J. Agric. Sci. Mansoura Univ., 26 (11): 7469 - 7487, 2001.

RESPONSE OF CORN TO K-FERTILIZATION UNDER DIFFERENT SOIL MOISTURE CONDITIONS: 2-CROP-WATER PRODUCTION FUNCTIONS: COMPARISON OF SOME MODELS.

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ABSTRACT

A field experiment was carried out during the 1998-growing season of corn (*Zea mays* L.) variety Hageen 310. The objectives of the present study were to develop the crop-water production functions (CWPF) of corn and determine how the levels of K- fertilization affect the crop-water production functions. The irrigation was applied when the soil moisture depletion in the root zone reached to 20, 40, 60 and 80% of available soil water. Potassium fertilization was applied at four levels i.e., 0, 15, 30 and 60 kg K_2O/fed in the form of potassium sulphate (48% K_2O). The texture of the experimental soil was a clayey. The treatments were arranged in a split plot design with four replicates. The CWPF's used in the present study were: De Wit (1958), Jensen (1968), Penman (1970), Hanks (1974), Stewart *et al.* (1977), Helweg (1991), Gaussian, Exponential, Linear, and Logarithmic models. The comparison for the accuracy of the predicted yield responses from each model was examined. Accordingly, the Gaussian and polynomial models have the highest values of R^2. It is account as 0.9680** and 0.9337**, respectively. The Jensen and Logarithmic models have the same values of R^2, 0.9008** and 0.9003**, respectively. Likewise the Penman and modified Stewart models have the same values, 0.8828** . The De Wit, Linear, Exponential and Hanks have approximately the same values, 0.8006**, while the Stewart model has the lowest R^2 value, 0.4255^{ns}. The present results support the hypothesis that K fertilization can improve the water utilization efficiency by plants. Therefore, more study is needed to explain the role of fertilization in the shape of crop-water production function as related to rate and frequency of fertilizer application.

Keywords: Crop-Water production function – water utilization efficiency – growth model – Gaussian model – K-fertilization

INTRODUCTION

Water is essential for crop production. Available water must be used rationally for efficient crop production and high yields. Therefore, it is requires a proper understanding of the effect of applied water on crop growth and yield under different growing conditions.

The yield of any crop in response to applied water depends on different factors such as irrigation timing, water quality, irrigation application method, critical crop stages, soil type, and climatic conditions.

Knowledge of when irrigation is needed and of the likely response of crop yield to irrigation is desirable for both irrigation scheme planners and farm managers. Irrigation scheme planner needs such information to estimate the likely demand for water and to carry out economic analysis of proposed irrigation schemes. Farm managers also need this information in order to maximize returns from the available irrigation water (Baird *et al.*, 1987).

Crop responses to different rates of applied water have been used for many crops to determine irrigation strategies for optimal yield and maximum efficiency of water use (Black, 1966 and Bauder *et al.*, 1975).

Crop response to water can be described by the so-called Crop-Water-Production Function (CWPF, yield vs. applied water). It is important in defining the marginal crop production for maximum profit. The CWPF has been used to evaluate the economic viability of irrigation management schemes, such as determining the relationship between amount of water application and maximum net benefits, and studying how different environments might alter a CWPF. Clumpner and Solomon (1987) investigated more than 300 crop water production function and found that most were described as linear. The linear function cannot be used effectively for economic analysis or to find the optimal amount of water to apply because there is no maximum point on the net benefit curve.

Taylor *et al.* (1983) discussed water and crop production, perhaps one reason CWPF is assumed to be linear is that yield vs. evapotranspiration (ET) is reported as linear (Doorenbos and Kassam, 1979 and Doorenbos and Pruitt, 1977).

Many researchers (Penman, 1962; French and Legg, 1979 and Hanks and Rasmussen, 1982) have shown that simple models incorporating rain, irrigation and estimates of Evapotranspiration (ET) can adequately describe the response of yield to irrigation. These simple models can in principle provide guide lines for irrigation. Which are of greater generality than recommendations based on the analysis of variance in individual experiments done on different sites and its different seasons.

