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Irrigation Scheduling for Maize Grown under Middle Egypt Conditions

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Abstract: Two field experiments were conducted at Giza Agricultural Research Station, Agricultural Research Center, Egypt during the two successive seasons of 2005 and 2006. The objectives of this research were: (i) to study the effect of scheduling irrigation using three different pan evaporation coefficients on maize yield and its components; (ii) to determine the most important yield components of maize using different statistical procedures. Irrigation treatments were irrigation using 1.2, 1.0, and 0.8 pan evaporation coefficient devoted to control, about 7% reduction in irrigation water than the control, about 14% reduction in irrigation water than the control, respectively. Actual evapotranspiration and water use efficiency were estimated. Simple correlation coefficients analysis, multiple linear regression analysis and principle components analysis were used to determine the most important yield components. Analysis of variance revealed that all the studied characters were significantly affected by irrigation treatments over the two growing seasons, except for number of rows/ear for both growing season and number of grain/ear in 2005 growing season. Results also showed that under irrigation with 1.0 pan evaporation coefficient maize yield was reduced by 6.15 and 8.05% in 2005 and 2006 growing seasons, respectively. Furthermore, maize yield was reduced by 36.07 and 35.97% under irrigation with 0.8 pan evaporation coefficient for 2005 and 2006, respectively. The highest consumptive water used was obtained under irrigation with 1.2 pan evaporation coefficient i.e. 5894 and 6170 m^3/ha for the first and second season, respectively. Whereas, the highest water use efficiency was obtained under irrigation with 1.0 pan evaporation coefficient in 2005 growing season and in 2006 growing season, the highest water use efficiency was obtained under either irrigation with 1.2 pan evaporation coefficient or 1.0 pan evaporation coefficient. Therefore, to increase water use efficiency and to save irrigation water, it could be recommended to irrigate maize using 1.0 evaporation pan coefficient under middle Egypt conditions. Simple correlation coefficients analysis revealed that ear length, ear diameter, number of grains/ear and 100-grain weight were positively and significantly correlated to maize grain yield. Multiple linear regressions analysis indicated that three characters were found positively and significantly correlated with maize yield i.e. grain weight/ear, number of grain/ear and 100-grain weight. Whereas, results of principle components analysis over the two growing seasons showed that ear length and grain weight/ear accounted for 69.07 % of the total variation. Therefore, it is recommended to select for ear length and grain weight/ear in the breeding programs.

Keywords: Maize, irrigation scheduling, water use efficiency, important yield components., Irrigation scheduling, consumptive water use, water use efficiency, maize yield and its components.

INTRODUCTION

Irrigation scheduling is the technique to timely and accurately give water to a crop. Jensen[16] referred to irrigation scheduling as “a planning and decision-making activity that the farm manager or operator of an irrigated farm is involved in before and during most of the growing season”. Irrigation scheduling has been described as the primary tool to improve water use efficiency, increase crop yields, increase the availability of water resources, and provoke a positive effect on the quality of soil and groundwater[11]. Irrigation requirement of maize varies with soil type, and agro-climatic conditions. Technique of pan evaporation for irrigation scheduling is extensively used by many researchers[17,3,18]. The knowledge of water requirement of maize is important for planning water management practices at farm level. Musick and Dusek[22] studied

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the maize yield response to water deficits, and concluded that the seasonal irrigation water requirement was 400 mm, grain yields were 9.52-10.85 ton/ha and seasonal water use efficiencies were 1.25-1.46 kg/m^3. Doorenbos and Pruitt[6] reported that the water requirements of maize for maximum production varied between 430-490 mm per season depending on climate and length of growing period.

Under scarce and costly water supplies, it may sometimes be advantageous to stress the crop to some degree. Water stress may reduce the crop yield to some extent but it will remain economically feasible as long as the marginal benefit from reduced cost of water is equal or greater than marginal cost of reduced yield[30]. Water stress during maize growing season resulted in reduction of plant height, reduction in leaf area index[5] and in total leaf area[9]. In addition, number of ovules that fertilized and developed into grains decreased rapidly when drought occurred during flowering[12]. Moreover, both final maize yield and kernel number were reduced as a result of water stress during grain filling period[25].

