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# Impact of controlled subsurface drainage on water saving and the productivity of Wheat in north Nile Delta soils (Egypt)

Abo Waly. M.E[a]., S.A. Gaheen[a]., F. F Karageh[b]., M.K. El-Ghannam [c] * and A. A Gendy[c]

[a]Dept. Soil Sci., Fac. Agric., Kafr EL-Sheikh Univ, Egypt
[b]Food and Agriculture Organization, Cairo office, FAO
[c]Soils, Water and Environment Res. Inst., Agric. Res. Center Egypt.

## ABSTRACT

Nowadays, the world and especially arid and semi-arid regions are facing the challenges of providing water and food for the expanding population. These challenges necessitate reducing the losses of irrigation water and optimizing the use of drainage water to maximize the agriculture production. Controlled drainage is an essential component of Integrated Water Resource Management (IWRM) and Water Demand Management (WDM). Controlled drainage can play an important role to save water and nutrients and to improve and optimize downstream water availability and quality. The objectives of study were to determine the effect of controlled drainage on water saving and wheat (Sads12) productivity in north Nile Delta of Egypt.

Results showed that controlled drainage at 40 cm depth of water table reflected the lowest amount of water applied 1870.68 $m^3$/fed, (44.54 cm) in 2013 season distributed on 5 irrigation events and 1879.5 $m^3$/fed as (44.75cm) in 2014 season with 4 irrigation events. Whereas the highest one 2311.68 $m^3$/fed (55.04cm) was recorded with 120 cm in 2013 and 2362.5 $m^3$/fed (56.25 cm) in 2014. Data revealed that by increasing the water applied, less value of water table contribution was obtained. For the treatments 100 cm and 120 cm depth of water table there were no contribution from water table. For the other treatments under the same irrigation events of 5 times 40, 60 and 80 cm depth of water table, the values of contribution were 12 and 9.3 and 5 cm for first season respectively. In the second season, as the same trend of contributions values were 10, 7.3 and 3.5 cm for 40, 60, 80 cm of water table depth respectively.

The obtained data showed that seasonal values of SMD during first season 2013 were 38.43, 40.18, 43.03, 45.09 and 46.92 cm for 40, 60, 80,100 and 120 cm depth of water table respectively. While, the corresponding values were 39.41 and 49.10 cm for the treatment (40 ) and treatment (120) in second season. The other treatments were in between. It can be observed that the most of the water extracted by wheat was removed from the upper (15 cm) of the soil profile and less values were extracted from subsequent layers under controlled drainage, in the two growing seasons.

Data revealed that Showed that the highest values of water productivity were 1.98 and 1.78 kg/m3for 2013 and 2014 respectively at a shallow depth of water tale 40 cm. Whereas the lowest values of water productivity were observed at 120 cm depth, 1.30 and 1.14 kg/m3for 2013 and 2014. Data indicated that wheat yield was significantly affected by watertable depth treatments. Wheat yield was maximum (3190 and 2952.5 kg/ fed) in 2013 and 2014 seasons respectively, at 0.4 m depth, with the water table below this level, wheat yield was reduced.

**Keywords.** Controlled drainage, water saving, watertaable, crop productivity, Nile Delta.

# INTRODUCTION

Today, the world and especially the development countries are facing the challenges of providing water and food for the expanding population. These challenges necessitate reducing the losses of irrigation water and optimizing the use of each drop of water to maximize the agriculture production**. Bahaa (2005)** reported that, Egypt has reached a stage where the quantity of water is imposing limits on its economic development. The present share is below 1000 m3/capita/year, and it is expected to drop to 500 m3/ capita/ year in the year 2025, which would indicate “water scarcity”.

