EVAPORATION AS AN AID IN CALCULATING IRRIGATION REQUIREMENTS FOR CROPS

by

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A THESIS

submitted to the

OREGON STATE COLLEGE

in partial fulfillment
of the requirements for the
degree of
Master of Science

August, 1948

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ACKNOWLEDGMENT

The author is indebted to Dr. W. L. Powers of the Soils Department, who suggested the problem for this thesis and cooperated to make it possible.

Indebtedness to Oregon Agricultural Experiment Station and its Branches for supplying some of the necessary data is also acknowledged.

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INTRODUCTION

The rapid development of irrigation throughout America during the Twentieth Century has encouraged the study of the economic use of water and the ways by which water is lost.

Pioneers in the field of irrigation, until recently, have been unable to determine scientifically the economical amounts of water necessary for projects with different climatic cropping and soils conditions.

In the search for an accurate method for determination of the economical irrigation requirement or duty of water, emphasis was placed on run-off, percolation and plant absorption, and only recently the evaporation of water from a free water surface was suggested as an accurate and simple indicator of irrigation requirements.

The huge water resources in irrigation areas have only lately been developed, and experience has indicated that less water may be delivered to the land than was formerly thought necessary.

Knowledge concerning water movement into soils as rain, snow or irrigation is rather incomplete. Various methods have been used to determine the amount of irrigation required by agricultural crops, and consumptive use plays an important role in this problem.

The aim of the author is to make a comparison of the Lowry-Johnson, the evaporation method, and the water variation trial for estimating irrigation requirements of an area.

HISTORICAL

Evaporation.

Considerable work has been done on various phases of evaporation. Perhaps the first studies were made by Perroult[36] in 1670. Dalton[16] in 1798 organized existing knowledge of evaporation and announced his law, which has been used as a basis for calculating evaporation rates based on temperature, altitude, vapor tension, and others.

As early as 1888, Fitzgerald[20] stated that the evaporation depends on the difference between the loss of water at the surface, temperature, and the condensation of water vapor taking place at that surface. This difference is now called net evaporation. He studied the temperature of the air, the dewpoint, water vapor pressure, quantity of water vapor in a cubic foot of air, total and relative humidity, and the weight of air at various pressures. As a result of these studies he proposed the formula:

$$E = .114(V-v) + .0012(V-v)^2$$

He developed another formula to be used when the water surface is exposed to the movement of the air. The formula was:

$$E = \frac{V-v(1+\frac{W}{2})}{60}.$$

In the above formulas: V means vapor pressure in the atmosphere; v, vapor pressure in the water; and w, wind velocity.

Russell[45] studied the significance of variations in the evaporation rate and derived a new formula which takes into account the barometric pressure, but not the wind velocity.

Carpenter[12] carried on experiments, at the Colorado Agricultural Experiment Station, on measurements of evaporation from a free water surface of three square feet in a sunken tank to determine the constant of Fitzgerald's formula. In a later paper[13] he reported that diminished barometric pressure tends to increase evaporation.

Bigelow[3] showed that if pans for evaporation were buried in the ground they would absorb heat from the soil and therefore show error in evaporation. Fortier[22] used galvanized iron tanks 2 to 3 feet in diameter and 30 to 36 inches deep, which were placed in the soil and filled with water. As a result of these measurements, he concluded that an increase in the temperature of 10° Fahrenheit causes an evaporation increase of one inch per week. He concluded that the evaporation decreased rather regularly with the altitude. In another report [21] studying the effect of evaporation on moisture content on soils, he concluded that the evaporation from soils varies directly with the amount of moisture in the top layer. Fortier worked also on the relation between temperature and evaporation and found that reducing the temperature from 88°F. to 80°.4F. decreased evaporation 20 percent.

Cameron and Gallagher(11) worked with soils of different levels of moisture content and under controlled moisture conditions. They arrived at the conclusion that after a certain wetness is reached there is little increase in water loss. Widtsoe(53) after four years of experimental work concluded that the evaporation of water from bare soils increases as saturation of the soil is approached, and the increase in loss is usually larger than the increase in soil moisture. In another paper (54) he reported that (a) the higher the moisture content at the surface the more rapid is the evaporation, and (b) the loss by evaporation was 29 percent greater in sunshine than in shade.

Harris and Robinson(24) considered that one of the important factors influencing evaporation is the moisture content of the soil or its initial percentage. In the same report they found that slight changes in temperature have a marked effect on evaporation. In 1917, Horton(26) developed a new formula based on the equilibrium produced by the rate of vapor emission and vapor condensation to the liquid surface. The formula is as follows:

$$E = C(\varphi V - v).$$

In which $\varphi = \left[2-e^{-k(w-\rho)}\right]$; $\rho = \frac{10d}{D}$; E, means evaporation in inches per 24 hours; C, coefficient (0.4 for small areas) V, vapor pressure of the liquid surface; v, vapor pressure of the air; e, base of Neperian logarithm; w, wind velocity; ρ, factor of correction the wind; d, depth of water in evaporimeter; D, diameter of evaporimeter in inches. Day[17] considered that the evaporation from soils including transpiration from vegetation is the primary source of vapor in the atmosphere. He found that aqueous vapor is added to the atmosphere only from points in contact with the surface of the earth, so, the lowest layers of the air contain the greatest absolute quantity of moisture.

