Potential evapotranspiration as measured at Valentia Observatory over the period August 1952 to February 1962 and a comparison with values as computed by the Penman formula

DEPARTMENT OF TRANSPORT AND POWER
METEOROLOGICAL SERVICE

TECHNICAL NOTE No. 29

POTENTIAL EVAPOTRANSPIRATION AS MEASURED AT VALENTIA OBSERVATORY OVER THE PERIOD AUGUST 1952 TO FEBRUARY 1962 AND A COMPARISON WITH VALUES AS COMPUTED BY THE PENMAN FORMULA

BY

W. A. MORGAN M. Sc.

U.D.C.
551.573

DUBLIN
OCTOBER 1962
Price: 1s. 0d.

Potential Evapotranspiration as measured at Valentia Observatory over the period August 1952 to February 1962 and a comparison with values as computed by the Penman formula.

by

W.A. MORGAN

SUMMARY:

Observations of potential evapotranspiration for a grass covered surface at Valentia Observatory are available since August 1952. Monthly, seasonal and annual values for the period are compared with the values as computed by the Penman formula. It is found that data for most months support the hypothesis that there is no difference between the mean monthly values of potential evapotranspiration as measured and as calculated by the Penman formula. However, the data for the seasons spring and summer and for the years, indicate there is a real difference between the mean values as measured and as computed by the Penman method. There is found to be no correlation between the measured and Penman values in the months January to April inclusive, August and December. The range of variation of the Penman values is significantly lower than for the measured values in a number of months and in most seasons.

If the "actual" amounts of evapotranspiration are taken to be the measured values increased by 5% of rainfall, then there is a decrease in the number of months supporting the hypothesis that there is no difference between the mean monthly amount of evapotranspiration and the Penman value. Data for the seasons spring, autumn and winter and annual values indicate there is a real difference between the "actual" mean values and those given by the Penman formula. Again there is no correlation between "actual" and Penman values in the months January to April inclusive, August and December. The range of variation of the Penman values is significantly lower than for the "actual" values in many months and in the seasons Autumn and Winter.

There is no correlation between rainfall and the difference between measured values and those computed by the Penman formula.

INTRODUCTION:

An installation consisting of four sunken tanks for measuring potential evapotranspiration has been in use at Valentia Observatory since mid-July 1952. The tanks, as described by Guerrini [1], are set out in the form of a square, the diagonal distance between the centres of pairs of tanks being 36 ft. and the run off from each tank is collected in a container in a central pit. The surface of the soil in the tanks is covered with grass similar to that of the surrounding ground and is at the same level as the surrounding ground. The rims of the tanks project 2 inches above ground level to prevent ingress of surface water from the surrounding area. A raingauge situated nearby is used to measure the rain falling on the tanks and when there is insufficient to keep the soil in the tanks moist, a measured quantity of water is sprinkled on the surface of the soil in the tanks. The rainfall and the amount of water percolating through each tank is measured each day at 1800 h GMT and the rainfall plus added water, if any, minus runoff is taken as the potential evapotranspiration.

Data as available up to July 1956 were analysed by Guerrini [2] who investigated various methods of estimating potential evapotranspiration and found that the Penman formula [3] gave the best fit to the Valentia observations. In the present paper the more extensive data now available are used to provide a comparison with monthly seasonal and annual values calculated by the Penman formula. Details of some of the constants used in the Penman computation are also given.

POTENTIAL EVAPOTRANSPIRATION MEASURED AT VALENTIA OBSERVATORY

Monthly, seasonal and annual values of potential evapotranspiration measured at Valentia Observatory up to February 1962 are given in Table 1. These values are the means of the observations for the four tanks comprising the evapotranspirometer, except when one or more tanks may have been out of order, in which case the values given are means of the values for the remaining tanks. There were a few occasions where all tanks were out of order for some days. In each of these cases the value for the month has been obtained by making a proportional correction on the basis of number of days lost. Original measurements are to 0.1 mm. but they have been rounded to whole mm. owing to the variability in values between the different tanks. A number of the values in Table 1 differ slightly from those given in [2] and arise mainly as a result of a re-scrutiny of the original daily values.

Owing to the time lag in percolation, the difference between rainfall and run-off in a period as short as a day can often be negative. The frequency with which this happens diminishes with increase in period considered and for periods of one month, only one case arises. In that month, December, 1954, the amounts recorded by all tanks were negative. There were five months when the monthly evapotranspiration measured by one tank was negative, four months when the values by two tanks were negative but only one when three tanks or four tanks gave negative totals. These results underline the increased variability that may arise if only one tank is used.

From a study of the daily values of rainfall and runoff for December, 1954, the large negative value of evapotranspiration could not be wholly accounted for by percolation time lag. However, the amount of rain falling on the surface of the tanks could be greater than the amount recorded by the associated raingauge. The results of a comparison between the catch of raingauges set at different heights above ground are given in "British Rainfall" for 1868, [4], and the catch at a height of 2 inches above ground level is given as 5% greater than that at 1 foot, which is the height of the rim of the standard gauge used at Valentia Observatory. Stanhill [5] found that in 1956 a gauge with rim 0.3 inch above ground level also collected 5% more rain than that collected by a standard gauge with rim at the standard height of 1 foot. Applying this correction of 5% of rainfall to the rainfall for December, 1954 results in the potential evapotranspiration becoming a positive amount. Values of potential evapotranspiration, as increased by taking the rainfall at ground level to be 5% greater than that recorded by the raingauge, are given in Table 2.

