 days after a heavy irrigation or rain. If more water is applied than the soil of the root zone can hold, the excess, over field capacity, is lost by percolation into the sub-soil. If the irrigation is too light only the upper part of the root zone, in proportion to the quantity of water applied, is brought to its water-holding or field capacity.

Wilting point may be defined as the percentage of moisture held by the soil after permanent wilting begins. It is usually expressed as percentage of the dry weight of the soil, or as inches of water per foot depth of soil.

Available capacity is the quantity of water that may be stored in the soil in a condition accessible to plants. This represents the difference between the field capacity and the moisture retained after the wilting point is reached. It is not a good practice to let the soil moisture throughout the root zone fall too close to the wilting point before beginning the next irrigation. This is particularly poor practice under irrigation systems where the volume of the delivered stream of water may be small compared to the area of the field to be covered. The irrigation should be begun, if possible, in time to prevent wilting in any part of the field. Under extreme conditions, to avoid serious damage to parts of fields which might not be reached in time, irrigation may need to begin a few or even several days before the crops or soils show any visible moisture deficiency. It is also well to keep in mind that no crop makes efficient use of water when more of it is put on than is needed.

Crops normally obtain most of their sustenance from the upper portion of the root zone. Thus, this part of the root zone may approach or reach the wilting point before deeper available moisture is used. Even when the lower root zone may be at or near available capacity the crop may not be able to draw moisture fast enough to sustain it in a thrifty condition.

Because of the slow movement of water through some very fine-textured soils, it is almost impossible or impracticable to use their full water-holding capacity. Such soils absorb water so slowly that it is often impossible or not practicable to store water in them to their field capacity during a reasonable irrigation period. Also, these clay-type soils sometimes release their available moisture so slowly that crops may suffer when there is evidence of a plentiful supply. Plants are able to obtain water more rapidly from the more open-textured loams and especially the sandy soils.

Movement of water into and through soil is important in both irrigation and drainage. In saturated soil (below the water table) water moves down the steepest slope. The rate of this movement is many times faster in sand and gravel than in loams and clays on similar slopes. Knowledge of soil types, slopes, and movement of ground waters is essential to the location of the most effective drains as well as to good irrigation practice. Overapplication of irrigation water may not be visibly manifest on deep sandy and gravelly soils, except in increased fertilizer requirements to maintain top production. The results of misuse of irrigation water on tight soils may be visibly evident after a few irrigations.

Percolating water tends to move directly downward at a comparatively fast rate in soils of uniform texture—the lateral movement is slower; the upward movement is slowest of all.

As the soil moisture approaches field capacity its movement becomes slower, but its direction is always from the wetter to the drier areas. Generally, the movement of soil moisture is sufficiently rapid to feed the roots of growing crops through only short distances. Also, as the soil moisture decreases toward the

Table 1.—Relation between sizes of irrigation streams and approximate time required per acre per irrigation or to produce a given number of acre-inches in a given length of time.*

Approximate time (t) required, per acre per irrigation or to produce a given number of acre-inches of water, in hours and minutes.*

(From the formula $t=\frac{ad}{q}$ where q=c.f.s., a=area in acres, t=time in hours and d=depth in inches)

Size of stream			Time required to deliver enough water to apply to 1 acre a depth of —														
			2 inches		3 inches		4 inches		5 inches		6 inches		7 inches		8 inches	
g.p.m.	sec.-ft.	acre-in. per hr.	hr.	min.	hr.	min.	hr.	min.	hr.	min.	hr.	min.	hr.	min.	hr.	min.
100	0.22	1/4	9	03	13	35	18	06	22	38	27	09	31	41	36	12
150	.33	5/16	6	02	9	03	12	04	15	05	18	06	21	07	24	08
200	.45	7/16	4	32	6	47	9	03	11	19	13	35	15	50	18	06
250	.56	9/16	3	37	5	26	7	14	9	03	10	52	12	40	14	29
300	.67	11/16	3	01	4	32	6	02	7	33	9	03	10	34	12	04
350	.78	3/4	2	35	3	53	5	10	6	28	7	45	9	03	10	21
400	.89	7/8	2	16	3	24	4	32	5	39	6	47	7	55	9	03
450	1.00	1	2	01	3	01	4	01	5	02	6	02	7	02	8	03
500	1.11	1 1/8	1	49	2	43	3	37	4	32	5	26	6	20	7	14
600	1.34	1 5/16	1	31	2	16	3	01	3	46	4	32	5	17	6	02
700	1.56	1 9/16	1	18	1	56	2	35	3	14	3	53	4	32	5	10
800	1.78	1 3/4	1	08	1	42	2	16	2	50	3	24	3	58	4	32
900	2.01	2	1	00	1	31	2	01	2	31	3	01	3	31	4	01
1,000	2.23	2 3/16	..	54	1	21	1	49	2	16	2	43	3	10	3	37
1,100	2.45	2 7/16	..	49	1	14	1	39	2	03	2	28	2	53	3	17
1,200	2.67	2 5/8	..	45	1	08	1	31	1	53	2	16	2	38	3	01
1,300	2.90	2 7/8	..	42	1	03	1	24	1	44	2	05	2	26	2	47
1,400	3.12	3 1/16	..	39	..	58	1	18	1	37	1	56	2	16	2	35
1,500	3.34	3 5/16	..	36	..	54	1	12	1	31	1	49	2	07	2	25

*After table by R. T. Burdick, in Colorado Farm Bulletin, Colorado A and M College, July-September 1940.

wilting point, the rate of its movement decreases and becomes so slow that plants must extend their roots to meet it. A heavy stand of a rapidly growing crop may soon exhaust the available moisture, particularly in the sandy-type soils. Capillary water will move greater distances in the finer-textured soils than in the sands and gravel types.

The infiltration capacity of a soil is generally of greater importance than the rate at which water will move through the soil. The infiltration rate may be so slow as to require almost constant water application. On other soils it may be so rapid that it may be impossible to make a non-erosive stream cross a field of reasonable length. These conditions on porous soils may be overcome with modern sprinkling methods.

Rate of infiltration or infiltration capacity may be defined as the quantity of water, in inches, absorbed per hour.

Simple Soil Test Tells When To Irrigate

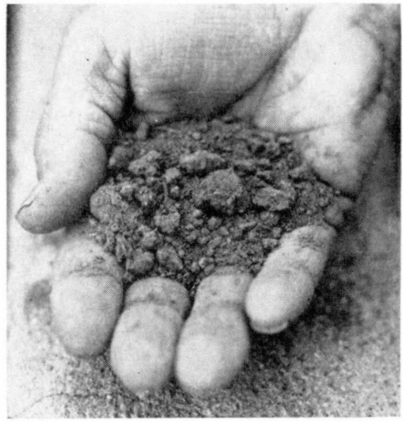
By C. H. DIEBOLD

The following material is reproduced to provide a method for farmers to determine when to irrigate. It was prepared by C. H. Diebold, survey supervisor, United States Soil Conservation Service, Albuquerque, New Mexico. It originally appeared in "What's New in Crops and Soils," published by the American Society of Agronomy. The accompanying pictures are by John Land, regional photographer for the Soil Conservation Service.

"When do you need to irrigate? To what level should the 'readily available' moisture in the crop root zone drop before you put on water?

1. *As the first step in estimating the readily available moisture in the soil, take a typical handful of soil from a depth of between* 6 *and* 12 *inches.*

2. *Squeeze the ball of soil firmly three or four times. Use just about the squeeze you would on a hard-milking cow—not too much, not too little.*



3. *If the soil is too dry to form a ball, it contains less than one-fourth as much readily available moisture as it would have when at field capacity.*

4. *When the soil is moist enough to form a ball, it contains at least one-fourth the amount of readily available moisture it would have at field capacity.*

5. *Take the moist ball and toss it about 1 foot into the air. Then catch it just as you would catch a baseball.*

6. *If the ball breaks with five tosses or less, it is fragile. Such fragile balls contain from one-fourth to one-half readily available moisture. Now is the best time to put on irrigation water.*

7. *If the ball still remains intact after it has been tossed five times, it is durable. Durable balls contain more than one-half readily available moisture. You will not need to irrigate at this level.*

8. *Note the durable ball when moisture is at a level of three-fourths field capacity.*

9. *If a thickness of one-fiftieth of an inch or more sticks to your thumb after the soil is squeezed firmly, the readily available moisture is between three-fourths and* 100 *percent of field capacity.*

"For most row crops, you can delay irrigation for several days if the readily available moisture is more than one-half the total amount that can be held in the soil at a depth of 6 to 12 inches. In contrast, growth has slowed up and you have missed the best time to irrigate when the level of readily available moisture is lower than one-fourth in the 6- to 12-inch layer.

"The best way to maintain rapid growth is to irrigate when the level of readily available moisture in the 6- to 12-inch layer is between one-fourth and one-half.

Plant Can Get It Easily

"What is readily available moisture? It is the volume of water occurring between the moisture level, field capacity, and the level at which plants with mature root systems begin to show drouth symptoms. It is the moisture that a plant can obtain easily from the soil while maintaining rapid growth.

"We consider that a soil is at field capacity 2 days after it has been well soaked by irrigation or by heavy rain. We say it is at the other limit when plants with well-developed root systems begin to show signs of wilting. 'Readily available' moisture, then, is the amount of water that a soil can deliver easily to plants between these two points.

"We have calculated the readily available moisture values for the surface foot of various soils in the Southwest.

"These values are based on irrigation trials, and they cover the common ranges of soil texture. They represent the average depth of water that can be held in readily available form.

"Table 2.—Moisture-holding capacity of soils.

Inches of moisture per foot of soil	Character of soil
2.1	Medium to fine texture.
1.2	Sandy loams containing more than 70 percent sand and for loamy sands up to 85 percent sand.
1.0	Loamy sands containing 85 to 95 percent sand.
0.7	Sands containing more than 95 percent sand."

"As expected, sandy soils hold smaller amounts of readily available moisture than heavier soils. But, to our surprise, there was little difference between fine sandy loams (less than 70 percent sand), loams, silt loams, clay loams, and clays.

"Now with this information, if you learn to estimate the percentage of readily available moisture present in the soil, you can then estimate the inches of water to be applied to bring the root zone to field capacity.

"You can also better determine when the moisture content is suitable for tillage. Just because the soil is not sticky do not think you can operate without creating a tillage pan.

"Preliminary studies indicate that tillage pans may be created by most farm implements when more than one-half of the readily available moisture is present in the soil. Of course, the one-way disc is especially bad in creating tillage pans, but do not overlook the other tillage implements.

"Although this article is directed largely toward irrigation farming, the writer has found that estimating the percentage of readily available moisture present is helpful on dry-farm lands also.

"Here, the amount of readily available moisture at the time of planting winter wheat may be the difference between success and failure. You can also evaluate different tillage and management practices as they affect storage of moisture in the soil.

"The author has tried several methods of estimating readily available moisture over a period of years in New Mexico, Colorado, Utah, and Arizona. Of these, the 'ball test' for estimating readily available moisture in medium-to-fine-textured soils appears to be the most practical.

Shovel or Spade Is Best Tool

"A shovel or spade is perhaps the most satisfactory tool for examining the surface foot of soil. For deeper depths, a soil tube or an auger is helpful in taking samples quickly.

"For the steps to be followed in estimating readily available moisture, please refer to the photographs (pages 10 to 12) and to table 2, page 13.

"The same clues apply to the sandy soils except that the balls of soil are usually fragile for the entire range from one-fourth readily available moisture up to field capacity.

"If you follow the procedures, you should be able to estimate within 1 inch the depth of water that you need to apply to fill the root zone. The ball test is a sound, proven guide for the farmer who wants to apply water efficiently."

Close observance of the color and general appearance of the crop is another method of determining when irrigation is needed. Plants of most of the crops grown in this area give advanced warning of approaching moisture stress by a darkening of the color of the foliage, rolling of the leaves or wilting. When the foliage does not recover its normal turdigity by late afternoon or early evening the need for moisture has reached the critical stage. The lapse of time since the previous irrigation is also an important guide to the experienced irrigation farmer.

Preparing Land for Irrigation

Obtaining even or uniform distribution of water over fields is one of the most serious and difficult problems of irrigation agriculture. Uniform application of irrigation water cannot be accomplished on fields with uneven or rough surfaces. This is particularly true when water is applied by surface methods. It is also true, to some extent, for sprinkling.

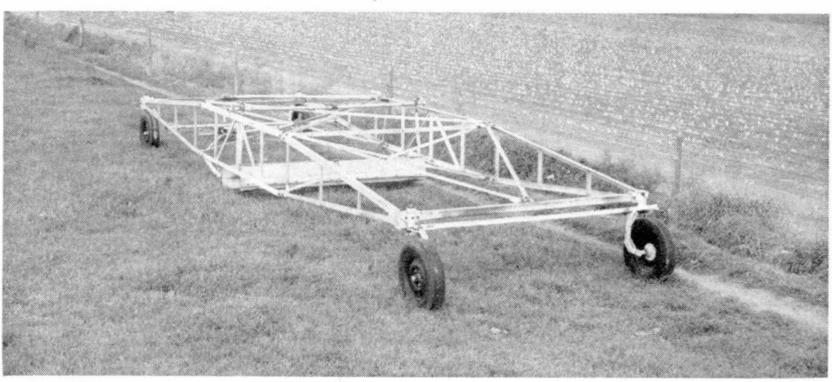
The optimum amount and type of leveling and surfacing varies with topography, depth and quality of soil and subsoil, type of crops to be grown, and economic considerations. Field surfaces should be sufficiently even in slope to prevent any ponding of irrigation water or unirrigated spots. Since the rate of absorption of a given soil may vary considerably during a crop-rotation period and even during a season, no more leveling should be done than will provide reasonably even penetration of irrigation waters.

The cost of surfacing fields to a single plane or slope, in one direction only, is often not justified and may even be undesirable. Such surfacing frequently fails to appreciably improve uniformity of penetration of irrigation water and may be quite expensive. A slightly steeper slope at the upper end of comparatively flat fields will often keep wastage of water into the deep sub-soil at a minimum by permitting irrigation water to reach the lower end of the field more quickly. Several qualifying factors must be considered in determining this extra slope; such as the overall slope of the field, the length of run, rate of absorption of water by the soil, and the danger of erosion.

Perfectly flat fields should generally be avoided unless they are small and excess water can be drained away quickly. Where large flat fields occur naturally, they should be surfaced to a moderate slope to permit excessive rainfall or flood waters to drain away before crops are damaged. Slopes of .1 to .2 percent will usually provide sufficient drainage. Outlet ditches and culverts through road embankments and other obstructions should be provided to prevent water backing up into ends of fields. Rough or rolling fields are not well adapted for the production of intensively cultivated crops. Where rough areas must be farmed without surfacing or grading, the deep-rooted crops are to be preferred. Sod-forming grasses and perennial legumes may be the only safe use that can be made of steep hillside soils.

The movement of large quantities of soil requires deep cuts and fills or long hauls. The economics of such undertakings should be carefully considered as well as the engineering and fertility problems. Deep cuts and fills over extensive areas should not be contemplated without a thorough knowledge of the character and depth of both the soil and sub-soils. The field should be logged to a depth of 4 or 5 feet to locate any gravel, shale or other sub-soil conditions which may need special consideration. Where undesirable sub-soil areas are exposed, it is advisable to return 3 to 5 inches of stock-piled top-soil to them. Laboratory analysis may be necessary to determine if certain exposed sub-soils can be brought into production with reasonable applications of fertilizers and manure.

Deep cutting and filling should be done as far in advance of planting as possible to permit settling and resurfacing. Under extreme conditions, a year or more may be desirable before regular cropping begins. A wide-planted row crop, such as corn, is best adapted for such fields until final resurfacing is completed. Small grain and sweetclover may also be used to provide some income or green manure.



The land plane is the sandpapering equipment used after the deep cuts and fills have been made. It is useful each spring to smooth out irregularities caused by tillage operations.

Detrimental soil packing may result from the use of heavy earth-moving equipment when surface and sub-soils are too moist. If packing occurs, where frost will not break it up before planting time, deep ripping may be applied.

