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EVAPOTRANSPIRATION AND IRRIGATION WATER REQUIREMENTS IN NILE DELTA REGION

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التبخر الكلى واحتياجات مياه الرى فى منطقة دلتا نهر النيل

خلاصة :
يتناول هذا البحث محاولة لإختيار أفضل طرق حساب التبخر الكلى (الإستهلاك المائى) لمنطقة دلتا نهر النيل بالاعتماد على عوامل المناخ والطقس المسجلة لعام ١٩٩٥ وذلك من خلال ستة محطات قياس (سخا - المنصورة - طنطا - الزقازيق - شبين الكوم - دمنهور) الطرق المختارة فى هذا البحث هى :
(FAO - Penman & FAO - Radiation & FAO - Blaney - Criddle)
بإستخدام معامل المحصول العملى تم حساب الإستهلاك المائى (احتياجات مياه الرى) لستة من أهم المحاصيل التى تزرع بمنطقة الدلتا ، ثلاثة شتوية (قمح - فول - برسيم) ، وثلاثة صيفية (قطن - أرز - درة) وقد قورنت النتائج بنظيرتها المستخدمه بمعرفة وزارة الأشغال والموارد المائية - مصر .
أيضا تم إستنتاج معادلة وضعية لكل محصول على حدة للتنبؤ بقيم الاستهلاك المائى من واقع حساب قيم التبخر الكلى من العوامل الجوية طبقا لمعادلة بنمان المعدلة . (FAO-Penman)

ABSTRACT

FAO-Penman method is reliable to predict the reference evapotranspiration, ETo under climatic conditions in Nile-Delta region, Egypt. This method is developed by comparing and evaluating selected estimation methods (FAO-Penman, FAO-Radiation, and FAO-Blaney-Criddle) with results obtained from field data (Class A Pan). Monthly values of ETo are estimated by each of the selected methods using climatic data collected from six observation stations (records of 1995) within the area under study. The irrigation/crop water requirements, ETc, for main crops growth in this region are then computed. Considering FAO-Penman formula, an empirical equation is developed to predict ETc for each crop under climatic data. The predicted seasonal ETc are generally comparable with those adopted by Ministry of Public Works and Water Resources, (MPWWR) with an average relative error of 15% for most of the main crops.

INTRODUCTION

Evapotranspiration is a key factor for estimating the irrigation water requirements. Evaluation of that factor is

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important at planning, design operation and management levels in water resources projects, particularly in the regions that have limited share of water (semi-arid region) or extremely arid conditions. Estimates of daily evapotranspiration, ETo, or consumptive use, are extensively used in irrigation scheduling and in determining regional irrigation/crop water requirements. These estimates are usually reached through direct measurements (i.e., lysimeters, water balance, soil moisture, etc.) or by using empirical formulae based upon climatic conditions (i.e., Penman, Hargreaves, Blaney-Criddle, etc.). In order to predict the crop water requirements, the empirical methods are used due to the difficulty of obtaining accurate field measurements. The methods often need to be applied under certain climatic and agronomic conditions. To meet this need, water requirements of crops are presented based on the recommendation formulated by the FAO-Group, Doorenbos and Pruitt (1977).

Before going to point the objectives of this paper, few previous works can be presented. Semaika and Rady (1987) estimated the monthly reference evapotranspiration in Giza region, Egypt, using five estimation methods, namely: the original Blaney-Criddle, the modified Blaney-Criddle by FAO, the modified Penman by FAO, the radiation and the Eagleman methods. The results of that work showed that estimation of ETo values in Giza area were obtained with any of the modified Blaney-Criddle or modified Penman or the radiation method that gave highest accuracy. They also calculated the seasonal water consumptive use of three crops (wheat, field beans and clover) as 47.54, 37.34 and 67.68 cm, respectively.

Hussein and El Daw (1989) used four methods to predict the reference ETo and consequently, estimated the ETc for main crops in Sudan, Gezira region. These methods were Jensen-Haise, Hargreaves, FAO-Penman and FAO-class A pan. It was found that the FAO-Penman method was reliable to predict ETo of short warm-season grass when growing at its optimum temperature in Sudan Gezira. The Hargreaves method was not as reliable as FAO-Penman for estimating ETc of crops.

