Predicting the Crop Coefficient Values for Maize in Iraq

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Received on: 4/5/2014 & Accepted on: 7/5/2015

ABSTRACT

The objectives of the study are to predict the crop coefficient for Maize using watermarks gypsum blocks and atmometer apparatus during the growing stages, 201٣, compare the estimating values with Food and Agriculture Organization in United Nations (FAO) and local study work. The study work was conducted in the Al-Yusufiya field Township, 30km south of Baghdad under semi-arid weather conditions. The watermarks and atmometer were used to measure crop evapotranspiration and reference evapotranspiration, respectively. The predicted average value of crop coefficient for initial, develop, mid and late of seasons were: 0.14, 0.6, 0.91 and 0.57, respectively. The results from the comparison between the estimating crop coefficient and FAO values showed that the average values of relative error was 36.29% and with mean absolute error was 0.27. Moreover, root mean square difference was 0.32. Additionally the comparison between the estimating crop coefficients with the local study values showed that the average values of relative error was 33.57% and with mean absolute error was 0.24. Moreover, the root mean square difference was 0.29.

Keywords: crop coefficient, evapotranspiration, soil moisture sensor.

أستنباط قيم لمعامل نبات الذرة الصفراء في العراق

الخلاصة

يهدف هذا البحث الى أستنباط معامل نبات الذرة الصفراء بأستخدام متحسسات الجبس وجهاز الاتموميتر خلال الموسم الزراعي ٢٠١٣، ومقارنة القيم المستنبطة مع القيم المقترحة من منظمة الزراعة والغذاء العالمية في الامم المتحدة (الفاو) ولقيم مقترحة من قبل دراسات محلية . الدراسة تمت في حقل ضمن منطقة اليوسفية التي تبعد ٣٠ كم جنوب بغداد تحت ظروف جوية شبه جافة. أستخدمت متحسسات الرطوبة الجبسية وجهاز الاتموميتر لقياس الاستهلاك المائي للنبات والاستهلاك المائي المرجعي على التوالي. كانت القيم المستنبطة لمعامل النبات لمرحلة الانبات، التطور، منتصف و نهاية الموسم كما يلي: ٠.١٤ و ٠.٦ و ٠.٩١ و ٠.٥٧ على التوالي. أظهرت نتائج المقارنة بين القيم المستنبطة لمعامل النبات مع القيم المقترحة من قبل منظمة الزراعة والغذاء العالمية أن معدل الخطاء النسبي كان ٣٦.٢٩% ومعدل الخطاء المطلق كان ٠.٢٧ .بينما كان معدل الجذر التربيعي للفرق ٠.٣٢. كذلك أظهرت نتائج المقارنة بين القيم المستنبطة لمعامل النبات مع القيم التي اقترحت محليا ،أن معدل قيمة الخطاء النسبي كانت ٣٣.٥٧% ومعدل الخطاء المطلق كان ٠.٢٤ ، بينما كان معدل الجذر التربيعي للفرق يساوي ٠.٢٩.

https://doi.org/10.30684/etj.34.2A.8
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INTRODUCTION