Leveling costs may be reduced by dividing the farm into two or more fields which can be leveled separately. This will generally reduce the quantity of soil to be moved and the total distance hauled. If the land owner or operator does not have a background of experience and knowledge he would do well to seek expert advice and engineering assistance, before attempting any large-scale land preparation.

Irrigation Planning

The object of irrigation is to supplement precipitation to meet the moisture requirements of crops. Irrigation is far from an exact science. Only a few of the contributing factors are subject to reasonably satisfactory control. It is very important that the irrigation farmer learn all he can about his particular situation.

Topography, texture, and depth of soil and sub-soil, climatic and seasonal conditions with their variations, together with water supply and the type of crops should all be considered in planning the farm irrigation system and irrigation practices to be used. The irrigation farmer must be able at all times to make quick changes and adjustments in his operational plans to meet sudden changes in weather and water supply. A heavy rain may stop an irrigation already begun, or a sudden rise in temperature may make irrigation desirable days sooner than expected.

One of the finest reservoirs available to the irrigationist is his soil. But, as great as the capacity of this reservoir may be it is much more limited than many irrigators believe. Many irrigators are mislead in the belief that great amounts of moisture can be coaxed up into the root zone from depths below it. Capillary action seldom draws water to the surface from depths greater than 2 or 3 feet. Water which percolates below the maximum root depths must be considered a total loss, except when applied to leach out alkali. This deep-percolating water too often accumulates on an impervious sub-soil stratum or on an existing water table and creates a detrimental water-logged condition, either in the immediate field or on some adjoining area.

Water-storage capacities of soil can be generally increased by the addition of humus or organic matter. Soils in a high state of organic fertility can absorb water more rapidly and retain more of it than can the depleted soils. This means faster irrigation and longer in-between periods which save both time and labor. It also increases the opportunity for maximum production.

All of the foregoing factors should be kept in mind when planning a new or reorganized farm irrigation system. They, together with economic and other considerations determine field layouts, length or duration of run, method of applying water and amount of leveling needed. The crop or types of crops and soil types also are contributing factors to consider when planning the irrigation system and selecting methods of water application.

A new or replanned and rebuilt irrigation system may develop many faults the first season. —Photo by L. A. Moorhouse

Quality of Water

Most irrigation farmers in Colorado have little cause to worry about the quality of their irrigation-water supplies. With few minor exceptions the waters of the snow- and rain-fed mountain streams are of excellent quality. However, as these streams pass through the irrigated valleys their quality is gradually lowered by the accumulation of salts in drainage and seepage waters. During periods of normal and above normal flows there is usually sufficient water of good quality to dilute the salt content of these waters.

The greatest concern about the quality of irrigation supplies arises with the direct use of drainage, seepage, and well water.

Waters from such sources should be analyzed whenever there are indications that their salt content may be detrimental to soils or injurious to crops. Water from test holes in new or unproved areas should be analyzed before irrigation wells are developed. There are a few areas where the use of underground water for irrigation may eventually create a disasterous soil situation.

The most important factors in determining the quality of irrigation water are: (1) the amount of salt, (2) the proportion of sodium in the salt solution, and (3) the boron present. All irrigation supplies, even the mountain streams, contain dissolved salts. However, water containing up to 1 ton of dissolved salts per acre-foot (700 ppm) can be safely used, providing calcium salts predominate. Water containing the same total amount of salt may be injurious to soil, if the sodium salts in it are excessive. Most authorities agree that there is cause for concern when the amount of sodium in the dissolved salts exceeds 50 percent. Fortunately, the boron factor in Colorado irrigation supplies is of little importance.

In areas where the irrigation-water supplies are stretched to cover every possible acre, the soil may seldom be wet below the first few feet. The salts from the water may eventually accumulate in the soil to a point detrimental to crop production. Obtaining additional water supplies, for even an occasional irrigation, to leach the accumulated salts below the root zones is most desirable.

There is little that can be done to remedy, or improve the quality of a water supply containing excessive amounts of sodium salts. Where water supplies are limited, whatever is available must usually be either used or discarded. It is possible to improve irrigation water of low total-salt content, which has a high percentage of sodium, by dissolving gypsum in the water as it is being applied. It is a tedious and long-drawn-out process. Special equipment is necessary to slowly sift gypsum into the stream of water.

Magistad and Christiansen of the United States Regional Salinity Laboratory, Riverside, California, in U.S.D.A. Circ. 707, state:

"Plants in saline soils are adversely affected by high concentrations of salts in the soil solution and by poor physical condition of the soil. Both conditions are greatly affected by the type of irrigation water used. An irrigation water having a high sodium percentage will, after a time, give rise to a soil having a large proportion of replaceable sodium in the colloid, which is often designated as black alkali soil. Even on sandy soils with good drainage, waters of 85 percent sodium or higher will give rise to impermeable soils after prolonged use. With higher total-salt content there is a flocculating that tends to counterbalance the poor physical condition caused by a high sodium concentration in the water. On a heavy soil already high in replaceable sodium, the poorest water that one could use would be one low in total salts but having a high sodium percentage. (A water supply high in gypsum—calcium sulphate—would be most desirable).

Table 3.—Standards for Irrigation Waters.

Water class	Conductance (K x 10^5 at 25°C.)	Salt Content Total ppm	Salt Content Per acre-foot tons	Sodium percent	Boron ppm
Class 1[1]	100	700	1	60	0.5
Class 2[2]	100 to 300	700 to 2,000	1 to 3	60 to 75	.5 to 2.0
Class 3[3]		2,000+	3+	75	2.0

"1. Excellent to good—suitable for most plants under most conditions.

"2. Good to injurious—probably harmful to the more sensitive crops.

"3. Injurious to satisfactory—probably harmful to most crops and unsatisfactory for all but the most tolerant. If a water falls in class 3 on any basis, i.e., conductance salt content, it should be classed as unsuitable under most conditions. Should the salts present be largely sulfates, the value for salt content in each class can be raised 50 percent."

"The concentration of the soil solution also modifies plant growth and is usually 2 to 100 times that of the irrigation water used, and is seldom more dilute. In heavily irrigated sandy soils the soil solution will tend to approach the same concentration as that of the irrigation water. On heavy soils, where evaporation may greatly exceed drainage losses, the concentration of the soil solution may be 100 times that of the irrigation water and become too great for plant growth.

"It is recognized that few farmers can modify their irrigation water, but the table of standards given will help them appraise what they have or assist them in evaluating supplies (Table 3)."

Concentrations of white alkali in the surface soil while seed is germinating may reduce the stand of the crop. A preplanting irrigation or a plentiful application after planting may be necessary to carry the salts below the young root zones or to dilute the soil solution until the crop can establish itself. Care should be used to avoid water-logging or causing other damage to the soil by applying more water than is necessary.

Alkali Soils

An alkali soil is one which contains excessive amounts of soluble salts which are harmful to plant production, or one which has absorbed sodium sufficient to prevent normal plant growth by direct toxicity because of impaired soil structure. Soils which contain only soluble *white alkali* salts are usually classified as *saline*. Those containing substantial percentages of absorbed sodium, with or without appreciable amounts of the soluble salts, are usually classified as *alkali soils*. A truly alkali or *black alkali* soil is different both physically and chemically from a saline soil.

Essentially all irrigation water contains some soluble salts. These salts tend to accumulate in irrigated soils to amounts harmful to crop production. These conditions are particularly common where most or all of the moisture supply comes from irrigation. The problem will eventually become acute if the irrigation supply is not sufficient, at least periodically, to remove the accumulating salts, or if the land is poorly drained.

Magistad and Christiansen, of the United States Regional Salinity Laboratory, in their Circ. 707, state as follows:

"On soils commonly called white alkali, which contain accumulations of neutral salts as (*calcium, magnesium, etc.*) chlorides and sulfates, a soil basis of 0.2 percent will reduce yields of salt-sensitive plants and 1.0 percent will cause marked yield reductions in most crops. (One percent is equal to 10,000 parts per million.)"

White alkali salts can be removed by leaching where subsurface drainage exists or can be provided. They are seldom found in detrimental concentrations in well-drained soils, unless such soils have been irrigated for a prolonged period of years with an insufficient supply of water carrying dissolved salts. Where white alkali is a problem, periodic leaching irrigations are recommended.

For the leaching application, it is preferable to use the highest quality water available during the season. This condition is most common during the spring run-off or when water stored during flood periods is available. If the salt content of the soil cannot be held or reduced to a point compatable with the crop, more frequent irrigations may be necessary to keep the soil solution diluted to a tolerable point, or a more salt-resistant crop should be grown.

Table 4.—Salt tolerance of principal Colorado crops.*

I Good tolerance	II Moderate tolerance	III Poor tolerance
	FRUIT CROPS	
	Grape	Pear
		Apple
	Cantaloupe	Plum
		Peach
		Strawberry
		Apricot
	FIELD CROPS	
Barley	Rye	Field beans
	Wheat	
Sugar beets	Oats	
	Sorghum (grain)	
Milo	Corn (field)	
	Flax	
	Sunflower	
	VEGETABLE CROPS	
Garden beets	Tomato	Radish
	Broccoli	
Asparagus	Cabbage	Celery
	Bell pepper	
Spinach	Cauliflower	Green beans
	Lettuce	
	Sweet corn	
	Potato (white rose)	
	Carrot	
	Onion	
	Peas	
	Squash	
	Cucumber	
	FORAGE CROPS	
Alkali sacaton	White sweetclover	White dutch clover
	Yellow sweetclover	
Saltgrass	Hubam clover	Meadow foxtail
	Strawberry clover	
Fescue grass	Perennial ryegrass	Alsike clover
	Mountain brome	
Canada wild-rye	Alfalfa (California common)	Red clover
	Tall fescue	
Western wheatgrass	Rye (hay)	Ladino clover
	Wheat (hay)	
Barley (hay)	Oats (hay)	
	Orchard grass	
Birdsfoot trefoil	Blue grama	
	Meadow fescue	
Beardless wild-rye	Reed canary	
	Smooth brome	
	Tall meadow oatgrass	
	Sudan grass	

*Selected from report to collaborators 1952—U. S. Salinity Laboratory.

Black alkali or sodium soils do not have a physical condition favorable to plant development. To reclaim such soils they must be changed chemically and improved physically. This change is accomplished by applying adequate quantities of gypsum and then leaching the soluble sodium salts from the soil with good-quality irrigation water. The success of this treatment depends on adequate drainage. In some few locations irrigation water may be found which contains the needed calcium. Most generally, however, the calcium must be supplied to the soil in the form of gypsum.

Crop plants can tolerate only a very small amount of black alkali salts. The foregoing table gives the comparative tolerence of plants to the neutral or white alkali soils.

The Irrigation System

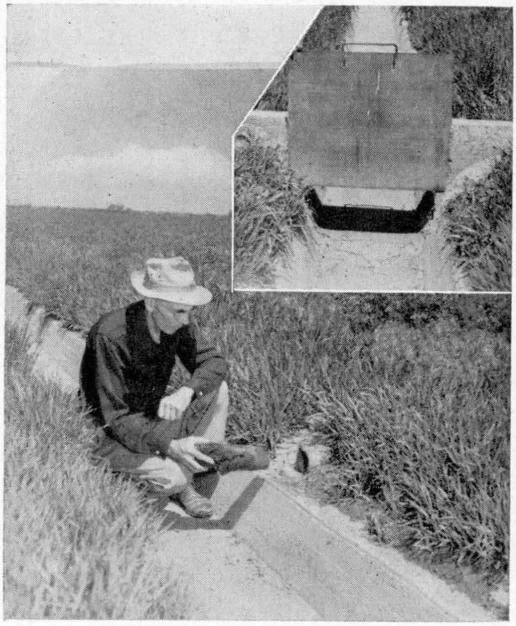
The first step in constructing or rebuilding a farm-irrigation system is to determine the water-application method to be used. (See Sprinkler Irrigation, page 44.)

Surface-application systems may be grouped into three general types. Each of these types may have many variations to fit local conditions and preference.

Type 1.—An elevated type on a slow grade in which the surface of the water in the ditch or lateral is several inches to a foot above the land surface. Siphon tubes, spiles, and gated surface pipe, along with various other kinds of outlets can be used with convenience and little or no checking to maintain a head over them. The same effect can be obtained on steeper grades with checks and drops located and constructed to create flat sections where the overflow or pressure-type distribution equipment can be used.

Type 2.—A sunken ditch or lateral in which the water, when not checked-up for local distribution, flows below the outlets or ground level to another part of the field. A well-planned system of checks is important. The water can then be raised in sections to flow through open outlets or spiles. Lined ditches or those with well-sodded banks in stable soil often require only the closing of a check to make a complete irrigation set.

Type 3.—Another type is the underground tile or pipe line with gate- or valve-equipped risers at convenient locations.



The sunken type of field lateral, concrete lined with checks to raise water to permanent spiles. Wooden plugs wrapped with burlap or an old potato sack are used for spile plugs when needed. The banks are planted to brome-grass to stabilize them and to eliminate most weeds.

There are three common kinds of pipe material generally available. Vitreous clay tile is the most durable in soils containing salts which may destroy metal or concrete. Metal pipe can be selected which will resist many chemical combinations found in soils. Asphalt-type coatings add to the life of metal pipe lines. Concrete tile is often the most economical pipe material where the alkali salts are not too concentrated. Tile made with aggregate and water free of alkali is to be preferred.

Care must be used in constructing pipe or tile lines which will be used under pressure. Pressures built-up by natural fall or grade in a pipe line can become great enough to break the line if gates at the lower end are closed. The same situation may develop where pipe lines are attached to pumps. Relief stands or surge tanks must be provided to prevent building up destructive pressures.

There are several other safety measures that should not be overlooked. Pipe lines on rolling topography may require several drain valves as well as relief columns. Drain valves should be placed to completely drain lines which may freeze. They should also be placed, as needed, to provide for flushing out accumulating mud. Trash grills and safety overflows should be provided at the entrance for lines obtaining water from open ditches.

The location of risers and the type of risers and control valves should be carefully selected to fit into the crop-rotation system

Riser and measuring weir combined, on an underground ditch system.

and field conditions. Risers may be constructed with one or several outlets of the same or different types. Openings can be provided to feed surface laterals or connections provided to feed gated surface pipe or canvas tubes. There are many kinds and models of valves and gates from which to make selections.

Combinations of two or all three of the above types of systems may be desirable on some farms to meet unusual conditions or special needs. The farm ditch and lateral system should fit the size, the topography, the water supply, and the preferences of the operator as nearly as possible for ease of operation and convenience. It should have capacity sufficient to handle safely the maximum quantity of water regularly or accidentally available. Where water supplies often carry heavy loads of silt, open ditches should be constructed on gradients which will permit the silt to be carried on by or located so they can be easily and economically cleaned. A minimum of permanent structures is desirable where frequent cleaning is required and power equipment can be used.

Construction of Open Field Ditches and Laterals

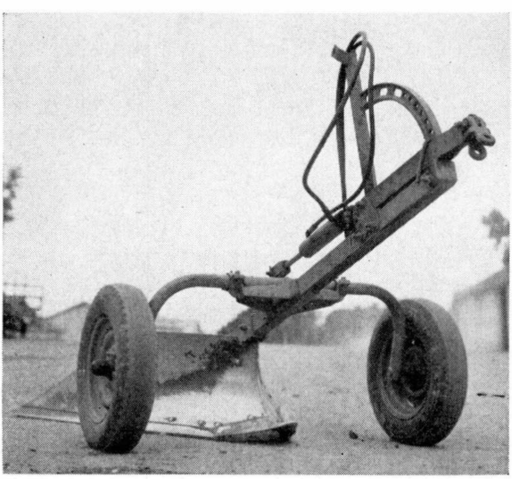
If the location of field ditches and laterals is not fixed by field or property boundaries, a grade to suit the ditch size and the character of the soil can be chosen. Size and grade to fit soil conditions are especially important in the construction of temporary or seasonal field laterals, which are generally not protected by drops, turn-outs, and checks.

Erosion in ditches is largely related to velocity. Small streams have a lesser velocity on a given grade than larger streams. Grades should be selected with the size of stream in mind. Sandy soils erode easily and should not be subjected to velocities greater than 1.5 feet per second. Velocities in loams should be between 1.5 and 2.0 feet per second and in clays up to 3.5 feet per second. Suitable velocities for flat-bottom ditches constructed with modern V-type ditchers can be calculated from table 5 on page 27.

