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IRRIGATION REQUIREMENTS IN LATIN AMERICAN COUNTRIES

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INTRODUCTION

With increasing needs for the developments of their natural resources, many Latin American countries are placing increased emphasis upon irrigation and the evaluation of the availability of moisture requirements for agricultural production. This is especially true of the northern South American and Central American countries such as Venezuela, Colombia, Ecuador, El Salvador, Honduras and Nicaragua, where studies have been initiated. In some instances, project development has been undertaken where more careful studies may have indicated that the benefits to be derived from irrigation could not justify the expenditures involved. The need for irrigation in many places was not clearly established before the projects were constructed. This is unfortunate in that development capital might be more profitably used for other purposes such as fertilizers, flood control, transportation, etc. There appears to be a need for an overall study to more precisely determine the irrigation requirements. There is also a real need to define and use procedures that can be applied to all of the countries involved.

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Development of Formulas & Equations

The development of formulas and other relationships used in this study has been accomplished primarily by the senior author over a period of years working with graduate students at Utah State University. To date, some 14 Master of Science theses and some special reports have been completed on various phases of this problem. Concurrently, the junior author worked on the problems under the auspices of the Bureau of Reclamation, Agency for International Development and the Inter-American Geodetic Survey, and published several papers. These papers and theses are listed in the Bibliography. Space does not permit references to the vast bibliography now available on this subject.

Geographical & Climatological Characteristics

The countries in which studies have begun have many geographical and climatological characteristics in common, but they also have some very distinct differences. They all lie in the tropical zone, and have a twelve-month growing season when soil moisture is available. At any given location, mean monthly temperatures are fairly constant, generally varying less than 3°C during the year. The temperature, however, varies greatly from place to place, depending primarily on the elevation above sea level, and agriculture is carried on to elevations well above 3,000 meters in some of the Andean valleys of Ecuador, Colombia and Venezuela. The mountains are generally lower in Central America but rise to fairly high elevations in Guatemala.

The precipitation patterns are generally similar, but the mean annual amounts vary widely from less than 400mm per year in the more arid regions to more than 6,000mm per year in the wetter areas. In some places, the mean annual precipitation varies more than two to one in distances of only a few kilometers. This is particularly noticeable in the states of Lara and Merida in Venezuela, where there are very arid and very humid areas in close proximity. In general, the dry period begins in November or December and ends in April or May. There are, however, differing seasonal lags. The rainy season extends to February from Curarao to Trinidad,

while it terminates in early October in the Yucatan. In some places precipitation is insufficient for optimum crop growth during every month of the year, and in other locations, precipitation is adequate during every month.

Although for any given location there is little variation in mean temperature from month to month, there is usually a relatively large variation in relative humidity, precipitation, sunshine percentage and wind velocity, and this is reflected in evaporation measurements. Evaporation is sometimes more than twice as much during the months of March and April as for the months of May to October. The daytime period from sunrise to sunset is fairly constant from month to month, generally varying less than one hour from January to July. Methods of estimating evapotranspiration based primarily on day length and mean monthly temperature, consequently, do not yield satisfactory results.

Terminology

The terminology used in the paper is that generally employed by American Engineers and Agriculturalists, but some terms have not been well standardized and may need defining. The following definitions and explanations are given to avoid misunderstanding.

Potential Irrigation Requirement, on a monthly basis, as used here is the estimated potential evapotranspiration less the dependable precipitation, as hereinafter defined. This potential irrigation requirement may be less than the actual irrigation requirement because it does not consider the irrigation efficiency, conveyance losses and drainage characteristics. For some months, where annual crops are grown, it may be more than the actual requirement because it assumes a full (100%) crop cover. Therefore, in project development, allowance must be made for storage and transmission losses in the system, for the irrigation application efficiency and kind of crop to be grown. These factors can be best estimated on a local basis so that proper allowances can be made in the project design.

Potential Evapotranspiration, ETP, is defined as the evapotranspiration loss from a short, vigorously growing, green crop that completely shades the ground (crop cover 100%) and where soil moisture is not a limiting factor. This corresponds to definitions given by Penman, Thornthwaite, Pruitt and others. This potential evapotranspiration may be less than that consumed by some taller crops, having a much greater total leaf surface, such as alfalfa, sugar cane, and bananas. It is greater than the consumptive use of annual crops during certain stages of growth. Total consumptive use requirements, on a project basis, must consider the crops to be grown and their monthly crop coefficients.