King[30] studied the color of the soil as a factor influencing evaporation and found that dark soils absorb and radiate more heat. He concluded that the rise in temperature due to the dark color is the important factor. Mc Donald[33] found that, evaporation depends upon the temperature of the evaporating surface, the dryness of the air, and the velocity of the wind. Bowie[7] stated that, evaporation due to wind occurs by contact of the air with the moist soil surface. Buckingham[10] showed that the moisture escapes by diffusion and the loss is proportional to the square of the porosity.

Brigg and Shantz[8,9] made measurements of transpiration of various kinds of plants and found a close correlation between transpiration and evaporation from free water surfaces, air temperatures, solar radiation and relative humidity. They noticed that, evaporation continued at a reduced rate during the night while transpiration stops. In 1921, Horton[27] used evaporation tanks of 6 and 8 feet diameter and 24 inches deep. These extended into the soil 20 inches and were kept filled with water to the soil surface level or 4 inches below the rim of the pan in different latitudes and elevations, and the results were tabulated.

Mead[34] stated that, evaporation takes place from moist surfaces or from water surfaces whenever such surfaces are in contact with unsaturated air. Fisher[19] and Keen[29] show that the rate of evaporation is practically constant at high moisture contents. Fisher[19] stated that the moisture content at which the rate changed was a characteristic for each soil and a function of the surface. Keen[29] came to the conclusion that the evaporation is dependent upon the available surface, and the vapor pressure in the moist soil.

Cumming and Richardson[15] in 1927 developed a new formula taking as a basis the first law of thermodynamics. They did not take into consideration the wind velocity. Air temperature and humidity entered into the calculation only as a correction term having a relatively small average value under California conditions. This formula was:

$$E = \frac{H - S - C}{L\,(1 + R)}$$

In which E means evaporation in inches; H, difference between incoming and outgoing radiation; S, heat stored in the body of water; C, a correction factor for heat carried by flowing water and leakage of heat through the walls of the vessel; L, latent heat of water; R, Bower's ratio. Rohwer[43,44] observed the rate of evaporation from different types of pans, and concluded that, wide variations exist between various types of pans, and for comparison the evaporation ratio of a type of pan and larger water surface should be known.

Wilson[56] quoted the following paragraph in his textbook:

"Experiments in England indicate that the amount of evaporation from soils is about the same as that from water. From sandy soil surfaces this was found to be 0.25 to 0.20 that from water. It was found that the mean evaporation from water was 20.4 inches, and from earth was 17.9 inches, and from sand 3.7 inches. Assuming evaporation from water to be 1.0 the following values have been obtained: bare soils 0.6, sod 1.92, cereals 1.73, and forest 1.51. Evaporation from ground covered with forest leaves is 10 to 15 percent, and sand 33 percent, when from bare soils it is 100 percent."

Baver[1] indicated that evaporation from a free water surface varies approximately with the square of the mean monthly temperature in Fahrenheit degrees. In another paper [2] he reported that a rise in temperature increases the vapor pressure of water and the rate of evaporation is enlarged.

Total Heat Units Method. For many years engineers have used temperature data in estimating consumptive use in arid and semiarid regions of the West[23]. Hedke[25] investigated the relation of consumptive use of water to the quantity of heat available to the crop during the growing season, and concluded that, the use of water is directly proportional to the heat available. Hedke used the values 0.000423 as a correlation factor between heat units and consumptive use. He assumed in his work that precipitation falling on the soil surface, evaporates twice as rapidly as normal soil moisture.

Meeker[35] suggested the value 0.00039 as the correlation factor instead of the one determined by Hedke. Lowry and Johnson[32] developed a method in which consumptive use is shown as a straight line relation, within narrow limits, to accumulated daily maximum temperature above 32°F. during the growing season.

Water Variation Trials. Stevens[46] used the Brigg and Shantz data in estimating consumptive use by applying the relation between transpiration and dry matter produced by crop yield. White[52] made observations of ground water levels in an alfalfa field in the Escalante Valley, Utah, and it showed a distinct lowering of the water table during daylight hours and a recharge at night. He observed a marked decrease in transpiration on cloudy days from that on clear days.

Widtsoe[55] worked on field plots with a water table 75 feet below the surface. He measured the water used for 14 crops during 10 years and found that the yield increases rapidly to a certain point with the increase of total water used, and then decreases or increases very slowly with further increases of water. The peak value was considered as the consumptive use. Lewis[31] used 9 crops divided into two groups, those producing good yields and those of average yield. He found that 7 grain crops and potatoes used less than 2 feet per acre, alfalfa and clover used the largest quantities. Israelsen and Winsor (28) found that the quantities of water necessary to sugar beets, potatoes and alfalfa were 2.5, 2.0, and 2.8 acre-feet per acre respectively.

Powers has made systematic soil moisture studies of soils and water variation trials for 31 years [42], he found values from 1.4 to 2.0 feet for 4.1 to 5.2 ton per acre of alfalfa and a little less for clover. He found an average use of 21.03 inches per acre for dairy pastures at the College Farm, Corvallis. Experiments with the Willamette Valley floor indicate an average of 12 inches as the economic net duty of water per annual crop and 18 to 24 inches for meadow crops[42]. He concluded that the net weighted duty for good irrigable soils in the valley floor is approximately 18 inches to each 40 acres, if half of the farm is in meadow.