Determining the most important yield components that would be used in breeding for high yield in maize could be attained by using different statistical procedures. Simple correlation coefficient analysis[29] could be helpful in determining important yield components. Grain number per ear and total leaf area were found to be highly and positively correlated with maize plant yield[23]. Furthermore, Mohamed *et al.,*[21] found that number of rows/ear, ear diameter and number of kernels per ear and 100-kernel weight were highly and significantly correlated with maize yield. Multiple linear regression[7] is another procedure that could be used to determine the important yield components. Ear length and number of grains/ear were found to be the most effective traits affecting grain yield of maize[21], whereas Ashmawy and Mohamed[1] reported that ear diameter, number of ears per plant and ear weight were found to be the most important yield factors. Furthermore, principal component analysis[4] could be use to determine the independent components affecting a common factor (yield), in addition to its contributing percentage. Number of kernels per row and ear weight was found to be accounting for 98.4 % of the total variation in maize yield[28].

The objectives of this research were: (i) to study the effect of scheduling irrigation using three different pan evaporation coefficients on maize yield and its components; (ii) to determine the most important yield components of maize using different statistical procedures.

MATERIALS AND METHODS

Two field experiments were conducted at Giza Agricultural Research Station, Agricultural Research Center, Egypt during the two successive seasons of 2005 and 2006. The aim of the experiment was to study the effect of three irrigation treatments on yield and water relations of maize and to determine which irrigation treatment would results in the highest yield. The experimental treatments were arranged in a randomized complete block design with three replicates. Maize hybrid TWC 310 was used in the experiments. Maize seeds were sown on June 9th in both growing seasons. Nitrogen fertilizer was applied in the form of urea (288 kg/ha, 46% N) and was applied before the 2nd irrigation. Phosphorus fertilizer was applied in the form of single super phosphate (480 kg/ha, 15.5% P_2O_5) and was incorporated into the soil during land preparation. Potassium sulfate was applied before planting (120 kg/ha, 48% KO_2). Surface irrigation was used. The second irrigation (after planting irrigation) was applied on June 26th in both growing seasons. Evaporation data were obtained from a standard Class-A-Pan located near the experimental field and the readings was collected on a daily basis. Irrigation treatments were initiated after the second irrigation for both seasons. Irrigation amounts were calculated with the following equation[6]:

- $I = Epan*Kp$ (1)

Where: I is the applied irrigation water amount (mm), Epan is the cumulative evaporation amount in the period of irrigation interval (mm), Kp is the pan evaporation coefficient. Irrigation treatments consisted of: irrigation using 1.2 pan evaporation coefficient (control), irrigation using 1.0 pan evaporation coefficient (about 7% reduction in irrigation water than the control) and irrigation using 0.8 pan evaporation coefficient (about 14% reduction in irrigation water than the control). Soil mechanical analysis[19], of the experimental field in the depth of 0-60 cm is shown in Table (1).

The soil moisture constants (% per weight) and bulk density (g/cm^3) in the depth of 0-60 cm are shown in Table (2).

Table 1: Soil Mechanical analysis at Giza Agricultural Station

Soil fraction	Content (%)
Coarse sand	2.91
Fine sand	13.04
Silt	30.51
Clay	53.18
Texture class	Clay

Table 2: Soil moisture constants of the experimental field at Giza Agricultural Station

Depth (cm)	Field capacity (%, w/w)	Wilting point (%, water)	Available water (mm)	Bulk density g/cm^3
0 – 15	41.85	18.61	40.0	1.15
15 - 30	33.68	17.50	30.1	1.24
30 - 45	28.36	16.92	20.6	1.20
45 - 60	28.05	16.54	22.1	1.28

Metrological data were collected for Giza Agricultural Research Station and are included in Table (3).

