AGENCY FOR INTERNATIONAL DEVELOPMENT
WASHINGTON, D. C. 20523
BIBLIOGRAPHIC INPUT SHEET

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0064

1. SUBJECT CLASSIFICATION	
A. PRIMARY	Agriculture — AP10-0000-0000
B. SECONDARY	Water resources and management

2. TITLE AND SUBTITLE
The evaluation of water deficiencies

3. AUTHOR(S)
Hargreaves,G.H.

4. DOCUMENT DATE	5. NUMBER OF PAGES	6. ARC NUMBER
1972	19p.	ARC

7. REFERENCE ORGANIZATION NAME AND ADDRESS
Utah State

8. SUPPLEMENTARY NOTES *(Sponsoring Organization, Publishers, Availability)*
(Presented at Am.Soc.of Civil Engineers,Irrigation and Drainage Div.Specialty Conf.,Spokane,Wash.)

9. ABSTRACT

10. CONTROL NUMBER	11. PRICE OF DOCUMENT
PN-RAA-013	

12. DESCRIPTORS	13. PROJECT NUMBER
Evapotranspiration Moisture Precipitation Water supply	
	14. CONTRACT NUMBER CSD-2167 Res.
	15. TYPE OF DOCUMENT

AID 590-1 (4-74)

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THE EVALUATION OF WATER DEFICIENCIES

KEY WORDS: water deficiency; potential evapotranspiration; dependable precipitation; moisture-availability index; adequacy percentage; moisture deficit.

ABSTRACT: A new equation is presented for estimating potential evapotranspiration. The seventy-five percent probability level of precipitation is used as dependable for determining moisture deficits and moisture availability yield relationships. Use of a moisture availability index is proposed. The percentage of time that rainfall is fully adequate is suggested for use.

THE EVALUATION OF WATER DEFICIENCIES

By George H. Hargreaves,[1] F. ASCE

INTRODUCTION

With increasing demands for development and for greater agricultural production, improved methodology in planning becomes more important. Sound development planning requires methods of comparing the needs for increased production with the natural resource potentials. The measurement of precipitation and the mean values of rainfall are not adequate for determining water adequacy or water deficiency. The amounts of water available need to be compared with requirements for production. The dependability of available water supplies should also be evaluated.

Many large areas having excellent soil conditions for crop and forage production are located in arid and semi-arid climates. A better evaluation of water deficiencies will permit more efficient use of water and land resources for increased production. Some investigators have made use of vegetation as an indicator of deficiencies and degrees of adequacy of moisture. Vegetative cover is, however, influenced to a large degree by past history of land use and by management practices. Methods of analyses using precipitation and temperature to estimate an index of degree of moisture adequacy have been widely used and appear to give satisfactory results under some climatic conditions.

This paper proposes concepts that further define both needs for moisture and its availability. Potential evapotranspiration, ETP, is used as an index of moisture need. Dependable precipitation, PD, that precipitation equaled or exceeded seventy-five percent of the time, based on available rainfall records, provides an index of dependable

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Note.— The work presented herein was financed in part by the Agency for International Development through its contract AID csd-2167 with Utah State University. The views presented herein are those of the author and do not necessarily represent those of the Agency for International Development or Utah State University.

moisture supply. A moisture availability index, MAI, is proposed as the index of moisture adequacy or deficiency. The percentage of occurrence with respect to time, adequacy percentage, AP, is proposed to further define the adequacy of precipitation for production. The data required to estimate these indices or relationships are precipitation, temperature, relative humidity, wind velocities and elevation. Records of percentage of possible sunshine or of measured incoming radiation are also useful. Equations have been developed from these parameters based upon a wide range of climatic conditions. These equations have been found to be applicable to weather conditions encountered in the various arid and semi-arid regions of the world.

DEFINITION OF TERMS

Actual Evapotranspiration, ETA, is the actual use of water by agricultural crops including direct evaporation from moist soils and wet vegetation. It depends on the climate, the crop, and the soil moisture supply. The climatic factors are considered in the estimation of potential evapotranspiration. Crop factors include percentage of ground cover, height and total leaf surface. Evapotranspiration is limited by soil moisture availability within the root zone.

