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IRRIGATING MAIZE CROP VIA SOME DIFFERENT ETO–ESTIMATING FORMULAE AND CONSEQUENT INFLUENCE ON CROP WATER USE AND WATER USE EFFICIENCY

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ABSTRACT: *The herein research trial was conducted at Gemmeiza Agric. Res. Stn.(Middle Nile Delta Region) during 2006 and 2007 seasons to investigate the extent to which the yield and water use efficiency for maize crop were influenced due to irrigating the crop using some ETo- estimating methods ,in comparison with the traditional one. Modified Penman, Doreenbos and Pruitt, Evaporation pan and Penman- Monteith methods were assessed for estimating maize crop water use through ETo-Kc relationship .The agroclimatological data ,1997 – 2006 average, of Gharbia governorate and Kc values of different growth stages of maize crop, FAO , Irri. and dr. paper 24, were used in the present study. The adopted treatments were arranged in randomized complete block design with 3 replicates. The obtained results could be summarized as follows :-*

1- The tested ETo – estimating methods differentially influenced the ETo value and the highest figure was recorded with modified Penman method, while the lowest one with Penman- Monteith.

2- Vlues of ETcrop resulted from ETo – estimating methods were higher than that under the traditional method, however , Penman – Monteith method exhibited the nearest figures to those of the traditional method.

3- Maize grain yield was almost increase as irrigation was practiced using Penman – Monteith method. Moreover, the same trend was obtained for Water Use Efficiency and Water Utilization Efficiency values. So, it is possible to use Penman–Monteith method in irrigating maize crop, in Gemmeiza area, instead of the time and labor– consumer traditional method.

Key words: Reference évaporatranspiration (ETo) , maize yield , Water use efficiency , maize water use.

INTRODUCTION

Direct field measurement of the actual crop water use, either via monitoring soil moisture content (soil moisture depletion method) or through water balance (Lysimeter method), are the most common approaches in such connection,however,they are laborious, time-consumer and highly expensive. So, a large number of more or less empirical methods were developed by numerous scientists and specialists worldwide to estimate evapotranspiration from different climate variables through ETo–Kc relationship . The effect of climate on crop water requirement is given by reference evapotranspiration (ETo), while the effect of plant and soil is impacted on crop coefficient (Kc). Blaney–Criddle, radiation, Penman and Pan-evaporation methods are the most common methods used for estimating ETo value (FAO, paper 24). Although, a performance analysis for American Society of Civil Engineers (Smith, 1996) revealed widely varying performance of such methods which did not behave the same way in different locations around the world. So, the ET-Kc relationship must be subjected to rigorous local calibration and proved to have limited global validity.. In Egypt, El-Mowelhy et al.(1999) found that, at Sakha, North Delta, Jensen-Hiase equation gave the nearest ETactual figure to that of wheat consumptive use determined via soil moisture depletion method . In addition, EL-Marsafawy and Eid (1999) stated that modified Penman, Penman-Montieth and evaporation pan methods could be efficiently used in calculating ETo and ETactual in Egypt. Furthermore,On estimating potential evapotransp-iration (ETo) for Bahteem area (South Delta), Omar and Eid (1999) stated that both Doorenbos and Pruitt (model WATER) and class A pan (calculated manually ,FAO paper 24) gave reliable ETo estimates, comparable to Penman-Montieth method. The authors also added that the average value of Penman-Montieth and Penman modified (according to CROPWAT) methods introduced a new reliable method giving ETo value near to that obtained using Doorenbos and Pruitt method. El-Sabbagh (1993), found that Blaney – Criddle and pan–evaporation methods resulted in lower ETo estimates, whereas, Penman modified and radiation ones gave higher estimates for Sakha area, Kafr EL-Shiekh governorate. Sadek et al.(1996) stated that modified Penman was the most efficient equation in estimating Etc value for maize grown at Giza area, comparable with either Doorenbos and Pruitt or evaporation pan equations. Khater et al.(1997), stated that Doorenbos and Pruitt and Penman–Monteith methods were efficiently used in estimating ETactual for wheat crop grown at Gemmeiza area (Middle Nile Delta). EL-Marsafawy et al. (1998), found that Penman- Monteith method was more accurate to estimate ETactual, for wheat crop grown at Giza (Middle Egypt), than both Doorenbos and Pruitt and Penman modified methods. Rayan et al. (1999), stated that Penman modified method proved to be most efficient to estimate water consumptive use for wheat crop, grown at Upper Egypt (Shandweel area), comparable with both Penman- Monteith and Doorenbos and Pruitt methods.