Much economic analysis is conducted by linear programming (LP) which is a popular method of optimization. Only a non-linear production function can produce a non-linear benefit function (Al-Besher and Helweg, 1986).

The main requirements for a CWPF's are that the function has a right shape and that it be robust (Helweg, 1991). To be robust means that even with limited data, the correct curve may be closely approximated. In other words, if a function that gives that correct shape is used even limited data can generate an adequate crop production function.

Recently published models describing the response of yield to water (CWPF) vary in complexity but can grouped into four categories: 1) simple input-output models (number of irrigations or applied water), 2) potential deficit models (active ET), 3) actual deficit models (actual ET and Stewart S-1), and 4) phasic models (estimated actual deficits).

The objectives of the present study were to develop the crop-water production functions of corn and to determine how the rates of K-fertilization affect the crop-water production functions.

MATERIALS AND METHODS

A field experiment was conducted at Abis experimental Station Farm, Faculty of Agriculture (Saba Bacha)- Alexandria during the 1998 growing season of corn. The texture of the experimental soil is clayey. Some of its physical and chemical properties determined for collected samples (Carter, 1993) are presented in Table (1).

The moisture depletion treatments were as follows:

1. Irrigation at soil moisture depletion of 20% from available soil moisture in root zone.
2. Irrigation at soil moisture depletion of 40% from available soil moisture in root zone.
3. Irrigation at soil moisture depletion of 60% from available soil moisture in root zone.
4. Irrigation at soil moisture depletion of 80% from available soil moisture in root zone.

Table (1). Some physical and chemical characteristics of the experimental used in the present study

Parameters	Soil depth , cm		
	0 – 30	**30 - 60**	**60 - 90**
Particle –size distribution , %			
Sand	29.1	26.0	25.2
Silt	27.1	30.0	28.1
Clay	43.8	44.0	46.7
Texture class	Clay	Clay	Clay
Bulk density, Mg/m^3	1.30	1.28	1.28
Saturation water content, m^3/m^3	0.509	0.516	0.517
Field capacity, m^3/m^3	0.378	0.384	0.395
Permanent wilting point, m^3/m^3	0.241	0.248	0.255
Available water content, m^3/m^3	0.137	0.136	0.140
Saturated hydraulic conductivity, cm/hr	0.24	0.21	0.22
Organic matter content, %	1.70	1.78	1.81
$CaCO_3$, %	8.53	9.22	9.11
pH (1: 1 water suspension)	8.45	8.48	8.40
Electrical conductivity (1: 1 water extract) , dS /m	3.22	3.12	3.18
Soluble Cations, meq/L			
Ca^{2+}	0.79	0.77	0.76
Mg^{2+}	0.64	0.67	0.71
Na^{+}	1.70	1.56	1.58
K^{+}	0.06	0.09	0.09
Soluble Anions, meq/L			
$CO_3^{=} + HCO_3^{-}$	0.75	0.79	0.74
Cl^{-}	1.98	1.76	1.91
$SO_4^{=}$	0.46	0.53	0.50
Available soil nutrients, mg/Kg			
N	56	79	72
P	15.1	16.3	14.0
K	211	203	216
Fe	3.5	3.4	3.2
Mn	2.6	2.5	2.3
Cu	1.0	1.1	0.9
Zn	1.3	1.4	1.2

Sulphate ion was determined by subtraction

Potassium fertilization was applied at four levels i.e. 0, 15, 30 and 60 kg K_2O/fed. Potassium fertilization was applied in the form of potassium sulphate (48% K_2O) at two doses; the first dose was applied with the first irrigation and the second dose at one month later. Calcium super-phosphate (15.5% P_2O_5) was applied at rate of 45 kg P_2O_5 /fed before planting. Nitrogen fertilization as ammonium nitrate (33.5% N) at rate of 120 kg N/fed was divided into two equal doses, the first dose was applied with the first irrigation and the second dose was one month later.

