

## INFLUENCE OF IRRIGATION INTERVAL AND POTASSIUM FERTILIZATION ON WATER PRODUCTIVITY OF SESAME *Sesamum indicum* L. UNDER SULAYMANIYA CONDITIONS

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### ABSTRACT

This study was performed to test the influence of irrigation interval under different levels of potassium fertilization on water productivity of sesame (*Sesamum indicum* L.) crop for two growing seasons (2011 and 2012) under Sulaimaniya conditions. The main objective of this study was to select the appropriate irrigation interval and irrigation requirements to acceptable values so that maximum water saving can be achieved with minimum yield lost. Also, the role of K fertilizer in reducing water stress with the increase of the time of irrigation periods. Some empirical models (linear, parabolic, exponential and power function) were used to evaluate the crop responses to irrigation quantity and/or actual ET ( $ET_a$ ). Completely Randomized Block Design was used in this experiment. The treatments (main plots) were six irrigation intervals (namely; 5, 10, 15, 20, 25, and 30 days), with three replications. Potassium fertilizer levels (namely; 0, 100, 200 and 300 kg K ha<sup>-1</sup>) were implemented in subplots. Water was applied to plants by using drip irrigation system of 1.2 liters/hr per dripper. Seeds weight and actual evapotranspiration ( $ET_a$ ) were used to fit some water productivity functions for the different treatments. The results showed that both seeds yield and  $ET_a$  parameters decreased with the increase in irrigation interval due to water deficiency and hence water productivity was affected. Application of K fertilizers minimized the influence of water stress on both parameters. The irrigation interval of 20 days and K fertilizer level of 300 kg ha<sup>-1</sup> seemed to be the most wisely selection for sesame crop under Sulaimaniya conditions. The percent of seeds yield decreased with the increase of irrigation interval and this percent of decrease was generally reduced with the increase of K application levels. For example using 20 days as irrigation interval (in comparison with 5-day interval) has saved nearly 70% of irrigation water while the reduction in yield was 16.2% for no K application and this was reduced to only 6.6% for the 300 kg K ha<sup>-1</sup> K level. In terms of the goodness of water productivity functions, the power function model proves superiority over the other models followed by parabolic model and then the exponential model. The weakest model was that of Stewart et al. (29), the linear model. This is because of the fact that the relationship between the yield and ET is not linear which what this model is.

### INTRODUCTION

The crop water production function (CWP function) expresses the relation between obtained marketable yield ( $Y_a$ ) and the total amount of water evapotranspired ( $ET_a$ ) (10, 19, 29, 30). The highest water efficiency level in the CWP function is determined using WP as a benchmark. The CWP function has a logistic shape. Its axes are made dimensionless by plotting relative yield ( $Y_{rel}$ : ratio of actual,  $Y_a$ , to maximum possible yield under given agronomic conditions,  $Y_m$ ) versus relative ET ( $ET_{rel}$ : ratio of actual ET,  $ET_a$ , to crop ET under non-

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Part of M.Sc. thesis for the second author.

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stressed, standard conditions, ET<sub>m</sub>). Water productivity is dependent on several factors, including crop genetic material, water management practices, agronomic practices and the economic and policy incentives to produce corresponding to this, there are many people working in parallel on means to increase the productivity of water but the effort remains disjointed. Part of the reason is that we do not have a common conceptual framework for communicating about water productivity.

Crop production functions are mathematical relationship between yield and production factors as inputs and use these functions to estimate crop production (18). In other words, the crop production function identifies the conversion rate of input to output. The statistical data obtained from field observations or controlled experimental design can be used to estimate of production functions (23). Overall form of the crop production function can be written as follows:

$$Y = F(X_1, X_2, \dots, X_n) \quad \dots\dots\dots (1)$$

This equation shows the amount of production determined by different amounts of inputs (n). Production factors can be classified in different ways. Some factors are variables and some others are fixed. Some of the factors are very important and some others not significant. The crop production function is usually estimated based on a few variable factors under control. Using the estimated production function can be defined different scenarios based on user-defined. The amount of yield in different levels of inputs used to crop production function, marginal production, the final value of each of the factors of production and marginal rate of technical substitution factors could be calculated (21).

Crop water productivity (WP) or water use efficiency (WUE), as reviewed by Molden and Rijsberman (25), is a key term in the evaluation of deficit irrigation (DI) strategies. Water productivity with dimensions of kg m<sup>-3</sup> is defined as the ratio of the mass of marketable yield (Y<sub>a</sub>) to the volume of water consumed by the crop (ET<sub>a</sub>):

$$WP = Y_a / ET_a \quad \dots\dots\dots (2)$$

ET<sub>a</sub> refers to water lost either by soil evaporation or by crop transpiration during the crop cycle. Since there is no easy way of distinguishing between these two processes in field experiments, they are generally combined under the term of evapotranspiration, ET (2).

Determining optimal timing of irrigation applications is particularly difficult for crops with CWP functions in which maximal WP is found within a small optimum range of ET. Irrigators should have unrestricted access to irrigation water during sensitive growth stages. This is not always the case in large block designs (31) or during periods of water shortage; a minimum quantity of irrigation water should always be available for application (14, 17, 20, 32). This is not always possible in extremely dry regions where irrigation water is scarce (11).

In some areas, water markets and other financial incentives might be implemented to encourage farmers to implement DI strategies that will enhance communal production values. Reasons for increased water productivity under deficit irrigation can be attributed to the following reasons: water loss through evaporation is reduced; the negative effect of drought stress during specific

phenological stages on biomass partitioning between reproductive and vegetative biomass (harvest index) (14, 19, 27). Past studies have also shown that yield relationships based on water consumption or ET are often linear this implies that the marginal productivity of the water is constant and deficit irrigation may be no more productive per unit water consumed than full irrigation. If this is the case, where deep percolation and runoff losses can be reused and have value, full irrigation on a reduced irrigated area may provide higher economic returns for the watershed. Increasing the productivity of water in agriculture will play a vital role in easing competition for scarce resources, prevention of environmental degradation and provision of food security. The argument for this statement is simple: by growing more food with less water, more water will be available for other natural and human uses (25, 28). Increasing productivity of water is particularly important where water is a scarce resource (25).

