EVAPOTRANSPIRATION PROBLEMS IN IRAQ¹⁾

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SUMMARY

The Dujailah Experimental Station, situated in the river plain of Mesopotamia, was established in 1955 by the Development Board of Iraq for the study of the reclamation and salinity control of saline and alkali soils of Mesopotamia.

When it became clear that one of the problems of the reclamation and salinity control was insufficient knowledge of the evapotranspiration, a special study was made of this subject.

The actual net irrigation requirement of the inundated, irrigated and drained plots was therefore compared with empirical and theoretical methods based upon climatic conditions.

As a result of this study it can be stated that in general the PENMAN formula seems to be in agreement with the empirical results of the Dujailah experimental fields, whereas the usefulness of the BLANEY and CRIDDLE equation is limited without determination of a monthly K factor for the area concerned. THORNTHWAITTE's formula, like BLANEY and CRIDDLE's method, is based on a correlation between radiation and temperature, but since this formula has no crop coefficient in which other factors influencing the evapotranspiration can be included, no practical results can be drawn.

Evaporation pans are subject to the energy balance of the pan concerned in which are included wind, rim, edge, oasis effect and the energy taken up or delivered by the body of the pan. Since no reliable literature on this subject, comparable for Iraq, could be found, only the huge evaporation from the pans used is shown.

The PICHE evaporimeter was found unsuitable for Iraq on account of the high evaporation rate, while with the LIVINGSTONE atmometer no single relationship could be found with anything at all.

The determination of evapotranspiration from the Dujailah experimental fields showed that PENMAN's formula can be used after more detailed knowledge has been collected on this subject.

Hitherto, almost all projects in Iraq have been based on the BLANEY and CRIDDLE equation with crop coefficients as used in the U.S.A., which results in a substantial difference in the area irrigable during summer and winter, the capacity of the water distributing system, and the drainage requirement after reclamation.

1 INTRODUCTION

When planning agricultural projects, water requirement is a very important factor under arid conditions.

Hitherto neraly all water requirements, for projects proposed in Iraq have been based on U.S. experience, it being assumed that similar conditions obtain in Iraq. However, there appear to be differences in the water requirement assumed by the different agencies for similar conditions. This was made clear in a number of meetings on this subject in the First Technical Section of the Development Board of Iraq (figure 1).

Even a provisional study of data collected by the staff of the Development Board showed that the standards at present in use deviate considerably from actual measurements, particularly in the case of summer crops.

For alle these reasons it was felt important to present and discuss all information available on this subject and to compare measured and calculated quantities according to the different relationships assumed.

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FIG. 1 COMPARISM BETWEEN SOME SUGGESTIONS ON WATERREQUIREMENT FOR PLANT GROWTH IN IRAQ.

Notwithstanding the fact that the data collected and the conclusions thereof are subject to reservations, it may be useful to arrive at some recommendations as to the best possible method of calculating water requirement.

2 THE DUJAILAH EXPERIMENTAL STATION

The Dujailah Drainage and Land Reclamation Experimental Station (figure 2) was established in 1955 by the First Technical Section of the Development Board of Iraq in order to obtain more information on the reclamation and salinity control of the saline and alkali soils of Mesopotamia.

It became increasingly clear that one of the secrets underlying the fall of the ancient civilisation of Mesopotamia was insufficient knowlegdge of the use of irrigation water and its toxic effect.

It was therefore decided in 1957 to add to the Experimental Station a more or less complete Agrometeorological Station, in cooperation with certain consultants working for the Development Board for general project design purposes.

3 THE PROBLEM

The water balance of the soil in use for agricultural or hydrologic purposes over a certain period can be expressed as follows :

FIG. 2.

$$RA + IR + SE = ET + DR + SR + \Delta h$$

in which: RA = rainfall

IR = irrigation

SE = seepage into the field

ET = evapotranspiration

DR = drainage

SR = surface runoff

Δh = difference of water stored in the soil

For design purposes, the most important factor to know is irrigation. According to the above formula this is :

$$IR = ET + \Delta h + DR + SR - SE - RA$$

To calculate the amount of irrigation water required on the plot over a

certain period, all variables, except irrigation have to be measured, culculated or eliminated, i.e. all variables have to be known.

