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Irrigation Requirement of Arable Oregon Soils

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FOREWORD

THE irrigation requirement, or duty of water, is perhaps the broadest problem with which irrigationists have to deal. Information is needed if the highest productive values are to be reached and the greatest yield of high-quality crops is to be maintained. The amount of water provided affects estimates and final costs, determines the area that it is possible to irrigate, and has its effect upon the security of investments in agriculture.

During the past three decades the Oregon Agricultural Experiment Station soils department has given special attention to the water requirement of crop plants and the irrigation requirement of major irrigated and irrigable soil types of the state.

With the cooperation of the Umatilla Branch Station at Hermiston the strip-border method of irrigation was adapted to sandy loam and other Oregon soil conditions. This practice, together with rotation in use with larger "irrigating heads," almost cut in two the water use on the Hermiston Project. The economic irrigation requirement of pear orchards has been developed in cooperative work with the Medford Branch Station. Experiments initiated in 1915 worked out the irrigation requirement for wild meadow land in southeastern Oregon. When these studies began, the water cost or irrigation requirement of grasses was unknown. These studies led to experimental well irrigation at the Harney Branch Station and the use of ground water for irrigation there. The soils department has cooperated with the Water Resources Division of the

U. S. Geological Survey in the study of ground water and irrigation requirements in the Willamette Valley, in the Walla Walla and the Harney Basins, and the Wasco Area.

Western Oregon has led the country in adaptation of the sprinkler method for supplemental irrigation for intensive crops. A 4-year study of irrigation efficiency has been made and the results used in streamlining pumping plants and distribution systems. Irrigation experiments in western Oregon started 32 years ago. They have proved the value of irrigation here and have led to Extension work in the development of some 45,000 acres of irrigated land.

Existing data, including contributions made in cooperation with the Branch Stations, are summarized herein. As yet, the data are incomplete and the need for further studies is indicated. Completion of fundamental irrigation requirement data is essential for economic development of our basic water resources and necessary for the development of a permanently profitable system of agriculture under irrigation.

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INTRODUCTION

INFORMATION as to the quantity of water required for irrigation is of great value in connection with many irrigation problems. Without such information no irrigation project, from the 5-acre pasture on a Willamette Valley farm to the several-million-dollar irrigation project involving huge dams and long canals in eastern Oregon, can be intelligently planned. Duty-of-water data are required by the state engineer and the courts in adjudicating the surface waters of the state and in distributing those waters after such adjudications have been made. Similar information will be necessary, moreover, for the proper administration of the ground waters of the state. The required capacity of irrigation reservoirs, canals, and laterals can only be determined by the use of such data. The economic feasibility of all irrigation projects is dependent upon the duty of water as well as value and quality of crops. A reasonable amount of water in accord with the requirement for good yields with suitable systems of cropping should be provided for each important soil type or group rather than one flat rate for a great valley or project. It is better economy to provide only a moderate allowance of water with structures of fair capacity rather than a liberal supply at greater expense and with the danger of additional drainage assessments later on.

In this publication an attempt has been made to present the pertinent data on duty of water obtained by the Oregon Agricultural Experiment Station and cooperating agencies during the past 30 years. In order that these data may be properly interpreted, definitions are given for some of the important terms; duty-of-water studies are described and their values discussed. The factors affecting net and gross duty are also listed and considered before the data are presented.

* The investigations in part have been carried on cooperatively by the Soils Department, Oregon Agricultural Experiment Station, the Division of Irrigation, U. S. Bureau of Agricultural Engineering and its predecessors, and other State and Federal agencies. The writers are indebted to Superintendents H. K. Dean and Obil Shattuck for cooperating in obtaining data and in reading the manuscript for this report. They are also indebted to Medford Branch Experiment Station for a summary of data obtained there through the cooperation of Arch Work and W. A. Aldrich.

DEFINITIONS

The term DUTY OF WATER is used to mean the quantity of water required to irrigate a certain area of land. Ordinarily the duty of water is stated as the depth of water in inches or in feet required per season for irrigation. Thus we may speak of a duty of water of 30 inches or of 2.5 feet. Occasionally, however, the area of land that may be irrigated with a stream of a certain size is stated, as 80 acres per cubic foot per second of water. It is from this usage that a *high duty* has come to mean a relatively small use of water while a *low duty* indicates the use of relatively large quantities of water.

NET DUTY OR FARM DUTY indicates the measured quantity of water that should be delivered to the farm for the irrigation of the land on that farm.

GROSS DUTY OR DIVERSION DUTY refers to the quantity of water that should be diverted from the stream or reservoir.

Obviously a field may be irrigated with too little water or with too much water, carefully or carelessly, and the duty of water will vary with the conditions. Under any particular set of conditions, however, there is an ECONOMIC DUTY OF WATER.

The LAW OF DIMINISHING INCREMENTS comes into play to reduce the increase as the maximum yield is approached. Other factors limit crop yields so that smaller and smaller increases in crop per unit increase of water are realized.

Depending on the conditions, the economic duty of water may be considered as that resulting in the (1) maximum yield per acre, (2) maximum yield per acre-foot of water, (3) maximum net profit per acre of land, (4) maximum net profit per acre-foot of water, or (5) maximum net profit per man. From the point of view of the greatest utilization of natural resources one of the first criteria, depending on whether land or water is the limiting factor, provides the proper standard (measure). From the point of view of the economic return to the farmer the third or fourth criterion, again depending on the relative abundance of his holding of land or water, should control. Since most farm units are fixed and limited either by land or water supply, the fifth criterion will agree, in general, with either the third or fourth, and maximum profit per acre or per acre-foot may be the best measure of economic duty. Ordinarily this will be somewhere between the quantity required to produce the maximum crop per acre-foot of water and that required to produce the maximum crop per acre of land.

Even under the best irrigation practice, some water will be allowed to return to the natural channels by surface waste and some will be allowed to reach the ground water and return to natural channels by underground movement.

The term CONSUMPTIVE USE OF WATER is used to cover the quantity of water transpired by crops and evaporated from the surface of the soil. Ordinarily the consumptive use is given in terms of depth of water per season.

Another method of stating the use of water by crops is in terms of the weight of the crop produced. The terms WATER COST OF DRY MATTER, ABSOLUTE DUTY, WATER REQUIREMENT, and EVAPO-TRANSPIRATION RATIO are used to refer to the quantity of water transpired by the crop and evaporated from the soil of the cropped area in the production of one unit of dry crop. Unavoidable losses by deep percolation or subbing are included in most studies.

The term duty of water is used in the adjudication and administration of natural streams and in the design and operation of irrigation systems. A closely related term is the IRRIGATION WATER REQUIREMENT, which may be defined as the quantity of irrigation water required to produce normal crops, as found by experimental methods and excluding all avoidable waste.

HIGHEST PROBABLE DUTY OF CROP-PRODUCING POWER OF WATER based on the water cost per pound dry matter, is used to refer to the least probable amount required by plants from soil, rain, and irrigation water for most profitable yields under modern methods of farming as determined by several years of experiments. Where rain and soil water are practically negligible in quantity the figure should indicate the least probable amount of irrigation per unit produced within reasonable limits. If 6 inches is required per ton then 24 inches is highest probable duty for a 4-ton crop.

METHODS OF NET DUTY OF WATER STUDIES

Use records. The earliest and most common duty of water data are simply records of water delivered to individual farms. A vast mass of such data is available in the records of the various water masters, the state engineer, the various irrigation districts, and the U. S. Bureau of Reclamation projects. Such data give the best information as to the actual quantities of water used by farmers in the different sections of the state. Study of such data indicates, however, that, in the main, they are more closely tied in to the quantities of water available for irrigation than to the quantities required for the economical production of crops.

Experience has shown that, where use records were made without soil-moisture control, the results are of doubtful validity. Where such experiments were carried on with soil-moisture control, the records show how efficiently irrigation water was used under a particular set of conditions. Such experiments, however, did not necessarily indicate whether irrigation water was applied at those times and in those quantities that would result in the best use of water.

Water variation trials. The next type of study consisted of varying either the time or the quantity of irrigation applications in an attempt to determine what total quantity of water in each season would give the best yield. The quantities of water used and the resulting yields were determined. Ordinarily such studies were carried on by varying the seasonal total by using an equal number or an equal size of individual applications and varying the opposite factor. Experiments including variations in both time and amount permitted the exercise of judgment to a greater extent and were an advance over those in which seasonal totals only were varied. There was still danger, however, that either intervals between applications or the quantity of single applications might be too great or too small.

Trials with soil-moisture control. The next logical step was the use of soil-moisture studies in connection with time and amount experiments. These enabled the experimenter to be sure that applications were of the right size for efficient use of the irrigation water but did not enable him to tell whether he was applying water as it was needed by the crop. Such experiments were initiated with clover and potatoes at Corvallis in 1909. Studies of effect of irrigation on crop quality were included.

In all these experiments the final yields of crops from the different fields or plots were determined, and in many of them such observations of crop response to moisture conditions as could be seen easily in the field were made.

Trials with soil-moisture and crop-response control. This led to the most modern type of duty-of-water studies in which both the time and amount of water applied are governed by determinations of the moisture content of the soil and the reaction of the crop to the moisture content is studied throughout the season by measurements of rate of growth of fruit, stems, etc. Even such experiments must be carried on over a period of several years in order that the effect of climatic variations, which are very little understood, may be determined. By means of such experiments the true water requirement of crops may be determined. It is then necessary to add the unavoidable losses and relate these requirements to the different economic factors in order to arrive at the true economic duty of water. It should not be assumed that all duty-of-water studies at any period have been of the same type. Some of the early Oregon work included soil-moisture studies, and studies of all degrees of refinement are still being carried on at various locations.

FACTORS AFFECTING THE NET DUTY

Many factors affect the net duty of water and most of them are so interrelated that it is impossible to determine exactly what effect any individual factor may have. The more important of these factors are briefly discussed below.

Climate and altitude are so intimately related in Oregon that they may be considered as a single factor. Several elements of climate affect irrigation water requirements; namely, precipitation (amount and distribution), wind, relative humidity, per cent total possible sunshine and barometric pressure. Precipitation during the growing season is promptly utilized by crops, while that stored in the soil from winter rains and snows is available in the spring.

The evaporating power of the air during the growing season and the length of that period have marked effects on the transpiration of water by crops. Evaporation from a free water surface gives a valuable measure of evaporating power of the atmosphere.

Soil texture, structure, and depth affect the irrigation water requirement in several ways. Perhaps most important is the effect of soil texture. While it is probable that the actual consumptive use of water by crops is not affected markedly directly by the texture of the soil, yet practical irrigation cannot be carried on as efficiently on a very coarse textured soil as it can on one of medium texture. The much more frequent irrigation required will necessarily result in larger losses by evaporation directly from the wet soil surface if not from the irrigation water itself during the process of application, even when water can be applied by sprinkling or other methods so uniformly and in such small applications that no water is lost by deep percolation.

To a somewhat smaller extent but in the same way, the structure of the soil may affect the water requirement.

The depth of soil also affects the water requirement by radically changing the required frequency of irrigations. Texture, structure, and depth affect useful water capacities.

It is important to know the wilting point, field capacity or excess point, volume weight, and infiltration rate in estimating irrigation water requirement, and irrigation-application efficiency for a soil. A high water-table may reduce the irrigation water requirement, because crops may obtain part of this water from the capillary fringe.

The topography influences the irrigation water requirement because it is impossible to irrigate rolling land without some surface waste unless that land has an unusually permeable surface.

The preparation of the land for irrigation has a very marked effect on the irrigation-water requirement, because it is impossible to apply water uniformly over improperly prepared fields. If satisfactory crops are to be grown on the high spots of such fields, excessive water must be applied to the low spots, with resulting waste.

The distribution-ditch system of a farm has considerable influence on the irrigation-water requirement, since irrigation water cannot be effectively distributed over the fields from poorly located, ill shaped, weedy, or undersized ditches or without proper structures for controlling the water.