A split plot in randomize complete block design with four replicates was used. The main plots were devoted to the irrigation regimes (SMD) and the subplots were assigned for the K-fertilization levels.

Corn (*Zea mays*, L.) seeds, variety Hageen 310 were used in this study. Planting took place on May 21, 1998 and harvesting was done at October 10, 1998. The experimental plot consisted of 5 rows, 5 m long and 0.70 m wide making an area of 17.5 m^2. Seeds were planted at 0.3 m apart within the row.

At harvesting time, ten plants were randomly selected from the three central rows to determine the grain yield.

The soil samples were taken from soil profile down to 90 cm depth before and 24hr after each irrigation to determine the seasonal consumptive use (ETa) using the soil moisture depletion method (Robins, 1965). The soil moisture content was measured gravimetrically at three different soil depths namely 0-30, 30-60 and 60-90 cm at each treatment. The seasonal consumptive use was calculated according to the following equation (Isrealson and Hansen, 1962):

$$ETa = \sum_{i=1}^{n} (\theta_2 - \theta_1)_i * Dr_i \qquad (1)$$

Where:

ETa is the seasonal consumptive use, mm/season.
i is the number of soil layer.
n is the total number of soil layers
θ_2 is the soil moisture content after irrigation for layer i, m^3/m^3
θ_1 is the soil moisture content before irrigation for layer i, m^3/m^3
Dr is the thickness of soil layer i , mm

Potential Evapotranspiration (ETp) was computed according to the FAO penman-Montieth method (Allen *et al.*, 1998). All meteorological data were taken from El-Nozha meteorological station.

$$ETp = \frac{0.408\,\Delta\,(R_n - G) + \gamma \frac{900}{T + 273} U_2 (e_s - e_o)}{\Delta + \gamma\,(1 + 0.34\,U_2)} \qquad (\quad (2)$$

Where:

ETp is the potential Evapotranspiration, mm/day.
R_n is the net radiation at the crop surface, MJ m^{-2} day^{-1}

G	is the soil heat flux density, MJ m^{-2} day
T	is the mean daily air temperature at 2 m height, °C.
U_2	is the wind speed at 2 m height, mS^{-1}
e_s	is the saturation vapor pressure, KP_a
e_a	is the actual vapor pressure, KP_a
(e_s-e_a)	is the saturation vapor pressure deficit, KP_a
Δ	is the slope of vapour pressure curve vers air temperature, KP_a °C^{-1}
γ	is the psychrometric constant, KP_a °C^{-1}

The potential Evapotranspiration (ET_p) was account as 857.7 mm/season.

There are several Crop-Water Production Functions to describe the water-yield relationship. Table (2) presents these models.

All obtained data were statistically analyzed according to Steel and Torrie (1982) .The correlation and regression analysis were done according to the method of Draper and Smith (1981).

Table 2: The crop water production functions used in the present study.

Model	Function
DeWit (1958)	Ya = K (Eta/ ETp)
Jensen (1968)	Ya = A * ETa ^B
Penman (1970)	Ya = K * ETa + C
Hanks (1974)	Ya / Ym = K *(ETa / ETp)
Stewart *et al* (1977)	(1 – Ya/Ym) = b*(1 – ETa/ETp)
Helweg (1991)	$Ya = b_0 + b_1*ETa + b_2*ETa^2$
Gaussian model	$Ya = a * EXP-(ETa – b)/2c^2$)
Microsoft Corporation (1993)	
Exponential model	Ya = a * EXP(b*(ETa/ETp))
Linear model	Ya = K * ETa
Logarithmic model	Ya = a * Log (ETa /ETp) + b

Ya is the actual grain yield , Kg/fed. – Ym is the maximum grain yield , Kg/fed. - ETa is the seasonal crop Evapotranspiration, mm/season – ETp is the seasonal potential Evapotranspiration, mm/season – K, A, B, C, b_0 , b_1, b_2, a and b are empirical coefficients

