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Within rapidly developing economies there is increasing demand for better planning fo: the use of resources for agricultural production. Planned agricultural development depends upon a variety of resources and conditions including soils, climate, land use history, management and cultural practices. Other factors can be more accurately defined providing one of these can be singled out and correctly evaluated. This paper deals principally with the evaluation of moisture available from the atmosphere and its effect upon crop production and crop yields. The methodology can, however, also used for irrigation planning and for irrigation scheduling.

Definitions are given for actual evapotranspiration, potential evapotranspiration, dependable precipitation, moisture availability index and moisture deficit. Moisture adequacies are related to crop growth and yields. Methods for estimating evapotransp tion are presented. A classification of moisture adequacies or deficits is proposed.

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MOISTURE AVAILABILITY AND CROP PRODUCTION

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SUMMARY

Definitions are given for actual evapotranspiration, potential evapotranspiration, dependable precipitation, moisture availability index and moisture deficit. Moisture adequacies are related to crop growth and yields. Methods for estimating evapotranspiration are presented. A classification of moisture adequacies or deficits is proposed.

INTRODUCTION

Within rapidly developing economies there is increasing demand for better planning for the use of resources for agricultural production. Planned agricultural development depends upon a variety of resources and conditions including soils, climate, land use history, management and cultural practices. Other factors can be more accurately defined providing one of these can be singled out and correctly evaluated. This paper deals principally with the evaluation of moisture available from the atmosphere and its effect upon crop production and crop yields. The methodology can, however, also be used for irrigation planning and for irrigation scheduling.

DEFINITION OF TERMS

Some of the concepts or terms used in this paper have been defined by Hargreaves (1972) and are given with some modifications.

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

Potential Evapotranspiration, PET, is the amount of water transpired from actively growing, short green plants (usually grass) with a full vegetative cover and a continuously adequate moisture supply. It is considered to be dependent upon the climate and can be estimated from climatic parameters.

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 (the rainfall that may be expected to occur three years out of four years) has been selected as a reasonable value for most conditions. For some crops, or special conditions, a different probability level may be more appropriate.

Moisture-availability Index, MAI, is the ratio of the dependable precipitation to potential evapotranspiration (MAI = PD/PET). MAI is an index of the adequacy of precipitation in supplying moisture requirements.

Ratio of Moisture Availability, RMA, is the ratio of actual precipitation to potential evapotranspiration (RMA = PREC/PET). RMA is an index of precipitation adequacy based upon monthly data from individual years.

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

EFFECT OF SOIL CONDITIONS

Moisture availability to crops depends on the amount and frequency of rainfall, the moisture holding capacity of the soil, and the depth of rooting of the crop. Ideally, rainfall should occur in amounts and at frequencies such that soil moisture in the root zone of the crop is always adequate. Some alluvial soils are almost uniform in texture and other characteristics to depths of two meters or more. Other soils are highly stratified with barriers to root development which restrict rooting depths to 30 cm or less, even for some normally deep rooting crops such as alfalfa.

In terms of available moisture-storing capacity in the root zone, soils may vary from about 25 mm (1 inch) of available moisture to more than

200 mm (8 inches) depending on the rooting depth of the crop and the soil characteristics.

In some instances, the rooting depth of crops depends on the chemical characteristics of the soil as well as soil physical characteristics. For example, in a study of three oxisols (soils with high oxic concentrations, but nearly featureless throughout the normal soil profile) corn and similar crops had rooting depths limited to about 30 cm, and available soil moisture capacities of 36 to 60 mm (Wolf, 1973). Under these conditions, corn wilted after about 6 days without rain. Although mean monthly rainfall may appear adequate, low values of dependable rainfall and frequencies of drought periods of 10 days or more may result in soil moisture deficiencies.

For soils and crops where available soil moisture storage is adequate to supply the requirements for two weeks or more, short drought periods are of lesser importance. Under these conditions a moisture availability index, MAI, as defined above, can be expected to have a good correlation with crop production.

ESTIMATION OF EVAPOTRANSPIRATION

Potential evapotranspiration can be estimated from mean temperature and a factor based upon latitude. For mean relative humidities in excess of 64 percent, a correction is also desirable for relative humidity. There is also some increase with increasing advection, turbulent mixing and increased hot dry wind velocities. These effects are difficult to quantify however, For the data used by Hargreaves (1973) for developing and testing equations, these effects tend to compensate. Thus a high degree of correlation results between measured and estimated evapotranspiration using only temperature and relative humidity data to calculate potential evapotranspiration.