Actual Evapotranspiration or Consumptive Use depends not only on the potential evapotranspiration but on many other factors that reflect local conditions, including primarily, the percentage of crop cover, the availability of soil moisture, and depth and distribution of rooting of the crop. Much research has been done to determine relations between the soil moisture potential and evapotranspiration. Space does not permit a thorough discussion of this subject. The crop cover percentages, and the effect of maturity of the crop on evapotranspiration varies widely with different crops and is quite different for annual crops than for perennial crops.

The timing for planting, cultivation, and harvesting of annual crops in the tropics is very different than in the temperature zone and depends primarily on the precipitation patterns rather than upon the temperature. It has been found in Venezuela, for example, that little field work such as planting or cultivating, can be done in any month when the precipitation exceeds about 80mm. Some fairly dry periods during the year are, therefore, essential for the production of such crops. Harvesting can also be accomplished more effectively during the drier periods. A fully adequate moisture supply every month of the year is not necessarily the most desirable for annual crops, but is generally most desirable for perennial crops, including pastures and orchards.

Pan Evaporation is that evaporation measured with a Class A evaporation pan under standard conditions. Many Class A pan installations do not meet these standards, and the effect is generally to increase the evaporation. For example, in comparing the evaporation from a standard pan in a large grassed area, with a nearby pan on bare soil, Pruitt[9] found that the evaporation from the pan on bare soil was more than 20% higher during the summer months than that from the pan on the grassed area.

Discoloration inside the pan, or on the outside increases the absorption of radiant energy and increases the evaporation. Shading, reduced air movement over the pan resulting from nearby obstructions, screens over the pan, etc., may reduce the evaporation below that of a standard pan.

Class A pans provide a convenient drinking fountain for birds and sometimes for animals in many arid places, and measurements may be unreliable unless the pans are screened. The effect of screens is to reduce evaporation, but the relative amount is not well understood. For these reasons, pan evaporation measurements are not always reliable and are usually somewhat higher than for a standard pan properly cared for.

Dependable Precipitation, PD, is herein defined as the mean monthly precipitation that occurs on a probability basis three years out of four, or seventy-five percent of the time. This 75% probability basis is arbitrary but has been selected by the authors as being a practical and realistic value to use for general conditions.

In most agricultural areas precipitation varies widely from year to year, both in annual amounts and with respect to monthly values. These variations are particularly notable during transition months. For example, in the tropical areas of Central America, the Carribean, and northern South America, April is a transition month. Rainfall in April of one year may be as much as one-hundred-times the rainfall during April for the preceeding year. Under these conditions average precipitation is not a reliable measure of the amount of moisture that can be depended on for agricultural production.

In defining dependable precipitation it is necessary to consider the crops to be grown. Bananas and tobacco are much more sensitive to drought than are general crops. In the planning for the production of bananas on a commercial scale, it seems desirable to select conditions where the probability of having adequate moisture in any one month is in the order of 85% to 90% of the time. Since there will be some moisture carryover from previous months, some deficiency one year in ten or one in seven is not considered critical to economic production.

This study considers general agricultural production. For a diversified agriculture including most tree and field crops it is believed that some deficiency can be tolerated in a given month during one year out of four. The seriousness of economic loss is decreased because of the probability that one deficient month will not follow or be followed by a deficient month and also because many soils are capable of carrying forward 100 to 200mm of available moisture in the crop root zone.

For the precipitation data from Latin America that have been analyzed, the dependable precipitation has been found to vary from zero for the driest months, to from 20% to 40% of the mean monthly precipitation in the more arid locations and for the transitional months, to more than 80% of the mean monthly precipitation for the wettest months.

Effective Precipitation, PE, is the amount of the precipitation that enters the soil and is held within the root zone for utilization by the crops grown. This effective precipitation is dependent upon many factors, including rainfall intensities, vegetative cover and soil infiltration rates, land slopes, root zone depths, soil drainage conditions, the soil moisture and storage capacity and the evapotranspiration rates. It does not appear feasible to include estimates of the effective precipitation in country-wide or regional studies. It seems preferable to leave consideration of this subject to those engaged in local project studies. In areas where precipitation intensities are high and infiltration rates relatively low, runoff may account for an appreciable percentage of the precipitation, and the effective precipitation may be appreciably less than the dependable precipitation as used herein.