Many of the recent studies indicated the importance of the integration between irrigation and drainage systems to avoid the negative impacts of working separately by each of the systems. Some results of these studies recommended that the maximum intensity provided by surface drains is not usually needed at all times during the growing season, so there is opportunity to reduce drainage rates during some periods without compromising objectives of the drainage system (**Skaggs, 1999).** The new water management tool emphasizes the relation between land functions, water management and aims at managing conflicting objectives. **Wahba et al 2001,** The results of evaluating the different water table management strategies indicate that by increasing the spacing between drains to 2 times the design spacing and applying the controlled drainage (CD) a depth of 60 cm at the beginning of the growing season and switching to the free drainage (FD) during the rest of the growing season about 20% had been saved of irrigation water. By applying the CD at 60 cm at the beginning of the growing season with increasing drain spacing to 1.5 times and switching to the FD at the rest of the season we can save 15% of irrigation water. **Ibrahim and Emara (2009)** stated that deeper uncontrolled water tables also allow increased deep percolation from irrigation which translates to increased drainage flow. Controlled drainage has been applied to conserve water and increase crop yield. It is also effective in reducing losses of plant nutrients and other pollutants to surface waters **(Evans et al. 1996).** The future design of drainage will require that a subsurface drainage system be part of a water management system that includes both irrigation and drainage **(Christen and Ayars, 2001).** Water management techniques may be used to reduce drainage outflow during the growing season of rice. The use of controlled drainage and other water management practices play an important role for reducing the amounts of irrigation water. **Wahba et al (2008**), reported that application of controlled drainage has the potential to maintain and even increase yields per unit land whilst increasing the irrigation water use efficiency (yield per unit water) by 15 - 20%.When the potential on-farm water savings by using controlled drainage are applied to large areas then the potential for water saving in Egypt is large. For the Western Delta area of about 0.4 million ha this could amount to about 0.4 BCM over a two year rotation. These water savings can then allow an increase in cropping intensity or irrigation of new lands. Implementation of subsurface drainage management such as the low cost and easily understood options need to be undertaken as part of an integrated approach to water saving. When controlled drainage is implemented then appropriate reductions in irrigation application needs to occur. This will require coordination and training between irrigation authorities, drainage authorities and farmers. **Awan, et al (2014),** Showed that the soils with shallow groundwater-silt loam (S-SL), medium groundwater-silt loam (M-SL) and deep groundwater-silty clay loam (D-SCL) have capillary rise contribution of 28, 23 and 16 % of the cotton water requirements, 12, 5 and 0 % of the vegetable water requirements and 9, 6 and 0 % for the wheat water requirements, respectively. **El-Nagar (1980)** showed that a contribution from water table to water requirement of corn at 50 to 70 cm depth all over the season was a function of the irrigation treatments and the time of growth. The highest contribution of ground water was 46.82% and 57.67% in case of conventional, -1 bar and -5 bar (water deficit) irrigation treatments. The higher contribution due to the period of growth was during July and August which can be considered as the most active time of the plant life which needs to absorb more water and where the plant were severely stressed. **Tripathi and Mishra (1986).** Found that seasonal evapotranspiration (E) was affected by number of irrigations and water table depths under wheat crop. Water table contribution ranged from 61.6–64.5% of the total E in clay loam, from 39.0–46.8% of the total E in silty clay loam and from 4.0–8.1% of the total E in loam. Irrigations after late jointing contributed largely to the drainage. **Ayars and Hutmacher (1994)** found that use of the modified coefficient resulted in 25% of the cotton water requirement beginning in extracted from shallow groundwater with a salinity of 5 dS/m without any adverse effects on vegetative plant growth and yield. **Kahlown *et al.* (2005)** in Pakistan showed that the contribution of groundwater in metting the crop water requirements varied with the water table depth. With the water table at 0.5 m depth, wheat met its entire water requirement from the groundwater and sunflower absorbed more than 80 percent of its required water from groundwater. Maize and sorghum were found to be water logging sensitive crops whose yields were reduced with higher water table. **Ayars and Shouse (2007)** demonstrated that up 50% of the crop water use could be met from shallow groundwater with an electrical conductivity less than 4 dS/m and that the potential crop water use from deeper groundwater increased over the years. The columns with high salinity in the shallow groundwater experienced increased salinity in the soil profile with time, which resulted in reduced crop water use from shallow groundwater. Crop water use from shallow groundwater improved the water use efficiency of alfalfa crop.

**Cooper *et al.* (1992)** observed a 2-year average yield increase of 43% in sub irrigated soybeans in Ohio. **Madramootoo et al. (1995)** obtained an average soybean yield increase of 35 % with a controlled water table of 0.6 m, over that of conventional drainage. **Liu and Luo (2011)** stated that, the water table contribution should be recognized as the predominant source of evapotranspiration when water table was very shallow (_ 150 cm), and the irrigation and drainage system should be managed to maximize the WUE and yield of winter wheat by controlling water table at desired depth. This study helps to raise the yield of winter wheat and control shallow water tables. **Chaudhary et al (1974),** Showed that, the ground water of 0.5 mmhos/cm at 60 and 90 cm depths gave highest wheat yields. Comparable increase in the salinity of ground water caused greater reduction in yield with shallow water tables than with deep water tables. It is indicated that critical depth of ground water, for optimum crop production, would vary in relation to its salinity. Growth and yield response of wheat to soil submergence was investigated in another set of lysimeters with water table at 60 cm. **Evans and Skaggs (1996)** indicate that managed drainage would increase potential yields by 10% to 20%, compared to conventional subsurface drainage.

The aim of this study is to investigate the impact of different controlled water table levels (controlled drainage) on wheat yield and some water relations, in addition to water uses efficiencies at the different treatments.

## Materials and methods

A Field experiment was conducted in two successive winter seasons during the 2013/2014 and 2014/2015, at Sakha Agricultural Research Station Farm, Kafr El-Sheikh Governorate, Egypt (31˚ 07¯ N and 30˚ 57¯ E, 6m msl). The study area is characterized by semi-arid Mediterranean climatic conditions.