Example: To determine permissible grades for a lateral with a 12-inch bottom in loam soil to carry 2 c.f.s. From table 5 under the section for 12-inch bottoms and in the column headed 6 in. fall per 100 ft. or .5% grade, find the discharge closest to 2 c.f.s. It is 2.09 c.f.s. and is close enough for the purpose. In the adjacent column the velocity given is 1.90 ft. per sec. which is allowable. Any flatter slope will result in a lower velocity with greater depth of water. The depth in the example is 8 in. For a slope of 2 in. per 100 ft. the depth would be about 10 in.

Table 5 also gives some idea of the capacity of flat-bottom ditches with 45-degree or 1-to-1 side slopes.

When locating a ditch on some predetermined grade, the level is set up along the route in such a way that about 600 feet can be located from each set-up. The first reading is taken not in the bottom of the supply ditch but on the water line or the natural ground surface nearby. If the crew is composed of three men, one will be at the instrument, the other two at opposite ends of a 100-foot tape. The rear man stays at the point of beginning, the other with the rod pulls out the tape in the approximate direction of the ditch location, stopping when the rear man calls. The rod is set up on the ground and the instrument man reads. He wishes to read the original reading plus the fall in 100 feet and signals the rodman either up or



A modern one-man ditcher.

Table 5.—Capacity of earth ditches with 1-to-1 side slopes.

n=.025*

Water depth inches	Fall in inches per 100 feet or percentage grade									
	2 in. or .17%		3 in. or .25%		4 in. or .33%		5 in. or .4%		6 in. or .5%	
	Vel. f.p.s.	Disch. c.f.s.	Vel. f.p.s.	Disch. c.f.s.	Vel. f.p.s.	Disch. c.f.s.	Vel. f.p.s.	Disch. c.f.s.	Vel. f.p.s.	Disch. c.f.s.
	Bottom width 6 inches									
4	0.61	0.17	0.73	0.20	0.84	0.23	0.96	0.27	1.03	0.29
5	0.71	0.27	0.86	0.33	0.97	0.37	1.13	0.43	1.23	0.47
6	0.79	0.40	0.96	0.48	1.12	0.56	1.28	0.64	1.35	0.68
7	0.87	0.55	1.05	0.66	1.24	0.78	1.41	0.89	1.52	0.96
8	0.96	0.75	1.15	0.89	1.33	1.03	1.52	1.18	1.65	1.28
9	1.04	0.97	1.24	1.16	1.43	1.34	1.64	1.54	1.80	1.69
10	1.10	1.22	1.33	1.48	1.55	1.72	1.76	1.95	1.92	2.13
11	1.17	1.52	1.41	1.83	1.65	2.14	1.88	2.44	2.07	2.69
12	1.23	1.85	1.49	2.23	1.77	2.65	2.00	3.00	2.20	3.30
	Bottom width 12 inches									
4	0.72	0.32	0.87	0.39	1.00	0.44	1.12	0.50	1.25	0.56
5	0.81	0.48	1.01	0.60	1.16	0.68	1.34	0.79	1.46	0.86
6	0.92	0.69	1.11	0.83	1.28	0.96	1.47	1.10	1.60	1.20
7	1.01	0.93	1.22	1.13	1.42	1.31	1.60	1.48	1.77	1.63
8	1.11	1.22	1.34	1.47	1.55	1.71	1.75	1.92	1.90	2.09
9	1.20	1.58	1.44	1.89	1.68	2.20	1.90	2.49	2.10	2.76
10	1.28	1.95	1.54	2.35	1.78	2.72	2.00	3.05	2.20	3.36
11	1.34	2.35	1.63	2.86	1.90	3.33	2.12	3.72	2.32	4.07
12	1.40	2.80	1.72	3.44	2.00	4.00	2.24	4.48	2.50	5.00
15	1.61	4.52	1.98	5.57	2.32	6.52	2.60	7.30	2.80	7.86
	Bottom width 18 inches									
4	0.77	0.47	0.94	0.57	1.10	0.67	1.24	0.76	1.32	0.81
5	0.88	0.70	1.06	0.85	1.24	0.99	1.40	1.12	1.51	1.21
6	1.00	1.00	1.20	1.20	1.40	1.40	1.58	1.58	1.71	1.71
7	1.10	1.34	1.33	1.61	1.55	1.88	1.75	2.13	1.91	2.32
8	1.20	1.73	1.44	2.08	1.68	2.42	1.90	2.74	2.10	3.03
9	1.29	2.17	1.56	2.63	1.81	3.05	2.05	3.46	2.25	3.80
10	1.38	2.68	1.66	3.23	1.92	3.73	2.18	4.24	2.38	4.63
11	1.46	3.23	1.76	3.90	2.03	4.50	2.30	5.10	2.52	5.58
12	1.54	3.85	1.85	4.62	2.13	5.32	2.42	6.05	2.64	6.60
15	1.72	5.91	2.09	7.18	2.42	8.31	2.74	9.41	2.90	9.96

*Kutter's coefficient of roughness. This is for reasonably clean ditches with a fairly rough bottom.

down the slope to find the rod reading. Should the rod be equipped with a target, the rodman moves this **up** the required fall each time. In finding the point he must keep at the end of the tape which means he must whip it sideways as he moves. When found, the point is marked with a stake and both men move ahead to find the next point. When the station—about 300 feet beyond the instrument—is reached, the point where the rod is held is closely noted so that it can be held at the same point when read from the new position of the instrument when it is carried ahead. The procedure is then repeated.

Water Control Equipment

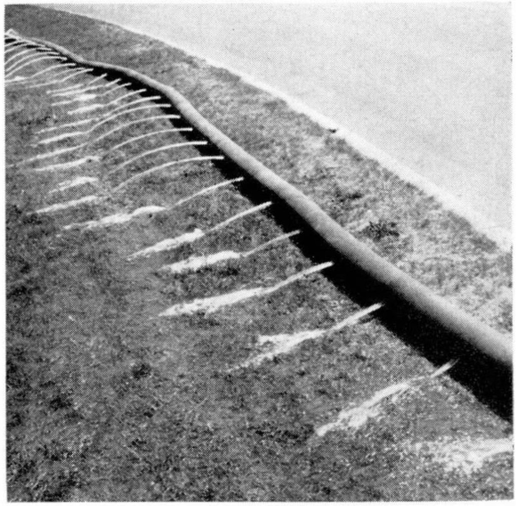
Surface Pipe with Gates

Steel and aluminum pipe, equipped with gate outlets, eliminate field laterals and provide almost positive distribution and control of water. This pipe is available in several sizes with standard gate spacings of 20 inches and multiples thereof. Special pipe sizes and gate spacings to fit unusual row spacings can be secured on special order.

Steel gated pipe generally fits together like stovepipe and without gaskets. Aluminum pipe is available with quick make-up joints and rubber gaskets. Both can be laid on the contour but the rubber-gasket type of joint permits sharper curves. All

Gated pipe in use in a corn field.

types of fittings and gates are available to complete pipe line systems and to control water pressures in them. In setting up such systems to be fed from ditches, trash screens must be used to insure satisfactory operation.



Plastic-coated or other treated canvas tubing with eyelet openings spaced to fit crop rows or other conditions. This tubing can be used for both furrow and flood irrigation, as shown.

Canvas Tubing

Canvas tubing with eyelet outlets or small sleeves with drawstrings provides another type of movable distribution system. This tubing is put together by slipping about 1½ to 2 feet of one tube into the end of another. Water pressure holds it together while operating. This tubing and gated pipe are useful in cutting fields into shorter runs after planting to eliminate cross ditches that take up land and interfere with cultivation. The minimum tubing or pipe purchased should be sufficient to make two complete sets of available water. This will permit one set being moved while the other is operating. Gated pipe and canvas tubing provide excellent control of water.

Siphon Tubes

Siphon tubes are available in many designs of aluminum, steel, plastic, or rubber. They also provide excellent control of the quantity of water turned into each row or bordered land. Plastic and metal siphon tubes are made in two general styles—single bend and double bend. The double bend straightens out the stream of water into the furrow and causes less erosion. Flexible rubber tubes fit themselves to the ditch bank and furrow. Some metal tubes are equipped with adjustable gates or reducers for better regulation of water.

Siphon tubes are made in sizes from ½ inch to 8 inches or more. The larger sizes are used for bordered lands and diversions into field laterals. Tubes without adjustable gates should be

Aluminum siphon tubes operating in a concrete-lined lateral provide even distribution of water to a maturing sugar beet crop.

smaller in size than required to deliver maximum desired quantity of water per furrow. Two or more such tubes are set per furrow to start the run and then one or more removed to reduce the flow per furrow to a soaking stream.

The capacity of a siphon tube, without a gate, can be adjusted within small limits by changing its position in the ditch. Pushing it back into the ditch, thereby raising the outlet end, decreases the flow. Pulling it over toward the furrow, thereby lowering the outlet end with respect to the suction end, increases the flow.

The approximate capacities of plastic and metal siphon tubes under various head pressures are shown in table 6. Tubes with rough inside walls will discharge a smaller quantity of water than those with smooth walls. Allowance must be made for shape of tube ends and overall length. Greater friction in longer tubes reduces flow.

To use siphon tubes, head ditches must be built on top of or above the ground to create head pressure to make them work. Trash screens at some point in the ditch may be needed to insure against siphons becoming plugged.

Table 6.—The approximate capacities of plastic and metal siphon tubes under various head pressures.

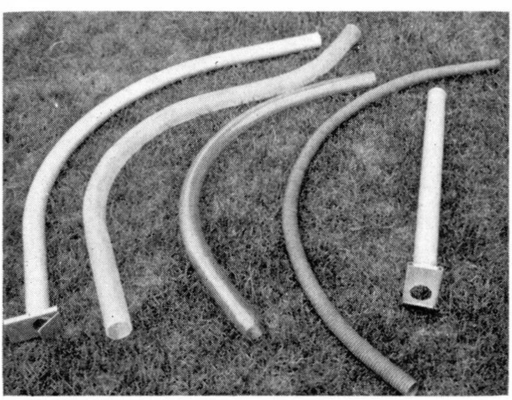
Tube Di-ameter	*HEAD PRESSURE							
	2 in.	3 in.	4 in.	6 in.	9 in.	12 in.	15 in.	18 in.
inches	gpm.	gpm.	gpm.	gpm.	gpm.	gpm.	gpm.	gpm.
½	1.3	1.6	1.8	2.1	2.7			
¾	3	4	5	6	7			
1	5	6	7	9	11			
1¼	8	10	12	15	18			
1½	13	16	18	24	23			
2	21	27	32	41	50			
3		57		82				
4		100		143	180	204	220	
6		166		268	312	368	422	464
7		215		313	393	463	526	580
8		295		413	508	580	658	725
9		378		563	658	769	844	951
10		570		725	825	948	1030	1180

*Head is height of water in ditch above siphon outlet.

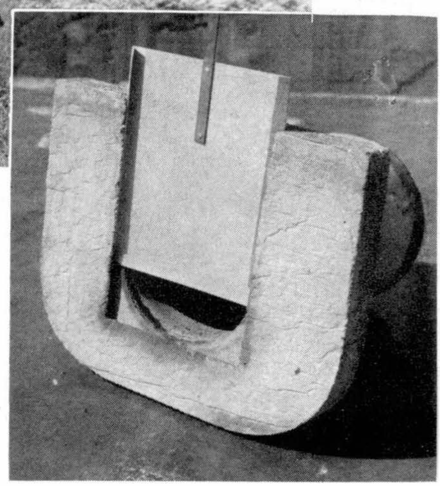
Spiles

Spiles have probably been used for ages by irrigators to make even distribution of water. Modern spiles are made of many materials including sheet metal, gas pipe, boiler tubes, plastics, rubber, wood, etc. Some aluminum and sheet steel tubes are equipped with gates to provide adjustments for different quantities of water.

Gas pipe and boiler tube spiles may be left in banks of permanent ditches if properly located and if care is used in cleaning the ditch. Spiles should be well "mudded in" when set. Dry trashy soil in the backfill will almost guarantee them washing out.



Some of the common shapes and materials used in siphon tubes and spiles found on the market. From left to right: a single-bend aluminum siphon tube with adjustable gate, a double-bend plastic tube, a single-bend plastic tube, a flexible coiled-wire reinforced rubber tube, and an aluminum spile with adjustable gate.



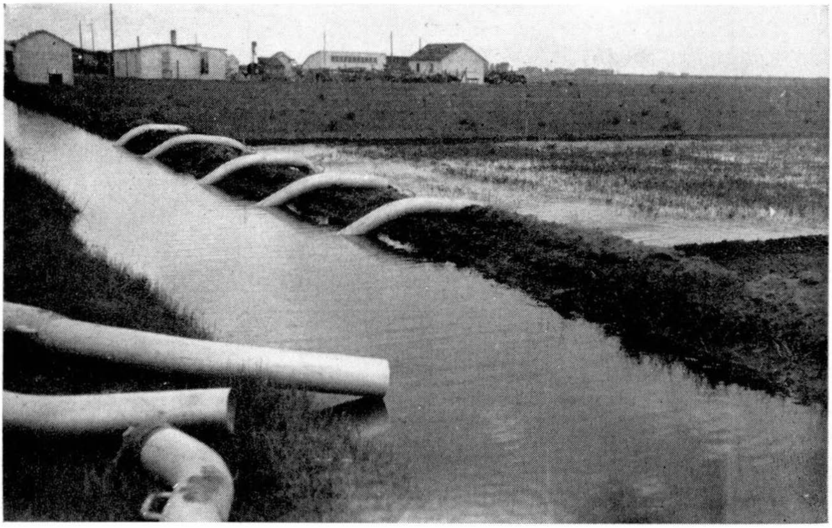
The two gates (upper center) are steel sheets installed in pre-cast concrete head walls attached to lengths of concrete pipe. In the left center is a quick-opening and closing steel gate built into a short length of corrugated steel pipe. At the right is a steel gate installed in a precast head wall and tube.

Methods of Applying Water

There is no one best method of applying irrigation water that is applicable or usable in all parts of Colorado. After all the factors such as different varieties of crops, types of soil, topographical features, water supply, local precipitation patterns and quantities are considered, there is still the matter of personal preference. The irrigation farmer should select methods which meet all local requirements and his personal preferences as nearly as possible.

Wild Flooding

The distribution of water through field ditches and laterals from which it flows over the field, guided only by the slope of



Large siphon tubes are useful in feeding water to bordered lands and laterals.

the land, is not usually recommended. It is often extremely wasteful of soil, water, and plant food. It is particularly poor practice on fallow or plowed fields. This method of applying water to well-sodded pastures, mountain meadows, and alfalfa fields is permissible, but should have close attention by the irrigator. A moisture probe or soil auger is particularly essential in this type of irrigation.

Laterals for Flooding

In general, the use of temporary or seasonal field laterals on gradients of more than .4 percent is poor practice. Laterals on faster gradients are conducive to erosion and require excessive labor to check and dam. Temporary field laterals should not be made larger than necessary. Straight-down-the-slope laterals on too-fast gradients have a tendency to errode and become larger. Parallel straight-down-the-slope laterals, 40 to 60 feet apart across a field, exclusive of the header lateral, may take as much as 10 percent of the field out of crop production. On most soils such laterals often move much top soil from the higher to the lower end of the field. They also provide poor control over water and foster excessive weed production. Wherever possible, bordered lands should be considered for hay, grain, and pasture crops as soon as necessary leveling can be done. They aid in obtaining even application and penetration of water with the minimum of effort by the irrigator.

Contour laterals are recommended for flood irrigation of close-growing crops on fields too rolling or too steep for bordered lands. Such laterals are usually run on grades of .1 to .3 percent, depending on erodability of the soil, and quantity of water to be used. Very silty water will soon fill up laterals on grades of .1 percent or less. Large streams of water will erode many soils on grades greater than .3 percent.