RESULTS AND DISCUSSION

The amount of water required by crop depends on atmospheric demand, crop type, growth stage, root system distribution and soil type (Doorenbos and Pruitt, 1977 and Allen *et al.*, 1998). The seasonal water consumptive use (actual evapotranspiration, ETa) as affected by soil moisture depletion in root zone and K fertilization level are presented in Table (3). The data revealed that increasing soil moisture depletion in root zone significantly decreased the cumulative Evapotranspiration. Likewise, increasing K- fertilization significantly decreased the seasonal water consumptive use (Abdel-Nasser and Hussein, 2001). Fig. (1) shows the relation between water applied (seasonal evapotranspiration, mm/season and grain yield of corn, Kg/fed).

Table (3): Seasonal water use and grain yield of corn as influenced by soil moisture depletion in root zone and K- fertilization.

SMD, %	K Fertilization Kg/fed	Water use mm/season	Grain yield kg/fed
20	0	622.6	1671.0
	15	611.5	1793.7
	30	601.3	1857.0
	60	595.7	1925.0
40	0	599.3	1786.8
	15	578.6	1827.8
	30	568.8	1889.8
	60	561.9	1931.4
60	0	536.9	1567.2
	15	519.8	1582.5
	30	503.1	1623.4
	60	487.7	1687.1
80	0	454.1	1207.7
	15	445.4	1289.9
	30	435.8	1328.0
	60	425.3	1357.8
Mean effect of SMD(%):			
20		607.8	1811.90
40		577.2	1858.95
60		511.9	1615.05
80		440.2	1295.85
$LSD_{0.05}$		12.40 **	50.91**
Mean effect of K-fertilization(Kg K_2O/fed):			
0		553.2	1558.40
15		538.8	1623.48
30		527.3	1674.55
60		517.7	1725.33
$LSD_{0.05}$		12.40**	50.91**
$LSD_{0.05}$ (SMD X K)		**NS**	**NS**

**** significant at 1% probability level NS Non-significant**

fig 1

Some crop-water production functions (CWPF) were performed in relation to different levels of K fertilization. The following are the description of each function.

1. De Wit (1958) model:

The CWPF's of corn were performed according to the following equation(De Wit, 1958):

$$Ya = K^*(ETa / ETp) \qquad (3)$$

The results clearly indicated a good correlation between seasonal Evapotranspiration and grain yield (Table, 4). The equation is linear and the slope (K) is representing the water response factor, it represent the increase in grain yield per unit increase in relative Evapotranspiration (ETa/ETp). The results indicated that K values were increased as a result of increasing K fertilization level .It means that increasing K fertilization resulted in increasing the water utilization in the root zone (Abdel-Nasser and Hussein, 2001). The determination coefficient ranged between 0.8175** and 0.9202**

Table 4: The De Wit (1958) crop water production function

K rates Kg K_2O / fed	Equations	R^2
0	Ya = 2414.2* (ETa /ETp)	0.8175**
15	Ya = 2585.6* (ETa /ETp)	0.8806**
30	Ya = 2727.3* (ETa /ETp)	0.9042**
60	Ya = 2859.2* (ETa /ETp)	0.9202**

**** highly significant at 1% probability level**

2- Jensen (1968)model:

The nonlinear model suggested by Jensen (1968) represents as follows:

$$Ya/Ym = K^*(ETa / ETp)^{\lambda} \qquad (4)$$

The λ value is called a stress exponent, it is equivalent to the elasticity of relative grain yield (Ya/Ym) with respect to the relative water use (ETa/ETp). The Jensen model has a good fitting of data and the determination coefficient ranged between 0.8533** and 0.9259** (Table, 5).