The method of irrigation will affect the irrigation-water requirements in that haphazard or unsuitable methods such as excessively long surface runs will result in double or triple irrigation of some spots and the missing of other spots.

The size of irrigating stream and length of run should be such that the plat irrigated can be covered by the time the irrigation has been sufficient to wet the root zone. A large stream forces rapidly over the land, and is necessary in flood irrigation or in irrigating loose soils. Longer runs can be used on more sloping land, and shorter runs with a larger stream should be used on the flatter lands in order to cover the land without waste. Use of the strip-border method of flooding could well be extended where surface irrigation is provided. With a small water supply and rolling or open-textured soil sprinklers placed equidistant and triangularly may save leveling labor and water with intensive crops.

Transpiration or evaporation from the plants is a major factor affecting irrigation-water requirement. It takes from 300 to 1,000 or more pounds of water to produce a pound of dry matter. More than a score of plant, soil, and atmospheric factors are known to affect transpiration. The appended outline presents these factors in condensed form.

Some control of transpiration can be accomplished by use of some crops of relatively low transpiration requirement, such as corn or potatoes, rather than too large a proportion of grass, for which the transpiration requirement is high. Good farming practices that result in a large yield of marketable dry matter an acre result in lower transpiration ratios.

The crop including kind, diversity, area, and yield, will affect the water requirement. Some crops, particularly forage crops and pasture, require more water than do the cultivated crops and orchards. Other things being equal, a heavy crop will require more water than a light crop. If the crops are diversified, the irrigation systems will more likely be adequate for economical irrigation, and in that way the irrigation water requirements will be affected.

The relation between costs of land, water, and production and crop values will affect the irrigation water requirement. Obviously if water is cheap and all other values are high, it will be more profitable to use large quantities of irrigation water. On the other hand, if water costs are high, and land and production costs and crop values are low, it will not be economically wise to use irrigation water extravagantly.

The fertility of the soil has a very marked effect on the water requirement per unit of crop, that is on the evapo-transpiration ratio. Any farm management practice, such as good cultivation, mulches, crop rotation, and use of commercial fertilizers or barnyard manure, which results in better crop growing conditions will ordinarily lower the evapo-transpiration ratio or increase dry-matter yield an acre or an acre-foot. However, the irrigation-water requirement per acre of land may not be markedly affected by difference in fertility.

The method of purchase and delivery of water will have an effect, since if water is purchased on the basis of a flat rate per acre of land, regardless of the quantity of water used, there will be no direct economic incentive for the irrigator to use water economically. On the other hand, if water is purchased on the basis of the quantity of water used, it will be directly in the financial interest of the irrigator to use that water economically. If water is delivered in uneconomical streams, as for instance where water is delivered on a continuous flow basis to small farms, there is a tendency for its uneconomic use and, therefore, an increase in the irrigation-water requirements.

The skill and economy of the irrigator are of very great importance in determining the irrigation-water requirement. Where irrigators are skilled and are interested in using water economically, the efficiency of irrigation is markedly higher than where they are unskilled men with no particular incentive to economical use of water.

The time and amount of individual applications of irrigation water greatly affect the total irrigation-water requirement, since water applied at a time when the soil is already filled to near its field capacity, or water applied so late in the season that the crops do not have an opportunity to utilize it before the end of the growing season, will be lost.

The quantity of soluble salts in the soil and irrigation water will affect the requirement since some water must be allowed to percolate through the soil to the ground water and thence out through deep underground drainage (natural or artificial) in order to prevent the accumulation of dangerous quantities of alkali. Crops require more moisture in the soil, moreover, if much alkali is present. Large quantities of water are required to leach excess salts from the soil during reclamation of alkali land after drainage.

ADDITIONAL FACTORS AFFECTING GROSS DUTY OF WATER

The length of the transmission and distribution channels is probably the most important factor affecting the loss of irrigation water between the diversion from reservoir or stream and the farmer's field. Where water is pumped directly from a stream onto the field irrigated, there may be no transmission loss and, therefore, the gross and net duties are identical. In other instances when ditches, sometimes scores of miles in length, are required to transmit the water, it is obvious that transmission losses will be large, regardless of the character of the soil or of the construction methods. In such cases evaporation alone may be a considerable factor.

Compactness of the irrigated area. Closely related to the length of distribution channels is the compactness of the irrigated area. An irrigation project that consists of a long, narrow area will necessarily have a long transmission canal as compared with the irrigated acreage, and therefore a higher loss.

The character of the soil and subsoil through which irrigation channels are constructed will have a large bearing on the transmission losses. If unlined earth canals are built through sandy or gravelly soil, the losses may be very great. On the other hand, open ditches in heavy clay soils may lose very little water.

The character of construction will have a great deal to do with transmission losses. Carefully constructed concrete lining may reduce losses by seepage almost to zero. On the other hand, the construction of canals or ditches by blasting through easily shattered rock may result in excessive transmission loss.

The method of delivery of irrigation water may affect the transmission losses. If a system of rotation between laterals is used, it is sometimes possible to decrease losses as compared with a continuous flow system in which water is allowed to flow in all laterals at all times.

The regularity of the water supply and of the demand for irrigation water may also affect the transmission losses and quantity required to prime or reprime the canals.

The skill of the operating force is an important factor. It is impossible to operate a large canal system and meet all requirements of irrigators without some waste, but the direct waste from canal systems may be reduced to a comparatively small percentage if the operating force is skilled and if sufficient measuring devices are available and proper hydrographic studies are made.

The capacity of canals and laterals must be large enough to take care of the peak seasonal demands. If the irrigation season is short, this peak will be large as compared with the total quantity of water.

In determining the gross duty of water and canal capacity, the proportion of nonirrigated land (road and railroad rights of way, seeped or fallow land, etc.) included in the gross area will need to be taken into account.

A water table above the bed of the channels will affect the gross duty by reducing the seepage losses from canals and laterals.

INTERPRETATION OF DATA

In this study the data have been grouped according to the six watersheds used by the National Resources Board (Figure 7), namely:

1. Oregon-Pacific Basin, including the Umpqua, Rogue, or Southern Oregon area with the coast region (below 1,500 feet elevation)
2. Willamette-Columbia Basins west of the Cascades (500 to 3,600 feet elevation)
3. Mid-Columbia Basin (50 to 4,000 feet elevation)
4. Snake River Basin (1,500 to 3,600 feet elevation)
5. Klamath, Lost River, and Goose Lake Basins (3,600 to 5,000 feet elevation)
6. Great Basin (3,600 to 5,000 feet or more elevation)

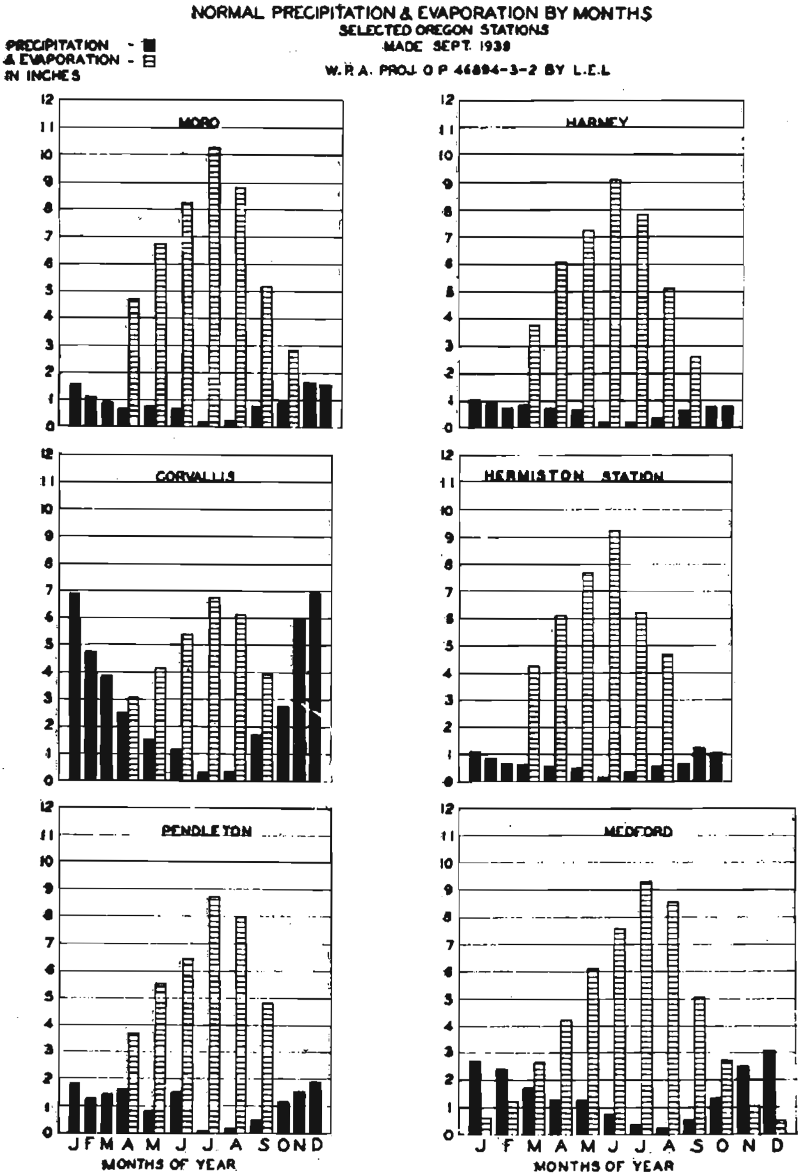

Figure 1. Normal precipitation and evaporation by months, selected Oregon stations.

Precipitation and evaporation for selected stations will be found in Figure 1 and the surface water by drainage basins in Table 1.

Western Oregon climate is characterized as coastal, while east of the Cascade Mountains it is continental. In general, precipitation decreases and aridity increases from northwestern to southeastern Oregon. There are droughty periods during the dry summer months, even in northwestern Oregon, while little effective summer rainfall occurs in some irrigated sections of southeastern Oregon.

Table 1. OREGON DRAINAGE BASINS—WATER RESOURCES

Basin	Area	Annual precipitation: Agricultural lands	Annual precipitation: Extremes*	Mean annual runoff†	Reservoir capacity	Irrigated area (1936)
	Square miles	*Inches*	*Inches*	*Inches*	*Acre-feet*	*Acres*
Oregon Pacific (including southern Oregon)	17,900	20–100	16–130	18–100	45,382	71,034
Willamette, lower Columbia (west of Cascades)	13,200	35–70	34–125	24–67	....	20,000
Mid-Columbia, Hood River, Deschutes Basin, John Day-Umatilla	23,700	8–36	8–43	3–33	311,680	227,674
Snake River Basin	18,300	8–30	7–44	2–27	1,127,720	376,098
Klamath, Goose Lake	6,500	7.5–23	7–54	3.5–7	748,960	131,412
Great Basin	17,300	7–16	7–16	2–6	21,560	218,035
Total	....	....	....	....	2,255,302	1,044,253

* U. S. weather data. Precipitation stations are not necessarily at wettest points.
† U. S. Geological Survey data by George Canfield.

