Mausam, (1986), 37, 2, 153-158

551. 573 : 633 (621)

Comparison of measured and estimated crop evapotranspiration over Egypt

M. H. OMAR and A. M. MEHANNA

Meteorological Authority, Cairo (Egypt)

(*Received 23 January 1985*)

सार — मेहन्ना ने (1976 में) मिस्र के अनेक मौसम केन्द्रों के विभव वाष्पोतसर्जन (वि० वा०) का आकलन किया। इसके लिए इन्होंने विकिरण पद तथा वायुगतिकीय पद के स्थिरांकों के समायोजन सहित पैनमान विधि का उपयोग किया ताकि वे मिस्र में विकिरण के माप तथा ओमर द्वारा (1970 में) गिजा में एक बड़े क्षेत्र के वि० वा० के लिए एक आकलन के साथ मेल खा जाए। विभव वाष्पोत्सर्जन मापियों का उपयोग करके श्री ओमर तथा श्री मेहन्ना ने काहिरा के पास बहतीम के विभव वाष्पोत्सर्जन के ऋतुनिष्ठमापों की मेहन्ना द्वारा बहतीम के विभव वाष्पोत्सर्जन आकलनों तथा खाद्य एवं कृषि संगठन के सिंचाई एवं जल निकास लेख 24 में दी गई विधियों द्वारा किए गए आकलनों के साथ तुलना की। यह लेख डूरेनबो व रूट (1977) द्वारा "फसल की जल आवश्यकता" पर लिखा था। मेहन्ना का आकलन और खा० एवं कृ० सं० के तीन आकलन (ब्लानी-किडल, विकिरण तथा पैन वाष्पन) मापों के ± 10% के भीतर थे जबकि पैनमान आकलन 15% अधिक था। ये तुलना की मुख्य बातें थीं।

मेहन्ना के अनुमानों का उपयोग मिस्र के 9 मौसम केन्द्रों में मिस्र की 4 मुख्य फसलों (कपास, मक्का, गेहूं तथा बरसीम) के शस्य के वाष्पोत्सर्जन (खा० एवं कृ० सं० के लेख की परिभाषा के अनुसार) के आकलन के लिए किया था। इसके लिए मौ० केन्द्रों पर खा० एवं कृषि संगठन के लेख में दिए गए फसल गुणांकों का उपयोग किया गया है। मौ० केन्द्रों पर इन्हीं आकलित शस्य वाष्पोत्सर्जन मूल्यों द्वारा अनेक कृषि अनुसंधान केन्द्रों में शस्य वाष्पोत्सर्जन मूल्य का आकलन किया जा सका। शस्य वाष्पोत्सर्जन के अनुमानों की तुलना शस्य वाष्पोत्सर्जन मापों से उन्हीं अवस्थाओं में की गई जो श० वाष्पो० की थी। साथ ही इन अनुमानों की सभी अवस्थाओं में, जिनमें श० वाष्पो० वाली भी शामिल हैं, लिए गए मापों से भी इसकी तुलना की गई। चार फसलों के लिए मापे गए वाष्पोत्सर्जन से अनुमानित वाष्पोत्सर्जन की औसत अनुपात क्रमशः 0.95 तथा 0.80 था। जब खा० एवं कृषि संगठन की ब्लानीक्रिडल, विकिरण तथा पैनमान विधियां विभव वाष्पोत्सर्जन के आकलन के लिए उपयोग में लाई गई तब उन मामलों के संदर्भ में औसत अनुपात दिए गए थे। इसका यह निष्कर्ष निकलता है कि तुलना सम्भवतः इस बात की पुष्टि कर दे कि मिस्र पर श० वाष्पो० के अनुमानन के लिए मेहन्ना द्वारा किए गए विभव वाष्पोत्सर्जन अनुमान खा० एवं कृषि संगठन के लेख में दिए फसल गुणांक पर लागू करना विश्वसनीय है।

ABSTRACT. Mehanna (1976) estimated potential evapotranspiration (PE) for a number of meteorological stations in Egypt, using Penman's method with adjustment of the constants of the radiation term and the aerodynamic term, such that they would agree with measurements of radiation in Egypt and with estimates by Omar (1971) of PE in a large field at Giza. Omar and Mehanna (1984) compared seasonal measurements of PE at Bahtim (near Cairo) using potential evapotranspirometers with Mehanna's estimates of PE at Bahtim and with estimates by the methods given in the FAO Irrigation and Drainage Paper No. 24 on "Crop Water Requirements" by Doorenbos and Pruitt (1977). The main features of the comparisons were that Mehanna, and three of the FAO estimates (Blaney-Criddle, radiation, and pan evaporation) are within ± 10% of the measurements while the Penman estimate was 15% higher.