The measurements and calculations made at the Dujailah Experimental Station show how the problem was approached.

4 POSSIBILITIES OF ESTIMATING EVAPOTRANSPIRATION AT DUJAILAH

4.1 *Direct from the Dujailah Experimental Station fields*

It should be stated beforehand that the experimental work was not specially intended for research on water requirements. This is why the most suitable solution was chosen afterwards.

The Dujailah Experimental Station is situated in the river plain between Baghdad and Basrah (figure 2).

The large area as a whole is abandoned ; latitude 32.30 N. approximately ; height above M.S.L. 12.50 metres.

Within the reclaimed area of the station, a catchment area balance sheet was chosen from which the most reliable results could be drawn. To give an idea of the conditions, a lay-out and cross-section of a part of the experimental station are shown in figure 3 and 4.

The soil consists of a fairly uniform stratified silty loam, clay loam and light clay deposits, overlying a heavy dense impermeable reddish-brown basin clay. The latter is from 4.5 metres below the surface of the soil which extends downwards to at least 7 metres.

The soil permeability was measured, below the water table, by the augerhole pump-out method developed by HOOCHOUT and ERNST. The average permeability derived from the field tests was 0.77 metres per 24 hrs.

Collectordrains were dug 2 metres deep, bottom width 1 metre, slope 1 : 1. Tile drains covered clay pipes at a depth of 1.20 metres, spacing 25 metres.

Water level observations were made daily in a great number of observation wells.

The discharge quantities of the tile drains were recorded daily at the outlet pipe by a bucket of known capacity and a stopwatch. In addition to the measured discharges of the drainpipes, the water draining directly to the collector drain was calculated from the gradients observed in the groundwater table and the known permeability of the soil strata.

The irrigation supplies were measured with rectangular suppressed weirs. As the water level upstream of the weirs was kept constant by a self-adjusting gate, only time readings had to be made.

Irrigation was carried on by local inhabitants who used the local method of estimating the amount of water, as well as rotation, resulting in over-irrigation.

Since all factors except *ET* were approximately known, the following equation, according to the above formula could be derived :

$$ET = IR + RA + SE - DR - SR - \Delta h$$

in which : irrigation and rainfall are measured ; drainage is measured and culculated ; seepage was only of importance into the uncultivated area (right-hand cross-section) ; surface runoff did not exist owing to ridges around the field ; owing to the irrigation practices employed, Δh was only important at the beginning and end of a cultivation period.

FIG. 3 LAY-OUT OF A PART OF THE EXPERIMENTAL STATION AT DUJAILAH.

However, what is measured as a result of irrigation minus drainage is not the actual evapotranspiration, which is the real evaporation from crop and cropped soil under local conditions, but the net irrigation requirement. The difference will be described below.

4.2 Empirical and theoretical methods based upon climatic conditions

The Agrometeorological Station at Dujailah was completed in the course of 1957. The apparatus consists of :

Air, soil, and water thermometers ; rain gauge ; sunshine recorder ; psychrometer ; anemometer ; evaporation pans ; PICHE evaporimeters, and LIVINGSTONE atmometer.

FIG. 4 CROSS-SECTION OF A PART OF THE EXPERIMENTAL STATION AT DUJAILAH.

FIG. 5 CALCULATIONS ON EVAPOTRANSPIRATION AFTER FIGURES FROM THE METEOROLOGICAL STATION KUT EL HAI.

Since leaching and crop production started early 1956 at the Dujailah Experimental Station, the meteorological results obtained at Dujailah over 1957 and 1958 were plotted against those obtained from the Meteorological Observation Station of the Ministry of Communications and Works at Kut el Hāi (figure 2).

The results obtained from the two stations are satisfactory and sufficiently close to enable calculations for evaporation purposes at Dujailah to be made with figures from Kut el Hāi. To check the figures from Hai, a comparison was made of the average of the stations at Baghdad and Basrah over a period of 12 years.

As the different methods of computing *ET* on the basis of climatic data and evaporimeters are sufficiently known in the literature, only the methods used at the experimental station will be mentioned in this paragraph.