Dean[18] working on Umatilla soils found that the finer textured soils require 30 inches for alfalfa, and the economic duty of water on loamy sand was found 5 to 6 feet in season for alfalfa and 2 to 3 feet for annual crops with an average duty of 4 to 4.5. Powers and Lewis[42] working in Malheur County near Warm Spring project area found an economic net duty of water of 30 to 48 inches. Powers and Johnston[37] found a weighted economic duty of 30 inches for the Klamath project on loamy fine sand. At the Harney Field Station it was found [42] that 18 inches on the field gave the maximum yield.

<u>Other</u> <u>Methods</u>. In attempting to find an accurate method, much work has been done. Blaney and co-workers[4] by studies made in 1931 demonstrated the adaptability of

the evaporation pan as an index in estimating evapotranspiration losses from moist areas. In a swamp area in California, by growing tules in a large tank, he demonstrated that the percent of consumptive use with reference to evaporation from an exposed Weather Bureau pan was 95 percent.[51]

Blaney, Taylor and Young[6] used the integration method to determine the consumptive use of various types of crops, native vegetation and native habitat of plants. The rates of use so determined were weighted by the area devoted to that type of use within the studied area or valley to obtain the total consumptive use and weighted average use. Young and Blaney[57] indicated that the consumptive use by native vegetation with an ample ground water supply may be considerably greater than precipitation in semiarid regions. They stated that the evaporation from a water surface may be used as an index of the consumptive use.

Blaney and Morin[b] by plotting average annually observed data, varying from 12 to 14 years, found the relation between temperature, humidity and evaporation. From the curve they developed the following equation:

$$E_L = 0.00167\ T\ (114-H)$$

In which E_L is annual evaporation in inches (0.7

times observed U. S. Weather Bureau Class A pan); T, annual mean temperature in degree Fahrenheit; H, average relative humidity in percent. Then, by introducing a factor of evaporation force (heat) which was obtained by multiplying the mean monthly temperature in degrees Fahrenheit by the monthly percentage of annual daylight, the former formula became:

$E = k\ (t.p)(114-h)$ and for $t.p = f$ the formula was transformed to:

$$E = Kf(114-h)$$

In which K is equal to the monthly coefficient varying with the type of pan or water surface.

Thornwhite and Holzman(49) have developed a method for determination of evaporation and transpiration. They observed the vapor pressure gradient between two different levels in the atmosphere. In another report(50) they found that, the evaporation from moist soils may be more rapid than from free water surfaces. Increased surface of the soil particles present larger evaporating surfaces. Thornwhite(47) suggested that, in order to evaluate the moisture factor in climate, the moisture supply must be compared with the water needs or the potential evapotranspiration ratio. When the precipitation is deficient there is drought; when the precipitation is in excess of the need, the surplus goes to recharge the water table, and produce run-off.

In another paper[48] he noticed that, in some areas nearly all of the precipitation enters the soil, while in others only a very small percentage reaches the subsoil before being evaporated. Indices of effective precipitation are more satisfactory than total rainfall. He developed an Index of precipitation effectiveness based on the fact that evaporation and transpiration increase with increases in temperature. Thornwhite's Index was: $115\left(\frac{P}{T-10}\right)^{\frac{10}{9}}$ where P and T mean precipitation in inches, and temperature in degrees Fahrenheit respectively.

Criddle[14] worked in Idaho with several experiments to calculate the water requirements of crops. He took as a basis climatological data and found that: (a) consumptive use varies directly with the temperature, available sunlight hours, and the length of the growing season. (b) normal precipitation during the growing season is enough to take care of the consumptive use by crops in Idaho areas. In his report he used the formula:

$$U = F.k-R$$

In which $F = \frac{t.p}{100}$ and U, consumptive use in feet depth; F, index for consumptive use during the growing season; K, consumptive use coefficient; t, temperature in degrees Fahrenheit; p, percent of daylight; and R, rainfall in feet.

EXPERIMENTAL

Methods:

In this thesis a comparison is made between:

(a) Lowry-Johnson method,

(b) Evaporation method, and

(c) Water Variation Trial method.

The procedure followed is based on a comparison of the first two methods with the results obtained by the water variation trial method, using data from Oregon and Venezuela field station.

The Lowry-Johnson method, also known as "Heat units method", is found by multiplying the maximum daily temperature of each month above 32°F. by the number of days in the growing season. The total number of heat units accumulated is referred to the Lowry-Johnson curve where the consumptive use is indicated on the vertical axis and heat units on the horizontal axis. For this method the mean maximum daily temperature for a period ranging from 9 to 57 years were used. The average mean monthly maximum temperatures are summarized in Table No. 2.

The Evaporation method, consists in measuring the loss from an open tank filled with water, making allowance for various positions and shapes of tanks by introducing comparable factors for each type of tank.

The Water Variation trial method, consists in the determination of the quantity of water that gives the best yield of the various crops tested growing in field plots. Moisture is measured by taking soil samples before and after each irrigation. The moisture equivalent and moisture content are determined, to c alculate the useful soil moisture capacity.