USEFUL WATER CAPACITY OF IRRIGABLE SOILS

The useful soil-moisture range lies between what is removed by gravity and what is held against extraction by plant roots. The useful water capacity of a soil profile ranges from the wilting point to the moisture equivalent or excess point for the root zone. The wilting point may be determined by growing sunflowers in the plant house until permanent wilting occurs. The moisture equivalent is determined by centrifuging saturated soil samples at a

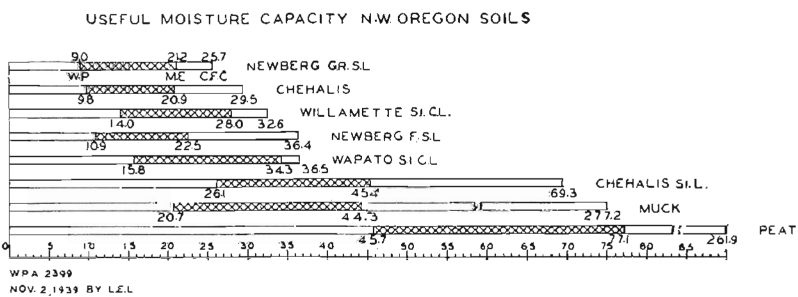

Figure 2. Useful moisture capacity of northwestern Oregon soils. (The useful capacity is shown by the hatched portion of the bars between the wilting point (W.P.) and the moisture equivalent (M.E.). The capillary field capacity (C.F.C.) or capillary capacity is also shown. All data are given in percentage of dry weight.)

centrifugal force of 1,000 times gravity. These points may be checked by field moisture before needed irrigation and 48 hours after irrigation. The useful range is shown for major soil types of western Oregon in Figures 2 and 3. The data given are the averages for the first 2 feet. Capillary field capacity (CFC) (Figure 2) is the moisture content of a 1-foot soil core when saturated and then drained to constant weight in a saturated atmosphere.

The moisture equivalent for many soils from eastern Oregon drainage basins is given in Table 2 in percentage of dry weight. Since the wilting point is approximately one-half the moisture equivalent in per cent the useful moisture range can be estimated from the single value.

The dry weight per cubic foot (Table 2) will be useful in conversion of useful moisture from per cent to inches depth per cubic foot.

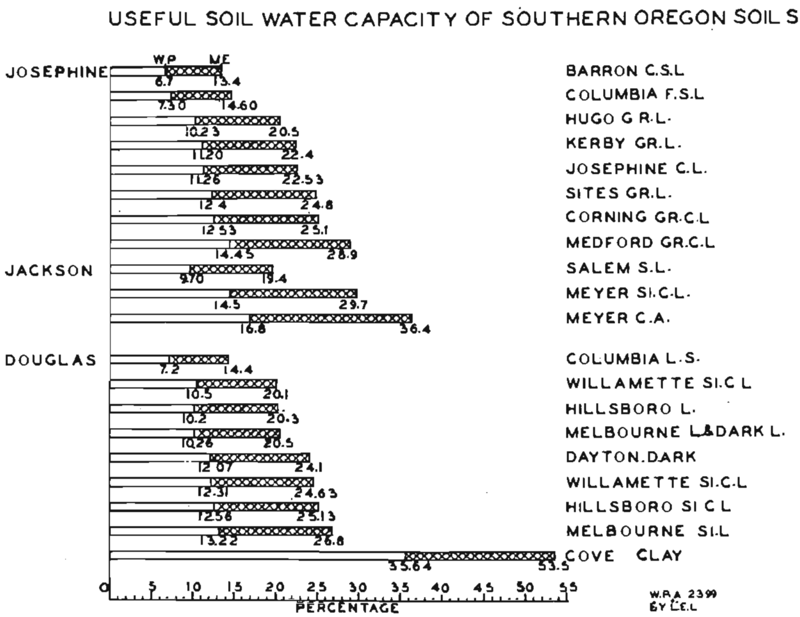

Figure 3. Useful moisture capacity of southern Oregon soils. (The useful capacity is shown by the hatched portion of the bars between the wilting point (W.P.) and the moisture equivalent (M.E.). All data are given in percentage of dry weight.)

CONVERSION OF USEFUL SOIL MOISTURE FROM PER CENT TO INCHES

Since the useful soil moisture is expressed in per cent by dry weight, the pounds useful water can be obtained by multiplying the per cent useful moisture by the dry weight of a soil in pounds (Table 2). Since an inch-foot of water (the equivalent of a board foot volume) weighs 5.2 pounds, the pounds useful water divided by 5.2 gives the storage capacity for useful water in inches depth per foot of soil depth.

In general, useful moisture capacity of soils is of the order of 1 inch per foot depth for fine sand, 1½ inches for sandy loam, and 2 inches for silty clay loam. Soils of coarse texture or limited depth require more frequent irrigations; each of which incurs some water losses.

The aim in irrigation should be to add water as the moisture content falls toward the wilting point, in just sufficient amount to raise the moisture content throughout the root zone to the excess point or moisture-equivalent point, without waste. Aim to get the highest possible efficiency out of every inch of rain or irrigation water made available to the crop.

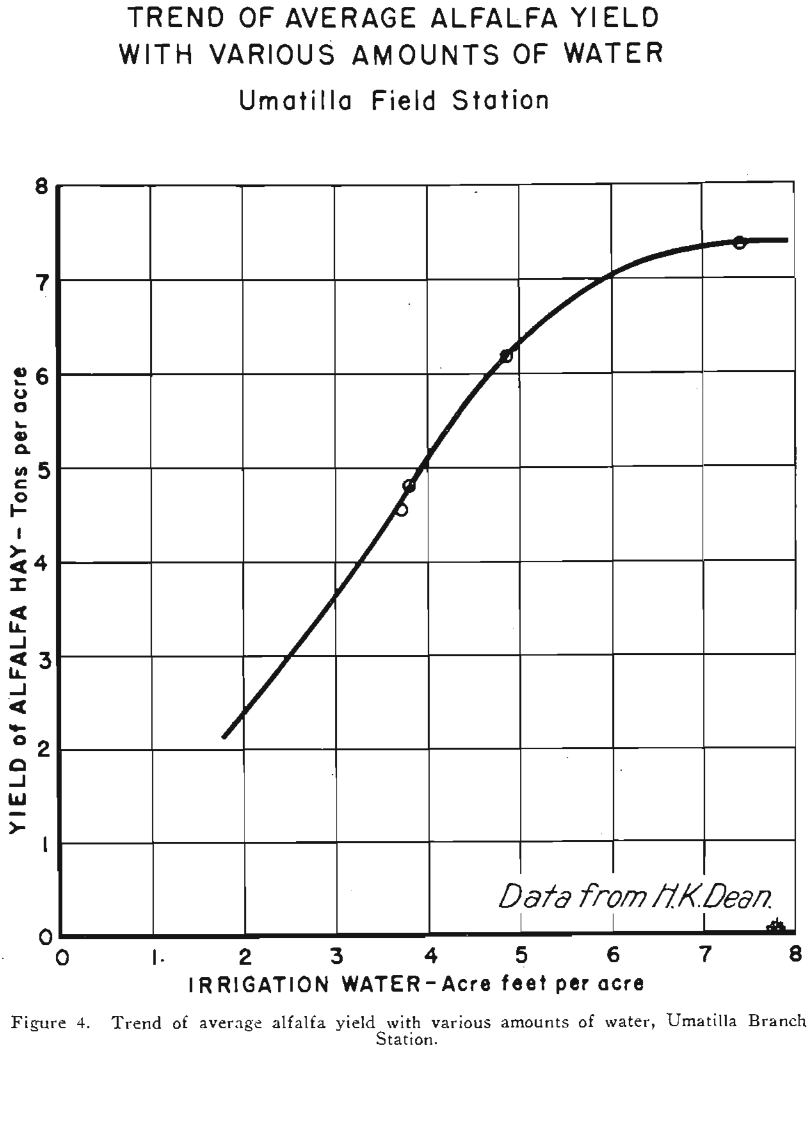

Figure 4. Trend of average alfalfa yield with various amounts of water, Umatilla Branch Station.

Table 2. MOISTURE EQUIVALENT AND WEIGHT PER CUBIC FOOT OF EASTERN OREGON SOILS

Soil type or class	Source of sample	Depth	Moisture equivalent	Weight per cubic foot
		Inches	*Per cent*	*Pounds*
Mid-Columbia Basin				
Winchester coarse sand	Umatilla County	8–16	4.5	......
Winchester sand	Umatilla County	0–22	5.5	......
Rupert sand	Umatilla County	0–8	7.3	100
Rupert loamy sand	3¼ miles north of Hermiston	0–8	8.2	......
Ephrata fine sand	3¾ miles northeast of Stanfield	0–26	8.6	......
Ephrata sand	Umatilla County	0–8	9.0	95
Ephrata loamy sand	Umatilla County	0–21	9.8	105*
Stanfield fine sand	Umatilla County	0–23	12.4	......
Ritzville loamy fine sand	Umatilla County	0–19	13.9	......
Ephrata fine sandy loam	2½ miles northeast of Stanfield	0–8	14.2	......
Onyx loamy fine sand	Umatilla County	0–8	15.5	......
Medium coarse sandy loam	1½ miles west of Center, Oregon Canal, southeast of Bend	0–14	16.7	......
Ritzville fine sandy loam	Umatilla County	0–8	17.4	......
Stanfield very fine sandy loam	7½ miles west and ½ mile south of Echo, Oregon	0–23	17.6	......
Ritzville very fine sandy loam	Umatilla County	0–23	18.2	88*
Deschutes sandy loam	Mr. Baker Plats, Tumalo	0–20	19.0	......
Walla Walla very fine sandy loam	Umatilla County	0–21	19.1	......
Medium sandy loam	½ mile south of P.O., Powell Butte	0–16	19.1	70
Milton stony gravelly loam	1½ miles northwest of Freewater	0–26	19.1	120
Very fine sandy loam	¼ mile west of Culver, Oregon	0–14	20.1	......
Fine sandy loam	Metolius-Dean Farm	0–14	20.3	......
Deschutes sandy loam	Fleck Potato Plats, Redmond	0–18	20.8	......
Walla Walla silt loam	Umatilla County	8–21	21.1	......
Ritzville silt loam	Umatilla County	0–19	21.4	......
Milton gravelly loam	¼ mile southeast of Umapine	0–24	22.8	......
Walla Walla silt loam (dark)	Umatilla County	0–24	23.5	......
Umapine fine sandy loam	Wheeler Plots, 4 miles west of Freewater	0–30	24.6	......
Adams very fine sandy loam	¼ mile northeast of Saxe	0–15	24.7	......
Fine sandy loam (gritty)	Agency Plain, 1 mile north of Madras Grade	0–27	25.5	......
Adams silt loam	1½ miles southwest of Athena	0–16	26.1	......
Pilot Rock silt loam	Section 33, T. 1 N., R. 32 E.	0–20	26.4	......
Caldwell silt loam (heavy)	¼ mile south of Athena	0–8	27.0	......
Onyx loam	Umatilla County	0–14	28.3	......
Underwood silt loam	Umatilla County	0–21	28.6	......
Buttercreek silt loam	Umatilla County	0–20	29.6	67*
Waha silty clay loam	Near Center Section 12, T. 2 N., R. 34 E.	0–21	30.1	......
Basket Mountain loam	5½ miles south and 3 miles east of Weston	0–8	33.1	......
Meadows silt loam	Umatilla County	0–24	37.5	......
Helmer very fine sandy loam	2 miles southeast Basket Mountain School	0–26	40.1	......
Meadows silty clay loam	3½ miles west and 1 mile north of Umapine	0–20	44.6	......

* From H. K. Dean.

