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# Maximizing Water Use Efficiency in Wheat Yields Based on Drip Irrigation Systems

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**Abstract:** Maximizing irrigation water use efficiency is one of the most important policies under arid ecosystems conditions. Therefore, the aim of this study was to estimate the wheat yield response to drip irrigation systems and the attributed water use efficiency and saving water indices under sandy soil conditions of arid regions. Results revealed that about 16.33 and 26.57% of wheat grain yield reduction had been observed under the alternative irrigation systems (subsurface and surface drip) compared with the solid-set sprinkler irrigation system. On the other hand, data revealed that attributed water use efficiency and water saving had been enhancement with about 43.13 and 76%, respectively, when using drip irrigation systems. It can be concluded that the alternative irrigation system (subsurface drip irrigation) has an effective way for irrigating intensive field crops, but more studies have to be conducted under similar field conditions.

**Key words:** Irrigation. Hydraulic design. Sprinkler irrigation. Sandy soils. Arid regions. Water saving.

## INTRODUCTION

Maximizing irrigation water use efficiency is a common concept used by irrigation project managers; also, the visual quality of the crop yield is the primary criteria on used to assess irrigation systems effectiveness. In recent years, however, growing competition for scarce water resources has led to applying modified techniques for maximizing water use efficiency and improving crop yields and quality, particularly in arid and semi arid regions as like Egypt. Subsurface drip irrigation system has successfully been used to irrigate wide range of crop patterns, but on the other hand, no studies had been conducted under intensive field crops (Grabow *et al* 2004 and 2002).

Wheat (*Triticum aestivum L.*) is one of the key crops in Egypt with a cultivation area of about 0.6 million hectares (Ministry of Agriculture and Land Reclamation 2005). With increasing human demand for food more efforts had been done to expand wheat cultivation area in sandy soils based on new technologies as using biofertilizers and developed new varieties (Girgis 2006).

Few technically, economically and environmentally feasible studies had been focused on the application possibility of the alternative drip irrigation systems (surface and subsurface drip); an evaluation and performance consideration exists under intensive field crop conditions, which had been carried out by (Alam *et al* 2000, Suarez-Rey *et al* 2000, Camp *et al* 2000 and Camp 1998). Therefore, this study has the priority on emphasizing and description of the engineering design criteria to evaluate and determine the suggested alternative irrigation system and technique and its effect on wheat crop yields under drought ecosystems in sandy soils of Egyptian agriculture. El-Gindy *et al* (2000) speculated that there is a highly significant effect of irrigation systems on the mango fruits. Moreover, they stated that for maximizing the net-return profits of irrigation water unit, either productivity or attributed yield quality parameters have to be in an agreement combination.

## MATERIALS AND METHODS

To achieve the objectives of this study, two field experiments had been carried out for two successive growing seasons (2005/06 and 2006/07) at the Experimental Farm of the Agricultural Engineering Research Institute, ARC, which located at El-Bustan region, Beheira Governorate (Sandy soil). Some physical properties of soil and chemical analysis of irrigation water were conducted according to standard procedures and represented in Tables (1 and 2) as described by Page (2003).

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***i- Experimental Layout and Design:***

Three pressurized irrigation systems (surface and subsurface drip and solid-set sprinkler) had been evaluated in sandy soils for irrigating intensive field crop conditions, wheat crop *Triticum aestivum L.)* Giza 168 cultivar, which had been sowed in December and harvested in May of each growing season.

Data had been analyzed statistically using least square method (SAS, 1988) according to the following model

$$Y_{ijk} = U + I_i + M_j + (I*M)_{ij} + e_{ijk}$$

Where, $Y_{ijk}$ is the observation (eradication percent, wheat yield) of $k^{th}$ record in the $i^{th}$ irrigation system and $j^{th}$ either spacing or buried depth of lateral lines; U is the overall mean of Y; I is the effect of irrigation systems (i= 1, 2 and 3); $M_j$ is the effect of either spacing or buried depth of lateral line; $(I*M)_{ij}$ is the effect of interaction between $i^{th}$ and $j^{th}$ and $e_{ijk}$ is the effect of random error.