The equation for potential evapotranspiration, PET, can be written:

$$PET = MF \times T \times CH \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (1)$$

in which MF is a monthly factor depending upon latitude, T is mean temperature in degrees Fahrenheit and CH is a correction for relative humidity. CH is calculated from mean 24-hour relative humidity in percent, H, using the equation:

$$CH = 0.166 \times (100\text{-}H)^{1/2} \quad . \quad . \quad . \quad . \quad . \quad . \quad (1a)$$

Values of MF are presented in Table 1.

The actual crop evapotranspiration, ETA, can be estimated by multiplying the potential evapotranspiration by a crop coefficient (ETA = KC x PET). For perennial crops and in the warmer climates, the crop coefficients remain fairly constant throughout the growing season, but for annual crops they depend on the ground cover and increase from emergence to full crop cover and then decrease after maturity. Generalized crop coefficients are given in Table 2.

DEPENDABLE PRECIPITATION

The Economic Research Services and the Environmental Science Services Administration (1969) published monthly precipitation probabilities for the 23 Eastern States. Dependable precipitation, PD, as defined above can be approximated for many areas with a fair degree of accuracy from mean precipitation, PM. The equation based upon graphical analysis of the data from the 23 eastern states, Nicaragua, Colombia, and Ecuador can be written:

$$PD = -10 + 0.70 \times PM \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (2)$$

in which PD and PM are expressed in mm or

$$PD = -0.4 + 0.70 \times PM$$

where PD and PM are in inches.

For some arid areas where the rainfall is less predictable, the slope factor in the equation may be much lower. For the ten states of the Brazilian Northeast, for example, the slope factor varied from 0.42 to 0.74 and the constant (intercept) from -6 to -36 mm in the best fit regression equations which had R^2 values of 0.62 to 0.90 (Hargreaves 1974). The lower percentage of variance predicted (lower values of R^2) were from states having two distinct types of climate. Useful relationships which facilitate the estimation of dependable precipitation, PD, can be developed for any area or type of climate.

The range in relationships found indicate that mean rainfall is frequently not a reliable indication of moisture available for crop production. In the 23 eastern states, Nicaragua, Colombia and Ecuador, a mean monthly precipitation of 100 mm indicates that three years out of four a precipitation of 60 mm or more can be anticipated. For the northeastern states of Brazil a mean monthly rainfall of 100 mm indicates a dependable precipitation of 30 to 40 mm or only about half as much.

In order to relate precipitation to crop production it seems desirable to evaluate rainfall amoutns at a given level of probability and relate dependable supply to potential water use. The concept of a moisture availability index, MAI, was developed for this purpose. This concept could also be considered as a moisture dependability index.

For shallow rooted crops, and for soils with low moisture holding capacities, the dependable precipitation estimated from mean monthly precipitation may not always be a reliable indication of adequacy of rainfall because of the frequency of drought periods of 10 days or more. For some crops and under some conditions a different probability of precipitation occurrence would seem desirable. For bananas, a deficiency with a one in four probability would be economically undesirable. However, it seems probable that use of a higher MAI for such crops would result in a satisfactory index. For most crops a deficiency in any one month, one year in four, if not preceded or followed by a deficient month, would not result in large economic losses.

Allowable deficiencies are also related in some degree to land values and development costs. If land values and other production costs are high and water is relatively inexpensive then there is less justification for allowing deficiencies. The converse is also valid. It would seem desirable that additional work be completed relative to the economics of various levels of moisture deficiencies for specific crops and other conditions.

MOISTURE AND CROP PRODUCTION

Mirnezami (1972) made a study of the relationship of moisture availability and yield of dry farmed wheat in Iran. Values of MAI were generally in the range of 0.20 to 0.53. For the unfertilized trials regression equations were developed for yield as a function of MAI, of ETDF, and of PD, on both an annual basis and a seasonal basis. In each case the coefficient of correlation, R, was 0.98 or higher. If MAI can be taken as an index of moisture adequacy, this correlation indicates a good straight line relationship between yield and moisture in the range of 20 to 53 percent of adequacy.