Table 2. MOISTURE EQUIVALENT AND WEIGHT PER CUBIC FOOT OF EASTERN OREGON SOILS—*Continued*

Soil type or class	Source of sample	Depth	Moisture equivalent	Weight per cubic foot
		Inches	*Per cent*	*Pounds*
Snake River Basin				
Loam	J. Ridder Vale Bench	0–22	25.2	......
Fine sandy loam	K. S. and D. Farm, Ontario, Oregon	0–24	11.0	......
Loam	F. Weaver, Ontario	0–20	23.2	......
Fine sandy loam	West of O. T. Wells, Dead Ox Flat	0–24	12.8	......
Clay loam	6 miles northwest Ontario	0–18	29.9	......
Langrell gravelly loam	Baker County	0–21	19.2	......
Baker loam	Near southeast corner Sec. 11, T. 9 S., R. 40 E.	0–15	19.9	63
Very fine sandy loam	Jacobson Farm, Vale, Oregon	0–24	21.1	......
Very fine sandy loam	8 miles south of Ontario, Verne Butler Plots	0–21	21.2	......
Very fine sandy loam	3 miles north of Vale, Willow Creek Farm	0–18	22.4	......
Langrell stony gravelly loam	Baker County	0–24	22.6	......
Fine sandy loam	Vale Bench Sage Land 3 miles west of Vale	0–20	22.7	......
Ladd loam	Baker County	0–22	24.8	......
Applegate clay loam	Baker County	0–16	25.0	......
Silty loam	¼ mile south Turner Bros. Dead Ox Flats	0–18	27.0	73
Langrell loam	Baker County	0–29	27.0	......
Melhorn stony clay loam	Baker County	0–11	27.5	......
Baldock silt loam	¼ mile west of southeast corner Sec. 10, T. 9 S., R. 40 E.	0–30	28.5	73
Jeldness clay	Baker County	0–24	29.2	......
Melhorn clay loam	Baker County	0–22	29.3	......
Halfway clay loam	Baker County	0–19	29.3	......
Jeldness silt loam	Baker County	0–21	30.7	......
Magpie silt loam	Baker County	0–18	31.1	......
Malheur heavy loam	Vale Alkali Plats	0–20	31.4	......
Very fine sandy loam	Bench south of Pheasant Farm (Sageland)	0–28	31.6	......
Hibbard silt loam	Near Center Sec. 10, T. 9 S., R. 39 E.	0–24	31.7	80
Underwood loam	Baker County	1½–22	31.9	......
Halfway silt loam	Baker County	0–24	32.3	......
Virtue loam	Baker County	0–21	32.5	......
Sumpter loam	Sec. 7, T. 9 S., R. 40 E. (⅛ mile east Center)	0–30	32.7	67
Clay loam	1939 Fertilizer Plots, south of Malheur Butte	0–24	33.4	......
Baldock fine sandy loam	Near northwest corner Sec. 15, T. 8 S., R 39 E.	0–25	33.7	.....
Halfway clay	Baker County	0–22	35.2	......
Haines silt loam	Near west ¼ corner Sec. 19, T. 8 S., R. 40 E.	0–24	35.9	68
Baldock silty clay loam	Baker County	0–25	37.2	......
Wingville silt loam	¼ mile south center Sec. 34, T. 8 S., R. 39 E.	0–30	38.9	56
Goose Lake Basin				
Sandy loam	E. ¼ corner Sec. 7, T. 40 S., R. 19 E.	0–24	14.8	84
Dark sandy loam	N.E. ¼ Sec. 14, T. 39 S., R. 19 E.	0–24	16.3	84
Dark sandy loam	N.E. ¼ Sec. 5, T. 40 S., R. 19 E.	0–24	17.4	84
Brown silt loam	N.E. ¼ S.E. ¼ Sec. 5, T. 40 S. R. 19 E. (Hansen's)	0–24	17.5	84

When water is not available for use throughout the crop season advantage should be taken of the full capacity of the soil for storage of water. This requires the application of water whenever it may be available, even if the soil is not approaching dryness, and in sufficiently large quantities completely to fill that storage capacity.

A typical yield-water curve (Figure 4) shows that the law of diminishing increments comes into play as larger amounts of water are added. The break in the curve where it flattens off is usually taken as the economic duty.

IRRIGATION REQUIREMENT OF THE COASTAL DRAINAGE BASIN, OREGON

In addition to use records of irrigation enterprises, especially in Rogue River Valley, duty-of-water experiments have been maintained for several years including several soils and crops. The greater part of the data have been made available in reports by C. I. Lewis and others (1912), Powers (1917), Aldrich and Work (1932), M. R. Lewis et al (1934), Fortier and Young (1933), and Work and Lewis (1934, 1936). The latter studies are being continued. The progress reports indicate the economic duty of water for pears on heavy-textured soils is approximately 21 inches in depth a season. Cultivated annuals seem to require 12 to 24 inches, the meadows from 18 to 30 inches. The weighted economic duty is estimated to be on the order of 21 to 24 inches. (See Table 3.)

Little experimental evidence is available as to water requirements of cranberry bogs or meadows near the coast. Use with moisture control on several Tillamook pastures in 1938 and 1939 averaged approximately 15 inches depth an acre (Table 4).

IRRIGATION REQUIREMENT OF WILLAMETTE VALLEY BASIN SOILS

Irrigation experiments were initiated in Willamette Valley floor in 1907 by Mr. A. P. Stover of the United States Office of Experiment Stations, partly in cooperation with the State Agricultural Experiment Station (1910). These experiments were extended by W. L. Powers in 1909 to include systematic soil moisture studies and water variation trials (1911, 1914). The trials have been maintained for 31 years on the main valley floor soils and progress reports have been issued in several bulletins (Powers 1910, 1928, 1932 and Powers and Johnston 1920 and 1922).

Water variation trials have been conducted for 12 years on the Chehalis loam of the second bottom land on the College East Farm with horticultural as well as field crops (Powers and Ruzek, 1932).

In 1911 some water variation trials on Sifton gravelly fine sandy loam near West Stayton and at various times other cooperative experiments have been conducted so that data are available for several soils and numerous field, orchard, and garden crops as to irrigation requirement.

Use of water on the dairy pastures at the College West Farm, Corvallis, 1918 to 1936, averaged 21.03 inches; and the area during the period increased from 11.25 to 59 acres, according to Dr. I. R. Jones.

During the past four seasons some two dozen cooperative farmers' fields have been used to study the efficiency of irrigation and the irrigation require-

Table 3. Annual Yields and Amounts of Water Applied Rogue River Valley

Year, soil type or class	Area irrigated	Irrigation water	Yield per acre	Yield per acre-inch	Water per pound dry matter
	Acres	*Inches*	*Tons*	*Tons*	*Pounds*
*Sugar beets**					
1916 Neal silty clay loam	0.109	2.0	28.39	14.196	....
	.109	10.1	37.34	3.690	....
	.109	14.5	36.17	2.495	....
Fine sandy loam	.125	6.0	11.20	1.886	909
	.125	10.5	12.00	1.143	1,046
	.125	26.5	12.40	.467	2,060
Corn			*Bushels*	*Bushels*	
Fine sandy loam	.125	1.9	43.6	22.90	787
	.125	3.4	43.2	12.70	890
	.125	5.8	55.5	9.56	879
Alfalfa†			*Tons*	*Tons*	
1920 Antelope clay adobe	.14	0	3.18	....	....
	.14	5.0	4.53	.906	....
	.14	12.0	5.09	.424	....
	.14	13.5	4.35	.322	....
	.14‡	12‡	3.39	.282	....
1921 Antelope clay adobe	.14	0	1.36	....	....
	.14	5.0	1.91	.383	....
	.14	10.0	2.22	.222	....
	.14	15.0	1.92	.128	....
	.14	10‡	2.13	.213	....
Bartlett Pears§			*Boxes*	*Boxes*	
1930 Meyer silty clay loam..	.33	6.1	480	79	....
	.33	9.5	516	54	....
	.33	11.0	437	40	....
	.33	13.4	637	48	....
1931 Meyer silty clay adobe	.33	5.4	481	89	....
	.33	7.2	452	63	....
	.33	9.5	480	50	....
	.33	11.4	518	45	....
Anjou Pears§					
1930 Meyer clay adobe	.25	4.7	282	60	....
	.25	5.8	249	43	....
	.25	7.7	355	46	....
	.25	14.2	425	30	....
1931 Meyer clay adobe	.25	4.2	106	25	....
	.25	6.8	176	26	....
	.25	9.8	221	23	....
	.25	19.3	286	15	....
1932 Meyer clay adobe§	.25	3.8	270	71	....
	.25	10.8	256	24	....
	.25	13.1	354	27	....
	.25	24.2	395	16	....
1932 Meyer clay adobe‖	.84	6.6	256	39	....
	.71	8.6	357	42	....
	1.00	11.0	429	39	....
	.95	19.2	499	26	....
1933 Meyer clay adobe	.84	7.4	119	16	....
	1.00	14.6	490	34	....
	.71	15.1	154	10	....
	1.00	16.7	406	24	....
	.95	25.6	616	24	....
1934 Meyer clay adobe	.84	11.4	150	13	....
	1.00	15.1	424	28	....
	.71	16.1	231	14	....
	1.00	16.9	357	21	....
	.95	22.4	570	25	....
1935 Meyer clay adobe	.84	7.1	322	45	....
	1.00	13.8	504	37	....
	1.00	15.6	413	26	....
	.71	16.6	284	17	....
	.95	19.0	382	20	....
1936 Meyer clay adobe	.84	8.0	231	29	....
	1.00	12.4	462	37	....
	1.00	16.3	539	33	....
	.71	18.8	564	30	....
	.95	21.0	651	31	....
1937 Meyer clay adobe	.84	11.8	294	25	....
	1.00	14.8	420	38	....
	.71	16.7	220	13	....
	1.00	16.8	486	29	....
	.95	18.8	304	16	....

* Data from Bulletin 140, Oregon Agricultural Experiment Station.
† Data from Bulletin 189, Oregon Agricultural Experiment Station.
‡ Ten tons of manure applied per acre.
§ Data from Bulletin 432, United States Department of Agriculture.
‖ Unpublished data from Medford Branch Experiment Station.

Table 4. WATER USE WITH SOIL MOISTURE CONTROL GRASS AND CLOVER PASTURE

Irrigation Efficiency Studies in the Tillamook Area, 1938-1939
Oregon Agricultural Experiment Station, Soils Department

Farm	Soil type	Irrigation season	Number of irrigations	Area irrigated	Irrigation stream	Depth of irrigation	Carrying capacity per acre*
		Month and day		*Acres*	*Gallons per minute*	*Inches*	*Cow months*
1938							
J. C. Edwards	Chehalis silty loam	5/26–9/27	9	40	134	15.5	8.8
R. McGinnis	Chehalis silty loam	6/4–8/27	6	20	90	15.5	8.8
J. Jenck	Chehalis silty loam	5/27–8/27	5	42	156	14.8	8.8
Chris Wyss	Salem Gr. silty loam	6/7–9/13	6	20	150	16.0	10.5
1939							
J. C. Edwards	Chehalis silty loam	6/2–9/23	7	35	112	14.0	12.0
R. McGinnis	Chehalis silty loam	5/22–8/29	3.5†	17	......	7.0	12.0
Chris Wyss	Salem Gr. silty loam	5/17–9/8	3.5	35	112	7.0	10.5

* Little or no supplemental feed was used.
† Rain interrupted fourth irrigation when one-half the usual amount was applied.

ment of more than a dozen valley soils and crops including methods of application (Table 5). Infiltration and soil-moisture tests to determine useful water capacity have been included. Table 5, in general, shows use with soil-moisture guidance and applied in amounts and at times needed. The irrigated area in

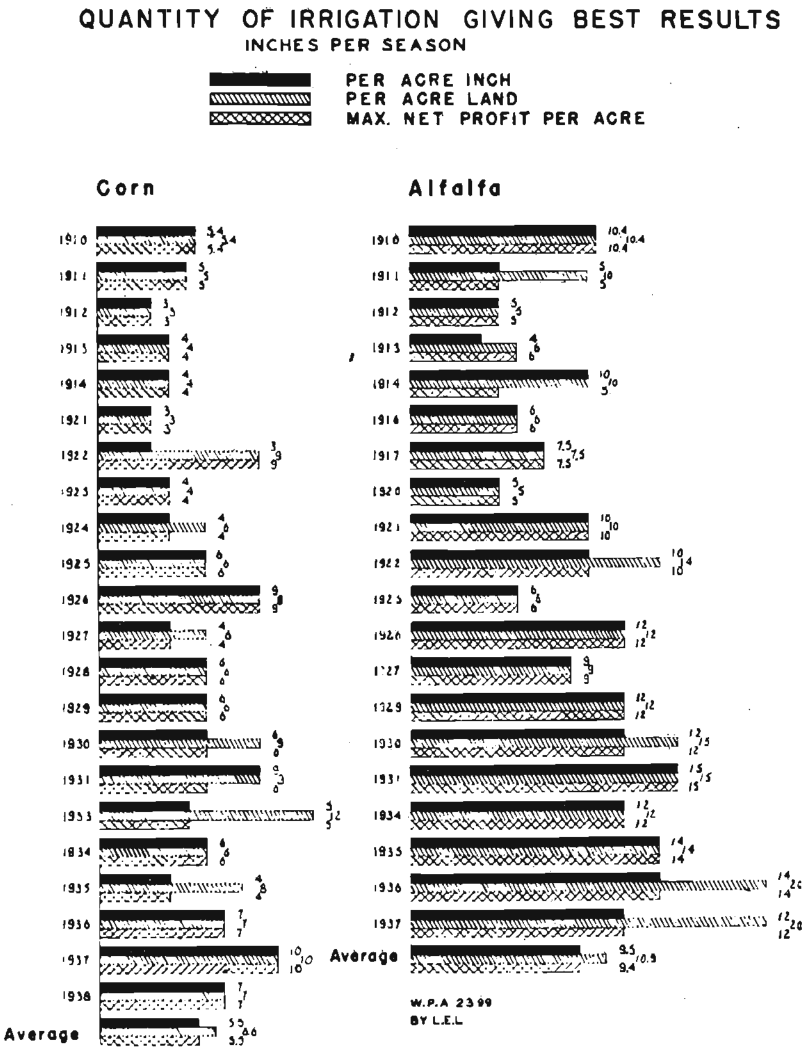

Figure 5. Quantity of irrigation giving best results. (Corn and alfalfa on Willamette silty clay loam at Corvallis, Oregon)
a. Maximum yield per inch water.
b. Maximum yield per acre land.
c. Maximum net profit per acre.