Distances between contour laterals are varied to fit slopes and soils. Steeper slopes and easily eroded soils require closer spacings. On moderate slopes, up to .3 percent on medium-loam soils, the distance between contour laterals should be such that a thin sheet of water will cover it in 1 to 2 hours. On slopes greater than .3 percent, the laterals will need to be closer together to permit more frequent redistribution to obtain more even penetration and avoid erosion. Run-off or "waste" water from the upper land is caught and redistributed in the next lower lateral and so on across the field. Little, if any, water need be wasted from such fields if the water is reasonably clear and the sets properly made. Waste or run-off is difficult or impossible to avoid when the water supply is carrying a heavy load of silt as it sometimes does in many areas.

Many fields have slopes in two directions with respect to the boundary along which the main field lateral is situated. To irrigate some such fields on an ideal gradient would result in undesirable point rows. Pointed bordered lands can generally be tolerated. Point rows can often be avoided or modified by constructing a main lateral down the steeper slope for distribution to furrows, corrugations, or temporary contoured laterals. Such main laterals will need protection against erosion.

Permanent head ditches and field laterals, on steep slopes, should be equipped with drops, checks, and turnouts as needed to fit the cross-field temporary laterals used when the field is in grain or alfalfa. These ditches may be lined with concrete or still better put into a covered pipe or tile line with suitable valves and risers.

Furrows

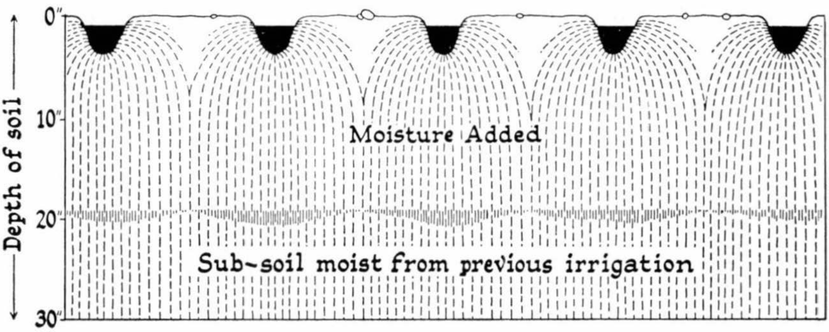
Field grades of 3 percent or less are most desirable for furrow irrigation. Irrigation on steeper grades requires care and close attention. Crop rows should be planted at an angle to the main slope where possible to reduce gradients greater than 3 percent. This is particularly desirable on the more erodible soils. Gradient contour furrows on these steeper fields will save water and eroded soil. Breaking together is a hazard with gradient contour furrows. Therefore, on steep cross slopes especially, water should be turned into every other furrow at a time.

Furrows should be designed and located to fit stage of crop development, soil, and field conditions. Shallow furrows should be used near seed for pre-germination irrigation or near newly transplanted or young plants, with variations to fit slope of field and soil conditions. Larger furrows are necessary on flat fields or in porous soils where larger streams of water are needed to reach the end of the furrow quickly. Smaller furrows are preferable on steeper fields or in tight soils. The furrow should be made to fit field conditions and the quantity of water to be used.

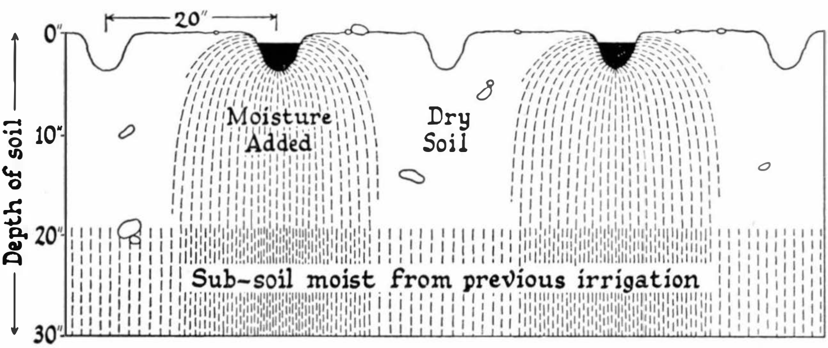
As crops develop, furrows may be deepened and located at a greater distance from the plants, if crop rows permit variations in distance. This is often desirable in some vine crops. Construction of furrows after crops are well started, should not destroy too much of the plant root systems. Furrows must be large enough to carry the proper quantity of water without flooding or ponding. This is especially important on soils which crust badly when flooded.

Field conditions and silt content of the water determine the quantities of water to be run in furrows. The slope of the field, character of the soil, and length of the run are all important factors. Quantities may vary from 2 gallons per minute on steep clay soils to 100 gallons per minute or more on very flat gravelly soils. Erosive streams should be avoided but the volume should be great enough to reach the end of the run in about one-fourth to one-sixth the time required to penetrate the desired depth into the root zone. The amount of water per furrow, in the same set, should be approximately equal in all furrows, except that furrows packed by tractor wheels may require much smaller quantities than those not packed. The water should advance about evenly in all furrows. Under many field conditions relatively large streams of water, the largest non-erosive streams, are started and later reduced to a "soaking stream" when the water has reached the end or near the end of the row. Use soil auger or moisture probe to check penetration.

A simple usable rule for determining when surface or sprinkler irrigation sets should be changed can be easily worked out for each farm or field. When a moisture probe can be pushed to about half the depth of the desired irrigation on loam soils, there is sufficient water in process of percolation to complete the irrigation. On sandy soils the percolating water in the upper one-third of the irrigation zone should be sufficient to complete the irrigation. On heavy clay soils the stopping point may be at the three-fourths mark. Soil-auger borings, 1 or 2 days after irrigating, is the best way to determine total depth of penetration. A little investigation and experience with a moisture probe on each farm will provide sufficient information for quick determinations. Similar investigating and experience will provide



This illustration represents an idealistic, but not always true penetration pattern resulting from correct spacing of furrows or corrugations with water being run the proper length of time in each furrow. Many soils do not permit such perfect penetration patterns. Water in every furrow for the adapted period of time wets all the root zone, limits deep percolation losses, and reduces run-off or waste water to a minimum.



Furrows or corrugations too widely spaced may not wet the root zone unless water is run for long periods which tends to increase losses from deep penetration and run-off. Alternate irrigations in every other furrow are sometimes desirable to keep the ground surface dry to retard development of insects and fungus diseases, or to obtain quick partial coverage of a field in an emergency. This system is also useful on fields where lateral penetration of top soil is very rapid.

necessary information for furrow irrigation. Slender moisture probes can, at times, be pushed to full depth in some dry soils. Where this is possible, probes of larger cross section or soil augers should be used to fit the situation.

The illustration at the bottom of page 36 does not necessarily apply to the practice of setting water in every fourth or sixth row across a field. Labor can often be saved where the head ditch is on a moderate grade or effectively equipped with checks, drops, and turn outs. This system of furrow irrigation eliminates moving and adjusting dams for new sets every few hours. Setting in these wide spreads may not be usable or produce the desired results where the water supply fluctuates or where it is distributed under a rotation system, such as 3 days out of every 10, for example. Neither is this practice recommended for use until cultivation has been completed for the season. Alternating applications in every other row may prove a better practice in emergencies or where water deliveries are intermittent or irregular.

Furrows in cloddy, trashy, or porous soils or in flat fields, or combinations of such conditions, should be smoothed or cleaned. Such furrows may be improved by dragging a round concrete block, loaded pipe of suitable size or sledded with 6- by 6- or 8- by 8-inch square or suitable round wood runners. Such treatment will increase the rate of advance of water along furrows and permit desired penetration at lower end of field before the upper end is over-irrigated.

Length and Duration of Run

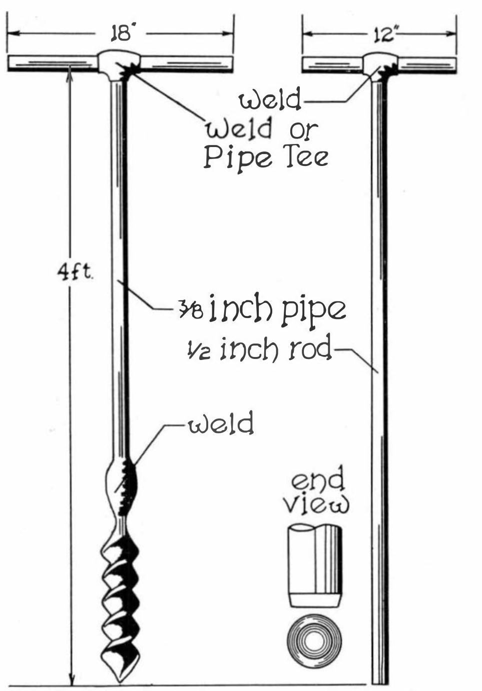
Length of rows or duration of runs must fit field conditions, grade, and soil characteristics for highest efficiency from water used. Determination of proper length of run for a given field is a technical process. An irrigation engineer or technician should be called in if close determinations are to be made. The duration of a set or run is governed by the absorptive or infiltration rate of the soil, quality of water (clear or silty), and depth of root zone to be wet. (See definition of rate of infiltration, page 10.)

The duration of the run and the quantity of water per furrow or turn-out should be varied with the silt or mud content of the water. Very muddy water flows faster across the field than clear water because it seals or smears over surface of the soil and reduces the rate of infiltration. Therefore, it must be run longer to wet the root zone. The quantity turned out at one place or into each furrow should be kept to a practicable minimum to eliminate or reduce run-off or waste water.

Over-length rows or too-long sprinkling periods waste water and reduce yields. On porous soils, such as sand and gravel, in flat fields, rows of 330 feet or less in length are recommended. Loams and clays on steeper slopes are favorable to longer rows and heavier applications of water at one irrigation. Small furrows should very seldom exceed a maximum of 1,300 feet in length. The duration of a sprinkler application should be just sufficient to wet the desired depth of root zone, except when leaching alkali.

A practicable and usable length of run can be determined as follows: Select several adjoining furrows in an average part of the field. Measure off and stake stations every 50 or 100 feet along plot selected. Make necessary preparations for equal distribution and control and turn into all furrows, simultaneously, equal quantities of water. The quantity of water per furrow should usually be the maximum non-erosive stream for the prevailing conditions. Note time water is turned in and when it reaches each station.

While water is running, make occasional examinations of the vertical penetration near the upper end of the furrows with a moisture probe or a soil auger. When the penetrating water has reached the bottom of the normal root zone of the mature crop, note the time. Then note the station reached by the water in the furrows in one-sixth to one-fourth the time required to wet the root zone at the upper end of the field. This indicates the length of run. (For common root zone depths, see page 48.) Run a cross lateral at the station indicated, before next irrigation. Such cross laterals may be put in after crop is planted and crossed with culti-



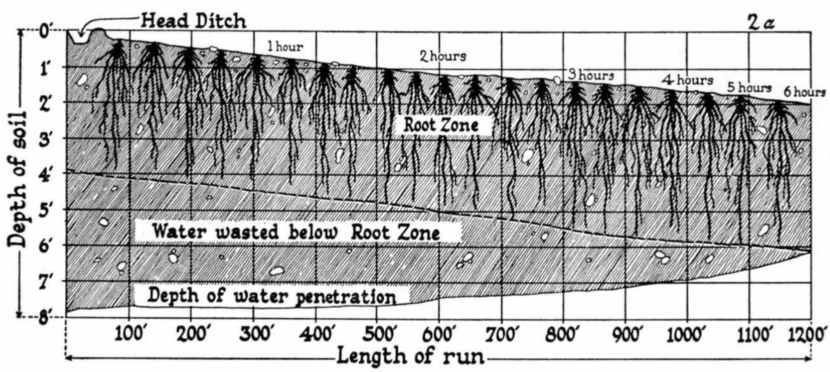
Soil Auger Moisture Probe

vating equipment. Gated pipe or gated canvas tubing may be substituted for cross laterals, with less loss of crop and moved aside to permit cultivation.

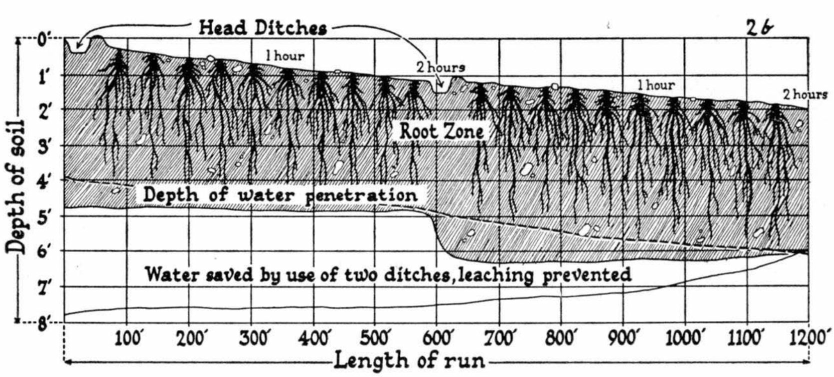
The duration of an irrigation run is determined by penetration of water into plant root zone. The normal root zone must be moistened to properly feed the crop.

Corrugations

Like furrows in row crops, corrugations should fit soil and crop conditions with respect to grade, spacing, size, and length. They are very useful in obtaining economical use of water and high labor efficiency on close-drilled or broadcast crops and fal-



The normal results of too-long furrows or duration of run.



Runs of proper length in distance or time, save water and prevent leaching of plant nutrients.

low lands. They are often very useful on fields that cannot be leveled to uniform grades, and on very flat fields, or to reduce the gradient on steep slopes where water velocity should be reduced to obtain desired penetration. They are popular in some areas to prevent flooding emerging seedlings of crops such as clover and alfalfa with silty water. Corrugations should be kept as small as possible to perform their service. Corrugations can be made with cultivators equipped with furrow openers, wooden corrugators or wheel-mounted corrugators. Sledding or smoothing out clods in corrugations or furrows on flat land will aid in obtaining more equal penetration by permitting the water to reach the lower end before the upper end of the field is over-irrigated. The distance between corrugations varies from 16 to 30 inches, generally, depending on the nature of the soil and slope of the land. The spacing should be such that the soil between corrugations will be thoroughly moistened by the time the penetration has reached the desired depth. Wider spacings are preferred for heavy soils and closer spacings for porous soils. They should not be quite as far apart as the depth of the root zone of the mature crop. The same rules for length of corrugation and duration of run apply here as in furrow irrigation and floodings.

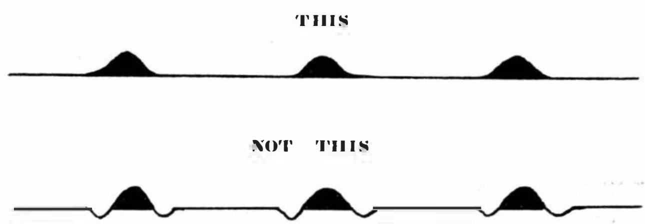
Furrows in center of wide rows are too far from crop. The root zone of these tomato plants was almost entirely dry after 30 hours of irrigation.

Bordered Lands

Bordered lands provide an excellent method of controlling water and securing even distribution and penetration. They are particularly useful for the irrigation of close-growing crops such as small grains, alfalfa, and pasture.

They are strips of land, of suitable widths, which are level crosswise and bordered on each side by dikes or ridges to retain and guide irrigation water. Fields on reasonably uniform slopes —up to 3 percent in one direction—are most favorable for border irrigation. Border irrigation may be used on steeper slopes, particularly on the less errodible soils, if care is exercised.

Borders should not be established until after land is well leveled and surfaced. They may be constructed with an open-end V-drag, a grader or bull-dozer blade, or other suitable equipment. The area between the borders should be as nearly level crosswise as it is possible to obtain. Extra effort to obtain perfectly flat lands crosswise will save labor and assure more even irrigation. Soil removed for border building must be replaced.



To aid in spreading water evenly across the full width of land, the first 10 to 15 feet from the head ditch may be made level. This flat area will be the turning row and, if desired, the secondary water adjustment area when the field is in row crop.

Good preparation of land for irrigation and the laying out of good irrigation systems require good engineering and soil surveying. Competent engineering assistance is to be recommended when a major operation is to be undertaken.

Bordered lands should be laid out in the direction of the steepest slope. If a check with an engineer's level indicates that borders can not be laid out parallel to the farm or field boundary, a topographic map may be made or contour lines run not more than 200 feet apart and the borders run at right angles to them.