Salih and Sendil (1984) selected five of the most popular methods (Jensen-Haise, Modified Penman, Hargreaves, Blaney-Criddle and its modified) to estimate monthly of reference ETo under extremely arid climatic in central Sadui Arabia. It was found from the evaluation results that the Jensen-Haise method has a top rank followed by class A pan and Blaney-Criddle method on the bottom scale as the worst.

Jensen-Haise method has been recommended as a one practical reference evapotranspiration under arid climatic conditions.

Moharram and Zaki (1995) compared eight estimation methods of reference evapotranspiration under the climatic conditions of Dakahlia region, Egypt. Results reported that the original Penman, FAO-radiation and FAO-Penman gave reliable estimate of the ETo values and that modified Blaney-Criddle method gave a comparable results with those obtained by original Penman method in winter season.

Accordingly, the main purposes of this paper are (1) To select a few of the most widely estimation methods and utilize them for estimating reference evapotranspiration under climatic conditions of six stations in Nile Delta region, then estimate the water requirements of the main crops growth in the region, and (2) To introduce an empirical equation for each crop which can be used to predict the water irrigation requirements under the climatic factors. It is hoped that from these analysis and evaluation, the selected methods would be ranked in merits of their suitability for the study region.

ESTIMATION METHODS

The criterion adopted in this work for choosing suitable methods for estimating reference evapotranspiration, ETo, from the numerous methods in the literature, was based on the works of Hargreaves and Samani (1982) and Moharram and Zaki (1995). In addition, Shih and Cheng (1991), ranked the FAO-Blaney-Criddle as the second best method from four methods used to estimate monthly ETo in the Everglades Agricultural Area (EAA) in Florida and Puerto Rico areas. Thus only FAO-Penman and FAO-radiation methods are selected for utilization in this work together with the additional method of FAO-Blaney-Criddle. Procedures to estimate reference crop evapotranspiration are reported by Doorenbos and Pruitt, (1977).

Accurate determination of the water requirement of the main crops is prerequisite for good water management. Zaki (1996) carried out extensive work at Kafr El-shiekh region under the available data of sakha station in the period of 1985-1994 to determine the crop factors and consequently estimated the crop water requirements for main crops growth in the region. The crop factors of each crop at a given stage of its growth are adopted in this study as a reference for whole Nile-Delta region since these values were close to those reported in Master plan for water resources development (1981) for use in Delta region.

The crop factor is defined as the ratio of crop evapotranspiration, ETc, in a certain time period to the reference evapotranspiration, ETo, at the same period calculated from climatic conditions. Thus

$$kc = ETc/ETo \quad (1)$$

Crop factors are used widely by MPWWR for planning purposes to develop the irrigation water requirements for agricultural land, Egypt.

DATA COLLECTION AND ORGANIZATION

The Nile Delta irrigation scheme is the largest of its kind in the world. It is formed at confluence of the two large Nile branches (Rosetta and Demietta). The total extend area is about 4.5 million feddans of which 62 % of agricultural land, laying in the flat north plains of Egypt. At Cairo the Delta barrage was built to supply irrigation water to the scheme by gravity through an extensive canals system. Fig. (1) shows the map of the region. The irrigation water releases from this barrages to the Nile Delta scheme amount to $28.5 * 10^9\ m^3$ yearly. This represents about 60 % of Egypt's water share for agriculture land.