Potential Evapotranspiration, ETP, is the amount of water transpired from an actively growing, short, green plant cover (usually grass) with a full crop cover and a continuously adequate moisture supply. It is considered to be dependent upon the climate and can be estimated from climatic parameters, the most important of which are available incoming radiation, temperature, relative humidity, and wind velocity. The incoming radiation is related to the extraterrestrial radiation that reaches the outer atmosphere, and the factors that influence its transmission through the atmosphere such as thickness of the atmosphere as determined by elevation, and the percentage of possible sunshine or cloudiness. These climatic parameters are not independent of each other but are interrelated in a complex manner. Evapotranspiration as measured by Pruitt (5)[2] at Davis, California, using twenty-foot diameter weighing lysimeters planted to grass is used as standard for potential evapotranspiration.

Dependable precipitation, PD, is the precipitation that has a specified probability of occurrence based on an analysis of long-time precipitation records. For irrigation development, a seventy-five percent probability level, or the rainfall that may be expected to occur three years out of four years, has been selected as a reasonable value for

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[2] Numerals in parentheses refer to corresponding items in the Appendix-References.

most conditions. For some crops, or special conditions, a different probability level may be more appropriate.

Moisture-Availability Index, MAI, is a measure of the adequacy of precipitation in supplying moisture requirements. It is computed by dividing the dependable precipitation by the potential evapotranspiration.

Adequacy Percentage, AP, is the percentage of years in the precipitation record during which precipitation for any given month equals or exceeds the potential evapotranspiration.

Moisture Deficit, ETDF, is the difference between potential evapotranspiration and dependable precipitation. A moisture excess is indicated by a negative deficit.

MOISTURE AND YIELDS

Production and yields vary with many factors. It is sometimes difficult to separate the effect that can be reasonably attributed to the availability of moisture. Draught resistance of crops and plants vary considerably. Some soils are capable of storing several times as much readily available soil moisture as others. Soil fertility and response to fertilizer application vary widely. Taking these conditions into consideration, a review of papers on alfalfa, pasture and grain responses to moisture and fertility indicate that moisture is considerably less effective in producing plant growth until moisture supplied is adequate in amount and distribution for establishing and maintaining a fair stand of vegetation. Between this point and about eighty to eighty-five percent of potential evapotranspiration, the effect of increased available moisture on alfalfa yields and range carrying capacity is roughly linear, unless yields at the higher moisture levels are increased due to fertilization or other factors. As potential evapotranspiration is approached the yield curve falls off, and for alfalfa, maximum yields are reached at about one hundred percent of potential evapotranspiration. Yields then sometimes decline with increasing moisture availability, depending upon level of fertility and adequacy of surface and sub-soil drainage. An approximation of the relationship between yield or production and the moisture availability index, MAI, is presented as Figure 1.

In many arid areas the occurrence of salinity makes it desirable that there be some leaching of salts from the soil profile. This consideration may make deficit irrigation undesirable. In the absence of soil salinity problems and in locations where rainfall during part of the year provides adequate leaching, deficit irrigation frequently provides the most economical use of water. The steepest portion of the yield curve is estimated to be between forty and eighty percent of potential