Crop-water Relation Parameters:

Seasonal Actual Water Consumptive Use (Evapotranspiration): Actual evapotranspiration (ET) was estimated by soil sampling just before and after 48 hours of each irrigation, and before harvest and calculated according to the equation of Israelsen and Hansen[15] as follows:

$$CWU = (\theta_2 - \theta_1) * Bd * RD \quad (2)$$

Where: CU is water consumptive use (mm), θ_2 is soil moisture percentage by weight 48 hours after irrigation,θ_1 is soil moisture percentage by weight 48 hours before next irrigation, Bd is bulk density in (g/cm^3) and RD is root depth.

Water Use Efficiency (WUE): Water use efficiency (kg/m^3) values for the different treatments were calculated by the following equation[31].

$$WUE = \frac{\text{Seed yield (kg/ha)}}{\text{Consumptive use } (m^3/ha)}$$

At harvest, ear length (cm), ear diameter (cm), grain weight/ear (g), number of rows/ear, number of grains/ear, 100-grain weight (g), and grain yield (ton/ha) were measured.

Statistical Analysis:

- Data were statistically analyzed according to Snedecor and Cochran[27] and treatment means were compared by least significant difference test (LSD) at 0.05 level of significance.
- Simple correlation analysis was computed among the studied characters according to the method described by Steel and Torrie[29].
- Multiple linear regression analysis was used to determine the most important yield components, as independent variables, which significantly contribute to the total variability in grain yield as the dependent variable[7]. The studied characters were screened and only the significant characters were regressed with maize grain yield.
- Principle components analysis was used according to the methods of Berenson *et al.,*[4]. The basic purpose of principal components is to account for the total variation forming a new set of orthogonal and uncorrelated composite varieties. Hence, the first composite (i.e. principle component) will have the largest variance; the second will have a variance smaller than the first but larger than the third, and so on. Therefore, yield characters that included in the first components are considered the most important ones.

RESULTS AND DISCUSSIONS

Effect of Irrigation Treatments: Regarding to maize grown under different irrigation treatments, results in Table (4) indicated that all the studied characters were significantly affected by irrigation treatments over the two growing seasons, except for number of rows/ear for both growing season and number of grain/ear in 2005 growing season. Ear length, ear diameter and number of grains per ear could be indirect indicative of the ability of ear to bear grain. Results in that table also showed that the highest maize yield and its components were obtained under irrigation using evaporation pan coefficient equal to 1.2, over all the two growing seasons. This could be attributed to the fact that increasing available soil moisture during vegetative and reproductive growth of maize increased maize yield and its components[2,20]. Furthermore, maize yield and its components tend to be higher in 2006 growing season, compared with 2005 growing season. This could be attributed to favorable climatic conditions that were prevailing during 2006 growing season.

Results in Table (5) also showed that under irrigation with 1.0 pan evaporation coefficient (7% reduction in irrigation water than control); maize yield was reduced by 6.15 and 8.05% in 2005 and 2006 growing seasons, respectively. Furthermore, maize yield was reduced by 36.07 and 35.97% under irrigation with 0.8 pan evaporation coefficient (14% reduction in irrigation water than control) for 2005 and 2006, respectively. These yield reduction could be attributed to low level of soil moisture in the root zone area during the growing season,which reduced crop evapotranspiration to a limit that resulted in yield reduction.

Table 3: Meteorological data for Giza region in 2005 and 2006 seasons

Season	2005						
Month	Tmax (ºC)	Tmin (ºC)	WS (m/s)	RH(%)	SS (h)	SR (cal/cm²/day)	Epan(mm/month)
May	31.6	19.2	3.9	54	11.4	647	4.4
June	33.9	23.1	3.9	49	12.2	679	8.3
July	35.2	25.1	2.8	38	12.1	670	7.1
August	35.0	25.5	3.4	42	11.8	646	6.5
September	34.0	23.2	7.6	47	10.8	572	5.4
October	28.3	18.1	3.7	53	10.1	488	4.0
Season	2006						
Month	Tmax (ºC)	Tmin (ºC)	WS (m/s)	RH(%)	SS (h)	SR (cal/cm²/day)	Epan(mm/month)
May	32.1	18.9	3.0	47	11.4	647	7.6
June	35.4	23.4	3.8	35	12.2	679	8.0
July	35.6	24.9	2.7	59	12.1	670	7.7
August	36.4	25.8	2.8	61	11.8	646	7.6
September	34.3	23.6	3.3	53	10.8	572	6.7
October	31.8	21.7	3.8	59	10.1	488	4.3

Tmax=Maximum temperature; TMin=Minimum temperature; WS=Wind speed; RH=Relative humidity; SS=Actual sunshine duration; SR= Solar radiation; Epan=Evaporation pan.