Climatic Parameters. The climatic parameters that have greatest influence on the evapotranspiration are: temperature, humidity, in min, solar radiation, and wind velocity. In most countries, radiation is measured at relatively few locations. Sunshine hours, or sunshine percentage, is generally measured and reported for many more stations. Precipitation is measured in many locations where no other measurements are made. In Venezuela there are many locations where precipitation and pan evaporation are measured, and some places where temperature, or temperature and relative

humidity, are also measured. Where Class A pan evaporation is measured, wind velocities at a height of 60 cm above ground level are usually measured and reported but not always. Wind velocities are also sometimes measured at two, six or ten meters above ground level. Sometimes, wind velocities are measured and reported but no mention is made of the height of annemometer, or method of measuring the wind velocity.

Since the available data range from a large amount of precipitation data to relatively few data from stations that measure and report complete data, much time and effort has been spent in developing relationships from which missing data can be reliably estimated from that reported. Wind velocities vary with height above ground. A study of available data by Gutierrez[18] indicated that none of the published formulas can be used to obtain reliable estimates of the wind velocity at a standard height when measured at another height. Several formulas for adjusting wind velocities that give satisfactory results have been developed for this purpose.

Many of the climatic parameters are interrelated. For example, a correlation has been found between sunshine percentage and the mean relative humidity and also temperature differences. In the countries involved in these studies, there are fairly satisfactory relationships between mean temperature and elevation, when considered on a monthly basis. All of these relationships have been used to fill in and expand the available data so that they can be analyzed with a digital computer. The development of the many relationships involved in these studies has consumed much time and effort.

OBJECTIVES AND PROCEDURES

Potential Irrigation Requirement

As has been indicated, the principal objective of the studies has been to reliably estimate the potential irrigation requirement as previously defined. Since this depends on the dependable precipitation, as well as on the potential evapotranspiration, it was necessary also to make the best possible estimates of these parameters, and then to combine the results in tabular form, and where feasible to plot the results on maps.

Dependable Precipitation, PD

Precipitation for a large number of stations (more than 100 in Venezuela, 110 in Ecuador, 62 in Colombia, and 13 in El Salvador) have been tabulated, key punched, and frequency analysis have been made. Periods of record for these stations have ranged from a minimum of 4 years to 75 years for one station in Venezuela. The 75% probability values, together with the minimum, mean and maximum monthly values, were then key punched and several relationships have been developed from which the dependable monthly values could be estimated from either the mean precipitation, where only mean values are available, or from the mean and minimum monthly values where such data are available. For the Venezuela data, the best fit was obtained when separate equations were used for each month, but a very satisfactory general relationship was developed using coefficients (A and B) based on the mean annual precipitation. In the following equations, the notation is, PM, mean monthly precipitation, PL, minimum monthly precipitation for period of record, and PMA, mean annual precipitation.

The monthly equations were of the form,

$$PD_M = A_M + B_M P_M + C_M PM^2 \qquad [1]$$

$$PD_M = A_M + B_M (PM + PI) \qquad [2]$$

in which the subscript M refers to the month and where the monthly values of A_M ranged from -5 to -20 (mm/mo), B_M from .412 to .797, and C_M from .0004 to .0005.

The best general relationship was of the form,

$$PD = A + B (PM) \qquad [3]$$

where

$$A = -.02\ PMA \qquad [4]$$

and

$$B = .27\sqrt{PMA/100}, \text{ with a maximum value of } 0.91 \qquad [5]$$

Estimating Pan Evaporation, EVP and Potential Evapotranspiration, ETP

Since Class A pan evaporation data are numerous in comparison with potential evapotranspiration data, and also because most investigators reporting evapotrans-

spiration data have compared their results with pan evaporation, the first attempts at developing a general equation were for pan evaporation. This work was done in connection with a study of Water Requirements of Marshlands (Christiansen and Low 1969), and the studies of Patil[15,25]. A later study by Patel (Patel and Christiansen[24]) showed that this type of formula developed from data from semi-arid locations gave better results than several with which it was compared when applied to data from more humid locations.