The width of bordered lands or strips should be adjusted to slope, erodability of the soil, and the minimum quantity of water that may be available. Sandy or gravelly soils take moisture rapidly. The water should be forced over such areas quickly to avoid overirrigation. Since heavy soils absorb water more slowly, smaller streams of water should be used or the length of run or width of the land or strip increased. Water should cover the lands from border to border hence wide lands or strips of 50 feet or more are not suitable for small streams of water. The following table may serve as a guide to quantity of water and width of lands.

Table 7.—Guide for laying out and operating bordered lands.*

Volume of water per border		Soil Types					
		Sands		Loams		Clay	
Second feet	Gallons per minute	Width feet	Length feet	Width feet	Length feet	Width feet	Length feet
1	450	20-30	200-300	30	300-400	30	440-660
1-2	450-900	30-40	300-400	30-40	440-660	30-40	660
2-4	900-1800	30-40	400-500	40	440-660	50	660-880

*Based on "Border Irrigation" by Ivan D. Wood, Soil Conservation Service and Extension Service.

The narrower widths of lands are recommended for the steeper slopes. Thickness and height of border dykes depend on slope, soil and quantity of water. After settling, a border should be sufficient to contain the necessary quantity of water used, that is, 5 to 8 inches high and about 2 feet in width, especially on soils that check badly, such as heavy clay. Close-growing crops like grain, alfalfa, and clover may be planted over the dykes to utilize all of land and discourage weed growth. Furrows or corrugations may be used in bordered lands for pre-germination irrigations. Such lands can be farmed in row crops without destroying borders, if desired.

The use of bordered lands should be increased in Colorado. They provide excellent control of water for flood irrigating close-drilled crops and pasture. They conserve both labor and water and reduce areas otherwise occupied by ditches and weeds. Fields surfaced for border irrigation fit into the general crop-rotation scheme because they are perfectly adapted to furrow irrigation.

Sub-irrigation

Artificial Sub-irrigation

Sub-irrigation is practicable under favorable soil conditions for gardens and limited areas of high-priced crops. It is not recommended for sandy or gravelly soils. It functions best where 1 to 2 feet of soil is underlain with a hardpan stratum.

Water is applied through perforated or porous pipe or tubing buried below depth of tillage—12 to 14 inches below the surface generally and 6 inches for strawberries or other shallow-rooted plants. Spacing between underground lines varies with capillarity of the soil—usually about 4 feet—but often to fit plant rows. Lines of about 50 feet in length are recommended for best distribution of water. (See Extension Service Bulletin D-22.)

Natural Sub-irrigation

This method of irrigation is practicable only where certain geologic conditions prevail. It must be possible to provide a water table that can be adjusted or regulated with respect to the root-zone area. A porous soil of sufficient depth to provide necessary root zones is preferable to tight deep soils which are difficult to drain. The area should be on comparatively flat, or gently sloping topography.

The major requirement is to hold the water table up to or into the lower root zones during the growing season. As the crop matures the water table is lowered. This method is practiced quite successfully in parts of Alamosa, Rio Grande, and Saguache Counties, Colorado. It is not recommended where it can be avoided because of the problems arising from accumulating alkali salts and the leaching of plant food elements.

The first requirement is good field leveling and surface maintenance so that the water table can be held at a uniform depth below the surface, usually about 18 to 24 inches over the entire field, to provide moisture directly to the crop root zones. The area must also have adequate drainage—natural or artificial. Closed or open drains are both used and are provided with checks so the water table can be accurately maintained during the growing season. Checks should be opened during winter months to drain out accumulated alkali salts.

Water is applied in "sub-ditches" spaced from 40 to 60 feet apart across fields or by a combination of flooding and "sub-ditches." Since the water table is maintained over a large area, the success of this method of irrigation depends on community cooperation. It is generally not practicable on individual farms, and is not usable in areas of deep soils and rolling topography.

Pre-planting irrigations are essential, in the sub-irrigated and semi-sub or high-water-table areas, to remove the winter accumulation of "white alkali" from root-zone soil and provide germinating moisture. The quantity of water applied should be adjusted to the needs if irrigation supplies are adequate. Drains should be maintained in good repair and kept open as much as conditions permit to carry away accumulating salts.

Sprinkler Irrigation

In an irrigated section sprinkling should be considered a means of applying water where adverse conditions indicate that other methods would be inefficient or hazardous. Some thin soils, especially when underlain by gravel, cannot be conditioned by leveling for surface irrigation to any great extent. Very sandy or porous soils hold but small amounts of water and require frequent and relatively light applications. In surface irrigation these conditions are difficult to meet and on steep grades extreme care is required to prevent even moderate erosion. All these conditions are probably best met with sprinkling. Should irrigation be contemplated for new lands, the capital expense of a sprinkler system might easily equal the expense of land preparation for a surface system including ditches, pipe lines and control devices. A considerable additional expense is involved when ditches are lined. An important point often overlooked is that of space occupied by ditches which can amount to from 5 to 10 percent of farmed area and in addition present a weed and pest problem.

Labor saving is not necessarily an attribute of sprinkling. It may or may not be less than for a well-developed surface system. Systems on wheels require much less time for moving than hand-moved systems, but are limited, practically, to such crops as alfalfa, pastures and young grain. A less experienced type of labor may be used on sprinkler systems than with surface irrigation which is advantageous. Frequently on farm set-ups, the moving of pipe is looked upon as a farm chore to be incorporated with other regular duties.

Sprinkling has been used satisfactorily on nearly all field crops grown in Colorado. The possible exceptions are lettuce in advanced stage of growth, cantaloupes, and tomatoes and beans after blossoming begins. Incidence of blight propagation is possible, but as yet this has not been observed. Sprinkling has been found particularly advantageous for starting new seedlings, transplanted crops, and irrigating-up such crops as sugar beets. There is evidence that damage will occur from streams hitting nearly ripe sour cherries, and ripe sweet cherries may split on being wetted.

Much land has gone out of production or become marginal through water logging and alkali accumulation. This has come about in part through wasteful surface irrigation causing a high water table. The fact that a measured amount of water can be applied by a sprinkler making it possible to avoid losses to the water table, should alleviate much of that kind of trouble.

The principal disadvantages of sprinkling lies in the high capital investment and the cost of operation. These should be thoroughly investigated before a decision to purchase is made. It must be remembered that irrigation in Colorado is an all-season operation which may be 9 months long. One irrigation in a humid climate may do wonders for a crop, but four to six will be necessary in Colorado. While a sandy soil type may be ideal for a sprinkler the very heavy types may not be because of their low-intake rate. The sprinkler application rate must be less than the absorption rate of the soil otherwise undesirable ponding and soil puddling will result. Although general equal distribution of water can be anticipated for an entire field, there may be small local spots where applications may be inadequate or excessive. These spots may be caused by a poor sprinkler pattern, by improper spacing of sprinkler heads or wind interference. By avoiding setting a lateral in the same place each irrigation, this uneveness can be broken up. Another point which should be mentioned here is that a sprinkler system puts out a fixed quantity of water; hence a variable water supply may introduce some difficulties. In such cases, some place on the farm should be prepared to receive surface applications or else the surplus will need to be wasted.

The design of a sprinkler system requires much experience and should not be attempted by the inexperienced. It should be precisely fitted to a particular situation. Firms selling sprinkler systems usually have competent engineers to provide proper design. Buying a second-hand system without advice can lead to trouble or unusual expense. The engineer, or designer, should obtain the best available data on the soil characteristics, preferably from a soils specialist, and complete information about the source, and amount of the water supply, the crops, crop rotation, and the farm-labor program. The source may be from canals or well water pumped into ditches to be picked up with a portable pump or from a well equipped with a pump designed to provide the additional pressure through pipe lines. Soil absorption rates may be as low as ¼ inch and as high as 2 inches per hour. The crops grown will fix the maximum irrigation requirements and therefore the rate and length of time of an application. The designs will also take into account the loss occurring through evaporation which, under some conditions, may be as high as 30 percent.

Many new sprinkler irrigators make the mistake of applying too little water at an irrigation. This may have come through ignorance of sprinkler agents and misleading advertising as to the savings in water through sprinkling. Sufficient data are available as to crop requirements and these can be met with proper engineering design and management. The irrigator should not be guided too much by set routine. He has the means with soil probes and augers to determine whether or not he has done a good job of wetting the root zone of the plant. He should use this as a guide rather than an arbitrary duration of set for all crops at all stages of growth. A rough guide as to the quantity of water to be applied per foot of root zone is shown in table 2, page 13.

Pressures are ordinarily chosen in one or two categories, 30 to 40 pounds per square inch and 60 to 65 pounds per square inch and the spacing of sprinklers is fixed accordingly. A common pressure for orchards is 30 pounds per square inch for 20- by 40-foot spacing. Low-angle sprinklers are used for this purpose which do not cover as much area as the higher-angle field-crops types. From the labor standpoint, it is desirable to make the fewest possible number of lateral moves. Inadequate applications increase the number of moves because more irrigations are required. An average pressure of 35 pounds per square inch makes possible 60-foot moves with high-angle sprinklers and is quite popular. Spacing along the lateral can be either 30 or 40 feet since tubing is obtainable in either 20-, 30-, or 40-foot lengths. Pressures of 60 to 65 pounds per square inch with large nozzles permit 80-foot spacing between laterals and 60 feet along the lateral. Although this wide spacing may reduce capital and labor costs under some conditions, power requirements are doubled.

A few half lengths of pipe and some extra fittings, as may be needed, will help overcome spotty irrigation patterns caused by wind or continuously setting sprinkler heads on the same spots.

Existing pumping plants can seldom be used for direct attachment of sprinkler systems. In a very few cases, where a low-pressure system has been used on a favorable slope, direct attachment has been possible. The usual situation is that of employing a booster pump or replacing the well pump with one adequate for the additional load.

Trash screens and sand traps are common prerequisites where water is pumped from natural streams and ditches. Moss can present serious screening problems in using reservoir water. These installations must be designed to meet local situations and conditions. A continuous discharge of sand through the system will cause extensive wear on the sprinkler heads. Sand also lodges in the pipe joints and makes for difficulty in disconnecting.

Application of Liquid Fertilizer Through Sprinklers

Liquid, or readily soluable forms of fertilizer may be applied through a sprinkler system. The efficiency of distribution is higher than with surface irrigation, except with anhydrous ammonia. Much of this very volatile form of nitrogen fertilizer would escape into the air from the sprinkler streams. Fertilizer in liquid form can be injected into a closed system with a pressure pump. But, it is more easily introduced on the suction side of the pump. It may also be introduced into an open ditch and picked up with the water, if the sprinkler uses all the flow. Since the area covered on setting of the sprinkler is known, the quantity of fertilizer needed in the determined application period can easily be computed.

Fertilizers are needed in the upper root zone, hence they should be applied near the end of the run followed by sufficient plain water to wash off the foliage and clean out the sprinkler pipe. No good evidence has been cited as to damage by corrosion from fertilizers when systems are thoroughly washed out.

Irrigating for Germination

On most soils "irrigating up" or irrigating after planting to cause germination should be avoided, if possible. Such irrigations cause many soils to form crusts which hinder the emergence of young plants. This situation is most likely to occur when water is permitted to pond or overflow the surface of the field. There is also danger of washing out shallow-planted seed, and of erosion on the steeper slopes. Irrigation before planting is to be preferred, wherever sufficient moisture can be retained in the surface soil during final seedbed preparation and planting, to sprout the seed and produce suitable stands.

However, in some parts of Colorado, irrigation before planting can seldom be depended on to produce suitable stands of certain crops common in those areas. This condition also occurs occasionally, for shallow-planted crops, in almost every part of the State. Therefore, since "irrigating up" will, or may be necessary, care should be used in "leveling" fields for irrigation, in preparation of the seedbed, and in planting the seed. These precautions are particularly important on soils which may bake or crust. A well-prepared seedbed assures an even depth of planting and a more even rate of absorption with either surface or sprinkler methods of application.

Since irrigating up may be necessary, furrow openers adjusted to soil conditions and seed-germination requirements, should always be used when drilling shallow-planted row crops. If furrow openers are not used, suitable irrigation furrows or corrugations should be made for surface irrigating. (Furrows or corrugations are also beneficial on flat or gently sloping fields to drain off excessive rainfall.) Corrugations in grain and alfalfa are usually made immediately after planting. Furrows should be large enough to carry the required amount of water without breaking over. They should not be so deep that the seed will not be thoroughly wet, in a reasonable length of time, by lateral and upward absorption.

When it must be done, irrigating up is usually the most important and difficult irrigation of the season. It should be carefully done to assure even stands of crops, and to avoid erosion of the generally unstabilized soil. Applying too-little water will fail to cause suitable germination and excessive amounts may bring about soil conditions which handicap desirable crop development.

Root Zones

The characteristics of crop root zones are of great importance to the irrigation farmer. They largely determine both the pattern and depth of tillage operations, together with the water-holding capacity of the soil. The crop root zone is the guide to the quantity of water needed for each irrigation and thus to some extent governs the frequency of irrigations.

Depths to which roots of different crops penetrate are controlled by: (1) the natural characteristics of the crop; (2) the penetrability of the soil, the supply of moisture and plant food and the water table, if any; (3) the stage of development of the crop.

The following tabulation of root zones is given as a guide to the irrigator. The depths shown are for mature plants and are approximate averages under favorable soil conditions. Under irrigation, root zones may be greatly modified. They may become very shallow where the ground water table is high or where irrigations are more frequent than necessary or where heavy machinery has compacted the sub-soil. Witholding needed irrigation does not induce abnormally deep root zones. However, over-irrigating often prevents normal root development.

Table 8.—Depths to which moisture generally should be applied to reach root zones of representative crops.

Irrigated grass pastures	1.5 to 2 feet
Beans and potatoes	2 feet
Small grains	3 feet
Corn and sugar beets	3 to 4 feet
Sweetclover and alfalfa	4 to 6 feet
Orchards	3 to 4 feet

The above figures cover main root mass and optimum depths to be reached under average conditions. Root zones of these crops may extend below the depths indicated, especially the perennials, which should receive at least one deeper irrigation each year, preferably in late fall or early spring. Different varieties of many crops vary considerably in the root systems they develop.

Determination of depth of penetration on crops like corn, beets, beans, etc., should be made in the plant row, not in the irrigation furrow. Penetration continues after water is shut off, therefore, water should be changed when penetration has reached approximate depth described on page 36, earlier on sandy soils and later on clay and heavy loam soils. Use shovel or soil auger after 24 hours to determine final depth of soil moistened.

Most other field and vegetable crops develop root systems similar to those of the same or like families shown in table 9.

Table 9.—Field and vegetable crop root zones.

Crop	Normal working depth	Normal maximum effective depth
Grains, etc.	**feet**	**feet**
Barley	3	4.5
Oats	2.5	4
Wheat (winter)	3.5	5
Wheat (spring) about 1 foot less than for winter wheat		
Corn	3	5
*Sorghums	2.5	4.5
Grasses		
Brome	2.5	4
Orchard	2	3
Meadow fescue	3	4
Blue grass	1.5	5
Alfalfa and Clovers		
Alfalfa	5	10
Red clover	3	8
Yellow sweetclover	2.5	5
White sweetclover	3	5
Ladino sweetclover		
Field Crops		
Sugar Beets	3	6
Potatoes	1.5	4
Onions	1	2
Melons	2	4
Head lettuce	1	1.5
Beans	1	3
Peas (garden)	1	3
Peas (field)	1.5	3.5
Tomatoes	1.5	4

*The sorghum family, being very large, has a wide variation among the root zones of its members. Their usually compact and dense root systems are able to quickly use all available near surface moisture as well as that from greater depths.

Obviously, seedling crops have not developed root systems to the working depths they normally attain as they approach maturity. By keeping this in mind during early irrigations, the irrigator can often save water and retain very soluble plant food in the root zone of the young crop.

Alfalfa

As noted in the section on Irrigation Planning, alfalfa is a comparatively heavy user of water per pound of dry matter produced. Add to this the high yields frequently obtained and reasons for heavy water applications become obvious.

