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# OPTIMIZING IRRIGATION WATER MANAGEMENT PRACTICES TO IMPROVE WATER PRODUCTIVITY.

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## ABSTRACT

The aim of this study is to reflect the current knowledge for conserving water resources through the use of modern and efficient irrigation system and moisture regime, and to study their influence on water productivity.

Green snap beans (*Phaseolus vulgaris*, L.) as the largest vegetable in value terms exported from Egypt, was cultivated in the Faculty of Agriculture Experimental Farm - Cairo university - (30˚ 02` N latitude, 31˚ 12` E longitude) for two seasons; spring and autumn plantations.

Crop yields of two seasons were measured under the use of different irrigation systems [drip, and furrow with gated pipe]. Also with using different irrigation regimes [$SMD_{0.10}$, $SMD_{0.25}$, $SMD_{0.40}$, and $SMD_{0.55}$ in which irrigation was applied at 10%, 25%, 40%, and 55% soil moisture depletion from soil available water, respectively].

Under field experiment, higher crop yields and the highest water productivity were obtained using drip irrigation system with $SMD_{0.10}$ compared to high yield obtained under furrow irrigation even if gated pipes were used for applying irrigation water.

Model programs were used for estimating crop water requirements and irrigation scheduling to save time and efforts of the field work. "CropWat" program gave similar results as the actual ETa values. Unfortunately the program can't carry out actual daily irrigation scheduling before the month elapse as it needs average monthly reference evapotranspiration (ETo) data. "BUDGET" program gave lower similarity compared to the actual data, but it has the possibility to carry out actual daily irrigation scheduling as it is possible to take ETo data as daily value. As for "IRRI-CLAC" program, it gives the lowest similarity and has weak possibility and flexibility to be used to calculate irrigation scheduling.

**Keywords:** Irrigation management, Drip, Furrow, Irrigation model programs, Green beans, Cropwat, Budget, Irri-clac.

## INTRODUCTION

Current demographic trends and future growth projections indicated that as much as 60% of the global population may suffer water scarcity by the year 2025 (Qadir *et al.*., 2007). It is no longer that countries exploit their new water resources that it almost limited or highly cost resourced as desalination issues. Demand management procedures seem to be one of the optimum strategies for water saving. The improvement of on-farm irrigation management has been identified as key component of reducing agricultural water demand (Horst *et al.*., 2005).

One potential way to optimizing irrigation management for increasing water productivity is through reliable irrigation scheduling depend on type of irrigation system and crop. Soil water must be maintained between desirable upper and lower limits of availability to the plant. Monitoring and measuring soil water available to irrigate crops is part of an integrated management package and helps avoid: 1) the economic losses due to effects of both underirrigation and overirrigation on crop yields and crop quality, and 2) the environmentally costly effects of overirrigation: wasted water and energy, the leaching of nutrients or agricultural chemicals into groundwater supplies and soil degradation.

George *et al..* (2000) reported that irrigation scheduling deals with two questions, when and how much to irrigate a crop. Quantitative irrigation scheduling methods are based on three approaches, namely: crop monitoring, soil monitoring and water balance technique. The major drawback of soil monitoring is that process is labor-intensive and time consuming and thus it may not be economical.

Tasumi and Allen (2007) reported that early planting and crop development has been suggested in some regions as a means to reduce seasonal water consumption by shifting crop growth into early time periods (for spring planted crops) when weather-based ET demands are lower. However, earlier planting can extend the length of the crop development due to lower air temperatures and shorter day length so that total lengths of periods from planting to harvest are extended.

Green bean (*Phaseolus vulgaris*, L.) crop is the largest vegetable in value terms export from Egypt or imported by Europe in 2004. Green beans production in Egypt was stands in year 2004 at 215,000 metric tons and covers more than 21300 hectare (FAOSTAT, 2007).

Webber *et al..* (2006) experimented three irrigation schedules (recommended, moderate and severe depletions) and combinations of the two irrigation strategies (conventional and alternate furrow irrigation) and two crops (green gram and common bean). These results suggest that common bean is not as well suited to water scarce conditions as green gram. Alternate furrow irrigation and deficit irrigation are appropriate methods to increase irrigation use efficiency (WUE), allowing application of less irrigation water, particularly, for green one gram production.

Martinez *et al..* (2007) found that the yield component of common beans (*Phaseolus vulgaris* L.) that was more affected by the water stress treatments was the number of pods per plant.

Sezen *et al..* (2005) examined the effects of different irrigation regimes on yield and water use of green beans irrigated with a trickle system**.** Irrigation intervals influenced significantly green bean yields. However, with the lower irrigation frequency, lower yields were obtained**.** Seasonal water use values in the treatments varied from 253 mm to 338 mm. Water use efficiency (WUE) ranged from 4.14 kg $m^{-3}$ to 6.16 kg $m^{-3}$.

Soil water balance based irrigation scheduling models use soil water budgeting over the root zone. A number of computerized simulation models (Rowse *et al..*, 1983; Camp *et al..*, 1988; Smith, 1992; Foroud *et al..*, 1992; George *et al..*, 2000; El-Gindy *et al..*, 2005) for crop water requirements have been developed using this approach. These models have been widely accepted and used by irrigation researchers and other professionals, but their adoptions by farmers have been very slow.

The aim of this study is to reflect the current knowledge for conserving water resources through the use of modern irrigation systems and efficient irrigation regime, and to study the influence of these systems and regimes on irrigation application efficiency, irrigation scheduling and water productivity.

## MATERIALS AND METHODS

The present investigation was conducted in sector 4 at the Faculty of Agriculture Experimental Farm - Cairo university - (30˚ 02` N latitude, 31˚ 12` E longitude) aiming at studying the effect of different plantation seasons, different irrigation systems and different water regimes on water productivity for green beans. The treatments consisted of two factors with three replicates in a randomized complete block design with split plot. Two irrigation systems were used as a main plot; drip system, and furrow system using gated pipe system for irrigation water application. Four levels of soil moisture depletion (SMD) as a subplot; $SMD_{0.10}$, $SMD_{0.25}$, $SMD_{0.40}$, and $SMD_{0.55}$ treatments were applied i.e. irrigation when soil moisture content was depleted to 10 %, 25 %, 40 %, and 55 % of available water (AW) respectively. Thus, the experiment consisted of 24 plots; each plot area (28 $m^2$) includes 4 rows with 70 cm apart and 10 m in length, and a 2.1 m as buffer zone between each two treatments.