***ii- Irrigation Systems Description:***

In order to achieve the objectives of this study two irrigation methods were investigated "sprinkler irrigation method: solid-set sprinkler irrigation system and drip irrigation method: surface and subsurface drip irrigation systems" were used in this study as shown in Fig. (1). However the technical specifications of each irrigation network, could be summarized as following:

***●Solid-set Sprinkler Irrigation:***

sprinklers are fixed at 10x10 m spacing (four sprinklers for each plot), with 1.6 $m^3$/h discharge at 2.5 bar operating pressure.

***●Subsurface and Surface Drip Irrigation Systems:***

PE laterals of 16 mm outer diameter with 20m length. Built-in drippers with discharge of 4 lph/50cm spacing at 1.0 bar operating pressure. Different lateral spacing (0.5 and 0.6 m) and different buried depths (0.15 and 0.2 m) had been investigated for the experimental achievements. However, the lateral spacing had been selected to give the flexibility and suitability and simplicity of using the same irrigation network for irrigating different crops (vegetable or row-field crops) without vital replacement, necessary modification and extra equipments of the irrigation systems.

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

| Soil depth, cm | Particle size distribution % | | | Total Ca $Co_3$ | F.C, % | W.P.,% | B.D.,g/$cm^3$ | TextureClass |
|---|---|---|---|---|---|---|---|---|
| | Sand | Silt | Clay | | | | | |
| 0-30 | 94.2 | 4.1 | 1.7 | 1.08 | 4.3 | 9.4 | 1.68 | Sandy |
| 30-60 | 93.5 | 5.0 | 1.5 | 0.94 | 4.4 | 8.5 | 1.57 | Sandy |

**Table 2:** Some chemical analysis of irrigation water at the experimental site

| pH | EC, dS/m | Soluble Cations, meq/l | | | | Soluble Anions, meq/l | | | SAR |
|---|---|---|---|---|---|---|---|---|---|
| | | $Ca^{++}$ | $Mg^{++}$ | $Na^+$ | $K^+$ | $HCO_3^-$ | $SO_4^{--}$ | $Cl^-$ | |
| 7.74 | 1.02 | 1.03 | 0.74 | 8.01 | 0.42 | 1.95 | 4.52 | 3.73 | 8.51 |

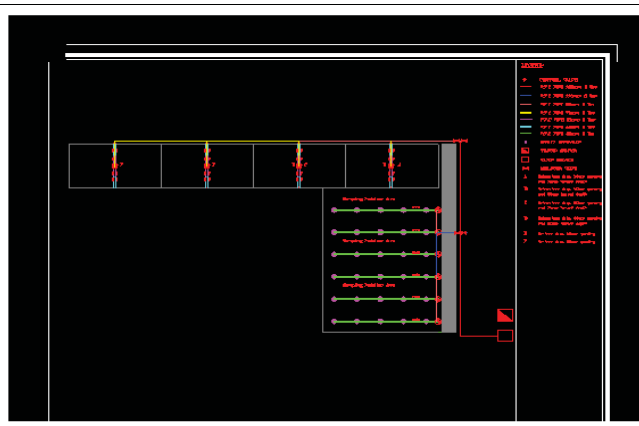

**Fig. 1:** Layout of the experimental site.

***iii- Theoretical Approach and Prerequisite of Drip Irrigation Systems Design:***

***1- Domain Therapy and Concepts of Drip Irrigation Systems Design:***

Design of drip irrigation systems depend on many factors, but finally the system design will be constrained by economic factors such as feasibility, investment, labor and return on investment. Due to the uncertainty associated with many phases on the system design, the optimal design will yield a configuration which best meet the requirements while remaining within the constraint boundaries.

***a- Distributors Selection Concepts:***

A distributor represents a demand point in an irrigation system network and is always associated with laterals or manifolds. The flow rate through the distributor is a function of its inlet pressure. Non-flow control type of distributors can be described with the orifice equation.