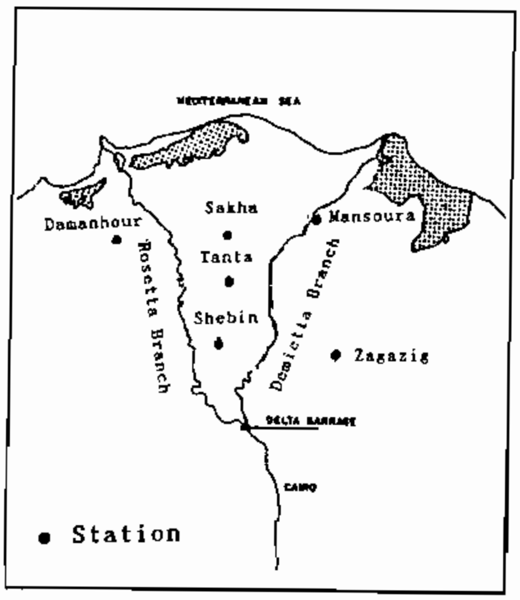

Fig.(1) Plan of Nile-Delta Region.

The climate of the region is nearly moderate and semi-arid. Practically, there are two distinct seasons for agriculture (winter from Nov. to Apr. and summer from May to october). The mean daily temperature is varying from 28 °C to 12°C. The mean daily relative humidity is generally about 55% in winter and 70% in summer season. The region is characterized by high sunshine, about 11.5 hours in summer season. The wind is moderate (about 1.0 - 3.5 m/s) blowing mainly from north in most months of year and sometimes from east and west in summer. The main crops grown in this region are long staple cotton with traditionally crop of rice. other crops beside the cotton and rice are maize, wheat, broad beans and alfa-alfa.

Six climatological stations (Sakha, Mansoura, Tanta, Zagazig, Shiben-Elkom and Damanhour), laying through the Nile-Delta region, are chosen for this study. Information of these stations are summarized in Table 1. Summarized climatic conditions of these stations are also listed in the table.

ESTIMATION OF REFERENCE EVAPOTRANSPIRATION (ETo)

The monthly values of ETo using FAO-Penman, FAO-Radiation and FAO-Blaney-Criddle methods have been computed from the corresponding climatic factors observed at the six stations. The climatic observations have been recorded for one year (1995). Data from Class A Pan at Sakha station (records of 1985-1994) are considered as a base criterion to evaluate the three methods used.

A summary of the results obtained from that computation is listed in Table 2 while Fig.(2) showed the different estimates of ETo from each method at different stations. It can be noticed from this figure that Class A Pan values are the highest, then followed by FAO-Penman and FAO-Radiation which have relatively comparable estimates while FAO-Blaney-Criddle reflect the lowest estimates among other methods. The results reflect considerable variations between the methods for the data used at Zagazig and Mansoura stations but in the other stations the FAO-Penman and FAO-Radiation provided relatively small variations. Evaluation of these methods, based on mean relative error as a comparison criterion, are presented in Table 3. It is shown in the Table that FAO-Penman and FAO-Radiation method give close estimates, but FAO-Penman is a better method for whole Nile-Delta region due to estimates obtained from the average climatic data of the six stations.

Table 1: Information Stations and Summarized climatic data (1995).

Sl. no.	Station name	coordinates Latitude	Altitude, m	mean climatic data T, °C	Sunlight, hr	R.H., %	U, km/d
1.	Sakha	31°04'N	6.00	19.84 (27.4 Aug)[1] (12.7 Jan)[2]	9.67 (11.8 Aug) (8.1 Dec)	59.02 (66. Mar) (53. Oct)	143.17 (205 Apr) (88 Dec)
2.	Mansoura	31°00'N	5.30	20.26 (28.2 Jul) (12.7 Jan)	9.38 (11.5 Aug) (7.7 Dec)	66.25 (74. Dec) (55. May)	214.50 (267 May) (166 Oct)
3.	Tanta	30°29'N	8.30	20.49 (26.8 Jul) (12.9 Jan)	9.47 (11.8 Jul) (7.1 Jan)	66.17 (78. Sep) (53. May)	182.42 (239 Apr) (154 Oct)
4.	Zagazig	30°21'N	13.00	20.93 (27.3 Jul) (13.2 Jan)	9.54 (11.6 Jun) 7.3 Dec)	62.42 (71. Jun) (52. Jan)	198.00 (297 May) (107 Dec)
5.	Shbin-Elkom	30°22'N	17.90	21.05 (27.5 Aug) (13.4 Jan)	9.58 (11.9 Jul) (7.3 Jan)	62.58 (71. Dec) (52. May)	154.00 (178 Apr) (132 Nov)
6.	Daman-hour	31°01'N	4.20	19.77 (26.6 Aug) (12.5 Jan)	9.52 (11.6 Jan) (7.1 Dec)	69.25 (74. Oct) (62. May)	148.50 (201 May) (112 Nov)

Note: Altitude above M.S.L.; 1. Maximum value.; 2. Minimum value.