For efficient water use, the amount of water irrigated must not exceed the maximum amount that can be used by plants through evapotranspiration [1]. Accurate estimation of reference evapotranspiration (ET_o) in irrigated lands is necessary for improving the planning and efficient use of water resources. The atmometer is one of the alternative tools that can be used to measures the amount of water evaporated to the atmosphere from a wet, porous ceramic surface, it measures evaporation rates affected by weather conditions and plant transpiration [2]; this information can be utilized for irrigation scheduling. The simplicity of the use and interpretation of the atmometer data as well as the economic feasibility can also encourage farmers to monitor their own crop water use and irrigation practices using this alternative tool [3]. Farmers have been using the atmometer to estimate the crop evapotranspiration, for better irrigation management practices through proper scheduling of their irrigation [4]. However, the atmometer measures reference evapotranspiration (ET_o), so values of ET_o obtained from the atmometer should be multiplied by the K_c value to determine ET_c, which can provides the ET_o [3]. A comparison of observations for atmometer with pan evaporation method, indicated that atmometer had similar trends but slightly higher than pan evaporation [5]. Estimates of ET_o using the atmometer appeared to be more accurate in non-windy conditions and moderate temperatures, as well as, under windy conditions and high temperatures [6]. Although the values of crop evapotranspiration and crop water requirement are identical, crop water requirement refers to the amount of water that needs to be supplied, while crop evapotranspiration refers to the amount of water that is lost through evapotranspiration. The irrigation water requirement basically represents the difference between the crop water requirement and effective precipitation. Crop evapotranspiration, ET_c, is influenced by air temperature, humidity, solar radiation, and wind speed [1]; crop characteristics including canopy cover, and length of growing season [7]; and soil characteristics [8]. Crop evapotranspiration can be observed and measured by monitoring soil moisture content, when no rainfall and irrigation are added to the soil. Soil water status can be measured directly with sensors such as gypsum block, tensiometers, and capacitance probes. The choice of sensor will depend on soil water range to be measured, cost effectiveness, easiness to maintain, the sensor's performance reliability, type of soil, climate, plant root zone depth, soil salinity, and soil temperature [9]. Watermark sensors are widely available and have a number of favorable technical characteristics for farm use, due to low cost, ease of installation and durability [10]. These sensors typically require site calibration of the threshold soil-moisture content to which the soil will be allowed to dry before irrigation will be permitted [12]. The threshold value is determined relative to field capacity, the permanent wilting point, and the management allowed depletion among irrigation events [11]. Since the development of the watermark sensors, many researchers have used the sensor in irrigation scheduling [13], [14] and [15]. The crop coefficient (K_c) incorporates the effect of characteristics that distinguish a typical field crop from the grass (or alfalfa) reference. As a result, for each crop there is a crop coefficient values. One of the most important factors that produce changes in K_c values is the crop growth stage. While the crop develops there are variations in the ground cover, the plant height and the area of the leaf. This growing season is divided into four stages: initial, crop development, mid-season and late season. In the initial stage, evaporation exceeds transpiration but K_c is low because soil water evaporation which occurs from a shallow surface layer is limited [8]. More arid climates and conditions of greater wind speed will have higher values for Kc. More humid climates and conditions of lower wind speed will have lower values for K_c [16]. The main objective of this paper was to estimate crop coefficient for maize under Iraqi conditions and compared with others available resources.

Materials and Methods

Location of the field study

The field study was located within Al-Yusifyah township, Al-Qasir region which lies north of Almohmodiya district, 30 km away from south of Baghdad. The field was located at (Latitude~ 36° 62` 18″ N and Longitude ~ 43° 09` 16″ E Altitude ~ 30m).The main source of the water for the Yusifiya River was fed from the Euphrates River through Fallujah channel. The usual method used to irrigate the field study was the furrow irrigation system. Maize (***Zea mays L.***) was used in the study in the growing season of 2013; the field area was about ١٦٠٠ m^2. The laboratory analyzes of the soil samples were conducted in the laboratories of the National Center for Water Resources (NCWR) in Ministry of Water Resources (MOWR), Baghdad/Iraq. The objective of the analysis was to verify the physical characteristics of the soil and all physical properties. The soil texture was loamy clay.

Devices and Apparatus

The followings are specifications of devices were used in the study field work.

Atmometer apparatus

An atmometer, the brand name (Etgage), has gained increasing popularity. It is one of the alternative tools that can be used to measures the amount of water evaporated to the atmosphere from a wet, porous ceramic surface. Two numbers of atmometers were installed in the field as shown in figure 1. One atmometer was located in the beginning of the field and the other one was located in opposite side of the field. Comparison was done between atmometer recorded data with reference evapotranspiration calculated from modified Penman – Monteith equation. The result shows that root mean square difference, mean absolute error and relative error were: 0.42mm/day, 0.36mm/day and 6.2%, respectively. Good agreement was observed.

Watermarks (soil moisture sensor)

Watermark sensors are widely available and have a number of favorable technical characteristics for on farm use, due to its low cost, ease of installation and durability. These sensors typically require site calibration of the threshold soil-moisture content to which the soil will be allowed to dry before irrigation will be permitted. The threshold value is determined relative to field capacity, the permanent wilting point, and the management allowed depletion between irrigation events. The patented watermark sensor is a solid-state electrical resistance sensing device that is used to measure soil water tension. This type of sensor consists of two electrodes embedded in a reference matrix material, which is confined within a corrosion-proof and highly permeable case (unit range from 0-wet- to 200 cb- dry). Figure 2 shows parts of the watermark soil sensor. Total of five numbers of watermarks sensors were used in the field area within the root zone of maize at depths 15, 30, 45, 70 and 100 cm.

Plate (1) Location of the atmometers in the field of maize [18].

Plate (2) Watermark soil sensor inside PVC pipes and before installation.