The physical significance of $\lambda > 0$ is that for a given level of stress (ETa/ETp), the greater stress exponent the greater the reduction of grain yield. If $\lambda < 0$, the yield increases with increasing stress. Under normal conditions it is impossible to increase crop yield by decreasing the water available to crop in the root zone. Decreasing the amount of water in the plant root zone following excessive water can increase crop production. Then, decreasing the amount of water in the root zone improves aeration and crop yield response. Normally the stress exponent λ must exclude $\lambda < 0$ in order to have physical meaning.

Table (5). The Jensen (1968) crop water production function.

K rates Kg K_2O / fed	Equations	R^2
0	$Ya/Ym = 1.3767^* (ETa/ETp)^{1.1115}$	0.8533^{**}
15	$Ya/Ym = 1.4209^* (ETa/ETp)^{1.0724}$	0.9003^{**}
30	$Ya/Ym = 1.4396^* (ETa/ETp)^{1.1042}$	0.9238^{**}
60	$Ya/Ym = 1.3767^* (ETa/ETp)^{1.0467}$	0.9259^{**}

The Jensen model has not been widely used, but Lorber and Haith (1981) applied it to describe the response of corn grain yield to irrigation.

3- Penman (1970)model:

For many crops where water is the principal limiting factor, a linear relationship exist between grain yield (Ya) and total seasonal ET.

$$Ya = K * ETa + C \qquad (5)$$

where K is the grain yield increase per 1 mm of ETa .

The present results have given evidence to support this model as indicated by high determination coefficients (Table, 6).

Table (6). The Penman (1970) crop water production function

K rates Kg K_2O / fed	Equations	R^2
0	$Ya = 2.9751*ETa – 90.014$	0.8199^{**}
15	$Ya = 3.1255*ETa – 60.617$	0.8817^{**}
30	$Ya = 3.4300*ETa – 133.9$	0.9091^{**}
60	$Ya = 3.3695*ETa – 18.884$	0.9203^{**}

Several studies have been support this model for a wide range of crops and locations, e.g. wheat (Stewart and Hagan, 1973), barley (Hanks, 1983), grain sorghum (Hanks *et al.*, 1969; Stewart and Hagan, 1973), and both corn grain and dry matter yield (Stewart *et al.*, 1977). The response of yield per unit of ETa has sometimes been found to fall when ETa becomes large. Plant growth is closely linked to the transpiration (T) component of ET, but the soil evaporation component (E) has only an indirect influence (Sinclair *et al.*, 1983). However, T is difficult to determine accurately under field conditions. In most other studies (e.g., Hanks *et al.*, 1969; Stewart *et al.*, 1977; Musick and Dusek, 1980; Stegman and Lemert, 1981 and Sammis, 1981), the two component did not separated, and yield was regressed directly on ET.

4- Hanks(1974) model:

Hanks (1974) suggested the following equation:

$$Ya/Ym = K_y *(ETa/ETp) \quad (6)$$

The K_y coefficients of different K fertilization rates were calculated by least square method and presented in Table (7). The K_y values were increased as K fertilization increased. This is true because K_y value express the water utilization efficiency (WUE) to produce the grain yield. The K_y can be regressed on K rates (K) and the following equation was obtained :

$$K_y = -8.8E\text{-}06 * K^2 + 0.0024 *K +1.3226 \quad (R^2 = 0.9127^{**}) \quad (7)$$

The present model has a good fitting, where the determination coefficient ranged between 0.8175^{**} and 0.9202^{**} (Table, 7).

Table (7). The Hanks (1974) crop water production function

K rates Kg K_2O / fed	Equations	R^2
0	Ya/Ym = 1.3152*(ETa / ETp)	0.8175^{**}
15	Ya/Ym = 1.3765*(ETa / ETp)	0.8806^{**}
30	Ya/Ym = 1.3723*(ETa / ETp)	0.9042^{**}
60	Ya/Ym = 1.4390*(ETa / ETp)	0.9202^{**}

5- Stewart *et al*.(1977) model:

The Stewart model (Stewart *et al.*, 1977) incorporates a linear relationship between relative yield reduction and relative ET deficit (crop water stress index):

$$(1 – Ya/Ym) = b *(1 – ETa / ETp) \quad (8)$$

The value of b gives the ratio of the fractional decrease in grain yield to the fractional ET deficit.