Table 2: Summarized Estimated Reference Evapotranspiration, ETo (mm/d), for Six Stations in Nile-Delta Region.

Station name	FAO-Penman summer mean	Cv	FAO-Penman winter mean	Cv	FAO-Radiation summer mean	Cv	FAO-Radiation winter mean	Cv	FAO Blaney-Criddle summer mean	Cv	FAO Blaney-Criddle winter mean	Cv
Sakha	5.61	.17	3.18	.26	5.77	.12	3.27	.28	4.72	.20	2.56	.30
Mans-oura	6.45	.14	3.19	.22	5.82	.13	2.99	.24	5.01	.17	2.27	.25
Tanta	6.09	.15	3.16	.29	6.06	.14	2.96	.31	4.98	.19	2.34	.30
Zagazig	7.04	.16	3.1	.32	6.33	.13	3.10	.27	5.03	.19	2.64	.33
Shebin-Elkom	6.02	.12	3.11	.27	6.34	.15	3.05	.28	5.05	.20	2.48	.25
Daman-hour	5.58	.11	2.84	.24	5.66	.12	3.01	.28	4.86	.21	2.41	.32
Delta	6.12	.12	2.98	.25	5.98	.11	2.90	.26	4.83	.17	2.55	.30

C_v = coefficient of variation.