**Table (1): Some soil physical properties of the experimental site.**

| Soil depth (cm) | Particle size distribution % | | | Texture class | Soil bulk density ($Kg.m^{-3}$) | Moisture content θv% | | Available soil water (AW) % |
|---|---|---|---|---|---|---|---|---|
| | Sand | Silt | Clay | | | F.C | W.P | |
| 0-20 | 41 | 29 | 30 | C.L | 1160 | 35.4 | 16.0 | 19.4 |
| 20-40 | 42 | 31 | 27 | C.L | 1260 | 34.5 | 15.5 | 19.0 |
| 40-60 | 50 | 19 | 31 | L | 1220 | 32.8 | 13.1 | 19.7 |

**Table (2): Some soil chemical properties of the experimental site.**

| Soil depth (cm) | PH | $EC_e$ $dS\ m^{-1}$ | Soluble cations (meq/L) | | | | Soluble anions (meq/L) | | | $CaCO_3$ % |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | $Ca^{++}$ | $Mg^{++}$ | $Na^{+}$ | $K^{+}$ | $CO_3^{=}$ + $HCO_3^{-}$ | $SO_4^{=}$ | $Cl^{-}$ | |
| 0-20 | 7.42 | 1.51 | 5.31 | 5.02 | 4.31 | 0.46 | 9.78 | 1.50 | 3.82 | 4.02 |
| 20-40 | 7.51 | 1.72 | 8.89 | 4.67 | 3.22 | 0.42 | 8.64 | 2.02 | 6.54 | 3.78 |
| 40-60 | 7.39 | 1.42 | 4.97 | 5.64 | 3.21 | 0.38 | 4.54 | 1.71 | 7.95 | 1.97 |

Green snap beans (*Phaseolus vulgaris*, L.) of Paulista variety were sown in two plantation seasons; (1) spring plantation (called summer plantation) was sown on Feb. 21, 2006 and harvested after 90 days and (2) autumn plantation (called nili plantation in Egypt) was sown on Sep. 17, 2006 and harvested after 75 days. Bean seeds were planted with 20 plants/$m^2$ density. All the agronomic practices were applied as commonly used for growing snap beans and carried out according to the recommendation of the Ministry of Agriculture. The recommended NPK fertilizers were added at rate of 50 kg N – 30 kg $P_2O_5$ – 50 kg $K_2O_5$/feddan. The amounts devoted of N and K fertilizers were banded for each plot at two doses: 50 % at planting and 50 % at the end of development stage. All recommended P fertilizer was applied at planting time.

The physical and chemical analyses of the experimental soil site are shown in Tables.(1) and (2).

**Actual crop evapotranspiration (ETa):**

Actual crop evapotranspiration (ETa) under different treatments was measured directly by measuring changes in soil water content. Soil moisture content was monitored daily using ThetaMeter type HH1 after calibration. It measures the volumetric soil moisture percentage based on Time Domain Refractometer (TDR) technique (Kaffka *et al.*., 1997; Iles and Dosmann, 1999). The goal of any irrigation scheduling scheme is to keep the water content in the root zone above soil moisture depletion level (SMD) tested.

Actual crop evapotranspiration for any period was determined according to Huang *et al..* (2005), and Oweis *et al..* (2005) as follows:

$$ETa = \sum((\theta_{F.C} - \theta_{SMD}) \times D_s + P_e) + \Delta S \qquad mm \qquad (Eq.1)$$

where:

ETa = actual evapotranspiration (consumptive use) [mm/ interval];

$\theta_{F.C}$ = percentage of volumetric soil water content at field capacity;

$\theta_{SMD}$ = percentage of volumetric soil water content before irrigation time (as level of soil moisture depletion SMD);

$D_s$ = depth of soil layer [mm].

$P_e$ = effective rainfall which storage in the root zone [mm];

$\Delta S = (\theta_1 - \theta_2)$ = the changes in soil storage water content at the root zone during a growth period [mm].

**Irrigation water requirements: -**

According to Ayers and Wastcot (1994) the depth of irrigation water requirements was calculated using the following equation: -

$$I = \frac{ETa}{E_i(1 - LR)} \qquad mm \qquad (Eq.2)$$

where:

I = total depth of irrigation water requirements [mm];

ETa = actual evapotranspiration (consumptive use) [mm];

LR = leaching Requirements [R= 8 %, calculated according to Ayers and Wastcot (1994) , as $EC_{water}$= 0.37 dS $m^{-1}$]

$E_i$ = irrigation efficiency.

**Irrigation application efficiencies (Ea):**

The irrigation application efficiencies (Ea) for furrow system using gated pipe for irrigation water application was evaluated using the measured inflow size, inflow time, advance of water, and recession of water data according to the method described by James (1988).

From the measured data under field experimental condition, the application efficiency (Ea) at different depths of water applied follows equation:

$Y = 26.901 \ln(X) + 1.8481$ (Eq.3)

$R^2 = 0.9925$

where:

Y = application efficiency (%);

X = depth of water applied (mm).

Equation (3) is limited as X ≤ 26 mm, if X > 26 so Y= 90 %.

Table (3) summarizes the average application efficiency of the furrow irrigation system at the different irrigation regimes under the experimental conditions.

However, evaluation of drip irrigation system was carried out according to the method described by Merriam and Keller (1978), James (1988), and Camp *et al..*, (1996). The emission uniformity (EU) of drip irrigation system under experimental condition was excellent (93%), uniformity coefficient (UC) was excellent (95%), and the application water efficiency (Ea) was 95.5% under different irrigation regimes and seasons**.**

**Table (3): Average application efficiency (Ea%) of furrow irrigation system under different irrigation regimes for the two different seasons .**

| Irrigation Regimes | Ea % | | |
|---|---|---|---|
| | Spring Season | Autumn Season | Average |
| $SMD_{0.10}$ | 69.9 | 68.2 | 69.1 |
| $SMD_{0.25}$ | 87.7 | 87.0 | 87.4 |
| $SMD_{0.40}$ | 89.7 | 89.2 | 89.5 |
| $SMD_{0.55}$ | 90.0 | 90.0 | 90.0 |

**Reference evapotranspiration (ETo):**

As recommended by Allen *et al..* (2006), the daily ETo values were calculated from daily climatological data for Giza agrometrological station - Egypt (Altitude: 19 m; Latitude: 30.03 N ; Longitude: 31.20 E) during the two growing seasons using Penman-Monteith equation presented by Allen *et al..* (1998) as follows:

$$ET_o = \frac{0.408\,\Delta\left(R_n - G\right) + \gamma\,\dfrac{900}{T+273}\,U_2\left(e_s - e_a\right)}{\Delta + \gamma\left(1 + 0.34\,U_2\right)} \qquad \text{(Eq.4)}$$

where:

$ET_o$ = reference evapotranspiration [mm day$^{-1}$];

$R_n$ = net radiation at the crop surface [MJm$^{-2}$ day$^{-1}$];

G = soil heat flux density [MJm$^{-2}$ day$^{-1}$]);

T = mean daily air temperature at 2 m height [˚C];

$U_2$ = wind speed at 2 m height [m s$^{-1}$];

$e_s$ = saturation vapour pressure [kPa];

$e_a$ = actual vapour pressure [kPa];

$e_s - e_a$ = saturation vapour pressure deficit [kPa];

$\Delta$ = slope vapour pressure curve [kPa ˚C$^{-1}$];

$\gamma$ = psychrometric constant [kPa ˚C$^{-1}$].