Some physical and chemical characteristics of the soil under investigation are given in Table (1).The area served by tile drainage system, which was adapted to carry out the current study (Fig. 1). It is divided into five treatments each one drained by three laterals connected to riser through a manhole and the drain spacing is 20 m. five drainage treatments were adopted in this study i.e.:

a. Controlled drainage: (1) water table depth is 100 cm below soil surface.
b. Controlled drainage: (2) water table depth is 80 cm below soil surface.
c. Controlled drainage: (3) water table depth is 60 cm below soil surface.
d. Controlled drainage :( 4) water table depth is 40 cm below soil surface.
e. Conventional drainage: (5) drain depth is 120 cm below soil surface.

Construction of c ontrolled drainage system:

"Controlled drainage" a device to the fix the level of ground water to a delimit depths in the different treatments (0, 1, 2, 3, 4) .

Approach needs to be that the irrigation and drainage systems become an integrated water management system. This implies into reactivity between the operation of the irrigation system and the management of the drainage system.

In this instance, the drainage system will be managed to control the flow and water table depth in the course of time in response to the irrigation management and deep percolation.

Controlled drainage devices were installed at different treatments. The system consists of 3" vertical pipe of 120cm height. The riser was connected at the bottom to the lateral inside the manhole. The watertable is controlled at the required level using opened stop-log as follow:

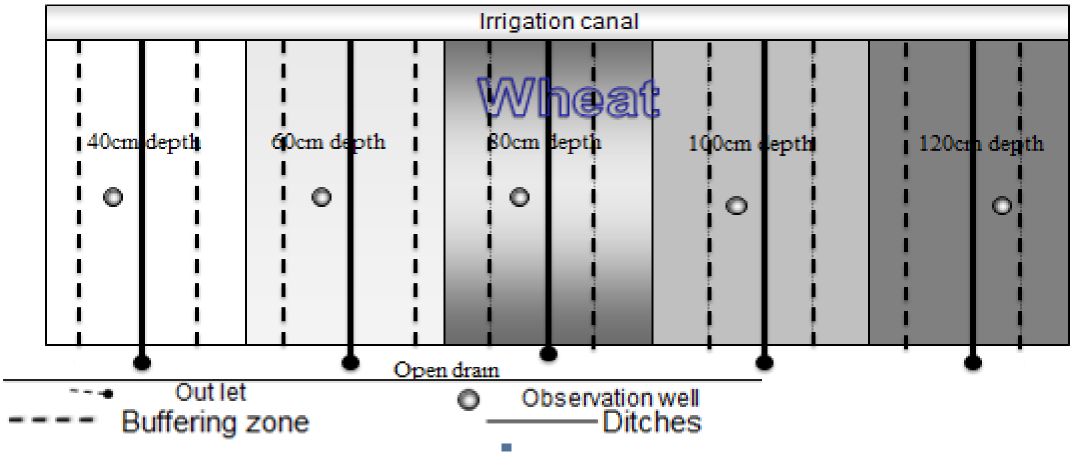

**Fig 2. The layout of the controlled drainage experiment.**

### Agricultural practices:

- Wheat crop:

Wheat crop (variety Sids 12) was sown on the 30th of November, 2013. Harvesting date was on the 15th of May, 2014. At the same time, wheat was sown and harvested during winter season 2015. Nitrogen, phosphorus, and potassium fertilizers were added according to the recommended doses of North Delta area.

- **Soil samples:**

Soil samples were collected from soil surface down to the watertable depth each 30cm intervals. Soil samples were collected for chemical and physical properties analysis. Soil samples were analyzed according to recommended methods as shown in table (1).

**Wheat yield and yield components:**

**Wheat crop:**

- Grain yield: the grains of each plot were collected from the harvested plants, weighed and the grain yield was expressed as kg/ha.
- Straw yield: it was calculated by subtracting the grain yield from the total biological yield and expressed as kg/ha.
- 1000 grain weight were counted and weighed in gm/1000 grain
- Harvest index: it was calculated according to the following formula (Wheeler 1994):

$$Harvest\ Index = \frac{grain\ yield}{biological\ yield}$$

**Table (1). Some physical and chemical properties for the soil at the experimental site.**

| Parameter | Value |
|---|---|
| 1- Physical properties : | |
| - Particle size distribution (%) | |
| Clay | 50.03 |
| Silt | 33.27 |
| Sand | 16.70 |
| Texture class | Clay |
| Bulk density | 1.21 |
| - Field capacity (%) | 39 |
| - Welting point (%) | 21 |
| - Available water (%) | 18 |
| 2- Chemical analysis : | |
| ECe (dS/m) | 1.29 |
| pH | 8.05 |
| - Soluble cations (meq/l) | |
| Na+ | 7.30 |
| K+ | 0.16 |
| Ca++ | 4.20 |
| Mg++ | 5.13 |
| - Soluble anions ( meq/l) | |
| CO3- | 0.00 |
| HCO3-- | 3.40 |
| SO4-- | 7.79 |
| Cl- | 5.60 |

**Some water relations:**

- **Applied irrigation water**:

Amounts of applied irrigation water were measured using a weir installed in the main irrigation canal. Applied water was calculated according to:

$$Q = 1.84\, L\, (H)^{1.5}$$

Where: Q is the amount of applied water ($m^3/s$), L is the weir's width, and H is the head above the weir.