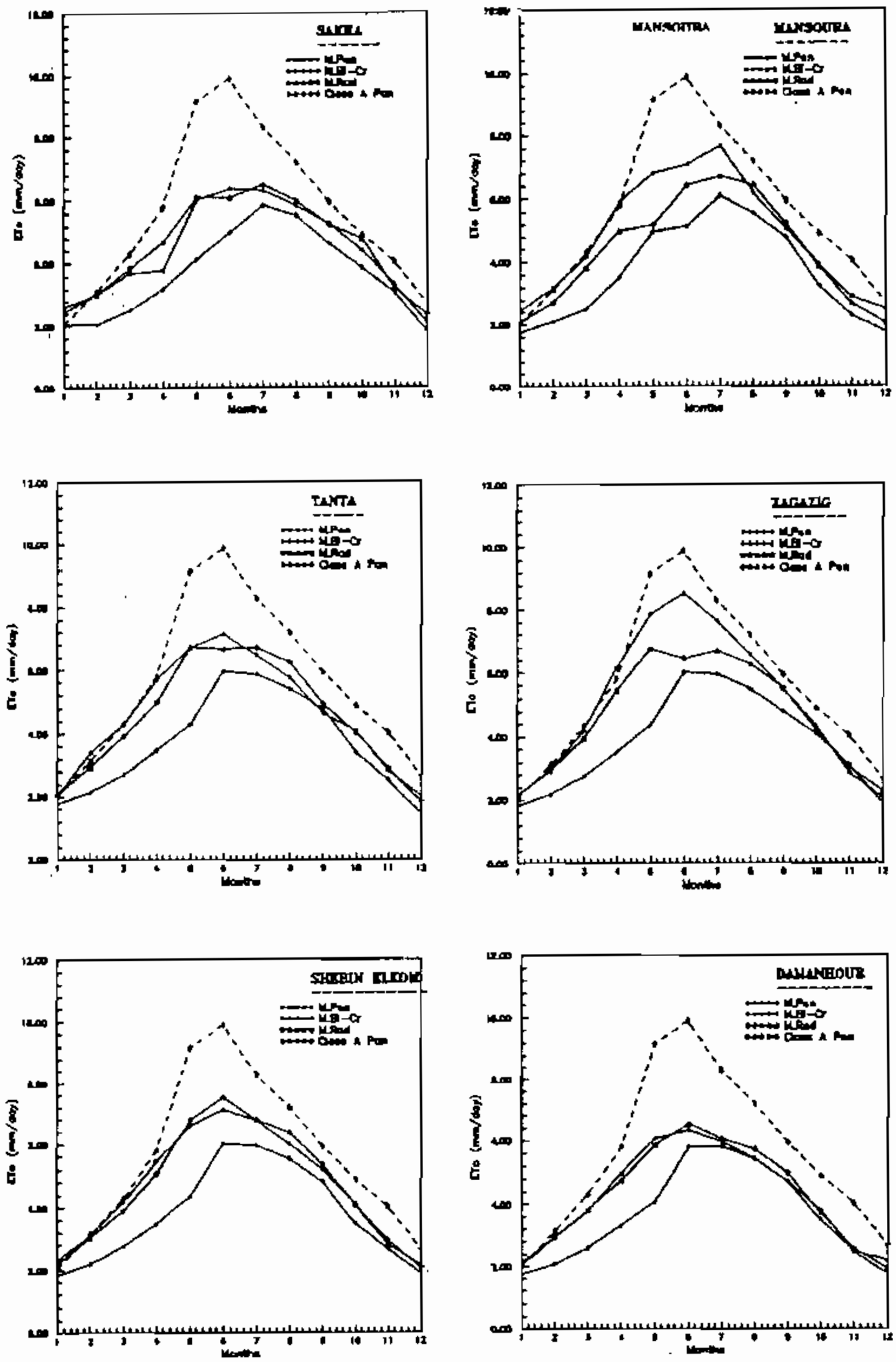

Fig.(2) Monthly Reference ETo at Different Stations in Nile-Del Region (1995).

Table 3: Values of RMSE (%) Based on Measured Class A Pan of Sakha Station for Period 1985-1994.

Metod	station						Delta region
	1	2	3	4	5	6	
FAO-Pen.	22.4	17.3	19.6	13.3	18.3	24.6	19.3
FAO-Rad.	21.1	23.2	20.3	16.1	17.1	24.2	21.4
FAO-Bl-Cr.	36.9	35.2	35.1	31.1	32.4	35.1	33.6

RMSE = Root mean square error.

ESTIMATION CROP ETc

Crop evapotranspiration can be estimated from reference evapotranspiration using empirical crop coefficients. According to FAO-Penman method as the best method in this study and the crop coefficients reported by Zaki (1996), the values of crop ETc are computed for each crop and each station. Figs.(3) and (4) show the estimated crop ETc for wheat, alfa-alfa and broad beans as winter crops and cotton, rice and maize as summer crops. Average computed daily ETc for these crops are summarized in Table 4. ETo values of Nile-Delta region are also presented in the table according to FAO-Penman method. These figures showed that the crop ETc values for three winter crops are generally the same in the first three months of season (Nov., Dec., Jan.) while its values increase in the other months of growth. The deviations between the crop ETc values are generally small for the six stations. For summer crops, the rice has high ETc values while cotton has less values if it is compared with rice in the region. In addition, maize also has ETc values higher than cotton.

Generally, there are no essentially deviations between the values of crop ET for different stations since the climatic conditions in the region are similar from one station to the other. Table 5, shows the average seasonally crop water requirements (m^3/fed.) for different stations and each crop. Average crop water requirements of the region for each crop are computed and compared with those values adopted by MPWWR. The average seasonal values of water requirements of the region are generally lower than used by MPWWR for all crops. Relative error between estimated values and those obtained by MPWWR are computed and listed in Table 5.

