FIELD MEASUREMENTS OF POTENTIAL EVAPOTRANSPIRATION IN MALTA

PETER K. MITCHELL

University College of Sierra Leone, Freetown (Sierra Leone)

(Received December 15, 1964)

(Resubmitted April 7, 1965)

SUMMARY

Simple evapotranspirometers were established at two contrasting sites in Malta as part of a programme aimed at assessing the moisture characteristics of the climate. Measurements were obtained for 18 months. Evaluation illustrates the operation of the "oasis effect" and other problems. A method is proposed for determining when the effect is operative and appropriate adjustment factors should be applied. Residual contrasts between values from the two sites may reflect differences of exposure and local climate—or deficiencies of method. A plea is made for more measurement in semi-arid environments, using large experimental areas, despite the inevitably high cost.

INTRODUCTION

During the years 1955 to 1958, a team of Durham Colleges' research workers were recording and assessing the land-use patterns of the Maltese Islands. Evaluation of these patterns necessitated the detailed analysis of relevant aspects of the physical, social and economic environments of the archipelago (BOWEN-JONES et al., 1961).

In view of their obvious relevance to problems of husbandry and water supply, the writer was asked to contribute studies of the moisture characteristics of the local climate. These studies were planned in terms of the "water balance" concept elaborated by THORNTHWAITE (1948) and THORNTHWAITE and MATHER (1955). Moisture income could readily be calculated from the considerable amount of rainfall record material which has been amassed since 1840 (BOWEN-JONES et al., 1961; MITCHELL, 1963). Dewfall, though unmeasured, is thought to be quantitatively of little importance. On the expenditure side of the balance is the much more elusive term: evaporation. No acceptable record of evaporation was available in 1956. Estimated values of potential evaporation might have been computed from one or other of the formulae then available (MATHER, 1954; PENMAN, 1948, and CROWE, 1957). However, since no formula was without its empirical elements it was resolved to essay field measurement of this phenomenon.

HET CONCEPT OF EVAPOTRANSPIRATION

Although the literature of evaporation has increased greatly in recent years, some of the basic concepts still appear not to be fully understood. Preliminary discussion of some of these would, therefore, appear to be helpful. Central to the "water balance" idea is the concept or hypothesis of potential evaporation. Rates of evaporation are known to be controlled by two sets of factors. The first set is entirely meteorological and includes, on the one hand, those elements which make available the energy for the change of state from liquid to water vapour, and, on the other hand, those which control the rate of diffusion of water vapour from the layer of air which is in direct contact with the evaporating surface. The second set concerns the evaporating surface itself: its albedo, aerodynamic roughness, and, for want of a better term, its "wetness". On land surfaces, "wetness" is clearly dependent, directly or indirectly, upon the income side of the water balance equation. The concept of potential evaporation eliminates this unhelpful dependence. Conditions are postulated under which there is optimum "wetness" or, expressed differently, conditions which ensure that evaporation is never inhibited by shortage of moisture. Satisfaction of such a condition means that evaporation will proceed at the potential rate dictated by all other factors.

Under uniform weather conditions there will be somewhat different potential rates for different types of surface. For purposes of standardization, a uniform low grassy sward is specified. To indicate the use of plant material in this way, the term potential evapotranspiration is adopted. The "water balance" approach to climatic description applies in the regional or local space, not at a point—it is macroclimatic, not microclimatic. In this context, potential evapotranspiration is also macroclimatic and it therefore follows that the values required are those which would result from measurements within a large uniform wetted area. The exposure of any instruments used is thus quite as important as the exposure of screened thermometers or any other of the standard meteorological instruments. Problems raised during the Malta experiments by these qualifications will be examined later.

FIELD MEASUREMENT

The work recorded here was intended as preliminary to more elaborate and refined experimentation by the writer, which, due to a number of circumstances, just failed to reach the stage when results were expected. However, more recently there has been some elaboration of the equipment at one of the pilot stations. Work there under the direction of F. H. W. Green and Commander Spraggs is expected to yield results pertinent to some of the problems raised in the present paper.

Two "pilot" installations were established early in 1957 and maintained for a period of three years, by which time structural failure was clearly apparent. Adequate results are available for eighteen months, and, though preliminary, have yielded useful information of methodological as well as of climatological interest.