**** For Drip Irrigation Systems:***

An assumption that the pressure at the distal end and use backward calculation procedure, to set the flow and pressure over each emission point up to the inlet end. The resulting pressure is compared to the desired one. Similar calculations with different distal end pressure are made until the difference between the calculated inlet pressure and the desired one is acceptable.

$$H_{i+1} = H_i - h_{f(i)} + h'_{f(i)}$$

Where, ($H_{i+1}$) is the pressure head on emitter (i+1) "m"; ($H_i$) is the pressure head on emitter (i) "m"; ($H_{f(I)}$) is the friction head loss in section (i) "m" and ($h'_{f(i)}$) is the head loss or gain due to slope "m". The emitter flow rate at any point can be computed based on the assumed pressure at the distal end not exceed that 10%.

***c- Laterals Design:***

The pressure head at any point along the lateral can be computed by using the following formula:

$$H_i = H_{in} - h_1 \pm \Delta h_1$$

Where: ($H_i$) is the pressure head at any length from the lateral inlet "m"; ($H_{in}$) is the inlet pressure head to the lateral line "m"; ($h_l$) is the friction head loss from the lateral inlet to the given length "m" and ($\Delta h_1$) is the pressure changes due to non-uniform slope from the lateral inlet to the given length "m".

***d- Mainlines Design:***

The flow rate or pressure control or adjustment is provided at the manifold inlet. Therefore, energy losses in the main-lines should not affected system uniformity and the sized is based on economic comparisons of power costs and pipe costs. The most practical design criteria for the mainline, consists in selecting the diameter, so that, the mean water velocity ranges from 1.5 to 3.0 m/s (1.5 m/s "3 fps" for plastic pipes and 2 m/s "5 fps" for iron pipes). A value of 2.0 m/s is recommended.

***2- Analysis of the Hydraulic Design of Drip Irrigation Systems:***

To evaluate the hydraulic design of the applied irrigation systems, data had been exposed to LIS-ES program, which had been developed by Arafa (2004) and El-Gindy *et al* (2005). Results of the evaluation processes revealed that the friction losses ratio had been conserved in the allowable ratio (not exceed than 10%), however, it was 7.34, 7.14 and 8.23% for solid-set sprinkler, drip irrigation with 0.6 m lateral spacing and drip irrigation with 0.5m lateral spacing. This may be due to the small of the irrigating plot size; selecting of the economic pipe sizes and more irrigation control had been considered.

Therefore, the effect of pressure drop and losses had been avoided, hereby, the effectiveness of the applied irrigation systems for delivering irrigation water, had been considered the major factor for evaluating the possibility of applying drip irrigation systems under intensive field crop conditions.

***iv- Crop-water Considerations***

FAO 56. Penman-Monteith method, which had been described by (Allen *et al*, 1998), had been used for estimating the potential evapotranspiration under the studied area conditions. However, the main required climatic data had been collected from a weather station that located in the experimental farm.

Irrigation net-depth is the amount of water that allowed to be consumed by the crop between two consecutive irrigation events and that the soil must store temporarily in the root zone as readily available water. It can be calculated by the following equation, according to Heurta and Hernandez (1980).

$$D_n = f\ \frac{FC - PWP}{100}\ \frac{\zeta_b}{\zeta_w}\ D_{rz}$$

Where: ($D_n$) is the irrigation net-depth "cm"; (f) is the allowable depletion moisture factor "dimensionless"; (F.C) is the field capacity "%'; (P.W.P) is the permanent wilting point "%"; ($D_{rz}$) is the depth of the root zone to be wetted "cm"; ($\zeta b$) is the soil bulk density "g/cm$^3$" and ($\zeta w$) is the water density "g/cm$^3$".

Applied irrigation water for wheat crop was calculated according to Heurta and Hernandez (1980).

$$I.R. = \left[\frac{ET_c \times (1 + L.R.) \times 4.2}{E_a}\right] \times I$$

Where, I.R. is the applied irrigation requirement (m$^3$/fed.irrigation event), L.R. is the leaching requirement (%), Ea is the application efficiency (%) and I is the irrigation intervals (days).

$$L.R. = \frac{EC_i}{2 \times EC_d}$$

Where, $EC_i$ is the salinity of irrigation water (dS/m) and $EC_d$ is the salinity of drainage water(dS/m).