The general equations for pan evaporation, EVP, and potential evapotranspiration ETP, are

$$EVP = K_{EV}\, R_T\, C_T\, C_{HV}\, C_{WV}\, C_S\, C_E \qquad [6]$$

$$ETP = K_{ET}\, R_T\, C_T\, C_{HT}\, C_{WT}\, C_S\, C_E \qquad [7]$$

in which

K_{EV} is an appropriate dimensionless constant for pan evaporation;

K_{ET} is a similar constant for potential evaporation;

R_T is the extraterrestrial radiation, computed for month and latitude, and expressed as equivalent evaporation by dividing the radiation (cal/cm^2/day) by the heat of vaporation at the mean temperature, T_M, and converting to appropriate units, usually inches or mm per day or per month (Table 1);

C_T is a dimensionless coefficient dependent on the mean temperature (the same value can be used for estimating pan evaporation and for evapotranspiration);

C_{HV} is a similar coefficient dependent on the mean humidity (the humidity coefficient for evapotranspiration, C_{HT}, is somewhat different, since potential evapotranspiration varies less with humidity than does pan evaporation);

C_{WV} is a dimensionless coefficient for wind velocity, likewise slightly different from the coefficient for wind, C_{WT}, used for estimating evapotranspiration;

C_S is a coefficient for sunshine percentage;

C_E is a coefficient for elevation.

The coefficients are dimensionless and most of them are of the general form,

$$C_P = A + BX + CX^N$$

where

C_P represents the coefficient for the specific parameter, P;

X represents the ratio, P/P_0, where P is the parameter and P_0 is the standard value of the parameter, approximately a mean value;

N is an exponent of X, usually having a value of 2.

Note that A + B + C = 1.00.

Tentative values of these constants and coefficients for pan evaporation and evapotranspiration are:

$$K_{EV} = .35 \qquad [6a]$$

$$K_{ET} = .28 \qquad [7a]$$

$$C_T = .40 + .50\,(TM/25) + .10\,(TM/25)^2 \qquad [6b]\ [7b]$$

(TM is mean temperature in °C)

$$C_{HT} = [(1.00 - HM)/.30]^{.25} \qquad [7c]$$

(HM is mean relative humidity expressed decimally)

$$C_{HV} = -.60 + 1.60\, C_{HT} \qquad [6c]$$

$$C_{WV} = .60 + .46\,(W\ 10/8) - .06\,(W\ 10/8)^2 \qquad [6d]$$

(W 10 is wind at an instrument height of 10m in Km/Hr.)

$$C_{WT} = .70 + .36\,(W\ 10/8) - .06\,(W\ 10/8)^2 \qquad [7d]$$

$$C_S = .48 + .66\,(S/.5) - .14\,(S/.5)^2 \qquad [6e]\ [7e]$$

$$C_E = 1.00 + .06\,(EL/1000) \qquad [6f]\ [7b]$$

(EL is elevation in meters)

ETP is defined as that equivalent to evapotranspiration for rye grass measured with a 20-foot (6.1 m) diameter weighing lysimeter (Pruitt[8,9,10]).

Pan evaporation and potential evapotranspiration can likewise be estimated from measured solar radiation R_S, and climatic data.

The general equations are:

$$EVP = K_{SV} R_S C_T C_{WV} C_{HV} \quad [8]$$

$$ETP = K_{ST} R_S C_T C_{WT} C_{HT} \quad [9]$$

in which K_{SV} and K_{ST} are appropriate constants and R is the measured incoming radiation expressed in terms of equivalent evaporation. When using measured radiation, coefficients for sunshine and elevation can be omitted.

Our studies have shown that reliable estimates of incoming radiation can be made from an equation originally developed by Pizarro[26].

$$R_S = K_R R_T C_S C_E \quad [10]$$

in which the coefficients C_S and C_E are the same as given in 6e, 6f.

Values of K_{SV}, K_{ST} and K_R that give fairly good results for both Davis, California, and Venezuela and Ecuador are:

$$K_{SV} = .69 \quad [11]$$

$$K_{ST} = .55 \quad [12]$$

$$K_R = .51 \quad [13]$$

It can be seen that for consistant relationships,

$$K_{EV} = K_R K_{SV}, \text{ and} \quad [14],$$

$$K_{ET} = K_R K_{ST} \quad [15]$$

ETP Using Vapor Pressure Deficit

Since according to Dalton's law, evaporation is a function of the vapor pressure deficit, an attempt was made to develop a satisfactory formula using the vapor pressure deficit, or a coefficient for vapor pressure deficit, in lieu of the separate coefficients for temperature and humidity. The best fit was obtained with the latter, and the equation for the coefficients for vapor pressure deficit in millibars, VPDMB, were