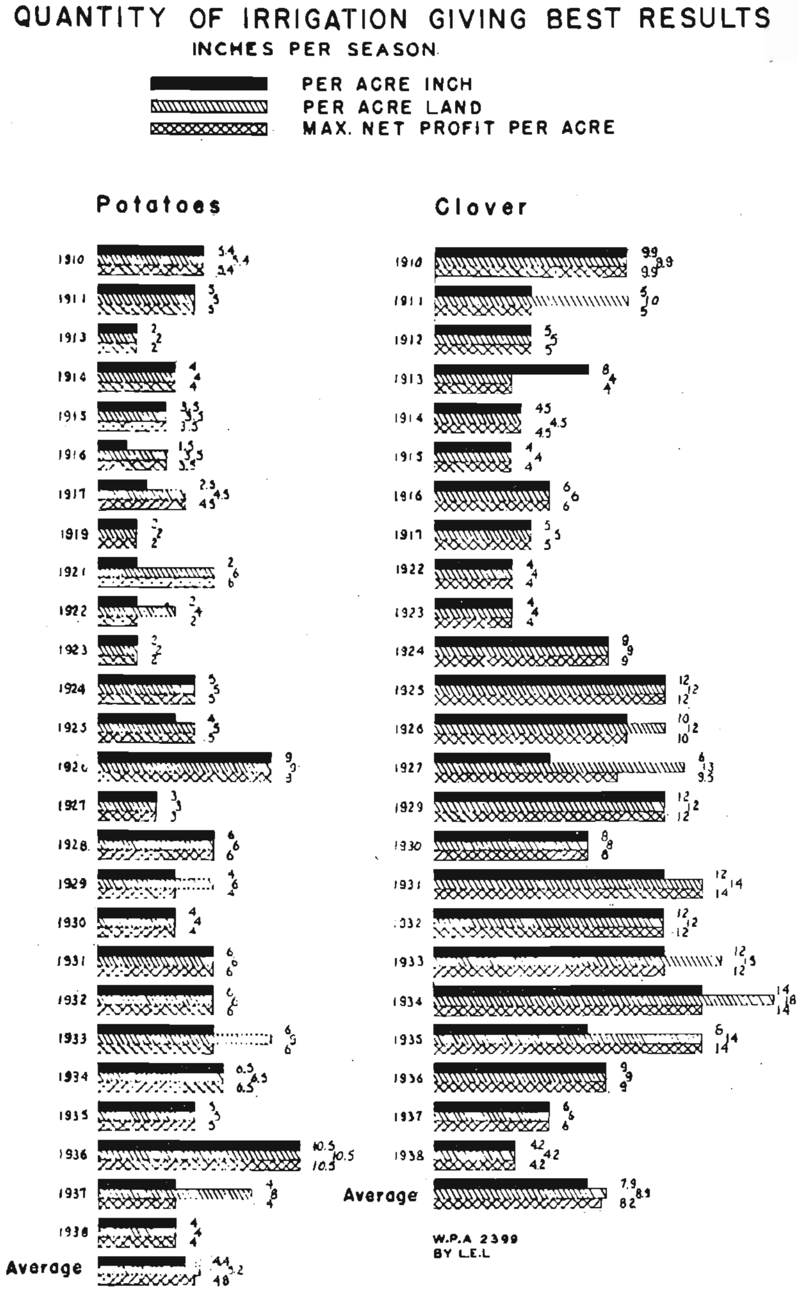

Figure 6. Quantity of irrigation giving best results. (Potatoes and clover on Willamette silty clay loam at Corvallis, Oregon)
a. Maximum yield per inch water.
b. Maximum yield per acre land.
c. Maximum net profit per acre.

Table 5. Use of Water on Annuals, etc., Cooperative Irrigation Efficiency Test Fields—1937

Data by Oregon Agricultural Experiment Station, Department of Soils

Name	Crop	Irrigation season	Number of irrigations	Area of plots	Irrigation head	Depth applied	Acre yield
				Acres	*Cubic feet per section*	*Inches*	*Tons*
1936							
Cox	Beans	7/1–8/30	11	1.55	.83	15.0	12.8
Rear	Early beets	6/28–9/22	6	1.00	.1	12.3	22.0*
Bartholomew	Beans	7/14–7/30	4	1.75	.5	8.0	14.0
Chase	Beans	7/13–8/16	6	6.0	.5	12.0	11.0
Chase	Beets	7/13–8/16	5	4.0	.5	10.0	13.0
Shaffner	Beans	7/7–8/24	8	1.25	.2	15.71	14.0
Putnam	Corn	7/16–8/20	....	......	....	6.00	3.0
Cummings	Lily bulbs	7/2–8/4	5	.1	.5	9.81	3.5†
	....	....	....	......	......	12.65	3.5
	....	....	....	......	......	14.07	3.5
Corum	Beans	6/30–7/24	5	7.0	.2	11.57	10.0
1937							
Cox	Beans	7/10–8/23	7	1.6	.38	9.4	11.56
Bartholomew	Late cabbage	8/6–	2	.127	.46	2.74	
	....	....	....	......	......	4.37	14.00
	....	....	....	......	......	5.46	
Voss	Beets	7/17	3	......	.9	5.0	7.00
Chase	Beets	6/24–8/19	5	7.4	......	10.0	15.00
Shaffner	Beans	6/24	....	6.25	......	....	12.00
Corum	Beans	7/11-8/10	5	1	....	11.09	9.00
Gentry	Beans	7/12–8/19	4	.1	.195	5.25	7.00
	....	....	....	......	......	6.5	....
	....	....	....	......	......	7.75	....
Shishido	Celery	6/16–	3	10.0	.136	10.35	1,000 crates
1939							
Hammersley Bros.	Red clover seed	6/1–8/10	5	30.0	.91	10.00	700†

* Double cropped.
† Bulbs.

Willamette Valley has increased from some 1,000 acres in 1910 to more than 45,000 by 1941.

The data for Willamette Valley floor soils in the summary (Table 6 and Figures 5 and 6) indicate the average amount of water that has been used to obtain the yield giving the maximum net profit each season. The data obtained in the earlier years were largely with 1/10-acre plats and represent a net duty with practically no deep percolation and little surface wastage.

The crop-producing power of water based on net use with good modern methods of farming and giving the maximum net profit each season, taken from the water-variation trials covering a 30-year period at Oregon Agricultural Experiment Station, averages approximately:

- 5.0 inches per ton of alfalfa hay and red clover,
- 10.0 inches per 25 bushels grain,
- 5.0 inches per 100 bushels of potatoes,
- 8.2 inches per 10 bushels white beans,
- 6.9 inches per 10 tons beets,
- 1.1 inches per ton corn ensilage.

The water cost of dry matter will vary somewhat from one season to another.

Established meadows constitute a class of crops having large requirement as compared to annuals, since they produce throughout the full growing season. Small grain has a short growing period and may include some winter growth. Cultivated row crops may make little demand for water until midsummer.

Table 6. NET AVERAGE QUANTITY OF WATER GIVING MAXIMUM NET PROFIT PER ACRE
.1-acre plats (through 1940)
Oregon Agricultural Experiment Station

Crop	Years in average	Irrigation	Total use	Yield	Water per pound dry matter
	Years	*Inches*	*Inches*	*Tons*	*Pounds*
Alfalfa	23	10.8	20.88	5.212	545
Red clover	25	8.2	18.11	5.485	581
Grass (mowed)	5	11.2	20.62	4.780	657
Potatoes	28	4.8	10.39	212.1*	787
Corn (ensilage)	28	6.2	11.47	9.861	536
Beets	8	5.3	11.38	16.556	521
Beans	26	4.0	8.44	19.93	1,739

* Bushels.

CONCLUSION AS TO CURRENT ECONOMIC IRRIGATION REQUIREMENT FOR WILLAMETTE BASIN

During the dry period in recent years, increased interest in pasture irrigation has led to use of somewhat greater quantities of water than formerly applied. Based on the data available, it appears that for valley floor soils 12 inches would be the estimated economic duty for annual crops (Tables 5 and 6) and 18 to 24 inches for meadow crops (Table 7). Economic duty for ladino pastures appears to be about 2 feet. Eight years' use on fiber flax has averaged 5.34 inches and increased yield .92 ton an acre. The duty on good irrigable soil in the main valley floor is estimated to be on the order of 18 to 24 inches for meadows delivered to the field or to each 40-acre tract, and 12 inches for

Table 7. Water Use With Moisture Control, Cooperative Irrigation Trials With Ladino Pastures—Willamette Valley
Oregon Agricultural Experiment Station, Soils Department

Farm	Irrigation	Soil type	Number of irrigations	Area	Irrigation head	Depth for season	Yield per acre
				Acres	*Cubic feet per section*	*Inches*	*Cow days*
1936							
J. Thornburgh	7/14–8/15	Chehalis silty loam	2	130	3.6	17.4	......
Ohling	6/25–8/25	Wapato silty clay loam	2	5	1.0	18.0	360
Putnam Bros.	7/14–8/20	Chehalis loam	2	4	1.94	13.0	360
College West Farm	6/23–9/5	Cove clay	6	5	.50	27.0	180*
College West Farm	7/6–9/5	Wapato silty clay loam	7	5	.95	21.0	450
1937							
Ohling	7/22–8/18	Wapato silty clay loam	2	1/17	.61	6.88 Min.	
		....	....	....	......	7.00 Med.	360
		....	....	....	......	9.34 Max.	
Brown (new seeding)	7/29–8/27	Willamette silty loam	2	5	1.83	11.16	40
Duda (new seeding)	7/11–8/14	Willamette silty loam	2	1.85	1.83	8.08 Min.	
		....	....	....	......	9.70 Med.	
		....	....	....	......	11.20 Max.	
Findley	6/26–8/29	Wapato silty clay loam	5	.14	.94	12.5 Min.	
		....	....	....	......	15.0 Med.	384
		....	....	....	......	22.5 Max.	
Harper	7/15–	Willamette silty loam	3	.61	.25	11.5	585
1938							
Harper	5/31–8/29	Willamette silty loam	5	.1	.25	10	714
Duda	6/7–8/10	Willamette silty loam	3	5	1.83	15	†
Brown	6/9–8/12	Willamette silty loam	4	5	1.83	16	540
1939							
Harper	5/1–10/1	Willamette silty loam	6	.61	.25	12	735

* After cutting twice.
† 180 sheep days in addition to 120 pounds of seed.