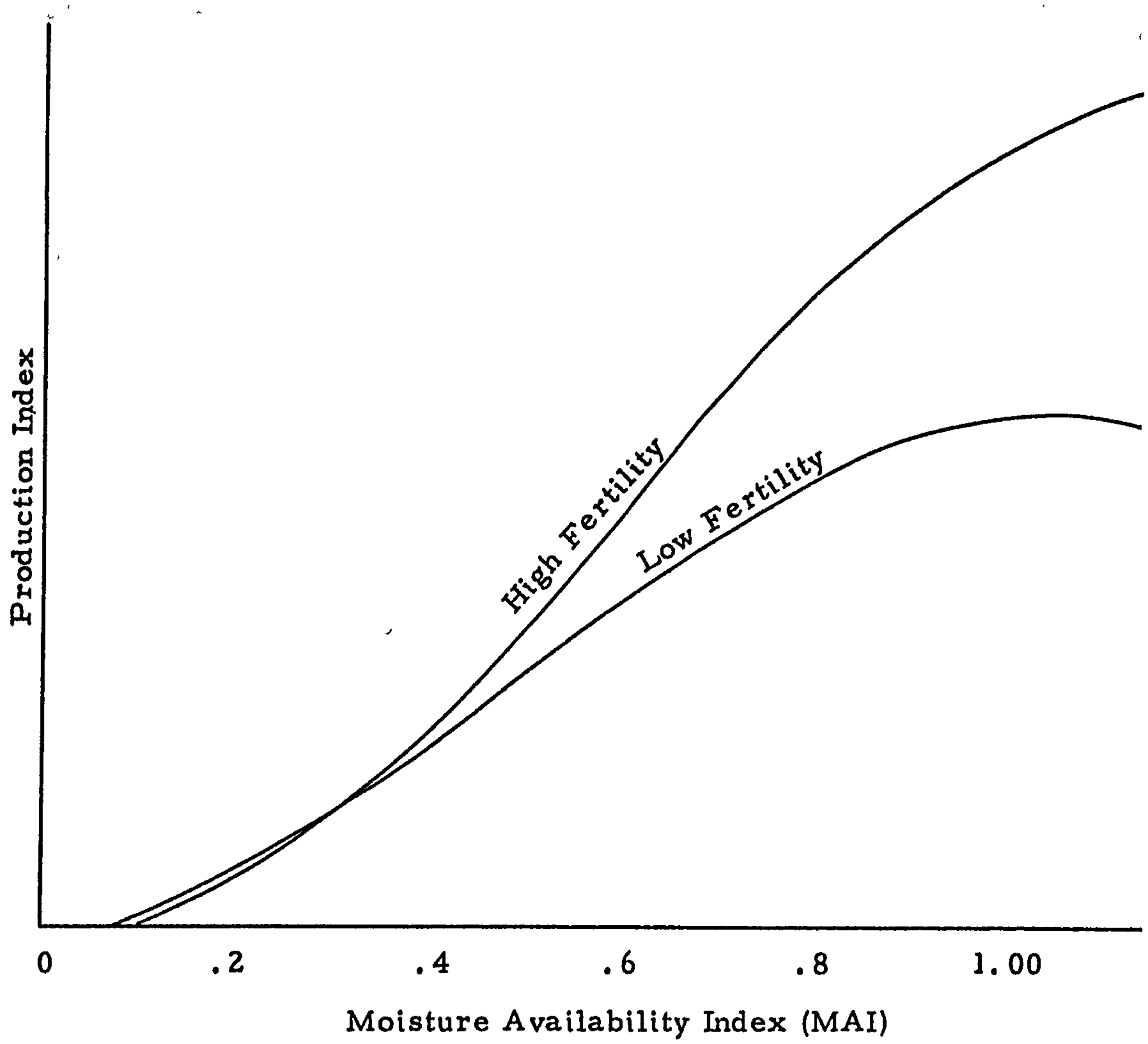

Figure 1. Approximate MAI-Production Function

evapotranspiration. Additional moisture within this approximate range produces the greatest increase in production per unit volume of water applied.

CLIMATE AND EVAPOTRANSPIRATION

Potential evapotranspiration is determined principally by climate. Major factors include the availability of energy and the removal and/or transfer of water vapor. Actual evapotranspiration of a given plant cover or crop depends upon potential evapotranspiration and plant and cultural characteristics such as rate and stage of growth, degree of ground cover, plant or crop roughness factor, irrigation or rainfall frequency and distribution, frequency and area of soil wetted, crop color and plant biological factors. Actual evapotranspiration is estimated by multiplying the potential evapotranspiration by a crop coefficient.

Potential evapotranspiration as defined above can be calculated with a good degree of accuracy from climatic data, providing reliable data are available for temperature, relative humidity, wind velocity and elevation. Christiansen and Hargreaves (2) give equations for potential evapotranspiration that can be written in the form

$$ETP = K \times RT \times C \qquad (1)$$

in which

ETP is potential evapotranspiration

K is a dimensionless constant

RT is the extraterrestrial radiation expressed as equivalent evaporation by dividing the radiation (cal/cm^2/day) by the heat of vaporization at the mean temperature, TM, and converting to appropriate units, usually inches or mm per day or per month (Tables 1 and 2)

C is a climatic coefficient.

The relationship between climate and grass evapotranspiration was evaluated from data supplied by Pruitt (6) for Davis, California. Class A pan evaporation data from several countries were related to extraterrestrial radiation, temperature, humidity, wind and elevation. In deriving equations an attempt was made to use reliable data from first order stations. Many of the evaporation pans were inspected to evaluate exposure conditions. The influence of climatic elements on evapotranspiration-pan evaporation (ET/EP) ratios was evaluated using data furnished by Pruitt (6), Pruitt and Lourence (7), the California State Department of Water Resources (1), and Goldberg and Gornat (3).