Mehanna's estimates of PE were used to calculate ET crop (as defined in the FAO paper) for 4 main crops in Egypt [cotton, maize, wheat and berseem (clover)] at 9 meteorological stations, using crop coefficients given in the FAO paper. The estimated ET crop values at meteorological stations enabled to calculate ET crop at a number of agricultural research stations. Estimates of ET crop were compared with measurements of crop evapotranspiration in conditions similar to those of ET crop, and also with measurements in all conditions including those of ET crop. The average ratio, for the four crops, of measured to estimated evapotranspiration was 0.95 and 0.80 respectively. Average ratios were also given corresponding to cases when the FAO Blaney-Criddle, radiation and Penman methods were used to estimate PE. It is concluded that the comparisons may probably confirm the reliability of applying Mehanna's estimates of PE to the crop coefficients given in the FAO paper to estimate ET crop over Egypt.

1. Introduction

Mehanna (1976) estimated potential evapotranspiration (PE) for a number of meteorological stations in Egypt using Penman's method with adjustment of the constants of the radiation term and the aerodynamic term, such that they would agree with measurements of radiation in Egypt, and with estimates by Omar (1971) of PE in a large field at Giza.

TABLE 1

Ratios of Mehanna's and FAO's paper estimates of PE to measured PE at Bahtim

Season	Mehanna	Blaney/ Criddle	Radiation	Penman
Summer	1.00	1.00	1.05	1.16
Equinoxes	1.02	1.00	1.04	1.16
Winter	1.00	0.99	1.00	1.03
Year	1.01	1.00	1.04	1.14

Omar and Mehanna (1984) compared seasonal measurements of PE at Bahtim (near Cairo) using potential evapotranspirometers with Mehanna's estimates of PE at Bahtim and with estimates by the methods given in the FAO Irrigation and Drainage Paper No. 24 on "Crop Water Requirements" by Doorenbos and Pruitt (1977). The main features of the comparisons were that Mehanna, and three of the FAO's estimates (Blaney-Criddle, radiation, and pan evaporation) are within $\pm 10\%$ of the measurements while the Penman estimate was 15% higher.

Further study of Mehanna's estimates of PE at Bahtim showed that they are appreciably lower than estimates obtained by using the isolines of PE over Egypt given in Mahanna (1976). This matter was investigated and calculations were made using the data for the 10-year period 1971-1980. An average value of 4.57 mm/day was obtained while the previous value was 4.23 mm/day. The previous calculations were for the data of four years (1967, 1969, 1970, 1971). The ratios of Mehanna's, Blaney-Criddle, radiation and Penman's estimates to measured PE at Bahtim, after making the necessary adjustments are given in Table 1 (Ratios are not given for the pan evaporation method as it is not used in the present study because of the lack of evaporation pans in some stations over Egypt). It can be seen from the table that the Mehanna, Blaney-Griddle, radiation estimates of PE are within 0.99-1.05 of the measurements while the Penman estimate is about 15% higher.

As mentioned in Omar and Mehanna (1984) an estimate of PE at Aswan was based on measurements of pan evaporation and estimates of evaporation from a large water surface at both Bahtim and Aswan, together with measurements of PE at Bahtim. The estimate by the methods by Mehanna, Blaney-Criddle, radiation and Penman lay in the limits of 0-6% of the estimate based on measurements. Comparison of the estimates at 8 stations over Egypt showed that the Penman estimate is higher than the other estimates in Northern and Middle Egypt.

Concerning the accuracy of Mehanna's method, the effect of using the constants of the aerodynamic term, based on measurements at Giza, on the estimates at other distant locations in Egypt was discussed (Omar and Mehanna 1984). It was concluded that these effects on estimated PE are probably not large and would not be more than a few percent.