The meteorological data were taken from Corvallis, Moro, Pendleton, Harney, Warm Spring Reservoir (Malheur County), Klamath (the evaporation measured at Tulelake), and Medford in Oregon and Guataparo, Suata and Neverí in Venezuela.

The data from these stations are summarized in Table No. 1 and Table No. 2 as used for the methods in this thesis.

TABLE I

GROWING SEASON, PRECIPITATION AND EVAPORATION

Station	Elevation	Growing Season				No. of Days	Total Evaporation	Total Precipitation
Oregon[1]	Feet	Mo.	Date	Mo.	Date	--	Inches	Inches
Corvallis	226	April	1	Oct.	1	184	28.3	7.95
Moro	1838	May	3	Oct.	15	165	39.3	2.87
Pendleton	1495	May	3	Oct.	5	155	32.5	3.24
Harney	4139	June	7	Sept.	3	88	23.9	1.15
Warm Spring Reserv. (Malheur)	3310	May	20	Sept.	20	123	40.0	2.11
Hermiston	624	April	24	Oct.	9	163	36.4	2.07
Tulelake	4055	May	23	Sept.	17	117	23.1	2.70
Medford	1425	May	6	Oct.	14	161	34.0	4.45
Venezuela[2]								
Guataparo	1500	Nov.	1 to	March	31	151	30.5	5.05
Suata	1600	Dec.	1 to	April	30	151	27.3	4.00
Neverí	10	Jan.	1 to	Dec.	31	365	51.2	1.16

[1] Oregon data were supplied for Ore. Agr. Exp. Station and its branches.

[2] Venezuelan data were taken from Unpublished report about those Projects.

TABLE II

MONTHLY TEMPERATURE - PRECIPITATION AND EVAPORATION
MEAN MONTHLY MAXIMUM TEMPERATURE

Stations	Length of Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
<u>Oregon</u>													
Corvallis	52	-	-	-	72	75.2	83.0	88.4	88.6	85.0	72.3	-	-
Moro	25	-	-	-	-	71.0	77.0	85.0	84.3	75.7	63.5	-	-
Pendleton	57	-	-	-	-	72.5	78.2	88.9	87.2	78.0	67.1	-	-
Harney	9	-	-	-	-	-	76.2	88.0	85.0	73.1	-	-	-
Warm Spring	25	-	-	-	-	70.8	79.5	89.1	87.4	77.3	-	-	-
Hermiston	41	-	-	-	69.3	78.3	83.9	93.1	90.4	81.5	68.5	-	-
Tulelake*	51	-	-	-	-	61.9	74.4	85.5	84.7	76.9	-	-	-
Medford	37	-	-	-	-	73.5	79.2	88.6	86.4	83.1	69.4	-	-
<u>Venezuela</u>													
Guataparo	40	84.2	88.3	89.6	-	-	-	-	-	-	-	85.5	88.0
Suata	40	95.0	95.4	96.2	98.2	-	-	-	-	-	-	-	92.1
Neverí	40	91.0	93.2	94.3	95.9	-	-	-	-	-	-	95.4	94.1

TABLE II (Cont.)

PRECIPITATION IN THE GROWING SEASON

Stations	Length of Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Oregon													
Corvallis	38	-	-	-	2.56	1.88	1.14	0.28	0.43	1.57	0.09	-	-
Moro	25	-	-	-	-	0.74	0.65	.18	.21	.67	.42	-	-
Pendleton	57	-	-	-	-	.26	.98	.41	.52	.89	.18	-	-
Harney	16	-	-	-	-	-	.68	.20	.23	.04	-	-	-
Warm Spring	42	-	-	-	-	.24	1.0	.30	.19	.38	-	-	-
Hermiston	41	-	-	-	.04	.53	.55	.16	.27	.33	.19	-	-
Tulelake*	51	-	-	-	-	.91	.72	.27	.25	.55	-	-	-
Medford	37	-	-	-	-	1.31	1.17	.29	.16	.68	.84	-	-
Venezuela													
Guataparo	40	.17	.71	.34	-	-	-	-	-	-	-	2.66	1.17
Suata	40	.60	.25	.26	1.92	-	-	-	-	-	-	-	.97
Neverí	40	.49	.13	.19	.35	-	-	-	-	-	-	2.47	.91

TABLE II (Cont.)

EVAPORATION IN THE GROWING SEASON

Stations	Length of Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Elevation
Oregon														
Corvallis	35	-	-	-	3.0	4.3	5.1	6.0	6.1	3.8	0	-	-	266
Moro	34	-	-	-	-	5.9	7.9	10.0	8.8	5.3	1.4	-	-	1838
Pendleton	16	-	-	-	-	4.9	6.3	8.7	7.9	4.7	0	-	-	1495
Harney	20	-	-	-	-	-	6.5	9.1	7.8	.5	-	-	-	4139
Warm Spring	21	-	-	-	-	2.8	9.1	12.6	11.0	4.5	-	-	-	3310
Hermiston	31	-	-	-	.1	6.2	7.7	9.6	7.9	4.9	0	-	-	624
Tulelake*	22	-	-	-	-	1.5	6.3	6.7	6.0	2.6	-	-	-	4055
Medford	11	-	-	-	-	4.7	6.8	8.9	7.7	4.8	1.0	-	-	1425
Venezuela														
Guataparo	10	5.8	6.9	8.3	-	-	-	-	-	-	-	4.6	4.9	1500
Suata	10	5.3	5.3	7.4	5.4	-	-	-	-	-	-	-	3.9	1600
Neverí	10	9.1	8.6	9.1	9.0	-	-	-	-	-	-	7.5	7.9	10

This table represents the weather condition during the growing season only.
The blanks represent the months outside of the growing season.
The months marked 0 means no evaporation or precipitation was recorded.
* Temperature was measured at Klamath Falls.