Table 4: Effect of irrigation treatments on maize yield and its components in 2005 and 2006 growing seasons.

	1.2		1.0		0.8		LSD	
Characters	2005	2006	2005	2006	2005	2006	2005	2006
Ear length (cm)	23.13	24.93	22.47	24.97	18.73	19.73	2.00	2.12
Ear diameter (cm)	4.37	4.83	4.53	4.77	3.93	4.46	0.31	0.27
Grain weight/ear (g)	161.67	206.00	145.33	209.33	97.00	149.00	19.48	32.30
No. of rows/ear	12.27	14.00	12.00	14.27	11.60	13.93	n.s.	n.s.
No. of grains/ear	608.32	759.73	558.35	762.93	494.93	653.96	n.s.	83.57
100-grain weight (g)	40.13	34.69	38.53	33.67	32.60	28.44	5.80	4.31
Grain yield (ton/ha)	7.80	7.83	7.32	7.20	4.68	4.61	0.64	0.43

Table 5: Reduction in maize yield under irrigation with 1.0 and 0.8 pan evaporation coefficient for the two growing seasons.

Growing season	% reduction under 1.0 pan evaporation coefficient	% reduction under 0.8 pan evaporation coefficient
2005	6.15	36.07
2006	8.05	35.97

Table 6: Consumptive water use (CWU) and water use efficiency (WUE) for maize in 2005 and 2006 growing seasons

Irrigation treatments	2005 growing season			2006 growing season		
	Yield (kg/ha)	CWU(m^3/ha)	WUE (kg/m^3)	Yield (kg/ha)	CWU(m^3/ha)	WUE (kg/m^3)
1.2	7800	5894	1.32	7830	6170	1.27
1.0	7320	5313	1.38	7200	5686	1.27
0.8	4680	5052	0.93	4610	5304	0.87

Table 7: Correlation coefficients between maize yield and its components under three irrigation treatments over the two growing seasons

	Ear length (cm)	Ear Diameter (cm)	Grain weight/ear (g)	No. of grain/ear	100-grain weight (g)	Grain yield (ton/ha)
Ear length (cm)	1.00					
Ear Diameter (cm)	0.73*	1.00				
Gain weight/ear (g)	0.86**	0.84**	1.00			
No. of grain/ear	0.76*	0.80**	0.89**	1.00		
100-grain weight (g)	0.43	0.10	0.16	-0.14	1.00	
Grain yield (ton/ha)	0.90**	0.61*	0.70*	0.53	0.63*	1.00

* and ** donates significant at 0.05 and 0.01 level.

Table 8: Regression equations, coefficient of determination (R^2) and standard error of estimates (SE%) for maize under both growing seasons

Treatments	Regression equations	R^2	SE%
1.2	y^=7.93+0.02GW/E*-0.001GN/E +0.02W100	0.82	1.70
1.0	y^=-4.34+0.03GW/E**+0.01GN/E**+0.06W100	0.97	1.20
0.8	y^=8.55+0.03GW/E**+0.01GN/E**+0.21W100**	0.98	0.47

GW/E=grain weight/ear; GN/E= number of grain/ear; W100=100-grain weight.
* and ** donates significant at 0.05 and 0.01 level.

Actual Water Consumptive Use and Water Use Efficiency: Actual consumptive water use for maize in 2005 and 2006 growing seasons are included in Table (6). The highest consumptive water used was obtained under irrigation with 1.2 pan evaporation coefficient i.e. 5894 and 6170 m^3/ha for the first and second season, respectively. Differences between such results may be due to the variation in the weather conditions, especially air temperature. These results indicate that consumptive use decreased as the available soil moisture decreased in the root zone i.e. irrigation with 1.0 and 1.2 pan evaporation coefficient. These results are in agreement with the results obtained by El Marsafawy[8]and Ashoub *et al.,*[2].