POTENTIAL EVAPOTRANSPIRATION COMPUTED BY THE PENMAN FORMULA:

In the Penman formula [3] the daily evaporation E_0 (in mm.) from an extended sheet of open water exposed to the weather conditions found over the site is given by the semi-empirical formula.

$$E_o = (\Delta H + 0.27E_a) \; / \; (\Delta + 0.27) \qquad (1)$$

Where Δ = slope of the vapour pressure curve for water (mm. of mercury/°F) at mean air temperature, T.

$H = R_a(1-r)(0.18+0.55n/N)-\sigma T^4(0.56-0.092\sqrt{e_d})(0.10+0.90\ n/N)$

$E_a = 0.35(e_a-e_d)(1+0.01u_2)$ mm./day.

R = theoretically calculable amount of radiation that would reach the earth in the absence of an atmosphere, converted to an evaporation equivalent by putting 59 cal/cm^2 = 1 mm evaporation.

r = reflection coefficient, taken as 0.05

n/N = actual/possible hours of sunshine.

σT^4 = theoretical black-body radiation at mean air temperature T in evaporation units like R.

e_a = saturation vapour pressure at mean temperature T.

e_d = mean vapour pressure of the air.

u_2 = average wind speed in miles/day at 2m above ground.

Converting equation (1) to be appropriate for use with vapour pressure measured in millibars and mean daily wind speed in knots, as available for stations in Ireland, and taking mean wind speed at a height of 2 m as 0.78 of that at 10m, we have

$$E_o = (\Delta H + 0.36\, E_a) \;/\; (\Delta + 0.36)$$

or

$$E_o = \left\{H + E_a(0.36/\Delta)\right\} \;/\; \left\{1 + (0.36/\Delta)\right\}$$

For the determination of R, values of total daily solar radiation at the top of the apmosphere as given for particular dates and latitudes in Table 132 of the Smithsonian Tables [6] were plotted and monthly mean values for different latitudes determined graphically. A diagram was then drawn to give monthly mean values for any latitude in the range 40^o to 65^o. As this diagram may be of general interest it is shown in Figure 1. Values of $0.36/\Delta$ were also calculated, from values of saturation vapour pressure over water at different temperatures in [6], for the range of temperature from 32°F to 80°F and are given in Table 3.

Penman [3] suggests that values of potential evapotranspiration E_T may be taken as 0.6 E_o for the months November to February, 0.7 E_o for March, April, September and October, 0.8 E_o for May to October and 0.75 E_o for the year as a whole. Monthly, seasonal and annual values of E_T on this basis are given in Table 4. Values in this table are not in exact agreement with those given previously by Guerrini [2]. All values used in this paper were obtained and checked by desk calculation machines. It is understood that the values in [2] were obtained by means of a slide rule.

From Table 4 we see that in each year the sum of the twelve monthly values of E_T was greater than the calculated annual value. The ratio of the sum of the twelve monthly values to the annual value ranged from 1.08 to 1.15 compared with ratios of 1.09 to 1.21 found by Penman [3] using long term mean values of meteorological elements. The mean of the ratios, 1.10, is in good agreement with the value 1.14 found by Penman Loc. cit.

COMPARISON OF MEASURED AND COMPUTED MONTHLY POTENTIAL EVAPOTRANSPIRATION:

Tables 1 and 4 show that over the period of years considered the mean monthly potential evapotranspiration as measured was less than that by the Penman formula in eight months of the year and greater in the four remaining months. The mean differences are significant at the 5% level, in April, May, June and September.

Using measured values corrected by the addition of 5% of the rainfall i.e. comparing values as given in Tables 2 and 4, the mean corrected monthly amounts are less than the Penman values for only five months of the year. The mean differences are significant at the 5% level, in January, May, June, September and November.

A feature of the sets of values for most months is the greater variability of the measured amounts, compared with the Penman values. The standard deviations for the different months are as follows:

	Measured values	Penman values		Measured values	Penman values
Jan.	5.9	1.6	July	16.7	11.2
Feb.	8.1	2.2	Aug.	17.1	4.7
Mar.	11.5	3.4	Sept.	12.1	3.8
Apr.	10.5	2.3	Oct.	12.5	4.9
May	14.2	7.8	Nov.	10.1	1.8
June	12.7	10.0	Dec.	7.9	1.4

The differences between measured and Penman values are significantly large in all months except May, June and July.

When the correction for rainfall is applied to the measured values (Table 2) the variability is reduced in 6 months but increased in the remaining cases: the actual standard deviations found are as follows:

	Measured		Measured
Jan.	7.2	July	16.3
Feb.	8.9	Aug.	16.3
Mar.	10.7	Sept.	12.0
Apr.	10.6	Oct.	13.6
May	13.7	Nov.	12.2
June	11.8	Dec.	9.1

Again the differences between these and the Penman values are significantly large in all months except May to July.

These comparisons are of course affected by the time lag in percolation of water through the soil in the tanks. To reduce this effect consider only those months in which the rainfall on the last day of the month and that on the last day of the previous month was in each case not more than 5.0 mm. The measured values for these months are given in Table 5 and measured values corrected by the addition of 5% rainfall in Table 6. For these months the mean differences between measured and Penman values are now significant, at the 5% level, in May and June only, and the mean differences between measured amounts plus 5% rainfall and Penman values, significant at the 5% level, in January, February, June, July and September. At the 5% level the standard deviations for the Penman values were significantly smaller than for the measured values in April, May, August, September and November and compared with measured values plus 5% rainfall, the standard deviations of the Penman values were significantly smaller in February, April, May, August, September and November.