Computations.

With the available data, maximum daily temperature, precipitation, evaporation from pans, and net duty determined by water variation trials method, in various sections of Oregon and Venezuela, the calculation for net duty of water and irrigation requirements were made to check against those data already obtained by the water variation trial plot method.

The average maximum daily temperature above 32° F. was determined for each station and each month or fraction thereof during the growing season. The growing season is the length of time between killing frosts. The product of the mean daily temperature above 32°F. multiplied by the number of days of each month or fraction, is the total number of heat units for each month. These products are added to find the accumulated heat units in the growing season. The total number of heat units accumulated is then checked on the Lowry-Johnson curve. This curve has as its vertical axis consumptive use in feet of water, and as the horizontal axis the accumulated heat units in thousand degrees Fahrenheit.

The result for each station is summarized in Table No. 3.

The evaporation data were tabulated. These data were corrected to measure the evaporation losses from large surfaces of water, and they were considered to be equal to the evaporation losses from soils, and the transpiration losses from plants. The factors used were 0.77 for U. S. Weather Bureau Class A pan [58] and 0.83 for a sunken tank.

The precipitation data for each station were corrected for effective precipitation and deducted from consumptive use found under Lowry-Johnson and evaporation methods. The effectiveness of the precipitation for each station was considered by comparison among the temperature, evaporation, soil water holding capacity and texture.

Soil Characteristics.

The humid soils of Willamette Valley are Chehalis loam and Willamette silty clay loam with good water holding capacity. Newberg and Chehalis series are found in the river bottom and Willamette loam or silty loam in the Valley floor [38]. Soils used at Moro are mostly Walla Walla silt loam with good water holding capacity. At Hermiston the soils are of low water holding capacity, low in organic matter, and of sandy structure ranging from fine sand to medium sand. They are of open structure and rapid percolation, so, the precipitation result with little effect for crop.

In the Pendleton area, the soils are Walla Walla silty loam, but of little fertility. In Klamath project, the soils are sandy loam on slope, with basaltic subsoil. The run-off is great and very little quantity is taken in by the soil. The soils at Warm Spring and Harney Branch Station are good, with relatively good water holding capacity. These soils belong to the Wingville silty loam series for Harney Station, and the Warm Spring soils are loam.

Venezuelan soils are fairly good with high water holding capacity, high organic matter and calcium content. These soils are mostly loam to silty clay loam (Maracay and Valencia series) with good drainage, plastic clay subsoil (39,40). The soils in Guataparo project were developed from lacustrine and stream alluvium. The parent rock is mostly serpentine with veins of quartz. They were developed under moderate rainfall and high temperature, 73.1° F. being the mean annual temperature. They present differentiated horizons with various stages of maturity or development.[39]

Soils of Suata irrigation project were developed from conglomerates and mica including serpentine. Soil profile development is not so sharp. In a limited area, the soils show compact accumulation in the B-horizon. The climatological conditions in which these soils have been developed are moderate rainfall and high temperature.[40]

Soils of Neverí irrigation project are: (a) recent river bottom, (b) old valley filling and, (c) residual hills. Amount of bottom land is subjected to innundation. The soils are higher in clay, darker and richer in organic matter. Soil profiles are slightly leached. They are good clay loam soils, the temperature is extremely high most of the year; the evaporation is also very high.

Estimated precipitation efficiency.

When the soil surface is saturated following a heavy rain, evaporation is very rapid, perhaps more rapid than from a free water surface. An accurate method has not been found for correcting the total rainfall for evaporation losses, run-off and deep percolation. Allowances have been made in this thesis in estimating the effective precipitation. These allowances are based upon the amount of available moisture held in each foot of soil depth, and the temperature. It is believed that this assumption based on the wetted depth of soil and usable moisture of soil is the most satisfactory approach to effective precipitation.

The estimated efficiency for each station was as follows:

Stations	Estimated efficiency
Corvallis	80 percent
Moro	80 "
Pendleton	65 "
Harney	80 "
Warm Spring	80 "
Hermiston	50 "
Klamath Project	60 "
Medford	80 "
Guataparo	65 "
Suata	60 "
Neverí	55 "

Once the effective precipitation is known it is subtracted from the consumptive use to find the water requirements of the crops. The results for each station are found in Table No. 3 in column 8 and 12. Then, to the water requirement was added a percentage for deep percolation and other minor losses occurring in the delivery of water to the land.