At the lower values of MAI on an annual basis, MAI of 0.35 and lower, there was no response to fertilization. Yields of fertilized wheat averaged slightly less than the unfertilized. At higher moisture levels (MAI of 0.40 or above) fertilizer application produced very significant increases in wheat yields.

In general, it is difficult to obtain crop production data related to various levels of moisture adequacy. Sometimes irrigation is reported but records of initial soil moisture and growing season rainfall are omitted. Procedures for determining the degree to which moisture is adequate or deficient have not been well standardized. Usually only a portion of the full range of moisture adequacies is correlated with yields. Yield data are presented in a wide variety of units.

Hargreaves and Christiansen (1973) summarized yield and water use data from a variety of sources. Available moisture was either calculated or estimated to include moisture stored in the soil at the beginning of the growing season plus growing season precipitation and irrigation water. Yield data were used from Hawaii, California, Utah, Israel and other locations. Principal crops studied were sugar cane, alfalfa, corn and forage crops. Some data for potatoes, peas and sugar beets were also used.

Not all crops are equally sensitive to moisture stress. The timing of moisture deficiencies may play an important role. Adequate moisture is of greater importance during the flowering, fruiting and fruit or grain sizing stages than at other times in the growth cycle. For crops such as sugar cane, alfalfa, and forage, recovery from short periods of moisture stress is frequently good. If cell division is not seriously retarded cell enlargement can often catch up during a later period of moisture adequacy. Also for soils with good moisture storage capacities there is a tendency towards a reduction in the adverse effects of poor distribution of rainfall or water applications.

In order to standardize the data and to compare the results from different crops, Hargreaves and Christiansen (1973) used Y to express a ratio of yield to the maximum yield under the prevailing fertility and cultural conditions and X as the ratio of the actual moisture available to the amount for which theyield is a maximum. The real values of Y vary from 0 to 1.00 and of X from 0 to 1.00 or more.

Most of the yield data analyzed indicated a relationship that can be expressed by the equation:

$$Y = 0.8X + 1.3X^2 - 1.1X^3 \quad . \quad . \quad . \quad . \quad . \quad . \quad (3)$$

Good data coverage was available for the range of X = 0.35 to X = 1.00.

Some worthwhile information may be had from the curve for the first derivative. This can be written:

$$dY/dX = 0.8 + 2.6X - 3.3X^2 \quad . \quad . \quad . \quad . \quad . \quad . \quad (4)$$

For the range X = 0.086 to X = 0.701, dY/dX is 1.00 or more with a maximum value of 1.31 at X = 0.394. If it is assumed that Equation 3 provides a good representation of the moisture adequacy-yield relationship, then maximum increase in production per unit of water applied is attained at approximately 40 percent adequacy. Above about 70 percent adequacy dY/dX is less than 1.00 declining to zero at full moisture adequacy. These relationships are shown graphically in Figure 1.

By changing Y to a scale representing value of the production and X to cost of water the dY/dX curve then becomes an economic model. If an increased irrigation is not required for the maintenance of a favorable salt balance, it is logical to consider how far dY/dX should be permitted to decline before additional application of water becomes uneconomical.

Equation 3 is believed to be a good generalized representation of the moisture-yield function. However, the yield data from Cache Valley, Utah, do not fit Equation 3 very well. Five crops studied indicate a relationship that can be written:

$$Y = 2X - X^2 \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (5)$$

indicating higher yields with lower moisture availability than is the case for the other data. Some technicians have attributed this to lateral soil water movement. Another possible explanation could be an underestimation of initial available moisture stored in the soil and of the effective rooting depths.

Although Equation 3 appears to be the best generalized relationship available, it should be further tested using yield data from a wider range of crops and conditions. Evaluation can be facilitated providing accurate measurements are made of total moisture available from all sources.

CLASSIFICATION OF MOISTURE DEFICITS

Moisture deficits and adequacies depend upon amount and distribution of moisture and upon soil conditions. Based upon the data from Iran (Mirnezami, 1972) there is considerable doubt concerning the economic feasibility of dry farmed wheat production where the annual MAI is less than about 0.33. A higher index would be required in areas of shallow soils with little capacity to retain winter rains as available soil moisture. A composite index based upon both soils and climate might be developed. However, due to the complexity of soils in many areas such a combined index might be difficult to use.