All elements of equation (4) can be calculated from maximum and minimum daily air temperature, wind speed, relative humidity, and sunshine hours according to method described by Allen *et al..* (1998).

**Crop Coefficient (Kc):**

According to Allen *et al..* (1998), the crop coefficient; Kc under standard conditions was calculated by relating the measured crop evapotranspiration (ETc) under standard conditions and the calculated ETo as in equation (5):

$Kc = ETc / ETo$ (Eq.5)

where:

Kc = Crop coefficient under standard conditions;

ETc = Crop evapotranspiration under standard conditions [mm];

ETo = Reference crop evapotranspiration [mm].

Also, the crop evapotranspiration under non-standard conditions ($ET_{c\ adj}$) is the evapotranspiration from crops grown under management and environmental conditions that differ from the standard conditions as follows in equation (6).

$Kc_{adj} = ETc_{adj} / ETo$ (Eq.6)

where:

$Kc_{adj}$ = Crop coefficient under non-standard conditions (i.e. water stresses);

$ETc_{adj}$ = Crop evapotranspiration under non-standard conditions [mm];

ETo = Reference crop evapotranspiration [mm].

**Yield response to water function (Ky):**

Yield response to water function (Ky) was introduced by Doorenbos and Kassam (1979) to predict the reduction in crop yield when crop growth under soil water shortage (stress conditions) as follows in equation (7).

$$Ky = \left[1 - \frac{Ya}{Ym}\right] \Big/ \left[1 - \frac{ETc_{adj}}{ETc}\right] \qquad \text{(Eq.7)}$$

where

$K_y$ = yield response factor;

$Y_a$ = actual yield of the crop [kg fed$^{-1}$];

$Y_m$ = maximum yield in absence of water stress [kg fed$^{-1}$];

$ETc_{\ adj}$ = actual crop evapotranspiration under non-standard conditions as a result of water stress [mm];

ETc = crop evapotranspiration in the absence water stresses i.e. under standard conditions [mm].

**Model programs for estimating actual evapotranspiration (ETa):**

The ETa – whether under standard condition (ETc) or under non-standard condition ($ETc_{adj}$) - was calculated using crop coefficient under different experimental conditions multiplied by ETo. Different programs were also used to calculate the ETa and irrigation scheduling such as "CropWat" program (Smith, 1992), "IRRI-CLAC" program which developed by Central Laboratory for Agricultural Climate in Egypt (CLAC, 1998) and "BUDGET" program which developed by Land Management Department, Faculty of Applied Bioscience and Engineering, Leuven university, Belgium (Budget, 2005). These models can carry out irrigation scheduling or predict crop water requirements from the metrological data instead of the field experiments.

**Water Productivity:**

Water productivity can be expressed as physical productivity as the quantity of the product divided by the amount of water depleted or diverted (Seckler *et al.*., 1998).

The term of water depleted was considered as (kg $m^{-3}$) and the denoted crop water productivity is CWP according to the equation: -

$$CWP = \frac{\text{Total yield (Kg/fed.)}}{\text{Total amount of seasonal evapotranspiration (ETa) (m}^3\text{/fed.)}} \quad Kg/m^3 \qquad (Eq.8)$$

While the term of water diverted was considered as (kg $m^{-3}$) and the denoted irrigation water productivity is IWP according to the equation: -

$$IWP = \frac{\text{Total yield (Kg/fed.)}}{\text{Total amount of irrigation water applied (m}^3\text{/fed.)}} \quad Kg/m^3 \qquad (Eq.9)$$

**Crop measurements:**

At green maturity stage, green pods of each replicate plot were harvested, weighted and calculated total yield of green pods as ton per feddan.

**Statistical analysis:**

The results were statistically analyzed using F-value test, and the means were compared by the L.S.D at the level of probability of 5%. MSTAT-C program (Michigan State University) was used to carry out statistical analysis.

## RESULTS AND DISCUSSION

**Green beans crop production:**

Data shown in Table (4) present the effect of irrigation system and irrigation regimes on the green bean yields. The total yield varied from 6.01 ton $fed.^{-1}$ (using drip system with $SMD_{0.10}$ at spring season) to 2.47 ton $fed.^{-1}$ (using furrow system with $SMD_{0.55}$ at autumn season).

With respect to the total yield in both seasons of cultivation, data indicate a relative significant decrease in yield for autumn plantation (4.15 ton $fed.^{-1}$) compared to that obtained at spring (4.59 ton $fed.^{-1}$). This may reflect the climatological changes especially during repining stage, April to May for spring season and November for autumn season.

As for the effect of irrigation system on the green beans yield for both seasons, data presented indicate that crop yield is higher under drip system compared to that obtained under controlled furrow system. This trend is achieved for both seasons.

Dealing with the effect of irrigation moisture regime on crop yield under different irrigation systems, data presented in table (4) indicate that no significant differences were obtained between $SMD_{0.10}$ treatment and $SMD_{0.25}$ treatment for both seasons. The highest crop yields were obtained within $SMD_{0.10}$ treatment (almost very low deficit) under drip irrigation system for both seasons. While under furrow irrigation system, higher crop yields were obtained within $SMD_{0.25}$ treatment compared to other SMD treatments.

**Table (4): Total yield (ton/fed.) of green bean plant as effected by different irrigation systems and regimes at spring and autumn seasons.**

| Treatments \ Seasons | Total Yield (ton/fed.) | | | | | |
|---|---|---|---|---|---|---|
| | **Spring** | | | **Autumn** | | |
| **Irri. Regime \ Irri. System** | **Drip** | **Furrow** | **Mean** | **Drip** | **Furrow** | **Mean** |
| $SMD_{0.10}$ | 6.01 | 4.60 | 5.31 | 5.29 | 4.65 | 4.97 |
| $SMD_{0.25}$ | 5.77 | 5.43 | 5.60 | 5.08 | 4.74 | 4.91 |
| $SMD_{0.40}$ | 4.78 | 4.25 | 4.52 | 4.24 | 3.71 | 3.98 |
| $SMD_{0.55}$ | 3.11 | 2.75 | 2.93 | 3.01 | 2.47 | 2.74 |
| Mean | 4.92 | 4.26 | 4.59 | 4.41 | 3.89 | 4.15 |
| L.S.D at 5% level for: | | | | | | |
| Irrigation systems (IS) | 0.17 | | | 0.46 | | |
| Irrigation regimes (SMD) | 0.21 | | | 0.40 | | |
| (IS) X (SMD) | 0.58 | | | 0.75 | | |

The previous discussion lead to a conclusion that using both irrigation systems with $SMD_{0.25}$ irrigation regime treatment resulted in high crop yields with no significant differences with $SMD_{0.10}$ treatment with the tendency of increasing yield under drip system compared to furrow system and for spring season compared to autumn season.