If now we calculate the product moment correlation between the Penman values and corresponding measured amounts as given in Table 1, 2, 5 and 6 we obtain the following series of values

	For Table 1	For Table 2	For Table 5	For Table 6
Jan.	-0.34	-0.12	-0.70	-0.39
Feb.	+0.11	+0.13	+0.87 s	+0.14
Mar.	-0.51	-0.42	-0.64	-0.27
Apr.	+0.44	+0.42	+0.44	+0.72 s
May	+0.73 s	+0.71 s	+0.87 s	+0.89 s
June	+0.84 s	+0.84 s	+0.84 s	+0.90 s
July	+0.77 s	+0.69 s	+0.76 s	+0.68 s
Aug.	+0.42	+0.36	+0.45	+0.39
Sept.	+0.75 s	+0.70 s	+0.78 s	+0.76 s
Oct.	+0.69 s	+0.70 s	+0.74 s	+0.77 s
Nov.	+0.50	+0.59 s	+0.91 s	+0.85 s
Dec.	+0.05	+0.12	+0.52	+0.20

Values indicated by s are significant at the 5% level which in this case is also the 5% point as we assume that any negative value arises only by chance. We see that the Penman values are correlated with the measured values and with measured values plus 5% rainfall in the months May to July, September and October.

The significant value of +0.87 for February under Table 5 is in contrast with the negative values found for January and March and can be expected to be a chance value. The value of +0.72 for April under Table 6, although numerically significant, is also considered to be of doubtful real significance. The value of 0.50 for November under Table 1 is very close to the 5% significance level and it is considered that significance can be assumed for this month. Accordingly, it is considered that the Penman values are correlated with the measured values and with measured values plus 5% rainfall in the months May to July and September to November.

Comparative values as measured and as computed by the Penman formula are shown in Figures 2a and 2b.

Greene [7] found a rough correspondence between the rainfall and the difference between the calculated and measured potential evapotranspiration over a period of a year. To test this consider the values of the coefficient of correlation between rainfall and the difference between Penman and measured values for Valentia Observatory as given in (a) Table 1 and (b) Table 5; they are as follows:

	(a)	(b)		(a)	(b)
Jan.	-0.13	+0.68	July	-0.19	-0.26
Feb.	-0.04	-0.44	Aug.	+0.33	+0.40
Mar.	+0.42	+0.74	Sept.	+0.09	+0.28
Apr.	-0.06	+0.68	Oct.	-0.13	-0.58
May	+0.14	+0.43	Nov.	-0.38	-0.77
June	+0.43	+0.33	Dec.	-0.48	-0.05

None of the values is statistically significant at the 5% level.

Accordingly, these data for Valentia Observatory indicate there is no correlation between rainfall and the difference between the potential evapotranspiration as measured and as given by the Penman formula.

COMPARISON OF MEASURED AND COMPUTED VALUES OF SEASONAL POTENTIAL EVAPOTRANSPIRATION:

From Tables 1 and 4 it is seen that over the period of years considered the mean seasonal potential evapotranspiration as measured was greater than by the Penman formula for autumn but less for the other seasons. The greatest mean differences occurred in spring and summer and both differences are statistically significant at the 5% level.

Considering the measured values as increased by 5% of the rainfall, then the differences between the means of these values and of the calculated values are less than when using the measured amounts alone, for spring and summer but larger in the case of autumn and winter. The larger differences in means occur in autumn and winter and the differences are significant at the 5% level in the case of all seasons except summer.

The standard deviations of the measured values, measured values plus 5% rainfall and of the Penman values are as follows:

	Measured	Measured + 5% Rainfall	Penman
Spring	17.7	17.0	7.7
Summer	27.1	25.3	15.1
Autumn	23.6	23.9	6.3
Winter	11.4	15.3	3.1

The differences between standard deviations of the measured and Penman values are significant at the 5% level in all seasons except summer. For the values as measured plus 5% rainfall, the standard deviations are significantly different in autumn and winter.

The correlation coefficients between Penman values and (a) measured values as given in Table 1 and (b) measured values corrected for rainfall - given in Table 2 are as follows:

	(a)	(b)
Spring	+0.48	+0.52
Summer	+0.54	+0.47
Autumn	+0.79	+0.77
Winter	+0.05	+0.15

Only the values for Autumn are statistically significant at the 5% level.

Comparative values as measured and as computed by the Penman formula are shown in Figure 3.

Values of the coefficient of correlation between rainfall and the difference between Penman and measured values of potential evapotranspiration are as follows:-

Spring	+0.44
Summer	+0.17
Autumn	+0.10
Winter	+0.42

None of these values is statistically significant i.e. the differences between potential evapotranspiration as given by the Penman method and that measured are not correlated with the rainfall in any season of the year.

COMPARISON OF ANNUAL VALUES:

The mean annual evapotranspiration as measured (471.1 mm) is 8.2% lower than the Penman valueof 513.2 mm; the difference is statistically significant. If 5% of rainfall is added to the measured potential evapotranspiration then the mean annual value becomes 541.7 mm which is 5.6% higher than the Penman value. Again the difference is statistically significant.

The standard deviation of the annual values of potential evapotranspiration as measured, is greater than for the Penman values but the difference is not statistically significant. If measured values are increased by 5% of rainfall the standard deviation of annual values is decreased a little and again the difference between it and the standard deviation of the Penman values is not statistically significant.

The coefficient of correlation computed from the annual values by the Penman method and those actually measured is +0.85. Using the Penman values and measured amounts increased by 5% of rainfall the correlation coefficient is +0.87. Both values are statistically significant.