Table 1. Mean Monthly Values of Extraterrestrial Radiation

Latitude Degrees	Expressed as Equivalent Evaporation in Millimeters Per Day											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	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

Table 1. (Continued)

Latitude Degrees	Expressed as Equivalent Evaporation in Millimeters Per Day											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
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. Mean Monthly Values of Extraterrestrial Radiation

Latitude Degrees	Expressed as Equivalent Evaporation in Inches Per Month											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
North												
60	1.73	3.70	8.40	13.35	18.47	20.14	19.83	15.90	10.24	5.59	2.26	1.17
55	3.11	5.10	9.87	14.39	18.98	20.29	20.14	16.74	11.54	7.14	3.67	2.47
50	4.60	6.49	11.26	15.33	19.44	20.43	20.42	17.50	12.75	8.66	5.14	3.92
45	6.15	7.87	12.58	16.17	19.81	20.53	20.64	18.15	13.86	10.13	6.65	5.45
40	7.72	9.21	13.79	16.90	20.08	20.53	20.76	18.70	14.87	11.54	8.15	7.02
35	9.27	10.50	14.91	17.50	20.23	20.44	20.76	19.12	15.77	12.86	9.63	8.59
30	10.79	11.73	15.91	17.98	20.26	20.23	20.65	19.40	16.55	14.10	11.06	10.15
25	12.26	12.87	16.79	18.33	20.16	19.91	20.41	19.56	17.20	15.24	12.43	11.67
20	13.67	13.93	17.54	18.55	19.92	19.46	20.04	19.57	17.72	16.26	13.74	13.14
15	15.00	14.89	18.16	18.63	19.55	18.89	19.55	19.45	18.11	17.17	14.95	14.53
10	16.24	15.75	18.64	18.57	19.05	18.21	18.93	19.18	18.35	17.95	16.07	15.85
5	17.37	16.49	18.98	18.37	18.42	17.41	18.18	18.78	18.46	18.60	17.09	17.07
0	18.40	17.12	19.17	18.04	17.67	16.50	17.32	18.25	18.43	19.11	17.99	18.18

Table 2. (Continued)

Latitude Degrees	Expressed as Equivalent Evaporation in Inches Per Month											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
South												
- 5	19.30	17.62	19.22	17.57	16.79	15.49	16.34	17.58	18.26	19.48	18.77	19.18
-10	20.08	18.00	19.13	16.97	15.81	14.39	15.26	16.79	17.95	19.71	19.43	20.07
-15	20.73	18.24	18.89	16.25	14.71	13.19	14.09	15.88	17.51	19.79	19.95	20.82
-20	21.24	18.36	18.50	15.41	13.53	11.93	12.83	14.86	16.93	19.72	20.34	21.45
-25	21.62	18.35	17.98	14.45	12.26	10.60	11.49	13.73	16.22	19.51	20.59	21.94
-30	21.85	18.21	17.32	13.39	10.92	9.22	10.10	12.51	15.39	19.16	20.71	22.30
-35	21.96	17.94	16.52	12.24	9.52	7.80	8.66	11.21	14.44	18.67	20.70	22.53
-40	21.94	17.55	15.61	10.99	8.07	6.38	7.19	9.83	13.38	18.04	20.56	22.63
-45	21.80	17.04	14.57	9.67	6.60	4.95	5.72	8.40	12.23	17.28	20.30	22.63
-50	21.55	16.42	13.43	8.29	5.13	3.56	4.26	6.93	10.98	16.41	19.93	22.53
-55	21.24	15.71	12.18	6.86	3.68	2.25	2.86	5.44	9.64	15.43	19.48	22.37
-60	20.89	14.93	10.84	5.40	2.29	1.07	1.56	3.96	8.24	14.35	18.98	22.21

These relationships were compared with ratios found for shallow lake and reservoir evaporation divided by Class A pan evaporation from various climatic atlases and from U.S. Weather Bureau, Technical Paper 37 (11).