**Actual Evapotranspiration (ETa):**

Data illustrated in Fig.(1) show the actual evapotranspiration (ETa) values under different treatments and at different growth stages i.e. the initial, development, mid and end (harvesting) stages. The period of each stage for spring plantation reached 20, 30, 30, and 10 days respectively (90 days in total) and it reaches 10, 25, 25, and 15 days respectively for the autumn plantation (75 days in total). The growth stages classification is based on plant growth and guide lines presented by Allen *et al..* (1998).

The differences in ETa values at each stage depend on season of plantation, accordingly the climatic parameters exist. Total ETa amounts at the development stage are relatively higher with autumn cultivation compared to amounts needed at mid stage. Differences between the two stages are not so large, maximum 8 mm. This is expected as crop is going towards low temperature climate (cold season) with short period of growth. On the other hand and within the spring cultivation, mid stage has higher ETa values compared to that for the development stage as warmer climatic conditions exists, also growth period is longer for spring season compared to that for autumn season.

Data presented in table (5) show the statistical analysis carried out to study the effect of different treatments on ETa and irrigation requirement (IR), data reveal the following:

Total amount of the actual evapotranspiration (ETa) for the spring cultivation is more than the autumn cultivation under all tested treatments i.e. irrigation systems and irrigation regimes. The effect of cultivation season on ETa is more than the pronounced effect of irrigation systems or irrigation regimes (general average reach 383.3 mm in spring and 217.7 mm in autumn). This is expected since spring cultivation needs longer growth period compared to autumn cultivation. Also climatological conditions are mostly warmer through spring season compared to autumn accordingly higher ETo values is recorded for spring season.

Under experimental conditions, the high control and excellent management of water application for furrow system tend to decrease the differences in ETa between drip system and furrow system. Accordingly data in table (5) indicate that there isn't significant difference in ETa between both systems in the two seasons.

The statistical analyses in table (5) show the effect of the interaction between irrigation systems and irrigation regimes on the ETa values. Data indicate that differences between treatments are significant. The highest ETa is obtained for $SMD_{0.25}$ under the controlled furrow system in the two seasons, while the lowest ETa value is obtained for $SMD_{0.55}$ under drip system.

**Table (5): Actual evapotranspiration (mm) of green bean plant as effected by different irrigation systems and regimes at spring and autumn seasons.**

| Treatments / Seasons | Actual evapotranspiration (mm) | | | | | |
|---|---|---|---|---|---|---|
| | **Spring** | | | **Autumn** | | |
| **Irri. Regime / Irri. System** | **Drip** | **Furrow** | **Mean** | **Drip** | **Furrow** | **Mean** |
| $SMD_{0.10}$ | 422.2 | 397.0 | 409.6 | 239.4 | 228.8 | 234.1 |
| $SMD_{0.25}$ | 407.4 | 424.8 | 416.1 | 232.3 | 241.7 | 237.0 |
| $SMD_{0.40}$ | 368.2 | 385.8 | 377.0 | 208.5 | 218.4 | 213.5 |
| $SMD_{0.55}$ | 318.8 | 341.9 | 330.4 | 179.8 | 192.4 | 186.1 |
| Mean | 379.2 | 387.4 | 383.3 | 215.0 | 220.3 | 217.7 |
| L.S.D at 5% level for: | | | | | | |
| Irrigation systems (IS) | n.s | | | n.s | | |
| Irrigation regimes (SMD) | 5.8 | | | 8.2 | | |
| (IS) X (SMD) | 8.1 | | | 11.6 | | |

**Irrigation requirements (IR):**

**Data presented in table (6) indicate the following:**

In general, the IR values are slightly higher than ETa values for all treatments. This is expected since irrigation efficiencies are high and leaching requirements are low (8 %), except for $SMD_{0.10}$ treatment under controlled furrow irrigation which has the lowest irrigation efficiency, this leads to an increase in IR for this treatment (furrow+$SMD_{0.10}$) significantly more than other treatments.

Green beans grown at spring season needs more amount of the irrigation water requirement (IR) compared to that grown at autumn season. On the mean time, IR values under furrow system are higher than that for drip system in the two seasons for all moisture regimes.

Data indicate that increasing water stress tend to decrease the IR in the two seasons. Whereas IR for green beans planted under non-stress conditions ($SMD_{0.10}$) need the highest IR values reaching 549.0 mm at spring season and 318.6 mm at autumn, while it is only 387.9 mm at spring season and 204.7 mm at autumn under water stress ($SMD_{0.55}$).