The expression of crop water productivity is most often given in terms of mass of produce, or monetary value, per unit of water. Depending on how the terms in the numerator and denominator are expressed, water productivity can be expressed in general physical or economic terms.

The four physical levels of crop water productivity defined are expressed by the following equations (1, 24):

$$CWP_{Y-Ig} = C. (Y/I_g) \quad \dots\dots\dots (3)$$

$$CWP_{Y-Irr} = C. (Y/I_{rr}) \quad \dots\dots\dots (4)$$

$$CWP_{Y-ET_{act}} = C. (Y/ET_{act}) \quad \dots\dots\dots (5)$$

$$CWP_{Y-Ta} = C. (Y/T_a) \quad \dots\dots\dots (6)$$

Where : CWP is the crop water productivity ( $kg\ m^{-3}$ ), Y is the actual yield ( $kg\ ha^{-1}$ ),  $I_g$  is the difference of gross inflow and storage in the water balance equation (mm),  $I_{rr}$  is the irrigation requirements water (mm),  $ET_a$  is the actual ET (mm),  $T_a$  is the transpiration alone (mm) and C is the conversion factor, 0.10 ( $ha\ mm\ m^{-3}$ ). When considering CWP relation from a physical point of view, one should consider transpiration only. The partitioning of ET in evaporation and transpiration in field experiments is, however, difficult and therefore not a practical solution. Moreover, evaporation is always a component related to crop specific growth, tillage and water management practices. This water is no longer available for other use or reuse in the basin. Since ET is based on root water uptake, supplies from rainfall, irrigation and capillary rise are integrated. Therefore, CWP ( $kg\ m^{-3}$ ) efficiency is defined as the crop yield over actual ET.

Production functions governing the transformation of water into agricultural yields are difficult to establish. In a large review of literature, Zwart and Bastiaanssen (33) investigated the crop water productivity, defined as the marketable crop yield over actual ET ( $ET_a$ ) for four crops in a large number of situations. In areas where water is the most limiting factor, maximizing WP may be economically more profitable for the farmer than maximizing yields (12). Field observations indicate that crops under serious drought stress during the season might still produce reasonable yields when only a small amount of fertilizer is applied. Fox and Rockstroim (15, 16) reported that combining DI and optimum fertilizer application leads to a higher yield increase (higher WP) than the sum of the separate yield increases obtained by both factors.

This study was performed to test the influence of irrigation interval under different levels of potassium fertilization on water productivity of sesame (*Sesamum indicum* L.) crop.

## MATERIALS AND METHODS

A field experiments was carried out during two successive seasons 2011 and 2012 at the Experimental Farm of the Faculty of Agricultural Sciences-University of Sulamaniya, to study the influence of irrigation scheduling and potassium fertilization on water use efficiency of sesame (*Sesamum indicum* L.). The study area is located in southwestern of Sulaimaniya city (35° 33' N, 45 27 E on altitude of approximately 752 m above sea level. The climate of the region is semi-arid of Mediterranean type: winter is mild and not long followed by hot and dry long summer. Mean annual precipitation is about 680 mm mostly rainfall. The soil texture of the field is silty clay loam. Physical and chemical properties of soil were determined (22, 26), and the results are presented in Table (1). Primary and secondary tillage were carried out with moldboard plough and rotivator, respectively. Nitrogen fertilizer was applied as urea (46%N) at rate of 200 kg N ha<sup>-1</sup> in band application. The quantity of N-fertilizer divided into two halves, the first half was at sowing and the second half was at plant height of about 30 cm. Phosphorus fertilizer was also applied before planting as total soluble phosphate (48% P<sub>2</sub>O<sub>5</sub>) at rate of 200 Pha<sup>-1</sup>. The experiment was designed according to split-plots design within factorial experiment of three replicates. Irrigation *interval* treatments (5, 10, 15, 20, 25, 30 days) were implemented in the main plots and conducted with split plot design and four levels of potassium treatments (0, 100, 200 and 300 kg K ha<sup>-1</sup>) were implemented in subplots. Each main plot consisted of four subplots with 2.4 meters length by 2 meters width. Each subplot consisted of four rows, 2.4 meters long, 0.5 meter apart, and 0.3 meter within plants in the row. The crop was seeded on May 11, 2011, for the summer cultivation. The length of the growing season was 105 days from emergence on May 14 to maturity on August 25, 2011. Schedule of irrigation requirement is show in Table (2). Same experiment repeated on May 10, 2012 the schedule of irrigation requirement is show in Table (3) and the length of the growing season was 110 days as average from emergence on May 14 to maturity on August 30, 2012. Drip irrigation system was used for irrigation. The discharge of the dripper was 1.2 L hr<sup>-1</sup> and the volume of water added to each experimental plot was calculated by the following equation (8):

$$V = (d_n * A * \%w) * 1000 = a d_n * 1000 \quad \text{..... (7)}$$

$$d_n = (FC - WP / 100) ( \rho_b / \rho_w ) * D * \% \text{ wetted area} \quad \text{..... (8)}$$

$$\% \text{ wetted area} = [(w_d * x * n) / A] * 100 \quad \text{..... (9)}$$

Where: V = volume of water added for each plot (L); d<sub>n</sub> = depth of water added (m); FC = moisture content at field capacity (%); WP = moisture content at wilting point (%); ρ<sub>b</sub> = soil bulk density (Mg/m<sup>3</sup>); ρ<sub>w</sub> = water density (Mg/m<sup>3</sup>); D = depth of soil that must be wetted (m); w<sub>d</sub> = wetted diameter of the dripper = 0.30 m; w = the length of land wetted (m); n = number of planted rows in each plot=3; a = wetted area. A = area of each plot (4.8 m<sup>2</sup>).