Results and Discussion

Predicted crop coefficients (K_c) for maize were calculated from water consumption by dividing daily measured crop evapotranspiration (ET_c) by reference evapotranspiration (ET_o) which measured from the atmometer as follows [17]:

$$K_c = \frac{ET_c}{ET_o} \quad \text{.... (1)}$$

Crop coefficient was calculated from watermarks sensors reading, in days when there was no irrigation and rainfall and according to the water balance equation. Reference evapotranspiration (ET_o) was calculated from atmometer. The crop coefficient for the maize was estimated for each growing stages (development, improvement, mid of season and harvest time or end of season) and starting from the date of planting till harvest time as shown in Table1.

Table (1) Date, ET_c, ET_o, daily estimated K_c, growing stage and average K_c for the maize [18].

Date	ET_c (mm/day)	ET_o (mm/day)	Estimated K_c	Growing stage	Average estimated K_c
19-Jul	0.32	8.5	0.04	Initial Stage	0.14
20-Jul	0.40	10	0.04		
21-Jul	0.45	9	0.05		
22-Jul	0.63	9	0.07		
23-Jul	0.79	9	0.09		
25-Jul	1.11	9	0.12		
26-Jul	1.24	10	0.12		
27-Jul	1.21	8.5	0.14		
28-Jul	1.23	9	0.14		
29-Jul	1.53	10.5	0.15		
01-Aug	1.72	10	0.17		
02-Aug	1.76	9.5	0.18		
03-Aug	1.79	9	0.20		
04-Aug	2.17	9.5	0.23		
05-Aug	2.14	8	0.27		
06-Aug	2.45	9	0.27		
08-Aug	3.69	7.5	0.49	Development Stage	0.6
09-Aug	4.25	8	0.53		
10-Aug	4.12	8	0.51		
11-Aug	4.13	7.75	0.53		
12-Aug	3.60	7	0.51		
13-Aug	3.91	7.5	0.52		
14-Aug	5.15	9	0.57		
15-Aug	5.01	9	0.56		
17-Aug	5.22	9	0.58		
18-Aug	4.14	7	0.59		
19-Aug	4.13	6.75	0.61		
20-Aug	4.01	6.25	0.64		
21-Aug	5.61	7.25	0.77		
22-Aug	5.77	7.25	0.80		
23-Aug	6.42	7.75	0.83		

24-Aug	6.50	7.5	0.87		
25-Aug	6.78	7.75	0.88		
26-Aug	6.23	7.25	0.86		
27-Aug	6.47	7.5	0.86		
30-Aug	6.10	6.75	0.90	Mid-Season	
31-Aug	5.97	6.5	0.92		
01-Sep	7.35	7.5	0.98		
02-Sep	6.56	7	0.94		
03-Sep	6.68	7.5	0.89		
04-Sep	7.15	8	0.89		
05-Sep	7.20	8	0.90		
06-Sep	6.86	8	0.86		
07-Sep	6.38	7.5	0.85		
08-Sep	6.03	7	0.86		
09-Sep	6.35	7.5	0.85		
10-Sep	6.06	7	0.87		
11-Sep	5.39	6.5	0.83		
12-Sep	6.27	7.5	0.84		0.91
13-Sep	5.61	7	0.80	Mid-Season Stage	
15-Sep	4.78	6	0.80		
16-Sep	4.97	6	0.83		
17-Sep	5.33	6.5	0.82		
18-Sep	5.12	6	0.85		
19-Sep	5.13	6	0.86		
20-Sep	4.56	5	0.91		
21-Sep	5.93	5.5	1.08		
22-Sep	5.56	5	1.11		
23-Sep	7.39	7	1.06		
24-Sep	5.58	5.5	1.01		
25-Sep	5.40	5.5	0.98		
26-Sep	5.38	5.5	0.98		
27-Sep	5.88	6	0.98		
28-Sep	6.24	6.5	0.96		
29-Sep	4.51	5	0.90		
30-Sep	4.57	5	0.91		
01-Oct	5.48	6	0.91		
02-Oct	4.83	5.5	0.88		
03-Oct	5.27	6	0.88		
04-Oct	4.37	5	0.87		
05-Oct	4.58	5.5	0.83		
06-Oct	3.82	5	0.76	Late-Season Stage	
07-Oct	3.56	5	0.71		
08-Oct	3.76	5.5	0.68		

09-Oct	3.26	5	0.65	Late-Season Stage	0.57
10-Oct	3.26	5	0.65		
13-Oct	3.51	5.5	0.64		
14-Oct	2.24	4	0.56		
15-Oct	2.20	4	0.55		
16-Oct	2.15	4	0.54		
17-Oct	2.10	4	0.52		
18-Oct	2.06	4	0.51		
19-Oct	2.77	6	0.46		
20-Oct	1.81	4	0.45		
21-Oct	1.78	4	0.44		
22-Oct	1.75	4	0.44		