- **Water applied (Wa):**

Water applied (Wa) was calculated as**, Giriapa (1983):**

$$\mathbf{Wa = Iw + Re + S}$$

Where:

Iw = irrigation water applied
Re = effective rainfall
S = amount of soil moisture contributing to consumptive use either from stored moisture in root zone and / or that from shallow water table.

- **Soil moisture depletion (SMD)**:

Soil moisture depletion was calculated using the following equation (Hansen *et al.*, 1979).

$$\mathbf{Cu} = \sum_{i=1}^{1=4} D_1 \text{ x } D_{b1} \text{ x } \frac{PW_2 - PW_1}{100}$$

CU = Water consumptive use (cm)
$D_1$ = Soil layer depth (15 cm each).
$D_{b1}$ = Soil bulk density, ($Mg/m^3$) for this depth.
$PW_1$ = Soil moisture percentage before the next irrigation (on mass basis, %).
$PW_2$ = Soil moisture percentage, 48 hours after irrigation (on mass basis, %).
I = Number of soil layers each (15 cm) depth

- **Crop coefficient adjusted for the contribution of the water table ($K_{cw}$)**

The crop coefficient $K_c$ is generally obtained from the ratio $ET_c$ / $ET_0$. But under conditions of high water table (the present case), $ET_c$ cannot directly determined. SMD may be used instead of ETc.

**Table (2): Reference evapotranspiration ($ET_0$), Kc (FAO), $ET_c$ mm/day and $ET_c$ mm/month**

| **Months.** | **Dec.** | **Jan.** | **Feb.** | **March.** | **April.** | **May.** | **June.** |
|---|---|---|---|---|---|---|---|
| Wheat | | | | | | | |
| $ET_0$ mm/day | 1.7 | 1.8 | 2.30 | 3.30 | 4.40 | 5.50 | 5.90 |
| Kc (FAO) | 0.7 | 0.7 | 1.15 | 1.15 | 1.15 | 0.33 | 0.33 |
| $ET_c$ mm/day | 1.2 | 1.25 | 2.65 | 3.80 | 5.06 | 1.82 | 2 |
| $ET_c$ mm/month | 37.2 | 38.75 | 74.2 | 117.8 | 151.8 | 56.42 | 60 |

- **FAO Penman-Monteith**

FAO-PM shows the best performance under both humid and arid conditions, although a slight underestimation is observed in arid zones during the summer months. FAO-PM is recommended as the standard method for ETo estimate.

- **Contribution of the ground water table (S):**

Water movement by capillary rise from water table into active plant root zone is recognized as an important supplementary water resource for irrigation. The contribution of groundwater as percentage of the consumptive use was calculated as follow:

$$\mathbf{S = [( ET_c - SMD)}$$

Where :

$ET_c$ = Crop evapotranspiration = $ET_0 \times K_c$
SMD = Soil moisture depletion.

- **Determination of soil moisture percentage:**

Soil moisture samples were taken before and after each irrigation from each plot with an auger at depths of 0-20, 20-40, and 40-60cm. The samples were immediately transported in tightly closed aluminum cans and weighed in the laboratory, then dried in an oven on 105°C for 24 hours and reweighed to calculate their moisture content as described by **Garcia (1978).** And moisture, salinity and temperature were measured by TDR, time domain reflect meter in the field.

- **Soil moisture extraction pattern (SMEP):**

It was calculated according to Israelson and Hansen (1962) as follows:

$$SMEP = \frac{SME\ per\ layer}{Total\ SME}$$

Where: SME per layer = soil moisture extracted for specific layer.
Total seasonal SME = total of the SME for all layers.

- **Productivity of irrigation water (PIW):**

It was calculated according to the following formula (**Ali et al 2007**):

$$\boxed{\text{PIW}} = \frac{Yield\ (kg)}{m^3\ water\ applied}$$

- **Water productivity (WP):**

It was calculated according to the following formula **(Ali et al 2007**)

$$\boxed{\text{WP}} = \frac{Yield\ (kg)}{m^3\ water\ consumed}$$

- Statistical analysis

All the collected data for the yield and yield components of wheat crop was subjected to the statistics analysis according to **Snedecor and Cochran (1967)** and the mean value were compared by L.S.D test at 5% probability level.