Water requirements for sesame can be calculated directly by using water balance equation according to this equation (9):

$$(I + P + C) - (ET_a + D + R) = \pm \Delta S \quad \text{..... (10)}$$

Where: I = irrigation water added (mm); P= precipitation (mm); C= upward movement of water by capillarity (mm);  $ET_a$ = actual evapotranspiration (mm); D= deep percolation (mm); R= surface runoff (mm);  $\Delta S$ = Difference in soil moisture storage at the beginning and end of season. For: R= 0 (because the land is nearly level and runoff is almost zero); C= 0 (because the ground water table is deep, more than 3 m); D= 0 (because the water was added according to the equation (10) and there was no surplus water to go deeper). So equation (10) will be reduced to:

$$I + P = ET_a \pm \Delta S \quad \dots\dots\dots (11)$$

Because each term of I, P, and  $\Delta S$  can be measured easily,  $ET_a$  can be computed by using Eq. (11).

**Table 1: Physical and chemical properties of the study soil**

| Property                             | Unit                             | Value           |
|--------------------------------------|----------------------------------|-----------------|
| Sand                                 | g/kg                             | 187.5           |
| Silt                                 | g/kg                             | 476.5           |
| Clay                                 | g/kg                             | 336.0           |
| Soil Texture                         |                                  | Silty clay Loam |
| Organic Matter content               | g/kg                             | 20.5            |
| Bulk Density (0-30 cm)               | Mg/m <sup>3</sup>                | 1.29            |
| Bulk Density (30-60 cm)              | Mg/m <sup>3</sup>                | 1.35            |
| Volumetric water content at 33 Kpa   | cm <sup>3</sup> /cm <sup>3</sup> | 0.305           |
| Volumetric water content at 1500 Kpa | cm <sup>3</sup> /cm <sup>3</sup> | 0.162           |
| Available water                      | cm <sup>3</sup> /cm <sup>3</sup> | 0.143           |
| Hydraulic conductivity               | cm/hr                            | 5.9             |
| pH                                   |                                  | 7.84            |
| ECe                                  | dS/m                             | 0.47            |
| Cl <sup>-</sup>                      | meq/l                            | 0.169           |
| CaCO <sub>3</sub>                    | g/kg                             | 38.33           |
| Na <sup>+</sup>                      | meq/l                            | 0.9             |
| K <sup>+</sup>                       | meq/l                            | 0.21            |
| Ca <sup>2+</sup>                     | meq/l                            | 6.37            |
| Mg <sup>2+</sup>                     | meq/l                            | 0.51            |
| HCO <sub>3</sub> <sup>-</sup>        | meq/l                            | 6.26            |
| CO <sub>3</sub> <sup>2-</sup>        | meq/l                            | 0.00            |

**Table 2: Water requirement for each treatment during spring season 2011**

| Treatment | Irrigation interval (days) | Number of Irrigations | Water Requirement (mm) |
|-----------|----------------------------|-----------------------|------------------------|
| I1        | 5                          | 19                    | 812.71                 |
| I2        | 10                         | 9                     | 475.44                 |
| I3        | 15                         | 6                     | 364.27                 |
| I4        | 20                         | 4                     | 251.61                 |
| I5        | 25                         | 3                     | 194.58                 |
| I6        | 30                         | 3                     | 187.03                 |

**Table 3: Water requirement for each treatment during spring season 2012**

| Treatment | Irrigation interval (days) | Number of Irrigations | Water Requirement (mm) |
|-----------|----------------------------|-----------------------|------------------------|
| I1        | 5                          | 20                    | 824.07                 |
| I2        | 10                         | 9                     | 410.62                 |
| I3        | 15                         | 6                     | 303.3                  |
| I4        | 20                         | 4                     | 201.35                 |
| I5        | 25                         | 3                     | 196.94                 |
| I6        | 30                         | 3                     | 161.67                 |

## RESULTS AND DISCUSSION

### Seeds yield and actual evapotranspiration

Tables (4) showed the seeds yield as results of applying different quantities of irrigation quantities ( $ET_a$ ), respectively, at different K fertilizer applications.

Increasing the irrigation interval and hence lowering the irrigation quantity (low  $ET_a$ ) resulted in a significant low seeds yield. Aoda and Mahmood (4,5) concluded that even there was a decrease in yield for the intervals up to 20 days but this decrease was acceptable for the sake of water saving and suggested that the 20 days interval be most wisely interval for irrigating sesame crop under Sulaimaniya conditions. Data in Tables (4) and (5) were used to fit the crop water productivity functions used in this article.