Comparative values as measured and as computed by the Penman method are shown in Figure 3.

The coefficient of correlation between rainfall and the difference between the potential evapotranspiration by the Penman method and as actually measured is +0.42 which is not statistically significant.

References

[1] Guerrini, V.H. : Evaporation and transpiration in the Irish Climate. Technical Note No. 14: Meteorological Service, Dublin. 1953.

[2] Guerrini, V.H. : An analysis of evapotranspiration observed at Valentia Observatory, August 1952-July 1956. Technical Note No.25: Meteorological Service, Dublin 1957.

[3] Penman, H.L. : Evaporation over the British Isles. Q.J. Roy. Met. Soc. Vol. 76. 1950. pp. 372-383.

[4] Symon's British Rainfall, 1868.

[5] Stanhill, G. : Rainfall measurements at ground level. Weather. Vol. XIII, 1958, p.33.

[6] Smithsonian Meteorological Tables, 6th Revised Edition, 1951.

[7] Greene, F.H.W. : Rainfall at ground level. Weather, Vol. XIII 1958, p.275.

Table 1 Values of potential evapotranspiration (mm.) measured at Valentia Observatory.

	1952	1953	1954	1955	1956	1957	1958	1959	1960	1961	1962	Mean
Jan.		11	13	5	6	4	6	5	7	22	2	8.1
Feb.		6	20	26	10	3	17	21	28	15	18	16.4
Mar.		37	37	13	19	22	41	16	18	40		27.0
Apr.		52	49	46	53	35	22	32	49	43		42.3
May		39	84	65	73	86	68	70	60	78		69.2
June		63	74	48	73	86	60	88	74	64		70.0
July		91	69	100	72	55	54	78	66	52		70.8
Aug.	92	60	100	93	64	65	48	66	65	63		71.6
Sept.	62	50	44	73	32	50	56	55	35	49		50.6
Oct.	23	25	13	32	24	25	3	52	23	23		24.3
Nov.	2	5	4	26	19	8	5	20	27	24		14.0
Dec.	3	5	-7	9	10	5	10	19	4	20		7.8
Total		444	500	536	455	444	390	522	456	493		471.1
Spring (Mar-May)	-	128	170	124	145	143	131	118	127	161		138.6
Summer (June-Aug)	-	214	243	241	209	206	162	232	205	179		210.1
Autumn (Sept.-Nov.)	87	80	61	131	75	83	64	127	85	96		88.9
Winter (Dec.-Feb.)	20	38	24	25	17	28	36	54	41	40		32.3

Table 2 Values of potential evapotranspiration + 5% of monthly rainfall (mm.) measured at Valentia Observatory

	1952	1953	1954	1955	1956	1957	1958	1959	1960	1961	1962	Mean
Jan.		14	20	12	15	13	13	11	15	35	11	15.9
Feb.		10	29	32	12	10	23	23	35	21	20	21.5
Mar.		39	46	17	27	32	47	24	24	41		33.0
Apr.		57	51	50	54	38	25	37	54	50		46.2
May		44	88	72	76	90	74	73	64	80		73.4
June		66	78	53	76	88	67	91	77	67		73.7
July		101	74	101	77	62	59	81	75	57		76.3
Aug.	95	65	105	95	72	69	56	69	68	65		75.9
Sept.	64	57	51	79	36	58	66	58	43	59		57.1
Oct.	28	32	23	36	29	32	8	63	28	32		31.1
Nov.	4	13	12	32	25	11	10	30	41	29		20.7
Dec.	11	11	1	16	18	11	18	35	16	25		16.2
Total		509	578	595	517	514	466	595	540	561		541.7
Spring		140	185	139	157	160	146	134	142	171		152.7
Summer		232	257	249	225	219	182	241	220	189		223.8
Autumn	96	102	86	147	90	101	84	151	112	120		108.9
Winter	35	60	45	43	41	47	52	85	72	56		53.6

Table 3 **Values of .36/Δ Where Δ = saturation vapour pressure over water at temperature T+0.5 °F minus saturation vapour pressure over water at temperature T-0.5 °F, in mb.**

Temperature °F	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
32	1.460	1.454	1.448	1.442	1.437	1.432	1.427	1.423	1.419	1.414
33	1.409	1.404	1.399	1.394	1.389	1.383	1.378	1.373	1.368	1.364
34	1.359	1.354	1.349	1.344	1.340	1.335	1.331	1.327	1.322	1.317
35	1.313	1.308	1.304	1.300	1.295	1.290	1.286	1.281	1.276	1.272
36	1.267	1.263	1.258	1.254	1.249	1.245	1.241	1.236	1.232	1.228
37	1.223	1.219	1.215	1.211	1.207	1.203	1.198	1.194	1.190	1.187
38	1.183	1.179	1.175	1.171	1.166	1.162	1.158	1.153	1.149	1.145
39	1.141	1.137	1.133	1.129	1.125	1.121	1.117	1.113	1.110	1.106
40	1.102	1.098	1.095	1.091	1.088	1.084	1.080	1.076	1.072	1.068
41	1.065	1.062	1.058	1.054	1.050	1.047	1.044	1.040	1.037	1.033
42	1.029	1.026	1.023	1.019	1.016	1.012	1.009	1.006	1.002	.999
43	.996	.993	.989	.985	.981	.978	.975	.972	.969	.965
44	.962	.959	.955	.952	.949	.946	.943	.940	.936	.933
45	.930	.927	.924	.921	.918	.915	.912	.909	.906	.903
46	.899	.896	.893	.890	.887	.884	.882	.879	.876	.873
47	.870	.867	.864	.861	.858	.856	.853	.850	.847	.845
48	.842	.839	.836	.833	.831	.828	.825	.822	.819	.816
49	.814	.812	.809	.806	.804	.801	.799	.796	.794	.791
50	.788	.786	.783	.781	.778	.775	.773	.770	.767	.765
51	.763	.760	.758	.755	.753	.750	.748	.746	.743	.740
52	.738	.736	.733	.731	.729	.726	.724	.722	.719	.717
53	.715	.713	.711	.708	.705	.703	.701	.699	.697	.694
54	.692	.690	.688	.685	.683	.681	.679	.677	.675	.672
55	.670	.668	.666	.664	.662	.660	.657	.655	.653	.651
56	.649	.647	.645	.643	.641	.639	.637	.635	.633	.631
57	.629	.627	.625	.623	.621	.619	.617	.615	.613	.611
58	.609	.608	.606	.604	.602	.600	.598	.596	.594	.592
59	.590	.588	.587	.585	.583	.581	.579	.577	.576	.574
60	.572	.570	.569	.567	.565	.563	.561	.560	.558	.556