Available yield data from California and Hawaii indicate that maximum yields are possible when available moisture is equal to 1.00 to 1.25 times ETA (actual crop evapotranspiration) under conditions of supply and distribution adequate to meet the evapotranspirative demand. In general, monthly values of MAI of 1.00 or somewhat more indicate an adequate supply of moisture from precipitation. However, for some soils and for some crops rainfall distribution may be less than adequate.

It would seem desirable to develop some form of standard classification for measuring moisture adequacies or deficits from the atmosphere and then modify this for distribution or special soil and crop conditions as the necessity arises. Hargreaves (1972) proposed that MAI be adopted as a standard index for measuring water deficiencies and excesses, and that the following classification be used:

MAI = 0.00 to 0.33	very deficient
MAI = 0.34 to 0.67	moderately deficient
MAI = 0.68 to 1.00	somewhat deficient
MAI = 1.01 to 1.33	adequate
MAI = 1.34 and agove	excessive.

This classification seems applicable for the more favorable soil conditions and is proposed for general usage. Where the soil moisture storage capacity is adequate for less than one week the correlation between MAI and crop production probably will be lowered. The minimum values for economic production can then be expected to be correspondingly higher.

CONCLUSION

Although yield data are available for agricultural crops at many locations, there is a scarcity of data relating yield to moisture availability Improved evaluation of the effect of moisture could be accomplished through improved standardization and more uniformity in reporting procedures.

Many interacting factors result in various levels of crop yields. However, there is a surprising degree of uniformity in response to level of moisture availability when data from various experiments are analyzed in a standardized manner. General acceptance of more complete and thorough methods for the quantitative evaluation of moisture deficiencies will improve the valuation of climate as a resource to be considered in development

The methodology given also provides a useful tool for irrigation development planning, irrigation design and the scheduling of irrigation applications.

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TABLE 1. Potential Evapotranspiration Factor, MF, for PET in mm per Month