**Table 4: Seed dry weight ( $\text{kg ha}^{-1}$ ) at maturity as influenced by irrigation intervals and K applications, for year 2011(1<sup>st</sup> row data) and 2012 (2<sup>nd</sup> row data)**

| Row data                                     |           |                          |                            |                            |                            |                                              |                               |
|----------------------------------------------|-----------|--------------------------|----------------------------|----------------------------|----------------------------|----------------------------------------------|-------------------------------|
| Irrigation Intervals<br>(I)                  | ETa<br>mm | Potassium Levels (K)     |                            |                            |                            | Avg.<br>Seed yield<br>(kg ha <sup>-1</sup> ) | LSD<br>(P≤0.05)<br>for<br>(I) |
|                                              |           | 0<br>kg ha <sup>-1</sup> | 100<br>kg ha <sup>-1</sup> | 200<br>kg ha <sup>-1</sup> | 300<br>kg ha <sup>-1</sup> |                                              |                               |
| 5 days                                       | 812.71    | 195.7                    | 254.3                      | 351.7                      | 402.0                      | 300.9                                        | 2.90<br>1.84                  |
|                                              | 824.07    | 264.3                    | 352.3                      | 456.0                      | 552.7                      | 406.3                                        |                               |
| 10 days                                      | 475.44    | 187.0                    | 244.0                      | 346.3                      | 396.3                      | 293.4                                        |                               |
|                                              | 410.62    | 252.3                    | 343.0                      | 442.3                      | 542.0                      | 394.9                                        |                               |
| 15 days                                      | 364.27    | 174.7                    | 235.0                      | 336.3                      | 387.0                      | 283.3                                        |                               |
|                                              | 303.30    | 242.3                    | 324.7                      | 431.0                      | 532.0                      | 382.5                                        |                               |
| 20 days                                      | 251.61    | 164.0                    | 225.0                      | 325.7                      | 375.3                      | 272.5                                        |                               |
|                                              | 201.35    | 232.3                    | 312.7                      | 423.7                      | 519.0                      | 371.9                                        |                               |
| 25 days                                      | 194.58    | 152.3                    | 207.7                      | 308.7                      | 353.0                      | 255.4                                        |                               |
|                                              | 196.94    | 215.7                    | 304.7                      | 406.0                      | 506.3                      | 358.2                                        |                               |
| 30 days                                      | 187.03    | 121.0                    | 194.0                      | 217.0                      | 323.3                      | 213.9                                        |                               |
|                                              | 161.67    | 197.7                    | 296.3                      | 387.0                      | 491.7                      | 343.2                                        |                               |
| Avg.<br>Seed yield<br>(kg ha <sup>-1</sup> ) |           | 165.8<br>234.1           | 226.7<br>322.3             | 314.3<br>424.3             | 372.8<br>523.9             | -                                            |                               |
| LSD<br>(P ≤ 0.05)<br>for (K)                 |           | 1.38<br>1.96             |                            |                            |                            |                                              |                               |
| LSD<br>(P < 0.05) for (I*K)                  |           | 3.38<br>4.79             |                            |                            |                            |                                              |                               |

### Crop water productivity functions

Some empirical models are used to evaluate the crop responses to irrigation quantity and/or actual ET ( $ET_a$ ). The linear model was first proposed by Stewart et al. (29), which can be written as the following:

$$Y_a = Y_m [1 - K_y (1 - ET_a / ET_m)] \quad \dots\dots\dots (12)$$

Where  $Y_a$  and  $Y_m$  are actual and maximum yields, respectively,  $ET_a$  and  $ET_m$  are actual and maximum evapotranspiration, respectively. This model was used by different researchers (6, 7, 13) to evaluate plant response to water under different conditions. Most of the work was done by using this model showed a very high correlation between plant production as either biological yield or seeds yield and  $ET_a$ . The linear model (Equation 8) is used in this study to show weak correlation between seeds yield ( $Y_a$ ) and  $ET_a$ . The results of the fittings seeds yield and  $ET_a$  are presented in Tables (5) and (6) for both years' data. The coefficient of determination ( $R^2$ ) is not significant for both years' fittings (range of  $R^2$  values were between 0.3532 to 0.8449 for both years). Figure (1) is a typical example of the nonlinear regression fit for the seeds yield versus actual ET along with the fitted equation (12) and the  $R^2$  value and the residual mean squares of  $Y_s$  (RMSYs). A wide variation between the experimental and the fitted line is quite obvious indicating the weakness of fit through the low non-significant values of  $R^2$  and the high values of RMSYs.

**Table 5: Fitting results of productivity functions for sesame seeds yield vs. ET<sub>a</sub> for year 2011.**

| productivity functions |                      |                | Potassium application |          |         |         |
|------------------------|----------------------|----------------|-----------------------|----------|---------|---------|
|                        |                      |                | K0                    | K100     | K200    | K300    |
| Fitted Parameters      | Linear               | Ky             | 0.3069                | 0.2167   | 0.2208  | 0.1486  |
|                        |                      | R <sup>2</sup> | 0.6346                | 0.7279   | 0.3532  | 0.5553  |
|                        |                      | RMSYs          | 264.1                 | 139.5    | 1621.5  | 396.0   |
|                        |                      | A              | 81.822                | 154.785  | 164.692 | 271.83  |
|                        | Parabola             | B              | 0.3539                | 0.299    | 0.665   | 0.4402  |
|                        |                      | C              | -0.00026              | -0.0002  | -0.0005 | -0.0003 |
|                        |                      | R <sup>2</sup> | 0.8446                | 0.9293   | 0.6016  | 0.8465  |
|                        |                      | RMSYs          | 187.2                 | 60.5     | 1648.2  | 227.8   |
|                        | Power Function       | A              | -18.006               | 1.3738   | -78.528 | 2.0268  |
|                        |                      | B              | 4.4487                | 2.5887   | 15.4172 | 4.5207  |
|                        |                      | C              | -0.223                | -0.1527  | -78.528 | -0.2711 |
|                        |                      | D              | 0.0034                | 0.0025   | 15.4172 | 0.0045  |
|                        | Exponential Function | R <sup>2</sup> | 0.8784                | 0.9674   | 0.7004  | 0.9152  |
|                        |                      | RMSYs          | 219.7                 | 41.8     | 0.0120  | 188.7   |
|                        |                      | A              | 0.00425               | 0.00366  | 0.0025  | 0.0024  |
|                        |                      | B              | -0.067960             | -0.10063 | -0.0879 | -0.1240 |
|                        |                      | R <sup>2</sup> | 0.8132                | 0.9324   | 0.5520  | 0.8376  |
|                        |                      | RMSYs          | 168.8                 | 43.3     | 1404.0  | 180.8   |

Ky= Fitted parameter of Eq.(12) (yield response factor); A, B, C, and D are fitted parameters in the indicated equations; R<sup>2</sup> is the coefficient of determination and RMSYs is the residual mean square of seeds yield [(kg ha<sup>-1</sup>)<sup>2</sup>].