Water use efficiency was the highest in 2005 growing season, compared with 2006 growing season (Table 6). Furthermore, in 2005 growing season, the highest water use efficiency was obtained under irrigation with 1.0 evaporation pan coefficient (7% saving in irrigation water than control). Whereas, in 2006 growing season, water use efficiency was similar under irrigation with either 1.2 or 1.0 evaporation pan coefficient (Table 6). Therefore, to increase water use efficiency and to save irrigation water, it could be recommended to irrigate maize with 1.0 evaporation pan coefficient.

Simple Correlation Analysis: Simple correlation coefficient between grain yield (ton/ha) and its component are presented in Table (7). Results in that table showed that ear length, ear diameter, number of grains/ear and 100-grain weight were positively and significantly correlated to maize grain yield with correlation coefficient values equals to 0.90, 0.61, 0.70, and 0.63, respectively. The above mentioned characters are important yield components. These finding are in agreement with those obtained by Hassib[14] and Mohamed *et al.,*[21].

Table 9: Results of principal component analysis over both seasons of 2005 and 2006 growing seasons.

Character	Component 1	Component 2	Component 3
Ear length	0.471	0.123	-0.334
Grain weight/ear	0.463	0.172	0.037
Ear diameter	0.425	-0.218	0.828
No. of grain/ear	0.419	-0.403	-0.269
100-grain weight	0.165	0.784	-0.254
Percentage variance	69.07	22.70	4.22

Multiple Linear Regression Analysis: Results from multiple linear regression analysis indicated that for under irrigation with 1.2 pan evaporation coefficient (control treatment), only grain weight/ear was found positively and significantly correlated with maize yield (Table 8). Under irrigation with 1.0 pan evaporation coefficient (7% saving in irrigation water from the control treatment), two characters were found positively and significantly correlated with maize yield i.e. grain weight/ear and number of grain/ear. Furthermore, three characters were found positively and significantly correlated with maize yield i.e. grain weight/ear, number of grain/ear and 100-grain weight, under irrigation with under irrigation with 1.0 pan evaporation coefficient (14% saving in irrigation water from the control treatment) (Table 8).

Principal Component Analysis: Results of principle components analysis over the two growing seasons are included in Table (9). The analysis showed that three components were considered. The first component accounted for 69.07 % of the total variation. This component included ear length (cm) and grain weight/ear (g). The second component accounted for 22.70% of the total variation. This component was represented by 100-grain weight (g). The third component accounted for 4.22% of the total variation and accounted for 4.22% and included ear diameter. These results were in agreement with what was obtained by Ashmawy and Mohamed[1] and Khalil and Mohamed[18].

Conclusion: The traditional goal in irrigated agriculture is the achievement of the highest yield per unit land surface; only in relatively recent years it was realized that such a goal entails a wasteful use of water resources and the principles of deficit irrigation were developed[10], aiming to obtain the highest yield per unit of water. The results of our work indicated that the highest plant yield for maize planted in both growing seasons of 2005 and 2006 was obtained when the plants were irrigated using 1.2 pan evaporation coefficient. However, the highest water use efficiency was obtained under irrigation with 1.0 pan evaporation coefficient in both growing season (7% saving in applied irrigation water). Therefore, it is recommended to apply irrigation water using 1.0 pan evaporation coefficient to save irrigation water and to increase water use efficiency.

Three statistical procedures were used to determine the most important yield components. Simple correlation analysis revealed that five yield components were found to be highly significant and correlated with yield. Whereas, multiple linear regression analysis exposed that there were three yield components that had the highest contribution to maize yield. However, principle component analysis was more efficient than simple correlation analysis and multiple linear regression analysis, which assigned only two yield components, which could accounted for 69.07 % of the total variation. These two yield components were ear length and grain weight per ear. Therefore, it is recommended to select for ear length and grain weight per ear in the breeding programs.

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