- a. BLANEY and CRIDDLE method
- b. THORNTHWAITE method
- c. PENMAN method
- d. Evaporimeters ; evaporation pans, PICHE evaporimeters, LIVINGSTONE atmometer.

5 RESULTS OBTAINED

A method such as the soil water balance method seems the most reliable one, so that other methods will be compared with this.

The final results from the fieldwork at Dujailah, the climatic conditions at the meteorological station at Hai and the calculations thereof will first be given in the tables below.

Table 1 Facts and figures from the catchment area of the Dujailah Experimental Station.

Year	1956									1957
Month	4	5	6	7	8	9	10	11	12	1
Crop	leaching			green gram				barley		
Sowing date				14			10	27		
Harvesting date										
Irrigation from	10	1	3	5	2	3			1	17
To inclusive	27	31	15	24	26	25			18	
Irrigation in mm.	473	727	467	242	297	239			196	52
Effective rainfall in mm. ...									10	10
Total water supply in mm. ...	473	727	467	242	297	239			206	62
Total drainage in mm.	255	446	209	107	85	50	13	6	35	21
Net irr. requirement in mm.	218	281	258	135	212	189	-13	-6	171	41
Year	1957									
Month	2	3	4	5	6	7	8	9	10	11
Crop	barley				green gram					barley
Sowing date					1					28
Harvesting date				10				29		
Irrigation from	17	6			1	6	5	1		
To inclusive		28			27	28	19	19		
Irrigation in mm.	65	122	23		398	355	310	248		
Effective rainfall in mm. ...	33	25	23	10						60
Total water supply in mm. ...	98	147	46	10	398	355	310	248		60
Total drainage in mm.	31	48	21	16	94	21	16	38	8	2
Net irr. requirement in mm.	67	99	25	-4	304	334	294	210	-8	58
Year	1957/1958									
Month	12	1	2	3	4	5	6			
Crop	barley						green gram			
Sowing date							4			
Harvesting date						12				
Irrigation from	23	2	8	10	8	18	4			
To inclusive		26	22	21	17					
Irrigation in mm.	84	183	183	171	125	117	346			
Effective rainfall in mm. ...	40	35								
Total water supply in mm. ...	124	218	183	171	125	117	346			
Total drainage in mm.	45	128	98	52	42	19	47			
Net irr. requirement in mm.	79	90	85	119	83	98	299			

Note: — green gram = *phaseolus aureus*.

Using the monthly averages, the evapotranspiration according to PENMAN, BLANEY and CRIDDLE and THORNTONWAITE was calculated over the years 1956, 1957, and the first part of 1958 and shown in figure 5. This shows immediately that there is a great difference in the results obtained.

Before the water balance from the experimental station and the *ET* according to the Hāi figures can be compared it should be made clear what is actually measured in the field as a result of irrigation minus drainage.

In considering the evapotranspiration we can distinguish:

- The actual *ET*, viz. the real evaporation from crop and cropped soil under local conditions.

Table 2 Climatic data Meteorological Station Kut el Hai and the calculations thereof.