## RESULTS AND DISCUSSION

### Some water relations

### 1- Effect of controlled subsurface drainage on amount of water applied under wheat crop during the two growing season 2013 and 2014:

Results of water applied under different controlled drainage treatments are presented in Table (3) and fig. (3). The seasonal water applied (Wa) consists of three components; irrigation water (I.W), rainfall (R) and contribution of water table (S). Results showed that controlled drainage at 40 cm depth of water table reflected the lowest amount of water applied 1870.68 $m^3$/fed, (44.54 cm) in 2013 season distributed on 5 irrigation events and 1879.5 $m^3$/fed as (44.75cm) in 2014 season with 4 irrigation events. Whereas the highest one 2311.68 $m^3$/fed (55.04cm) was recorded with 120 cm in 2013 and 2362.5 $m^3$/fed (56.25 cm) in 2014. Difference in amount of water applied under controlled drainage treatments may belong to the mean rainfall and ground water table contributions. The decreasing of water applied under 40cm depth of water table might be due to maintaining of shallow water table depth by a control structure which reduces the deep percolation below the root zone by reducing hydraulic gradients and increases potential capillary up flow through careful water management at acceptable depth for the purpose of plant water used.

Also the managing of water table position will provide the opportunity to increase crop water use in situ, which should result in improved irrigation efficiency and reduced drainage flow **(Ayars and Meek, 1994).**

In 2013 season, the amount of water saving for wheat crop under different treatments were 441, 323.4, 147, and 105 $m^3$/fed, for the 40, 60, 80, and 100 cm water table depths, respectively as compared to the 120 cm depth. Concerning water table saving under wheat crop, the 40 cm depth of controlled drainage saved about 19.1% of irrigation water, meanwhile, the 100 cm depth realized less percentage of water saving of 4.3% as compared to 120 cm depth. The same trend was found for 2014 season, the results indicated that, the 40 cm treatment saved about 483 $m^3$/fed, or about 20.44% of applied irrigation water as compared to the 120cm depth treatment. These findings are in a great harmony with those obtained by **(Wahba, etal 2003),** they reported that, the evaluating of different water table management strategies indicate that by increasing the spacing between drains to 2 times the design spacing and applying the controlled drainage (CD) at depth 60 cm at the beginning of the growing season and switching to the free drainage (FD) during the rest of the growing season we can save about 20% of irrigation water. By applying the CD at 60 cm at the beginning of the growing season with increasing drain spacing to 1.5 times and switching to the FD at the rest of the season we can save 15% of irrigation water.

The amounts of rainfall were sharing in water applied with 0.54 cm in 2013 and 9.25 cm in 2014.

**Table (3). Seasonal irrigation water applied (IW), rainfall (R) , contribution from water table (S) , seasonal water applied (Wa)and contribution of ground water as percentage (%) for wheat in the two seasons .**

| Season 2013 | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Treats | IW | | R | S | Wa | Wa | Water saving | | Cont. | |
| | No | Cm | cm | cm | cm | $m^3$/fed | $m^3$/fed | % | $m^3$/fed | % |
| T 40 | 5 | 32 | 0.54 | 12 | 44.54 | 1870.68 | 441 | 19.1 | 504 | 26.9 |
| T 60 | 5 | 37.5 | 0.54 | 9.3 | 47.34 | 1988.28 | 323.4 | 14 | 390.6 | 19.6 |
| T 80 | 5 | 46 | 0.54 | 5 | 51.54 | 2164.68 | 147 | 6.5 | 210 | 9.7 |
| T 100 | 5 | 52 | 0.54 | 0 | 52.54 | 2206.68 | 105 | 4.3 | 0 | 0 |
| T 120 | 5 | 54.5 | 0.54 | 0 | 55.04 | 2311.68 | 0 | 0 | 0 | 0 |
| Season 2014 | | | | | | | | | | |
| T 40 | 4 | 25.5 | 9.25 | 10 | 44.75 | 1879.5 | 483 | 20.44 | 420 | 22.3 |
| T 60 | 4 | 30.8 | 9.25 | 7.3 | 47.35 | 1988.7 | 373.8 | 16 | 306.6 | 15.4 |
| T 80 | 4 | 39 | 9.25 | 3.5 | 51.75 | 2173.5 | 189 | 8 | 147 | 6.7 |
| T 100 | 4 | 45.5 | 9.25 | 0 | 54.75 | 2299.5 | 63 | 2.6 | 0 | 0 |
| T 120 | 4 | 47 | 9.25 | 0 | 56.25 | 2362.5 | 0 | 0 | 0 | 0 |

**Fig. (3): Seasonal amounts of water applied for different treatments as affected by controlled drainage under wheat crop.**

### 2. Contribution of water table in crop water needs (%):

Shallow ground water is a resource that is routinely overlooked when water management alternatives are being considered in irrigated agriculture. Even though, it has the potential to provide significant quantities of water for crop use under the proper conditions.

Contribution of water table to crop consumptive use is due to either capillary rises or penetration of roots to reach the capillary fringe of water table. Contribution of water table to crop water needs was calculated according to FAO Paneman monteith equation:

Contribution of water table values to crop evapotranspiration during the two seasons are given in Table (3). Data revealed that by increasing the water applied, less value of water table contribution was obtained. For the treatments 100 cm and 120 cm depth of water table there were no contribution from water table. For the other treatments under the same irrigation events of 5 times 40, 60 and 80 cm depth of water table, the values of contribution were 12 and 9.3 and 5 cm for first season respectively. In the second season, as the same trend of contributions values were 10, 7.3 and 3.5 cm for 40, 60, 80 cm of water table depth respectively.