Table 3 Contd.

Temperature °F	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
61	.555	.553	.551	.549	.548	.546	.544	.543	.541	.539
62	.538	.536	.534	.533	.531	.529	.528	.526	.525	.523
63	.521	.519	.518	.516	.515	.513	.512	.510	.508	.507
64	.505	.504	.503	.501	.499	.498	.496	.495	.493	.491
65	.490	.489	.487	.486	.484	.483	.481	.480	.478	.477
66	.476	.474	.473	.471	.470	.468	.467	.466	.464	.463
67	.461	.460	.459	.457	.456	.454	.453	.452	.450	.449
68	.448	.446	.445	.443	.442	.441	.440	.438	.437	.436
69	.434	.433	.432	.431	.429	.428	.427	.425	.424	.423
70	.422	.420	.419	.418	.416	.415	.414	.413	.412	.411
71	.409	.408	.407	.406	.404	.403	.402	.401	.400	.398
72	.397	.396	.395	.394	.393	.391	.390	.389	.388	.387
73	.386	.385	.383	.382	.381	.380	.379	.378	.377	.376
74	.375	.373	.372	.371	.370	.369	.368	.367	.366	.365
75	.364	.363	.362	.360	.359	.358	.357	.356	.355	.354
76	.353	.352	.351	.350	.349	.348	.347	.346	.345	.344
77	.343	.342	.341	.340	.339	.338	.337	.336	.335	.335
78	.334	.333	.332	.331	.330	.329	.328	.327	.326	.325
79	.324	.323	.322	.321	.320	.319	.318	.317	.316	.315
80	.315	.314	.314	.313	.312	.311	.310	.309	.309	.308

Table 4 Values of Potential evapotranspiration (E_T) in mm. at Valentia Observatory as given by the Penman Formula

	1952	1953	1954	1955	1956	1957	1958	1959	1960	1961	1962	Mean
Jan.		8	9	11	10	12	8	10	8	10	12	9.8
Feb.		13	16	13	12	16	14	17	15	19	17	15.2
Mar.		31	37	36	37	30	34	37	37	29		34.2
Apr.		53	52	52	50	54	48	50	54	48		51.2
May		72	89	85	80	86	73	84	75	95		82.1
June		83	76	69	80	95	78	96	91	71		82.1
July		80	70	106	74	72	69	83	78	79		79.0
Aug.	67	61	71	76	67	65	66	74	74	70		69.1
Sept.	43	40	43	49	37	39	44	48	41	40		42.4
Oct.	31	23	23	24	25	26	24	37	20	28		26.1
Nov.	10	13	12	12	13	11	9	10	15	12		11.7
Dec.	12	9	12	12	13	10	9	12	10	11		11.0
Total		486	510	545	498	516	476	558	518	512		513.2
Year (By formula)		444	463	472	455	464	436	501	468	472		463.9
Spring (Mar-May)		156	178	173	167	170	155	171	166	172		167.6
Summer (June-Aug)		224	217	251	221	232	213	253	243	220		230.4
Autumn (Sept-Nov)	84	76	78	85	75	76	77	95	76	80		80.2
Winter (Dec-Feb)	33	34	36	34	41	32	36	35	39	40		36.0

Table 5 Values of potential evapotranspiration (mm.) as measured at Valentia Observatory for months with 5.0 mm or less of rain on the last day of the month and on the last day of the previous month.

	1952	1953	1954	1955	1956	1957	1958	1959	1960	1961	1962	Total	Mean
Jan.		11	13		6		6	5			2	43	7.2
Feb.		6	20		10						18	54	13.5
Mar.		37	37		19					40		133	33.3
Apr.		52	49	46	53			32	49			281	46.8
May		39	84	65	73	86		70	60			477	68.1
June		63	74	48	73	86		88	74	64		570	71.3
July		91	69	100	72	55	54	78		52		571	71.4
Aug.	92		100	93	64	65	48	66		63		591	73.9
Sept.	62		44	73	32	50		55	35			351	50.1
Oct.	23			32	24	25		52	23			179	29.8
Nov.	2				19	8	5					34	8.5
Dec.	3	5			10	5	10					33	6.6

Table 6 Values of potential evapotranspiration as measured, plus 5% of monthly rainfall (mm.) at Valentia Observatory for months with 5.0 mm. or less of rain on the last day of the month and on the last day of the previous month.