***v- Data Processing and Analysis:***

The required measurements and calculations for evaluating the alternative irrigation system for irrigating intensive field crops (subsurface drip) compared with conventional one (solid-set sprinkler) and its impacts on wheat yields and quality had been conducted.

Statistical uniformity was calculated with the following equations for the tested pressurized irrigation systems (ASAE, 2004):

***a- for Drip Irrigation System:***

$$U_s = 100(1 - \frac{s_q}{\bar{q}_i})$$

Where, $U_s$ is the statistical uniformity, $S_q$ is the standard deviation of emitter flow rate (lph) and $q_i$ is the average emitter flow rate of the $i^{th}$ treatment

***ii- for Solid - Set Sprinkler Irrigation:***

Water distribution uniformity for sprinkler irrigation system was determined by using 45 cans placed in a uniform pattern in the wetted area between each four sprinklers at the corners of squares (2x2 m) for collecting sprinklers water. Water distribution uniformity was calculated according to following formula:

$$U_S = 1 - \frac{\sum |x_i - \bar{x}|}{n\ \bar{x}}$$

Where, xi is the single observation of application rate as depth (mm) and x is the average of the individual observation of the $i^{th}$ to $n^{th}$

To reduce experimental error and protection against the subjective assignment of treatment, a complete randomization procedure was used. As consequence of individual trials and combination of orders between the treatments and experimental units and subunits were randomly chosen.

***iii- Yield Evaluation:***

The wheat yield after being mature were picked manually from each treatment with area of about 1.0 square meter, then separated the straw and grain yields and weighed in kg. Total yield of character (grain and straw) was estimated for each treatment in Mg per feddan.

***iv- Irrigation Water Maximization Criteria:***

- Determine field water use efficiency (FWUE): It was calculated according to the following equation:

$$\text{WUE (kg/m}^3\text{)} = \frac{\text{Total yield (kg/fed)}}{\text{Total applied water (m}^3\text{/fed)}}$$

- Determine irrigation water saving index

## RESULTS AND DISCUSSION

***i- Wheat Yield Response to Pressurized Irrigation Systems:***

Data tabulated in Table (3) revealed that there was a significant effect of the applied irrigation systems and attributed drip irrigation systems treatments on the wheat yields (straw and grains) and irrigation water saving.

Regarding the wheat grain yield reduction percentage, data indicated that the subsurface drip irrigated wheat gain yields reduction had been varied from 16.33 up to 28.57% comparing with solid-set sprinkler irrigated wheat. This may be due to the high losses of irrigation water due to evaporation from the soil surface and evapotranspiration of plants under sandy soil conditions of El-Bustan region.

Considering the wheat yield under drip irrigation systems, data indicated that subsurface drip irrigation systems had improved the wheat yield either straw or grains with an average of about 27.55 and 26.67%, with using 0.6m lateral spacing, meanwhile, the average increment was about 7.74 and 40.8% when using 0.5m lateral spacing, as shown in Fig. (2). This may be due to the effectiveness of subsurface drip irrigation in conserving soil-moisture in the effective root zone comparing with surface drip irrigation system. Moreover, data speculated that the wheat yield either straw or grains had been improved with applying 0.5m lateral spacing compared with 0.6m lateral spacing, with all buried depths. This maybe due to the wheat plants had exposed to higher water-stress during the growing stages under 0.6m lateral spacing more than that under 0.5m lateral spacing.

Regarding the effect of buried depth of subsurface drip irrigation system on wheat yield, data indicated that 0.2m depth subsurface drip irrigated wheat had been increased with about 13.1 and 17.14% under 0.5 and 0.6m lateral spacing respectively.

***ii- Field Water Use Efficiency and Water Saving under Different Pressurized Irrigation Systems:***

Data tabulated in Table (3) revealed that, although there was crop yield reduction due to the application of drip irrigation systems in wheat yields, the FWUE values of grain yields were higher, however, it was varied from 1.72 and 1.76 kg/m$^3$, with using 0.6 and 0.5m lateral spacing and 0.2m depth compared with solid-set sprinkler irrigation systems (1.25 kg/m$^3$). On the other hand, solid-set sprinkler observed the high value of WUE regarding the straw yield compared with either surface or subsurface drip irrigation systems with all treatments.