$$C_{VPDV} = .25 + 1.00 (VPDMB/10) - .25 (VPDMB/10) \quad [16]$$

$$C_{VPDT} = .32 + 0.86 (VPDMB/10) - .18 (VPDMB/10) \quad [17]$$

These coefficients, however, did not give as good a fit as did the separate coefficients, CT and CH. The vapor pressure is seldom reported in meteorological records, and therefore must be computed from the temperature and humidity using certain assumptions that at best are only approximations. The principal difficulty is that the evaporation from the pan is actually a function of the difference in vapor pressure of the water in the pan and the vapor pressure in the atmosphere above the water surface. The water temperature is not the same as the air temperature. The water temperature lags behind the air temperature, and the mean daily value of the difference depends on the cooling effect of the evaporation, which in turn depends on parameters causing the evaporation, such as humidity and wind. From a practical point of view there appears to be no advantage in using vapor pressure deficit, or a more theoretical approach, because it greatly complicates the problem if one is to obtain an equally good fit.

Where Sunshine Percentage and Radiation are not available

A problem that has presented itself in connection with the Latin American study is how to obtain equally satisfactory results when neither sunshine percentage nor radiation data are available. In Ecuador, for example, only 18 of 114 climatological stations report the sunshine percentage, and for those that do, the mean value was about 30%, much lower than for any other country that has been studied. Only 5 stations report measured radiation. In Venezuela, 9 of 13 stations operated by the Ministry of Public Works, MOP, or Ministry of Agriculture, MAC, report sunshine, and only 8 report radiation. Because of the interrelationships between sunshine percentage, humidity and the difference between the mean monthly values of maximum and minimum temperature, three possible approaches were investigated:

(1) Determine the mean monthly value of sunshine percentage for the stations for

which it is available, and use these values for all stations for which it is not available.

(2) Determine the best relationship between sunshine percentage and other parameters, temperature, temperature difference, humidity, elevation, etc., and use such relationship to estimate sunshine percentage.

(3) Develop equations and coefficients for computing evaporation and evapotranspiration that do not include coefficients for sunshine percentage. This approach has given the best fit for the Davis, California, Venezuela, and Ecuador data. The equations that have been developed are:

$$ETP = K_{ET2}\ R_T\ C_{T2}\ C_{H2}\ C_{W2}\ C_{TD} \qquad [18]$$

$$EVP = 1.35\ ETP \qquad [19]$$

in which

$$K_{ET2} = .264 \qquad [18a]$$

$$C_{T2} = \sqrt{TM/25} \qquad [18b]$$

$$C_{H2} = .50 + .50\ (1.00-HM)/.30 \qquad [18c]$$

$$C_{W2} = .70 + .30\ W\ 10/8 \qquad [18d]$$

$$C_{TD} = .90 + .10\ TD/10 \qquad [18e]$$

(TD is mean maximum minus mean minimum temperature in °C)

R_T = as previously defined.

Potential Irrigation Requirements

Computer programs were developed for computing the monthly evapotranspiration deficit, or difference between the computed potential evapotranspiration and the dependable precipitation. Since for most locations, only precipitation data, or precipitation and pan evaporation data are available, potential evapotranspiration must be estimated from the relationships developed from the data for the limited number of stations for which climatic and/or evaporation data are available. For example, in Venezuela, the mean monthly ratios of the computed potential evapotranspiration to the measured pan evaporation were used to estimate potential evaporation for the 53 stations for which pan evaporation was available. For the other stations for which only precipitation was available, monthly estimates of pan evaporation or evapotranspiration were made from relationships that depended on location, elevation of the station, and monthly precipitation. Since the computed evapotranspiration does not vary nearly as much from place to place as does precipitation, the probable accuracy in the final result is more dependent on the reliability of the precipitation data than on estimated evapotranspiration.

Examples of computer print-out for two stations in Venezuela are given in Tables 2 and 3.

Table 2 represents a humid location where the mean annual precipitation is 2,616 mm, and where there is only a very small deficit during four months of the year. Irrigation would not be economically justified under such conditions. The precipitation pattern for this station is also not typical of most locations in Venezuela.

Table 3 is for an arid location where the mean annual precipitation is only 628 mm per year, and where the ET deficit, or potential irrigation requirement has a positive value every month of the year, ranging from a 78 mm in November to 266 in July. This monthly distribution is not typical of most places in Venezuela where the maximum ET deficit is for March.