**Table 6: Fitting results of productivity functions for sesame seeds yield vs. ET<sub>a</sub> for year 2012.**

| Productivity functions |                      |                | Potassium application |         |         |          |
|------------------------|----------------------|----------------|-----------------------|---------|---------|----------|
|                        |                      |                | K0                    | K100    | K200    | K300     |
| Fitted Parameters      | Linear               | Ky             | 0.2271                | 0.1682  | 0.1372  | 0.1033   |
|                        |                      | R <sup>2</sup> | 0.7297                | 0.8449  | 0.7421  | 0.7612   |
|                        |                      | RMSYs          | 161.3                 | 74.9    | 159.9   | 123.8    |
|                        |                      | A              | 158.52                | 257.82  | 350.09  | 452.59   |
|                        | Parabola             | B              | 0.3121                | 0.2559  | 0.3026  | 0.2939   |
|                        |                      | C              | -0.0002               | -0.0002 | -0.0002 | -0.0002  |
|                        |                      | R <sup>2</sup> | 0.9134                | 0.9818  | 0.9005  | 0.9482   |
|                        |                      | RMSYs          | 86.1                  | 14.6    | 102.9   | 0.9482   |
|                        | Power Function       | A              | -0.3134               | 60.202  | 38.758  | 72.946   |
|                        |                      | B              | 2.922                 | -4.846  | -0.0073 | -3.624   |
|                        |                      | C              | -0.1694               | 0.1855  | -0.0746 | 0.0771   |
|                        |                      | D              | 0.0028                | -0.0026 | 0.0016  | -0.00056 |
|                        | Exponential Function | R <sup>2</sup> | 0.9516                | 0.9853  | 0.9434  | 0.9709   |
|                        |                      | RMSYs          | 72.2                  | 17.8    | 87.9    | 37.8     |
|                        |                      | A              | 0.0035                | 0.0028  | 0.00215 | 0.0018   |
|                        |                      | B              | -0.0976               | -0.1269 | -0.1420 | -0.1635  |
|                        |                      | R <sup>2</sup> | 0.9191                | 0.9734  | 0.9285  | 0.9681   |
|                        |                      | RMSYs          | 60.4                  | 16.1    | 55.4    | 20.7     |

Ky= Fitted parameter of Eq.(12) (yield response factor); A, B, C, and D are fitted parameters in the indicated equations; R<sup>2</sup> is the coefficient of determination and RMSYs is the residual mean square of seeds yield [(kg ha<sup>-1</sup>)<sup>2</sup>].

The other models used are those proposed by Aoda and Hama (3) which are of parabolic (with simple modification), power function and exponential forms.

The parabolic model with an intercept A is of the form:

$$Y_a = A + B ET_a + C ET_a^2 \quad \dots\dots\dots (13)$$

Where A, B and C are fitted parameters. The result of fitting shows a correlation between seed yield Y and actual ET as representative quantity of irrigation. Range of values of R<sup>2</sup> were between 0.6016 to 0.9818\*\* for both years. Fitted parameters along with fitting statistics are shown in Tables (5, 6) for both years' data. Figure (2) is a typical example of the nonlinear regression fit for the seeds yield versus actual ET along with the fitted parabolic equation and the R<sup>2</sup> value and the residual Mean squares of Ys (RMSYs). A wide variation between

the experimental and the fitted line is quite obvious indicating the weakness of fit through the low non-significant values of  $R^2$  and the high values of RMSYs.