Table 8. AVERAGE WATER USE PER SEASON AND YIELD PER ACRE, CHEHALIS LOAM, COLLEGE EAST FARM, THROUGH 1939

Soils Department, Oregon Agricultural Experiment Station

Irrigation treatment	Potatoes 11-year average		Barley 12-year average		Clover hay 4-year average		Clover seed 11-year average		Beet seed 2-year average		Blackberries 3-year average	
	Yield	Irrigation	Yield	Irrigation	Yield	Irrigation	Yield	Irrigation	Yield	Irrigation	Yield	Irrigation
	Bushels	*Inches*	*Bushels*	*Inches*	*Tons*	*Inches*	*Bushels*	*Inches*	*Pounds*	*Inches*	*Pounds*	*Inches*
Heavy	197.3	13.94	35.69	10.0	1.12	21.8	2.30	10.0	2,015	9.65	11,211	29.0
Medium	196.0	11.09	36.01	8.0	1.15	16.3	2.48	8.0	2,029	7.40	11,095	20.3
Light	154.7	7.39	38.66	6.0	1.01	11.6	2.29	6.0	2,023	4.75	10,643	17.2
Dry	98.6	......	33.93	......	.86	......	1.83	......	1,553	......	8,830	......

annuals. The meadows may ultimately come to occupy 55 to 60 per cent of the area. This would give a net weighted duty for the valley floor of approximately 18 inches net delivered to the field.

On the river bottom land or Chehalis loam at the College East Farm, 10 to 20 inches has been commonly used with cultivated and other annual crops and 15 to 30 inches on meadows (Table 8). If 15 inches is the net use for cultivated and annual crops and 30 inches for meadows, when 50 per cent is in meadows, then ultimately weighted field duty may be on the order of 22.5 inches.

Perhaps two-thirds of the good irrigable soils are in the main valley floor, and probably three-fourths of the land that can be readily served by gravity irrigation is in the valley floor. This would somewhat affect the project duty, depending on the particular project and its soil areas.

Supplying 5 gallons per minute per acre irrigable land, has been found adequate for the dry periods with sprinklers.

MID-COLUMBIA BASIN DRAINAGE AREA

In Hood River Valley a water variation trial was conducted in a young orchard with a cover crop of clover. The indicated economic duty for this test was some 24 inches. Use on Hood River and other districts in the Valley indicates a general duty of water on the order of 2 acre-feet. The water rights have been fixed and are uniformly one-half miner's inch to the acre but not to exceed 3 acre-feet per acre.

Beginning in 1912 and extending from a period of 1912 to 1922, many variation trials were conducted in Deschutes Valley and some use records on test farms have since been obtained. (Powers, 1914, 1921; Fortier, 1930). On annuals the average seasonal application is perhaps 12 to 18 inches and the economic net duty appears to be a little less. Alfalfa and other meadow crops occupy about two-thirds of the area and they require more than twice the water annuals use. The studies in later years were largely with meadow crops. On a basis of 6 or 7 inches per ton, 3 feet of water should produce a maximum yield of alfalfa in the Deschutes Valley. Use records indicate applications of from 2 to more than 6 feet depth a season. Overirrigation is to be avoided because the soils are of coarse texture and of medium depth, and with good to rapid drainage the tendency with overirrigation would be to leach out the fertility. With careful crop rotation with soil-building legumes and the use of fertilizer, usable water capacity and fertility may be conserved.

At the Umatilla Branch Station and on the farms of cooperators on the Umatilla project, water variation trials have been conducted almost continuously since the establishment of the Station there. (Dean, 1921). The strip-border method of irrigation was introduced and modified to fit local conditions by the Umatilla Branch Station. During the past decade the alfalfa yield has tended to decline on the Umatilla project. The project use decreased from 8.55 feet in 1913 to use of 4.93 feet in 1923, partly due to use of the strip border method and the adoption of rotation and the use of large irrigating heads. On the finely textured soils as little as 30 inches is used on alfalfa. For medium loamy sand economic duty appears to be on the order of 5 to 6 feet a season for alfalfa (Figure 4) and 2 to 3 feet for annuals with an average duty of 4 to 4.5 feet. Organic manures are of first importance in securing economic production under irrigation on the sandy soils of the Umatilla Basin. On the finely textured soils the yield per acre and per unit water is significantly increased with applications of sulphur or sulphates. Table 9 shows the results of an experiment on the effect of length and width of strip borders on Rupert sand on the use of water. Table 10 is a summary of the use of water on alfalfa on the Ephrata loamy sand of the New Umatilla Field Station.

In the Walla Walla Valley near Milton, the dark stony, gravelly, sandy loam is intensively used for horticultural crops including tomatoes, that seem to require at least two irrigations a week, and with rather careful use the applications are on the order of 6 to 9 acre-feet a season. Alfalfa on fine sandy loam in this district receives 3 to 3.5 feet of water. Use data have been obtained on test farms, but water trials have not been made.

Table 9. WATER APPLIED AND YIELD OF ALFALFA HAY, IN TONS PER ACRE AND TONS PER ACRE-INCH OF WATER APPLIED, BORDER IRRIGATION EXPERIMENTS ON THE OLD UMATILLA FIELD STATION

Soil type—Rupert Sand

Description of borders	Years covered	Average water applied	Yields: Per acre	Yields: Per acre-inch of water
		Inches	*Tons*	*Tons*
Length experiments				
Steep land—				
25 by 90 feet	5	47	2.37	.050
25 by 120 feet	5	51	2.40	.047
25 by 150 feet	5	55	2.56	.047
25 by 180 feet	5	70	2.53	.036
25 by 210 feet	5	82	2.52	.031
Flat land—				
22 by 100 feet	10	54	4.69	.087
22 by 175 feet	10	65	3.82	.059
22 by 250 feet	10	81	3.23	.040
Width experiments				
Steep land—				
20 by 200 feet	5	49	1.92	.038
25 by 200 feet	5	63	2.09	.033
30 by 200 feet	5	62	1.78	.028
35 by 200 feet	5	81	2.54	.031
Flat land—(1)—				
20 by 200 feet	5	60	3.27	.055
25 by 200 feet	5	68	3.35	.049
30 by 200 feet	5	72	3.47	.048
35 by 200 feet	5	68	4.08	.060
Flat land—(2)—				
20 by 200 feet	9	45	3.60	.079
25 by 200 feet	9	45	4.04	.089
30 by 200 feet	9	52	3.92	.075
35 by 200 feet	9	54	4.49	.083
40 by 200 feet	9	61	3.75	.062

From H. K. Dean, *Work of the Umatilla Reclamation Project,* U. S. Department of Agriculture Circular 422.

Table 10. WATER APPLIED AND YIELD OF ALFALFA HAY, IN TONS PER ACRE AND TONS PER ACRE-INCH

Ephrata Loamy Sand, Umatilla Field Station

Years covered	Interval between irrigations	Irrigation water	Yield: Per acre	Yield: Per acre-inch
Years	*Weeks*	*Inches*	*Tons*	*Tons*
3	3	46	4.83	.105
3	2	58	6.21	.107
3	1	89	7.37	.083
5	....	45	4.56	.101

Unpublished data from Umatilla Branch Station.

Data on water variation trials in both the Deschutes and Umatilla areas are shown in Table 11.

Table 11. ANNUAL YIELDS AND AMOUNTS OF WATER APPLIED

Soil type or year, class	Area irrigated	Irrigation water	Yield per acre	Yield per acre-inch
	Acres	*Inches*	*Tons*	*Tons*
Deschutes Valley, 1912-1920				
Alfalfa				
1912 Medium sandy loam* ..	....	18	3.30	.18
	....	25	3.40	.13
1918 Medium sand	1	12	.90	.075
	1	15	1.00	.064
	1	19	1.10	.058
1918 Medium loamy sand	1.3	8	.95	.118
	1.3	10	1.00	.095
	1.3	14	1.10	.075
1919 Medium loamy sand	1	14	2.06	.147
	1	17	2.12	.124
	1	20	2.50	.125
1919 Medium loamy sand ..	1	19	2.40	.126
	1	24	2.90	.120
	1	29	3.00	.103
1919 Medium sand	1	18	3.70	.205
	1	22	4.20	.192
	1	26	4.70	.181
1919 Medium loamy sand	1	20	3.00	.150
	1	24	3.10	.129
	1	28	3.95	.141
1919 Medium loamy sand	1	22	3.30	.150
	1	26	4.55	.175
	1	32	5.59	.174
1920 Medium sand	1	20	3.00	.150
	1	24	3.50	.146
	1	28	4.00	.143
1920 Medium loamy sand	17.5	28	2.80	.10
	3	34	2.90	.085
1920 Medium coarse sand	4	28	3.70	.132
Alfalfa				
1920 Gravelly sand	6.5	28	2.60	.093
	6.5	46	3.10	.067
1920 Medium loamy sand	.75	20	2.60	.130
	.75	24	3.25	.135
	.75	28	3.50	.125
1920 Medium loamy sand	15.7	20	2.2	.110
	1.8	24	3.25	.135
	1.8	31	4.15	.134
1920 Medium sand	3	20	3.0	.150
Clover				
1912 Medium sandy loam† ..	....	16	4.3	.27
	....	24	4.9	.21
	....	18	3.9	.22
	....	20	4.0	.20
	....	24	4.6	.19
1918 Medium loamy sand‡ ..	1	16	2.25	.140
	1	20	3.12	.156
	1	24	3.69	.153
Wheat			*Bushels*	*Bushels*
1915 Medium sand§.............	1	8.3	22	2.66
	1	10.0	17	1.70
	1	11.4	20	1.75
1918 Medium loamy sand‡ ..	1	8.2	20.2	2.45
	1	11.8	19	1.608
	1	14	22	1.571
1918 Medium loamy sand‡ ..	1	11	28	2.58
	1	13	30	2.31
	1	16	35	2.18
Barley				
1912 Medium sandy loam† ..	....	5	53.9	10.78
	....	10	67.1	6.71
Oats				
1915 Medium sand§	2	3.3	27.35	8.2
	2	12.4	29.70	2.4
	2	17.9	32.15	1.8

Table 11. ANNUAL YIELDS AND AMOUNTS OF WATER APPLIED—*Continued*

Soil type or year, class	Area irrigated	Irrigation water	Yield per acre	Yield per acre-inch
	Acres	*Inches*	*Bushels*	*Bushels*
Potatoes				
1912 Medium sandy loam‖	....	2.5	92	36.8
	....	5	161.3	32.3
1917 Medium loamy sand‡	.1	4	90	22.5
	.1	6	100	16.6
	.1	8	166	20.7
1918 Medium loamy sand‡	.1	6.5	180	27.69
	.1	8.8	170	18.89
	.1	12.0	140	11.67
1918 Medium loamy sand	.1	9	204	23.31
	.1	11	283	25.73
	.1	14	233	16.65
1918 Medium loamy sand	.2	6.5	247	38.00
	.2	8	356	40.75
	.2	12	228	19.00
Alfalfa			*Tons*	*Tons*
1914 Coarse sand¶	.20	52.6	4.03	.077
	.20	63.1	5.31	.085
	.20	116.3	5.57	.047
1915 Coarse sand	.20	28.0	3.50	.125
	.20	44.0	4.63	.105
	.20	84.0	5.69	.067
1916 Coarse sand	.20	28.0	4.25	.151
	.20	44.0	6.36	.146
	.20	84.0	6.72	.080
1917 Coarse sand	.20	35.0	4.10	.116
	.20	44.0	5.97	.136
	.20	63.0	6.45	.102
1918 Coarse sand	.20	40.0	4.40	.110
	.20	45.0	5.48	.122
	.20	60.0	6.13	.102
1919 Fine sand	.20	25.0	8.83	.333
	.20	25.5	8.58	.327
	.20	35.0	9.12	.293
Alfalfa				
1919 Fine sand**	.10	39.0	5.03	.129
	.10	42.0	6.12	.146
	.10	42.0	5.75	.137
	.10	44.0	5.72	.131
	.10	47.0	3.06	.065
	.10	51.0	3.68	.071
1919 Coarse sand¶	.10	63.0	5.28	.082
	.10	84.0	4.00	.035
	.10	114.0	3.88	.034
1921 Medium sand	.10	32.0	5.35	.167
	.10	36.0	5.79	.154
	.10	39.0	6.27	.155
1921 Medium sand	.20	40.0	5.01	.068
	.20	106.0	5.35	.050
	.20	111.0	4.07	.036
1921 Very fine sand	.20	20.5	8.27	.402
	.20	25.0	7.40	.292
	.20	28.0	9.56	.341
1921 Very fine sand	.20	31.0	7.82	.251
	.20	38.0	7.86	.204
1921 Medium sand	.10	27.0	7.17	.236
	.10	32.0	6.97	.220
	.10	48.0	6.07	.127
1921 Coarse sand	.167	77.0	1.12	.030
	.167	89.0	2.35	.026
	.167	120.0	.97	.008
1921 Coarse sand	.10	48.0	1.81	.037
	.10	59.0	2.03	.034
	.10	72.0	2.21	.030
1921 Fine sand	.10	27.0	8.25	.310
	.10	37.0	8.50	.230
	.10	42.0	7.43	.170