Print-outs of this kind have been made for the 53 stations for which only precipitation and pan evaporation data are available. The evapotranspiration deficit (potential evapotranspiration minus dependable precipitation) provides an index of potential irrigation requirements.

CONCLUSION

Class A pan evaporation data have been widely used as a measure of irrigation requirements. Since, however, reliable and well-standardized evaporation data are not generally available, the authors recommend the use of equations for estimating potential evapotranspiration. These equations are evaluated in each area of use by comparing their results with measured pan evaporation data. Potential evapotranspiration can be calculated with a good degree of accuracy provided data are available for temperature, sunshine percentage, wind and humidity.

Table 1. Mean Monthly Values of Extraterrestrial Radiation

Latitude degrees	Expressed as equivalent evaporation in millimeters per day											
	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
North												
60	1.41	3.36	6.88	11.31	15.14	17.06	16.25	13.03	8.67	4 58	1.92	0.96
55	2.55	4.62	8 08	12.18	15.55	17.18	16 50	13.71	9.77	5.85	3.11	2.02
50	3.77	5.89	9.23	12.98	15.93	17.30	16.73	14.34	10.79	7.09	4.35	3.21
45	5.04	7.14	10.30	13.69	16.23	17.38	16.91	14.87	11.74	8.30	5.63	4.46
40	6.32	8.36	11.30	14.31	16.45	17.38	17.01	15.32	12.59	9.45	6 90	5.75
35	7.59	9 53	12 21	14.82	16.58	17.30	17.01	15.66	13.35	10.54	8.15	7.04
30	8.84	10.64	13.03	15.23	16.60	17.13	16 92	15.90	14.01	11.55	9.36	8.32
25	10.05	11 68	13.75	15.52	16.51	16.85	16.72	16.02	14.56	12 48	10.53	9.56
20	11.20	12.64	14.37	15.70	16.32	16.48	16.42	16.04	15.00	13.33	11.63	10.76
15	12.29	13.51	14.88	15.77	16 02	16.00	16 02	15.93	15 33	14 07	12.66	11.91
10	13.30	14.28	15.27	15.72	15.61	15.42	15.51	15.72	15.54	14.71	13.61	12.98
5	14.23	14 96	15.55	15.55	15.09	14.74	14.90	15.39	15 63	15.24	14.47	13.98
0	15.07	15.53	15.71	15 27	14.47	13.97	14.19	14.95	15.61	15.66	15.23	14.90
South												
—5	15.81	15.98	15.75	14.88	13.76	13.12	13.39	14.41	15.46	15.96	15.89	15.72
—10	16.45	16.33	15.67	14.37	12 95	12.18	12.51	13.76	15.20	16.15	16.45	16.44
—15	16 98	16.55	15.48	13.76	12.06	11.17	11.54	13.01	14.82	16.21	16.89	17.06
—20	17.40	16.66	15.16	13.05	11.09	10.10	10.51	12.17	14.33	16.16	17.22	17.57
—25	17.71	16.65	14.73	12.24	10.05	8.97	9.42	11.25	13.73	15.99	17.43	17.97
—30	17.91	16.52	14.19	11.34	8 95	7.80	8.28	10.25	13.03	15.70	17 54	18.27
—35	17.99	16.27	13.54	10.36	7.80	6.61	7.10	9.18	12.23	15.29	17.52	18.46
—40	17.98	15.92	12.79	9.31	6 61	5.40	5.89	8.06	11.33	14.78	17.40	18.54
—45	17.86	15.46	11.94	8.19	5.41	4.19	4.69	6.89	10.35	14.16	17.18	18.54
—50	17.66	14.90	11 00	7.02	4.20	3.02	3.49	5.68	9.29	13.45	16.87	18.46
—55	17 40	14.25	9.98	5.81	3.01	1.90	2.34	4 46	8.16	12.64	16.49	18.33
—60	17.12	13 54	8.88	4.57	1.88	0.91	1.28	3.24	6.97	11.76	16.07	18.20

Table 2. Analysis of Pan Evaporation and Precipitation Data at La Fria, Venezuela - Elevation 120 m