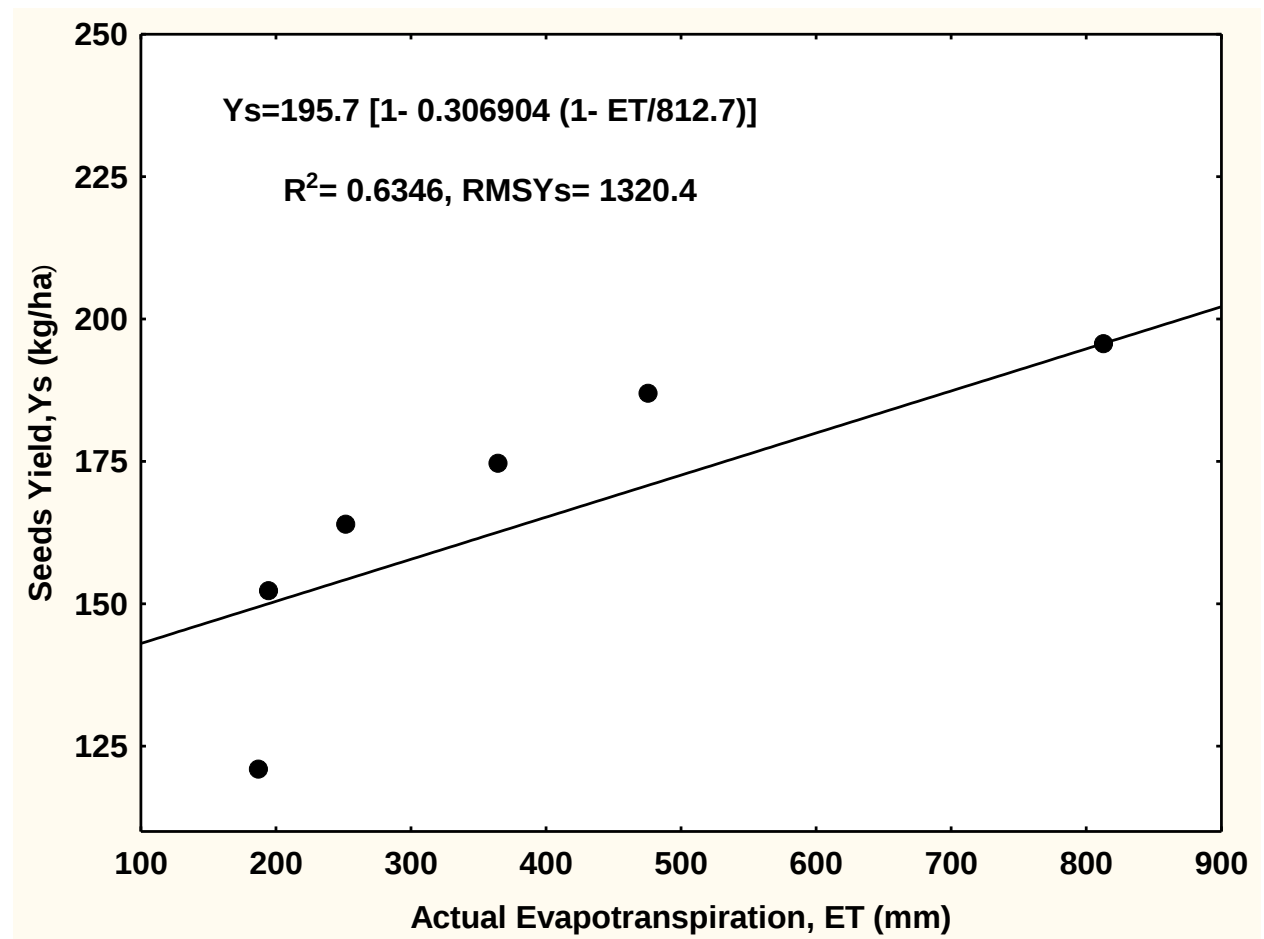


Figure 1: Fitting of seed yield versus actual ET for no K application using Eq.(12) for the year 2011.

The exponential model is of the following form:

$$Y_a = 1/A [1 - e^{BET_a^{1/2}}] \quad \dots\dots\dots (14)$$

Where A and B are fitted parameters

Result of fitting this equation to the experimental data seeds yield versus  $ET_a$  shows, in general, high correlation between seeds yield and  $ET_a$  (Tables 5 and 6). Values of  $R^2$  ranged between 0.5520 and 0.9734\*\*. The performance of this model proved to be very good but it is less than the last model in its goodness of fit. Figure (2) is a typical example of the nonlinear regression fit for the seeds yield versus actual ET along with the fitted exponential equation and the  $R^2$  value and the residual mean squares of Ys (RMSYs). Some variation between the experimental and the fitted line is obvious indicating some weakness of fit through the low non-significant values of  $R^2$  and the high values of RMSYs.

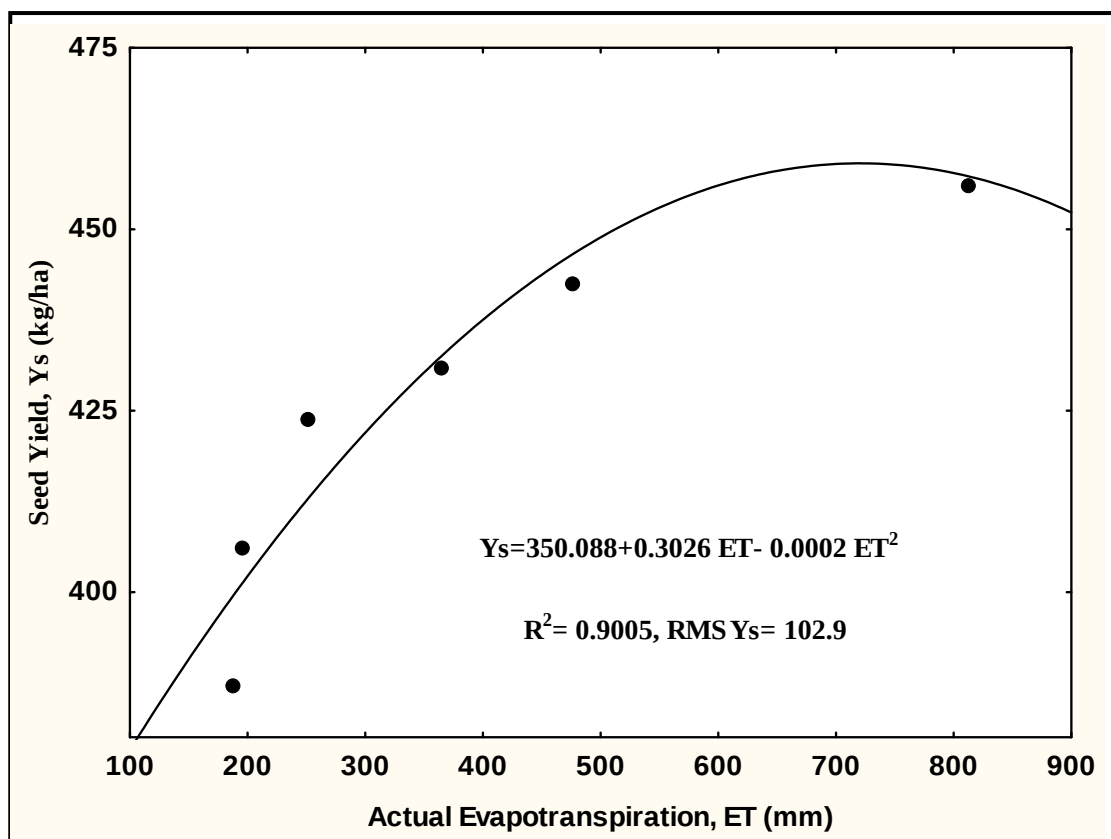


Figure 2: Fitting of seed yield versus actual ET for 200 kg ha<sup>-1</sup> K application using parabolic function, Eq. (13), for year 2012.

