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Principles of Irrigation Farming as Developed by American Field Experiments

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PRINCIPLES OF IRRIGATION FARMING

AS DEVELOPED BY AMERICAN FIELD EXPERIMENTS

by
Prabh Dyall Sikka

THESIS
Submitted to the Departments of Agronomy and Irrigation
Utah State Agricultural College

In Partial Fulfillment
of the
Requirements for the Degree of
Master of Science

Approved by

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Professors in charge

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P R E F A C E

Irrigation is an old art and has been practiced in various countries from time immemorial. Although in relation to world cultivated area the land irrigated is small, the food production on irrigated land is of tremendous importance to civilization.

Success in irrigation farming depends upon the joint efforts of the engineer and the farmer. The engineer has the great and heavy responsibility of constructing properly a permanent system of dams and canals from which water may be drawn, and the farmer has to utilize the water in the best manner for crop production.

From the engineering point of view, the greatest recent progress in irrigation on new scientific lines has chiefly occurred under the British directions in newly settled or in older settled countries. As regards the application of water to the land, the relation of soil moisture to plant growth, the most economic use of water in the production of crops, and other phases of irrigation farming, wonderful experimental work has been done by the United States Department of Agriculture and the Experiment Stations of the western states. This paper is a review of the major experimental conclusions drawn so far in irrigation practice in America.

In presenting this work the author is especially indebted to Dr. George Stewart, the Agronomist, and Dr. O. W. Israelson, the Irrigation Engineer, of the Utah State Agricultural College and Experiment Station who have carefully gone over this and have made very valuable suggestions.

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PRINCIPLES OF IRRIGATION FARMING

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I N T R O D U C T I O N

Irrigation is "the artificial application of water to the soil for the purpose of getting large and steady crop yields". It is supplementary to rainfall and the quantity of water applied and the time of application, therefore, must be determined by the character of the rainfall. Irrigation is usually practiced in those regions which have low rainfall as natural precipitation at such places is insufficient to meet the full water requirements of crops.

The field of irrigation is very great in the world. It has been estimated that about 60 per cent of the earth's surface has insufficient rainfall which makes the application of irrigation necessary in order to get paying yields of crops. About 25 per cent of the earth's surface gets ten inches or less of annual rainfall and this can only be brought under cultivation by irrigation. About 30 per cent of the earth's surface receives between ten and twenty inches of rainfall annually and to grow intensive crops in this area irrigation is essential. Every continental area has its arid and semi-arid regions where the rainfall is less than twenty inches. It has been estimated that with the total available water supply and a perfected system of irrigation, it would be possible to irrigate only one-tenth to one-fifth of the earth's surface requiring more water to produce satisfactory crops.

Under proper conditions of water supply, productive land and available markets, irrigation farming is really attractive. Average crop yields are relatively high in irrigated regions; crop failures are rare; and the farmer has an extraordinary control of the quality of his produce.

Summary of World Irrigation, 1926-27. (29)

Continent	Total Area in Sq.Miles	Population	Area Irrigated in Acres
North America	8,685,833	157,450,526	26,834,000
South America	7,169,587	69,749,645	6,613,000
Europe	3,723,081	477,560,161	14,800,000
Asia	16,217,166	1,037,854,722	140,754,000
Africa	11,514,050	143,335,419	10,310,000
Oceania	3,307,940	9,029,300	1,270,000

The total area irrigated in the world, according to statistics of 1926-27, is 200,581,000 acres. The area irrigated in the important countries is as follows:

India	55,800,000
China	50,000,000
United States	20,471,000
Java and Madura	8,350,000
Asiatic Russia	8,000,000
Japan	6,675,000
Germany	6,000,000
Mexico	5,700,000
Egypt	5,000,000
Italy	3,900,000
Spain	3,500,000
Indo China	3,470,000
Argentina	3,000,000
Chile	2,458,000
Siam	1,750,000
Mesopotamia	1,550,000
Madagascar	1,500,000
Morocco	1,500,000
Portugal	1,206,000
Peru	1,000,000

HISTORY OF IRRIGATION IN INDIA AND THE UNITED STATES

IRRIGATION IN INDIA

The total area irrigated in India, including the Provinces and States by both Govt. and private irrigation works, is about 55,800,000 acres. Out of this about 28,000,000 is irrigated by Govt. Canals according to 1926-27. In India the relation of soil to moisture acquires a greater significance than almost anywhere else on account of the rainfall being limited to particular periods instead of being distributed throughout the year, and because of the intense and prolonged heat with consequent rapid evaporation. The irrigation work in India is divided into three main classes; canal, tanks, and wells. So far as the canals are concerned, the Punjab, the land of five rivers possesses the greatest irrigation system in the world. In the year 1926-27 out of a total cropped area of 30,406,941 acres, 13,961,456 acres were irrigated and out of this, 10,068,746 acres were served by canals. The unfailing supply of its snow-fed rivers and the even surface of its arid plains have rendered it possible to construct the vast network of the canals in the Punjab. One of the most modern, as well as one of the largest, canals in India is the Lower Chenab canal in the Punjab. This canal draws its supply from the Chenab river. To prevent silt choking it and to give the canal a good head, a weir was built across the river with a water-way 4000 feet long. This weiris divided into eight sections, each 500 feet long. The supporting piers between the sections are solid masonry ten feet thick. On the crest of the sections are iron shutters arranged by geaving so that they can be dropped when the river rises and raised when the flood subsides. From off this weir the canal takes its water supply. The base of the canal is 250 feet wide and its depth is 11 feet. The main canal is 400 miles long and has more than 1200 miles of lateral branches. The tract which this canal serves was at one time a desert waste and now the whole region is most excellent crop land. The gross commanded area by this canal is more than three million acres.

Among the new canal projects, the Sutlej Valley project in the Punjab is a composite undertaking involving the construction of four barrages at Gandasingwala (Ferozepur), at Suleimanke, at Islam, 45 miles below Suleiwanke, and a fourth just below the confluence of the Sutlej and Chenab rivers. These four barages will provide a constant water supply for approximately 9,000,000 acres of land and make them available for cultivation. The Ferozepur head works was formally declared open by His Excellency the Viceroy on October 25, 1927 and also the Ganaga Nagar canal which is the largest lined canal in the world. This canal originates at the Ferozepur head works and proceeds for about 85 miles into and through the Bikawer desert, its entire length, both bed and sides, being lined with concrete.

Another new project under construction in India is the Lloyd barage and canal project in the Bombay Presidency. This scheme consists of the construction of a barage across the Indus three miles below the gorge at Sukhar, with three canals on the right and four on the left bank taking off therefrom, each with a separate head regulater. The right bank system comprises the North Western Perennial, Central Rice, and South Eastern Perennial canals. The left bank comprises the new Perennial Rohri canal, a perennial supply channel to feed the Eastern Nara river and the canal dependent thereon, and the two feeder canals for irrigating lands in the Khairpur state. The barage under scientific control will give the necessary supply to each canal, no matter how low the natural level of water in the river may be, provided there is sufficient water in the river Indus from time to time for the combined requirements of all seven canals. All the canals taken together will command about 7,500,000 acres and enable some 5,500,000 acres of crops to be irrigated annually. The total length of the main canals and branches will amount to nearly 1600 miles and that of the distributaries to 3700 miles. It is expected that irrigation from the new canals can be commenced in 1931.

Irrigation from tanks is mostly confined in the Madras Presidency. These are really lakes or reservoirs and are constructed by putting dams across the depressions or valleys. In them the rain water is collected for use in the dry season. The area irrigated from this source in India is about 7,000,000 acres. It is estimated that India irrigates over 13,000,000 acres of land by wells. The area which one well will irrigate depends very largely upon the method of distributing the water from the surface of the well, the method used in raising the water, the depth of the well, and the contour of the land. Well irrigation in South India averages two to three acres, in the United Provinces four acres, and in the Punjab twelve acres per well. The depth of these wells varies from a few feet to 50 and 60 feet. The cost of a well varies, of course, with the depth from 300 to 1000 rupees. The chief methods employed for lifting water from the well are:

(1) The Persian Wheel -- This is a wheel on a horizontal axis with a series of earthen pots so fastened that they act like the metal cups on the modern chain pump, going down empty and returning full. Upon reaching the surface each pot pours its contents into a trough from which the water is distributed on the land to be irrigated. The wheel is driven by oxen or camel. This method is used a great deal in the Punjab.

(2) The Mote -- In this case a rope drawn over a pulley is used to raise and lower a leather bag which brings the water to the point of delivery. This method requires a driver for the yoke of oxen attached to the rope for raising the water and a man at the well head or place of delivery to empty the water into the trough or channel prepared to receive it.

(3) The Picottah -- This is an application of a lever with a central support. It consists of a pole moving in a vertical plane, one end with a weight and to the other end is attached the bucket to lift the water from stream or well. It is worked by one attendant at the well head or stream.

IRRIGATION IN THE UNITED STATES (36)

The arid or semi-arid region in the United States extends west of the one-hundredth meridian to the Pacific Coast, where the rainfall is less than 20 inches per annum. All of the irrigation is confined to that region with the exception of some rice irrigation in the South and a comparatively small amount of irrigation for intensive cultivation of truck gardens and orchards in Florida and the Eastern States. Although some irrigation works were introduced by the Spanish in the Southern States, irrigation in the United States on a community scale and under the conditions of modern civilization began in the Great Salt Lake Valley on July 24, 1867 when a group of pioneers under the leadership of Brigham Young entered the Valley and settled there and irrigated the land and planted potatoes in the watered soil. Irrigation development in Utah and in other settlements was accomplished by cooperative efforts. After a project had been selected, the dams and ditches were built by the people who were to use the water. Little capital was employed and after the ditch was built, its maintenance was the concern of those who used water from it. The pioneers, practical men, first tackled the simple projects and when these were conquered and made to serve the needs of men, more difficult reclamation projects were taken.

The splendid results of irrigation development soon interested capitalists, as men of means felt that money could be invested safely in irrigation enterprises. The returns from the investment looked large. More failures than successes attended these commercial irrigation ventures because the project owner and the water users were too far apart and because capitalists did not take into sufficient account the stern necessity of securing earnest, suitable settlers.

When the pioneers and the capitalists had played their part, the government came forward and continued the work in the more difficult places. In 1902 the Federal Reclamation act was passed which implied that the lands of arid and semi-arid regions might be brought under irrigation and money to be used was derived from the sale of public lands and from royalties on oil and potash lands in the states to be benefitted. Those who settled on the reclaimed lands were required to pay, in easy installments and without interest, the money expended in the building of engineering structures necessary to make water available to the farmer. In 1902 nearly 9,000,000 acres of land were brought under irrigation by pioneers and capitalists. After this, when the reclamation act was possed, the area irrigated increased to 20,000,000 acres according to the census of 1920. It has been observed that most of the success in irrigation enterprises in the United States is due to the cooperative spirit of the farmers. Moreover, the American nation has always realized that the foundation of its prosperity rests with those who till the soil and hence every effort has been made to reclaim the western states quickly and completely.

It is estimated that a total of about 45,000,000 acres of land can be irrigated in the West when economic conditions and the growth of population require it. There is a gradual growth of the irrigated area and new projects are being constantly initiated by the Government and by private parties.

SOIL IN RELATION TO IRRIGATION FARMING

PROPERTIES OF IRRIGATED SOILS

The texture and structure of the soil regulate its readiness with which air penetrates it, its water holding capacity, the readiness with which water moves through it, and finally its conductance of heat. With a given amount of water the degree of saturation of a soil may vary widely, depending upon (a) texture, (b) structure, and (c) permeability.

(a) Texture -- The size of the particles is designated by the word texture. Sandy soils are classed as coarse textured, loam soils as medium textured, and clay soils as fine textured. The texture of a soil has a very important influence on the movement of water, the circulation of air, and on the rate of chemical transformations which are of importance to plant life. The size of the soil particles has in reality a great influence on crop production the world over, but to the irrigation farmer it is particularly important because it determines in a large measure the amount of water that can be stored in a given depth of soil. Moreover, the farmer is unable to modify the texture of his soil by any practical means. Buckingham (6) investigated the mean water content of:

Fine sand	10%
Sandy loam	15%
Clay	20%

This shows that as the texture becomes finer the greater is the average capillary content.

(b) Structure -- The arrangement of the particles is designated by the word structure. The compacting or loosening of the soil are merely structural changes as this affects the arrangement of particles and ultimately pore space. In the puddled condition, the pore space is reduced and the soil becomes impervious to air and water which condition is detrimental to crops and is thus undesirable. By the forming of granules or crumb structure, the pore space of the soil can be increased to a high percentage and this assures a very desirable soil structure and canbe brought about when the soil is cultivated at the proper moisture condition.

The experiments carried out at Cornell University (15) show that flocculation decreases as the moisture increases and it was especially small in the very wet soil. Twenty per cent moisture seemed, on the whole, about the most favorable to flocculation. The results also showed that there was much better flocculation in the cropped than in the uncropped soil.

The pore space is occupied by air and water. If the water content is low, the air space is large and vice versa. An ideal soil for plant growth is one in which there is both air and water, the proportions depending upon the texture and structure of the soil. A deficiency of either of these is attended with distress on the part of the plant.