	1952	1953	1954	1955	1956	1957	1958	1959	1960	1961	1962	Total	Mean
Jan.		14	20		15		13	11			11	84	14.0
Feb.		10	29		12						20	71	17.8
Mar.		39	46		27					41		153	38.3
Apr.		57	51	50	54			37	54			303	50.5
May		44	88	72	76	90		73	64			507	72.4
June		66	78	53	76	88		91	77	67		596	74.5
July		101	74	101	77	62	59	81		57		612	76.5
Aug.	95		105	95	72	69	56	69		65		626	78.3
Sept.	64		51	79	36	58		58	43			389	55.6
Oct.	28			36	29	32		63	28			216	36.0
Nov.	4				25	11	10					50	12.5
Dec.	11	11			18	11	18					69	13.8

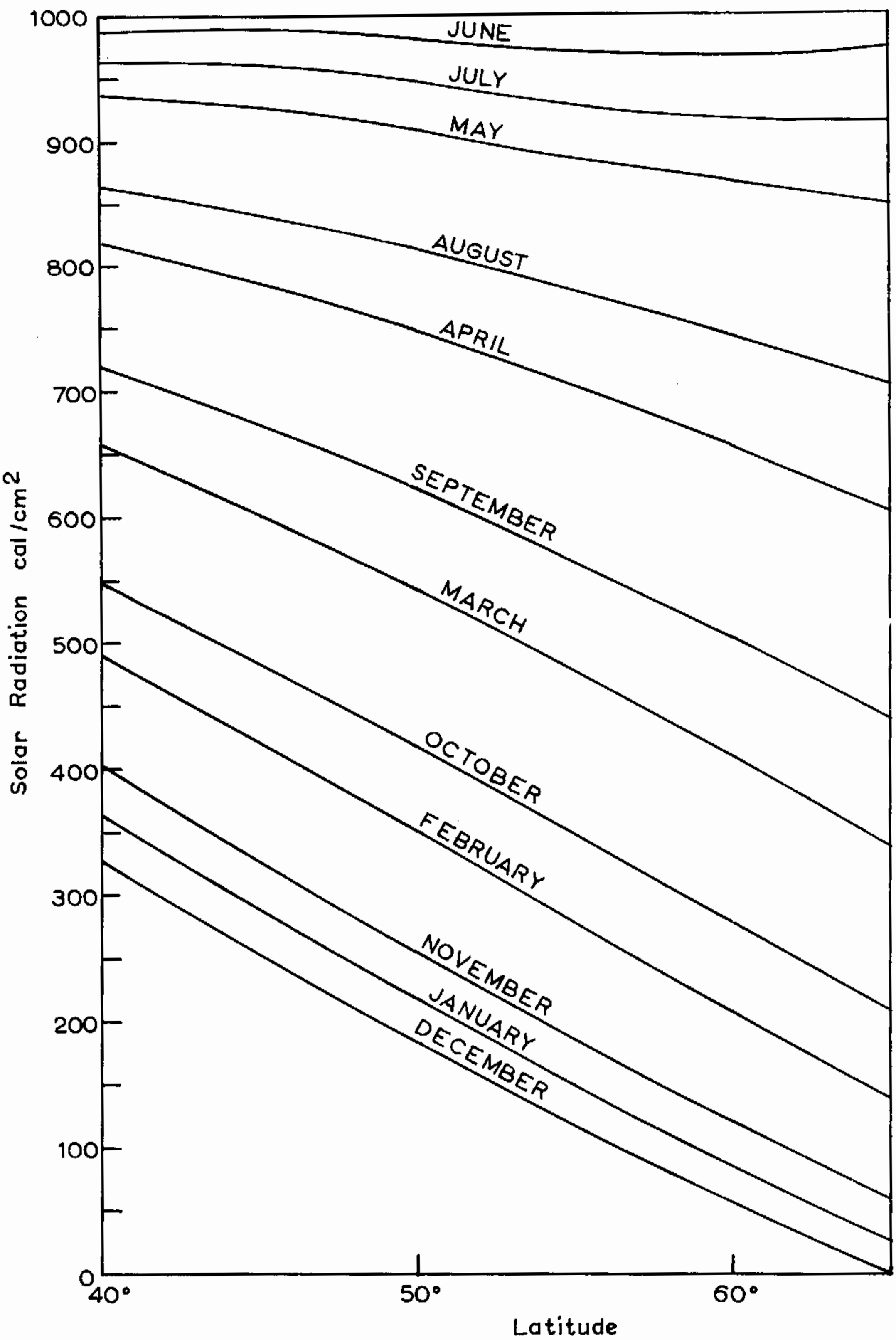

Fig. 1 Mean Daily Solar Radiation for different months between latitudes 40° and 60°.