When the crops are deep rooted the percolation is kept at a minimum. For many crops the root depth is so shallow that more water is required to obtain full irrigation coverage. Allowances for these losses were made according to the type of soil where water variation trials had been made. The factors used are:

Stations	Deep percolation losses in percent
Corvallis	20
Moro	20
Pendleton	35
Harney	20
Warm Spring Rsv.	20
Hermiston	50
Klamath Project	40
Medford	20
Guataparo	25
Suata	30
Neverí	30

To these results were added new allowances for canal losses estimated to be an average of 30 percent. The result is the "Gross Duty", which is the quantity that should be diverted from the stream or reservoir.(35)

The distribution of the net duty found by the three methods during the growing season was made according to the distribution of the evaporation in that period. The results obtained for Corvallis were plotted, and the curves shown in Fig. No. 1 were obtained. The accumulative distribution was shown in Fig. No. 2.

TABLE III

COMPARISON OF METHODS FOR ESTIMATION OF IRRIGATION REQUIREMENT

Stations	Elev. in Feet	Growing Season Date	Tot. Days	Tot. Heat	Lowry-Johnson's Method				Evaporation Method				Net Duty of Water by Field Plot		
					Cons. Use	Eff. Precip.	Wat. Req.	Net Duty	Inches	Corrected	Wat. Req.	Net Duty	Inches	Soil Used	Est. Prec. Eff.
Oregon															
Corvallis	266	4/1-10/1	184	9202	27.2	6.36	20.8	26.1	28.3	21.8	15.4	19.3	18	Willamette S.C.L.	80
Moro	1838	5/3-10/15	165	7490	24.0	2.29	21.7	27.2	39.3	30.3	28.0	35.5	36*	Walla Walla S.L.	80
Pendleton	1495	5/3-10/5	155	7545	24.2	2.11	22.0	33.8	32.5	25.0	22.9	35.2	36	Walla Walla S.L.	65
Harney	4139	6/7-9/3	88	4519	18.6	0.92	17.7	22.1	23.9	18.4	17.5	21.9	20	Wingville Silt Loam	80
WarmSpring (Malheur)	3310	5/20-9/20	123	6245	21.7	1.69	20.0	25.0	40.0	30.8	28.1	35.1	36	Loam Soils	80
Hermiston	624	4/29-10/9	163	8549	26.0	1.03	25.0	50.0	36.4	28.0	27.0	54.0	56	Aphreta Loamy Sand	50
Tulelake	4055	5/23-9/17	117	5567	20.5	1.62	18.9	33.0	23.1	17.8	16.2	27.0	30	Surprise Sandy Loam	60
Medford	1425	5/6-10/14	161	7951	24.9	3.56	20.3	25.4	34.0	26.2	22.6	28.3	30	Meyer Clay Adbe	80
Venezuela		Dry Season													
Guataparo	1500	11/1-3/31	151	8320	25.7	3.30	22.4	34.5	30.5	23.5	20.2	31.1	30	Maracay Silt C.L.	65
Suata	1600	12/1-4/31	151	9568	27.9	2.40	25.5	42.5	27.3	21.0	18.6	31.1	30	Valencia Sandy Loam	60
Neverí	10	11/1-31/4	181	11,186	30.8	0.64	30.2	43.1	51.2	39.4	38.8	55.4	56*	Barcelona Cl. L	55

* These data were estimated. At Moro, dry farming method is used. In Neverí was estimated.