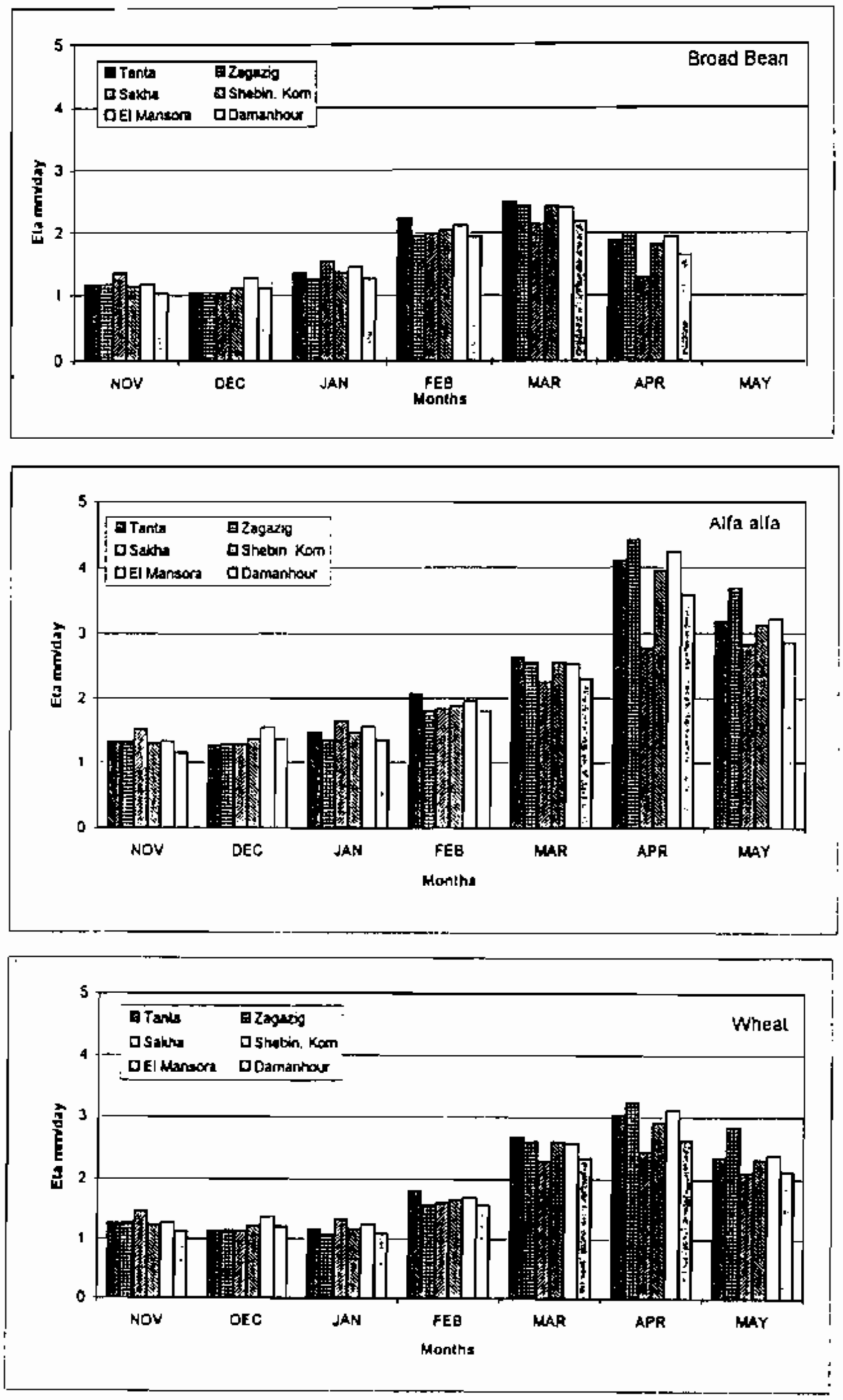

Fig.(3) Predicted Crop ETc (mm/d) for Three Winter Crops in Nile-Delta Region.