Statistical Analysis Methods

Comparison between estimated, local and FAO crop coefficient values are made on growing stages periods. The following statistical analysis were used:

$$RMSD = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(yi - xi)^2} \quad ....(2)$$

$$RE = \frac{RMSD}{xav} * 100 \quad .... (3)$$

$$MBE = \frac{\sum_{i=1}^{n}(yi - xi)}{n} \quad .... (4)$$

Where:
RMSD = root mean square difference,
n = number of observations,
yi = predicated crop coefficient,
xi = local or FAO crop coefficient,
xav = average value of crop coefficient (from local or FAO values),
RE = relative error (%), and
MBE = mean bias error.

The estimating crop coefficient (K_c) for maize was compared with the crop coefficient suggested by the Russian study under Iraqi conditions (Institute of Soyuzgiprovodkhoz, 1982) and by FAO (Allen et al., 1998). The Russian study for K_c values was presented as monthly starting from March as shown in table 2, while the crop coefficient recommended by FAO were classified according to crop growing stages as shown in table 3.

Table (2) Crop coefficient values as monthly distribution for maize reported by Russian study [19].

Crop type	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.
Maize (spring)	----	0.58	0.82	1.08	0.8	----	----	----	----

Table (3) Recommended values of crop coefficient for maize by FAO-56 [17].

Crop type	K_c (initial stage)	K_c (mid-season stage)	K_c (late of season stage)
Grain corn	0.7	1.2	0.6

In this study, the FAO crop coefficient values can be presented as: the initial stage correspond to second- third of July, and August, while from the first of September to the fifth of October, the growing stage correspond to mid of the season. Moreover after the fifth to end of October, the growing stage was presenting the end of the season. Figure 3 showed the comparison of average estimating, Russian and FAO crop coefficient (K_c) for maize through the growing stages. The statistical analysis have been conducted for the comparison between estimating, Russian, and FAO K_c values, using root mean square difference (RMSD), relative error (RE), and mean absolute error (MAE). Table 4 shows the statistical errors analysis for the comparison between estimated and Russian crop coefficient for maize. The statistical error analysis for the comparison the RMSD, RE, and MAE values were the maximum in the initial and development stages, and were the minimum in the mid and late of the season. The reasons for that the Russian study was conducted for more than thirty years ago when the weather parameters were differed from now due to global weather changes, environmental boundaries, and also in the recent time more advanced equations for calculating reference evapotranspiration had develop and accurate tools for soil moisture measurements are used. The average values for RMSD, RE, and MAE were 0.29, 33.57%, and 0.24 respectively.

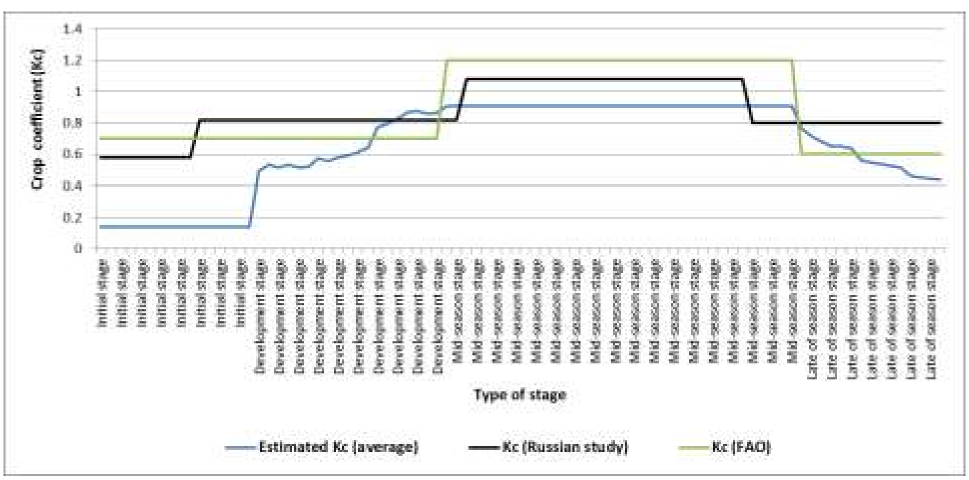

Figure (3) Comparison of estimating, Russian study, and FAO crop coefficient values through the growing stages of maize [18].

Table (4) Root mean square difference (RMSD), relative error (RE), and mean absolute error (MAE) for the comparison between estimating and local (Russian) crop coefficient values for maize [18].