Raising the outlet or closing the valves at predetermined depths to maintain the water table at a shallow depth induces capillary rise in the root zone, in this way plants meet part of their evapotranspiration needs directly from soil water.

These findings are in agreement with those obtained by **kahlown etal (2005**), they showed that the contribution of ground water in meeting the crop water requirements varied with the water table depth. With the water table at 0.5 m depth, wheat met its entire water requirements from the ground water and sunflower absorbed more than 80% of its required water from ground water.

On the other hand, contribution of water table was increased directly at shallow water table. Data suggest the rearrangement of the irrigation regime through two ways, first by applying less water during the growth stages to minimize the volume of water percolated to the ground water aquifer and second by increasing the irrigation interval, but not to degree of the significant decrease in crop production.

These findings are in agreement with those obtained by **El-Nagar (1980) and Eid (1994)**, they reported that the percentage of groundwater contribution differed according to growth stage and irrigation treatments. They added that the higher contribution due to the stage of growth was during April period which can be considered as an active stage to the plant which needs to absorb more water and where the plants were severely stressed.

### 3. Crop water consumptive use (CU):

Crop water consumptive use may be referred to as crop evapotranspiration (Etc) computed on the basis of soil moisture depletion from the effective root zone (60 cm) depth or so-called the direct method for determining Etc.

Values of seasonal SMD in cm are presented in Table (4) for wheat crop under different controlled drainage treatments 2013 and 2014. The obtained data showed that seasonal values of SMD during first season 2013 were 38.43, 40.18, 43.03, 45.09 and 46.92 cm for 40, 60, 80,100 and 120 cm depth of water table respectively. While, the corresponding values were 39.41 and 49.10 cm for the treatment (40 ) and treatment (120) in second season. The other treatments were in between.

The maximum water depletion value of wheat crop under control conditions (120 cm depth of water table) was about 49.10 cm, then decreased directly with managing of water table depth. This finding indicated that, in general, to get the maximum soil moisture depletion which consists of water consumed by growing plants and or the water percolated downward. In other words, the controlled drainage at 40 cm depth of water table could be minimized the value of SMD. This result could be explained by the fact that under the conditions of heavy clay soil and shallow water table of the Nile Delta, high probability for the feeding of the water table aquifer from the applied irrigation water could be existed. This result was in the same direction with those reported by **Eid (1994)** and **Ibrahim and Emara (2009).**Deeper uncontrolled water table also allow to increase deep percolation from irrigation water which translates to increase drainage flow.

**Tab (4). Monthly and seasonal water consumptive use (CU= SMD) for wheat crop as affected by different controlled drainage treatments**

| treatments | Monthly consumptive use ( SMD), cm (2013) | | | | | Seasonal | |
|---|---|---|---|---|---|---|---|
| | Dec. | Jan. | Feb. | Mar. | April | cm | $m^3$/fed |
| 40 | 8.55 | 7.50 | 6.97 | 6.41 | 9.00 | 38.43 | 1614.06 |
| 60 | 8.64 | 6.46 | 7.22 | 7.97 | 9.89 | 40.18 | 1687.56 |
| 80 | 6.64 | 5.48 | 8.95 | 9.35 | 12.61 | 43.03 | 1807.26 |
| 100 | 5.9 | 3.99 | 8 | 12 | 15.2 | 45.09 | 1893.78 |
| 120 | 6.5 | 4.51 | 8.21 | 12.25 | 15.45 | 46.92 | 1970.64 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Monthly consumptive use ( SMD), cm (2014) | | | | | | | |
| 40 | 7.95 | 6.90 | 7.60 | 7.28 | 9.68 | 39.41 | 1655.22 |
| 60 | 8.00 | 6.30 | 7.50 | 8.78 | 10.85 | 41.43 | 1740.06 |
| 80 | 6.35 | 5.90 | 8.13 | 10.28 | 13.18 | 43.84 | 1841.28 |
| 100 | 5.40 | 5.60 | 7.69 | 12.50 | 15.55 | 46.74 | 1963.08 |
| 120 | 6.35 | 6.30 | 9.33 | 12.45 | 15.67 | 49.10 | 2062.20 |

### 4. Soil moisture extraction patterns for wheat crop as affected by different water table depth treatments:

Results of soil moisture extraction pattern (SMEP) are presented in Table (5) for the successive soil depths by roots of wheat, as affected by controlled drainage treatments in both seasons. It can be observed that the most of the water extracted by wheat was removed from the upper (15 cm) of the soil profile and less values were extracted from subsequent layers under controlled drainage, in the two growing seasons. With regard to controlled drainage, data in table (5) showed that the values of SMEP for the first 30 cm of soil depth were (72.20, 68.17, 65.68, 63.58 and 61.63 %) in the first season and (69.50, 67.30, 63.45, 61.45 and 60.90 %) in the 2nd season, for 40, 60, 80, 100 and 120 cm depth of water table treatments respectively. The values of SMEP for the successive depths were (27.80, 31.83, 34.32, 36.42 and 38.37 %) in the first season and (30.50, 32.70, 36.55, 38.45 and 39.1 %) in the second season 2014, for 40, 60, 80, 100 and 120 cm depth of water table treatments respectively.