(c) Permeability -- A property of the soil of very great importance to the irrigator is the readiness with which water will penetrate it, or its permeability. Water standing on gravelly or coarse sandy soils penetrates the soil so rapidly that the water surface will be lowered several inches in an hour. On the other hand, some fine textured clay soils are so impermeable to water that it will collect and stand on such soils for many days with almost no penetration. Between these two extremes there are obviously many degrees of permeability. The greater the permeability of the soil the easier the water sinks and the thicker the layer of the soil which is moistened in a given time. A high degree of permeability, therefore, lessons the storage of water, since more or less of the irrigation water passes down into the lower depths of the soil. Soils of this kind are most uniformly moistened when there is at each irrigation not more water than the soil can retain. This shows the importance of greater frequency of irrigation for such soils. The need of frequent irrigation decreases as the water capacity of the soil increases and permeability decreases because the water supplied to the soil is stored up to a greater or less extent. In soils with difficult permeability a less frequent but more copious supply of water must be regarded as more advantageous.

Permeability is an essential property of soils because the roots of the growing plant require both air and water. The movement of soil air depends almost entirely on the movement of moisture and consequently soil permeability is concerned chiefly with the percolation of water. In irrigated regions the rate of water movement is of unusual importance because excessive permeability may cause waste of water and loss of soluble plant food, and low permeability may result in the accumulation of alkali and injury to the tilth and productiveness of the soil. The water moves most slowly in fine-textured soils; in fact, the rate of percolation is so slow in some heavy soils that the removal of alkali by leaching is almost impossible. The reclamation of these lands would be much facilitated by an improvement in permeability. In other irrigated land, where the soils are heavy and fine-textured, the maintenance of fertility depends largely on the prevention of a very low state of permeability.

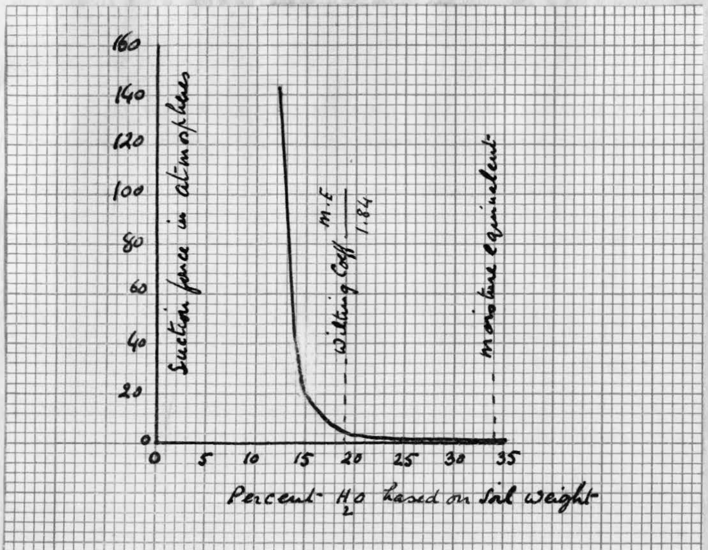
The effect of the constituents of alkali, fertilizers, and soil amendments on the permeability of clay and clay loam soils under irrigation was studied at the New Mexico Experiment Station (7) and it was observed that the penetration of water into the soils was retarded by sodium and potassium compounds (0.5 per cent), and by clay and silt (5 per cent). The sodium compounds caused a much greater depression of permeability than the other substances, the influence decreasing in the following order: carbonate, acetate, chloride, nitrate, silicate, and sulphate. The following substances (0.5 per cent concentration) increased the rate of water penetration into the air dried soil, the accelerating effect decreasing in the order named: aluminum sulphate, ferrous sulphate, aluminum chloride, calcium acid phosphate, manure, and ammonium sulphate. The soils treated with the depressing substances were more alkaline after percolation and were highly deflocculated. Substances improving permeability increased the acidity of the percolates and caused flocculation. Permeability was greatly decreased by deflocculation. The low permeability of fine-textured soils results from properties of colloids. In the dispersed condition, there is a high absorption of water, a large amount of swelling, a high fluidity and an absence of flocky structure and normal pore space. Consequently, a movement of water from or through the soil meets with great resistance and proceeds very slowly. In the flocculated condition, these properties are much less pronounced and the aggregated, flocky structure of the soil facilitates the settling of the soil in water or the percolation of water through the soil. Fertilizers which tend to decrease soil alkalinity, such as ammonium sulphate, manure, and acid phosphate, improved permeability and tilth. Sodium nitrate had an opposite effect; therefore, the cumulative influence of this fertilizer would be injurious.

SOIL MOISTURE AND ITS MOVEMENTS

In the saturated soil when all pore spaces are filled with water, three forms of water are found to be present, (a) Hygroscopic, (b) Capillary, and (c) Gravitational. These forms differ not in their composition but in the position that they occupy in relation to the soil particles. The hygroscopic and capillary water are both film forms and the line of demarkation between these is not sharp. The capillary form is, however, capable of movement. As the capillary water continues to increase and the film becomes thicker and thicker, a point is reached at which gravity overcomes the surface tension of the liquid and the water tends to move downward.

The hygroscopic water actually dissolves the plant food from the soil and fertilizer grains because this water is in close contact with them. But this can only work rapidly when capillary water is also present to carry away the dissolved products. The crops derive their supply of water in the capillary form and therefore the right amount at all times is very important. The plant food is held in solution and moved to the plants as needed. As soon as the capillary capacity of a soil column is satisfied, further addition of water will cause the appearance of free water in the air spaces. The rapid elimination of free water from the soil is necessary as the ideal condition for optimum plant growth is the unsaturated condition of the soil due to the presence of both moisture and air in the spaces.

All soil moisture is acted upon by three forces; adhesion, cohesion, and gravitation. Adhesion is the force of attraction between soil material and water molecules. Cohesion is the attraction which water molecules have for each other. In thick water films the major forces acting upon water molecules in the outer layer are cohesion and gravitation; while in the inner or thin water films the major force is adhesion. The magnitude of the force holding the water film to the soil particles is of great importance as this determines the availability of this film water to plants. The intimate relation between the water content of a soil, i.e., the thickness of the soil water films and the forces involved, have been treated in a paper (27). By means of vapor pressure determinations it has been shown that the force with which water is held by a soil varies from one atmosphere at the moisture equivalent to about 1000 atmospheres in the air dry condition. Thus at moisture contents above the wilting point, a large change in water content causes but a slight change in the magnitude of force with which that water is held. At water contents below the wilting point, a small decrease in moisture content increases tremendously the force with which the remaining water is held. A curve for a silty clay loam is given below.



Due to tremendous force by which moisture is held by soil particles, the water is not available to plants below the wilting point. The average value of the ratio moisture equivalent / wilting coefficient found by Briggs and Shantz is 1.84 (5). Plants grow in soil when the moisture content lies between the moisture equivalent and wilting percentage. At wilting point the force of gravity is insignificant in comparison with the forces of adhesion and cohesion which are in the neighborhood of 5 to 10 atmospheres. Therefore, at these water contents the force of gravity as affecting water movement may be ignored.

The maintenance of soil fertility in irrigated regions depends in part on the control of the movement of ground water and of capillary moisture. Therefore, the knowledge of the laws governing the flow of water in soil is essential to the control of its movement. It is generally known that pressure differences from point to point in a liquid give rise to motion from points of high to those of low pressure when other forces, such as gravity, are not involved. For example, in case of flow of water in a level pipe line, the driving force is dependent upon the space rate of change of pressure. The influence of pressure differences on the flow of liquid has an important bearing on the study of the movement of capillary moisture. Among irrigation engineers it is well known that the velocity of water flowing in open channels and in pipes is determined by two classes of forces, namely, the driving force and the resisting force. When a head gate is suddenly opened, permitting water to enter a canal, its velocity is accelerated because the driving force in a down stream direction parallel to the canal bed at the outset is greater than the resisting force in the opposite direction. The movement of moisture in soils is influenced by forces analagous to those which control the flow of water in open channels and pipes.

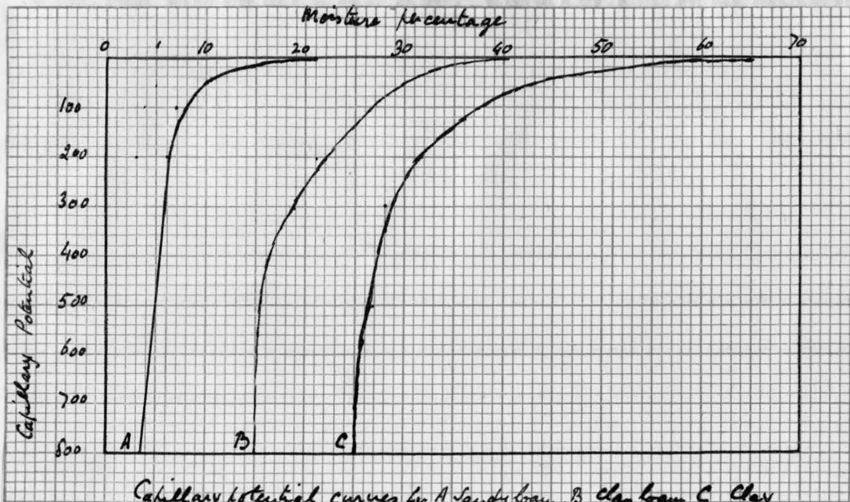
Capillary and gravitational forces are always involved as factors determining the condition of motion or of equilibrium of moisture in the soil.

By making use of potential functions, physicists have developed a dynamical method which has materially aided in studying the flow of heat and electricity. In recent research work the potential functions have proved as useful in soil moisture work as they have been in dealing with electricity or heat. In soil moisture movement the terms gravitational potential and capillary potential are used. The former represents the force due to gravity and the latter attraction between moist soil and water.

The movement of soil moisture occurs due to potential differences or more definitely due to the potential gradient which is a force per unit mass. When gravity and resultant capillary forces are just balanced, there is no motion and this condition of the water is called static equilibrium which results in a region of equal potential. There are no unbalanced forces in an equipotential region.

Soil moisture flow is largely determined by two factors, namely (1) the conductivity of the soil, and (3) the potential gradient within the moisture region. The capillary stream in a certain homogenous soil at a given moisture content flows in the direction of the gradient of the sum of the capillary and gravitational potentials and its velocity is proportional to the magnitude of this gradient.

Richard (26) studied the relation of moisture content at equilibrium to capillary potential in (a) sand, (b) loam, and (c) clay. The results are given in the following curves:



Capillary potential curves for A Sandy loam, B Clay loam, C Clay

This shows that capillary potential in all soils increases with the decrease in moisture percentage. For a given capillary potential the moisture content is highest in a clay, medium in a loam, and lowest in sand.

Under field conditions soil moisture is generally in motion, as the seasonal and diurnal fluctuations of temperature, evaporation, precipitation, irrigationand ground water, or drainage conditions make it unlikely that equilibrium is very closely approached in any actual case. The flow of water in unsaturated soil is designated as capillary flow. A steady flow of capillary water in irrigated soils, analagous to the ordinary flow of water in canals, seldom occurs; the flow is usually changing. However, under certain conditions, such, for example, as the capillary flow vertically upward from a high water table to the soil surface, the flow approximates a steady state if continued for a sufficiently long time. Knowledge of the quantity of such flow is of great importance in irrigated regions. Capillary flow vertically upward may be beneficial in supplying water to plant roots, yet it may be harmful, not only because of conveying water to the land surface where it is lost through evaporation, but also by carrying large amounts of alkali to the surface and thus rendering the soil non-productive.

In field conditions the major concern in a study of steady capillary flow is the quantity of flow vertically up or down. In the first case, the gradient of the capillary potential has such direction and magnitude that there is a resultant upward water moving force. If there is no evaporation or transpirational loss of water from the surface, the state of static equilibrium will ultimately be reached. However, when surface loss occurs the potential gradient is maintained and the upward flow continues. In the second case, provided the moisture content decreases with depth of soil, both the gravity and capillary forces tend to move the water downward. This downward motion will continue, provided there is no surface evaporation, until the moisture content increases with depth so that the capillary potential gradient is directed vertically upward and equal to the force of gravity per unit mass or until the moisture comes to equilibrium with an impermeable layer or with the ground water.

As mentioned above, the conveyance of water in canals is caused by the resulting action of driving and retarding forces. Similarly the driving and retarding forces influence the movement of water in soils. In soils the frictional resistance per unit volume is dependent on the effective use of the soil interstices and capillary channels, the pore space, the temperature of the water, and the percentage of water content. Because of the fact that there is great variability and lack of uniformity in a natural soil, it is impracticable to evaluate with precision for any particular soil the effective size of the capillary channels and of the frictional resistance. The retarding influence of the shape of the capillary channels cannot be measured and designated by a factor such as the hydraulic radius, r, which gives a measure of the retarding influence of the form of cross section of canals, rivers, and pipes. In unsaturated soil there is even greater variability of frictional force, due to the fact that water channels through which moisture moves are influenced by the moisture content of the soil which is variable. It is, therefore, a relatively complex problem to develop an equation that will give the velocity of water in soils analagous to Manning's equation for canals, in which

$$Q = A \times \frac{1.486}{n} r^{2/3} s^{\frac{1}{2}}$$

where Q = the quantity of water discharged by a flowing stream in cubic feet per second,
a = cross section area of flowing stream in square feet,
n = degree of roughness,
r = the hydraulic mean radius of a canal which is the cross section area divided by wetted perimeter, and
s = the slope of a canal, i.e., the vertical fall in a given length.