Low-cost evaporimeter tanks of the type used by the United Kingdom Nature Conservancy (GREEN, 1956) were installed at contrasting types of site in Malta. One tank was operated at the ta'Qali Pumping Station near the centre of the island, and the other at the Hal Far Royal Naval Air Station in the southwest. Modified from 44-gallon oil drums, 22 inches (56 cm) in diameter and of similar depth, the tanks were set in the ground each with its rim 2 inches (5 cm) proud of the surface. Within the tanks a sub-soil of local stone chippings was overlain by a mixture of local soils to provide a free-draining soil column. A mixed herbage was encouraged to grow within the tanks and this was kept as nearly as possible flush with the surrounding vegetation. From the base of each tank a pipe led into a collecting well, where all water draining from the soil column was held for subsequent measurement.

Following the procedure suggested by GARNIER (1952), and later adopted by MATHER (1954, p.10) at Seabrook, the "adequate moisture" qualification of the definition of potential evapotranspiration was met by irrigating the surface on those occasions when natural precipitation was likely to prove inadequate. The amount of irrigation water was adjusted periodically in an attempt to ensure continuous slight percolation from the tank during the 24-h period between measurements. This routine was based on the assumption that continuous slight percolation would ensure that the soil was maintained at or about field capacity, but not so heavily saturated as to inhibit plant growth and development. Experience showed that 0.80 inches (20 mm) per day might be required in high summer, while half this was usually more than adequate during the winter months. Observation was a simple matter. Each day, before irrigation, the amount of percolate was measured. This value was subtracted from the sum of the previous day's irrigation and natural precipitation: the difference gave the quantity of evaporation for that day.

This value will only represent the true evaporation if the moisture content of the soil column remains constant. Examination of daily records reveals that this condition is not satisfied, especially after heavy rain. On such occasions a significant time-lag is observed: examples are shown in Table I. Heavy rain falling during the 24 h before observation hour on the 10th is not fully reflected in the percolation amount for that day. Hence the high apparent "evaporation" of 1.83 inches (44.8 mm). Compensation begins during the next period, when percolation is almost equal to the total input of the two preceding days, giving an "evaporation" of –1.90 inches (–46.6 mm). The pattern is repeated on the 12th, but some of this surplus water does not drain through until the 18th, when negative "evaporation" is again recorded. Similar interruptions of a steady flow through the system are observed when there is no precipitation. GARNIER (1956) and GREEN (1959) consider that these are due to

TABLE I

October 1957	*7th*	*8th*	*9th*	*10th*	*11th*	*12th*	*13th*
Irrigation	0.73	0.73	0.73	0.73	0.73	Nil	Nil
Precipitation	Nil	Nil	Nil	1.69	1.02	4.90	0.20
Total input	0.73	0.73	0.73	2.42	1.75	4.90	0.20
Percolation	0.61	0.05	0.27	0.59	3.65	5.86	0.17
"Evaporation"	0.12	0.68	0.46	1.83	–1.90	–0.96	0.03

temporary blockages of the outlet pipe, but the writer is of the opinion that this effect may be a reflection of the cellular structure of the water body in the soil. It may also be relevant to note that when the infill of the ta'Qali tank was excavated in June 1960, marked concentrations of the clay fraction were found. One such concentration had been intermittently sealing a leak in the side of the tank since mid-October 1958. However caused, the existence of these fluctuations in the water content of the soil column means that daily values of potential evapotranspiration were not obtainable. Results must therefore be averaged over periods long enough to allow for time-lag. A shorter time may be legitimate, but the calendar month is here taken as a convenient period.

For practical reasons, the Hal Far observations had to be made at dusk, while those at ta'Qali were made at 09h00 local time. Measurement was done in the same way at each station, but there were other contrasts. For example, it was possible to surround the ta'Qali tank with an irrigated buffer zone approximately 20 ft. (6 m) in radius which carried a vegetation identical with that of the tank. Such irrigation was not feasible at Hal Far where, during the long summer drought, the grass in the tank stood as an isolated verdant oasis surrounded by parched grass and a few specialized xerophytes. There is also a contrast of site. The Hal Far tank is on exposed rising ground open to a strong and persistent on-shore breeze. At ta'Qali, wind values are lower, the site lies in a slight hollow and is further protected within a walled enclosure.