Alfalfa is the deepest rooting field crop with which this bulletin is concerned. It normally feeds from depths of 5 to 6 feet and in deep sandy soils often develops appreciable root systems to 10 and 12 feet and more. It is considered necessary and desirable to wet the normal root zone at each irrigation. One heavy application each year to penetrate to 8 to 10 feet or more, depending on soil depths and conditions, is advisable. Therefore, the heavy application may well be applied in late fall or early spring, but when the soil is free from frost.

The number of irrigations per season varies with: (1) the geographical location; (2) the climatic conditions prevailing during the season; (3) soil fertility and yield of forage. Preplanting irrigation is recommended for all of the state, except in a few favored areas like the Upper South Platte Valley where spring moisture is often sufficient to produce germination. Where pre-planting irrigation cannot be done, or is not done, the first irrigation must be applied with great care.

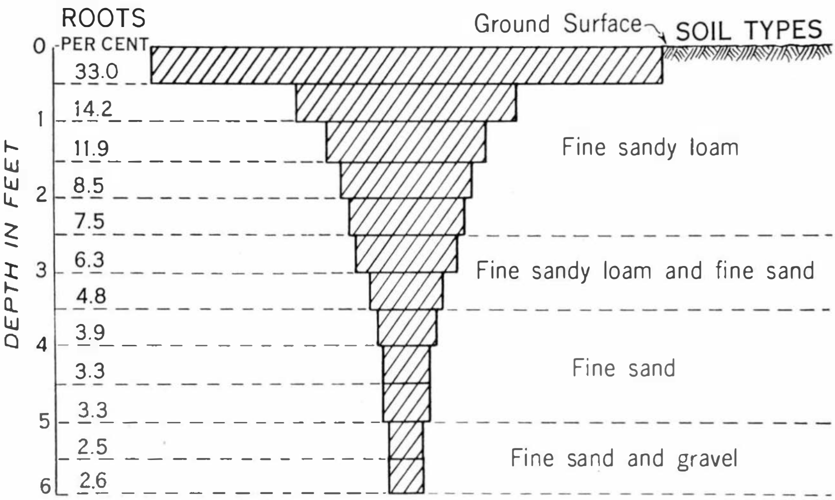
Uncontrolled wild flooding of newly planted or germinated fields can cause serious erosion and destroy much potential stand on the steeper slopes and erodible soils. Heavy soil crusts may seriously reduce stands. Silt-laden water will often kill young seedlings. Each field in every locality presents its own peculiar problems. The local irrigator should become familiar with them.

A normal irrigation for established stands on average soil conditions should consist of about 6 acre-inches per acre. However, the exact amount should be controlled by the depth of the soil and its water-holding capacity. Coarse, sandy root zones may not hold a 6-inch irrigation and may, therefore, require two or more lighter applications for each cutting of hay.

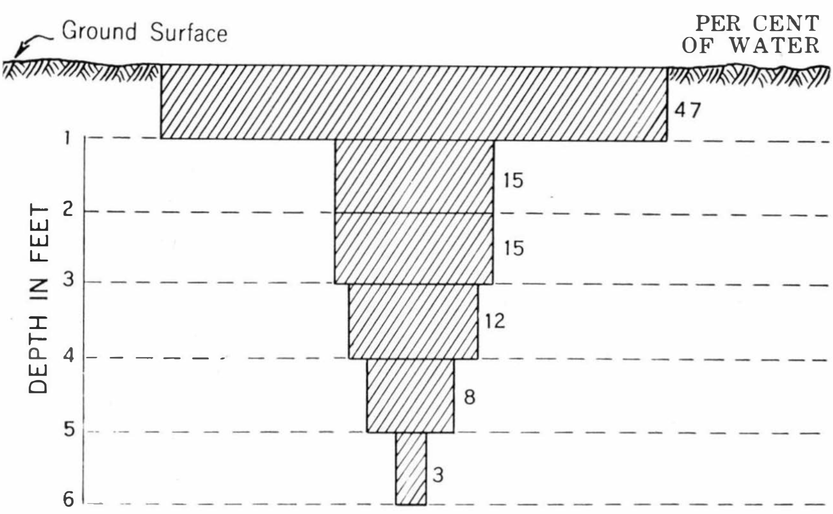
Much less water and fewer applications are required for producing seed than for hay. Often no irrigation water is applied to the cutting left for seed.

This crop fits into all methods of applying water, bordered lands, flooding from graded contour laterals and by corrugations and sprinkling. However, sprinkling should not be used on a seed crop at blossoming time. Corrugations should be no larger than absolutely necessary. They serve a very useful purpose in areas where silty waters might destroy young alfalfa seedlings and to prevent choking or sealing on heavy clay soils.

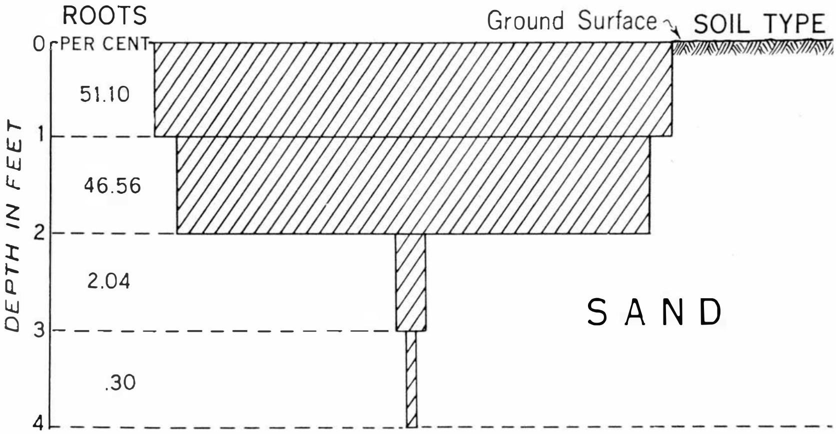
Alfalfa is a constant feeder and should not be permitted to suffer from lack of moisture.



Distribution of alfalfa roots by weight under favorable conditions. (From Scottsbluff, Nebraska, Experiment Station.)



Soil depths from which water is taken by alfalfa. (From Scottsbluff, Nebraska, Experiment Station.)



Distribution of alfalfa roots with a water table 3 feet below ground surface. (From Scottsbluff, Nebraska, Experiment Station.)

Flooding alfalfa from a graded contour lateral by using canvas dams.

Clover

Root systems of the different clovers are quite variable and their irrigation should be varied accordingly.

Since sweetclover is deep rooted, its irrigation requirements are similar to those for alfalfa. The shallower rooted clovers are more susceptible to drouth and need more frequent but lighter irrigations.

The Small Grains

Root systems of the small grains—barley, oats, rye, and wheat—vary to some extent. However, there is so much similarity in the depths from which they feed that irrigation practices need not be greatly different.

Rye and winter wheat develop feeding zones down to 3.5 to 4 feet under favorable soil conditions. Oats feed from depths of 2.5 to 3 feet. Barley and spring wheat generally have feeding zones of intermediate depths between winter wheat and oats, say 3 to 3.5 feet.

Wetting the root zone of any of these crops to 3 feet can be considered a sufficient (maximum) application, where soil conditions permit.

There are four general methods of applying irrigations to small grains:

1. Flooding. Where topographic conditions are favorable, bordered lands are recommended. Rolling fields or steep slopes may best be flooded from contour laterals spaced to obtain suitable penetration between them without undue waste or overuse of water.

2. Sprinkling is preferred on very rough fields, steep slopes, and very porous or erodible soils.

3. Corrugations or furrows are preferred in many areas in southeastern and western Colorado to reduce labor, obtain uniform wetting, reduce soil crusting, and reduce silting under of accompanying small legume seedlings. This method is also advantageous on slowly penetrable tight soils where water must be applied for long periods for an irrigation.

4. Flooding from laterals straight away down slopes of 3 percent or more should be avoided. This system is conducive to excessive soil erosion, wasted run-off water, and high-labor requirements.

Flooding before planting is advisable where insufficient moisture exists for germination. This is usually a necessary practice in the Arkansas Valley. It is also a necessity in much of the San Luis Valley and in some other areas to redistribute saline salts which have accumulated in the top soil and to provide moisture for germination. Flooding after planting may prevent aeration and cause serious soil crusting or removal of nitrogen from the seedlings' root zone. Working the seedbed after the preplanting irrigation should be kept to a minimum and shallow.

Small grains can be seriously injured by early over-application of water. Barley is most susceptible to over-irrigation or wet land. They should not be permitted to suffer for moisture after they are established. A few hours of wilting after the jointing stage begins may reduce yields by several bushels per acre.

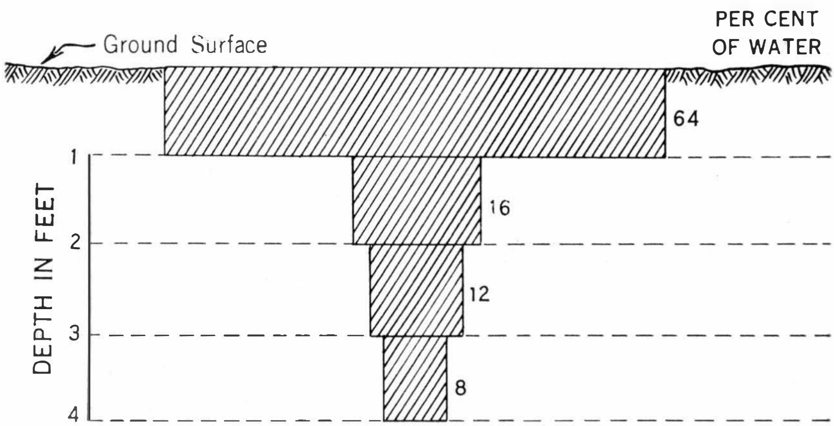
Length and duration of irrigation runs should be carefully considered and controlled. (See general statement, page 37.)

Small grains respond to frequent light irrigations during their development periods from germination to heading. Since a half dozen or more light applications of irrigation water are impossible and uneconomical for most farmers, fewer and heavier applications are the rule. One or two irrigations are usually sufficient in northern and northeastern Colorado and in the San Luis Valley. Two or three applications are generally required in the Arkansas Valley.

Graded contour laterals used on steep rolling fields for small grain, hay, and pasture crops.

The critical water-requirement period is from jointing time to blossoming. This means that irrigation should be applied in the jointing stage in sufficient quantity to wet the full depth of the root zone. This should provide moisture to assure a good fill. On large fields the irrigation may need to begin at early jointing stage to be completed by blossoming.

Oats is a cool-season crop which may quickly indicate need for additional moisture in suddenly rising temperatures.



Soil depths from which water is taken by oats. (From Scottsbluff, Nebraska, Experiment Station.)

Spring grains will generally require heavier irrigations than the winter varieties. Where the soils will not hold sufficient moisture to carry the crop through to maturity, a final light application may need to be added. Late irrigation of small grains, after the kernels have formed, adds little to the yield and may delay maturity.

Corn

With favorable conditions, corn develops a deep and wide-spread root system. It feeds from depths of 3 to 4.5 feet and some roots may penetrate to 6 or 7 feet or more. Unless soil conditions prevent, the irrigation zone should be about 3 to not more than 4.5 feet.

Corn enters a particularly critical period in its development, as the tassels begin to emerge. Drouthy conditions at this time may cause the pollen to fall before ear silks emerge, resulting in bare or partially filled ears. Later irrigations cannot remedy such damage.

Steady, continuous growth is desirable from germination to tasseling but care should be exercised to prevent overwatering if early irrigation is necessary. Rolling of leaves indicates high transpiration compared to intake and approaching need for moisture. When leaves fail to unroll by sundown or a little later, irrigation should not be delayed.

Moisture for germination should be available before planting. If irrigating up becomes necessary, shallow furrows should be made to insure moisture reaching the seed. Then irrigate carefully using a minimum of water. Flooding surface-planted corn often causes reduced stands due to crusting of some soils. Running water down lister furrows, after planting, washes some seed away or covers it and emerging seedlings too deeply.

The number of irrigations vary with local conditions, precipitation, temperature, soil, and variety of corn. Two to four should generally be sufficient, including preplanting or irrigating up where necessary. The greater number of applications will be needed in the Arkansas Valley and western parts of the State. The optimum time for the second application of water, if needed, is about the mid-jointing period. Under some conditions it may be needed earlier. Growth should not be arrested at any time. The major irrigation should be applied at tasseling time. It is also important that good soil moisture be available until the corn has dented. Excessive moisture after denting time may delay maturity, particularly in the cooler areas. Thick stands and heavy applications of nitrogen require more water.

Water may be applied by sprinkling for germination and during the early development period. Furrows are considered more economical of both labor and water after corn is too high to permit easy moving of sprinkler pipe. Flooding is not recommended because of the danger of corn falling over after stalks become large and heavy.

Sorghums

Root systems of the sorghums vary somewhat among varieties but are similar to those of corn. Sorghum roots are generally finer and more fibrous and do not penetrate quite so deeply as corn. The great number of small rootlets makes it possible for sorghums to *suck the soil dry.* The root system develops early and rapidly. Large numbers of fibrous roots near the surface enables this crop to benefit from very light precipitation. This crop is able to survive moisture shortages for considerably longer periods than other cultivated crops common to Colorado.

The feeding zone is in the upper 3 to 3.5 feet of soil and irrigation need not reach deeper and can be less in periods of water shortage. One or two irrigations are usually sufficient, including pre-germination watering; when needed, a third irrigation may be required under extreme conditions. While sorghums are not considered to have a critical period, such as corn, they thrive best on a steady diet. This is particularly true for the grain varieties.

The recommended method of applying water is by furrows except when such crops as cane are close drilled.

Field Peas

If sufficient moisture has not been stored in the soil by winter and spring precipitation to carry the crop until blooming time, pre-planting irrigation should be applied. Excessive moisture before buds appear tends to produce excessive vine growth.

An irrigation should be applied about when the buds appear but before blossoming. Irrigation during full bloom may cause the blossoms to drop, if soil has been allowed to become very dry.

Light irrigations of 3 to 4 inches are preferable. The lengths and duration of the run should be short. Water should not be on any one set for more than 2 hours. On the porous soils of the San Luis Valley the necessary root zone should be well wet by the time the water can be flooded over the surface. Field peas are easily overirrigated and seriously damaged.

Field peas require less water than spring grain but they should not be planted on dry land or where irrigation water is not available.

Sugar Beets

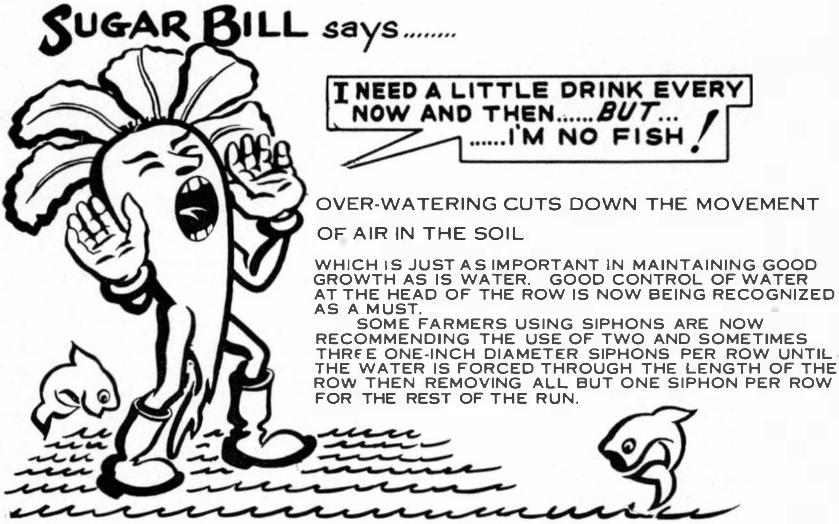
Land preparation is of prime importance in sugar beet production. It is important from the standpoints of good planting and good irrigation. A well-leveled and packed seedbed is most necessary where the seed must be irrigated for germination. This is especially true on soils which puddle easily and form deep crusts.

Irrigating up is a necessity every year in some areas and may be required at times in all beet districts in Colorado. This first irrigation of the season is of great importance in securing a satisfactory stand. It should not be delayed after planting, especially if light moisture in the soil may start germination without being sufficient to complete it. Furrows, adapted to local conditions, should be carefully made to permit uniform wetting of seed throughout their length. Flooding is moderately to seriously detrimental on most soils.