Year	1956					
Month	1	2	3	4	5	6
Mean monthly temp. °C.	11.5	14.7	16.3	21.8	27.8	33.9
Mean relative humidity %	73	55	55	53	28	22
Actual/possible cloudiness ratio n/N .	0.63	0.53	0.53	0.38	0.93	0.99
Mean wind speed m/sec.	3.1	4.1	3.6	4.1	5.7	6.7
Insolation cal./cm. 2/24 hrs.	470	650	735	885	935	990
BLANEY and CRIDDLE $f = U/K$ in mm.	97	103	131	158	201	227
THORNTHWAITE $P.E.$ in mm.	9	8	31	77	173	215
PENMAN E_o in mm.	51	102	119	152	301	387
Year	1956					
Month	7	8	9	10	11	12
Mean monthly temp. °C.	35.7	35.7	31.7	24.9	17.0	11.1
Mean relative humidity %	23	25	26	31	46	70
Actual/possible cloudiness ratio n/N .	0.96	0.89	0.94	0.91	0.76	0.49
Mean wind speed m/sec.	4.1	3.1	3.6	3.6	4.1	2.0
Insolation cal./cm. 2/24 hrs.	940	870	780	620	500	440
BLANEY and CRIDDLE $f = U/K$ in mm.	239	227	189	155	113	93
THORNTHWAITE $P.E.$ in mm.	223	212	176	99	29	8
PENMAN E_o in mm.	326	259	234	169	105	39
Year	1957					
Month	1	2	3	4	5	6
Mean monthly temp. °C.	9.0	12.6	17.3	20.8	26.3	32.5
Mean relative humidity %	69	62	64	63	49	31
Actual/possible cloudiness ratio n/N .	0.58	0.65	0.50	0.48	0.48	0.93
Mean wind speed m/sec.	2.6	3.1	4.1	3.6	4.6	4.1
Insolation cal./cm. 2/24 hrs.	470	650	735	885	935	990
BLANEY and CRIDDLE $f = U/K$ in mm.	88	97	134	155	195	221
THORNTHWAITE $P.E.$ in mm.	4	11	37	86	123	209
PENMAN E_o in mm.	46	81	117	137	208	326
Year	1957					
Month	7	8	9	10	11	12
Mean monthly temp. °C.	34.3	34.3	32.0	25.8	17.4	11.3
Mean relative humidity %	25	27	27	37	63	74
Actual/possible cloudiness ratio n/N .	0.99	0.99	0.98	0.74	0.54	0.63
Mean wind speed m/sec.	4.6	3.6	4.1	4.1	3.1	3.6
Insolation cal./cm. 2/24 hrs.	940	870	780	620	500	440
BLANEY and CRIDDLE $f = U/K$ in mm.	234	222	190	158	114	94
THORNTHWAITE $P.E.$ in mm.	220	208	178	100	32	9
PENMAN E_o in mm.	335	279	252	171	72	49
Year	1958					
Month	1	2	3	4	5	6
Mean monthly temp. °C.	11.2	12.2	19.4	25.1	30.6	33.4
Mean relative humidity %	73	55	43	38	28	26
Actual/possible cloudiness ratio n/N .	0.54	0.80	0.71	0.61	0.70	0.99
Mean wind speed m/sec.	3.1	3.1	3.6	3.6	3.1	4.1
Insolation cal./cm. 2/24 hrs.	470	650	735	885	935	990
BLANEY and CRIDDLE $f = U/K$ in mm.	95	95	142	171	213	225
THORNTHWAITE $P.E.$ in mm.	8	11	53	110	198	212
PENMAN E_o in mm.	50	89	152	192	239	309

FIG. 6 COMPARISON BETWEEN NET IRRIGATION REQUIREMENT AT THE DUJAILAH EXPERIMENTAL FARM AND E_o ACCORDING TO PENMAN AT THE METEOROLOGICAL STATION AT KUT EL HAL.

b. The potential ET , viz. the minimum water requirements under optimal conditions for the vegetation.

In addition, however, we have to take into account the amount of water to be supplied in the field which is necessary for growing the crop. This can be called net irrigation requirement.

The net irrigation requirement of a crop is the potential net amount of water needed on the land to grow the crop (drainage excluded). This differs from the potential ET because the potential ET is the amount of water which evaporates from the crop and the cropped soil. Over the whole growing period, net irrigation requirement and potential ET will be approximately the same, but the situation is different over the different months at the beginning and end of the period. This difference is caused by the fact that the land under cultivation, has normally been fallow for several months. During this period the soil profile will dry out to a certain extent. This has to be restored, and in practice this is done at the first irrigation needed for land preparation and germination. In the last month of the growing season the situation is reversed. Irrigation has ceased some time before the harvest. Between the last irrigation and the date of harvest the crop is still consuming water which it extracts from the water stored in the soil profile, even to a great depth, as at that time its root system will be well developed. This water, plus the water which evaporates during the fallow period, has to be replaced when the next crop is sown.

Table 1 shows the results obtained from the catchment area chosen. It shows that leaching started on 10-4-1956. The surplus water needed beyond the amount lost by evaporation and drainage was needed to increase the moisture content of the soil necessary for cropping conditions and overhead pressure for drainage.

The results are in agreement with the theory of the phenomenon and seem to prove that PENMAN's equation is the most reliable. A comparison was therefore made between the net irrigation requirement obtained from the experimental station and E_o according to PENMAN, using the Hai figures. The results are shown in figure 6. E_o over the various months is given as a total minus the part of the month during which the land was not under cultivation.