The present trial aims to determine the most reliable method in estimating

ETo and consequently ETactual (with aid of Kc values, FAO paper 24), comparable to soil moisture depletion method for maize crop grown at Gemmeiza area (Middle Nile Delta ,Egypt). The consequent influence on crop water use and water use efficiency is in consideration .

MATERIALS AND METHODS

This research work was executed at the experimental farm of Gemmeiza Agric. Res. Station (Middle Delta Region) during 2006 and 2007 seasons . The soil of the experimental site is clayey in texture and particale size distribution and some of soil water constants are shown in Table (1). The present trial aims to investigate how irrigating maize crop, according to some ETo-estimating methods in comparison to soil moisture depletion method, affected crop water use and water use efficiency . The agroclimatology data for Gharbia Governorate (average of 1997 – 2006, Table 2) were used in estimating the ETo values according to the assessed methods. A comparison was done to determine the most accurate ETo- estimating method giving the nearest ETactual value to that obtained using soil moisture depletion method.

The ETo– estimating methods assessed in the present study are as follows:-

Table (1): Particale size distribution, field capacity and wilting points of the experimental site

Soil depth (cm)	Clay %	Silt %	Fine sand %	Coarse sand %	Texture class	F.C. %,wt/wt	W.P. %,wt/wt	Bulk density gcm^{-3}
0 0-15	40.19	44.84	14.14	0.83	Clayey	43.20	23.4	1.10
15.-30	46-10	40.11	12.68	1.11	Clayey	41.10	22.34	1.26
30-45	48.90	39.73	10.12	1.22	Clayey	39.60	2152	1.29
45-60	49.00	39.95	10.00	1.05	Clayey	36.00	19.57	1.31

Table (2) : Agroclimatological data for El-Gharbia Governorate (average 1997-2006).

Lat.	30.47	Long.	31.00	Elev.	14.80 m	
Month	T. max.	T. min.	W.S	R.H	R.F	Epan
January	19.3	9.7	0.8	67.2	20.4	1.6
February	19.7	9.6	1.2	63.5	21.8	2.1
March	22.0	10.6	0.9	62.9	19.5	3.2
April	26.6	13.6	0.9	60.3	2.4	4.6
May	32.4	17.3	0.8	57.8	1.5	6.1
June	32.6	20.9	0.8	61.0	0.0	7.2
July	33.7	22.7	0.8	65.9	0.0	7.1
August	33.7	22.9	0.7	65.1	0.0	6.6
September	32.9	22.6	0.7	62.0	0.0	5.4
October	29.8	18.6	0.8	61.7	0.0	4.1
November	25.3	15.2	0.7	63.5	4.9	2.6
December	21.1	11.6	0.8	66.0	10.5	1.9
Year	27.4	16.3	0.8	63	81.0	4.4

where: T.max., T.min.=Maximum and minimum temperatures °C; W.S=Wind speed (m/sec); R.H.=Relative humidity (%) ; R.F = Rain fall (mm/month);S.S= Sun shine (%) and Epan = Evaporation pan (mm/day)

1- Modified Penman method

In the model, Penman equation was derived from the energy balance equation at the soil surface (Jones et al. 1984) as below :-

$$Rn = ET + H + G + P$$

where

Rn = net radiation.

ET = evapotranspiration latent heat flux density.

G = soil heat flux desity.

P = density of solar radiation stored as photochemical energy.

The potential ET/day can be expressed as :-

$$ETp = dRn / L + g\ Ea / d + g$$

where

ETp = daily potential evapotranspiration, mm/day.

d = slope of saturated vapor pressure curve of air, mb/cm.

Rn = net radiation, cal/cm^2/day.

L = latent heat of vaporization of water, [59.59 – 0.055] T aver. cal/cm^2 mm or about 58 cal/cm2 mm at 29c°

Ea = 0.263(ea – ed) (0.5 + 0.0062µ where

ea = vapor pressure of air = (e_{max} + e_{min})/2 ,mb

ed = vapor pressure at dew point temperature , Td,for practical purpose equals T_{min} , mb.

µ = wind speed at 2 height of meters, km/day.

g = psychrometric constant equals 0.66 mb/c° .