Ditcher shovels should be on drills at all times, in case irrigation should be necessary. They provide good guides to drive by if crust breakers have to be used before the crop comes up. If suitable furrows are not made at planting time, they should be rerun before water is applied.

The object in the germinating irrigation is to wet the seed zone thoroughly. Soils in which lateral and vertical absorption of water is slow require the application of water near the seed level. This may be accomplished with shallow flat-bottomed furrows and smaller streams of water on the steeper slopes and deeper furrows and larger streams on very flat slopes.

On some gently sloping loam and sandy-loam soils large furrows, in every middle can be used with the seed temporarily covered as deeply as possible. The quantity of water per furrow should be as large as possible to cross the field quickly and still avoid erosion. In this system the field must dry rapidly so that the excess covering over the seed can be removed very soon after the seed has sprouted.



OVER-WATERING CUTS DOWN THE MOVEMENT OF AIR IN THE SOIL

WHICH IS JUST AS IMPORTANT IN MAINTAINING GOOD GROWTH AS IS WATER. GOOD CONTROL OF WATER AT THE HEAD OF THE ROW IS NOW BEING RECOGNIZED AS A MUST.

SOME FARMERS USING SIPHONS ARE NOW RECOMMENDING THE USE OF TWO AND SOMETIMES THREE ONE-INCH DIAMETER SIPHONS PER ROW UNTIL THE WATER IS FORCED THROUGH THE LENGTH OF THE ROW THEN REMOVING ALL BUT ONE SIPHON PER ROW FOR THE REST OF THE RUN.

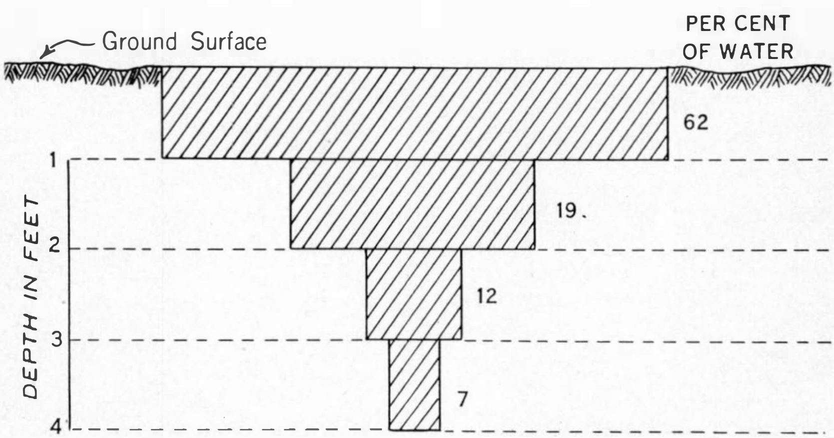
In any case the germinating irrigation should not be permitted to leach nitrogen so deeply into the soil that the young seedlings cannot reach it. Small beets do not require heavy irrigations to feed them.

Sugar beets develop root zones from 3 to 6 feet or more in depth and reach this extreme development slowly but steadily. Therefore, extremely heavy irrigations on small beets are unnecessary, wasteful of plant food and water, and often detrimental to the crop.

Sugar beets have no especially critical period in their development. They are constant feeders and gradually increase their need for moisture as they approach maximum development. Therefore, any loss of growing time due to a water shortage means lost tonnage. They should never suffer for water.

Number of Irrigations

The number of irrigations, while conforming roughly to certain patterns in each area, cannot be definitely fixed. They may vary from three to seven or eight depending on the area, the soil, and seasonal conditions. Generally four to six applications of from 2 to 5 inches are sufficient under most conditions. Size and number of applications depend largely on the water-holding capacity of the particular soil. Fifteen to 25 inches are usually sufficient to produce a maximum yield.



Soil depths from which water is taken by beets. (From Scottsbluff, Nebraska, Experiment Station.)

With few possible exceptions furrows should be made and used between all rows. Water need be run in only every other furrow for any given irrigation or at one time. This will provide dry furrows for use of the irrigator in checking the field. Using every other row for an irrigation and changing the setting to alternate furrows for the next irrigation is good standard practice in many areas. This is particularly desirable in areas where leaf spot may damage foliage.

Potatoes

Potatoes develop working root zones of 1½ to 2 feet and may reach maximum depths of 4 feet or more in favorable soils. Being constant feeders their moisture requirements increase as they develop. A large yield of potatoes with heavy vines will require from 20 to 25 inches of water during the season. When the vines are growing rapidly and nearing their peak, they may use as much as ½ inch of water per day if the temperatures are high. When vine growth has stopped the water requirements decrease rapidly. They should be irrigated whenever they need moisture, regardless of their stage of development. Their growth should not be checked for lack of moisture at any time. The darkening color of the vines will warn the experienced grower of needed irrigation, but the best practice is that of making frequent examinations to determine moisture conditions. Soil below the seed piece should ball in the hand, retain its form when released, and leave the hand slightly moist.

Frequency of irrigations depends on the water-holding capacity of the soil (see page 13) and the prevailing climatic and weather conditions. Frequency of irrigation varies from every second day in alternate furrows in real sandy soils to once a week in every furrow in heavy soils. Many Colorado soils need water at least once a week to keep the crop growing well.

The potato is a cool-season crop with a small root system. Occasional hot days may cause some wilting which does not necessarily indicate need for irrigation. Records in Colorado show from three to fourteen irrigations per season depending on variety, location, and seasonal conditions.

When to start irrigating potatoes has long been in controversy. Experiments covering 7 years at the Greeley Potato Experiment Station prove that withholding water till blooming or wilting occurs lowers yields and increases the percentage of culls. However, there is general agreement that they should reach maturity and harvest time in a comparatively dry soil.

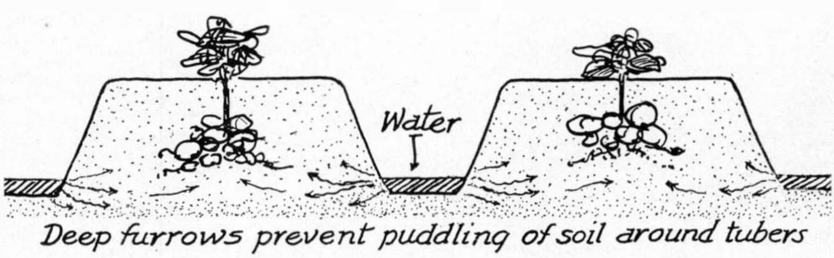
Table 10.—Average acre yields 1919 to 1925 at Greeley Potato Experiment Station in bushels.*

Time of irrigation	No. 1's and No. 2's	Culls	Total
When needed	291.3	21.9	313.2
Blooming	266.5	23.5	290.0
Wilting	210.2	26.2	236.4

*USDA Technical Bulletin 118. W. C. Edmundson, 1929, "Studies in Times and Rate of Irrigating Potatoes in Colorado."

The quantity of water to apply per irrigation depends on the water-holding capacity of the soil in the effective root zone, the rate of evaporation, and use by the crop.

Heavy soils which puddle should be irrigated in deep furrows (below the seed piece). This permits the soil around the tubers to remain loose and friable so the tubers can develop normally. A cross-section of a proper furrow type is shown in the following illustration.



Water should enter root zone below the seed piece to prevent puddling the soil around the potatoes.

Irrigating Up

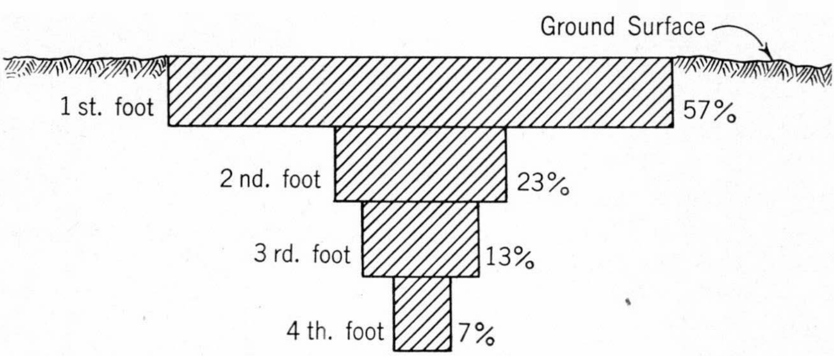
Irrigating up is a questionable practice. It can generally be avoided by an irrigation before planting. If the soil moisture is good at the time of planting, it is usually not necessary to irrigate until the plants are 4 or 5 inches tall. If water must be applied after planting and before the crop comes up, it should be applied with care in deep furrows to wet only the potential root zone below the seed piece. However, delaying the first irrigation too long may seriously reduce the yield, especially if the field was dry when planted.

Sub-irrigation

This method is used in parts of the San Luis Valley on shallow soils overlying coarse sand and gravel. It is essential that water levels be maintained at 18 to 24 inches below the surface during the growing season.

Fields should be flooded before the seedbed is prepared. The drains are closed about the time planting begins to raise the water table and assure moisture in the root zone by the time growth begins.

Some years the water table cannot be maintained at the necessary level and furrow irrigation must be used. Since soils in the sub-irrigated area of Colorado are coarse in texture and their rate of infiltration high, large streams of water should be used, for example, 100 gallons per minute, or two to three 2-inch siphon tubes per furrow. Variations should be made for coarser or finer soils. Runs should not be over ¼ mile in length and the water put through the row as fast as possible. Much water can be saved on the coarser soils by reducing the run to about 800 feet, that is, by using a head ditch and two cross ditches in each half mile. This can be an important item in dry years when most of the water may be pumped.



Soil depths from which water is taken by potatoes. (From Scottsbluff, Nebraska, Experiment Station.)

It is usually advisable or desirable to irrigate every other row to get over the field rapidly then follow up in the rows left dry.

Potatoes are quite sensitive to overirrigating. Water should not be permitted to puddle the potato hill or pond over it. Fields should be well graded and surfaced before planting. This applies to both sub-irrigated and surface-irrigated areas.

Pastures

Most irrigated pastures in Colorado include the shallow-rooted grasses and deeper-rooted legumes. The more commonly used grasses develop working root zones of from 2 to 3 feet. The legumes have a much wider variation in root zones depending on variety (see alfalfa and clover). These mixtures of plants should be kept in mind by the irrigator. One or two deep penetrating irrigations a year should be supplied for them.

Pastures lend themselves to either sprinkling, bordered lands or contour graded laterals, depending on topography and soil conditions. Very rough or porous soils should be sprinkled, if possible. Rolling fields can be handled with contour laterals and slopes up to about 7 percent in one direction can be irrigated in bordered lands if necessary. Table 7, page 42, may be used as a guide for laying out and operating bordered lands.

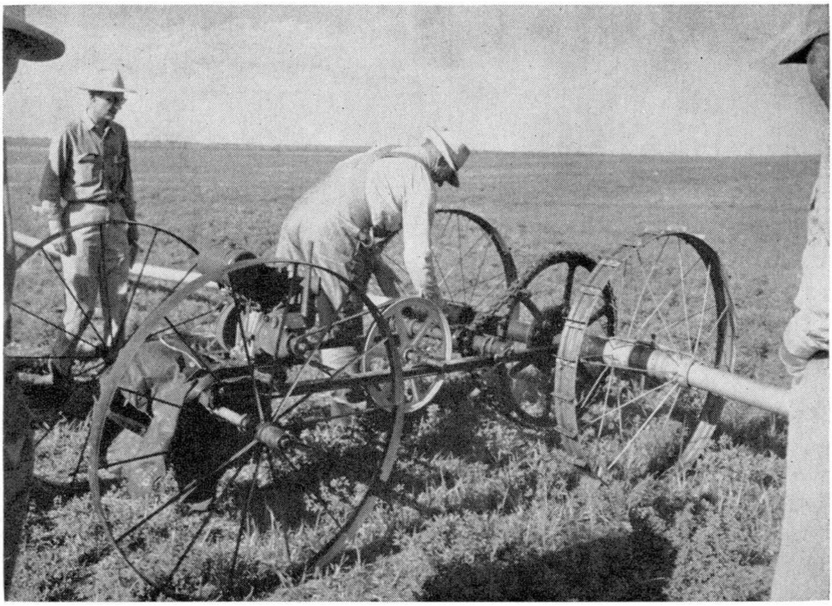
Irrigated pastures require about the same quantity of water per season as alfalfa but applications should be lighter and more frequent to assure maximum productions from the grasses. Water moves more slowly through close-growing pasture sod than through alfalfa stubble and penetrates the soil faster. Larger streams of water are therefore necessary, in surface irrigating, to obtain quick coverage and most efficient distribution of moisture in the root zone. This is especially true on flat grades and very porous soils.

The number and frequency of irrigations depends on location, soil, and seasonal climatic conditions. The more porous or sandy soils will require lighter but more frequent applications, while the loams and clays absorb heavier applications and therefore need less frequent irrigations.

***Table 11.—Usual range of desirable frequency of irrigation for pastures on soils of different textures.**

General soil classification	Approximate amount of water readily available to plants per foot of soil depth after irrigation	Desirable frequency of irrigation
	inches	days
Loamy sand	0.8	5-12
Sandy loam	1.0	7-14
Silt loam	1.3	12-18
Clay loam	1.1	7-14
Clay	.9	7-14

*From Farmer's Bulletin No. 1973 USDA.



Wheel move sprinkler systems are tailor made for meadows and pastures, with or without engine power.

Pastures should go into the winter with good moisture in the root zone. A late-fall irrigation is recommended and an early spring application also, if winter precipitation has not been sufficient to maintain desired moisture. Irrigation should not be applied during freezing weather.

Orchards

Water requirements for orchards vary from season to season and within seasons, according to weather conditions, soils, and all the variable factors as they do for other crops.

The irrigation of young, non-bearing trees and shrubs should stop the latter part of July or the first of August. Critical periods in producing orchards, as regards need for water and effect upon size of fruit, occurs with peaches and apricots shortly after bloom and again during the hot, dry days of July and early August. In apples, the greatest need comes in July and early August. Both sweet and sour cherries generally need a moderate irrigation soon after the petals shed and before fruits reach maturity. With bearing peaches and apricots, the last irrigation should be applied not later than 10 days to 2 weeks before harvest. On bearing apples, it is desirable not to apply water after the last of August. The Anjou pear suffers from any appreciable fluctuation in soil moisture during any part of the growing season.

In many cases of winter-killing in Colorado, the damage is not due to low temperature but to cold, dry air which draws moisture out of the trees and when the roots are unable to replace the loss from the dry soil. In late fall or early winter, after the trees have become dormant a *winter* irrigation should be applied. The soil should be wet down 4 to 5 feet.

Orchards should be irrigated when the need for water is apparent regardless of the season of the year. A uniform moisture supply should be provided throughout the growing season. The only exception to this is the time of full bloom when little moisture is needed. The need for irrigation can be determined by actual examination of the orchard soil to a depth of 4 feet. This can be done with a soil auger or a shovel. Fruit trees apparently need about 6 to 10 percent available moisture in the soil. An experienced grower can tell quite closely from the appearance of the tree when this amount is present. As a check, weigh out 6 pounds 4 ounces (100 ounces) of soil and dry it by direct exposure to the sun for 1 day. Reweigh the sample; the loss in weight in ounces will give the percentage of available water in the soil. If the loss is not more than 6 to 10 ounces, water is needed and should be applied. When water is applied the soil should be wet to a depth of 4 to 5 feet. Depth of wetting should be checked. This can be done with a moisture probe or soil auger.

Fairly deep furrows are often used in clean cultivated orchards. These may be 4 to 6 inches deep and as far apart as 4 or 5 feet. The use of these deeper furrows has advantages; excessive soaking of the top soil may be eliminated, reducing surface evaporation. Also water penetration through heavy soils may be faster. When a cover crop is planted, shallow furrows between the deeper ones may be needed until the crop is well established. Closer spacing of furrows may be necessary, for cover crops, on porous soils having low water-holding capacities.