The evaporation pan consists of the standardised land class A pan of the U.S. weather bureau. This pan was chosen as it is the one with which most data have been collected. Before the U.S. weather bureau pan was installed, a small pan similar to the land class A pan, but with a diameter of 50 cm. only, was read. This pan was kept in order to obtain comparable information as between the two types of pans. The results are listed below.

Small evaporation pan

Year	1956									1957
Month	4	5	6	7	8	9	10	11	2	3
Aver. over days ...	20	31	30	31	31	30	31	30	15	31
Evaporation in mm.	230	758	950	1020	904	650	525	322	101	239
Year	1957									
Month	4	5	6	7	8	9	10	11	12	
Aver. over days ...	30	31	30	31	31	30	31	30	31	
Evaporation in mm.	267	453	738	787	771	606	367	195	87	
Year	1958									
Month	1	2	3	4	5	6				
Aver. over days ...	31	28	31	30	31	30				
Evaporation in mm.	99	145	279	430	638	832				

Class A pan

Year	1957				1958					
Month	9	10	11	12	1	2	3	4	5	6
Aver. over month ..	30	31	30	31	31	28	31	30	31	30
Evaporation in mm.	539	335	149	87	84	139	257	419	544	737

The evaporation listed above is derived from directly measured quantities in which rainfall and time are calculated. The results from pan measurement are shown in figure 7 together with E_o according to PENMAN, from the Hai meteorological station.

The results obtained from the PICHE evaporimeters and the LIVINGSTONE black and white bulb are too unreliable for listing.

6 DISCUSSION

6.1 Soil water balance method

The main outcome of this method, is the possibility of a comparison with other methods and the best known way of proving them empirically.

However, as stated above, the results of the experiments, should be subject

FIG. 7 COMPARISON BETWEEN POTENTIAL EVAPORATION E_o AT KUT EL HAI AND PAN EVAPORATION AT DUJAILAH.

to reservations as there was no possibility of repeating this experiment under the same favourable conditions.

Of even greater importance is the question, which is still unanswered, as to what extent the ET from the experimental station was increased as a result of an oasis effect. This means that an irrigated area within a very large fallow arid area will evaporate more, than when the whole area is under cultivation.

6.2 Blaney and Criddle method

This method has been used in western U.S. with considerable success, but as the K factor in the equation is an *empirical* consumptive use factor, it is not justifiable, as has been shown, to apply the same factor to other regions without sufficient knowledge of the physical conditions of the region. The K factor is obtained by correlating the requisite meteorological information with actual evapotranspiration as measured in a variety of ways.

The usefulness of the BLANEY and CRIDDLE equation, without knowledge collected with methods such as lysimeters under irrigation practices in a large area, seems insufficient for determining the monthly K factors for the area concerned.

6.3 *Thornthwaite's formula*

In some respects this formula is similar to BLANEY and CRIDDLE's as it is also based upon means of monthly temperature and day length. THORNTWHAITE uses no crop coefficient, and as both the said methods are based upon a correlation between radiation and temperature, the application of these methods, especially THORNTWHAITE's, seems to be strictly limited.

6.4 *Penman's equation*

PENMAN arrives at a theoretical potential evaporation by combining the energy balance theory and the theory of the diffusion of vapour. Two basic steps are involved, first the evaluation of the net gain of radiation energy, and secondly the determination of how this energy is divided in heating the air and evaporation. The assumption is made that the gain in heat by the soil or water is relatively small over a short period of time. A further assumption is that advective heating (lateral heat transfer) is negligible. The latter is an open question, however.

The method is based upon a flat surface provided with a constant water-supplying power, generally a free hypothetical water surface. In order to convert the potential evaporation E_o to evapotranspiration ET , PENMAN introduced a factor $ET/E_o = f$, which is entirely empirical.

Owing to conditions at the experimental fields, as already mentioned, it is not justifiable to come to a conclusion concerning the f factor.

6.5 *Evaporation pans*

Standardised water pans have become the most widely used evaporation instruments in the world.