The effect of a given weather element on ET/EP ratios is not constant for all crops. However, the equations developed were selected so as to be as simple and usable as possible and to provide a good representation of the general relationship. A formula for potential evapotranspiration, ETP, was derived from the Davis data, from pan evaporation equations and from crop ET/EP ratios as influenced by the various weather elements. Since data for percentage of possible sunshine and/or incoming solar radiation data are not available in many developing countries, the equation was developed based on only temperature, relative humidity, wind speed and extraterrestrial radiation. This formula and the climatic coefficients can be written

$$ETP = 0.35 \times RT \times C \qquad (2)$$

in which

$$C = CT \times CH \times CW \times CE \qquad (2a)$$

$$CT = 0.40 + 0.024 \times TM \qquad (2b)$$
(TM is mean temperature in ^{o}C)

$$CT = 0.013 \times TMF \qquad (2c)$$
(TMF is mean temperature in ^{o}F)

$$CH = 0.05 + 1.58 \times (1.00 - HM)^{1/2} \qquad (2d)$$
with a maximum value of 1.00 for values of HM less than .64
(HM is mean relative humidity expressed decimally using integrated values over a 24-hour period)

$$CH = 0.05 + 1.42 \times (1.00 - HM7)^{1/2} \qquad (2e)$$
with a maximum value of 1.00 for values of HM7 less than .55
(HM7 is the mean of three readings taken at 0700, 1300 and 1900 hours)

$$CH = 1.35 \times (1.00 - HM8)^{1/2} \qquad (2f)$$
with a maximum value of 1.00 for values of HM8 less than .45
(HM8 is the mean of three readings taken at 0800, 1200 and 1800 hours)

$$CW = 0.80 + 0.025 \times W10 \qquad (2g)$$
(W10 is wind velocity at an instrument height of 10 meters in km/hr)

$$CW = 0.80 + 0.0017 \times W10M \qquad (2h)$$
(W10M is wind in miles per day at 10 meters)

$$CW = 0.80 + 0.050 \times WP \quad (2i)$$

(WP is wind measured above the pan in km/hr)

$$CW = 0.80 + 0.028\ W6 \quad (2j)$$

(W6 is wind measured at 6 meters in km/hr).

These equations are based upon 24-hour integrated wind measurements. If wind is measured during the daytime only, wind velocities should be reduced by multiplying by a factor of about 0.6.

$$CE = 1.00 + 0.04 \times EL/1000 \quad (2k)$$

(EL is elevation above sea level in meters)

$$CE = 1.00 + 0.012 \times ELF/1000 \quad (2l)$$

(ELF is elevation above sea level in feet).

With equal amounts of sunshine the effect of radiation increases upslope or with increasing elevation. Advective heat transfer and border effects generally increase with elevation. The elevation correction is a compensation for these influences.

CW has a value of 1.00 for a wind velocity of 8.0 km/hr at an anemometer height of 10 meters. This is approximately an average wind speed for many irrigated areas. Wind speed data are not always available or reliable. Therefore, it frequently becomes necessary to use an average value of CW = 1.00.

In arid areas the value of the correction for relative humidity becomes CH = 1.00. Assuming an average correction for wind and a constant elevation, potential evapotranspiration, ETP, for arid areas becomes a function of extraterrestrial radiation multiplied by temperature in ^{o}F.

The Blaney-Criddle equation uses monthly percentage of daytime hours of the year and temperature in ^{o}F. This results in a significant offset from the origin requiring changing coefficients for each temperature and for various areas. This problem can be eliminated through the use of temperature in ^{o}C resulting in a relationship that passes through the origin. By changing to temperature in ^{o}C and developing a new set of uniform "k" values, the Blaney-Criddle equation becomes a satisfactory equation for estimating potential evapotranspiration in arid areas. However, equations based upon extraterrestrial radiation are theoretically better since they relate evapotranspiration to energy. By using a dimensionless climatic coefficient these equations are dimensionally sound.

Wind velocities are sometimes measured at anemometer heights other than those given above. Various equations are available for converting velocities from one elevation to another. For a standardized height of 10 meters the wind velocity, W10, can be calculated from a measured velocity, WA, where WA is the measured wind velocity at the anemometer in km/hr and A is the height of the instrument in meters above the height of the solid plant cover such as grass or alfalfa. The equation based upon wind profile data from several locations can be written

$$W10 = WA \times (10/A)^{1/4} \quad (3)$$

Equation 3 is similar to that given in Technical Paper No. 37 (11). It is, however, subject to the use of effective height above the vegetative cover. Since vegetative cover is frequently irregular, resulting in some turbulence, the effective height of the vegetation is difficult to estimate. It is therefore recommended that whenever possible data be used from anemometers located at heights exceeding two meters above ground level.