FIGURE 1

DISTRIBUTION OF NET DUTY OF IRRIGATION WATER

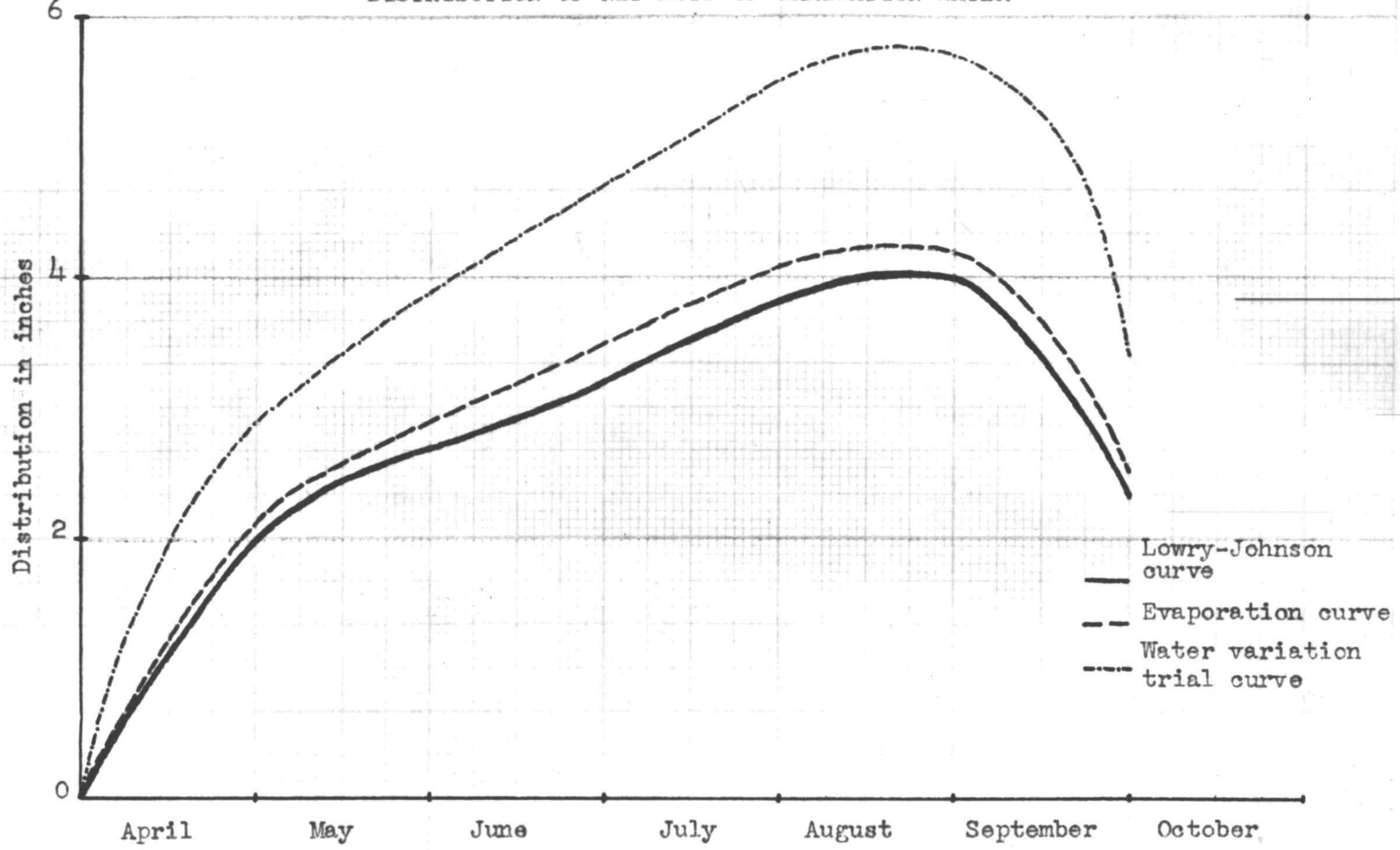
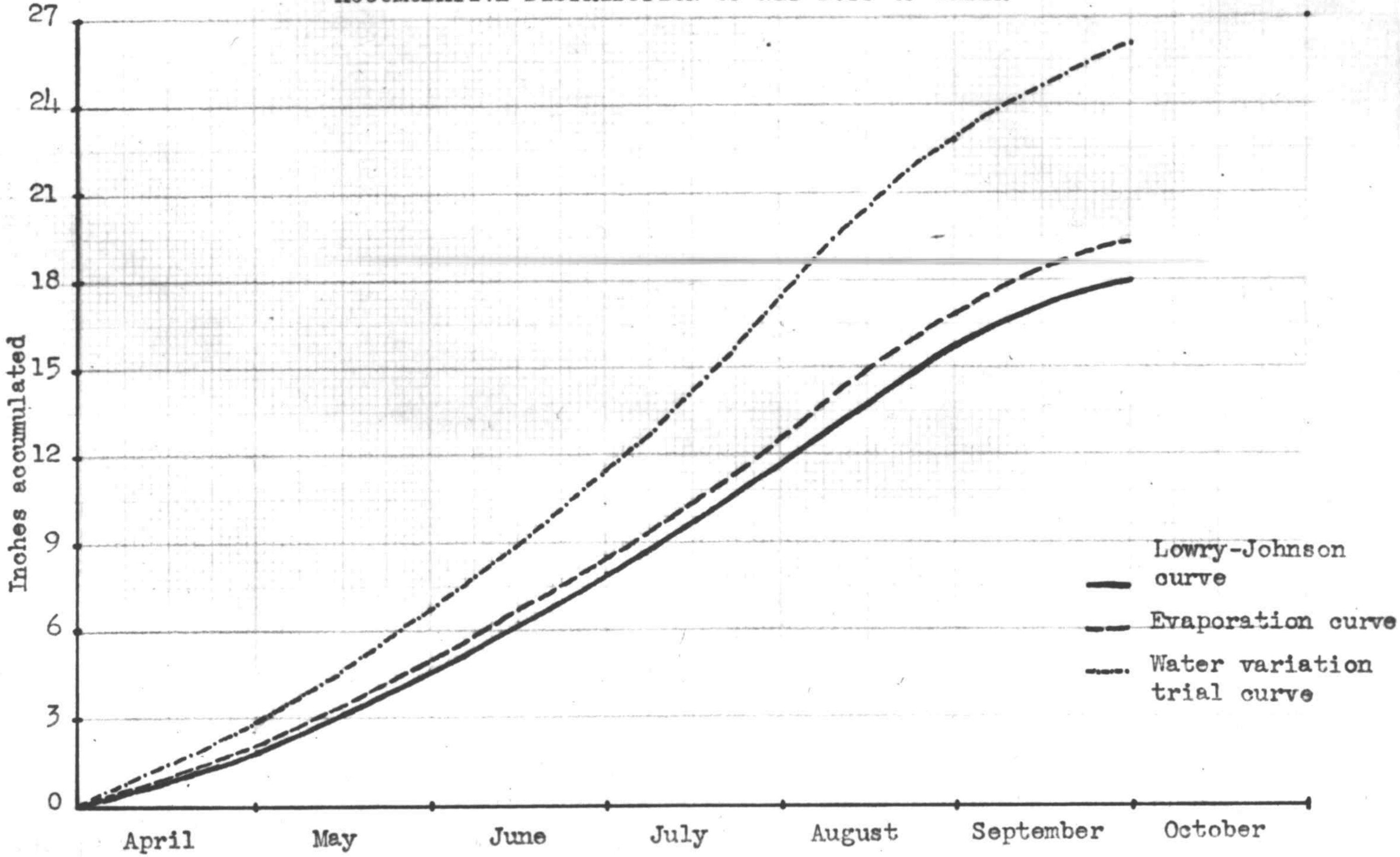