Concerning the accuracy of estimates of PE by the FAO methods it was mentioned in Part I of the FAO report that only approximate possible errors can be given since no base-line type of climate exists. The Penman method would offer the best results with minimum possible error of *plus* or *minus* 10% in summer and upto 20% under low evaporation conditions. The pan method can be graded next with possible error of 15% depending on the location of the pan. The radiation method in extreme conditions, involves a possible error of upto 20% in summer. The Blaney-Criddle method may overestimate or underestimate PE by upto 25% in humid, windy, mid-latitude winter conditions.

Concerning the increase of Penman's estimates above the other estimates in Northern and Middle Egypt it is noteworthy that Doorenbos and Pruitt (1977), in Appendix II of the FAO report indicated that the methods of Blaney-Criddle, radiation and Penman may possibly overestimate PE by 10-15% at some mid-latitude, semi-arid locations. It may be noted from the figure on page 117 of the FAO report that the Penman estimates of PE at Davis, California, are about 15% higher than measured PE.

The aim of this work is two-fold. The first aim is to estimate total ET crop for 4 main crops in Egypt [cotton, maize, wheat and berseem (clover)] at 9 meteorological stations using crop coefficients given in the FAO report. As given in the FAO report ET crop denotes the evapotranspiration of a disease-free crop grown on large fields under optimum soil water and fertility conditions and achieving full production potential under the given growing environment. The second aim is to compare measurements and estimates of total crop evapotranspiration at a number of agricultural research stations. Mehanna's estimates of PE at meteorological stations were applied to the crop coefficients given in the FAO report. Mehanna's method was chosen for this aim. This may be acceptable taking into account the closeness of Mehanna's estimate to measurements at Bahtim in Northern Egypt and at Aswan in Southern Egypt and the comments on the accuracy of the FAO methods mentioned above. Besides Mehanna's method is based on constants obtained in Egypt while the FAO-Penman method is based on constants obtained abroad. However, the results of comparison between measured and estimated total crop evapotranspiration in Egypt on the basis of PE estimates by the FAO methods were calculated by a simple method and will be given in the final results.

2. Estimations and measurements

2.1. *Estimation of PE by Mehanna's and FAO's methods*

The formula used by Mehanna (1976) is given and discussed in Omar and Mehanna (1984). Reference is made to the FAO report for details of the FAO methods.

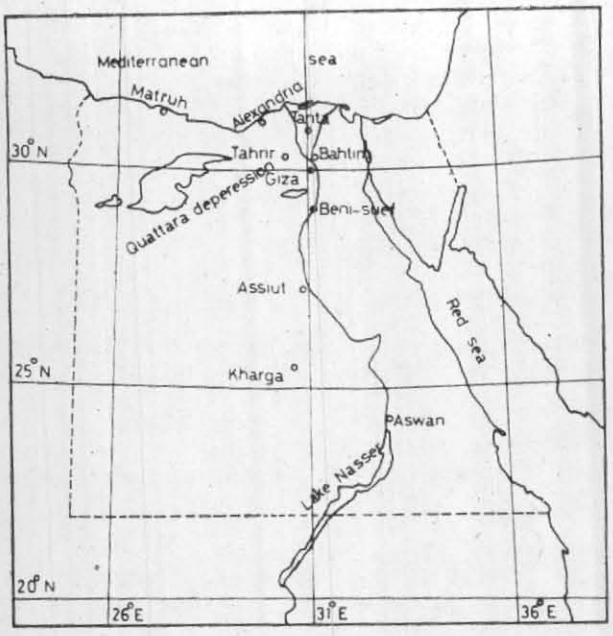

Fig. 1. Locations of meteorological stations over Egypt

TABLE 2
Planting dates and periods for the different crops

Crop	Planting date	Period
Cotton I	1 March	March-August
Cotton II	1 April	April-September
Maize I	15 May	May-September
Maize II	15 June	June-October
Wheat	15 November	November-April
Berseem	15 October	October-May

Mehanna's estimates of PE were based on data of a 10-year period while calculations by the FAO methods were for a 14-year period.

2.2. *Estimation of monthly and total ET crop at 9 meteorological stations*

Monthly values of ET crop were estimated for the 4 main crops : cotton, maize, wheat and berseem at 9 meteorological stations : Matruh, Alexandria, Tanta, Tahrir, Bahtim, Beni-suef, Assiut, Kharga and Aswan. The locations of those stations are shown in Fig. 1.

The crop planting or sowing date will affect the length of the growing season, the rate of crop development to full groundcover and onset of maturity. According to field conditions two dates for planting were used for cotton and maize. The first date indicates the best to get maximum yield while the second date took into consideration the field conditions, *e.g.*, the harvest of the previous crop or the ploughing of the soil. The planting dates and periods for the different crops are given in Table 2.