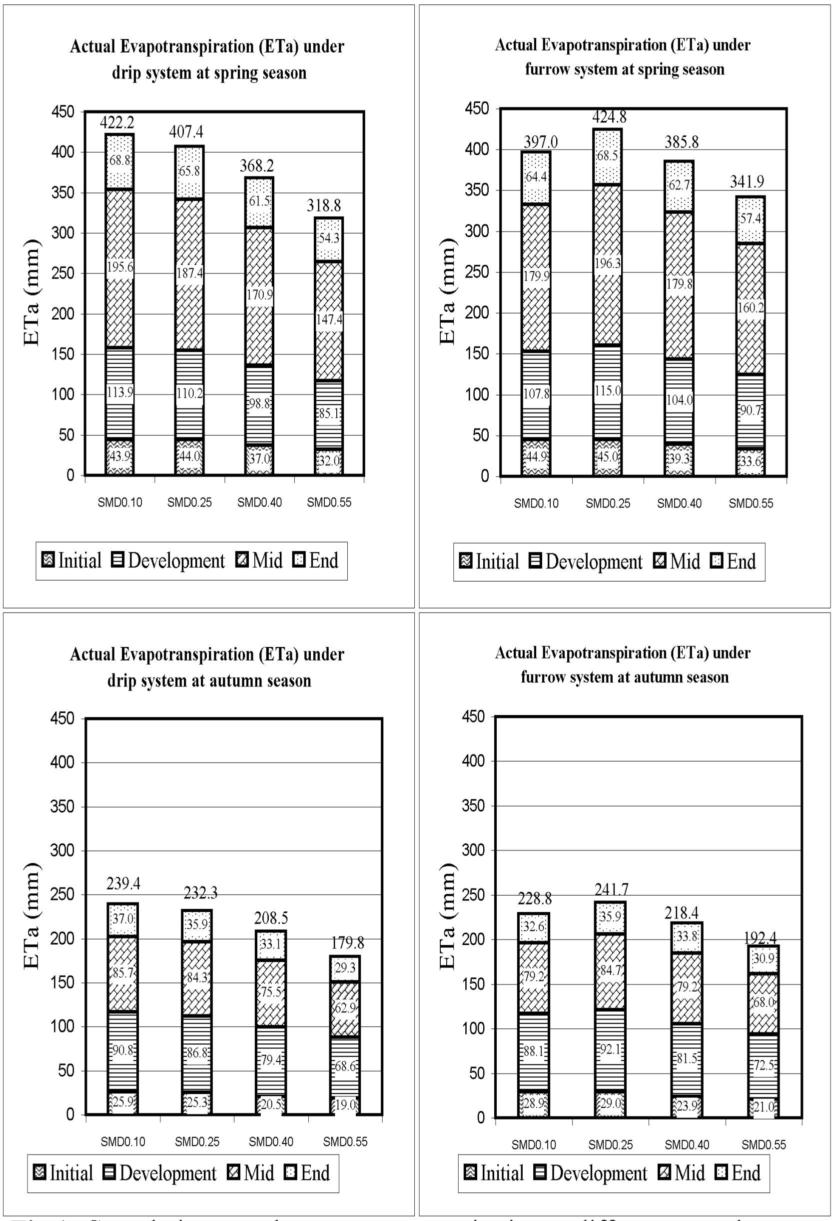


**Fig.1:** Cumulative actual crop evapotranspiration at different growth stages of green beans under different irrigation systems and irrigation regimes at different seasons.

Also, data indicate that the highest IR for green beans is obtained under furrow system with $SMD_{0.10}$ treatment in the two seasons.

**Table(6): Irrigation water requirement (mm) of green bean plant as affected by different irrigation systems and regimes at spring and autumn seasons.**

| Treatments / Seasons | Irrigation water requirement (mm) | | | | | |
|---|---|---|---|---|---|---|
| | Spring | | | Autumn | | |
| Irri. Regime / Irri. System | Drip | Furrow | Mean | Drip | Furrow | Mean |
| $SMD_{0.10}$ | 480.5 | 617.4 | 549.0 | 272.4 | 364.7 | 318.6 |
| $SMD_{0.25}$ | 463.7 | 526.5 | 495.1 | 264.4 | 301.9 | 283.2 |
| $SMD_{0.40}$ | 419.1 | 467.5 | 443.3 | 237.3 | 266.1 | 251.7 |
| $SMD_{0.55}$ | 362.8 | 412.9 | 387.9 | 204.7 | 232.3 | 218.5 |
| Mean | 431.5 | 506.1 | 468.8 | 244.7 | 291.3 | 268.0 |
| L.S.D at 5% level for: | | | | | | |
| Irrigation systems (IS) | 4.7 | | | 14.7 | | |
| Irrigation regimes (SMD) | 6.6 | | | 11.6 | | |
| (IS) X (SMD) | 9.4 | | | 16.4 | | |

**Water Productivity:**

**1. Crop Water Productivity (CWP):**

The CWP values obtained, table (7) for all treatments for autumn growing season are greater than that obtained for spring season, the CWP varied from 3.04 Kg $m^{-3}$ to 5.25 Kg $m^{-3}$ at autumn season, while it ranged from 1.90 Kg $m^{-3}$ to 3.37 Kg $m^{-3}$ at spring season. This may be due to the consumption of water during autumn season as it is less than spring season owing to the climatological conditions and growing season period.

**Table (7): Crop water productivity (Kg/$m^3$) of green bean plant as effected by different irrigation systems and regimes at spring and autumn seasons.**

| Treatments / Seasons | Crop water productivity (Kg/$m^3$) | | | | | |
|---|---|---|---|---|---|---|
| | Spring | | | Autumn | | |
| Irri. Regime / Irri. System | Drip | Furrow | Mean | Drip | Furrow | Mean |
| $SMD_{0.10}$ | 3.37 | 2.74 | 3.06 | 5.25 | 4.78 | 5.02 |
| $SMD_{0.25}$ | 3.34 | 3.02 | 3.18 | 5.16 | 4.62 | 4.89 |
| $SMD_{0.40}$ | 3.06 | 2.61 | 2.84 | 4.79 | 4.01 | 4.40 |
| $SMD_{0.55}$ | 2.31 | 1.90 | 2.11 | 3.91 | 3.04 | 3.48 |
| Mean | 3.02 | 2.57 | 2.79 | 4.78 | 4.11 | 4.45 |
| L.S.D at 5% level for: | | | | | | |
| Irrigation systems (IS) | 0.18 | | | 0.49 | | |
| Irrigation regimes (SMD) | 0.24 | | | 0.42 | | |
| (IS) X (SMD) | 0.34 | | | 0.60 | | |

Results presented indicate that CWP under drip system is significantly higher than CWP obtained under furrow system at the two seasons.

The effect of irrigation regimes reveal that the decreasing amount of water consumed for $SMD_{0.55}$ treatment lead to a decrease in CWP value. This is mainly due to the pronounced decrease in crop yields compared to the decrease of ETa values. The highest CWP at spring season is obtained for $SMD_{0.25}$, while it is obtained for $SMD_{0.10}$ at autumn season. In general, there isn't any significant difference between them in the two seasons. This result is logic as the differences in yield and ETa between $SMD_{0.10}$ and $SMD_{0.25}$ are small.

Table (7) shows the statistical analyses for interaction between irrigation system and irrigation regime for the two seasons, data indicate that the lowest CWP value is obtained for $SMD_{0.55}$ in the two seasons. In general, the highest CWP value is obtained under "drip + $SMD_{0.10}$" treatment - especially at autumn season as CWP increased to 5.25 Kg $m^{-3}$ - without significant difference with "drip + $SMD_{0.25}$" or "drip + $SMD_{0.40}$" for both seasons. Also, there isn't significant difference between "furrow + $SMD_{0.10}$" and "furrow + $SMD_{0.25}$" treatments at both seasons.

**2. Irrigation Water Productivity (IWP):**

In the general, autumn season has the higher IWP values compared to spring season. Table (8) shows that a significant difference is obtained between irrigation systems as drip system is higher in IWP value compared to controlled furrow for the two seasons. The highest IWP value obtained for $SMD_{0.25}$ reaching 2.69 Kg $m^{-3}$ at spring season and it increases to 4.12 Kg $m^{-3}$ at autumn season. As for the $SMD_{0.55}$, it has the lowest IWP among irrigation regime treatments in the two seasons.