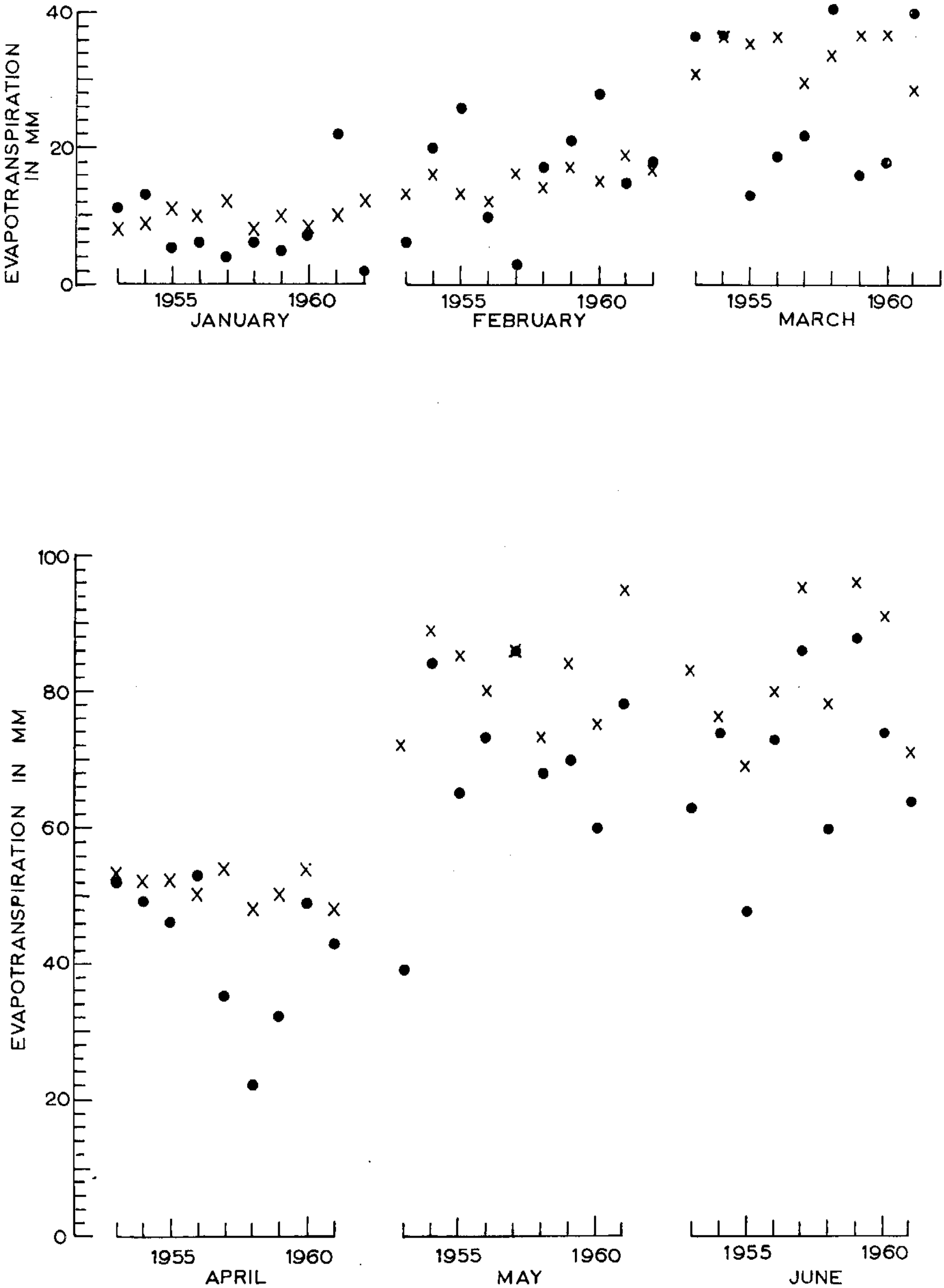

Fig. 2a Evapotranspiration as measured (•) and as computed by the Penman formula (X), January to June.