The power function model is of the following form:

$$Y_a = A ET_a^{1/2} + B ET_a + C ET_a^{3/2} + D ET_a^2 \dots\dots\dots (15)$$

Where A, B, C and D are all fitted parameters.

This model is constructed by starting with the first term and doing the fitting and then adding the second term and performing the fitting and so on till the last (fourth) term. As it was shown, every time a new term is added the fitting improves (having higher  $R^2$  and lower  $RMSY_a$ ). This model is superior over all tested model, it resulted in general the highest values of  $R^2$ . The range of  $R^2$  was between 0.7004 to 0.9853\*\*. Fitted parameters along with fitting statistics are shown in Tables (5, 6) for both years' data.

Figure (3) is a typical example of the nonlinear regression fit for the seeds yield versus actual ET along with the fitted power function (or polynomial) equation and the  $R^2$  value and the residual mean squares of  $Y_s$  ( $RMSY_s$ ). The variation between the experimental and the fitted line is minimal indicating the goodness of fit through the high significant values of  $R^2$  and the low values of  $RMSY_s$ .

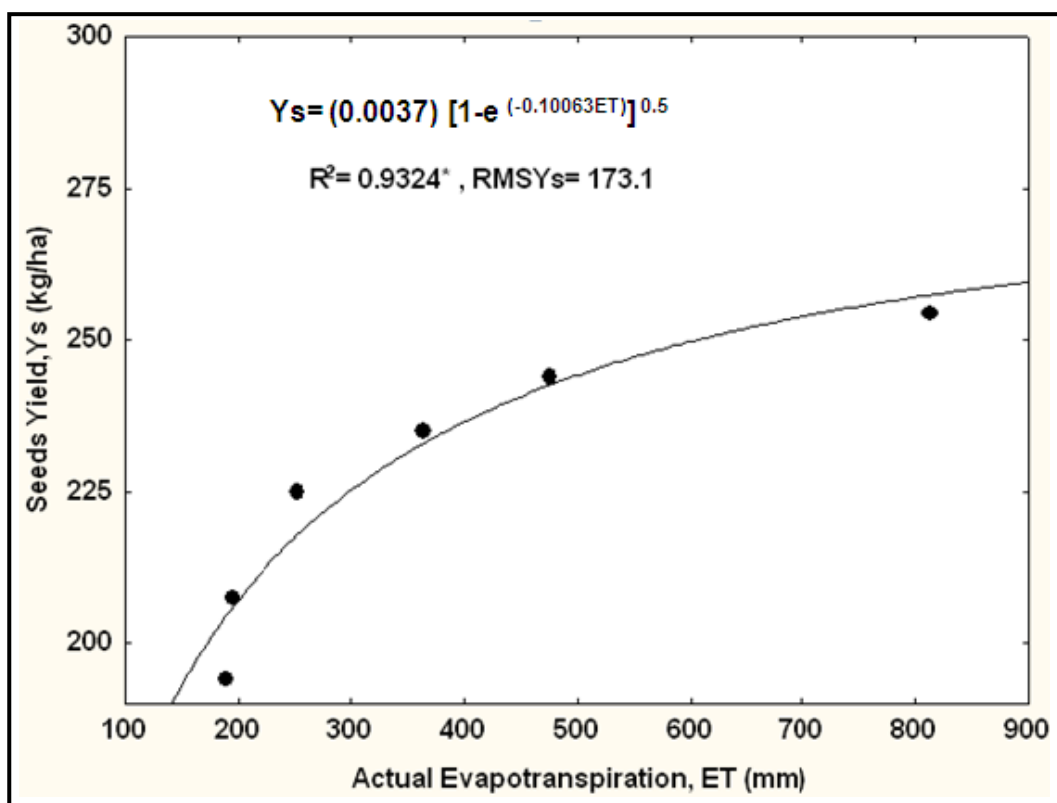


Figure 3: Fitting of seed yield versus actual ET for 100kg ha<sup>-1</sup>K application using the exponential function, Eq. (14), for the year 2011