**Table (8): Irrigation water productivity (Kg/$m^3$) of green bean plant as effected by different irrigation systems and regimes at spring and autumn seasons.**

| Treatments / Seasons | Irrigation water productivity (Kg/$m^3$) | | | | | |
|---|---|---|---|---|---|---|
| | Spring | | | Autumn | | |
| Irri. Regime / Irri. System | Drip | Furrow | Mean | Drip | Furrow | Mean |
| $SMD_{0.10}$ | 2.96 | 1.76 | 2.36 | 4.61 | 3.00 | 3.81 |
| $SMD_{0.25}$ | 2.94 | 2.43 | 2.69 | 4.53 | 3.70 | 4.12 |
| $SMD_{0.40}$ | 2.69 | 2.15 | 2.42 | 4.21 | 3.29 | 3.75 |
| $SMD_{0.55}$ | 2.03 | 1.57 | 1.80 | 3.44 | 2.52 | 2.98 |
| Mean | 2.66 | 1.98 | 2.32 | 4.20 | 3.13 | 3.66 |
| L.S.D at 5% level for: | | | | | | |
| Irrigation systems (IS) | 0.06 | | | 0.53 | | |
| Irrigation regimes (SMD) | 0.19 | | | 0.36 | | |
| (IS) X (SMD) | 0.27 | | | 0.51 | | |

In general data reveal that high productivity values are obtained under drip system for both seasons. No significant differences are obtained between $SMD_{0.10}$ and $SMD_{0.25}$ under drip system at both seasons. Accordingly, $SMD_{0.25}$ is considered the best treatment for higher productivity values under controlled furrow system. These results matching the previous findings concerning crop yields at both seasons.

**Crop coefficient:**

The obtained ETa values divided by ETo values that calculated according to Penman-Monteith equation (table 9) to calculate the crop coefficient values for the green beans under standard conditions. The selected ETa values represent the $SMD_{0.10}$ treatment under drip system and $SMD_{0.25}$ treatment under furrow system; these treatments gave the highest yields (table 4) and represent no stress conditions or over-irrigation conditions (Allen *et al.*., 1998).

Data presented in table (10) show the calculated Kc values for the two green beans growing seasons, and show the standard FAO-Kc values for presented by Allen *et al..* (1998) after adjusting it.

The data indicate that:

Due to the variations in the crop characteristics throughout its growing season, Kc values for a given crop changes from sowing till harvesting. The Kc begins to increase from the initial Kc value at the beginning and reaches a maximum value, $Kc_{mid}$, at the time of maximum or after maximum plant development. During the late season period, as leaves begin to age, the Kc begins to decrease until it reaches a lower value at the end of the growing period equals to $Kc_{end}$. Average $Kc_{end}$ value for green beans wasn't much smaller than $Kc_{mid}$ as the crop was harvested as green beans.

**Table (9): Calculated reference evapotranspiration (ETo) at different growth stages by using Penman-Monteith equation at different seasons.**

| Seasons | Growth Stages | | | | | | | | Gross Season |
|---|---|---|---|---|---|---|---|---|---|
| | Initial | | Development | | Mid | | End | | |
| | mm $d^{-1}$ | mm | mm $d^{-1}$ | mm | mm $d^{-1}$ | mm | mm $d^{-1}$ | mm | mm |
| Spring | 3.59 | 71.71 | 4.11 | 123.28 | 5.45 | 163.39 | 6.31 | 63.08 | 421.5 |
| Autumn | 5.17 | 51.66 | 4.90 | 122.51 | 3.25 | 81.20 | 2.59 | 38.91 | 294.3 |

**Table (10): Values of Kc under different irrigation systems for the best yield's treatment at different crop stages for green beans crop.**

| Irrigation System | Irrigation regime | Season | Kc average at different Growth Stages | | | | Kc | MAE [4] |
|---|---|---|---|---|---|---|---|---|
| | | | init. | dev. | mid | end | mean | |
| Drip | $SMD_{0.10}$ | Spring | 0.61 | 0.92 | 1.20 | 1.09 | 0.96 | 0.11 |
| | | Autumn | 0.50 | 0.74 | 1.06 | 0.95 | 0.81 | 0.02 |
| Furrow | $SMD_{0.25}$ | Spring | 0.63 | 0.93 | 1.20 | 1.09 | 0.96 | 0.12 |
| | | Autumn | 0.56 | 0.75 | 1.04 | 0.92 | 0.82 | 0.04 |
| FAO-Kc [1] (Allen *et al.*., 1998) | | Spring | 0.52 | 0.80[2] | 1.07 | 1.00[3] | 0.85 | - |
| | | Autumn | 0.50 | 0.78[2] | 1.05 | 0.96[3] | 0.82 | - |

[1] **The adjusted Kc values are calculated from standard Kc values for represent different weather during spring and autumn seasons according to Allen *et al..* (1998).**

[2] **Average crop coefficient value at development stage ($Kc_{dev.}$) is derived as average of $Kc_{ini}$. and $Kc_{mid}$.**

[3] **The value expresses of the average Kc for the end stage. It is converted from the Kc value of the end day of this stage.**

[4] **Mean absolute error (** $MAE = N^{-1}\sum_{i=1}^{N}\left|Kc_{es} - Kc_{FAO}\right|$ **).**

The normal FAO-Kc of Allen *et al..* (1998) for initial, development, mid, and end stages for green beans crop are slightly different between spring and autumn seasons. FAO-Kc values are smaller than the estimated Kc values in the spring season. In the autumn season, the deviation between the estimated Kc values and FAO-Kc are less than the results in spring.

Mean absolute error ($MAE = N^{-1}\sum_{i=1}^{N}\left|Kc_{es} - Kc_{FAO}\right|$) between the estimated Kc ($Kc_{es}$) and FAO-Kc ($Kc_{FAO}$) at spring season is greater than autumn season.

In general, the calculated values of Kc (especially for $Kc_{dev}$, $Kc_{mid}$, and $Kc_{end}$) for spring season are greater than the obtained values of autumn season.

**Evaluating model programs:**

**"CropWat" program:**

Evaluation method is carried out according to Smith *et al..* (2000) using the Kc values under standard conditions which gave the best yield (i.e. $SMD_{0.10}$ under drip system and $SMD_{0.25}$ under furrow system under experimental conditions) to predict crop water requirement under standard conditions. The ETa under non-standard conditions were derived and predicted by knowing soil moisture depletion (SMD) and factor of yield respond to water stress (Ky) calculated and presented in table (11).

**Table (11): Calculated Kc values and Ky values under experiential condition for the use in "CropWat" program.**

| Treatments / Characters | | | Kc | | | Ky | Depletion |
|---|---|---|---|---|---|---|---|
| **Season** | **Irr. system** | **Irr. Regime** | **ini.** | **mid** | **end [1]** | **mean** | **%** |
| Spring | Drip | $SMD_{0.10}$ | 0.61 | 1.20 | 1.00 | 1.57 | 10 |
| | Furrow | $SMD_{0.25}$ | 0.63 | 1.20 | 1.00 | 2.45 | 25 |
| Autumn | Drip | $SMD_{0.10}$ | 0.50 | 1.06 | 0.85 | 1.54 | 10 |
| | Furrow | $SMD_{0.25}$ | 0.56 | 1.04 | 0.82 | 2.30 | 25 |

**[1] The value expresses of the Kc for the end day of the end growth stage. It is converted from the Kc value of the average Kc of this stage and mid stage to be used in the blank of the end stage in the CropWat program.**

Data presented in table (12) indicate small differences between predicted and actual data for ETa and Ky values. This differences increase especially when using furrow system with high stress treatments. In general differences under drip system is acceptable. No feasible differences are obtained between the two seasons.