According to Doorenbos and Pruitt (1977) the crop growing season has been divided into 4 stages as follows :

(1) *Initial stage* — Germination and early growth when the soil surface is not or is hardly covered by the crop (ground cover $< 10\%$).

(2) *Crop development stage* — From end of initial stage to attainment of effective full ground cover (ground cover $\simeq$ 70-80%).

(3) *Mid-season stage* — From attainment of effective ground cover to time of start of maturing as indicated by discolouring of leaves or leaves falling off

(4) *Late season stage* — From the end of mid-season stage until full maturity of harvest.

The appropriate crop coefficient for each stage was applied to PE calculated by Mehanna's method. The total value of ET crop was obtained as the sum of the monthly values.

2.3. *Estimation of total ET crop at agricultural research stations*

Total ET crop at the agricultural research stations was estimated using PE estimates of the nearest meteorological station for which ET crop was estimated.

The agricultural stations are :

Ras-El-Hekma, about 60 km to the east of Matruh. Sakha, about 50 km to the north of Tanta. Gimmeza, about 5 km to the south of Tanta. Shebin-el-Kom, about 45 km to the south of Tanta. Giza, about 30 km to the south of Bahtim. Sids, about 20 km to the south of Beni-suef. Mallawi, about 60 km to the north of Assiut.

The agrometeorological station at Bahtim lies in the agricultural research station at Bahtim.

The estimation of total ET crop at an agricultural research station is based on the assumption that this item is equal to total ET crop at the nearest meteorological station multiplied by the ratio of the estimated annual PE at the agricultural station to the estimated annual PE at the meteorological station.

This assumption is reasonably reliable taking into account that the distance between the agricultural station and the nearest meteorological station is not big. PE at an agricultural station was estimated using Fig. 2(a) in Mehanna (1976) giving the distribution of annual PE over Egypt.

2.4. *Measurements of water use of crops*

Measurements were made by the water budget oven-drying method. Crop evapotranspiration was calculated as the difference in soil moisture contained in soil samples taken just before and two days after irrigation and taking rainfall into account. Drainage is neglected, but the little rainfall would have only slight effect on the accuracy of measured evapotranspiration. The cases given by Omar (1981) may be considered more accurate than previous measurements. According to Rijtema and Aboukhaled (1973) most of the previous measurements were made with soil sampling

to 50 or 60 cm depth in two or three replicates per treatment. This may prove not to be adequate in many cases. Large deviations may be expected on such small number of replicates. On the other hand, root development depends on the irrigation treatment and therefore sampling to such limited depth leads to some underestimation in measured water use.

3. Procedure

3.1. *Details of the comparisons*

The comparison is based on measurements of crop evapotranspiration given in the following publications :

(1) WMO Agriculture Meteorology Report No. 6— Report on water requirements of agricultural crops under arid and semi-arid conditions by Omar (1981).

(2) Crop water use in the Arab Republic of Egypt. FAO Report RNEA, Cairo, by Rijtema an Aboukhaled (1973).

(3) Crop water use in the New Valley of Egypt — A study for the New Valley project, FAO/UNDP/ EGY/71/06/B/01/12 by Aboukhaled (1974).

Two comparisons were made. The first one was between total ET crop and measured evapotranspiration in optimal conditions of water, fertility and maximum yield.

The second comparison was between estimated total ET crop and total measured crop evapotranspiration in all cases available, *i.e.*, including but not restricted to the optimum conditions mentioned above.

The first comparison included the cases given in Omar (1981) for cotton, maize and wheat. The cases given in this publication were associated with highest yields. Besides, the comparison included, from the cases of measurements given in Rijtema and Aboukhaled (1973) the cases that agreed with the optimum conditions mentioned above.

The cases studied and the locations of measurement are as follows :

The cases given in Omar (1981) include :

Cotton

Sakha (Mahrous 1977) — Bahtim (El-Serougy *et al.* 1973)

Maize

Sids (Tawadros *et al.* 1969).

Wheat

Sakha (Abdel Rasool *et al.* 1971).

The cases given in Rijtema and Aboukhaled (1973) include :

Cotton

Gimmeza (Badawi 1970 — Shebin-el-Kom (Labib Kunany 1964) — Bahtim (El Serougy *et al.* 1971) — Giza (Talha 1966; Chaudry 1969 and Gibali 1972).