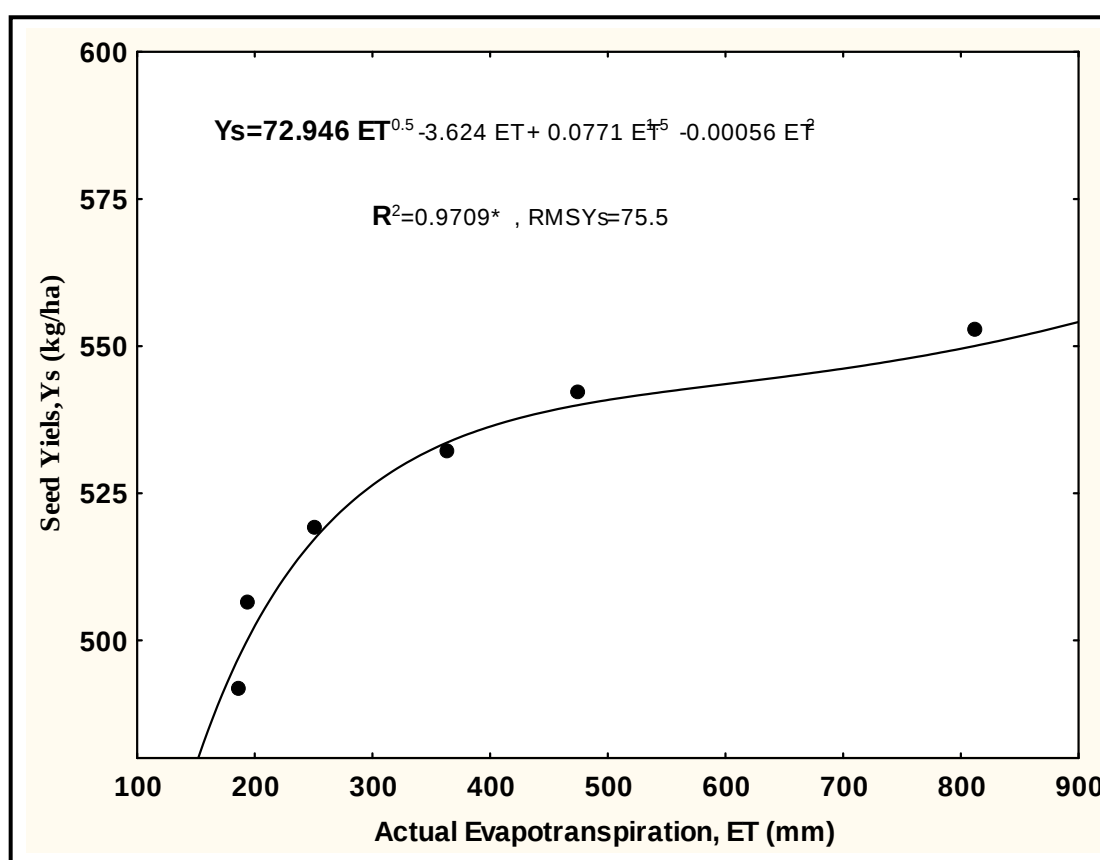


Figure 4: Fitting of seed yield versus actual ET for 300kg ha<sup>-1</sup>K application using the power function, Eq. (15), for the year 2012

It can be concluded that the power function (polynomial) model did an excellent performance. As a matter of fact, it is the best model of all {including Stewart et al. (29) model} in terms of the goodness of fit. One weakness in this model is that in comparison with the other models it has the highest number of fitted parameters (four), but this can be avoided by having a greater number of experimental data (seed yield vs.  $ET_a$ ). Results of the fitting obtained by this model are listed in Tables (5) and (6) which show that this model has the highest level of significance between yields and  $ET_a$ . It can be concluded that the power function model proves superior over the other models followed by parabolic model, and then the exponential model. The worst model was that of Stewart *et al.* (29). This is because of the fact that the relationship between the yield and  $ET$  is not linear which contradicts the linearity-type of this model.

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## تأثير مدة الري وازدانة السماد البوتاسي في انتاجية الماء لمحصول السمسم تحت ظروف محافظة السليمانية\*

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### الملخص

اجريت تجربة لفحص تأثير مدتي الري والسماد البوتاسي في انتاجية الماء لموسمين زراعيين (2011 و2012) تحت ظروف محافظة السليمانية. كان الهدف الرئيس لهذه الدراسة هو اختيار مدة ومتطلبات الري بشكل مقبول وبما يحقق اعلى توفيراً في المياه مع اقل خسارة في الحاصل. كذلك لمعرفة عمل البوتاسيوم في تقليل الاجهاد المائي الناتج عن زيادة مدة الري. استعملت بعض النماذج الرياضية الوضعية (خطية، الدرجة الثانية، الاسية ودالة القوة) لاختبار استجابة انتاجية المحصول للمعاملات المختلفة من كميات المياه المضافة او التبخر للنتح الحقيقي. استخدم نظام القطاعات كاملة التعشية في تصميم هذه التجربة. احتلت معاملات مدد الري الستة (5، 10، 15، 20، 25 و30 يوماً) الالواح الرئيسة وبثلاثة مكررات في حين وضعت معاملات مستويات السماد البوتاسي (0، 100، 200 و300 كغم بوتاسيوم. هكتار<sup>-1</sup>) في تحت الالواح. اضيف ماء الري للنبات باستخدام منظومة الري بالتنقيط مع تصريف 1.2 لتر. ساعة<sup>-1</sup> لكل منقط. أخذ حاصل الحبوب والتبخر للنتح الحقيقي لمطابقة النماذج الرياضية المختلفة ولمعاملات التجربة كافة. قلت قيم كلا المعيارين مع زيادة مدة الري بسبب نقص الماء. قللت اضافة السماد البوتاسي من تأثير الاجهاد المائي في كلا المعيارين. يتضح من النتائج ان اختيار مدة الري 20 يوماً مع اضافة 300 كغم. هكتار<sup>-1</sup> هو اختيار ملائم للظروف في محافظة السليمانية. ان النسبة المئوية للانخفاض في حاصل البذور قلت عموماً بزيادة مستوى اضافة السماد البوتاسي. على سبيل المثال، استعمال مدة الري 20 يوماً وفرت 70% من ماء الري المضاف (نسبة الى مدة الري 5 أيام) مع انخفاض في حاصل البذور بلغ 16.2% بدون اضافة بوتاسيوم وهذه النسبة قلت الى 6.6% عند اضافة 300 كغم بوتاسيوم. هكتار<sup>-1</sup> سماد بوتاسي لمدة الري نفسها. تبين من خلال مطابقة البيانات المختلفة ان الأنموذج دالة القوة تفوق على بقية النماذج الاخرى بمطابقته للبيانات التجريبية متبوعاً بأنموذج الدرجة الثانية، ثم الدالة الاسية. كان انموذج ستوارت وجماعته (29) - الانموذج الخطي - هو الانموذج الاضعف في المطابقة. وهذا يعود لحقيقة ان العلاقة بين الحاصل والتبخر نتح ليست خطية كما هي طبيعة هذا الانموذج.

جزء من رسالة ماجستير للباحث الثاني.

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