Regarding the effect of water table depth, data indicated that, the highest percentage of the moisture uptake by wheat roots occurred at the surface 30 cm of the soil profile (72.20 and 69.50 %) at 40 cm water tale during the 1st and 2nd growing seasons. While the lowest values of SMEP (61.63 and 60.90 %) were detected in the 0-30 cm soil layer under 120 cm depth for the 1st and 2nd growing seasons.

It was most probable that wheat roots extracted water from shallow soil layers during the early stages of growth, then moisture extraction extended vertically and to lower depths until most of the available moisture had been extracted. This finding could be attributed to the fact that most of plant roots are concentrated in the upper soil layers and those roots are the most effective in water extraction. Similar results were obtained by **Emara etal (2000).**

**Table (5). Soil moisture percentage extracted by wheat roots from different layers as affected by water table depths.**

| Water table depth (cm) | Soil moisture extraction pattern (%) season2013 | | | | Total surface layer (%) | Total subsurface layers (%) |
|---|---|---|---|---|---|---|
| | Soil layers (cm) | | | | | |
| | 0-15 | 15-30 | 30-45 | 45-60 | | |
| 40 | 41.38 | 30.82 | 16.65 | 11.15 | 72.20 | 27.80 |
| 60 | 39.58 | 28.59 | 17.15 | 14.68 | 68.17 | 31.83 |
| 80 | 38.50 | 27.18 | 18.70 | 15.62 | 65.68 | 34.32 |
| 100 | 36.62 | 26.96 | 21.50 | 14.92 | 63.58 | 36.42 |
| 120 | 35.15 | 26.48 | 22.90 | 15.47 | 61.63 | 38.37 |

| Soil moisture extraction pattern (%) season2014 | | | | | | |
|---|---|---|---|---|---|---|
| 40 | 40.35 | 28.95 | 17.05 | 13.45 | 69.50 | 30.50 |
| 60 | 38.75 | 28.55 | 17.90 | 14.60 | 67.30 | 32.70 |
| 80 | 37.65 | 26.00 | 19.10 | 17.45 | 63.45 | 36.55 |
| 100 | 36.15 | 25.40 | 20.10 | 18.35 | 61.55 | 38.45 |
| 120 | 35.95 | 24.95 | 20.50 | 18.60 | 60.90 | 39.10 |

## 5. Water use efficiencies of wheat crop during 2013 and 2014 seasons.

### 5.1. Water productivity (WP) of wheat

Water use efficiency determines the capability of the plants to convert water consumed to crop yields. It could be evaluated by wheat yield. The obtained results in table (6) Showed that the highest values of water productivity were 1.98 and 1.78 kg/m3for 2013 and 2014 respectively at a shallow depth of water tale 40 cm. Whereas the lowest values of water productivity were observed at 120 cm depth, 1.30 and 1.14 kg/m3for 2013 and 2014, it was reduced when wheat yield decreased. Other values of water productivity in the between.

Sorour etal (2009) and Khalifa (2013), found that decreasing water supply to wheat resulted in increasing water use efficiency.

### 5.2. Productivity of irrigation water (PIW)

Productivity of irrigation water (PIW) for wheat crop as affected by water table depth treatments are presented in Table (6), the obtained results revealed that the highest mean value of PIW (1.71 and 1.57 kg grain/m3) for 2013 and 2014, respectively was recorded under the 40cm depth of water table, followed by the 60cm treatment (1.55 kg grain/m3 in 2013 and 1.40 in 2014). While, the lowest mean value of 1.11 and 0.99 kg grain/m3 for 2013 and 2014 respectively, was obtained under the 120cm treatment.