Taver = (T_{max} + T_{min}) /2 , c°

a_{max} = maximum daily vapor pressure of air, mb

a_{min} = minimum daily vapor pressure of air, mb

T_{max} = maximum daily air temperature, c°

T_{min} = minimum daily air temperature, c°

2- Doreenbos and Pruitt method

Doorenbos and Pruitt method adapted the Makkink (1957) radiation formula to predict the potential ET as follows :-

$$ETp = bwR_s / L - 0.3$$

where

ETp = daily potential evapotranspiration, mm/day .

b = adjustment factor based on wind and mean relative humidity .

w = weighting factor based on temperature and elevation above the sea level .

R_s = total daily income solar radiation for the period considered , cal/cm^2/day .

L = latent heat of vaporization of water, cal/cm^2/day .

The factors b and w can be obtained from the table (Doorenbos and Pruitt 1977)

3- Evaporation pan method

The FAO pan evaporation formula can be expressed as follows:-

$$ETo = K_p \times E_{pan}$$

where

ETo = evapotranspiration , mm/day.

E_{pan} = pan evaporation, mm/day.

K_p = pan coefficient .

Value of K_p is depending on pan sitting and prevailing environmental factors affecting pan evaporation e. g. solar radiation, wind speed, air temperature and air relative humidity. Value of Kp is supposed to be 0.75 according to the weather data prevailing during the present experiment. So, reference evapotranspiration is calculated as follows:-

$$ETo, mm = Ep, mm \times 0.75$$

Hence , *ETc* value can be derived from the following relationship :-

$$Kc = ETc / ETo$$

where

Kc = Dimensionless value

ETc = actual crop evapotranspiration ,mm

ETo = Reference evapotranspiration ,mm

4- Penman – Monteith (ver. 4.2) method

According to FAO Penman- Monteith method , ETo could be calculated as follows:-

$$ETo = \frac{0.408\, \Delta\, [Rn - G] + \gamma\, 900/(T+273)\, u2[es - ea]}{\Delta + \gamma\, [1 + 0.34\, u2]}$$

where

ETo = reference evapotranspiration [mm day^{-1}],

Rn = net radiation at the crop surface [MJ m^{-2} day^{-1}],

G = soil heat flux density [MJ m^{-2} day^{-1}],

T = mean daily air temperature at 2 m height [°C],

u2 = wind speed at 2 m height [m s^{-1}],

es = saturation vapor pressure [kPa],

ea = actual vapor pressure [kPa],

es-ea = saturation vapor pressure deficit [kPa],

Δ = slope vapor pressure curve [kPa $°C^{-1}$],

γ = psychrometric constant [kPa $°C^{-1}$].

It is worthy to mention that the ETactual values were calculated through ETo estimates with the aid of Kc values, FAO paper 24, as follows:-

$$ETactual = ETo \times Kc$$

5- Water Consumptive Use (soil moisture depletion method)

Water consumptive use(Actual Evapotranspiration ,ETa) for maize crop was calculated from soil sampling, just before every irrigation and 48 hrs later, in 15cm increment system to 60 cm of soil profile as well as at harvest time. Water consumptive use was calculated according to Israelsen and Hansen (1962) as follows :-

$CU = [(\theta_2 - \theta_1)) \times \beta d \quad \times \text{soil layer depth}] / 100$

CU = Water consumptive use, cm .

Soil layer depth supposed to be 15 cm.

βd = Bulk density of the given soil layer , gcm-3 .

$\theta 2$ = Soil moisture (% wt,) 48 hrs after irrigation.

$\theta 1$ = Soil moisture (% wt,) just before next irrigation .

The adopted treatments (ETo–estimating methods + traditional soil moisture depletion method) were arranged in randomized complete block design with 3 replicates. All of the recommended agricultural practices for maize production i.e. prevailing hybrid (TWC 324), , N-fertilization, seed rate, plant density .....etc were executed . Sowing and harvesting dates were July,1 and October,10 in the 1st season and July,15 and October,25 in 2nd season, respectively. The quantity of irrigation water (to mach crop water requirement) was calculated by dividing ETactual by the irrigation efficiency which was supposed to be 55 – 60%. The time of water conveying was determined according to equation of immersed orifice as follows:-

$$Q = 0.61 \times 0.443 \times A\sqrt{h}$$

after James, 1988

where

Q = Orifice discharge, L/s

A = Area of orifice, cm2

h = Effective water head over the orifice center, m

Water Use Efficiency (WUE) and Water Utilization Efficiency (WUtE)