Stewart model was failed to describe the relationship between cumulative water use and actual grain yield, where the R^2 is no significant (Table, 8).

Table (8). The Stewart *et al*. (1977) crop water production function

K rates Kg K_2O / fed	Equations	R^2
0	1- Ya/Ym = 0.4735 *(1- ETa / ETp)	0.4462^{NS}
15	1- Ya/Ym = 0.4077 *(1- ETa / ETp)	0.4130^{NS}
30	1- Ya/Ym = 0.4483 *(1- ETa / ETp)	0.4503^{NS}
60	1- Ya/Ym = 0.3744 *(1- ETa / ETp)	0.3929^{NS}

A transformation of equation (8) to express relative yield (Ya/Ym) in terms of relative Evapotranspiration (ETa / ETp) was performed :

$$Ya/Ym = b^* (ETa/ ETp) + a \quad (9)$$

The data presented in Table (9) describe this relationship and presented the determination coefficients of these equations. This model has a good fitting to data in which they have high R^2 values.

Table (9). The modified Stewart crop water production function

K rates Kg K_2O / fed	Equations	R^2
0	Ya/Ym = 1.3902 *(ETa / ETp) – 0.049	0.8199**
15	Ya/Ym = 1.4271 *(ETa / ETp) – 0.0323	0.8817**
30	Ya/Ym = 1.4803 *(ETa / ETp) – 0.0674	0.9091**
60	Ya/Ym = 1.4545 *(ETa / ETp) – 0.0095	0.9203**

Hanks (1983) considered that values for b of 1.0 or less could not be physically correct as they implied growth without ET. Values of b, which are less than 1.0, imply the crop is insensitive to drought as the relative yield reduction is less than the relative ET deficit. Doorenbos and Kassam (1979) published values of b which were < 1.0 for many crops.

The values of b were increased according to the increase in K fertilization rate (Table, 9). The b values can be regressed on K rates (K) and the following equation was obtained:

$$b = -6E\text{-}05 * K^2 + 0.0045 *K + 1.3853 \quad (R^2 = 0.9332^*) \quad (10)$$

6- Helweg(1991) model :

The quadratic polynomial function of Helweg (1991) can be used for economical analysis and is also simple and mathematical well behaved. It has the form:

$$Ya = b_0 + b_1 * X + b_2 *X^2 \quad (11)$$

Where X is the actual evapotranspiration (ETa) and b_0, b_1 and b_2 are polynomial coefficients.

Fitting the present data to the polynomial function for the different rates of K fertilization are presented in Table (10). The results clearly indicate a good fitting of data to this model in which, it has a high determination coefficients ranging from 0.9084** to 0.9646** (Fig. 2).

Fig 2

Table (10). The Helweg (1991) crop water production function

K rates Kg K_2O / fed	Equations	R^2
0	$Ya = -0.0188*ETa^2 + 23.195*ETa - 5448.5$	0.9084^{**}
15	$Ya = -0.0145*ETa^2 + 18.501*ETa - 4079.5$	0.9332^{**}
30	$Ya = -0.0101*ETa^2 + 13.942*ETa - 2814.3$	0.9287^{**}
60	$Ya = -0.0149*ETa^2 + 18.619*ETa - 3852.6$	0.9646^{**}

Previously, Craig *et al.* (1981) used the polynomial function to describe the relation between seasonal Evapotranspiration and barley grain yield. They found a good fitting of data to this model.

7- Gaussian model:

The present data is fitted to the Gaussian model, Curve Expert Version 1.37 (Microsoft Corporation, 1993). The mathematical form is:

$$Ya = a * EXP(-(ETa - b)^2/(2c^2)) \quad (12)$$

where EXP is a natural logarithm and a, b and c is constants.