Comparatively recent research points the way toward measuring the driving force per unit mass but the frictional factors analagous to n in the above equation for different soils containing various amounts of capillary water and dissolved substances at different temperatures are yet to be established. To evaluate the frictional resistance due to each of the variables separately is impracticable . Attempt has been made to evaluate experimentally the combined frictional resistance per unit volume as a characteristic of each major type of soil at a given moisture content. In canals and pipes the frictional resistance per unit volume to flow of water varies with the square of the velocity, i.e.,

$Fr = KV^2$, where Fr is the friction force; V denotes velocity and K constant.

A very essential point of difference between the relation of frictional forces to velocity of flow of water in canals and pipes and to velocity of flow in soils is this: in soils, due to the relatively slow movement of water, the flow is said to be stream line and not turbulant and hence the frictional resistance varies with the first power of the velocity rather than with the second power. Mathematically stated for flow in soils

$$Fr = KV$$

Where Fr = the retarding frictional force per unit volume of water,
V = the velocity of flow in soils, and
K = a constant.

The driving force per unit volume is equal in magnitude and opposite in direction to the retarding force per unit volume.

The specific water conductivity of a soil is defined as the quantity of water (volume) that will flow in unit time through a soil column of unit cross section area due to the driving force of unit potential gradient. The specific water conductivity is the ratio of the specific permeability to the acceleration due to gravity. In irrigation practice it is customary to measure the permeability of soil to water in terms of cubic feet of water that will flow vertically downward through one square foot of soil surface in 24 hours under the force of gravity. The specific water conductivity is a definite measure of the capacity of a given soil to transmit water. The relation of specific water conductivity to soil permeability in the case of sandy loam and deep loam, which were measured experimentally, is given in the table following.

Class of Soil	Time	cu. ft. per sq. ft., per 24 hours	Surface inches per hour	c.f.s. per acre	Specific conductivity K
Sandy loam	1st hour	4.88	2.44	2.44	1.7×10^6
	2d hour	2.92	1.46	1.46	1.0×10^6
	3d hour	3.00	1.50	1.50	1.1×10^6
	4th hour	2.50	1.25	1.25	9.0×10^7
	5th hour	2.50	1.25	1.25	9.0×10^7
Deep loam	1st day	5.68	2.84	2.84	2.0×10^6
	2d day	2.24	1.12	1.12	8.0×10^7

King early found wide variation in the permeability of soil to water. Specific conductivity computed from his data show:

Fine-textured black marsh soil, $K = 2.1 \times 10^8$
clay, $K = 4.8 \times 10^8$
Fine sand, $K = 1.2 \times 10^6$
Coarse sand, $K = 9.0 \times 10^6$

Darcey's equation states that the velocity of the water is proportional to the force which is producing the velocity, hence $V = K$ potential gradients where V is the velocity of flow and K = a constant which will depend on texture, structure, and moisture content of the soil.

$V = K \times$ Potential gradient
$= K \times Fd$ - i.e., driving force,
as $Fd = g \times \frac{h}{l}$ where g is acceleration due to gravity and $\frac{h}{l}$ is slope.
Therefore, $V = K \times l$ -----------(I)

Discharge through a pipe or canal is given by the equation

$Q = AV$ ----------------(II)
where Q = discharge in c.f.s.,
a = cross section area in square feet, and
V = mean velocity of water in feet per second.

Substituting the value of V in equation (II),

$$Q = A \times K \frac{gh}{l} \text{ ----------(III)}$$

In soils, part of the total cross section area, represented in equation (II) by symbol a, is occupied by soil particles surrounded by tiny water films. Let Pf = percentage of water in a saturated soil on a volume basis that is free to move. Then, the net area at right angles to the direction of flow through which flow occurs is the product Pfa. Therefore, equation (III) becomes as follows:

$$Q = Pf\ K\ \frac{gh}{l}\ a \quad \text{------------------}(\ IV\ ).$$

For any given water content of a soil the percentage Pf is constant; therefore, the product PfK may be represented by K which denotes the specific conductivity of a soil. Therefore, the equation (IV) may be written as,

$$Q = K\ \left(\frac{gh}{l}\right) a \quad \text{----------------------}(\ V\ ).$$

The most common case of flow of water in saturated soils is vertically downward in which the driving force per unit mass (potential gradient) is numerically equal to acceleration due to gravity (g). This case is represented mathematically by making the area (a) and the ratio (h/l) of equation (V) each equal to unity. Representing the quantity of water that flows in unit time vertically downward through a soil column of unit cross section area due to the force of gravity by Q^1, it follows from equation (V) that

$$Q^1 = kg \quad \text{-------------------------}(\ VI\ ).$$

The quantity Q^1 is defined as the specific permeability of soil to water. It is apparent from equation (VI) that the specific water conductivity (k) is the ratio of the specific permeability to the acceleration due to gravity. In engineering units (foot-pound-second) Q is measured in c. f. s.; unit area is one square foot, and g = 32.2 pounds. In centimeter-gram-second units, Q is measured in cc. per second; unit area is one square centimeter, and g = 981 dynes.

STORAGE OF WATER IN SOILS

The importance of soil moisture in crop production is well understood. The rate of use of water by growing crops varies from day to day and week to week, but when the soil cannot supply water to plants, growth is at once retarded and soon prevented entirely. In irrigated regions the capacity of soil to store water for the use of growing crops is of special importance. The economical interval between irrigations is greatly influenced by the storage capacity of the soil for water. Moreover, irrigated soils of relatively large water holding capacity may produce profitable crops in places where and at times when the shortage of irrigation water makes it impossible to irrigate as frequently as would otherwise be desirable. Knowledge of the capacity of soils to retain irrigation water is essential to economical irrigation. In irrigated regions water is stored in the soil in capillary form. The amount of water which a well-drained soil can retain at equilibrium against the force of gravity is called the capillary moisture capacity. It is influenced largely by texture, structure, and organic content of the soil. Recent investigations have shown that the capillary capacity at equilibrium is also influenced by the position of the water table. In field soils it is doubtful if equilibrium conditions ever exist between unbalanced capillary forces and the force of gravity.

There are so many variable factors, notably evaporation and absorption of water by the growing plants, that the moisture in irrigated soil during the growing season is always moving. Observations made in Sacramento Valley, California (17) show that the percentages of pore space which are filled by the water that a soil holds immediately after irrigation increases with fineness of soil texture. Variations from 40 per cent in silt loam soils having fine sandy loam sub-soil, 51 per cent in the silt loams, 58 per cent in the clay loams, to 66 per cent in the clay soils have been noted. It has also been noted that the maximum amount of water found after irrigation quite agrees with that of moisture equivalent and hence the latter might be considered as a basis of judging the former.

The percentage of water retained by a soil when the moisture content is reduced by means of constant centrifugal force until it is brought into a state of capillary equilibrium with the applied force, is designated by the term moisture equivalent. By this method it is possible to determine the retentive power of different soils for moisture when acted upon by the same definite force, comparable in magnitude with the pulling force to which the soil moisture is subjected in the field. There is a direct relationship between the texture of a soil and its moisture equivalent as the results obtained were as follows:

Texture grade	Size of Particles	Moisture equivalent, per cent
Fine gravel	2.0 -- 1.0 m.m.	1.18
Coarse sand	1.0 -- .5 "	1.44
Medium sand	0.5 -- .25 "	1.85
Fine sand	.25 -- .1 "	2.34
Very fine sand	.1 -- .05 "	8.62
Silt	.05 --.005 "	24.99
Clay	.005 --.0001 m.m.	61.03

Moisture Equivalents of Various Soils

Coarse sand	6.38
Sandy loam	14.00
Fine sandy loam	15.04
Loam	20.85
Silt loam	25.91
Clay loam	26.11
Clay	34.82

The capacity of soils to retain water is influenced largely by texture, structure, and organic matter. The amount of water applied in a single irrigation is usually expressed in inches. The relationships of the irrigation water applied to the percent of moisture and the depth of soil moistened is expressed by the following equation:

$$d = P_W A_S D$$

where d = inches of water applied on the surface

P_W = per cent of moisture on dry weight basis

D = depth of soil moistened, and

A_S = apparent specific gravity of the soil

The amount of water applied in a single irrigation is usually expressed in acre inches or acre feet per acre. Investigations carried out on the irrigated farm in Utah (16) showed that the soils of medium texture, as a general rule, have the capacity to absorb from 1/2 to 1-1/2 inches of water to each foot depth of soil that needs moistening; the actual capacity for a given soil depending on its texture and structure and the moisture content before irrigation. Sandy or gravelly soils retain the smaller amounts and clay loam soils retain the larger amounts of capillary water. Deep soils hold much water; shallow soils hold little. When more water is added than the soil can hold, seepage with all its dangers begins. Proper plowing increases the storage capacity of the land.

Large losses occur when water is applied to land. These losses are due to evaporation from the wet soil, percolation into the soil beyond the reach of plant roots, and careless use. It has been estimated (31) that not more than one-half of the water diverted by the average earthen canal reaches the land for which it is diverted; of that which reaches the land, fully one-fourth is lost by evaporation under ordinary practice while still another large fraction is lost by careless use. It is a safe estimate that not more than one-third of the water diverted actually enters into the growth of crops. Some of this loss is unavoidable and some can be prevented only at a prohibitive expense, but a large part can be checked without expense by careful use and applying water to soil conditions.

Runn off can be prevented by perfect levelling of the fields, building dikes around the fields, and by keeping the top soil in loose, open condition before irrigation so that the water that falls upon it may be absorbed quickly.

In arid regions the air is very dry due t o high temperature, and this results in rapid evaporation from the soil. The movement of water is from the moister to the drier parts of the soil. When the soil dries at the surface there is a steady upward movement of water from particle to particle to supply that lost by evaporation at the top and to place the remaining water in full equilibrium with all active forces. Such loss of water is felt to the full depth of soil concerned in plant growth. Moisture evaporated from the soil is completely lost and is of no value to crops, hence it is important to reduce this loss to a minimum.

Various factors influencing water losses by evaporating are: (a) nature of the soil, (b) meteorological conditions, (c) initial percentage of water, and (d) the condition of the top soil.

The nature of the soil has great influence on evaporation: the finer the texture of the soil, the more rapidly does the water move upward to be changed into vapor. The darker the color of the soil, the more rapid the evaporation: the ricker the soil is in soluble salts, the slower is the evaporation into the air.

Meteorological conditions determining the rate of evaporation from soils are temperature, sunshine, relative humidity, and winds. These factors are mostly out of control.

The rate of loss of water from a soil increases as the initial percent of water in the soil increases. That is, the higher the initial per cent, the greater the loss; the lower the initial per cent, the smaller the loss. This vitally important principle was observed in the Utah work (32). The reason for this effect of the initial per cent is due to the fact that in case of high moisture content the film of water around the soil particles is thick and thus there is free movement of water. When the water evaporates from the surface of the soil, the thicker the film, the more rapid will be the evaporation; the thinner the film, the slower the evaporation. The per cent of water in the soil is a fairly good measure of the thickness of the soil water film. Therefore, the more water a soil contains to a given depth, the more is lost in a given time by sun action.

Shallow soils, or in soils with a hard pan near the surface, a given amount of water does not get the chance of wetting the soil to considerable depth and as a consequence the percentage of moisture is higher which causes a more rapid loss of soil moisture. From the point of view of the conservation of soil moisture, such soils are, therefore, less economical than deep soils. This principle teaches the important doctrine that moderate irrigations are in all probability more economical than heavy ones.

To diminish the rate of evaporation the best control comes from the proper treatment of the top soil. The various means of saving water in this way are:

1. Cultivation after irrigation -- cultivation tends to destroy the capillary connection between the top soil and the lower soil sections and in that manner prevent the capillary rise of water to the surface. In Utah work, it was found that by cultivation clay soil lost only 63 per cent of the quantity lost by the non-cultivated soil; a clay lom 13 per cent, and a loose sandy soil 34 per cent.

2. Soil mulches -- When the top soil is loosened, the points of contact between the loose soil above and the compacted soil become reduced. At the zone of loose earth, the ascending water finds it difficult to pass through the fewer points of contact and at the same time to maintain its rate of flow. In the experiments carried out at the Utah Experiment Station the soil received water enough to cover it to a depth of 3.14"; the losses in fourteen days were as follow:

With no mulch	0.72
With 4" mulch	0.21
With 8" mulch	0.1.

Taking the loss with no mulch as a basis, the saving with 4" mulch was 16.24 per cent of the amount applied; with 8" mulch, 19.75 per cent of the amount applied. The larger part of the loss occurs in the first few days of irrigation. Immediate cultivation after every irrigation until the crop covers the ground will check the evaporation to a great extent. There is a large loss when water is applied in frequent light irrigations as this practice keeps the water always exposed to the conditions causing the largest possible evaporation. Unless the nature of the soil or of the crop demands such irrigation, much water can be saved by irrigating less often.

Plants require in their growth certain quantities of water which are taken from the soil, passed through the plant, and evaporated at the leaves. The water requirements of crops have been determined by several investigators in various parts of the world under different climatic conditions. Some of the water required by the crop is furnished by rainfall. By proper cultural methods a large proportion of the rainfall may be held in the soil for the use of plants. Therefore, maximum advantage should be taken from the rainfall and irrigation be always considered supplementary to the natural precipitation.

Thus, factors of loss may all be controlled. Evaporation may be checked by tillage, seepage losses may be reduced by applying water in accordance with the knowledge of the soil; i.e., a sandy shallow soil would receive small, frequent irrigations and a deep clayey soil infrequent, heavy irrigations.