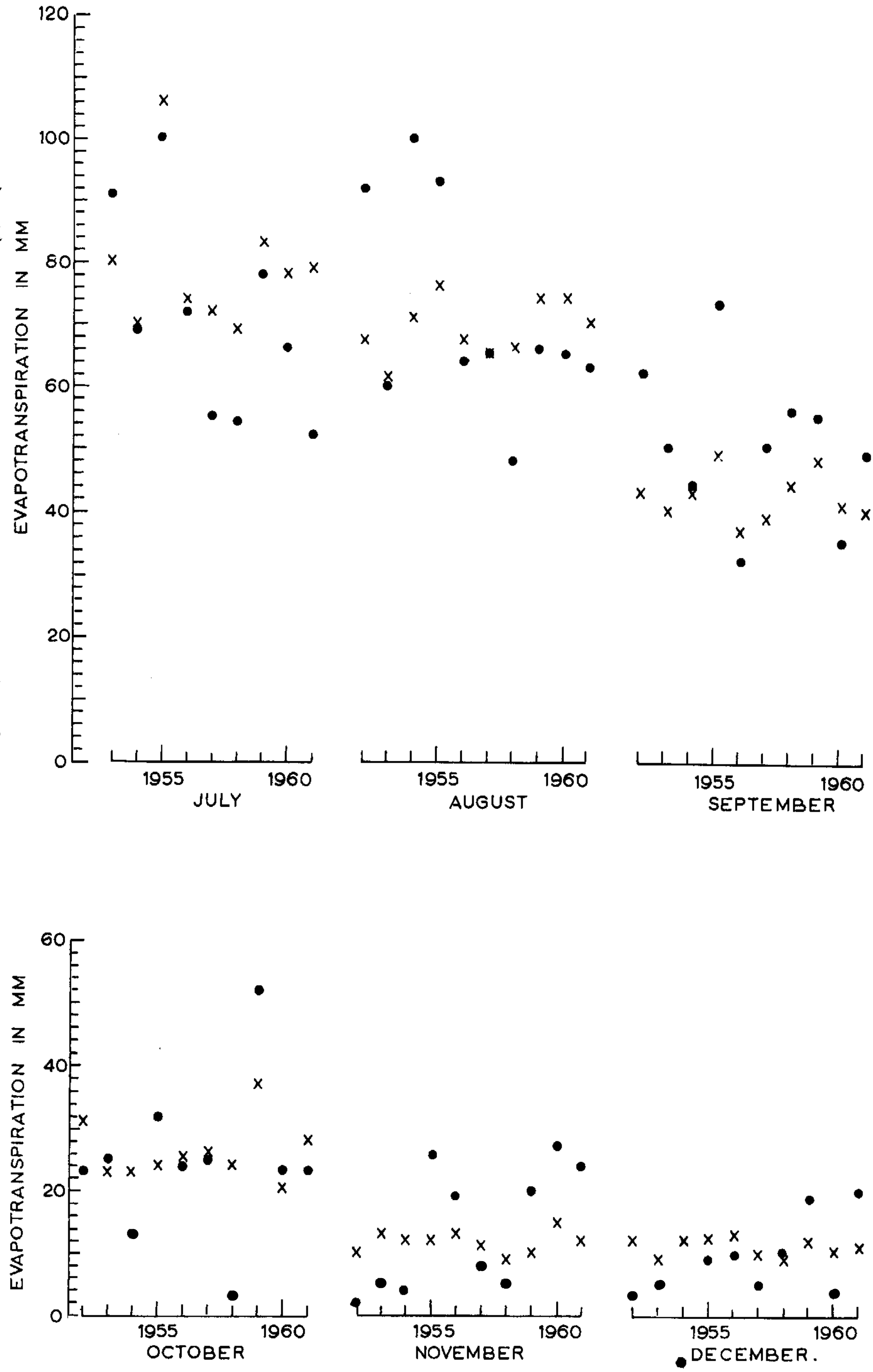

Fig. 2b Evapotranspiration as measured (●) and as computed by the Penman formula (x), July to December.

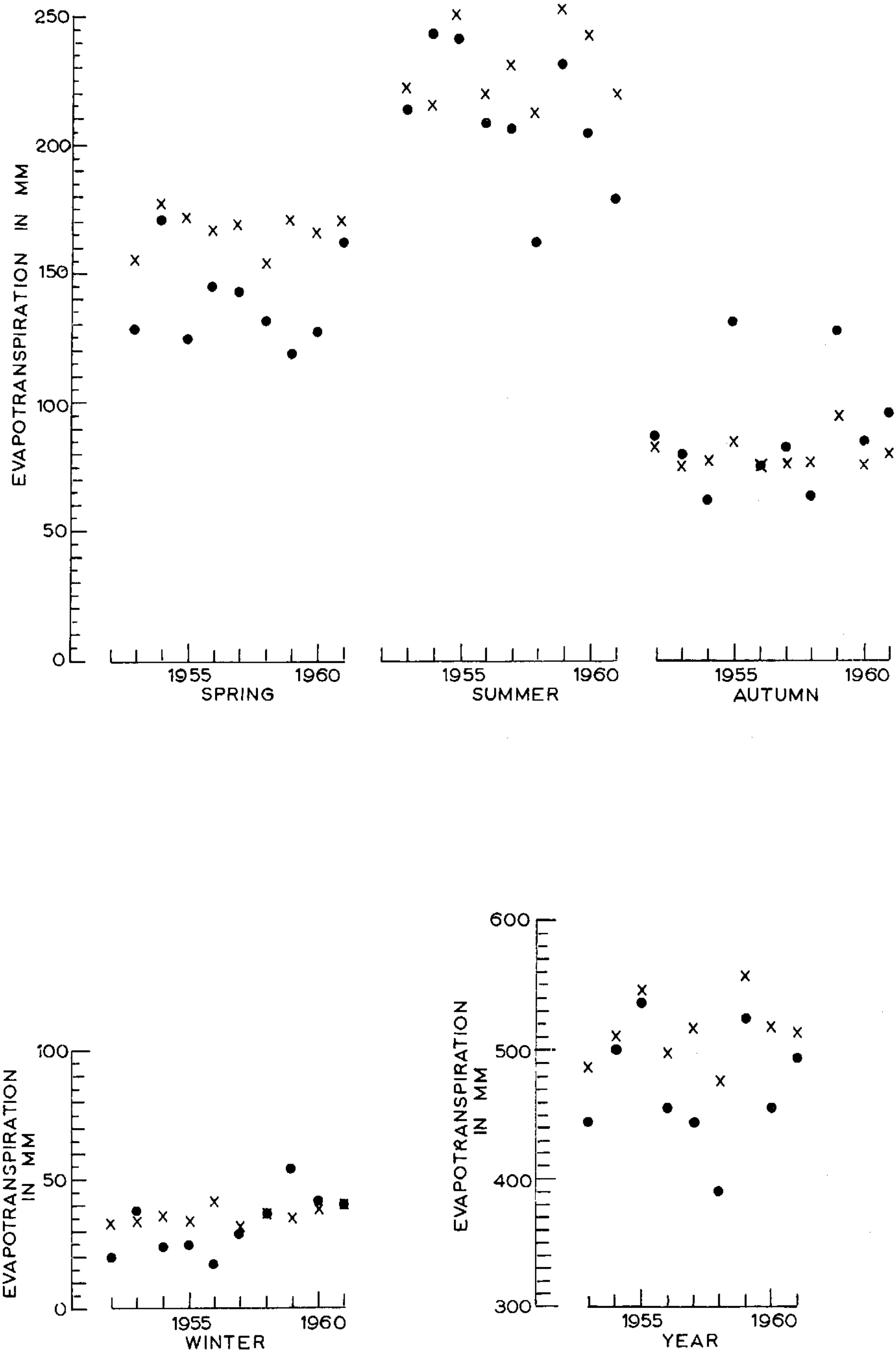

Fig. 3 Seasonal and annual evapotranspiration as measured (•) and as computed by the Penman formula (X).