NORTH LAT	JAN	FEB	MAR	APR	MONTH MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
60	.061	.177	.525	1.039	1.700	2.026	1.970	1.339	.705	.299	.089	.037
59	.077	.203	.571	1.101	1.770	2.091	1.989	1.402	.757	.339	.108	.049
58	.095	.230	.610	1.161	1.837	2.152	2.054	1.467	.809	.370	.120	.063
57	.114	.258	.666	1.219	1.901	2.210	2.117	1.531	.861	.408	.151	.079
56	.135	.288	.714	1.277	1.962	2.265	2.176	1.592	.913	.447	.174	.097
55	.159	.319	.762	1.334	2.021	2.317	2.233	1.652	.965	.487	.200	.116
54	.183	.352	.811	1.390	2.078	2.367	2.287	1.711	1.017	.528	.227	.138
53	.210	.385	.861	1.445	2.133	2.415	2.340	1.768	1.069	.570	.256	.161
52	.238	.420	.911	1.499	2.186	2.461	2.390	1.824	1.121	.614	.286	.186
51	.268	.456	.961	1.552	2.238	2.506	2.439	1.879	1.172	.658	.318	.213
50	.300	.493	1.012	1.605	2.288	2.548	2.485	1.932	1.224	.703	.351	.242
49	.333	.531	1.063	1.657	2.336	2.589	2.531	1.985	1.276	.749	.386	.272
48	.367	.570	1.115	1.709	2.383	2.628	2.574	2.036	1.327	.796	.422	.304
47	.404	.610	1.167	1.760	2.429	2.665	2.616	2.086	1.379	.844	.460	.337
46	.441	.651	1.219	1.810	2.473	2.702	2.656	2.136	1.430	.892	.499	.372
45	.481	.693	1.271	1.859	2.515	2.736	2.695	2.184	1.481	.942	.539	.409
44	.521	.736	1.324	1.908	2.557	2.769	2.733	2.231	1.532	.992	.580	.447
43	.563	.780	1.376	1.956	2.597	2.801	2.769	2.277	1.583	1.042	.623	.487
42	.607	.824	1.429	2.003	2.636	2.831	2.804	2.323	1.633	1.094	.667	.528
41	.651	.869	1.482	2.050	2.674	2.860	2.837	2.367	1.684	1.145	.712	.571
40	.697	.915	1.535	2.096	2.710	2.887	2.863	2.410	1.734	1.198	.758	.615
39	.744	.962	1.588	2.141	2.745	2.913	2.899	2.452	1.783	1.251	.805	.660
38	.793	1.009	1.641	2.186	2.779	2.938	2.928	2.493	1.833	1.304	.854	.707
37	.843	1.057	1.694	2.229	2.811	2.961	2.956	2.533	1.882	1.358	.903	.755
36	.893	1.106	1.746	2.272	2.842	2.983	2.983	2.572	1.930	1.412	.953	.805
35	.940	1.148	1.769	2.301	2.856	2.987	2.991	2.596	1.967	1.456	.999	.851
34	.979	1.181	1.816	2.309	2.844	2.964	2.972	2.595	1.987	1.491	1.036	.889
33	1.018	1.214	1.842	2.317	2.832	2.941	2.953	2.595	2.006	1.524	1.073	.929
32	1.057	1.246	1.867	2.324	2.819	2.918	2.934	2.594	2.024	1.557	1.110	.968
31	1.096	1.278	1.892	2.330	2.806	2.895	2.915	2.592	2.041	1.589	1.147	1.008
30	1.135	1.310	1.916	2.336	2.793	2.871	2.895	2.589	2.058	1.621	1.184	1.048
29	1.174	1.341	1.940	2.341	2.779	2.847	2.875	2.586	2.074	1.653	1.222	1.088
28	1.214	1.372	1.963	2.346	2.764	2.823	2.855	2.583	2.090	1.684	1.259	1.128
27	1.253	1.403	1.986	2.350	2.750	2.799	2.834	2.579	2.105	1.714	1.296	1.168
26	1.292	1.434	2.008	2.353	2.734	2.775	2.813	2.574	2.119	1.745	1.332	1.208
25	1.332	1.465	2.029	2.356	2.719	2.750	2.792	2.569	2.133	1.774	1.369	1.249
24	1.371	1.495	2.050	2.358	2.702	2.725	2.770	2.563	2.146	1.804	1.406	1.289
23	1.410	1.525	2.070	2.359	2.686	2.699	2.747	2.556	2.159	1.832	1.442	1.330
22	1.449	1.554	2.089	2.360	2.669	2.674	2.725	2.549	2.171	1.861	1.478	1.370
21	1.488	1.583	2.108	2.360	2.651	2.648	2.702	2.541	2.182	1.888	1.514	1.411
20	1.527	1.612	2.126	2.359	2.633	2.621	2.678	2.533	2.192	1.916	1.550	1.451
19	1.565	1.640	2.144	2.358	2.614	2.594	2.655	2.524	2.202	1.942	1.586	1.491
18	1.604	1.668	2.161	2.356	2.595	2.567	2.630	2.514	2.211	1.969	1.621	1.532
17	1.642	1.696	2.177	2.353	2.575	2.540	2.606	2.504	2.220	1.994	1.657	1.572
16	1.680	1.723	2.193	2.350	2.555	2.512	2.581	2.493	2.227	2.020	1.691	1.612
15	1.718	1.750	2.208	2.346	2.534	2.484	2.555	2.482	2.235	2.044	1.726	1.652
14	1.756	1.776	2.222	2.342	2.513	2.456	2.529	2.470	2.241	2.068	1.760	1.692
13	1.794	1.802	2.236	2.337	2.491	2.427	2.503	2.457	2.247	2.092	1.795	1.732
12	1.831	1.828	2.249	2.331	2.469	2.398	2.476	2.444	2.252	2.115	1.828	1.771
11	1.868	1.853	2.261	2.324	2.447	2.369	2.449	2.430	2.256	2.137	1.862	1.811
10	1.905	1.878	2.273	2.317	2.423	2.339	2.421	2.415	2.260	2.159	1.895	1.850
9	1.941	1.902	2.284	2.310	2.400	2.309	2.393	2.400	2.263	2.180	1.928	1.889
8	1.977	1.926	2.294	2.301	2.376	2.278	2.365	2.384	2.265	2.201	1.960	1.928
7	2.013	1.949	2.303	2.292	2.351	2.247	2.336	2.368	2.267	2.221	1.992	1.966
6	2.049	1.972	2.312	2.282	2.326	2.216	2.306	2.351	2.268	2.240	2.024	2.004
5	2.084	1.994	2.320	2.272	2.300	2.185	2.277	2.333	2.268	2.259	2.055	2.043
4	2.119	2.016	2.328	2.261	2.274	2.153	2.247	2.315	2.268	2.277	2.086	2.080
3	2.154	2.037	2.334	2.250	2.248	2.121	2.216	2.297	2.267	2.294	2.116	2.118
2	2.188	2.058	2.340	2.237	2.221	2.089	2.185	2.277	2.265	2.311	2.147	2.155
1	2.222	2.078	2.346	2.224	2.193	2.056	2.154	2.257	2.263	2.327	2.176	2.192
0	2.255	2.098	2.350	2.211	2.165	2.023	2.123	2.237	2.260	2.343	2.205	2.229