Maize

Ras-el-Hekma (Awadalla 1970) — Giza (El-Maghraby 1969) — Sids (El-Gibali and Miseha, unpublished data in 1967).

Wheat

Gimmeza (Badawi 1970) — New Valley (reference not given).

Berseem

Gimmeza (Badawi 1970).

The second comparison includes all cases given in Omar (1981), Rijtema and Aboukhaled (1973) and Aboukhaled (1974).

The cases given in Rijtema and Aboukhaled (1973) besides those given under the first comparison include :

Cotton

Sakha (El-Shal 1966; Khalil *et al.* 1966) — Gimmeza (Khalil *et al.* 1966; Badawi 1970) — Bahtim (El Serougy *et al.* 1971) — Giza (El-Shal 1966) — Sids (El-Shal 1966; Khalil *et al.* 1966) — Mallawi (El-Shal 1966).

Maize

Sakha (El-Shal 1966) — Gimmeza (Badawi 1970) — Giza (El-Gibali 1966; El-Shal 1966; Talha 1966) — Sids (Tawadros *et al.* 1969).

Wheat

Gimmeza (Badawi 1970) — Giza (Seif-el-Yazal 1971) — Mallawi (El-Shal 1966).

Berseem

Delta (El-Shal 1966) — Middle Egypt (Badawi *et al.* 1969).

The cases given in Aboukhaled (1974) include :

Wheat

Kharga (Report on crop-water use in New Valley 1972, in Arabic).

Berseem

Kharga (The same reference given above for wheat).

In case of the first comparison the data of measured evapotranspiration and estimated ET crop and the ratio of the former to the latter are given for each location. In case there is more than one observation at the same location average values of estimated and measured evapotranspiration are used. In case of the second comparison a similar procedure as for the first comparison is used but the data are given for a group of locations when these locations are near to each other, *e.g.*, Tanta including Sakha, Gimmeza and Shebin-el-Kom.

N. B.

In the case of wheat in New Valley, given in the first comparison, estimated ET crop for Kharga was used. In the case of Berseem in Delta, given in the second comparison, estimated ET crop for Tanta was

TABLE 3

Estimated ET crop (mm) for 4 crops at different meteorological stations

Station	Cotton I	Cotton II	Maize I	Maize II	Wheat	Berseem
Matruh	842	836	619	575	395	789
Alexandria	825	855	633	584	370	768
Tanta	886	922	651	591	346	749
Tahrir	957	964	711	637	370	796
Bahtim	941	943	691	627	368	791
Benisuef	1200	1215	888	819	475	1031
Assiut	1229	1223	886	825	546	1159
Kharga	1308	1423	1040	970	625	1322
Aswan	1359	1474	1074	1015	729	1489

TABLE 4

Comparison between estimated total ET crop (mm) and measured evapotranspiration (mm) in cases of optimum soil water, fertility and production

Crop	Location	Measured evapotranspiration (1)	Estimated ET crop (2)	Ratio (1)/(2)
Cotton	Shebin-el-Kom	990	890	1.11
	Sakha	630	890	0.71
	Gimmeza	800	890	0.90
	Bahtim	670	945	0.71
	Giza	1060	1050	1.01
			Average ratio	=0.89
Maize	Ras-el-Hekma	525	590	0.89
	Giza	670	755	0.89
	Sids	720	855	0.84
			Average ratio	=0.87
Wheat	Sakha	300	340	0.88
	Gimmeza	470	345	1.35
	New Valley	610	680	0.90
			Average ratio	=1.04
Berseem	Gimmeza	735	745	=0.99
			Average ratio for four crops	=0.95

used. In the case of berseem in Middle Egypt, given in the second comparison average estimated ET crop for Benisuef and Assiut was used.

3.2. *Estimation of ratios of measured to estimated crop evapotranspiration in the case when PE is estimated by the FAO methods*

The ratio required was considered to be nearly equal to the ratio obtained when Mehanna's estimates of PE are used divided by the average ratio, (for 5 meteorological stations : Alexandria, Tanta, Benisuef, Assiut & Aswan, assumed to be representative of the country as a whole) of the FAO annual estimate of PE to the annual Mehanna's estimate.