RESULTS

The measured monthly values of potential evapotranspiration were as given in Table II. Not only is there a wide disparity between the two sets of data, but the summer values are excessively high, appreciably above the theoretical maximum in some cases. A partial explanation is to be found in the fact that neither tank is exposed within the large wetted area which the concept demands, values being exaggerated by the advection of dry air. This effect is likely to be greater at Hal Far where the site is exposed and the wetted area is only some 400 square inches (2,580 cm^2). The wetted area at ta'Qali is larger, but still inadequate. GREEN (1959), applying Sutton's work

DAILY RECORDS FROM HAL FAR EVAPOTRANSPIROMETER (IN INCHES)

14th	*15th*	*16th*	*17th*	*18th*	*19th*	*20th*
0.	0.73	0.73	0.73	0.73	0.73	0.73
Nil	Nil	Nil	Tr	Tr	Nil	Nil
0.73	0.73	0.73	0.73	0.73	0.73	0.73
0.34	0.37	0.49	0.55	0.98	0.62	0.44
0.39	0.36	0.24	0.18	–0.25	0.11	0.29

on isolated totally wet surfaces in a completely dry environment, has suggested reduction factors as compensation for this "oasis effect". Since the "oasis effect" is as- ...ed to operate in such a manner that evaporation increases with the 1.88 power of the radius, it follows that the appropriate reduction factor will be larger for Hal Far than for ta'Qali. There will therefore be a tendency for the rather widely disparate values from the two sites to approach one another. For the three summer months of 1957, when the environment may be regarded as having been totally dry, adjustment yields very close agreement. Any residual differences might readily be accounted for in terms of relative exposure or local climatic variation (Table III).

TABLE II

...RED POTENTIAL EVAPOTRANSPIRATION

		Hal Far		*ta'Qali*	
		(inches)	*(mm)*	*(inches)*	*(mm)*
1957	May	11.96	303.8	5.29	134.4
	June	11.87	301.5	7.32	185.9
	July	14.26	362.2	9.79	248.7
	August	18.09	459.5	12.04	305.8
	September	13.20	335.3	5.58	141.7
	October	6.33	160.8	3.37	85.6
	November	5.40	137.2	2.01	51.1
	December	3.09	78.5	2.15	54.6
1958	January	2.52	64.0	1.59	40.4
	February	3.00	76.2	1.31	33.3
	March	5.13	130.3	2.73	69.3
	April	8.42	213.9	3.10	78.7
	May	13.23	336.0	5.44	138.2
	June	14.10	358.1	7.33	186.2
	July	15.17	385.3	7.53	191.3
	August	15.99	406.1	8.59	218.2
	September	14.18	360.2	8.90	226.1
	October	8.90	226.1	6.15	156.2
...nd total		184.84	4695.0	100.22	2545.7

TABLE III

ADJUSTED VALUES OF POTENTIAL EVAPOTRANSPIRATION

		Hal Far		ta'Qali	
		(inches)	*(mm)*	*(inches)*	*(mm)*
1957	June	5.45	138.4	4.86	123.4
	July	6.55	166.4	6.50	165.1
	August	8.26	209.8	8.00	203.2

TABLE IV

ADJUSTED VALUES OF POTENTIAL EVAPOTRANSPIRATION

		Hal Far		ta'Qali	
		inches	*mm*	*inches*	*mm*
1957	May	6.01	152.7	5.04	128.0
	June	5.45	138.4	4.86	123.4
	July	6.55	166.4	6.50	165.1
	August	8.26	209.8	8.00	203.2
	September	6.79	172.5	4.12	104.6
	October	4.85	123.2	3.18	80.8
	November	5.40	137.2	2.01	51.1
	December	3.09	78.5	2.15	54.6
1958	January	2.52	64.0	1.59	40.4
	February	3.00	76.2	1.31	33.3
	March	3.35	85.1	2.73	69.3
	April	3.87	98.3	2.41	61.2
	May	6.29	159.8	3.82	97.0
	June	6.49	164.8	4.88	124.0
	July	6.95	176.5	5.00	127.0
	August	7.35	186.7	5.77	146.6
	September	6.52	165.6	7.28	184.9
	October	4.82	122.4	4.46	113.3
Grand total		97.56	2478.1	75.11	1907.8
Twelve-monthly totals					
May–April		53.69	1363.7	43.90	1115.1
June–May		53.97	1370.8	42.68	1084.1
July–June		55.01	1397.3	42.70	1084.6
August–July		55.41	1407.4	41.20	1046.5
September–August		54.50	1384.3	38.92	988.6
October–September		54.23	1377.4	42.13	1070.1
November–October		54.20	1376.7	43.41	1102.6
Mean		54.43	1382.5	42.13	1070.2