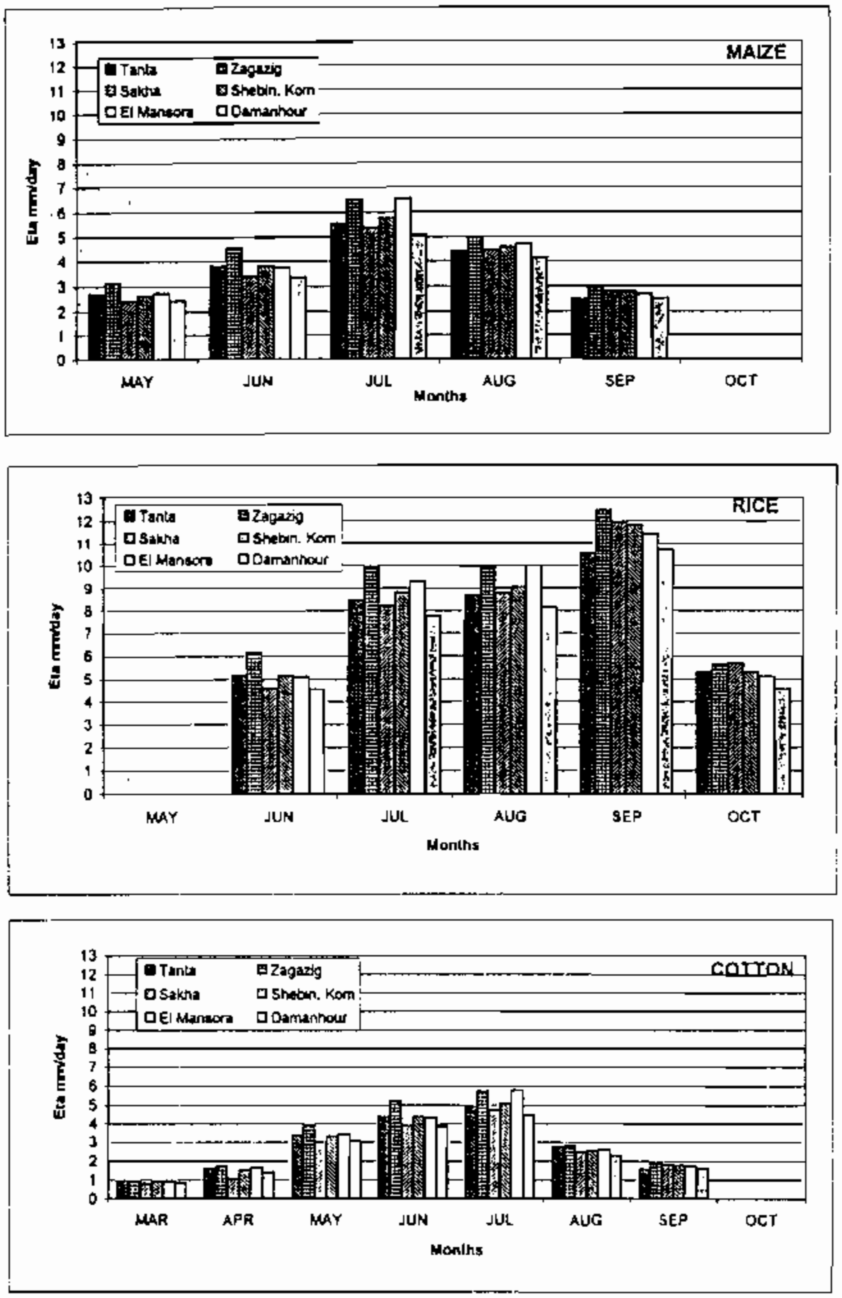

Fig.(4) Predicted Crop ETc (mm/d) for Three Summer Crops In Nile-Delta Region.

Table 4: Mean Computed Values of Crop ETc (mm/d) for Different Crops in Nile-Delta Region Using FAO-Penman Method.

month	Crop						ETo,
	wheat	alfa alfa	B.beans	cotton	rice	maize	FAO-Pen.
Jan	1.17	1.47	1.38	—	—	—	2.20
Feb	1.65	1.89	2.05	—	—	—	2.99
Mar	2.51	2.47	2.35	0.89	—	—	3.97
Apr	2.90	3.84	1.76	1.50	—	—	5.50
May	2.36	3.15	—	3.45	—	2.68	6.72
Jun	—	—	—	4.34	5.12	3.77	7.08
Jul	—	—	—	5.11	8.85	5.79	6.61
Aug	—	—	—	2.51	8.96	4.54	5.85
Sept	—	—	—	1.72	11.47	2.69	4.96
Oct	—	—	—	—	5.28	—	3.89
Nov	1.26	1.32	1.18	—	—	—	2.72
Dec	1.20	1.35	1.11	—	—	—	2.08
Average	1.865	2.215	1.655	2.785	7.935	3.895	

Table 5: Average Seasonally Crop Water Requirements (m^3/Fed).