FERTILITY RELATIONS

Soil fertility has great influence on the water holding capacity and the economical use of moisture by the plants. The presence of organic matter is a most desirable and beneficial element in the irrigated soils as it increases their capacity to hold more water and also induces better tilth which tends to facilitate ease in drainage and in good aeration. Organic matter, especially when it has been reduced to the form of humus, has great capillary capacity, far excelling in this regard the mineral constituents of the soil. Its porosity affords an enormous internal surface while its colloids exert an affinity for moisture which raises its water capacity to a very high degree. The following data give an idea of the capillary capacity of the soil organic matter:

	Percentage of water
Humus extract from peat	1200
Vegetable mold	309
Peat	190
Garden loam, 7% humus	96
Field loam, 3.4% humus	52.

The tendency of the organic matter to swell on wetting is but a change in condition incident to an approach to its maximum moisture content. Besides this direct effect, organic matter exerts a stimulus toward better granulation, a condition in itself favorable to increased water holding power.

The effect of different soil moisture contents on nitrification was observed in cropped and uncropped soil and the results were as follow:

Soil moisture (percentages)	Nitrates (in parts per million)	
	Cropped	Uncropped
11	38	--
13	21	188
15	10	177
20	19	156
25	23	195
30	17	233
$37\frac{1}{2}$	29	193
45	trace	3

The effect of the crop in reducing the nitrates is very marked. All quantities of moisture below 25 per cent seemed to affect nitrification in about the same manner. Thirty per cent was the most favorable for nitrification, while $37\frac{1}{2}$ per cent was decidedly inferior, and with 45 per cent there was actual denitrification.

Table showing total soluble salts and ratio of soluble salts to nitrates in cropped and in uncropped soil with different moisture contents.

Soil moisture (percentages)	Total soluble salts (in parts per million of dry soil)		Ratio of total soluble salts to nitrates	
	Cropped	Uncropped	Cropped	Uncropped
11	109	309	2.9 : 1	-----
13	83	258	4.0 : 1	1.4 : 1
15	86	296	8.6 : 1	1.7 : 1
20	85	267	4.5 : 1	1.7 : 1
25	88	270	3.8 : 1	1.4 : 1
30	97	360	5.7 : 1	1.5 : 1
37½	95	253	3.3 : 1	1.3 : 1
45	95	100	95.0 : 1	33.3 : 1

The soil with 30 per cent moisture contained the most salts while that with 45 per cent had the least where there was no crop. The soil with 11 per cent moisture, both cropped and uncropped, had more salts than did the soil with medium moisture. The relation between soluble salts and nitrates shows some very interesting relations. The nitrates were always proportionately lower in the cropped soils, which fact shows that plants take up the nitrates proportionately faster than the other soluble salts. The low relative amount of nitrates in the very wet soil shows that the excess of water interfered with nitrification more than with the making soluble of other salts. The nitrates were influenced much more by changing the moisture than were the other constituents.

PLANT RELATIONS TO IRRIGATION FARMING

AVAILABILITY OF WATER TO PLANTS

For the normal growth of the plant water is the most important factor, as it derives material from the soil. For each specie there is a certain water content in the soil which is most favorable for growth. In general, the development of the plant improves with increase of water in the soil up to a certain proportion of the water holding capacity of the soil. When this optimum proportion of water is exceeded or reduced, the development is retarded. The influence of the proportion of water in the soil also affects the length of the period of growth which is generally shorter as there is less and longer as there is more water in the soil. The chemical composition of the plant appears to be influenced more or less by the amount of water at its disposal in the soil. In case of cereal grains grown under differant conditions, it has been observed that a relatively low moisture content favors the development of a glossy grain with relatively high nitrogen content, while with more moisture the texture of the grain is looser, more mealy, and with less proportion of nitrogen. In general, the amount of favorable quantity of soil water for the growth of plants is from 60 to 80 per cent of the total quantity which the soil is capable of holding. With too much as well as with too little the crop is reduced.

As already mentioned under soil moisture, water present in capillary form in the soil is utilized by the plant. This usable water in the soil ranges from about 7 to 12 per cent of the weight of the soil for sand, 10 to 15 per cent for loams, and 15 to 20 per cent for clays.

Not all the water which soils will retain is available to plants. A certain amount must be kept over spreading the soil grains which the roots of the plants are unable to use. Those soils yield their moisture to the plant most completely whose grains have the largest diameter, or more precisely which have the smallest internal surface to which the moisture may adhere and one which it is spread. The light soils have low and heavy soils high wilting points due to this variation of thickness of moisture film or soil particles. The various forms of water in the soil and their availability to the plant can be illustrated diagramatically in the following figure:

Hygroscopic Coefficient Lento capillary point Maximum capillary capacity

Dry Soil Hygroscopic / / Optimum Water Content / Free water Saturated

$\longleftarrow$ Available moisture $\longrightarrow$

Wilting Point

The best moisture condition in the soil for plant development lies between Lento and Maximum capillary points. The optimum moisture for common field crops in general covers a range from 60 to 80 per cent of the water capacity of the soil, which shows relatively high percentage of moisture necessary for maximum crop growth. Granulated condition of the soil has considerable influence on the range of optimum moisture conditions and, therefore, in moisture conservation and control a granular soil is one of the first improvements to be aimed at and this can be done by good tillage, drainage, addition of organic matter, etc.

WATER REQUIREMENTS OF CROPS

A common way of expressing the water requirements of plants is to state the number of pounds of water required for the production of one pound of dry matter. A large number of experiments have been made by different investigators to determine the amount of transpiration. The results obtained are as follow:

Water Requirements of Crops by Various Investigators

Crop	Lawes Rothamsted, England	Wollney Munich, Germany	Hellriegel Dahme, Germany	King Wisconsin U.S.A.	Widtsoe Logan, Utah	Leather Pusa, India	Briggs & Shantz, Colorado
Wheat	235	--	359	--	546	554	507
Oats	--	665	401	--	--	469	614
Barley	258	774	297	388	--	468	539
Rye	--	--	377	--	--	--	724
Corn	--	233	--	350	386	337	369
Sorghum	--	--	--	--	--	437	306
Beans	214	--	--	--	--	--	--
Peas	235	416	292	477	843	563	800
Clover	--	--	--	--	--	--	709
Lucern	--	- -	--	--	--	--	1068
Rape	--	912	337	--	--	--	441
Potatoes	--	--	--	423	--	--	448
Sugar beets	--	--	--	--	497	--	337

These figures show that the amount of water transpired is very large and indicate not only the variation between crops, but also the great effect of climate and soil on transpiration in different countries. The quantity of water transpired varies with the leaf surface of the plant and with the length of the period of growth. With a given plant it is small in the earlier periods of development, increases with leaf development to a maximum, decreases again as the plant ripens and its vegetative functions become less active, and finally stops. Among the field crops the fodders, due to the large vegetative growth and close stand, consume the most water. Then come the legumes and oil plants and the last are cereals.

The work done at the Utah Station by Dr. Widtsoe shows that transpiration equivalent for a given crop on the same soil can be made to vary greatly by, (1) cultural treatments, (2) fertilizers, and (3) the amount of water applied.

(1) Cultural treatments -- The effect of cultivation is shown by the following average figures of three years obtained for corn crops at the Utah Experiment Station (33).

Soil	Transpiration ratio
Sandy loam (cultivated)	252
do (non-cultivated)	603
Clay loam (cultivated)	428
do (non-cultivated)	535
Clay (cultivated)	582
do (non-cultivated)	753

These results show that cultivation reduces materially the amount of water that must be transpired by a plant for the production of a certain definite quantity of dry matter. This phenomenon emphasizes the importance of careful and thorough tillage of the soil.

(2) Influence of fertility on transpiration -- The amount of available plant food is also concerned in the economic utilization of water.

Utah Experiment Corn Crop (33)

Soil	Treatment and transpiration ratio							
	None	Potash	Phosphate	Nitrate	K & N	K & P	N & P	K & P & N
Sand	1012	686	735	555	--	671	178	459
Loam	357	308	391	471	450	333	339	303
Clay	306	292	375	385	280	383	--	--

These results show the marked effect of manure on the ratio and this is the most important factor noticed in relation to plant transpiration.

(3) Effect of soil moisture on transpiration --

Utah Experiment (33)

Effect of Saturation on Transpiration

Soil	Crop	Saturation	Transpiration ratio
Sand	Wheat	8%	1733
do	do	15%	2861
Clay	do	15%	1127
do	do	25%	1142

Nebraska Experiment (20)

The Effect of Soil Moisture on Transpiration (Corn)

Soil Moisture Percentage of total capacity	Transpiration ratio
100	290
80	262
60	239
45	229
35	252

These data show clearly that an increase in the moisture content of a soil usually results in an increased transpiration ratio and thus an excessive amount of water in the soil is not a favorable condition for the efficient use of water. This is due to the fact that in case of high saturation the moisture film in the soil is thick, and thus the water moves with freedom. The plant in a given time and with the expenditure of a given amount of energy will obtain a larger quantity of water than would be possible if the film were thin, thereby offering greater resistance to the moving water. This fact implies that plants are not able to regulate the amount of water taken up by the roots but rather, assuming all other factors to be uniform, the rate of transpiration varies with the ease with which water may be obtained. If this be the case, plants may easily waste water if it is heaped in the zone of root growth unless, indeed, the rate of growth be proportional to the use of water, a condition which does not appear to be true. As soil moisture may be controlled this waste may to a certain extent be eliminated.

WATER REQUIREMENTS OF CROPS FOR MAXIMUM YIELDS

From the practical point of view generally the main consideration of the farmer is to get the largest possible yield per acre. To know the affect of various quantities of water on the yield of the crops, experiments were carried out on the various experimental irrigated farms and the results obtained are given as follows:

Effect of Total Depth of Irrigation Water on the Yield of Crops

Depth of irrigation water in	(8) Lucern hay yield per acre -tons	(39) Wheat yield per acre in bushels	(36) Barley yield per acre in bu	(36) Oats yield per acre in bushels	(2) Potatoes Yield per acre in tons	(21) Sugar beets Yield per acre in tons
5	--	35.55	--	62.28	--	--
6	--	--	--	--	--	18.54
6.5	--	--	--	--	3.67	--
7.0	--	--	--	--	--	24.20
7.5	--	--	68.76	--	--	--
8.5	--	--	--	--	--	19.95
10.0	--	45.00	--	54.76	--	--
11.0	--	46.90	--	--	--	--
12.0	6.5	50.12	--	--	--	21.32
13.0	--	--	--	--	--	20.95
13.5	--	--	--	--	9.30	--
14.0	--	43.39	--	--	--	--
15.0	--	--	67.66	71.54	--	--
15.5	--	--	--	--	--	20.63
18.0	7.2	--	--	--	5.97	--
20.0	--	--	--	80.70	--	--
24.0	8.32	--	--	--	--	--
24.5	--	--	--	--	6.47	--
25.0	--	--	66.15	--	--	--
26.5	--	--	--	--	8.37	--
30.0	9.38	--	- -	--	--	--
36.0	9.38	--	--	--	--	--
39.0	--	--	62.39	--	--	--
45.0	--	--	--	79.06	--	--
48.0	8.87	--	--	--	--	--

These results show that in general the yield increases with the increase of irrigation water until a maximum is reached. After that, further addition of water has a declining effect. The application of more irrigation moisture in the soil than the optimum requirement of the crop has also other depressing effects, such as increase in vegetative growth, quality deterioration, greater susceptibility to disease, delay in ripening, tillering diminished, and the percentage of protein content decreased.

From the experiments carried out at Utah (22), more than 30 acre inches usually reduced the yield of all crops grown except alfalfa which continued to return increased yield up to 60 inches or more of applied water.

EFFECT OF IRRIGATION ON CROPS

Under proper conditions of water supply, productive land and available markets, irrigation is really attractive. Average crop yields are relatively high in irrigated regions and crop failures are rare. Irrigation provides the farmer an extraordinary control of the quality of his produce, a factor of genuine merit, especially in fruit and vegetable growing. The plants respond quickly to irrigation and the life processes of plants growing on irrigated land become very active as soon as water is applied to the soil. Assimilation and all other processes favoring growth are especially rapid after each irrigation, gradually diminishing in intensity and almost ceasing before the next irrigation. In Utah experiments (35) it was found that during the first week after irrigation of peas, more than 500 pounds of dry matter were added to the weight; and of oats, more than 700 pounds of dry matter were added to the acre. This clearly shows that the crops respond readily to the application of water. In everyexperiment conducted to see the affect of varying quantities of water on grains, it has been found that while the length of the plant and the number of seed bearing stalks increase as the water increases, there is a limit to this correlation. The increase due to the increased irrigation continues only up to a definite limit beyond which, if more water is added, a diminution occurs and the plant becomes shorter, the seed bearing stalks less developed with fewer seed, and growth is arrested.

Many experiments have been conducted which deal with the proportions of the heads in grain crops as influenced by varying quantities of water. In the Utah experiments it was found that as the total quantity of irrigation water was increased, the proportion of heads in the plant above ground decreased with wheat from 38 to 25 per cent, with oats from 59 to 49 per cent, and with peas from 67 to 48 per cent. In every case it was seen that the more water applied, the smaller the proportion of heads in the whole plant.