This model has highest determination coefficients than other models. The values of constants, a, b and c are presented in Table (11) and Fig. (3).

Table (11). The Gaussian model (Microsoft Corporation, 1993) crop water production function

K rates Kg K_2O / fed	a Maximum yield	b Optimum water use	c	R^2
0	1721.4	610.9	187.2	0.954^{**}
15	1819.3	617.9	206.4	0.970^{**}
30	1924.6	639.8	237.9	0.965^{**}
60	1950.8	603.8	212.3	0.983^{**}

The physical meaning of these constants can be expressed as constant (a) represents the maximum yield, while the constant (b) represents the actual evapotranspiration at maximum yield (Table, 11). The values of a and b constants can be regressed on the K fertilization rate. The following equation can be obtained:

$$a = -0.0879*K^2 + 9.2225*K + 1715.8 \ (R^2 = 0.9883^{**}) \quad (13)$$

$$b = -0.0298*K^2 + 1.7432*K + 607.5 \ (R^2 = 0.8062^{*}) \quad (14)$$

8- Exponential model:

The proposed exponential model to describe the present data has the following form:

$$Ya = a * EXP(b*ETa/ETp) \quad (15)$$

Fig 3

The present data were fitted on the Exponential model and the results are presented in Table (12). The results indicate a good fitting of data on this model, where the determination coefficients have high values.

Table (12). The crop water production function (Exponential model).

K rates Kg K_2O / fed	Equations	R^2
0	Ya = 494.84 * EXP (1.7592*(ETa / ETp))	0.8270**
15	Ya = 542.75 * EXP (1.7289*(ETa / ETp))	0.8793**
30	Ya = 537.91 * EXP (1.8307*(ETa / ETp))	0.9093**
60	Ya = 593.33 * EXP (1.7519*(ETa / ETp))	0.9044**

9- Linear model:

The linear model has the form:

$$Ya = a * ETa \qquad (16)$$

Table (13) presents the slope (a) and the determination coefficient (R^2) for fitting the present data on this model. The data have a good fitting on this model for the different K fertilization rates. The determination coefficients ranged from 0.8175** to 0.9202**

Table (13). The crop water production function (Linear model)

K rates Kg K_2O / fed	Equations	R^2
0	Ya = 2.8148 * ETa	0.8175**
15	Ya = 3.0146 * ETa	0.8806**
30	Ya = 3.1798 * ETa	0.904**
60	Ya = 3.3336 * ETa	0.9202**

10- Logarithmic model:

The proposed logarithmic model has the following form :

$$Ya = a * Ln (ETa/ETp) + b \qquad (17)$$

The b value represents the yield at ETa = ETp and the a value represents the yield increase per unit of (ETa/ETp). The model has high values of determination coefficients which ranged from 0.8437** to 0.9380** (Table, 14).

The comparison for the accuracy of the predicted yield responses from each model was examined by calculating the determination coefficient. Accordingly, the Gaussian and polynomial models have the highest values of R^2. It is account as 0.9680** and 0.9337**, respectively. The Jensen and Logarithmic models have the same values of R^2, 0.9008** and 0.9003**, respectively. Likewise the Penman and modified Stewart models have the same values, 0.8828**. The De Wit, Linear, Exponential and Hanks have approximately the same values, 0.8006**, while the Stewart model has the lowest R^2 value, 0.4255^{ns}.

Table (14). The crop water production function (Logarithmic model)

K rates Kg K_2O / fed	Equations	R^2
0	Ya = 1610.0*Ln ETa + 2274.2	0.8437**
15	Ya = 1660.0*Ln ETa + 2407.7	0.8998**
30	Ya = 1770.4*Ln ETa + 2549.9	0.9196**
60	Ya = 1722.8*Ln ETa + 2610.2	0.9380**

As illustrated by Abdel-Nasser and Hussein (2001), K-fertilization significantly decreased the water use by corn plants. This result may be attributed to the role of K in improving the plant water status, thus decreasing water absorption or decreased the transpired water by plants. The grain yield (Kg/fed) of corn can be predicted from the combined effect of seasonal water use(mm/season) and K fertilization rates(Kg K_2O /fed) as follows:

$$Y = 3.20*ETa + 4.59*K - 186.52 \quad (R^2 = 0.878^{**}) \qquad (18)$$

It is clear that K fertilization has an important role in increasing the grain yield of corn through improving the plant water status and decreasing the water consumptive use. These conditions led to improving the water utilization by plants or by other meaning, increasing the crop-water production. The present results are very important especially in regions have limited water resources (arid and semi-arid regions).