These findings explained that PIW is affected by yield as nominator and water applied as dominator. So, by increasing the dominator of water applied, decreasing in water utilization efficiency could be attained and vise versa. These results are in somewhat agreed with those obtained by **Sonbol etal (2010) and Koksal etal (2011).**

This has led to extensive problems with large volumes of drainage water being generated and hence disposal problems and also reduced irrigation water use efficiency **(Christen and Ayars 2001).**

**Table (6). Wheat water use efficiencies as affected by different water table depths.**

| Treatment | Grain yield (kg/fed) | Total water applied (m3/fed) | Actual water consumptive use (m3/fed) | PIW (kg/m3) | WP (kg/m3) |
|---|---|---|---|---|---|
| **Water use efficiencies 2013** | | | | | |
| 40 | 3190 | 1870.68 | 1614.06 | 1.71 | 1.98 |
| 60 | 3081 | 1988.28 | 1687.56 | 1.55 | 1.83 |
| 80 | 2865 | 2164.68 | 1807.26 | 1.32 | 1.58 |

| | | | | | |
|---|---|---|---|---|---|
| 100 | 2706 | 2206.68 | 1893.78 | 1.23 | 1.43 |
| 120 | 2568 | 2311.68 | 1970.64 | 1.11 | 1.30 |
| **Water use efficiencies 2014** | | | | | |
| 40 | 2952.5 | 1879.5 | 1655.22 | 1.57 | 1.78 |
| 60 | 2776.25 | 1988.7 | 1740.06 | 1.40 | 1.60 |
| 80 | 2633.5 | 2173.5 | 1841.28 | 1.21 | 1.43 |
| 100 | 2518.5 | 2299.5 | 1963.08 | 1.10 | 1.28 |
| 120 | 2340.75 | 2362.5 | 2062.20 | 0.99 | 1.14 |

### 6. Wheat productivity as affected by controlled drainage during the two successive seasons.

The crop growth and subsequently the yield primarily depend on the favorable environment in the root zone, rooting depth, sensitivity of crop for water etc. The effects of different water table depths on wheat yield during the two growing seasons 2013 and 2014 are shown in table (7). Wheat yield was maximum (3190 and 2952.5 kg/ fed) in 2013 and 2014 seasons respectively, at 0.4 m depth, with the water table below this level, wheat yield was reduced. This reduction however, was more pronounced at 1.2 m depth probably due to less availability of water for crop use and low soil fertility.

It worth to mention that, wheat straw yield was significantly affected by the water table depth treatments. The highest mean values of 2888 and 2631.5 kg /fed in 2013 and 2014 seasons respectively were produced from the 40cm depth treatment. On the other hand, the lowest value of 2170 and 2238 kg /fed were recorded for the 120cm depth treatment. **(Wahba, et al. 2008)** reported that application of controlled drainage has the potential to maintain and even increase yields per unit land whilst increasing the irrigation water use efficiency (yield per unit water) by 15-20 %

It was observed that the controlled drainage at 0.4 m depth, increased the green yield of wheat by 19.5 and 20.7 % in 2013 and 2014 seasons, respectively compared the free drainage. This suggests that this practice could generate more profit than free drainage fields.

It can be clearly seen that, the wheat productivity values were decreased from 3190 to 2952.5 kg/fed in 2013 and 2014 season respectively, may be due to the stripe rust is most common and important wheat disease in 2014 season. It caused severe losses in grain yield **(Abu-Naga et al.,2001).**

**Tab (7). Effect of water table depth on yield and yield components of wheat**

| Treatments | Yield (kg/fed) | Straw (kg/fed) | H.I. | 1000 Grain (g) |
|---|---|---|---|---|
| Wheat yield 2013 | | | | |
| 40 | 3190 a* | 2888 a* | 52.48 b | 67.57 a |
| 60 | 3019 b | 2596 b | 53.77 a | 66.20 b |
| 80 | 2865 c | 2485 c | 53.55 a | 64.42 c |
| 100 | 2706 d | 2280 d | 54.24 a | 63.30 d |
| 120 | 2568 e | 2170 e | 54.18 a | 61.25 e |

| | | | | |
|---|---|---|---|---|
| F-test | * | * | NS | * |
| LSD 0.05 | 54.79 | 75.68 | 0.742 | 0.74 |
| LSD 0.01 | 76.8* | 106.08* | 1.04 | 1.037 |
| Wheat yield 2014 | | | | |
| 40 | 2952.5a* | 2631.5*a | 52.87a | 64.97a |
| 60 | 2776.25b | 2491.75b | 52.70b | 62.19b |
| 80 | 2633.5c | 2359.5c | 52.70b | 60.67c |
| 100 | 2518.5d | 2305d | 52.21b | 58.16d |
| 120 | 2340.75e | 2238e | 51.12b | 57.48e |
| F-test | * | * | NS | * |
| LSD 0.05 | 52.56 | 74.62 | .865 | .81 |
| LSD 0.01 | 74.5* | 109.44* | 1.55 | 1.155 |

## Conclusion:

1. The study focused on the validity of the controlled drainage concept from the point of view of saving irrigation water. CD saved 20 % for wheat crop of the irrigation water.
2. Raising the outlet or closing the valves at predetermined depths maintains the water table at a shallow depth induces capillary rise in the root zone, in this way plants meet part of their evapotranspiration needs directly from soil water. The values of contribution were 12 and 9.3 and 5 cm under wheat crop for 40, 60, 80 cm of water table depth respectively.
3. Controlled drainage increased yield by 19.5 % of wheat crop at shallow water table depth compared the free drainage can provide more profit to the framers.

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