Table showing (35) Percentage of grain in harvest

Depth of Water Applied in inches	Wheat	Oats	Barley	Corn
5.0 - 7.5	44.45 %	64.54 %	50.76 %	51.69 %
15.0	40.83	62.55	47.09	47.92
25.0 - 35.0	38.65	--	38.27	43.55
45.0 - 50.0	32.89	57.63	--	--

The fertile nature of the soil, the favorable climate, and the supply of irrigation water lead to intensive methods of cropping, to specialization in production, and to many cooperative enterprises. These intensive practices and the close personal association involved promote a high intellectual and social standard in the community.

THE TIME OF IRRIGATION

The time of irrigation is largely determined by the condition of the crop and the moisture content of the soil. Young plants use less water than do the larger and stronger plants some weeks older, and the mature plants, the life activities of which have ceased, has very little need of water. It is of prime importance for obtaining the best results that the soil be well filled with moisture at the time of planting. The water transpired by crops is generally, though not always, in proportion to the rate of growth. Water lost by evaporation from the soil increases and decreases largely in the same proportion because the conditions that determine the rate of plant growth also determine the rate of direct evaporation. The plants require little moisture in the earlier period of growth, due to the development of the root system and slow above ground growth, but as the rate of growth increases, the rate of adding water must be increased until the period of seed formation approaches when the supply may again be diminished.

In irrigated tracts, the water supply being more or less under the control of the farmer, moisture should be supplied to the soil according to the need of the crop. A series of experiments were conducted at the Agricultural Experiment Station at Cornell University (15) to see the effect of soil moisture on wheat crop.

The life of the plant was divided into three stages as follow: first, from planting until the plants had five well developed leaves; second, from the five-leaf stage until the swelling of the culms showed the development of the head (popular name, "boot stage"); third, from the boot stage to maturity. The soil used was clay loam and the water holding capacity of the soil was about 45% of its dry weight. The results were as follow:

Effect of High and of Low Moisture at Different Stages of Growth on the Length of the Various Growing Periods in Wheat

Percentage of soil moisture			Days from heading to maturity	Days from planting to maturity	Average number of days from planting to heading
First Stage	Second Stage	Third Stage			
30	30	30	47.3	208.3	161.0
30	30	15	44.7	205.3	160.6
30	15	15	47.0	204.0	157.0
15	15	15	48.3	212.3	164.0
15	15	30	53.4	214.7	161.3
15	30	15	45.7	207.7	162.0

On examining the number of days from planting to heading, it will be seen that the plants receiving low moisture all the time were slowest to head while those receiving high moisture up to the five leaf stage and low moisture all the time after that stage were first to head during both years. Lowering the moisture at the end of the first stage hastened heading more than did lowering it at any other time or keeping it high. The period from heading to maturity was cut short by changing the soil moisture from high to low at the boot stage, while changing it from low to high at the same time lengthened the period. When the total time from planting to maturity is considered, nearly the same relation is seen to exist as in the period from planting to heading.

Effect of High and of Low Moisture During Different Periods of Growth on the Dry Weight of Grain, Straw, and Roots of Wheat

Percentage of soil moisture			Weight per pot (in grams)			Ratio of straw to grain	Wt. of roots (gms)	Ratio of tops to roots
First stage	Second stage	Third stage	Grain	Straw	Grain & Straw			
30	30	30	9.94	34.94	44.88	3.5 : 1	5.41	9.1 : 1
30	30	15	8.55	31.98	40.53	3.7 : 1	6.76	6.1 : 1
30	15	15	8.24	26.40	34.64	3.2 : 1	6.06	5.9 : 1
15	15	15	4.14	15.75	19.89	3.8 : 1	5.99	3.3 : 1
15	15	30	7.25	20.66	27.91	2.8 : 1	5.73	5.0 : 1
15	30	15	7.38	25.81	33.19	3.5 : 1	8.58	3.8 : 1

From the above table it is seen that the greatest quantity of grain, as well as of straw, was always produced on the soil receiving 30 per cent moisture during the three periods, while the least quantity was produced on that receiving 15 per cent. When the soil humidity was maintained at 30 per cent or at 15 per cent during all periods there was nearly four times as much straw as grain, but raising or lowering the humidity at any time affected this ratio. The treatment giving relatively most grain was that in which the moisture was kept at 15 per cent during the first two periods but raised to 30 per cent during the third; while in the treatment giving relatively least grain the moisture was kept at

15 per cent during the entire growth of the crop. Those pots receiving high moisture at first and low moisture later always produced proportionately more straw than those receiving low moisture at first and high moisture later. The weight of roots was least in the soil receiving 30 per cent moisture continuously and greatest in that with 15 per cent in the first and third period and 30 per cent in the second period. The ratio of tops to roots was very much affected by the moisture treatment, being nearly three times as great in the moist as in the dry soil. The moisture received during early periods of growth was more important in influencing this ratio than that received later. These results bring out clearly the facts that the moisture variation in the soil at the different stages of the crop has marked effect on the growth of the various parts and yield.

The next point to be considered is the moisture content of the soil, as fundamentally the time of irrigation is greatly dependent on available soil moisture. In order to afford satisfactory growth of crops the soil should have necessary moisture to prevent wilting. If a soil upon which a crop is growing is thoroughly saturated with water by irrigation, the soil will become temporarily water logged and unsuited to the growth of plants. In a short time, however, under field conditions, depending upon the texture of the soil, the nature of the subsoil and other factors, the excess of water will be carried off by gravity, evaporation, or otherwise and the soil will reach its field carrying capacity with respect to water. Crops will now grow in this soil and draw water therefrom until the water content is diminished to a fairly definite percentage. This percentage is called the wilting point and while it varies widely with different soils for all plants, it is fairly constant for all plants with any particular soil. If the percentage of water falls below and is maintained below this point, nearly all plants will wilt and die at approximately the same percentage in the same soil. The optimum moisture content of a soil is often expressed as the "moisture equivalent", which is an empirical constant representing the water that is held by a soil against a centrifugal force of 1000 gravity exerted for a period of thirty minutes. The water that is included in the soil from its field carrying capacity down to its wilting percentage may be considered the available moisture of the soil.

The irrigation, therefore, should be applied when soil and crop indicate the need of water. Some farmers determine this period by the color of the plants which turn dark green when in need of water. Others examine the first few inches of soil and learn by this method when the crop needs water. Still others contend that the crop should be irrigated at regular intervals whether the crop needs it or not. The last method of determining the time to irrigate is most defective and thus the crop generally receives a great deal more water than is required and the yield and quality of produce are often greatly affected by this practice.

Irrigation should only be applied when the moisture content drops to near the wilting point for the particular soil and in sufficient amount to fill it up to the maximum field capacity. A sandy loam or clay loam which has a good retentive power for soil moisture will not receive frequent irrigations, whereas porous, coarse, sandy or gravely soil which has little retentive power will require frequent irrigations. The frequency of irrigation must be largely dependent on the quantity of water which it is practicable to apply with minimum losses of evaporation and deep percolation beyond the feeding zone of plant roots. Light irrigations applied frequently maintain in the surface soil a higher degree of moisture for a longer period than heavy irrigations applied less frequently and therefore increase the evaporation loss. On the other hand, very heavy irrigations will cause greater percolation losses, especially in non-retentive soils. On retentive soils it is practicable to largely eliminate deep percolation losses but on sandy, open soils it is frequently impracticable to apply only the moisture which can be retained by the soil. However, by proper irrigation methods the deep percolation loss can be much reduced.

METHODS OF IRRIGATION

The efficiency of irrigation can be defined as the ratio of that portion of the water actually utilized by the crop to the total quantity applied to the land. The farmer's endeavor should be to make this ratio as high as possible and one way of accomplishing this object is to avoid losses of water.

When the water is applied to the land, most serious losses are due to direct evaporation from the surface and seepage below the root zone. In all irrigation methods the idea should be to check these losses.

There are three established methods of applying irrigation water. The first, and perhaps theoretically the most satisfactory, is sub-irrigation. To accomplish this a system of pipes with holes at proper intervals through which the water enters the soil may be placed beneath the surface, or, under certain natural conditions, a layer of clay or hard pan underlying a light sandy or loamy soil may serve to retain the moisture within reach of the plant roots. In the latter case the water passes in a ditch along the edges of the field, penetrates the loose top soil, and moves along the impervious layer throughout the whole extent of the field. Sub-surface irrigation is advantageous primarily because there is no loss by direct evaporation. It is, however, a method of very limited application. If the pipes are laid underground the outlets soon become clogged with plant roots. The natural conditions that permit of sub-irrigation exist in only a few localities and, therefore, natural sub-irrigation cannot be widely applied.

Surface irrigation, the usual method of applying water, falls into two distinct sub-heads -- by means of flooding and by use of furrows. In the former case the water is spread over the whole field until the soil is completely covered. In the latter, furrows are made in the soil and the water turned into them. While the water is being applied to the surface in flooding, evaporation occurs first from the water layer and next from the moist topsoil. In furrowing, the water covers only half or less as much ground as in flooding and hence evaporation is reduced. There is little disturbance of the top soil and baking is largely eliminated.

The seepage loss from irrigated land is greater and severer than evaporation. It is particularly severe on light soils. It could be avoided to a large extent if no more water were applied at each irrigation than the amount that can be held by the soil within reach of the plant roots. An ideal irrigation consists in applying the right amount of water, evenly distributed over the field. In places where crop fields are laid out in long strips, water turned in at one end requires from one to three hours to traverse a land field to its other end. As soon as the water reaches the other end, the water is turned to another land. For one or two hours, then, the head end of a land gets water, part of which soaks downward beyond the reach of and beyond the needs of the plant roots, while at the far end the land receives water only for a few minutes. This is not an ideal irrigation. Several tests of the evenness of distribution of the water were made at the Arizona Experiment Station (28). In one case on heavy loam it was found that the percentage of soil moisture at the head of a field for 6 feet depth was increased from 24.1 to 26.3 per cent by a four-inch irrigation, while at the tail end the soil moisture was increased from 15.4 to 18.2 per cent. In another case on sandy loam, the soil moisture at the head end was increased from 14.3 to 21.1 per cent and at the tail end from 8.3 to 12.2 per cent. In both cases, therefore, the head end had more soil moisture before irrigating than the tail end had after irrigating - a preposterous condition. Many similar cases have been observed in Lucern irrigation and in furrow orchard irrigation where the quantity of water absorbed at the head end of the furrows was found to be excessive and wasteful. When these conditions exist, the remedy is more rapid application of the water by means of a larger head, shorter runs, or steeper slopes. Percolation is greater when the soil is coarse than when it is fine. Borders should be comparatively small on coarse soils so as to irrigate quickly. The damage from excessive irrigation and consequent water logging of the soil is particularly great on shallow soils and, therefore, borders should be narrow and short. In California, Arizona, and Utah the border practice as to size and the head of water varies with the soil type. On sandy loam soils borders are 30 to 50 feet wide, from 330 to 1320 feet long, and the head of water from 5 to 20 second feet. On clay soils the width is from 40 to 100 feet, the length from 660 feet to 1320 feet, and the head from 3 to 5 second feet. The small head on heavy soil is economical because more time is required for the water to soak into the soil.

The final adjustment to obtain an even distribution should be made by varying the head of water in each land or in each furrow because it is the easiest to make. The head of water, if it is large, should be divided into unit heads of such size as to give uniformity of irrigation throughout the length of furrow on land.

ECONOMIC ASPECTS OF IRRIGATION

DUTY OF WATER

The term duty expresses the relation between the area of land irrigated by the use of a given quantity of water. The duty of water is spoken as high when the area irrigated by a certain volume of water is comparatively large and as low when the area is comparatively small. In order to express the duty of water, various units of measurement of irrigation water are used, but the most common measure is one cubic foot per second, or one cusec, which may be defined as a volume of one cubic foot of water moving at the rate of one lineal foot per second. The duty varies very greatly and the chief factors which influence this are:

(a) The kinds of crops and diversification of crops. Some crops require more water than others. The growing of a single kind of crop will create a comparatively short period of maximum demand for water which will give a low duty for this period; while the growing of a variety of crops which have different water requirements and different periods of maximum demand will create a more constant demand and thus increase the duty.

(b) The preparation of the land, method of application of water, and the skill of the irrigation. Poor preparation of the land will cause water to accumulate at certain places and thus unifrom distribution is not obtained. In some cases water is lost by run off. Irrigation through furrows which are too long or by flooding over too great a distance when the irrigation stream is too small causes a large excess of water at the upper end which is lost by deep percolation. The practice of rotation, which permits the use of large irrigating heads for short periods, will decrease percolation losses and increase the duty. Careless irrigation will often produce an accumulation and waste of water at the lower end of fields or furrows. In furrow irrigation, unless care is taken in the division of water between furrows, there will be unequal distribution. Deep furrows expose less water and wet soil to the air and decrease the evaporation loss. Thorough cultivation of heavy soils as early as possible after irrigation decreases evaporation losses and removes weeds.

(c) Climate: precipitation, temperature, humidity in the air, wind movement, all have some effect. The rainfall and its distribution are important.

An increase in temperature and in wind movement will increase the soil evaporation.

(d) Character of the soil - Sandy soil will require two or three times more water than clay soil. On a fertile soil less water is required than on a depleted one.

(e) The value of the water, method of payment for water, judgement and knowledge of the irrigation. A high cost of water leads to higher duty. When water is sold on flat charge per acre of land cropped independent of the amount of water used, it is the tendency of the farmer to use an excessive amount of water and the duty is low. On the other hand when the price of water is based on the quantity actually used, careful irrigation practice prevails, resulting in high duty.