**Table 3.** Wheat yield response to different pressurized irrigation systems

| Irrigation system | Lateral spacing, m | Buried depth, m | Wheat yield, ton/fed | | Yield reduction percentage, % | | WUE, kg/m3 | |
|---|---|---|---|---|---|---|---|---|
| | | | Straw | Grain | Straw | Grain | Straw | Grain |
| Surface drip | 0.6 | - | 1.47 | 1.26 | 6.8 | 38.78 | 1.47 | 1.26 |
| | 0.5 | - | 1.68 | 1.18 | 55.2 | 42.86 | 1.68 | 1.18 |
| | 0.6 | 0.15 | 1.68 | 1.55 | 55.2 | 24.5 | 1.68 | 1.55 |
| | | 0.2 | 1.93 | 1.76 | 48.48 | 23.44 | 1.93 | 1.76 |
| Subsurface drip | 0.5 | 0.15 | 2.18 | 1.47 | 41.76 | 28.57 | 2.18 | 1.47 |
| | | 0.2 | 1.57 | 1.72 | 58.24 | 16.33 | 1.57 | 1.72 |
| Solid-set sprinkler | 10 * 10 | - | 3.75 | 2.06 | - | - | 2.29 | 1.35 |

Considering the irrigation water saving index, data speculated that drip irrigation systems saved an average of about 43.13% of the total amount of irrigation water during the all growing stages of wheat crop, as shown in Fig. (3). Meanwhile, the highest value of saving irrigation water appeared in the development stages; however it was about 48.84%.

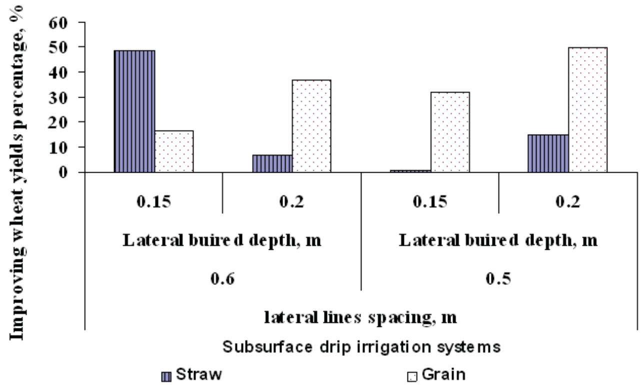


**Fig. 2:** Improving wheat yields under subsurface drip irrigation system compared with surface ones

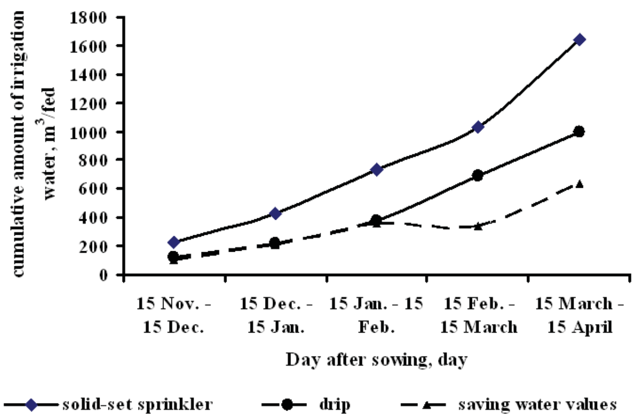


**Fig. 3:** Cumulative irrigation water and water saving index under pressurized irrigation systems.

This means that if the water saving percentage had been considered and reduced in this stage, the attributed crop yield reduction due to the application of drip irrigation systems may be decreased.

***iii- General Discussion:***

Observed data and attributed evaluation and analysis processing towards the application priorities of subsurface drip irrigation, as an alternative system of sprinkler irrigation systems, may be an effective technique for rationalizing irrigation water and maximizing water use and efficiencies under drought and arid system conditions.

In conclusion, results indicated that the alternative irrigation system (subsurface drip irrigation) can be applied effectively for irrigating intensive field crops, but more studies have to be conducted under similar field conditions.

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