Station	crop					
	wheat	alfa alfa	B.Bean	cotton	rice	maize
Sakha	1336.4	1515.2	1076.1	2114.2	4360.4	2029.4
Mansoura	1500.7	1681.6	1116.4	2452.3	4587.9	2278.0
Tanta	1465.4	1740.1	1092.9	2300.8	4216.0	2094.8
Zagazig	1476.9	1760.0	1050.0	2667.3	4894.6	2449.9
Shebin-Elkome	1429.0	1698.3	1068.1	2336.0	4468.5	2179.9
Dananhour	1333.6	1582.9	992.7	2061.2	3992.3	1931.1
Average	1424	1663	1066	2322	4120	2161
Ave. of MPWWR	1609	2365	1381	2818	4694	2430
Relative Error(%)	11.5	29.6	22.8	17.6	12.2	11.1

The results of the rating have ranked FAO-Penman and FAO-Radiation methods jointly in the first place. Noting that the peculiarity of FAO-Penman results in the region under study, as well as its applied to all climatic factors, it leads towards recommended FAO-Penman method to present the data of the study region. Thus to simplify the procedure of estimate the crop ETc values without using the crop factors, the relationships between the estimated reference ETo values by FAO-Penman and predicted crop ETc values have been developed for each crop in the region. These relations can be written as:

Wheat:

$$ETc = -1.882 + 1.701\ ETo - 0.159\ ETo^2 \quad (2)$$

Alfa-alfa:

$$ETc = -1.488 + 1.504\ ETo - 0.116\ ETo^2 \quad (3)$$

Broad beans:

$$ETc = -2.320 + 2.172\ ETo - 0.259\ ETo^2 \quad (4)$$

Cotton:

$$ETc = 3.628 - 1.789\ ETo + 0.274\ ETo^2 \quad (5)$$

Rice:

$$ETc = -52.436 + 23.167\ ETo - 2.121\ ETo^2 \quad (6)$$

Maize:

$$ETc = -49.222 + 17.534\ ETo - 1.425\ ETo^2 \quad (7)$$

inwhich ETc = reference crop evapotranspiration (mm/d), and ETo = computed reference evapotranspiration using FAO-Penman method (mm/d).

It is hoped that these equations give reliable estimates for monthly and seasonally values of actual evapotranspiration needed for planning irrigation schemes under the climatic conditions in the Nile-Delta region. It would also represent a considerable decrease in irrigation water requirements if compared with the practical/actual values in the region.

CONCLUSIONS

Since the estimation of the actual crop evapotranspiration ETc has some difficulties in field, several methods are used to estimate the reference ETo using different climatic data, then predicting the values of ETc for a crop using the crop factors. This paper is a trial to select the suitable method for estimating the ETo values under climatic data of six observation stations in Nile-Delta region, Egypt. Accurate estimates of crop ETc is of particular importance for the Delta scheme because of the scheme's large volume of irrigation water requirements. Thus, the prediction of water requirements for the main crops becomes very necessary to understand the development of the water share. From this study, several conclusion can be made as follows:

1. The FAO-Penman method is feasible to estimate the ETo for the available data of the Nile-Delta region.
2. The FAO-Radiation method gives a comparable results with those obtained by FAO-Penman while the FAO Blaney-Criddle method has less reliable results.
3. The seasonal irrigation/crop water requirements of the main crops growth in the region are underestimate within 15%, as an average error, of the actual values used by MPWWR, and about 30% for alfa-alfa crop.
4. An empirical equation for each crop under consideration is developed to predict the crop ETc values (Eqs. 2-7), according to the FAO-Penman method, which has been recommended for predicting the ETc values for region similar to the one studied in this work.

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