TABLE 1. Potential Evapotranspiration Factor, MF, for PET in mm per Month

SOUTH LAT	JAN	FEB	MAR	APR	MONTH MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
-1	2.288	2.117	2.354	2.197	2.137	1.990	2.091	2.216	2.256	2.358	2.234	2.265
-2	2.321	2.136	2.357	2.182	2.106	1.956	2.059	2.194	2.251	2.372	2.263	2.301
-3	2.353	2.154	2.360	2.167	2.079	1.922	2.026	2.172	2.246	2.386	2.290	2.337
-4	2.385	2.172	2.362	2.151	2.050	1.888	1.993	2.150	2.240	2.398	2.318	2.372
-5	2.416	2.189	2.363	2.134	2.020	1.854	1.960	2.126	2.234	2.411	2.345	2.407
-6	2.447	2.205	2.363	2.117	1.990	1.820	1.926	2.103	2.226	2.422	2.371	2.442
-7	2.478	2.221	2.363	2.099	1.959	1.785	1.893	2.078	2.218	2.433	2.397	2.476
-8	2.508	2.237	2.362	2.081	1.927	1.750	1.858	2.054	2.210	2.443	2.423	2.510
-9	2.538	2.251	2.360	2.062	1.896	1.715	1.824	2.028	2.201	2.453	2.448	2.544
-10	2.567	2.266	2.357	2.043	1.864	1.679	1.789	2.003	2.191	2.462	2.473	2.577
-11	2.596	2.279	2.354	2.023	1.832	1.644	1.754	1.976	2.180	2.470	2.497	2.610
-12	2.625	2.292	2.350	2.002	1.799	1.608	1.719	1.950	2.169	2.477	2.520	2.643
-13	2.652	2.305	2.345	1.981	1.767	1.572	1.684	1.922	2.157	2.484	2.543	2.675
-14	2.680	2.317	2.340	1.959	1.733	1.536	1.648	1.895	2.144	2.490	2.566	2.706
-15	2.707	2.328	2.334	1.937	1.700	1.500	1.612	1.867	2.131	2.496	2.588	2.738
-16	2.734	2.339	2.327	1.914	1.666	1.464	1.576	1.838	2.117	2.500	2.610	2.769
-17	2.760	2.349	2.319	1.891	1.632	1.427	1.540	1.809	2.103	2.504	2.631	2.799
-18	2.785	2.359	2.311	1.867	1.598	1.391	1.504	1.780	2.088	2.508	2.651	2.830
-19	2.811	2.368	2.302	1.843	1.564	1.354	1.467	1.750	2.072	2.510	2.671	2.859
-20	2.835	2.377	2.293	1.818	1.529	1.318	1.431	1.719	2.056	2.512	2.691	2.889
-21	2.860	2.385	2.282	1.792	1.494	1.281	1.394	1.689	2.039	2.514	2.710	2.918
-22	2.883	2.392	2.272	1.767	1.459	1.244	1.357	1.658	2.021	2.514	2.728	2.947
-23	2.907	2.399	2.266	1.740	1.423	1.208	1.320	1.626	2.003	2.514	2.747	2.975
-24	2.930	2.405	2.248	1.713	1.388	1.171	1.283	1.595	1.984	2.513	2.764	3.003
-25	2.952	2.411	2.234	1.686	1.352	1.134	1.246	1.563	1.965	2.512	2.781	3.031
-26	2.975	2.416	2.221	1.659	1.316	1.097	1.209	1.530	1.945	2.510	2.798	3.058
-27	2.996	2.420	2.206	1.630	1.280	1.061	1.172	1.497	1.924	2.507	2.814	3.085
-28	3.018	2.424	2.191	1.602	1.244	1.024	1.134	1.464	1.903	2.503	2.830	3.112