Therefore, the water production functions are required for water management and the design of irrigation systems. The level of water applied has a number of effects on the design of irrigation systems. Water management variable such as irrigation frequency, time of irrigation, and water allocation are important in the design of irrigation systems. Likewise, for many irrigation projects, water becomes a limiting factor for development; proper water management would maximize the water use efficiency of the irrigated crops.

The present results support the hypothesis that K fertilization can improve the water utilization by plants. Therefore, more study is needed to explain the role of fertilization in the shape of crop-water production function as related to rate and frequency of fertilizer application.

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استجابة الذرة للتسميد البوتاسي تحت ظروف رطوبة مختلفة:
٢ – دوال إنتاجية المياه : مقارنة بعض النماذج

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أجريت تجربة حقلية خلال موسم النمو ١٩٩٨ للذرة صنف هجين ٣١٠ ، الهدف الأساسي من هذه الدراسة هو مقارنة مجموعة من دوال إنتاجية المياه للذرة وبيان تأثير مستويات التسميد البوتاسي على هذه الدوال . تم الري عندما وصلت رطوبة التربة في منطقة انتشار الجذور إلى ٢٠ ، ٤٠ ، ٦٠ ، ٨٠% من الماء الميسر وأضيف السماد البوتاسي بمعدلات صفر ، ١٥ ، ٣٠ ، ٦٠ كجم بو٢أ/فدان في صورة سلفات بوتاسيوم (٤٨% بو٢أ) . وقد كانت التربة المستخدمة ذات قوام طيني . رتبت المعاملات في تصميم القطع المنشقة في أربعة مكررات . دوال إنتاجية المياه المستخدمة في هذه الدراسة هي :

DeWit (1958), Jensen (1968), Penman (1970), Hanks (1974), Stewart *et al*. (1977), Helweg (1991), Gaussian model, Microsoft Corporation (1993), Exponential model, Linear and Logarithmic models.

تم دراسة مقارنة دقة هذه النماذج للتنبؤ بالمحصول واستجابته للماء المستهلك . وطبقا لهذه المقارنة فإن نموذج جاوس والمعادلة متعددة الحدود من الدرجة الثانية كان لهما أعلى قيم لمعامل التقدير (**٠,٩٦٨٠ ، و** ٠,٩٣٣٧) على التوالي . أما نماذج جنسن واللوغاريتمي فكان لهما نفس معامل التقدير (**٠,٩٠٠٨، و** ٠,٩٠٠٣) على التوالي . في نفس الوقت فإن نماذج بنمان ونموذج ستيوارت المعدل كان لها أيضا نفس قيم معامل التقدير (**٠,٨٨٢٨) . أما نماذج دي ويت ، الخطي ، الأسي وهانكس كان لها تقريبا نفس قيمة معامل التقدير (٠,٨٠٠٦) بينما نموذج سيتوارت كان له أقل معامل تقدير (٠,٤٢٥٥) وهو غير معنوي . كما أن الدراسة الحالية تؤيد النظرية التي توضح تأثير التسميد البوتاسي على زيادة الكفاءة الاستعمالية للماء وتقليل كمية الماء المستهلك لهذا فإنه لابد من إجراء دراسات أخرى لتوضيح دور التسميد على شكل وسلوك دوال إنتاجية المياه مع الأخذ في الاعتبار معدلات ومرات إضافة الأسمدة .