The relationship between wind velocity and height of instrument can be approximated by assuming that wind velocity varies with the fourth root of height or distance above the effective vegetative level.

DEPENDABLE PRECIPITATION

In the evaluation of moisture deficiencies both the effectiveness of rainfall and its dependability need to be considered. Effective rainfall is difficult to determine. Management, soil conditions and vegetative cover have large effects upon the effectiveness of precipitation. Surface runoff from adjacent fields has been known to vary from nothing to as great as sixty-four percent, depending principally upon the differences in vegetative cover.

Dependability of precipitation can be more accurately and easily defined. Average rainfall is dependably available less than fifty percent of the time. In most agricultural areas precipitation varies widely from year to year. Variations are particularly marked during transition months. Some crops are much more sensitive to draught than others. It would seem, however, that for general agriculture and for forage production, moisture deficiencies in a given month one year in four should not be seriously limiting on economic productivity. Based upon this consideration, dependable precipitation, PD, is defined as equal to precipitation at the seventy-five percent level of probability.

The seventy-five percent probability can be obtained from a period of record by using a sorting procedure and a ranking distribution. A gamma distribution, using the procedures described by Thom (8), offers advantages over a ranking distribution. A gamma distribution from ten years of data provides a fairly good measure of the seventy-five percent probability. Shorter records are less reliable. Reliability increases with length of record. For those locations where published long-term mean monthly values are available and where it is difficult to obtain the records for the years within the period of measurement, dependable precipitation, PD, can be approximated from mean monthly precipitation. An equation based upon data from Nicaragua, Colombia, Ecuador and twenty-three eastern states (10) can be written

$$PD = 0.70 \times PM - 10 \tag{4}$$

in which

PD is dependable precipitation in mm, and

PM is mean monthly precipitation in mm.

A best fit equation for sixteen Venezuelan locations is

$$PD = 0.80 \times PM - 13.4 \tag{4a}$$

The best fit equation for thirty-six stations in Bolivia can be written

$$PD = 0.77\ PM - 15 \tag{4b}$$

Equations 4, 4a and 4b are quite similar and result in comparable values within the range where moisture availability is of major importance. For Chile, however, Tosso (9) developed an equation that is quite different. It can be written

$$PD = -7 + 31.5\ (PM/100) + 13.5\ (PM/100)^2 \tag{4c}$$

From this it would seem that a generalized equation may not have universal application but that equations that provide reasonable results can be developed for each climatic region.

CLASSIFICATION OF MOISTURE DEFICIENCIES

As described above, available moisture in excess of potential evapotranspiration does not make a large contribution to increasing yields or production. Until moisture becomes available in amounts equal to about one-third of potential evapotranspiration, an increase in available moisture does not produce a very significant increase in production. These relationships can be indicated by use of a moisture availability index, MAI, which is the ratio of dependable precipitation to potential evapotranspiration.

$$MAI = PD/ETP \tag{5}$$

It is proposed that MAI be adopted as a standard index for measuring water deficiencies and that the following classification of deficiencies and excesses be used:

MAI = 0 - 0.33	Very deficient
MAI = 0.34 - 0.67	Moderately deficient
MAI = 0.68 - 1.00	Somewhat deficient
MAI = 1.01 - 1.33	Adequate
MAI = 1.34 and above	Excessive

Mirnezami (4) made a study relating the yield of dry farmed, unfertilized wheat to various moisture levels. He concludes that, "annual and growing season values of moisture indices, MAI, are good indicators of the most effective factors of the climate and have a good correlation with yield," and also that "calculated potential irrigation requirements are valuable indicators of moisture deficit and can be applied for the calculation of a specific area's needs at a given location and time of growing season by using crop coefficients based upon crop and stage of growth."

Regression equations were determined for yield as a function of the annual MAI, MAIA; growing season MAI, MAIG: annual moisture deficit, ETDFA; growing season moisture deficit, ETDFG; annual dependable precipitation, PDA; and growing season dependable precipitation, PDG. The following regression equations and correlation coefficients were obtained.