-29	3.039	2.427	2.176	1.573	1.208	.988	1.097	1.431	1.881	2.499	2.845	3.139
-30	3.059	2.430	2.159	1.544	1.172	.952	1.060	1.397	1.859	2.494	2.859	3.165
-31	3.079	2.432	2.142	1.514	1.135	.916	1.023	1.364	1.836	2.489	2.874	3.191
-32	3.099	2.434	2.125	1.484	1.099	.880	.986	1.329	1.812	2.483	2.888	3.217
-33	3.119	2.435	2.106	1.453	1.063	.844	.949	1.295	1.788	2.476	2.901	3.242
-34	3.138	2.436	2.087	1.422	1.026	.808	.912	1.261	1.764	2.469	2.914	3.268
-35	3.157	2.436	2.068	1.391	.990	.773	.876	1.226	1.739	2.460	2.927	3.293
-36	3.148	2.415	2.030	1.348	.945	.731	.832	1.180	1.698	2.430	2.914	3.289
-37	3.120	2.378	1.980	1.297	.896	.686	.784	1.129	1.647	2.385	2.882	3.265
-38	3.090	2.340	1.929	1.246	.847	.643	.738	1.077	1.597	2.339	2.850	3.239
-39	3.058	2.302	1.878	1.196	.800	.600	.692	1.027	1.546	2.293	2.816	3.212
-40	3.025	2.262	1.826	1.146	.753	.559	.648	.977	1.495	2.245	2.780	3.183
-41	2.991	2.222	1.774	1.096	.708	.519	.605	.928	1.444	2.197	2.744	3.153
-42	2.955	2.180	1.722	1.047	.664	.480	.563	.880	1.393	2.147	2.706	3.122
-43	2.918	2.138	1.669	.999	.620	.443	.522	.832	1.343	2.097	2.666	3.088
-44	2.879	2.095	1.617	.951	.578	.407	.483	.786	1.292	2.047	2.626	3.053
-45	2.839	2.050	1.564	.904	.537	.372	.445	.740	1.241	1.995	2.584	3.017
-46	2.797	2.005	1.510	.857	.498	.339	.408	.696	1.191	1.943	2.540	2.979
-47	2.754	1.959	1.457	.811	.459	.307	.373	.652	1.141	1.890	2.496	2.939
-48	2.709	1.912	1.403	.766	.422	.276	.339	.609	1.091	1.836	2.450	2.898
-49	2.663	1.864	1.350	.721	.387	.247	.307	.567	1.041	1.781	2.402	2.855
-50	2.615	1.814	1.296	.677	.352	.220	.276	.527	.992	1.726	2.353	2.810
-51	2.565	1.764	1.242	.634	.319	.194	.246	.487	.943	1.670	2.302	2.763
-52	2.513	1.713	1.188	.592	.288	.170	.218	.449	.894	1.613	2.250	2.715
-53	2.459	1.661	1.133	.551	.258	.147	.192	.412	.845	1.556	2.196	2.664
-54	2.403	1.607	1.079	.511	.229	.126	.168	.376	.797	1.497	2.140	2.611
-55	2.345	1.552	1.025	.471	.202	.106	.144	.341	.750	1.438	2.082	2.556
-56	2.285	1.496	.970	.433	.176	.088	.123	.308	.703	1.377	2.022	2.498
-57	2.221	1.438	.916	.396	.153	.072	.103	.276	.656	1.316	1.959	2.437
-58	2.155	1.378	.861	.360	.130	.057	.085	.246	.610	1.253	1.894	2.374
-59	2.085	1.317	.806	.325	.110	.045	.069	.217	.564	1.189	1.826	2.307
-60	2.012	1.253	.751	.291	.091	.033	.055	.189	.519	1.124	1.755	2.236