The huge evaporation from pans at the experimental station, especially during summer time, and the comparison with E_o (fig. 7) proves the complexity of pan evaporation and how dangerous it is to use a given factor, e.g. 0.7, as done in the U.S.

A great deal of effort has gone into the search for a satisfactory pan coefficient, i.e. a multiplication factor to be applied to an evaporimeter pan reading to give the appropriate value for a large water surface, subject to the same weather conditions. However, very few authors take into account the local characteristics of the relevant water surface compared, which is of great importance owing to storage of heat capacity, turbidity and its rate of mixing. These together determine the vertical extent of water which shares in the incoming energy supply during the day (or in summer) and which supplies energy to the surface at night (or in winter).

In other words, they determine the effective heat storage capacity of the open water. Such phase differences, combined with appreciable amplitude difference, render a universal pan coefficient impossible. Although pan readings may have some use for indicating rates of evaporation from small, thoroughly moist soil or grass surfaces, they again become inapplicable as the soil dries out. Under arid conditions such as obtain in Iraq, natural evaporation may be virtually zero while a water pan is evaporating freely.

This means that no general direct relation is known between pan evaporation and free water surface or to potential evaporation. The only possible

method for a certain area is to determine the energy balance of a certain standardised evaporation pan which includes wind, rim, edge and oasis effect, as well as the energy taken up or delivered by the body of the pan. The present literature on this subject is very unreliable.

6.6 *Piche evaporimeter*

In the case of the PICHE evaporimeter many of the considerations on the evaporation pan can be applied. A piece of blotting paper clamped across the mouth of a glass tube filled with water is supposed to simulate the behaviour of transpiring plants, while the green blotting paper is said to be representative of a single leaf. When compared with the demand of the vegetation as a whole the atmometer overestimates the effect of wind and underestimates that of radiation. In addition, it ignores the effect of biological control of transpiration. The literature does not usually mention the altitude of the measurement, but this has been found important. No close relationship was found, however, and it is assumed that the instrument is rather unsuitable for use in countries with a high evaporation rate.

6.7 *Livingstone atometer*

No single relationship with anything could be found with the LIVINGSTONE black and white bulb, so that no comment can be made on this subject.

7 CONCLUSIONS AND RECOMMENDATIONS

For economic as well as salinity problems one should know the least amount of water which has to be supplied in the field in order to obtain good crop results and keep resalinisation under control.

In general, the PENMAN formula seems to be in agreement with the practical results of the Dujailah Experimental Station. This has a few consequences for agriculture in Iraq.

After studying the matter, several points are still unclear for which more knowledge should be collected, especially on the subject of water requirements. Of these will be mentioned:

- The usefulness of the BLANEY and CRIDDLE and PENMAN equation with data collected with lysimeters. In spite of the cost and effort involved, lysimeters or simple drain gauges should be run under irrigation conditions in a large field, after which, say, a monthly K , or f factor for different areas in Iraq can be determined.
- The reduction of actual water need caused by trees (windbreak) which means reduction of wind velocity, change in air humidity and radiations.
- The reduction of actual water need resulting from the supply of irrigation water in the early morning or night, as at that time the soil is relative cold and other meteorological conditions are favourable, so that less water will be evaporated before it infiltrates into the soil.
- The reduction of actual water need with lower crop production.
- The decrease of wind velocity caused by irrigation owing to the difference in temperature of the different air layers.
- Influence of the cloudiness on the radiation.
- Water requirements with respect to altitude.

- The optimum frequency of irrigation on saline soils, owing to the range between field capacity and wilting point (in saline soils except normal tension, osmotic pressure).
- Moreover, in a reclamation area, where in most cases land classification is applicable, some investigations on storage capacity and available moisture have to be made, and some information obtained on the amount of water required for land preparation. Factors directly influencing planning and design of the water balance system and hence the salt balance of the area concerned.

When more is known about many of these aspects it will be easier to determine a practical water requirement consisting of:

- a Net irrigation requirement (water requirement for tillage, profile storage and plant growth).
- b More detailed knowledge on required drain discharge for summer and winter crops.
- c Irrigable area during summer and winter.
- d Losses caused by farm waste and by seepage and evaporation in the distribution system.
- e Capacity of the water distributing system.

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