* Data from Bulletin 189, Oregon Agricultural Experiment Station.
† Data from Bulletin 119, Oregon Agricultural Experiment Station.
‡ Data from mimeographed report, Oregon Agricultural Experiment Station.
§ Data from Bulletin 140, Oregon Agricultural Experiment Station.
‖ Data from Bulletin 173, Oregon Agricultural Experiment Station.
¶ Data from Bulletin 189, Oregon Agricultural Experiment Station.
** Data from an unpublished report.

IRRIGATION REQUIREMENT OF SNAKE RIVER DRAINAGE BASIN AREAS, OREGON

In Malheur Valley use records indicate amounts of irrigation applied are similar to those on the Boise project across the Snake River, where 3.30 acre feet have been applied on the Wilder Unit, Boise project, as a 10-year average. The new projects there are designed to supply 3½ feet on the Owyhee and some 3 feet on the Vale project. The experiments by Bark (1914) in southern Idaho for several seasons indicated for the loam soils a net economic duty of water on the order of 27 inches a season. Some duty of water trials were conducted in Malheur Valley by W. W. Johnston for the Soils Department of the Experiment Station in 1922. The maximum yield of alfalfa was obtained on loam soil near Vale with 25 inches irrigation. Twenty-four inches of irrigation on potatoes east of Vale resulted in a higher yield than was obtained with

Table 12. ANNUAL YIELDS AND AMOUNTS OF WATER APPLIED SNAKE RIVER VALLEY

Year Soil type or class	Area irrigated	Irrigation in inches	Yield per acre	Yield per acre-inch	Water cost*
	Acres	*Inches*	*Tons*	*Tons*	*Pounds*
Alfalfa					
1915 Sandy loam†	4.30	18.79	3.09	.164	....
	4.30	22.33	3.05	.136	....
	4.30	33.68	3.09	.092	....
1915 Fine sandy loam	62.0	9.07	3.24	.357	660
Gravelly loam	21.0	17.49	4.22	.241	756
1916 Fine sandy loam	11.6	12.61	3.22	.225	....
	8.4	15.8	3.56	.225	....
	6.0	17.5	5.12	.298	....
1916 Dark loam	2.75	9.87	4.30	.435	....
	2.75	12.12	5.40	.446	....
	2.75	14.37	6.50	.452	....
1922	.14	11.60	4.65	.400	....
	.14	25.20	4.76	.190	....
	.14	38.40	4.28	.110	....
Barley			*Bushels*	*Bushels*	
1915 Fine sandy loam‡	6.08	8.90	53.1	5.90	605
	5.15	10.45	54.6	5.20	614
	4.47	12.85	63.6	4.90	618
1915 Gravelly loam	2.72	10.09	50.4	5.00	692
	5.04	15.74	52.3	3.32	1,184
	5.70	16.30	54.4	3.34	1,030
Oats					
1915 Fine sandy loam	3.56	3.81	55.0	14.40	796
	2.78	6.50	60.0	9.20	926
	3.68	12.46	65.0	5.20	1,112
Potatoes					
1915 Loam‡	1.67	4.49	116.6	25.90	389
	1.70	5.62	125.0	20.40	358
	2.27	7.79	133.3	17.10	502
1922	.1	7.63	167.0	21.90	....
	.1	15.71	268.0	17.00	....
	.1	24.49	347.0	14.00	....
Timothy			*Tons*	*Tons*	
1915 Gravelly loam	13.9	25.42	2.46	.0097	1,870
	4.48	30.56	4.14	.0135	1,116
	3.24	35.28	3.99	.0113	1,309
Gravelly loam	76.0	17.88	2.21	.0123	1,347
Wheat			*Bushels*	*Bushels*	
1915 Fine sandy loam	23.0	16.21	56.0	3.45	808

* Pounds of water per pound of total dry matter produced.
† Data from Bulletin 189, Oregon Agricultural Experiment Station.
‡ Data from Bulletin 140, Oregon Agricultural Experiment Station.

a 16-inch irrigation, but with somewhat less returns per acre inch. The economic net duty for Malheur Valley is on the order of 30 to 48 inches.

One trial in the Grande Ronde Valley in 1916 of alfalfa resulted in a maximum yield of 6.5 tons of hay with the use of 14.37 inches of water, perhaps supplemented with some subirrigation.

Trials in Wallowa Valley in 1915 with fine sandy loam soil resulted in the yield of more than 3 tons of alfalfa from 22.33 inches, when a 33-inch irrigation did not substantially increase the yield (Powers 1917). Nearly 13 inches of irrigation applied to barley gave a yield of 63.6 bushels. It appeared to be the economic use.

In Baker Valley three tracts were selected upon which it was possible to make water variation trials in 1915 and 1916, and water use was determined on four other farms. Potatoes grown on loam soil produced a maximum yield of 133.3 bushels with 7.6 acre inches of irrigation in 1915, while in 1922 a yield of 347 bushels was obtained with 24.5 inches. The most economic return per unit water was 26 bushels per acre inch and was secured with the minimum irrigation 4.5 inches. Barley on gravelly loam soil received from 10 to 16 inches and yielded from 50 to 54 bushels an acre. The most water gave the maximum yield. The minimum irrigation gave the largest yield per unit water and the most efficient production of dry matter per unit water. Timothy plats located on gravelly loam gave a maximum yield of timothy and clover with 30.5 acre inches per acre and yielded 4.1 tons. Measurements by C. E. Stricklin in 1914 showed use of 1.21 acre feet per acre. A 62-acre field of fine sandy loam received 3.14 acre feet and yielded 2.5 tons an acre. This field in 1915 received 9.07 inches irrigation and yielded 3.24 tons.

Results indicate an economic duty of perhaps 12 inches for annuals and 18 to 36 inches for meadow crops. The largest quantities were required on the coarse-textured soils. A weighted economic duty of 18 to 24 inches was indicated.

IRRIGATION REQUIREMENT OF KLAMATH, LOST RIVER, AND GOOSE LAKE DRAINAGE AREAS

Duty of water experiments were conducted in Klamath Basin both on marsh lands and on the sage-brush bench lands during the seasons 1917, 1918 and 1919, and were reported by Powers and Johnston (1920). The economic net duty of water for wild meadow land was indicated to be 12 to 18 inches. This is indicated by the data for the Klamath wild meadow land and medium peat in Table 13.

Conclusion and tentative duty. Heavy crops of potatoes on loamy fine sand as on Malin Irrigation District, use some 30 inches. The annual use on the Klamath project has averaged a little less than 2 feet, *and this, together with limited experimental data, indicates* a weighted economic duty on the order of 27 inches.

Experiments in 1915 reported by Powers (1917) indicated that annual crops in Goose Lake Valley used 12 to 18 inches. Recent use records on several farms indicate weighted economic duty, including perhaps 50 per cent meadow, would be on the order of 24 inches, with the requirement of 30 inches for some of the coarse-textured alfalfa soil.

Further experimental data are needed under current agricultural practice.

Table 13. ANNUAL YIELDS AND AMOUNTS OF WATER APPLIED TO CROPS IN THE KLAMATH BASIN

Klamath Valley

Year, soil type or class	Area irrigated	Depth of irrigation	Yield per acre	Yield per acre-inch	Water cost*
	Acres	*Inches*	*Tons*	*Tons*	*Pounds*
Wire Grass					
1917 Medium peat†	1.39	7	0.75	0.107	2,077
	....	11	1.39	.126	6,341
	....	20	3.47	.1735	1,938
Alsike and Timothy					
1917 Medium peat	1.39	8	1.95	.243	1,180
	....	11	3.08	.280	643
	....	17	3.58	.210	824
Sugar Grass					
1918 Medium peat	1.39	7	.759	.108	4,271
	....	13	1.487	.114	2,555
	....	25	1.045	.042	4,680
Alsike and Timothy					
1918 Medium peat	1.39	7	.377	.054	9,468
	....	13	1.437	.111	2,870
Wire Grass					
1919 Medium peat	1.39	8	1.122	.140	1,318
	....	16	1.455	.091	1,466
	....	24	1.379	.058	2,399
Alsike and Timothy					
1919 Medium peat	1.39	8	5.00	.625	460
	....	16	7.15	.446	492
	....	29.5	8.50	.288	717
1919 Medium peat	.887	5.280	2.333	.442	1,137
	.839	6.168	2.672	.433	1,002
	1.020	9.623	3.706	.385	490

* Pounds of water per pound of total dry matter produced.
† Data from Bulletin 167, Oregon Agricultural Experiment Station.

IRRIGATION REQUIREMENT OF GREAT BASIN DRAINAGE AREA

Cooperative duty of water experiments were initiated in the Great Basin Area in 1915 and reported by Powers (1917) and Powers and Johnston (1920), Shattuck and Ritchie (1922), and Shattuck and Hutchison (1930). Fortier also summarized earlier data (1925). A summary of all experimental data will be found in Table 14.

Two distinct conditions require consideration. Experiments have been conducted on each, namely: (1) the wild meadow peaty silt loam and medium peat lands, and (2) the black sage-brush or low bench lands of very fine sandy loam or loam texture. During the recent droughty years the irrigation requirement has been somewhat larger not only due to drier weather but also to increased yields with the development of better varieties and methods, especially at the Harney Branch Station. Weighted average use for all crops on the 80-acre irrigated farm unit at Harney Branch Experiment Station, 1927 to 1939 inclusive, has been 2.02 acre feet per acre. The second to lowest average use, 1.36 feet depth, was with winter wheat while the second highest, 2.66, was with new seeding of sweet clover and alfalfa.