Pan Evaporation for 1962 to 1967
Precipitation for 1950 to 1967

	JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEP	OCT	NOV	DEC	ANN
VALUES IN MILLIMETERS													
AVERAGE PAN EVAPORATION	136.	126.	140.	152.	148.	153.	172.	181.	182.	183.	121.	115.	1808.
AVERAGE EV-TRANS. POT.	93.	83.	89.	100.	107.	123.	140.	150.	143.	138.	92.	85.	1345.
AVERAGE PRECIPITATION	184.	163.	143.	278.	300.	144.	159.	163.	185.	320.	283.	300.	2616.
DEPENDABLE PRECIPITATION	129.	112.	95.	209.	228.	96.	105.	112.	131.	245.	214.	228.	2320.
AVERAGE ET DEFICIT	-37.	-28.	-6.	-109.	-120.	26.	35.	39.	12.	-107.	-121.	-143.	112.
AVERAGE MONTHLY PERCENTAGES													
PAN EVAPORATION	7.5	7.0	7.8	8.4	8.2	8.5	9.5	10.0	10.1	10.1	6.7	6.4	100.0
EVAPOTRANSPIRATION POT.	6.9	6.2	6.6	7.5	8.0	9.1	10.4	11.2	10.6	10.3	6.9	6.3	100.0
PRECIPITATION	7.0	6.2	5.5	10.6	11.4	5.5	5.9	6.2	7.1	12.2	10.8	11.5	100.0
DEPENDABLE PRECIPITATION	5.6	4.8	4.1	9.0	9.8	4.2	4.5	4.8	5.6	10.5	9.2	9.8	82.1
EVAPOTRANSPIRATION DEF.	.0	.0	.0	.0	.0	23.7	31.2	34.5	10.5	.0	.0	.0	100.0

Table 3. Analysis of Pan Evaporation and Precipitation Data at Carora La Granja, Venezuela - Elevation 420 m

Pan Evaporation for 1958 to 1967
Precipitation for 1950 to 1967

	JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEP	OCT	NOV	DEC	ANN
VALUES IN MILLIMETERS													
AVERAGE PAN EVAPORATION	256.	276.	306.	244.	231.	295.	328.	320.	264.	218.	182.	218.	3139.
AVERAGE EV-TRANS. POT.	175.	182.	194.	162.	168.	237.	266.	266.	207.	164.	140.	162.	2324.
AVERAGE PRECIPITATION	26.	11.	27.	50.	86.	27.	21.	39.	80.	119.	104.	33.	628.
DEPENDABLE PRECIPITATION	0.	0.	0.	21.	47.	0.	0.	7.	42.	75.	62.	2.	481.
AVERAGE ET DEFICIT	175.	182.	194.	140.	121.	237.	266.	259.	166.	89.	78.	160.	2068.
AVERAGE MONTHLY PERCENTAGES													
PAN EVAPORATION	8.1	8.8	9.8	7.8	7.4	9.4	10.4	10.2	8.4	6.9	5.8	7.0	100.0
EVAPOTRANSPIRATION POT.	7.5	7.9	8.4	7.0	7.2	10.2	11.5	11.5	8.9	7.1	6.0	7.0	100.0
PRECIPITATION	4.1	1.7	4.3	8.0	13.7	4.4	3.3	6.2	12.7	19.0	16.6	5.2	100.0
DEPENDABLE PRECIPITATION	.0	.0	.0	4.4	9.7	.0	.0	1.5	8.7	15.6	12.9	.4	53.1
EVAPOTRANSPIRATION DEF.	8.5	8.6	9.4	6.8	5.9	11.5	12.9	12.5	8.0	4.3	3.8	7.7	100.0

When sunshine data are not available, modified equations provide usable results.

The equations presented provide a measure of the effect of climatic zone differences upon plant or crop evapotranspiration. The principal other factors that determine the amounts of evapotranspiration are those relating to cultural practices and rates and stages of growth. Actual evapotranspiration can be made to vary over a considerable range by modifying cultural and irrigation practices.

Computations of potential evapotranspiration and of potential irrigation requirements prove a valuable starting point in the evaluation of climate as a development resource determination of the needs and requirements for irrigation and in the estimation of actual irrigation requirements. Methods described may be combined with crop coefficients given by Christiansen and Hargreaves[3] and used for the computer scheduling of irrigation applications or irrigation system operations. Dependable precipitation as herein defined is an important determining factor in the evaluation of climate or in the estimation of irrigation requirements.

The study reported here is still in progress and much remains to be done. The problem being studied at the moment is how to obtain the best estimate of potential irrigation requirement where only precipitation data are available.

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