Growing Stage	RMSD	RE (%)	MAE
Initial	0.49	83.76	0.48
Initial Development	0.34	41.05	0.27
Mid - season	0.19	17.53	0.17
Mid - season Late-season	0.22	27.39	0.19
Average for all stages	0.29	33.57	0.24

Table 5 shows the statistical errors analysis for the comparison between estimated and FAO crop coefficient for maize. The statistical error analysis for the comparison the RMSD, RE, and MAE values were also shows that the maximum in the initial stage only and were the minimum in the mid and late of the season. The reasons for that the FAO crop coefficients values were approximation under typical irrigation management and soil wetting conditions, and expected for a sub-humid climate with average daily minimum relative humidity (RH_{min}) values of about 45% and calm to moderate wind speed (u_2) averaging 2m/s. The average values for RMSD, RE, and MAE were 0.32 mm/day, 36.29% and 0.27 mm/day respectively. Figure (4) showed RMSD and MAE for the comparison between case study, Russian and FAO-56 crop coefficient values.

Table (5) Root mean square difference (RMSD), relative error (RE), and mean absolute error (MAE) for the comparison between estimating and FAO crop coefficient values for maize [18].

Growing Stage	RMSD	RE (%)	MAE
Initial	0.61	86.54	0.60
Initial Development	0.27	36.65	0.23
Mid - season	0.30	25.14	0.29
Mid - season Late-season	0.19	24.94	0.15
Average for all stages	0.32	36.29	0.27

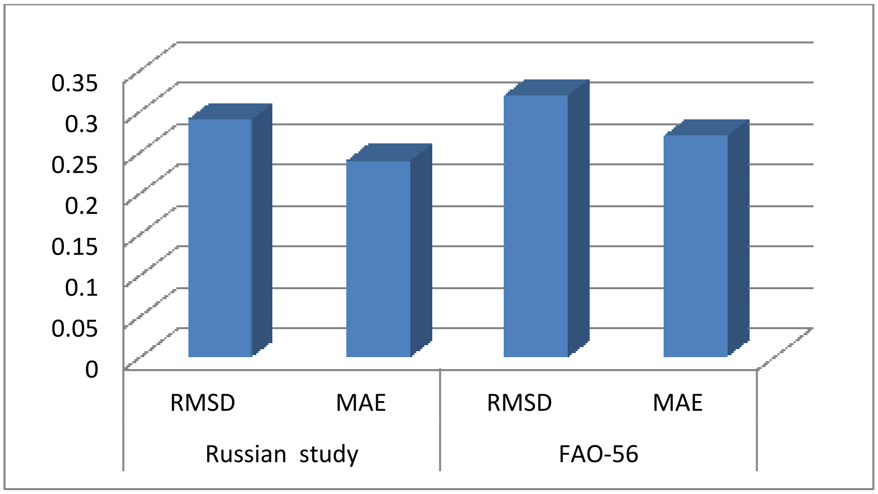

Figure (4) RMSD and MAE for the comparison between study case, Russian and FAO crop coefficient values.

CONCLUSIONS

1- The statistical analysis for the comparison between estimated and FAO crop coefficients for maize showed the same results conducted between estimated and local (Russian) study. The analysis for both comparisons shows that RMSD, RE, and MAE values were the maximum in the initial stage and were the minimum values in the mid and late of the season.

2- Values of K_c for initial, development, mid and late of season were: 0.14, 0.6, 0.91 and 0.57, respectively.

3- The predicted crop coefficient for maize was more accurate than the local and FAO recommended values due to the direct measuring for the crop (actual) evapotranspiration by using watermarks soil water sensors within the root zones. Where no crop stress was observed, and the soil depletion values were always below the allowable limit value.

4- Accurate crop coefficient values will effect on water crop requirements and schedule of irrigation, and then will effect on the water use efficiency and the yield value.

5- Moreover, the direct reading of reference evapotranspiration from the atmometer without using the weather station or complicated equations and meteorological information.

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NOTATIONS

ET_c = crop evapotranspiration (mm/day).
ET_o = reference evapotranspiration (mm/day).
K_c = crop coefficient.
MBE = mean bias error.
n = number of observations.
RE = relative error (%).
$RH_{min.}$ = min. relative humidity (%).
RMSD = root mean square difference.
U_2 = wind velocity measured at 2m height above ground surface (m/s).
xav = average value of crop coefficient (from local or FAO values).
xi = local or FAO crop coefficient.
yi = predicated crop coefficient.