TABLE 2. Crop Coefficients, KC (for use with potential evapotranspiration PET)

Crop	* Average KC for Full Crop Cover	** Average Seasonal KC
Field and oil crops including beans, castor beans, corn, cotton, flax, peanuts, potatoes, safflower, soybeans, sorghum, sugar beets, tomatoes, and wheat	1.15	.90
Fruits, nuts and grapes		
Citrus fruits (oranges, lemons and grapefruit)	.75	.75
Deciduous fruits (peaches, plums and walnuts)	.90	.70
Deciduous fruits with cover crop	1.25	1.00
Grapes	.75	.60
Hay, forage and cover crops		
Alfalfa	1.35	1.00
Short grass	1.00	1.00
Clover pasture	1.15	
Green manure	1.10	.95
Sugar cane	1.25	1.00
Summer vegetables	1.15	.85

* Recommended for designing system capacity

** To be used in estimating seasonal requirements and for economic analysis. Provides satisfactory results for irrigation scheduling for most soils with good capacity to store readily available moisture.

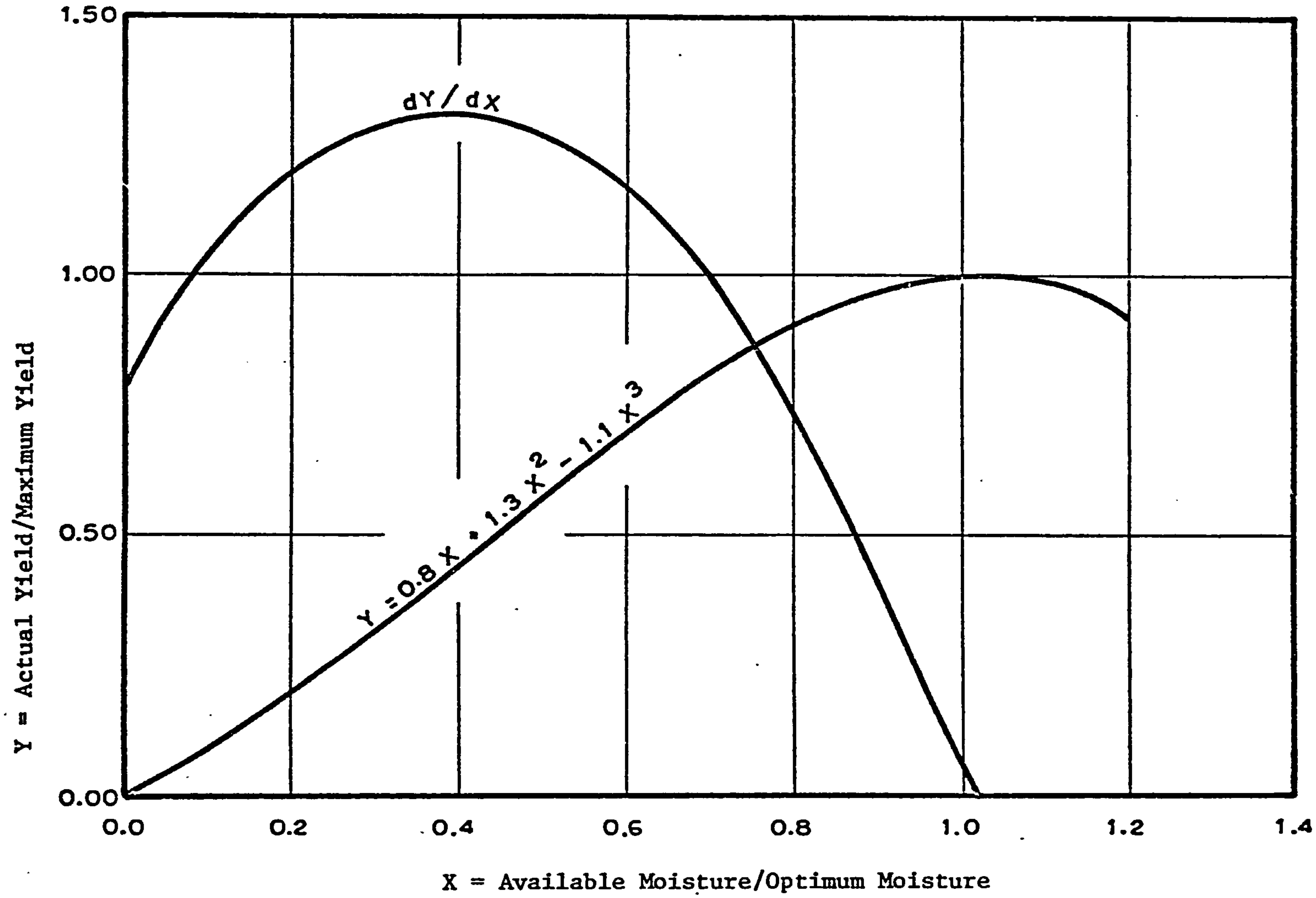

Figure 1. Moisture adequacy and yield function.

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