The improvement of land by the addition of farmyard manures, by the growing of leguminous crops, and by using a proper system of crop rotation is one of the most potent means by which the duty of water can be increased. The effects of these factors were noticed at the Agricultural Experiment Station of Idaho (39) and the results obtained are given in the following tables:

Treatment of Soil	Number of irrigations	Total water acre feet	Yield oats bushels per acre	Yield straw Tons per acre	Bushels grain per acre ft. water
Unmanured	4	1.015	49.38	.655	48.65
Manured	3	.857	83.11	1.181	96.98

Kind of soil	No of irrigations	Total water acre feet	Yield barley bushels per acre	Yield straw Tons per acre	Bushels grain per acre foot water
New soil	3	1.678	33.02	.79	19.68
Lucern sod	3	1.061	84.87	1.15	79.99

It has been observed that low duty has in many instances caused lands to deteriorate and has reduced their productiveness; whereas on lands where great economy in water application has been undertaken and thus duty has been maintained high, better condition of the soil and greater productiveness have resulted. The best studies in the subject lead to the belief that the differences in the duty of water lie mostly in the practices of the farmer. The irrigation farmer usually feels that he has insufficient water and he therefore labors under the impression that the more water he can give his crops the greater will be the reward. The result is that he overirrigates to the detriment of his crops. Most plants of economic importance to the farmer are sensitive to water. If an excess is applied, smaller yields are expected. The investigations (22) carried out at Utah and other places make it clear that the best quantity of water to be used for the various crops ordinarily grown is between 20 and 30 acre inches. When more than this amount is applied, not only does it affect the yield per acre, but also the quality of the crop produced. Therefore, it is essential for the farmer to be moderate in the irrigation of crops. By this economical use not only may the yield of crops be good, but also some water can be saved to cover other areas. The water must be used to cover the largest possible area consistent with economy so that more men may be given employment and more families maintained upon the irrigated lands.

SAVING OF WATER BY CULTIVATION

Among the cultural processes that reduce the rate of loss of water from the soil, none is more important than plowing and from the point of view of the irrigation farmer this operation has distinct advantages. Plowing permits the easier descent of water into the soil and consequently a more rapid and more uniform distribution throughout the soil. This results in a smaller rate of loss. In addition, thorough and careful plowing at the right time of the year gives every soil activity more freedom which results in more available plant food for the next crop. The frequent cultivation of the soil reduces the direct evaporation of water from its surface.

Many experiments at the Utah farm have been carried out to see the effect of cultivation on direct evaporation and water cost of dry matter. The results are as follow:

Soil	Treatment	Transpiration of corn
Loam	Cultivated	428
do	Uncultivated	535
Clay	Cultivated	582
do	Uncultivated	750

This shows the favorable effect of cultivation as regards the great reduction in the water cost of dry matter. In another experiment on the Utah farm the effect of cultivation was observed on the field scale on a corn crop (37):

Water applied in inches	Number of irrigations	Yield per acre	Cultivation treatment			
			None	2d day after irrigation & then weekly	4th day and then weekly	7th day and then weekly
20	4	dry matter in lbs.	13552	14205	15274	13809

These results are unique as they seek to establish the valuation of cultivation. The largest yield was obtained when the first cultivation occurred four days after irrigation and weekly thereafter; the next largest yield when the first cultivation occurred the second day after irrigation and then weekly, and the smallest yield when the first cultivation occurred the seventh day after irrigation and then weekly. That is, when cultivation occurred too soon after an irrigation, the soil did not pulverize properly but tended to puddle and a poor soil mulch resulted. Likewise, when as long a time as seven days elapsed before the first cultivation, there was a distinct loss in the yield of dry matter. The time for the first cultivation seems to be very important. Following each irrigation it should be performed immediately after the danger of puddling the soil is past.

SAVING OF WATER BY MANURING

The available plant food of the soil has a direct effect not only upon the yield, but also upon the transpiration.

A series of tests were undertaken to determine this effect on the Utah farm and the results are as follow (33):

Corn crop (loam soil 20% saturation). Pounds of water transpired per one pound of dry matter.

Nothing added	4 lbs. manure	.1%	.01%	.1% KCl
908	613	585	257	848

This shows that the quantity of water required to produce one pound of dry matter is greatly influenced by the plant food in the soil.

Different substances influence the transpiration ratio differently. Acids, for instance, tend to accelerate transpiration and to increase the ratio. Alkalis have the opposite effect. Lime, potash, nitrates, and phosphates tend to reduce the water cost of dry matter. Of first importance are the nitrates. Therefore, the maintenance of nitrates in the soil is undoubtedly of prime importance in reducing the water needs of crops. Increasing the concentration of the soil solution reduces the transpiration ratio only when the substances held in solution in the soil moisture are true plant foods.

On alkali lnds, which ordinarily contain chlorides, sulphates and carbonates of sodium, and other substances of a non-nutrient character, crops cannot be produced at a lower water cost than on soils containing less soluble matter.

Bouyouicos (3) showed that a solution of common salt or sodium sulphate or other substances not directly plant foods, reduced the rate of transpiration but did not diminish the water cost of the resulting dry matter.

The irrigation farmer who wishes to have an economical use of water must bear in mind the effect of fertility and, therefore, always keep the soil in such condition by cultivation, manuring, rotation, etc.

CONTROLLING WEEDS

Weeds cause losses to the farmer in many ways. To the irrigation farmer the greatest harm done is the robbing of soil moisture that should go to the main crop. Scientific workers have determined water requirements of some of the common weeds and they have concluded that such weeds drain heavily on soil moisture. The common sunflower (25) requires about twice as much water to produce a pound of dry matter as does corn. Thus the damage done by weeds is enormous and it should be the duty of the farmer to always keep them under check. Various methods are known to eradicate weeds. Crop rotation and cultivation are the best known methods of controlling weeds. Such practices insure good crop yields and at the same keep weeds in check.

METHODS OF DELIVERY

The proper delivery of the irrigation water to the various users is a very important problem on an irrigation project. Each irrigation must receive enough water and at such a time so that he may get a good crop every year. The success of an irrigation enterprise depends upon the successful system of delivery of water under the canal.

There are three general methods of delivering water to farmers: (1) a continuous flow of water to the farm during the whole irrigating season; (2) rotational delivery; (3) delivery of water to the farmer when he applies for it.

Under reservoirs where an ample supply of water is stored any of these three methods can be employed, but in case of canals taken from rivers only the first two methods are used and the third method is practically impossible.

The method chosen for distribution determines the crops to be grown and the areas to be devoted to each. The head of flow has great influence on the economical use of water in the field. With a sufficiently large volume of water the fields can be covered very quickly and there is less loss by evaporation and percolation; whereas in the case of small flow, too long a time is required to cover the field and thus a large portion of the water is lost. Continuous flow is suitable for large farms where diversity of crops are tried and thus water can be utilized to an advantage. On small farms the rotational system is always satisfactory as by this method the farmer receives a stream carrying a rather large volume of water for a certain definite number of hours, and during the time the stream is at his disposal he can give himself wholly to the work of irrigation which means very careful use. Experience has shown that the rotational system is the most satisfactory as in this method the waste of water is eliminated, whereas a continuous flow becomes burdensome and as a result some of the water is often allowed to go to waste.

Methods of Charging for Water -- Various systems are used for charging of irrigation water and these have great influence on the economic use of water. The most common systems are: (1) charging according to the area irrigated, and (2) sale of water by measure.

(1) Charging according to the area irrigated. - This system is followed all over India in various forms. In the Punjab, the farmer pays

according to the area of the crop matured. There is an enormous waste of water by the cultivator in the canal-irrigated tracts of India and it has been estimated that the amount of excess water applied to crops, such as wheat in Punjab, is from 30 to 50 per cent. This is due to the fact that the farmer has little incentive to economize water. The evil effects of this uneconomic use of water are not only confined to the wastage of water, which could be used more profitably elsewhere, but they often extend to definite damage to the soil.

(2) Sale by Measure. - The true method and to induce the farmer to make every effort in economising water is to sell the water by measure at the bank of the distributory channel. There are two ways of selling water by measure: (a) the charge by meter, and (b) the charge by module meter system, which means charging according to the number of units of supply (say foot acre) actually used, the quantity being measured on a self-recording meter, just as municipalities or public companies charge dwellers in towns for water used for domestic purposes. This method can only be applied on a small area, not on a big, extensive scale. In the module system the cultivator pays a rate for the volume of water allowed to pass through a sluice at prescribed intervals of time and in sufficient quantity to mature his crop, the discharge of the sluice bearing a certain proportion to the area to be irrigated. The function of a module is not like that of a meter to measure the volume of supply passing through it, but to control it so that when fully open the discharge will be constant and will not rise above or fall below the rate at which it is set, whatever variations may occur in the level of the water in the supply channel or in the drawing capacity of the water course leading to the farmer's land. A uniform rate cannot be charged per unit of supply when there is very great variation in the lengths of the channel leading to the

consumer's land. In America the system of charging by module is very common and gives satisfactory results. They are applied to channels of much greater capacity than that of the ordinary Indian village water course, which ordinarily varies from 1/2 to 4 cusecs. Moreover, American farmers are much better able to look after themselves and each other and to satisfy themselves as to the fairness of the distribution and the correct working of the module than the Indian cultivator.

EFFECT OF ROTATIONS

The term "rotation of crops" means a system of farm practice which groups field plants with different food requirements so as to give a definite cycle of crops in successive order. The main objects of a crop rotation are: (1) prevention of crop sick soils; (2) elimination of weeds, insect pests, and crop diseases; (3) maintenance and increase of the productivity of the field crop by conserving soil fertility. It has already been mentioned under weeds and soil fertility the effects that these factors have on soil moisture.

The irrigated soils generally lack in organic matter and nitrates; the former greatly increases the water holding capacity of the soil, while the latter reduce the moisture requirements of the crops. The growing of legumes in the rotation, therefore, is very important for the irrigation farmer as they add both humus and nitrates to the soil. Some farm stock raising combined with crop growing will furnish manure for making humus and building up the soil. The elimination of weeds is effectively accompanied by the introduction of a cultivated crop like potatoes. The irrigation farmer should include in his rotation: 1. at least one money or cash crop, 2. one cultivated crop, 3. one legume crop, and 4. one feeding crop.

These crops should be so arranged as to get the most economical distribution of labour throughout the year.

IRRIGATION OF BASIC CROPS

CEREALS

The grain crops are food crops for man and animal and are, therefore, usually grown on both irrigated and dry-farm lands. They bring quick returns and furnish feed. Some of these also fit very well into every rotation practiced on the irrigated areas.

WHEAT -- It is highly important to prepare a good seedbed for wheat. In order to accomplish this and to get a proper amount of moisture, where the seasonal rainfall is short, a thorough irrigation should be given before plowing. This will put the soil in a good condition and retain proper moisture for the quick germination of seed at the time of sowing. Wheat is sensitive to excessive soil moisture as well as to insufficient quantities. Where the soil was maintained at 20 per cent moisture content throughout the growing season (10), production was much better than where insufficient or excessive moisture was present at some period of growth. When normal moisture conditions prevail the crop has a light green color. When it begins to suffer for water it takes on a dark green color and the lower leaves begin to fire. For best results, maximum growth from seed time to harvest should be maintained by cultivation and irrigation. The plant procures from the soil, during its early growth, the larger portion of its total weight. In its later growth the seed is being formed largely from material stored in the stalk. Upon the early growth depends the future of the plant. Therefore, the farmer must not permit a lack of moisture occur here. In the later stage lack of moisture prevents the plant from using the elaborated material provided for filling the grain. Hence, shrunken grain is the result. Therefore, the farmer should note that a greater amount of moisture is required for the early and late stages of growth. On the Utah experimental farm (9) the highest yield of wheat was produced with three irrigations of 5 inches each, applied at the 5-leaf stage, the early heading stage, and the bloom stage.

The first irrigation of wheat, therefore, should be given at stooling time, the second on the first indication of heading, and the third when the heads are fully out, i.e., in the flowering stage. If the soil retains water well, this will carry the grain through to maturity unless excessive hot and dry weather ensues. If another irrigation be found necessary, then it should be given before the grain goes out of the milk stage as the heads weigh down heavily and a very strong wind is likely to lodge the grain.

The quantity of water to be used for wheat depends upon many factors. Less water is required on clayey than on sandy or gravely soils. Deep soils require less water than shallow soils. Idaho experiments (2) have shown that in actual practice grains received on medium clays and sandy loams about 18 inches of water, while on sands or gravelly soil nearly 36 inches were used to get the best results. More water is necessary on new than old land. A high temperature, a low relative humidity, and a steady wind increase the water requirements of crops.

CORN -- This crop thrives and yields well under irrigation. Cultivation is very essential for this crop and, therefore, the soil should be cultivated after every irrigation and this will result in the economic use of water by the crop. The soil should be well supplied with water before seeding. The young plant draws little water from the soil and the first irrigation after seeding should come as late as possible. As the plant continues its growth, the irrigation may be increased in frequency. The crop should have enough water at its disposal at the time of seed formation. Corn is not a water loving plant. It will use large quantities of water if available but it does not demand an abundance of water to produce a good yield. Like all other crops the increase in yield is not proportional to the increase in water supplied by irrigation. The following table, taken from work done in Utah, will illustrate this statement (12)

Inches of irrigation water applied	Bushels of grain to the acre
7.5	79.14
10.0	89.52
15.0	93.93
20.0	91.58
25.0	99.16
30.0	97.12
55.0	96.78

From 15 to 25 inches of water has been found to be best for corn. The highest yield of corn was obtained in Utah when four equal irrigations were applied at the following intervals: (1) when the plants were 12 inches high, (2) at the beginning of tassel, (3) at bloom, and (4) at the maturing stage of the grain.