Certain months, November 1957 to February 1958 inclusive, for example, experienced sufficient rainfall to ensure that the surroundings of the tanks would be constantly moist enough to yield evaporation at the potential rate. No correction would be necessary in these circumstances. Rather more difficult to deal with are the intermediate periods, when the surroundings are wet after rain, but subsequently dry out. A subjective assessment may be made by inspecting the ground and observing the vegetation. An approach with which the writer has experimented is based upon the "water balance" concept itself. It is assumed that, following rain, evapotranspiration will take place at the prevailing potential rate until the amount stored in the soil is exhausted. If the rain comes from an isolated dry season storm the amount stored is taken to be the amount of that rain; at the beginning of the dry season the value of the storage capacity of the soil is used. In the Malta cases a value of 2.5 inches (63.5 mm) for storage capacity has been adopted. When the available soil moisture is shown to be exhausted, then the reduction factor becomes applicable. Several objections might be raised against this technique of adjustment and a better approach is being sought.

In Table IV are shown the values of potential evapotranspiration, adjusted to eliminate the "oasis effect". It is apparent that overall agreement is less close than for the high summer of 1957, since Hal Far values are, in aggregate, some 30% greater than those for ta'Qali. This contrast is fairly well maintained from month to month—a correlation coefficient of +0.85 was obtained from the two sets.

For comparison, values of potential evapotranspiration for central Malta, computed according to CROWE's (1957) method from standard meteorological data are given at Table V. The aggregate value is very close indeed to the ta'Qali figure, but monthly amounts differ appreciably. There is, in fact, a better correlation (+0.89) with Hal Far than with ta'Qali (+0.85). Consideration of the three sets of monthly values indicates that adjustment for the "oasis effect" is of the correct order of magnitude.

Clearly evident is the seasonal trend of evapotranspiration, with maximum values of the order of 7–8 inches (180–200 mm) per month in high summer, falling to 1.5 inches (40 mm) or less during the winter months. Set against the prevailing Mediterranean rainfall regime, the major implications are obvious. The annual potential evapotranspiration must exceed annual rainfall except in the most unusual years—Valletta average (1841–1956): 20.54 inches (521.7 mm); range: 7.95 (201.9 mm) to 39.36 inches (1,000 mm). Also clear are the facts of a normal moisture surplus in winter, and a marked summer deficit. These implications are discussed more fully elsewhere (BOWEN-JONES et al., 1961; MITCHELL, 1959).

RESIDUAL PROBLEMS

Many problems remain. For example, it is not at all easy to explain why the adopted tank values for the autumn should normally be so much larger than the

TABLE V

COMPUTED VALUES OF EVAPOTRANSPIRATION (CROWE'S METHOD) FOR CENTRAL MALTA

	1957		*1958*	
	inches	*mm*	*inches*	*mm*
January	—	—	1.5	38
February	—	—	1.4	36
March	—	—	2.4	61
April	—	—	3.3	84
May	4.4	112	4.9	124
June	5.4	137	5.8	147
July	7.0	178	6.6	168
August	7.1	180	7.1	180
September	4.8	122	4.5	114
October	2.6	66	3.1	79
November	1.7	43	—	—
December	1.4	36	—	—
Grand total (1957–1958)	75.0	1,905		

Twelve-monthly totals	*inches*	*mm*
May–April	43.0	1,092
June–May	43.5	1,105
July–June	43.9	1,115
August–July	43.5	1,105
September–August	43.5	1,105
October–September	43.2	1,097
November–October	43.7	1,110
Mean	43.5	1,105

computation would suggest. Does this discrepancy indicate the inapplicability of the formula or an error in the field? Here lies the major lesson to be drawn from these investigations. Because the relationship between the true value of potential evapotranspiration and that measured in the field remains uncertain, it is impossible to judge where the error lies. Although it is generally accepted that the various formulae yield reliable results under humid mid-latitude conditions, they do not appear to do so under monsoonal conditions, as in Hong Kong (RAMAGE, 1954). Do they in other parts of the world, and especially in those regions which, either seasonally or constantly, might be described as semi-arid? In the light of the Malta experience, the writer would suggest that an assured answer can only be obtained if groups of field tanks are carefully exposed within large buffer zones of irrigated vegetation, identical in type, density and height with that in the tanks. This will prove expensive, financially and in terms of manpower and water in areas where none of these items is abundant. But the amount of effort already applied in these same areas to the production of data of dubious applicability from orthodox evaporation pans and such instruments as the piche evaporimeter (in the results from which there appears to be little general confidence), suggests that these costs could be justified, with great benefit, not only to the climatologist, but also to the agriculturalist and water engineer and hence to the underprivileged populations of these zones.

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