Water use efficiency and water utilization efficiency were calculated according to the following equations :-

WUE, kg /fed/mm = (Grain yield, kg /fed) / water consumed, mm

WUtE, kg /fed/mm = (Grain yield, kg /fed) / Applied water, mm

RESULTS AND DISCUSSION

ETo value estimated via the different methods

Data in Table (3) indicated ETo values ,monthly and seasonally, estimated according to different assessed methods. It is clear that modified Penman method exhibited the highest seasonal ETo value, which comprised 12.0 , 14.0 and 15.75 % more than those of Doorenbos and Pruitt, Evaporation pan, and Penman-Monteith in 2006 season, respectively. The increase values in 2007 season were 14.6, 18.1 and 19.1% in the same order. The differences in monthly and seasonally ETo, in the two seasons, are due to the different sowing and harvest dates. In connection, Jensen et al. (1990) indicated the superior performance of the procedures introduced by Monteith (1965) in the Penman equation, comparable with a range of 20 different ETo estimating methods including temperature- based , radiation - based ,pan evaporation-based and combination methods. The authors also stated that ETo values , estimated via mentioned methods, ranged from – 18 to +35% in humid region and from – 27 to +21% in arid one ,comparable with Monteith (1965) method. However, Amatya et al. (1995), found, at three sites in Eastern North Carolina, that ETo estimates using Mankkink, Priestely – Taylor, Turc , Hargreaves - Samani and Thornthwaite were good correlated with that of Penman-Monteith , as standard method, although, there were some differences. In Egypt, El-Sabbagh (1993), found that Blaney – Criddle , pan – evaporation , Penman modified and radiation methods resulted in different ETo estimates, for Sakha area, Kafr EL-Shiekh governorate

Table (3):- Monthly and seasonally ETo,mm, estimated from agroclimatological data for Gharbia Governorate (av. 1997-2006) using different methods.

Month	Modified Penman		Doorenbos & Pruitt		Evaporation pan		Penman-Monteith (ver. 4.2)	
	2006	2007	2006	2007	2006	2007	2006	2007
July	193.7	100	178.6	92.2	180.4	93.1	178.3	92
August	185.4	185.4	168.9	168.6	167.7	167.7	164	164
September	161.1	161.1	140.7	140.7	134.1	134.1	130.5	130.5
October	48.3	120	37.2	93	34	85	35.7	89.3
Seasonal	588.5	566.5	525.4	494.5	516.2	479.9	508.5	475.8

Monthly and seasonally Etc values under ETO–estimating methods and traditional one

Data in Table(4) revealed that the assessed ETo – estimating methods resulted in higher Etc values than the traditional method , and this was true in the two seasons of study . It is obvious that the increase ranged 7.6 – 23.6% in the 1st season and 1.7 – 18.8% in the 2nd one. The differences in monthly and seasonally Etc using ETo -,estimating methods, in the two seasons, are due to the different sowing and harvest dates. Data also exhibited that the highest Etc figure was recorded with modified Penman method ,whereas , Penman – Monteith method resulted in the lower Etc value which was close to the Etc value resulted from the traditional method. In connection, the FAO expert consultation, in 1990, reached unanimous agreement in recommending the Penman-Monteith approach as the most accurate method to estimate evapotranspiration of a reference crop ETo and adopted the estimates for bulk surface and aerodynamic resistance as elaborated by Allen et al. (1998) as standard values for the reference crop. Moreover, in Egypt, EL-Marsafawy et al.(1998), found that Penman- Monteith method was more accurate to estimate ETactual, for wheat crop grown at Giza (Middle Egypt), than both Doorenbos and Pruitt and Penman modified methods.

Table (4):- Monthly and seasonally Etc values for maize crop under ETo-estimating methods and the traditional one ,2006 and 2007 seasons

Month	Modified Penman		Doorenbos & Pruitt		Evaporation pan		Penman-Monteith (ver. 4.2)		Traditional	
	2006	2007	2006	2007	2006	2007	2006	2007	2006	2007
July	142.7	84	150	77.4	151.5	78.2	149.8	77.3	128.9	52.7
August	226.2	226.2	206.1	206.1	204.6	204.6	200.1	200.1	140.6	116.3
September	141.8	141.8	123.8	123.8	118	118	114.8	114.8	143.9	155.2
October	19.3	48	14.9	37.2	13.6	34	14.3	35.7	31.6	96.5
Seasonal	530	500	494.8	444.5	487.7	434.8	479	427.9	445	420.7