RICE -- It is a semi-acquatic crop and requires moist conditions and, therefore, heavy irrigations. The land under rice is divided into small fields separated by dikes to keep the water in. The seed is either sown in a nursery first and then transplanted, or directly sown in the field. In both cases the fields are first filled with water and the planting is done in the standing water. When the plants are 6 to 10 inches high the first irrigation is applied and from that time the water is made to stand on the land to a depth of 3 to 6 inches until the grain is in the dough stage, or about two weeks before harvest. The land for rice must have good drainage so that water may soak quickly and fresh water may be applied soon. The length of the irrigation season varies from two to three months. The careful investigations of the U. S. Department of Agriculture, Office of Experiment Stations (4), show that only from 12 to 18 inches of water above the rainfall are really used by the plant. In one series of experiments about 29 acre inches of water were applied throughout the season to the field, including rainfall; the evaporation was about 16 inches, leaving 13 inches that were actually used by the plants.

FORAGE CROPS

In irrigation farming forage crops are of high importance as a modern system of agriculture cannot be developed without the aid of livestock husbandry.

ALFALFA OR LUCERN -- This crop is the foundation of successful irrigation agriculture in the United States. If the corn crop is the King in U. S. A., then alfalfa is the Queen. This crop thrives best in the soil and climate of the arid and semi-arid regions provided water is available for irrigation. It prefers a deep, well drained loam soil, abundant sunshine, and a dry atmosphere if its roots are well supplied with water. It is the most valuable fodder crop and gives 8 to 10 cuttings in the year where there is no frost. Due to its leguminous nature it does not exhaust the soil. It is the richest hay food known. Eleven pounds of it are worth as much for feeding purposes as ten pounds of bran.

Alfalfa requires more water than most crops due to the character of the plant, the rapidity with which it grows, the number of cuttings produced in one season, and the heavy tonnage obtained. From the results of experiments (9) it has been seen that in localities having an annual rainfall of about 12 inches remarkably heavy yields may be obtained from the use of 24 to 30 inches of irrigation water provided it is properly applied.

Watter may be applied to the crop either by flooding or furrowing. The former is more common. Furrowing is practiced where the water supply is limited and the soil surface is liable to be baked after irrigation. As regards the proper time to irrigate, the general appearance and more particularly the color of the plant are the best guides as to when water is needed. When healthy and vigorous, alfalfa is of a light green color, but when the supply of moisture is insufficient the leaves take on a darker and duller shade of green and begin to droop and unless water is provided, the stems and leaves wither and die. The idea should be to maintain at all times, as nearly as practicable, the proper amount of moisture in the soil surrounding the roots of the plants to prevent a checking of their growth.

The yields of alfalfa can be considerably increased if more care is used in finding out when to apply water. In each kind of soil and under any given set of climatic conditions there is a certain percentage of soil moisture which will give the best results. The number of irrigations required depends upon the depth and nature of the soil, the depth to ground water, the number of cuttings, and the rainfall, temperature, and wind movement. Other things being equal, more frequent waterings are required in the warm sections than in the cooler portions.

IRRIGATION OF ORCHARDS

Orchard culture has proved to be the most paying method of irrigation farming. Care and good judgement should be exercised in the selection of an orchard tract. If it turns out well, the profits are high, but if it fails, the losses are heavy. It involves the setting aside of good land, the use of irrigation water, and somewhat heavy expenses in purchasing trees, setting them out, and caring for them until they begin to bear. If the climate and soil of the district are adapted to the kind of trees to be grown, the next most important things to consider are good drainage and freedom from early and late frosts. Low lands are not considered good for orchards due to the seepage of water from high lands after some years and their being subject to cold and stagnant air.

While experience has shown that orchard trees of nearly all kinds can be successfully grown on soils that differ widely in their mechanical and chemical composition, it has also shown that certain types of soils are best adapted to particular kinds of trees; e.g., orange orchards do best on medium grades of soil. All fruit trees require deep, rich, and well drained soil. As a rule fruit trees are planted on land previously cultivated and cropped. One of the best preparatory crops for orchards is alfalfa. This vigorous plant breaks up the soil and subsoil by its roots, collects and stores valuable plant foods, and when it is turned under at the end of the second or third year, leaves the soil in a much better condition for the retention of moisture and the growth of young trees. Under irrigation system, peaches should be spaced 20 to 22 feet and average 22 to 24 feet apart.

The usual method of irrigation is the furrow method. The number of furrows depends on the age of the trees, the space between the rows, the depth of the furrow, and the character of the soil. Nursery stock is irrigated by one or two furrows and young trees by 2 to 4 furrows. A common spacing for shallow furrows is $2\frac{1}{2}$ feet, while deeper furrows are made 3 to 4 feet apart. The general trend is toward deep rather than shallow furrows, a depth of 8 inches being frequently used.

Time of Irrigation -- The citrous fruits have a continuous growth. A tree while dormant gives off moisture, but the amount evaporated from both soil and tree in winter is relatively small, owing to low temperature, the lack of foliage, and feeble growth. The number of irrigations depends on the capacity of the soil to hold water. If it readily parts with its moisture, light but frequent applications will produce the best results, but if it holds water well, a heavy application at longer intervals is best, especially when loss by evaporation from the soil is prevented by the use of a deep soil mulch. The results of experiments (29) have shown that where the water is applied to the surface of orchard soils the loss by evaporation is very great so long as the top layer remains moist. Even in light irrigations this loss in 48 hours after the water is put on may amount to from 10 to 20 per cent of the volume applied. In order to reduce this loss and moisten the soil around the roots of the trees, the practice of running small streams of water in deep furrows has become quite common. In applying water in this way the top soil remains at least partially dry, the bulk of the water soon passes beyond the first foot and the surface can be cultivated soon after the water is turned off.

For inter-cropping, a plentiful supply of water and a deep rich soil are essential. Shallow rooted plants are considered the most desirable for this purpose. Squash, melons, sweet potatoes, ground nuts, onions, potatoes, turnips, etc., are very common in California. A clear space of 3 to 4 feet wide is left on each side of the young trees.

OTHER CROPS

POTATOES -- Next to rice, the potato is the most extensively grown food crop in the world. It is one of the most important irrigated crops and if carefully cultivated, brings good income to the farmer. It is deep-rooted and prefers deep soil and does best on land previously grown to Lucern. A workable loam soil with a good under drainage is the most desirable type of soil for good yield and good quality of potatoes.

Irrigation is done by the flooding and the furrow method but the latter gives better results. The soil should have enough moisture at the planting time. A well-fined, firm, moist seed bed affords opportunity for a well developed root system by means of which the young potato plants draw sustenance from the soil. After planting, just as soon as possible, give a good thorough cultivation. By cultivation the soil is aerated, weeds are killed, and the mulch produced on the surface checks too rapid evaporation of soil moisture. As soon as the plants are high enough to distinguish the rows, give a second cultivation which will give ample air for vigorous growth. In the case of potatoes vigorous vine growth is essential to obtain desirable tuber yields. Potatoes never fully recover from a stunted growth in early life.

The first irrigation should be delayed until the young tubers are set or the plant is in blossom. Earlier irrigations tend to make shallow rooting, sending the tuber beds too near the surface and thus lessening the yield and impairing the quality of the potatoes. More "irritation" with little or no "irrigation" during its early growing period is what makes the best potato crop returns. Yet the young plants must not be allowed to suffer for water. The darkening of the foliage is the way potatoes call for water. It is never wise to irrigate potatoes by the flooding system as this tends to solidify the ground, shutting off the abundance of air which the growing tubers demand. It is essential in potato culture that the right quantity of water be used and that it be uniformly distributed. Cultivate as soon as possible after the first irrigation as this lessens evaporation and insures a vigorous, uniform root and tuber growth without serious check. For succeeding irrigations, give the plants sufficient water to keep up vigorous growth but do not over-irrigate. The amount of water applied will vary with the kind of the soil and the climate of the season. On the Utah experimental farm irrigation experiments were carried out and the results are as follows (13):

Irrigation	Yield of tubers per acre
None	96.4 bushels
20" divided into ten 2" irrigations	254 "
20" " " five 4" "	248 "
15" " " five 3" "	226 "
15" " " three 5" "	193 "
10" " " ten 1" "	243 "
10" " " five 2" "	195 "
10" " " two 5" "	177 "

This shows that where a limited quantity of water was used, larger yields were obtained by applying it in several small irrigations. The suitable quantity of water lies between 10 and 25 inches. Decreasing or increasing this amount gives lower yields. Experiments on irrigation of potatoes were carried out at the Oregon Agricultural College Experiment Station (24) for twelve years on silt loam soil. The most economical returns were secured with light, frequent irrigations as these provided a uniform moisture content and the potatoes did best with a uniform moisture content. Moreover, the water cost of dry matter was also reduced by the use of a moderate amount of irrigation. Growing potatoes on irrigated legume sod reduced the water requirement by about 25 per cent. Heavy irrigation has been found to increase the moisture content of the potatoes, causing a higher proportion of vines to tubers. Proper irrigation has decreased the percentage of culls.

<u>COTTON</u> -- Cotton is usually a crop for long seasons, warm weather, and low altitudes. The longer the lint of the cotton, the longer the growing season required to mature the crop. A rich sandy loam soil, well supplied with humus, is best for the growing of cotton. Very light soils are not suitable and very heavy soils are unsatisfactory because of their tendency to bake. Proper preparation of a seed bed for cotton is necessary for the best yield of lint of a good quality. This preparation should begin as soon as possible after the removal of the preceding crop. The ground should be plowed deep and then allowed to weather until within 5 or 10 days of planting time when it should be irrigated. The soil should be soaked to a depth of 4 or 5 feet. The best seed bed is one that consists of a finely mulched surface 2 or 3 inches in depth with a firm moist soil underneath. The planting is done in rows $3\frac{1}{2}$ feet apart. With large and vigorous growing types of cotton in rich soil, it is better to put the rows 4 feet apart. Planting should be done when the ground is warm enough to insure prompt germination and vigorous seedling plants.

With warm ground and a seed bed that has been well prepared, good stands are often received from a very small amount of seed, but the best rule is to use at least 25 pounds of seed per acre.

Upland cotton is usually thinned when the plants are from 2 to 5 inches high. Delayed thinning helps to prevent the development of vegetative branches and has the effect of throwing the cotton into the fruiting period. earlier than otherwise would be the case. In Arizona, upland cotton is thinned so as to leave the vigorous plants 10 to 24 inches apart in the row. The wider spacings are used on the richer land.

Much of the success of growing cotton depends upon proper irrigation. The most important irrigation is made before the cotton is planted, at which time the ground should be soaked to a depth of at least 4 or 5 feet. If this is done and irrigation is then withheld for a considerable time after planting, the plants develop a deeper root system and are more vigorous and better able to withstand unfavorable conditions. Frequent light irrigations early in the season result in a shallow rooting of the plants. Sufficient moisture should be supplied to keep the plants in a healthy growing condition. Severe drying of the ground after the plants begin blooming causes them to shed buds, flowers, and small bolls. Irrigation or heavy rainfall after the plant has been suffering for water stimulates growth which also causes the plants to shed their bolls. Irrigation should be continued in the fall until the blossoming period is almost ended, but it is advisable to allow the soil to dry out to hasten the maturity of the crop as the time for frost approaches.

The intelligent irrigation of cotton involves a greater understanding of water requirements of the plant than is the case with any other irrigated crop. It is impossible to give definite rules to govern the proper intervals of time between irrigations, but ordinarily during the early growth watering should occur every 4 to 6 weeks, and during the fruiting stage water should be applied at intervals of from 10 to 15 days.

<u>SUGARCANE</u> -- Sugarcane is best adapted to loam soils rich in humus and nitrogen. For planting cane old alfalfa ground is generally selected in the state of Arizona. If this is not possible, then some winter legume is sown in winter and plowed in before planting cane. Farmyard manure is applied on the stubble cane and worked in with the plow or cultivator. Thus soil devoted to cane is always treated every other year in order to produce a profitable yield.

The usual time of planting is March, but it is considered better to plant in October than in the spring. If planted in October the winter cold spells will not seriously injure the crop, although the top parts may be frozen. Meanwhile, the root systems are expanding and the plants are, therefore, more vigorous when the spring warmth approaches and thus the length of the growing season is increased. The planting is done in rows five feet apart with the plants as thick in the row as they would naturally come from the buds of the stalk. Furrows are opened with a plow five feet apart and the seed cane placed in the bottom of the furrow. Ordinarily the stalks are cut into small lengths bearing at least two buds. Sometimes whole stalks are used, being placed butt to tip, slightly overlapping, in a continuous line. By either method the seed stalk is covered at first three or four inches but later the furrows are leveled and finally ridged along the row line.

<u>Irrigation of Ratoon Crop</u>: Immediate irrigation after harvest is considered the first and foremost need of the crop. The response to this practice of instantly invigorating the old stubble is often marvelous. The secret of good ratooning is the rapid application of the first water. Therefore, the soil moisture of ratoons should be brought up as soon as possible. There is a period following this first irrigation until the ratoons are 10 to 12 weeks old, depending on the season of the year, when the cane can withstand relatively

longer intervals. At this stage of growth this lack of response is due to the small leaf area as there is a direct correlation between the cane's need for water and the surface of the leaves which are exposed. It has been actually observed that the cane which is less than three months old will suffer least with rounds every three weeks up to four weeks, provided the initial irrigation has been given promptly. The ratoon crop irrigated in this way starts to make stalks when three months old. During the next months the water applied is most effective as these include the best growing period and the cane utilizes water to the best advantage.