Equation	Correlation Coefficient, R
Y = -0.582 + 4.91 x MAI	0.974
Y = -1.01 + 3.55 x MAIG	0.962
Y = 3.55 - 0.00308 x ETDFA	0.932
Y = 2.32 - 0.00431 x ETDFG	0.928
Y = -0.779 + 0.00459 x PDA	0.981
Y = -1.00 + 0.00538 x PDG	0.967

in which

Y = yield in metric tons per hectare (2.5 acres)

Data were from eight experimental areas. Yields from the unfertilized control plots were used for this portion of the study. For values of MAI less than .33 there was little significant response to fertilization. At higher levels of MAI, response to fertilization was most significant.

Calculated potential evapotranspiration did not vary much for the eight locations. The principal variability was in rainfall and dependable precipitation. The maximum annual value of MAI was 0.52 and the maximum seasonal value for MAI was 0.84. Results are therefore not applicable to the higher moisture levels where moisture-yield relationships no longer approximate a straight line.

CONCLUSION

Water deficiencies are frequently described in general terms. This paper provides a readily available numerical index for comparing deficits. A simplified method of determining potential evapotranspiration is proposed. Potential evapotranspiration is compared with availability of moisture. This relationship correlates well with reported yields and production. General acceptance of the proposed methods for quantitative evaluation of moisture deficiencies will improve the evaluation of climate as a resource to be considered in development planning.

In many tropical and subtropical climatic areas rainfall is adequate for a fair level of crop production but varying amounts of deficiencies are encountered. Sound irrigation planning requires an evaluation with respect to the adequacy of precipitation for the production of an economic level of agricultural returns. This is facilitated through the use of a moisture-availability index which provides an indication of the moisture-availability yield curve relationship. The moisture-availability index, MAI, also provides a convenient method for indicating possible benefits to be derived from deficit irrigation and for determining the moisture levels at which fertilization becomes a desirable practice.

ACKNOWLEDGMENTS

Most of the concepts presented in this paper were developed jointly with Jerald E. Christiansen, Professor Emeritus, Agricultural and Irrigation Engineering, Utah State University. The equations presented result principally from studies to evaluate climate as a resource and to determine irrigation requirements for various Latin American countries. These studies are financed by the Agency for International Development and are carried out at Utah State University by Latin American engineers, graduate students and officials, and by Professor Christiansen and the writer.

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APPENDIX II - NOTATION

A	= height of anemometer in meters.
AP	= adequacy percentage.
C	= a climatic coefficient.
CE	= a dimensionless coefficient for elevation.
CH	= a dimensionless coefficient for relative humidity.
CT	= a dimensionless coefficient for temperature.
CW	= a dimensionless coefficient for wind speed or movement.
EL	= elevation above sea level in meters.
ELF	= elevation above sea level in feet.
EP	= measured Class A pan evaporation.
ET	= measured crop or grass evapotranspiration.
ETA	= actual crop evapotranspiration.
ETDF	= evapotranspiration deficit or moisture deficit.
ETDFA	= annual moisture deficit.
ETDFG	= growing season moisture deficit.
ETP	= potential evapotranspiration equivalent to that for Pruitt's grass evapotranspiration.
HM	= mean relative 24-hour humidity expressed decimally.
HM7	= mean relative humidity expressed decimally - average for 0700, 1300 and 1900 hours.
HM8	= mean relative humidity expressed decimally - average for 0800, 1200 and 1800 hours.
K	= a dimensionless constant.
MAI	= moisture availability index (MAI = PD/ETP).
MAIA	= annual moisture-availability index.
MAIG	= growing season moisture-availability index.
PD	= dependable precipitation at the seventy-five percent level of probability in mm.
PDA	= annual dependable precipitation.
PDG	= growing season dependable precipitation.
PM	= mean monthly precipitation in mm.
RT	= extraterrestrial radiation expressed as equivalent depth of evaporation.
TM	= mean temperature in ^{o}C.
TMF	= mean temperature in ^{o}F.
WA	= measured wind speed at anemometer height A.
WP	= measured wind speed above pan (0.6 meter) in km/hr.
W10	= mean 24-hour wind velocity in km/hr at an anemometer height of ten meters.
W10M	= mean 24-hour wind velocity in miles/day at an instrument height of 10 meters (32.8 feet).
W6	= mean 24-hour wind velocity in km/hr at an instrument height of 6.0 meters.
Y	= yield in metric tons per hectare.