In general, the previous investigations show that "CropWat" program is useful to predict crop water requirement and irrigation scheduling, and it offer a simple way to predict the effect of water stress on yield instead of field estimation as field experiments consume much of time, efforts and expensive.

On the mean time "CropWat" program still needs to improve the Ky function to approach the actual. These results are in-agreement with Smith (1992) as he recommended that the FAO-Ky values should be used only as a guide to the likely effect of water shortage on crop yield. He recommended developing our own crop yield data (Ky factors) based on field experience. Also, "CropWat" program accepts only monthly average climate/ETo data. So it couldn't be able to carry out calculations for ETa or irrigation scheduling before the end of the month, accordingly one must wait for long period (end month) to calculate irrigation scheduling. Also, the program can't calculate irrigation water requirements, whereas it use irrigation efficiency only to calculate the field water supply (FWS) in liters per second per hectare (l/s/ha) and it hasn't any function for introducing leaching requirements.

**Table (12): Using CropWat program for predicting crop water requirement (ETa) and yield reduction under different irrigation systems and regimes for both seasons by using the actual Kc, yield respond to water stress (Ky), and soil moisture depletion.**

| Season | Treatments \ Characters | | CropWat predictions | | Actual field data | | Differences | |
|---|---|---|---|---|---|---|---|---|
| | | | ETa | Yield reduction | ETa | Yield reduction | ETa | Yield reduction |
| | Irr. system | Irr. Regime | mm | % | mm | % | mm | % |
| Spring | Drip | $SMD_{0.10}$ | 425.3 | 0.0 | 422.2 | 0.0 | 3.1 | 0.0 |
| | | $SMD_{0.25}$ | 405.4 | 7.3 | 407.4 | 4.0 | -2.0 | 3.3 |
| | | $SMD_{0.40}$ | 369.3 | 20.7 | 368.2 | 20.5 | 1.1 | 0.2 |
| | | $SMD_{0.55}$ | 322.5 | 38.0 | 318.8 | 48.3 | 3.7 | -10.3 |
| | Furrow | $SMD_{0.25}$ | 427.8 | 0.0 | 424.8 | 0.0 | 3.0 | 0.0 |
| | | $SMD_{0.40}$ | 411.2 | 9.5 | 385.8 | 21.7 | 25.4 | -12.2 |
| | | $SMD_{0.55}$ | 373.5 | 31.1 | 341.9 | 49.4 | 31.6 | -18.3 |
| | | | | | Mean Absolute Error | | 10.0 | 6.3 |
| Autumn | Drip | $SMD_{0.10}$ | 245.1 | 0.0 | 239.4 | 0.0 | 5.7 | 0.0 |
| | | $SMD_{0.25}$ | 232.7 | 7.8 | 232.3 | 4.0 | 0.4 | 3.8 |
| | | $SMD_{0.40}$ | 210.6 | 21.7 | 208.5 | 19.8 | 2.1 | 1.9 |
| | | $SMD_{0.55}$ | 181.3 | 40.1 | 179.8 | 43.1 | 1.5 | -3.0 |
| | Furrow | $SMD_{0.25}$ | 248.0 | 0.0 | 241.7 | 0.0 | 6.3 | 0.0 |
| | | $SMD_{0.40}$ | 237.9 | 9.3 | 218.4 | 21.7 | 19.5 | -12.4 |
| | | $SMD_{0.55}$ | 216.8 | 29.0 | 192.4 | 47.9 | 24.4 | -18.9 |
| | | | | | Mean Absolute Error | | 8.6 | 5.7 |
| | | | | | Average MAE | | 9.3 | 6.0 |

**"IRRI-CLAC" program:**

There are a lot of comments about this program but the main point is the big differences between the average input monthly ETo data the program gives and the output average daily ETo data that program predict as it is derived from monthly ETo. This gave an erratic daily ETo, accordingly an erratic calculation of ETc and irrigation scheduling as shown in table (13).

The high value of the mean absolutely error between the actual and calculate data by "IRRI-CLAC" program confirm this ideas. Also, one of the disadvantages of "IRRI-CLAC" program is the inflexibility for introducing: plant characteristics (Kc values, season period, root depth), and soil characteristics (initial soil moisture content). Also the program needs all monthly ETo data (from Jun. to Dec.) to start calculating ETa. So it couldn't be able to carry out calculations of actual evapotranspiration (ETa) or irrigation scheduling before the end of the year, so we have to use only historical ETo data in irrigation scheduling, even that some of historical data are mostly higher than the present ETo in mm.

**Table (13): Using Irri-Clac program for calculate ETa (with leaching requirement, LR) at different soil moisture depletion and irrigation system for different seasons.**

| Season | Treatments / Characters: Irr. system | Irr. regime | IRRI-CLAC ETa+LR ($m^3$/fed) | Actual ETa+LR ($m^3$/fed) | Differences |
|---|---|---|---|---|---|
| Spring | Drip | $SMD_{0.10}$ | 966.5 | 1927.4 | -960.9 |
| | | $SMD_{0.25}$ | 805.4 | 1859.9 | -1054.5 |
| | | $SMD_{0.40}$ | 644.3 | 1680.9 | -1036.6 |
| | | $SMD_{0.55}$ | 483.3 | 1455.4 | -972.1 |
| | Furrow | $SMD_{0.10}$ | 966.5 | 1812.4 | -845.9 |
| | | $SMD_{0.25}$ | 805.4 | 1939.3 | -1133.9 |
| | | $SMD_{0.40}$ | 644.3 | 1761.3 | -1117.0 |
| | | $SMD_{0.55}$ | 483.3 | 1560.8 | -1077.5 |
| | | | | MAE | 1024.8 |
| Autumn | Drip | $SMD_{0.10}$ | 1479.4 | 1092.9 | 386.5 |
| | | $SMD_{0.25}$ | 1232.9 | 1060.5 | 172.4 |
| | | $SMD_{0.40}$ | 986.3 | 951.8 | 34.5 |
| | | $SMD_{0.55}$ | 739.7 | 820.8 | -81.1 |
| | Furrow | $SMD_{0.10}$ | 1479.4 | 1044.5 | 434.9 |
| | | $SMD_{0.25}$ | 1232.9 | 1103.4 | 129.5 |
| | | $SMD_{0.40}$ | 986.3 | 997.0 | -10.7 |
| | | $SMD_{0.55}$ | 739.7 | 878.3 | -138.6 |
| | | | | MAE | 173.5 |
| | | | | Avg MAE | 599.2 |