FIGURE 2

ACCUMULATIVE DISTRIBUTION OF NET DUTY OF WATER



DISCUSSION OF RESULTS

The best indicator of water requirement for crops was considered the water variation trial plots method, because it follows closely the changes in the moisture content of the soil indicating the water used by the crops and lost by evaporation. It is also an indicator of the actual amount of moisture in the soil under optimum growing conditions of the crop.

The evaporation method gave results that closely approximated those of the water variation trial. The curves in Fig. 1 and 2 show small differences in the results of these two methods which are almost negligible under practical conditions.

The curves plotted from the data calculated under the Lowry-Johnson method gave somewhat different values as compared with the method outlined above. At the Stations of Corvallis, Harney, Klamath Project in Oregon and Guataparo and Suata in Venezuela, the net duty of water calculated by heat units gave larger results than the comparative data from water variation trial plots. At the other stations studied results were smaller as compared with the water variation trial method. The consumptive use under the Lowry-Johnson method is determined for average conditions and sometimes it has been found that in regions with the same number of heat units there are differences in consumptive use. These differences are mainly due to humidity, length of the growing season, type and distribution of the crop and many other factors. Another cause of variation is the necessity of correcting the result from the curve, because it represents the consumptive use for a full 12 months period and also includes water losses by bare soils and native vegetation, which results in higher irrigation requirements. Consumptive use calculated by Lowry-Johnson method is "valley consumptive use" and not "farm consumptive use".

A correction factor may be used for calculating the irrigation requirement for the cultivated area.

The differences between the evaporation, the Lowry-Johnson method, and the water variation trial, is partly due to the difficulty in estimating the effectiveness of the precipitation, and also in values given to take care of the losses by deep percolation in certain soils, which require large heads of water for irrigation. In the water variation trial, precipitation and deep percolation are already considered when the net duty is found. For example, when it is said a net duty of 30 inches is required for a certain crop, then, this means that under average climatological conditions and with a known type of soil, this crop used 30 inches including the effective precipitation and deep percolation losses, if any.

In the determination of net duty of water by variation trials, the study of the percolation and depth of the water table is of considerable importance in the accuracy of the results obtained.

The efficiency of the total precipitation depends upon the season of the year, frequency of storms and their intensity, type of vegetation, the slope of the ground, and character and condition of the soil, besides the climatological conditions. Allowances have been made in calculating net duty in the Lowry-Johnson method and evaporation method as shown under the column of the Table No. 3 headed "Estimated Precipitation Efficiency". Accurate determinations of efficiency were not possible because of the many variable factors involved, such as variations of soils and relatively small areas, lack of accurate equipment, personal error, uneven distribution of rainfall, variation of fertility level and differences in the cropping system followed.

Evaporation and Lowry-Johnson method may be used in the field, but experimental work should be done to determine as accurately as possible the water losses by percolation, and addition of water by precipitation or from the water table. This work should be done on experimental plots. The lack of precision in these methods does not void them, but on the contrary, they provide an easy way to calculate the water necessary to irrigate an area.

Figure No. 1 shows the distribution of water during the growing season. Evaporation is considered the more comparable to the water variation trial curve. The use of this method with the allowances stated, will give more accurate results in those regions where evaporation data are available.

In the Lowry-Johnson method the crops are a corollary to the number of heat units. In the application of this method to a particular location, careful consideration must be given and proper correction made for differences in consumptive use, which may arise from irrigation practices, crop types, etc. The net duty calculated on the basis of relative pan evaporation was more satisfactory, but temperature records are available nearly everywhere and the effective heat method has a correspondingly wider field activity.

CONCLUSION

1. The water variation trial on representative plots is considered the most appropriate indication of the quantity of water to be applied to meet the irrigation requirements of crops. This system takes much time and labor, but it is well adapted for obtaining reference data. However for practical considerations it is too laborious and time consuming to employ in larger areas. This is mainly due to variations in climate, altitude, soil topography, methods of irrigation and crops grown.

2. The Lowry-Johnson method presents a fair comparison to the water variation trial method. It is more usable because of the availability of the data used in its calculation. Maximum daily temperature and precipitation are used for calculation, and are found nearly everywhere. Correction factors should be introduced to adapt it to the region under study.

3. Evaporation is an expression of the combined effects of the drying capacity of the atmosphere. The losses of water from soil and plants are compared with the evaporation from an open water pan. Evaporation is used as an indicator of these losses, and has been found the best general indication of the farm consumptive use in any region. The meteorological condition influencing

evaporation from water surfaces likewise affect transpiration from vegetation and evaporation from soils. The relation between evaporation losses from free water surfaces and consumptive use is not always constant, but it provides a means of making an approximate estimation of the consumptive use and an approach to net irrigation requirements as determined by long continued water variation trials.

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