At this stage the cane is provided every favorable treatment and observations show that fields receiving this optimum treatment give maximum returns. When the cane gets old enough, there is a slackening of the rate of growth and, therefore, the big cane is not responsive to frequent irrigations. One cannot say definitely just when this slackening seems to take place as seasons play a big role. Close observations or measurements are necessary to determine when cane has reached the apex of its rate of growth and this varies greatly. Finally, the cane reaches a point known as the ripening stage when growth is of less concern and the formation of sucrose is of vital importance. Gradually reducing the irrigation at this stage brings favorable results. Soil conditions and seasons of the year with rainfall dictate the frequency of application, but it should be as in applying a brake, not too sudden a jolt.

Irrigation of Plant Cane: For plant cane there are no radical differences after the fourth month. Previous to this, the irrigator should see that the cane is firmly rooted with a solid stand.

EFFECTS OF IRRIGATION

OVER IRRIGATION AND ALKALI

In irrigated tracts where excessive quantities of water are applied to crops, there is always a danger due to the accumulation of excessive salts near the soil surface. Irrigation on high lands affects the low lands by causing a gradual rise of the water plane until in places what were formerly productive fields become bogs and marshes. As the soil water evaporates, it becomes more and more concentrated until the water and soil become so strongly alkaline as to check the growth of plants or prevent it entirely, leaving the ground bare of vegetation but covered with a crust of alkali. These salts, which were formerly distributed throughout a depth of many feet, are dissolved by the percolating water and are carried along until the water comes to the surface and is evaporated when the salts are deposited as a crust at the surface.

Before the land was brought under irrigation, the rainfall penetrated only a slight depth into the soil and when evaporation took place, salts were drawn to the surface from only a small volume of soil. When, however, irrigation water is turned on the land the soil becomes wet to a depth of many feet. When the soil is allowed to dry up, large quantities of salts are carried to the surface by the upward moving capillary water. Although these salts are in part carried down again by the next irrigation, the upward movement constantly exceeds the downward one. This is because the descending water passes largely through the non-capillary interstitial spaces, while the ascending water passes entirely through the capillary spaces. The smaller spaces, therefore, contain a considerable quantity of soluble salts after the downward movement ceases and the upward movement begins. In other words, the volume of water carrying the salts downward in the capillary spaces is less than that carrying them upward through these spaces. Surface tension causes the salts to accumulate largely in the capillary spaces and it is, therefore, the direction of the principal movement through these spaces that determines the point of accumulation of the alkali.

Many of the most fertile lands of the arid regions have been temporarily ruined by the bringing to the surface of soluble salts in such large quantities that the growth of the crop is prohibited.

Alkali is made up of anyone or a mixture of the following salts: sodium chloride, sodium carbonate, sodium sulphate, sodium nitrate, and magnesium sulphate. Generally no single salt is found alone but the soil contains a mixture of the substances mentioned. As a rule, one group, such as the chlorides, the carbonates or the sulphates, predominates in a given region. Alkali is often known as black and white. All the salts are themselves white but sodium carbonate dissolves organic matter from the soil and this produces a black color and hence is called black alkali. In a similar manner the nitrates produce a brown color. The carbonates and nitrates also cause a hard surface crust to be formed on the soil. This makes the passage of water difficult and interferes with the growth of crops. For this reason black alkali is more toxic than white.

Alkali causes injury to crops by preventing them from absorbing moisture and also by a direct corrosive action. Soils puddled by alkali are not favorable to crop growth. They do not allow a free movement of moisture and they are so hard that the plant is hindered from making its normal development. It is very difficult to place any very definite limit to toxicity on alkali soil since this is limited by several factors. The presence of abundant moisture and organic matter, as well as a desirable soil structure, helps to reduce harmful effects. Some salts are less harmful than others; e.g., sulphates, even if present in large quantities, cause little injury. In general, soils containing more than 0.5 per cent of soluble salts where the larger part is chlorides, carbonates, or nitrates, and one per cent where sulphates predominate, are unsuitable for crop production without reclamation.

Crops for Alkali Lands -- The crops to raise on alkali lands depend on the degree of salinity of the soil and the climatic factors suitable for these crops. Date palms are very resistant to alkali and are profitable where high temperature is available. Among ordinary farm crops the smaller grains can usually be raised with best advantage on alkali lands as they are fairly resistant. There is not a great difference in the resistance of barley, oats, rye, and wheat, but they do vary some in resistance according to the order mentioned. These crops are surer to succeed as a hay crop than for the grain. Root crops such as sugarbeets, while not resistant in the seedling stage, are fairly good crops. The legumes do not as a class do well in the presence of much alkali; however, sweet clover and alkali make fairly satisfactory crops for land of medium alkali content when a stand is once secured. Alfalfa and mangels, too, are resistant to some extent. Corn and potatoes are not successful on alkali lands.

The handling of alkali lands (14) -- There are two general ways in which alkali lands may be handled in order to avoid the injurious effects of soluble salts. The first is control and the second is eradication.

(1) Control - As mentioned above, alkali is most injurious if concentrated near the surface. If distributed evenly throughout the soil, relatively large quantities of alkali may be endured by plants. This condition may be secured by reducing evaporation and thereby preventing the rise of alkali. The intensive use of the soil mulch is, therefore, to be advocated in all irrigation operations. The land should be cropped constantly and proper use of irrigation water should be made. This method of control is the most economical, the cheapest and the one to be advocated on all occasions.

(2) Eradication - This has been mentioned under drainage.

RISE OF WATER TABLE AND WATERLOGGING

Water is lost by seepage from the fields due to excessive irrigation. Evil follows such excessive irrigations, especially if they succeed each other at short intervals. An irrigation applied to the soil before the plant roots have had time to remove the water added in the previous irrigation retards the growth of the crop and soaks down the soil to increase the standing water table. Consequently, in irrigated sections where such losses go on uninterruptedly, water rises slowly but steadily until it reaches near the surface and the land which was formerly productive becomes bogs and marshes in which the roots of all vegetation are drowned out.

The waterlogged lands of the irrigated regions form a very small fraction of the cultivable land at present, but there is a tendency to increase due to excessive seepage losses. It lies within the power of the irrigation farmers unitedly to check this area by wiser methods of conducting and using water.

DRAINAGE OF IRRIGATED LAND

Excessive irrigation and the occurrence of underground seepage has resulted in the waterlogging and in the serious accumulation of alkali salts in the surface soil. The permanent remedy to relieve land from excess of water and alkali is drainage. Three general methods of drainage are employed: (1) open ditches, (2) under drains, (3) pumping for drainage.

(1) Open Ditches - These are most satisfactory where the volume of water to be removed is very large. The general drainage of a region is usually carried in open ditches and these are used where the land is exceedingly flat. There are many objections to open ditches as they waste a considerable area of land in the channel and on the banks and interfere with free tillage operations. The cost of maintenance of a system of open ditches is heavy because

of erosion, the accumulation of silt, and the growth of weeds, all of which make frequent repairs necessary.

(2) Under drains - When properly constructed these are more permanent and cost less for maintenance than do open ditches. They do not interfere with surface operations. The better grade gives them a relatively larger carrying capacity than open ditches have and their greater depth below the surface permits much higher efficiency in the removal of excessive moisture from the root zone. Many methods and materials are being employed for under drains; the modern under drainage is accomplished by means of short sections of pipe of burned clay which are placed in the ground sufficiently deep to lower the water table in the subsoil to the desired depth. They are given an accurate grade and this, coupled with the smooth hard channel which is not subject to erosion, makes them a very efficient as well as a very permanent means of land drainage at relatively small cost. If they are well installed and of good material they continue to operate for centuries with very little attention.

(3) Drainage by pumping - This method of drainage promises, under favorable conditions, to be more successful than any other previously undertaken, and the apparent ease with which these pumps lower the water table has led western engineers to take an unusual interest in it. The high first cost of efficient tile or open drainage for alkali lands, together with the frequent necessity for additional expenditures in removing alkali from the surface of the soil after the lowering of the water table, has resulted in rather meager attempts at drainage for this type of land in California.

It is better, though difficult in practice, to prevent land from being waterlogged than to reclaim it after it has reached that stage. The main difficulty in this respect lies in the refusal of those concerned to admit that all lands irrigated from gravity systems are potentially subject to drainage difficulties.

It has long been recognized that in irrigated areas where the water supply is obtained by pumping from underground sources within the area irrigated the drainage problem is reduced to a minimum. Continued pumping in such cases has frequently resulted in a water table reach to such an extent that pumps have been lowered.

Drainage is accomplished by lowering the water table below the point where it can either directly or indirectly cause damage to growing crops and this can be done very effectively by pumping. The conditions necessary for successful drainage by pumping are: (1) there must be a direct connection between the ground water table near the surface and the deeper lying pervious water bearing strata from which the water is pumped. In other words, the water table as first encountered must not be artificial and have a layer of dry or impervious material between it and the normal ground water. (2) The underlying water bearing strata must be porous enough to give up their water freely under pumping. (3) There must be sufficient water pumped from the lower strata to cause that which is near the surface to move downward by gravity to replace that which has been pumped. The general effect on the water table should be the same whether the water is pumped from the bottom of the reservoir or taken from near the top by means of tile or open drains.

Effect of Pumping -- A particularly interesting example has occurred in San Bernardino County, California (38) where a large acreage operated by the American Beet Sugar Company was wet and alkaline. In places during the winter months water stood on the land and a few permanent swamps provided duck hunting sites. Because of this condition beet planting was delayed with the result that inferior crops were produced. This area was tile drained, the tiles having an average depth of 6 feet and an average spacing of 660 feet. As a result of these drains the water table was lowered, the ponds disappeared, and crop returns were enhanced. During the past few years this land has become more thickly settled and more intensively farmed, the water being pumped from wells on the property. These wells have so lowered the water table that the tile now lies above the level of the ground water and has ceased to flow. Drainage is no longer considered necessary and the pumps raise the water from about 30 feet below the surface.

Use of drainage water - When drainage is secured by tile or open ditches the water is usually not considered valuable and is allowed to waste into the rivers. With pumping, however, there is a tendency to put as much of this water to beneficial use as possible. This is undoubtedly due to two factors; first, that it is usually in a more convenient location and more readily diverted to land needing irrigation, and second, that putting the water to beneficial use offers a means of reducing the operation cost.

Organization - Pumping for drainage, or in fact drainage of irrigated lands in general, is a problem the solution of which can seldom be undertaken by the individual farmer.

Drainage is a matter which interests not only the individual who is unfortunate enough to have wet or alkali land, but the whole community in which he lives and, therefore, the community should undertake the solution of the problem. The individual farmer can seldom solve his drainage problem without assistance. The necessary construction is costly, particularly with regard to an outlet, and often the drainage of an individual farm, unless it is very large, will not justify the expense.

SUMMARY

Factors affecting the economic use of water are:

1. Soil texture affects the irrigation requirement. Coarse textured soils, or those with gravelly substrata, should have a distribution system that will permit or supply comparatively light and frequent applications which can be retained in the soil without percolation loss.

2. The kind of crop affects the amoung of water required. Alfalfa, for instance, requires relatively large amounts of water, grains medium amounts, and cultivated crops, like potatoes, still less.

(3) Soil fertility is one of the most important factors affecting irrigation requirements. Where there is a good supply of plant food, the plant requires comparatively less amounts of water to produce dry matter. In manuring and fertilizer experiments the total irrigation water has been saved from one-fourth to one-half.

4. The time of irrigation affects greatly the efficiency of the water applied, since irrigation, like cultivation, is worth more when applied just at the right time. By applying water at the proper time crop yields have been considerably increased.

5. The amount applied at each irrigation will affect the economical use of water or irrigation requirement. If the amount applied is in excess of the capacity of the soil strata within reach of the roots to retain it, deep percolation loss is sure to result.

6. The frequency of irrigation is related to the time and amount for each irrigation. Irrigation should only be applied when the moisture content drops to near the wilting point for the particular soil, and in sufficient amount to fill it up to the maximum capillary capacity.

7. The method of applying water affects the water requirement. The head and length of run should be such that the plot irrigated can be covered by the time the irrigation has wet up the root zone of the crops. A high head forces over the land rapidly and is necessary in flood irrigation or in irrigating loose soils. The longer length of run gives more time for soaking during irrigation on the heavier textured soils. Longer runs can be used on more sloping land and shorter runs with higher heads should be used on the flatter lands in order to cover the land without waste.

8. It is important for the irrigation farmer to have a moderate proportion of cultivated crops as these permit intertillage, kill weeds and control evaporation from the soil. This cultivation should be given promptly to be most effective and as soon after irrigation as the soil is dry enough to crumble and form a mulch.

9. Crop rotations - it is very important for the irrigation farmer to practice a careful system of rotation as in irrigated land it is entirely feasible to build up and keep the soil in a higher state of fertility.

Duty can be raised and water requirement can be greatly reduced in irrigation farming by practicing a good rotation, including legume crops, by using good varieties, by maintaining a good state of fertility and tilth, by irrigating at just the right time in the proper amount, and by practicing good general farm methods.

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