TABLE 5

Comparison between estimated total ET crop (mm) and measured evapotranspiration (mm) for all cases available (*i.e.*, not restricted to cases of optimum conditions

Crop	Location	Measured evapotranspiration (1)	Estimated ET crop (2)	Ratio (1)/(2
Cotton	Sakha, Gimmeza and Shebin-el-Kom	780	890	0.88
	Giza & Bahtim	845	995	0.85
	Mallawi	805	1165	0.69
	Sids	770	1210	0.64
			Average ratio	=0.76
Maize	Ras-el-Hekma	525	590	0.89
	Sakha & Gimmeza	495	620	0.80
	Giza	590	755	0.78
	Sids	720	855	0.84
			Average ratio	=0.83
Wheat	Sakha & Gimmeza	385	340	1.13
	Giza	290	400	0.72
	Mallawi	380	520	0.73
	New Valley and Kharga	560	680	0.82
			Average ratio	=0.85
Berseem	Gimmeza and Delta	645	745	0.87
	Middle Egypt	830	1040	0.80
	Kharga	675	1085	0.62
			Average ratio	=0.76
			Average ratio for four crops	=0.80

4. Results and discussion

Table 3 gives estimated total ET crop for each of cotton, maize, wheat and berseem at the 9 meteorological stations. The values for each crop give a general idea about the distribution of total ET crop over Egypt.

Table 4 gives the results of comparison between estimated total ET crop and measured total evapotranspiration in cases of optimum soil water, fertility and production. The average ratio of measured to estimated evapotranspiration varies between 0.87 for maize and 1.04 for wheat, with an average of 0.95 for the four crops. The results are close to 1.00 which may confirm the reasonable accuracy of the method used for estimating ET crop by combining PE estimates by Mehanna's method and the crop coefficients given in Doorenbos and Pruitt (1977).

Table 5 gives the results of comparison between estimated ET crop and measured evapotranspiration in cases not restricted to those of optimum conditions.

TABLE 6

Average ratio for four crops of total measured to total estimated evapotranspiration for PE estimated by Mehanna's and FAO's methods, for optimum soil water, fertility and production conditions and for all cases

Condition	Mehanna	Blaney-Criddle	Radiation	Penman
Optimum	0.95	0.94	0.91	0.84
All cases	0.80	0.79	0.77	0.71

The average ratio of measured to estimated evapotranspiration is 0.80. The reduction below unity is probably due to the measurements made in non-optimum moisture conditions. As indicated by Aboukhaled and Rijtema (1973) and Aboukhaled (1974) soil moisture depletion was determined by the ovendrying method to about 60 cm depth only regardless of the effective root depth while significant moisture extraction is expected to occur from below 60 cm in many cases.

Table 6 shows the values of the average ratios of measured to estimated evapotranspiration for PE estimated by Mehanna's and FAO's methods for optimum conditions and for all cases.

5. Conclusion

The values of the estimated total ET crop for the 9 meteorological stations give the average distribution of this item for the 4 main crops over Egypt. The comparison between measured and estimated evapotranspiration may probably confirm the reliability of applying Mehanna's estimates of PE to the crop coefficients given by Doorenbos and Pruitt (1977) to estimate ET crop. In view of this encouraging result it would be useful to use these methods for estimating ET crop for various crops in the different regions of Egypt.

References

Aboukhaled, A., 1974, Crop water use in the New Valley of Egypt, A study for the New Valley Project, FAO/UNDP EGY/71/06/B/01/12.

Doorenbos, J. and Pruitt, W.O., 1977, Guidelines for predicting crop water requirements, FAO Irrigation and Drainage paper No. 24, FAO, Rome.

Mehanna, A.M., 1976, Estimation of potential evapotranspiration over Egypt, *Met. Res. Bull.*, Meteorol. Auth. Cairo, **8** (1), 69-93.

Omar, M.H., 1971, Potential evapotranspiration at Cairo, Ph. D., Thesis, Cairo University (Unpublished).

Omar, M.H., 1981, Report on water requirements of agricultural crops under arid and semi-arid conditions, WMO Agriculture Meteorology Report No. 6.

Omar, M.H., and Mehanna, A.M., 1984, Measurements and estimates of potential evapotranspiration over Egypt, *Agr. and For. Meteorol*, **31**, 117-129.

Rijtema, P.E. and Aboukhaled, A., 1973. Crop water use in the Arab Republic of Egypt, FAO Report RNEA, Cairo.