**"BUDGET" program:**

**Table (14): Using BUDGET program for calculate ETa at different soil moisture depletion and irrigation system for different seasons.**

| Season | Treatments / Characters: Irr. system | Irr. regime | Actual Kc & $Kc_{adj}$ Mid | End | Calculate ETa (mm) | ETa (mm) | Differences |
|---|---|---|---|---|---|---|---|
| Spring | Drip | $SMD_{0.10}$ | 1.20 | 1.00 | 474.3 | 422.2 | 52.1 |
| | | $SMD_{0.25}$ | 1.15 | 0.95 | 447.3 | 407.4 | 39.9 |
| | | $SMD_{0.40}$ | 1.05 | 0.90 | 400.8 | 368.2 | 32.6 |
| | | $SMD_{0.55}$ | 0.90 | 0.83 | 340.0 | 318.8 | 21.2 |
| | Furrow | $SMD_{0.10}$ | 1.10 | 0.95 | 447.1 | 397.0 | 50.1 |
| | | $SMD_{0.25}$ | 1.20 | 1.00 | 463.1 | 424.8 | 38.3 |
| | | $SMD_{0.40}$ | 1.10 | 0.90 | 414.0 | 385.8 | 28.2 |
| | | $SMD_{0.55}$ | 0.98 | 0.85 | 362.2 | 341.9 | 20.3 |
| | | | | | | MAE | 35.3 |
| Autumn | Drip | $SMD_{0.10}$ | 1.06 | 0.85 | 286.6 | 239.4 | 47.2 |
| | | $SMD_{0.25}$ | 1.04 | 0.82 | 265.1 | 232.3 | 32.8 |
| | | $SMD_{0.40}$ | 0.93 | 0.78 | 229.0 | 208.5 | 20.5 |
| | | $SMD_{0.55}$ | 0.77 | 0.73 | 184.7 | 179.8 | 4.9 |
| | Furrow | $SMD_{0.10}$ | 0.98 | 0.72 | 270.1 | 228.8 | 41.3 |
| | | $SMD_{0.25}$ | 1.04 | 0.82 | 265.1 | 241.7 | 23.4 |
| | | $SMD_{0.40}$ | 0.98 | 0.77 | 236.7 | 218.4 | 18.3 |
| | | $SMD_{0.55}$ | 0.84 | 0.75 | 196.4 | 192.4 | 4.0 |
| | | | | | | MAE | 24.1 |
| | | | | | | Avg MAE | 29.7 |

"BUDGET" program have a lot of possibilities to predict water needs and budget irrigation amounts at different management and conditions e.x. under soil salinity, water stress, aeration stress, and mulching. Unlike "CropWat" program, "Budget" program could accept monthly, 10-days or daily ETo data. So it could be able to carry out calculations for actual evapotranspiration (ETa) or irrigation scheduling for any period. Despite all this possibility and flexibility, program hasn't the same flexibility for introducing initial Kc, this lead that the "BUDGET" program gives a quite good correlation with actual results from field whereas this correlation is still less than obtained for "CropWat" calculation table (14).

## CONCLUSION

1-The highest crop yields were obtained within $SMD_{0.10}$ treatment (almost very low deficit) under drip irrigation system for both seasons. While under furrow irrigation system, higher crop yields were obtained within $SMD_{0.25}$ treatment compared to other SMD treatments.

2-Autumn season has the higher irrigation water productivity (IWP) values compared to spring season. A significant difference is obtained between irrigation systems as drip system is higher in IWP value compared to controlled furrow for the two seasons. The highest IWP value obtained for $SMD_{0.25}$ reaching 2.69 Kg $m^{-3}$ at spring season and it increases to 4.12 Kg $m^{-3}$ at autumn season.

3-"CropWat" program gave similar results as the actual ETa values. Unfortunately the program can't carry out actual daily irrigation scheduling before the month elapse as it needs average monthly reference evapotranspiration (ETo) data. "BUDGET" program gave lower similarity compared to the actual data but it have the possibility to carry out actual daily irrigation scheduling as it is possible to take ETo data as daily value. As for "IRRI-CLAC" program, it gives the lowest similarity and has weak possibility and flexibility to be used to calculate irrigation scheduling.

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## تحسين إدارة مياه الري لتعظيم إنتاجية الماء

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الهدف من هذه الدراسة هو تطبيق الاتجاهات الحديثة في المحافظة على المصادر المائية برفع إنتاجية وحدة الماء من خلال المحافظة على نظام رطوبي في التربة مناسب للنبات باستخدام أنظمة ري حديثة, وكذلك إجراء مقارنة و تقييم لبعض برامج الحاسب الآلي المستخدمة في حساب الاحتياجات المائية وجدولة الري.

تمت زراعة الفاصوليا الخضراء - والتي تعد من أكثر المحاصيل التصديرية قيمةً في مصر- في المزرعة التجريبية التابعة لكلية الزراعة جامعة القاهرة وذلك لموسمين من مواسم الزراعة المختلفة (الموسم الربيعي والموسم الخريفي) وأنظمة الري المختلفة (نظام الري بالتنقيط ونظام الري بالخطوط الذي تصل إليه الماء بالأنابيب المبوبة) عند مستويات رطوبية مختلفة (أربع معاملات يتم الري فيها عندما تقل رطوبة التربة ب 10% , 25%, 40% و 55% من الماء الميسر).

أظهرت النتائج أن أعلى محصول وأعلى إنتاجية للماء كانت للمعاملة التي يتم ريها عندما تقل رطوبة التربة الى 10% من الماء الميسر باستخدام نظام الري بالتنقيط, وتزيد إنتاجية الماء في الموسم الخريفي عن الموسم الربيعي. أما فيما يخص استخدام برامج الحاسب الآلي فقد أظهرت النتائج أن حسابات الاحتياج المائي لمحصول الفاصوليا المحسوبة ببرنامج "CropWat" كانت مشابه للنتائج المتحصل عليها من الحقل لمختلف المعاملات, إلا إن البرنامج لا يستطيع إجراء عملية الجدولة المائية اليومية قبل انقضاء الشهر لأنه يحتاج إلى قيمة المتوسط الشهري للبخر نتح المرجعي ETo . ويتميز برنامج "BUDGET" بالإمكانيات العالية منها إمكانية حساب جدولة الري يومياً لأنه يمكن أن يأخذ قيم يومية للبخر نتح المرجعي ETo , إلا أنه يعطي ارتباط أقل بنتائج الحقل مقارنة مع برنامج "CropWat". كما تظهر النتائج أن برنامج "IRRI-CLAC" ذو إمكانيات ومرونة ضعيفة وتوجد به بعض المشاكل التي تجعل نتائجه هي الأقل ارتباطاً مع نتائج الحقل وبالتالي لا يمكن استخدامه في عملية جدولة الري بثقة كافية.

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