Grain yield, water use efficiency and water utilization efficiency

Data in Table (5) illustrated the maize yield was the highest under Penman-Monteith method, comparable with the other tested methods . The increase percentages comprised 7.22, 7.36 ,7.19 and 7.52 more than modified Penman, Doreenbos and Pruitt, Evaporation pan and traditional methods in 2006 season, respectively. The same trend was noticed in 2007 season with increase percentage values reached 8.09, 8.65, 7.90 and 9.41 in the same order, respectively. As for water use efficiency, irrigating maize crop via Penman-Monteith method, in comparison with the other assessed methods, proved to be superior to enhance the maize grains yielded due to the unite of consumed irrigation water, and the increase% ranged 0.13–23.02 in 2006 season and 7.62–26.33 in 2007 one. Moreover, on the basis of the unite of applied water, Penman-Monteith method still enhancing water utilization efficiency ,comparable with the other methods, since the increase% ranged 0.00 – 23.35 in 2006 season and 7.65 – 26.35 in 2007 one. So, in order to use the irrigation water efficiently, it is worthy to mention that the differences, in both WUE and WUtE values, under Penman-Monteith and traditional methods were slight indicating the possibility of irrigating the maize crop via Penman-Monteith method instead of the time and labor- consumer traditional method.

Table (5):Maize grain yield, water use efficiency and water utilization efficiency as affected by the adopted treatments .

Method	2006 season			2007 season		
	Yield, kg/fed	WUE	WUtE	Yield, kg/fed	WUE	WUtE
Modified. Penman	3199	6.04	5.44	2905	5.81	5.13
Doorenbos &Pruitt	3195	6.46	6.05	2890	6.51	5.84
Evaporation pan	3200	6.56	6.20	2910	6.69	6.06
Penman-Monteith	3430	7.16	6.75	3140	7.34	6.60
Traditional	3190	7.17	5.99	2870	6.82	5.17

CONCLUSION

Under Gemmeiza area conditions it is advisable to use Penman – Monteith in irrigating maize crop due to the improvements in grain yield and water use efficiency values and instead of the time and labor – consumer traditional method .

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ري الأذرة الشامية باستخدام بعض المعادلات المناخية وتأثيرة علي الإنتاجية وكفاءة استخدام المياه

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الملخص العربى

أجريت تجربة حقلية بمحطة البحوث الزراعية بالجميزة (وسط الدلتا) خلال موسمي ٢٠٠٦ و ٢٠٠٧ لدراسة تأثير استخدام بعض المعادلات المناخية في ري الأذرة الشامية علي الانتاجية و كفاءة استخدام مياة الري . تم تطبيق المعادلات التالية في حساب البخر – نتح القياسي ETo

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وتم حساب استخدام المياة Water use بقيم معامل المحصول Kc المذكورة في ال FAO, PAPER 24 وقورنت بقيم الاستهلاك المائي الفعلي المقدر من عينات الرطوبة الأرضية المأخوذة بعد و قبل الري (.الطريقة التقليدية). رتبت المعاملات في التصميم الاحصائي قطاعات كاملة العشوائية وكررت ثلاث مرات . كانت أهم النتائج كالآتي :–

١- اختلفت قيم البخر – نتح القياسي باستخدام المعادلات المناخية تحت الدراسة. أعلي قيمة تم الحصول عليها من معادلة بنمان المعدلة بينما أعطت معدلة بنمان – مونتيث أقل قيمة .

٢- كانت قيم المياة المستخدمة ، المحسوبة من المعادلات المناخية ، دائما أعلي من قيم الاستهلاك المائي الفعلي. أظهرت معادلة بنمان – مونتيث قيم للمياة المستخدمة بواسطة محصول الأذرة الشامية قريبة جدا لقيم الاستهلاك المائي الفعلي .

٣- دائما ازداد محصول الحبوب بالري باستخدام معادلة بنمان – مونتيث ، وتحسنت قيم كفاءة استخدام المياة (علي أساس المياة المستهلكة أو المضافة للحقل) باستخدام المعادلة المذكورة في ري الأذرة الشامية .

بناءا علي النتائج السابقة يوصي في ري الأذرة الشامية ، بمنطقة الجميزة – وسط الدلتا ، باستخدام معادلة بنمان – مونتيث بدلا من الطريقة التقليدية التي تحتاج الي وقت وجهد كبيرين .