Conclusion as to irrigation requirement from present information, Great Basin. The data presented indicate an economic net duty for annuals for the black sage lands of 12 to 18 inches and of alfalfa lands from 18 to 36 inches. Alfalfa has required about 6 inches per ton and has produced from 3

Table 14. Quantity of Water and Resulting Yields Giving Maximum Returns; per Acre-Inch of Water; per Acre of Land; and for Maximum Net Profit per Acre

Year and crop	Per acre-inch of water		Per acre of land		For maximum net profit per acre	
	Irrigation	Yield per acre inch	Irrigation	Yield per acre	Irrigation	Yield per acre
	Inches		*Inches*		*Inches*	
Harney Branch Station						
1918 Alfalfa	12.00	.286 tons	18.00	4.00 tons	18.00	4.00 tons
1919 Alfalfa	11.70	.215 tons	15.70	3.29 tons	15.70	3.29 tons
1920 Alfalfa	7.00	.706 tons	7.00	4.97 tons	7.00	4.97 tons
1921 Alfalfa	15.00	.440 tons	15.00	6.00 tons	15.00	6.00 tons
4-year average	11.43	.412 tons	13.93	4.57 tons	13.93	4.57 tons
1921-1929 and 1931 Federation wheat 10-year average	12.00	4.00 bushels	15.30	58.4 bushels	15.30	58.4 bushels
1920 Barley	12.00 M.*	.147 tons	12.00 M.*	1.765 tons	12.00 M.*	1.765 tons
1916 Kaiser field peas	4.00	.276 tons	8.00	1.690 tons	8.00	1.690 tons
1917 Kaiser field peas	6.00	.119 tons	10.00	1.149 tons	10.00	1.149 tons
1918 Kaiser field peas	4.00 M.*	.268 tons	8.00	1.445 tons	8.00	1.445 tons
1920 Kaiser field peas	12.00 M.*	.235 tons	12.00 M.*	2.830 tons	12.00 M.*	2.830 tons
4-year average	6.50	.225 tons	9.50	1.779 tons	9.50	1.779 tons
1920 Sunflowers	19.50	2.81 tons	19.50	54.7 tons	19.50	54.7 tons
1921 Sunflowers	24.00 M.*	2.25 tons	24.00 M.*	54.1 tons	24.00 M.*	54.1 tons
2-year average	21.75	2.53 tons	21.75	54.4 tons	21.75	54.4 tons
1921, 3, 4, 6, 7, 8 and 9 Kaiser field peas 7-year average	14.1	2.67 bushels	16.7	39.7 bushels	15.9	39.3 bushels
1923-6 and 1928 and 9 potatoes 6-year average	6.00	24.2 bushels	14.00	244.0 bushels	14.00	244.0 bushels
Chewaucan Valley						
1916 Alfalfa	11.16	.392 tons	32.00	6.10 tons	32.00	6.10 tons
1917 Alfalfa	5.50	.198 tons	99.00	1.70 tons	5.50	1.09 tons
2-year average	8.33	.295 tons	65.50	3.90 tons	18.75	3.60 tons
1916 Alsike clover and timothy	2.25	1.056 tons	4.25	2.56 tons	4.25	2.56 tons
1917 Alsike clover and timothy	3.07	.730 tons	8.49 M.*	4.05 tons	8.49 M.*	4.05 tons
2-year average	2.66	.893 tons	6.37	3.31 tons	6.37	3.31 tons
1917 Beans	4.40	3.40 bushels	12.60	24.00 bushels	12.60	24.00 bushels

* Plus manure.

to 6 tons an acre at the Harney Field Station in recent years. A summary of data for duty of water experiments in the wild meadow lands (Powers and Johnston, 1920) indicates that 18 inches of water on the field could produce the maximum yield now obtained, while an average of 12 inches has given the largest yield per acre inch. The average water cost of dry matter under good conditions for alsike and timothy has been some 600 pounds; whereas the water cost for wild hay has averaged 1,000 pounds or more.

Figure 7 shows the boundaries of the drainage basins already discussed and the irrigation water requirement for these basins.

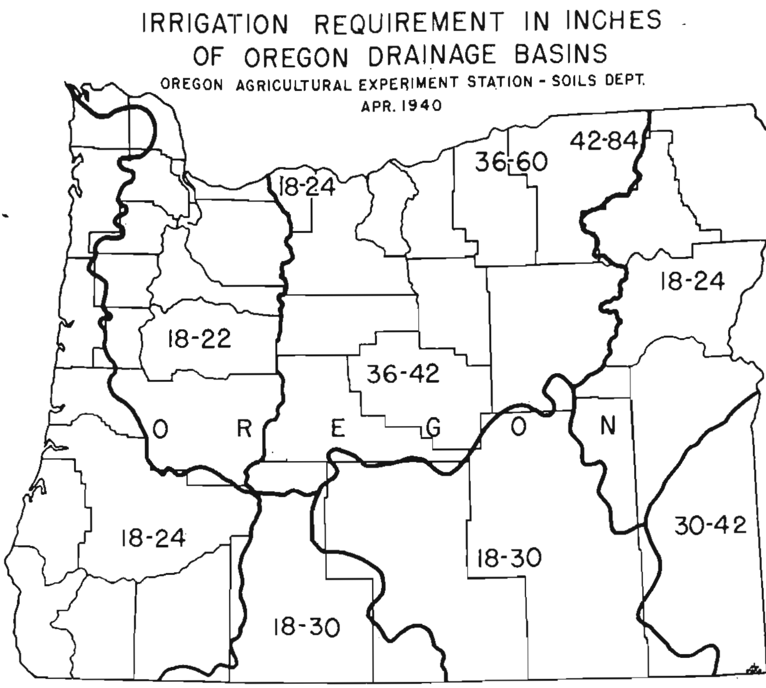

Figure 7. Irrigation requirement in inches of Oregon drainage basins.

GENERAL CONSIDERATIONS

Bark (1916) concluded that the nonirrigated areas (in roads, building sites, etc.), in a survey of 16,061 acres of a well improved irrigated section of southern Idaho amounted to 8.1 per cent. He found that 12.5 per cent was a reasonable allowance for surface runoff on rolling farms there. Recovery and reuse may reduce surface loss to some 5 per cent. Bark also reported that as the size of irrigating stream increased the per cent of deep percolation decreased. Loss increased with length of run. Southern Idaho ditches lost 0.5 to 1.5 cubic feet per square foot wetted surface per 24 hours. The average loss per mile was 7.1 per cent for small ditches while 1 per cent per mile was found a representative value for medium soils and canals of more than 200 cubic feet per second capacity. Consideration is given to maximum monthly demand in fixing canal capacities. Canal losses may run 20 to 50 per cent, and will average fully 30 per cent, usually being larger for newly excavated ditches than for older silted ones. Excessive grade may cause erosion of channels and increase percolation or prevent them from scaling up with silt. Measurements for small plats and for well defined valleys show consumptive use is of the order of 2.0 to 2.5 feet per acre for various growths. To the net water cost or consumptive use may be added farm lateral and other losses to arrive at an estimate of water delivery requirement at the forty corner. It has been estimated that deep percolation loss up to 10 per cent may be desirable, where water or soils carry large quantities of soluble salts, to provide for elimination.

OTHER INVESTIGATIONS NEEDED

An irrigability classification is needed to select the best lands for development first and to eliminate inferior lands, as has been found necessary by the Federal Reclamation Bureau. Much difficulty would have been avoided if such a program had been initiated in the beginning. The classification may include mapping soil areas as to irrigation requirement and thus increase the accuracy of design. Consideration should be given to avoidance of erosion by irrigation water and to future drainage requirements.

Duty-of-water investigations are needed, including methods of application to yield more definite information for use in administration of public water supplied, adjudication of water rights, and for economic design of new projects. If too little water is provided, crops burn up or dry out. If an economic irrigation requirement is established, it will help to develop and conserve the highest productive land values.

Carefully planned and executed experiments on the proper time and amount of irrigation will give the farmers much needed information on irrigation practices that will lead to the highest economic production.

The problem of economic duty of water is admittedly complex, but all the agricultural wealth, developed and undeveloped, in the arid West will be favorably affected by its proper determination. The cost of investigations would be returned many fold by security gained from the avoidance of water litigation. We must plan with the future in mind, each decade or generation being regularly provided with the duty or allowance according to the times. The great principle of beneficial use will permit us to make adjustments according to economic and other conditions so as to prevent waste and provide a practical economic duty of water.

LITERATURE CITATIONS

Aldrich, W. W., and Work, R. A.—1932, Preliminary Report of Pear Tree Responses to Variations in Available Soil Moisture in Clay Adobe Soil. Proc. Am. Soc. Hort. Sci. 20: 181-187.

Bark, Don H.—1916, Experiments on the Economical Use of Irrigation Water in Idaho. U. S. Dept. Agr. Bul. 339.

Dean, H. K.—1921, The Management of Sandy Soils Under Irrigation. Ore. Agr'l. Exp. Sta. Bul. 177.

Fortier, Samuel—1925, Irrigation Requirements of Arable Lands of the Great Basin. U. S. Dept. Agr. Bul. 1340.

Fortier, Samuel, and Young, Arthur A.—1930, Irrigation Requirements of the Arid and Semi-Arid Lands of the Columbia River Basin. U. S. Dept. Agr. Tech. Bul. 200.

Fortier, Samuel, and Young, Arthur A.—1933, Irrigation Requirements of the Arid and Semi-Arid Lands of the Pacific Slope Basins. U. S. Dept. Agr. Tech. Bul. 379.

Harding, S. T., et al—1930, Consumptive Use of Water in Irrigation. Trans. Am. Soc. Civil Engs. 94: 1149-1399.

Lewis, C. I., Kraus, E. J., and Rees, R. W.—1912, Orchard Irrigation Studies in the Rogue River Valley. Ore. Agr. Exp. Sta. Bul. 113.

Lewis, M. R., Work, R. A., and Aldrich, W. W.—1934, The Influence of Different Quantities of Moisture in a Heavy Soil on the Rate of Growth of Pears. Pl. Physiol. 10: 309-323.

Lewis, M. R., Work, R. A., and Aldrich, W. W.—1934, Studies on the Irrigation of Pears on Heavy Soil near Medford, Oregon. U. S. Dept. Agr. Tech. Bul. 452.

Shattuck, Obil, and Ritchie, Douglas W.—1922, Growing Irrigated Crops in Harney Valley. Ore. Agr. Exp. Sta. Bul. 191.

Shattuck, Obil, and Hutchison, Roy E.—1930, Progress Report of the Eighty-Acre Demonstration Farm Unit of the Harney Branch Experiment Station. Ore. Agr. Exp. Sta. Bul. 270. (1927-1930.)

Stover, A. P.—1910, Irrigation Experiments and Investigations in Western Oregon. U. S. Dept. Agr. Office Exp. Sta. Bul. 226.

Powers, W. L.—Jan, 1911, The Small Irrigation Pumping Plant. The Oregon Countryman 3: 10-16.

Powers, W. L.—1914, Irrigation and Soil Moisture Investigations in Western Oregon. Ore. Agr. Exp. Sta. Bul. 122.

Powers, W. L.—1914, Report of the Experimental and Demonstration Work on the Sub-Station Farm at Redmond, Oregon. Ore. Agr. Exp. Sta. Bul. 119, pp. 172-179.

Powers, W. L.—1917, The Economic Use of Irrigation Water. Ore. Agr. Exp. Sta. Bul. 140.

Powers, W. L.—1920, Duty of Water in Irrigation. Ore. Agr. Exp. Sta. Bul. 161.

Powers, W. L.—1921, Management of Irrigated Soils in Deschutes Valley. Ore. Agr. Exp. Sta. Mimeo. 18 pps.

Powers, W. L.—1928, The Economic Limit of Pumping for Irrigation. Ore. Agr. Exp. Sta. Bul. 235.

Powers, W. L.—1932, Twenty-five Years of Supplemental Irrigation Investigations in Willamette Valley. Ore. Agr. Exp. Sta. Bul. 302.

Powers, W. L., and Johnston, W. W.—1920, Irrigation of Potatoes. Ore. Agr. Exp. Sta. Bul. 173.

Powers, W. L., and Johnston, W. W.—1920, Improvement and Water Requirement of Wild Meadow and Tule Lands. Ore. Agr. Exp. Sta. Bul. 167.

Powers, W. L., and Johnston, W. W.—1922, Irrigation of Alfalfa. Ore. Agr. Exp. Sta. Bul. 189.

Work, R. A., and Lewis, M. R.—1934, Moisture Equivalent, Field Capacity, and Permanent Wilting Percentage and Their Ratios in Heavy Soils. Agr. Eng. 15: 355-362.

Work, R. A., and Lewis, M. R.—1936, The Relation of Soil Moisture to Pear Tree Wilting in a Heavy Clay Soil. Jr. Agron. 28: 124-134.

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