Frequently the furrows next to the rows in bearing orchards are placed close to the trees. This practice is particularly desirable in soils which absorb water slowly. In soils where water penetration is slow, deep sub-soiling is practical and effective. Sub-soiling or chiseling should be confined to a narrow strip in the middle between the tree rows and at right angles to the direction of irrigation. Deep working of the soil should be done only in the dormant season.

Sprinkler system and gated pipe in an apple orchard.

Chlorosis or yellowing of fruit trees may be caused by poor drainage or overirrigation. When yellowing is noticed the water table should be determined. If water has accumulated, then irrigation should be lighter and less frequent. In extreme cases, drainage systems may be necessary.

In young orchards, both cultivation and irrigation should cease in August. This will permit the trees to harden in preparation for winter. When cultivation and irrigation are continued in late summer and early fall the trees will enter the winter in a soft condition and winter injury is likely.

Excessive soil moisture lowers the keeping quality and reduces the storage life of fruit. Heavy irrigation near harvest may cause cracking of the fruit. Wide fluctuations in soil moisture are always objectionable. During the growing season, dying back of young top growth may result from such fluctuations. Fruit troubles such as water core, bitter pit or Jonathan spot may also be aggravated.

Trees and Shrubs

According to estimates, some plants on a hot day transpire from ½ to 1 pound of water per hour from each square yard of leaf surface. A single tree of average size may use 20,000 gallons in a season.

Great variation is found under which plants can secure water necessary for their life processes. Some woody plants will grow when standing in water; others will be killed if water stands about the roots for a few days. Some plants require much water, others very little. Because of these differences, care should be used in selecting plants and only those which are suited to the conditions should be planted.

Plants grown under irrigation should never be allowed to suffer from the lack of water. Flowering plants, particularly the herbaceous perennials require a plentiful supply of water as they approach bloom. All woody plants should be hardened for winter by withholding water in late summer and early fall. About leaf-fall time the soil should be thoroughly soaked to a depth of 4 or 5 feet. Winter watering may be necessary during dry winters. Weather records indicate that January is the driest month of the year in Colorado. A great deal of winter injury is caused by drought rather than low temperatures. The cold dry winter air draws moisture out of the trees and unless the roots can replace that moisture die-back will occur.

Ornamental plants are usually watered with a hose. Water should be applied so slowly that it does not run off and should be applied long enough so that it penetrates 5 to 6 inches into the soil for shrubs and deep enough to reach the feeding roots of trees. The small amounts of water supplied per minute by low-pressure units is often an advantage in large areas for applying water under shrubs and low-branched trees.

A basin should be ridged around newly planted trees and shrubs to prevent the water from running off before it has a chance to soak into the soil. When trees and shrubs in lawn areas suffer from the lack of water the lawn also suffers.

Trees planted in areas surrounded by a large amount of paving may suffer from the lack of water. Special devices such as drain tiles may be placed around the tree with the top even or slightly below the lawn surface. Tiles 3 or 4 inches in diameter are usually used. The bell end of the tile should be put upward so it will form a cup into which a block of wood may be placed for protection when the tree is not being watered. Sometimes the tiles are filled with coarse gravel which serves the same purpose.

Another method of tree watering on a lawn is to make crow-bar holes 1 to 2 feet deep at frequent intervals over the area but not near the trunk. Start placing the holes half way from the trunk to the tips of the branches and extend them beyond the ends of the branches.

A spading fork may be used to make smaller but more numerous openings in turf especially around smaller trees and shrubs.

Lawns

Moisture should be close to the surface when a new lawn is seeded. A mulch, applied after seeding, will help keep the moisture close to the surface. A new lawn seeded during hot weather requires almost constant but light sprinkling for a period of several weeks or until the grass is established. During the cooler weather of early spring, late summer or early fall the new lawn should be sprinkled lightly each evening until the grass is established. After the grass is established, a good soaking with wider intervals between each soaking as the grass roots go down, is much better than frequent light sprinkling.

In early spring keep the established lawn on the dry side to force the roots to go deeper. A deep-rooted turf has a larger area in which to feed for nutrients and moisture. It is better to soak the soil thoroughly once a week than to sprinkle it lightly every day. Frequent light sprinkling can ruin a bluegrass lawn. Light sprinkling encourages shallow rooting, crabgrass and other weeds and makes the grass highly susceptible to drought. Grass under trees and near shrubs will require more water than that in the open. Slopes, edges and terraces demand special attention. On slopes the canvas hose "soil soaker" or perforated plastic tubing, are excellent watering devices. The kind of sprinkler used is not important as long as it is left in one place long enough to thoroughly soak the soil.

After a few fall frosts and leaves fall, but before the ground freezes, the lawn should be thoroughly soaked to a depth of 2 to 3 feet. Watering in mid winter or late winter may be necessary if there is very little natural precipitation.

Dry spots in mid-summer that do not respond to frequent watering or where frequent watering is necessary may be repaired. With a pointed rod, ½ inch in diameter, make holes 8 inches apart and 8 to 12 inches deep over the dry area. These holes will help the grass secure water. If the pointed rod discloses a gravel pocket, it may be necessary to dig the gravel out and fill the hole that remains with good soil and reseed the area or replace with growing sod pieces from another area. Lawn sprinklers with fine sprays may be obtained that can be attached to the hose to sprinkle on an area for several hours without runoff. Canvas or plastic hoses with many fine openings are excellent watering devices. Sprinkling devices which can be attached to the hose in a series are good. The more units there are in a series the weaker the pressure at each, thus the shorter the distance the water will be thrown and the closer the units must be spaced together. Close spacing with low pressure is desirable for narrow strips.

Berries

Strawberries and red and black raspberries are of most importance in Colorado. Therefore, the grower need not be particularly concerned with the irrigation of other types although it is not greatly different.

Since several pests thrive best in wet shaded soil, strawberries should not receive water more often than necessary. For the same reason, irrigation by furrows is often preferable to sprinkling. It allows part of the soil surface to remain dry and discourages pest development.

However, withholding needed water during the bearing season reduces the size and quality of the berries. This makes it important to apply irrigation as local conditions demand. Close observation of the berry patch will soon provide the necessary experience for acceptable irrigation practice. Newly set strawberry plants require immediate and frequent watering until they are established.

New raspberry plants also need immediate irrigation to settle soil around the roots. As soon as plants are set a shallow furrow should be made a few inches from one side of the row and a small stream of water run in it until the soil is thoroughly wet around the roots. Sprinkling may be used, if convenient, but will probably require more water than the furrow method because of wetting the entire ground surface.

Raspberries will generally require a thorough irrigation about every 2 weeks, depending on soil and weather conditions. During the picking season, comparatively large quantities of water are needed to mature the berries. Two irrigations a week may be necessary in some soils. The fruit is generally picked every other morning. On irrigation days the water should be turned on as soon as the pickers are out of the way. This allows the maximum of drying before the next picking.

After about mid August irrigation should be only frequent enough to keep the plants from suffering. This will check rapid growth and permit the canes to mature before winter. In the case of black raspberries, which are generally covered for winter protection in this area, a thorough irrigation should be applied to put the soil in condition for covering and to maintain the plants during the winter. This fall irrigation is generally necessary, even if winter covering is not used, to eliminate or reduce winter killing.

An irrigation on berries should consist of wetting the soil at least 1 foot and in the case of raspberries to a depth of 2 feet. Often it is permissible to reduce the frequency of application.

Vegetable Crops and Gardens

Vegetable thirst varies. The amount of irrigation water and the frequency of irrigation required to mature a vegetable for table use will range from none to more than 30 inches. This variation is due to a number of factors, such as length of time required to mature the crop, type of plant and rooting habits, type of soil, natural precipitation, temperature, humidity, and wind velocity. In the home garden, competition from nearby trees and shrubs may also be an important factor.

The general rule in the home garden is to maintain an even supply of moisture and keep plants growing constantly. Alternate periods of flood and drought are harmful to most crops and result in vegetables of poor quality and a shorter storage life. See table 12, pages 73 to 76, for suggestions under average conditions in regard to the amount and frequency of irrigations for the common vegetable crops when grown on four different soil types.

The recommended method of applying water to the garden is to use the irrigation furrow. Sprinkling may be advisable or necessary until the small plants emerge. This is particularly true with the small seeds which are planted quite shallow. Light mulches over the row will hold moisture close to the surface and encourage emergence. Strips of burlap a foot or so in width make convenient mulch for the kitchen garden but must be removed before plants grow through them. Radish seed when planted in the row with other vegetable seeds, will help break the crust and assist the other plants in emerging. Crusts will likely form in the row on heavy soils under sprinkler irrigation or as a result of natural precipitation. Various soil conditioners, recently made available to the public, are recommended for trial on soils which are likely to crust.

After the plants have emerged, water should be applied in the furrow. A sack over the hose nozzle will prevent erosion or washing away of the soil. Furrow irrigation prevents soil packing and crusting.

Furrow irrigation conserves water and maintains a dry soil surface around plants discouraging garden slugs, snails, sow bugs, centipedes and other harmful and nuisance pests. Sprinkling and the resulting damp foliage may encourage plant diseases and may wash away and reduce the effectiveness of insecticides and fungicides.

Amount of Irrigation Water Required

The amount of irrigation water required and suggested number of irrigations under average Colorado conditions for four soil types are given in table 12, pages 73 to 76.

Some Irrigation Equivalents

1. One cubic foot per second (second-foot) equals:
   38.4 Colorado Statute or miners' inches:
   448.8 gallons per minute:
   Approximately 1 acre-inch per hour, 1 acre-foot in 12 hours or 2 acre-feet per day (24 hours).
   Example: to find the number of Colorado Statute or miners' inches in .45 c.f.s. - .45 x 38.4=17.28 Colorado Statute inches.
2. One acre-foot equals:
   43,560 cubic feet, 325,850 gallons, 12 acre-inches.
3. One acre-inch equals:
   3,630 cubic feet or 27,154 gallons.
4. One cubic foot equals:
   1,728 cubic inches, 7.48 gallons or approximately 62.4 pounds.
5. One Colorado Statute inch equals 11.7 gallons per minute, approximately. (Note: Statute or miners' inches are difficult and confusing to use and should be discarded whereever possible. Cubic feet per second combine the two necessary factors, quantity and time, thus making both measurement and computation comparatively simple.)
6. 1 c.f.s. or approximately 450 g.p.m. will divide into about:
   90 furrows at 5 g.p.m. per furrow
   45 furrows at 10 g.p.m. per furrow
   30 furrows at 15 g.p.m. per furrow
   22 furrows at 20 g.p.m. per furrow
   15 furrows at 30 g.p.m. per furrow
   11 furrows at 40 g.p.m. per furrow
   9 furrows at 50 g.p.m. per furrow
   7 furrows at 60 g.p.m. per furrow
   6 furrows at 70 g.p.m. per furrow

Table 12.—Amount of irrigation water required and suggested number of irrigations under average Colorado conditions for four soil types.

Shallow-rooted (down to 2 feet)*	Irrigation water required	Number of irrigations suggested: Sand	Sandy loam	Clay loam	Clay	Remarks
	acre-inches					
Broccoli	12-15	10-12	8-10	6-8	6-8	Soil must be kept moist at all times. A little less susceptible to adverse moisture conditions than cauliflower.
Brussels sprouts	12-18	10-12	8-10	6-8	6-8	Soil must be kept moist at all times.
Cabbage	12-15	10-12	8-10	6-8	6-8	Light frequent irrigations until heads begin to form. Overirrigation must be avoided after heads begin to form.
Cauliflower	12-15	10-12	8-10	6-8	6-8	Soil must be kept moist at all times.
Celery	24-30	16-20	12-16	10-12	10-12	Celery requires an even and constant soil-moisture supply. Over-watering and drought are both serious.
Lettuce	12-18	10-12	8-10	6-8	6-8	Light frequent irrigations are necessary. Do not overirrigate after heads begin to form.
Onion—late	18-24	12-14	10-12	8-10	8-10	Onions are very shallow rooted. It is necessary to maintain water in upper 10 inches for maximum yields. Growth checks will reduce yield materially.
Potatoes—early	20-30	12-15	9-12	6-9	5-6	Potatoes develop poor root systems. It is necessary to keep available soil moisture in the surface foot of soil, especially for the first part of the growing season.

Table 12 (Continued).—Amount of irrigation water required and suggested number of irrigations under average Colorado conditions for four soil types.

Shallow-rooted (down to 2 feet)*	Irrigation water required	Number of irrigations suggested				Remarks
		Sand	Sandy loam	Clay loam	Clay	
	acre-inches					
Potatoes—late	18-24	10-12	6-8	4-6	4-6	Light irrigations of 3 to 4 acre-inches at a time are most economical. Tuber development occurs 42 to 45 days after planting when the water use will increase rapidly.
Radish	4-6	6-8	6-8	6-8	6-8	Rapid growth is essential for quality.
Spinach	6-12	6-8	6-8	4-6	4-6	Water demands are high near harvest.
Sweet corn	16-18	10-12	8-10	6-8	6-8	Corn develops a poor root system. It is necessary to keep available soil moisture in the surface foot of soil, especially for the first part of the growing season.
Moderately deep-rooted (down to 4 feet)						
Bean, snap	14-18	6-8	4-6	3-5	3-5	Dark-green color indicates lack of water. Do not irrigate when in full bloom.
Beet	14-18	6-8	4-6	3-5	3-5	Too much water may cause excess foliage at expense of roots.
Carrot	18-24	10-12	8-10	6-8	4-6	Too much water may cause excess foliage. Uneven moisture supply may cause mis-shapen roots.

Table 12 (Continued).—Amount of irrigation water required and suggested number of irrigations under average Colorado conditions for four soil types.

Moderately deep-rooted (down to 4 feet)	Irrigation water required	Number of irrigations suggested				Remarks
		Sand	Sandy loam	Clay loam	Clay	
	acre-inches					
Chard	16-20	8-10	6-8	4-6	4-6	Light frequent irrigations are necessary.
Cucumber	14-18	8-10	6-8	6-8	6-8	Light frequent applications of water will increase yield and quality.
Eggplant	18-24	8-10	5-7	4-6	4-5	Plants must be kept growing continuously. Avoid irrigation during bloom period.
Peas	12-18	6-8	5-7	4-6	3-5	An adequate almost abundant supply of water needed after pods set. Too much water is indicated by bright-green foliage.
Pepper	20-24	8-10	5-7	4-6	4-5	Require a uniform moisture supply. Dry periods seriously stunt plants and reduce yields.
Squash, summer	16-20	7-8	5-7	4-5	3-4	Irrigation should be more frequent than for winter squash.
Turnip	14-18	6-8	4-6	3-5	3-5	Must be kept growing continuously with a constant moisture supply.
Deep-rooted (down to 6 feet)						
Asparagus	16-20	5-8	4-6	3-4	3-4	The spring production of spears is from food stored as a result of growth the previous year. Good care with continuous growth should follow the harvest season.

Table 12 (Continued).—Amount of irrigation water required and suggested number of irrigations under average Colorado conditions for four soil types.

Deep-rooted (down to 6 feet)	Irrigation water required	Number of irrigations suggested				Remarks
		Sand	Sandy loam	Clay loam	Clay	
	acre-inches					
Cantaloupe	12-20	5-6	4-5	3-4	3-4	The lack of moisture will reduce the set of late fruit. Yields will be increased by irrigation. The size of fruit is not materially affected by soil moisture.
Parsnip	18-24	5-6	4-5	3-4	3-4	
Pumpkin	12-20	4-6	4-5	3-4	3-4	Can be grown where adapted without irrigation under normal conditions with good winter moisture. Suggested irrigations will increase yield.
Squash, winter	12-20	4-6	4-5	3-4	3-4	Can be grown without irrigation under normal conditions in areas where adapted. Irrigations, however, will increase yield.
Tomato	18-24	5-7	4-5	3-4	3-4	First irrigation will be at transplanting. Plants must be kept growing continuously but it is desirable to keep them on the dry side until fruit has set. Overirrigation may follow fruit set and after fruits start to ripen. It is not usually necessary to water during harvest.
Watermelon	12-18	4-5	3-4	2-3	2-3	Soil should be full of water when seed is planted. Can be grown without irrigation with good winter moisture and average growing season precipitation.

*Depths of rooting based on "Western Vegetable Production" by J. H. MacGillwary, 1953, The Blackston Co., New York.

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