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# Evaluating The Impact of Deficit Irrigation Scenarios on Paddy Rice at The Nile Northern Delta, Egypt

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## ABSTRACT

Deficit irrigation is considered an effective technique to increase water productivity under limited water conditions. Especially in the case of rice, one of the largest crops consuming water, efforts are being try to find ways to rationalize and increase water productivity. For this purpose, an experiment was conducted to estimate the impact of deficit irrigation scenarios during summer seasons 2018 and 2019 in a randomized complete block design with three replications. A medium duration variety (Giza178) was chosen for the study. Three deficit irrigation scenarios were applied (low, moderate, and high-water stress levels) which applied to three crop growth stages; vegetative (VEG.), reproductive (PRO.), and repining (RIP), in addition to the full growth period (FULL). Measurements included: [grain yield production (tons/ha), harvest index (%), weight of 1000 grains (g), and grain filling ratio (%)]. The water use estimation includes: [Water productivity (WP) and evapotranspiration productivity (ETWP)]. The results showed a high correlation between grain production and actual evapotranspiration ($ET_a/ET_m$). Compared to the fully irrigated treatment, yield production at ripening stage treatments (8.52ton/ha) has the lowest reduction where the water productivity was 0.65 kg/m$^3$, while the reproductive growth stage produced the lowest yield production and water productivity (6.96 ton/ha, 0.51 kg/m$^3$).

***Keywords**: Deficit Irrigation - Growth Stages – Water Stress – Rice*

## INTRODUCTION

Water stress has a great impact in plant health. Thus, the reduction of the crop production occurs as an inevitable consequence. Subsequently, the water shortage affects the food security. Since the fresh available water in the world is limited, So, increasing food production must come in parallel with increasing water productivity (WP).

In order to cope with scarce supplies, (Fereres and Soriano, 2007) defined deficit irrigation as the application of water below full crop-water requirements, which is an important tool to achieve the goal of reducing irrigation water use. Deficit irrigation strategy aims to increase agricultural water productivity by reducing the volume of water while maintaining acceptable levels of production (Food and Agriculture Organizations, 2012).

The available water resources for use in Egypt are 56.9 BCM/yr includes the Nile River which is the essential water resource that shares 55.5 BCM/yr for Egypt, in addition to the other secondary water resources. On the other hand, the water requirements for various sectors were estimated 79.5 BCM/yr. As a result, by 2025, Egypt will have exceeded the absolute water scarcity threshold (500 m$^3$ /ca/yr) (Ministry of Irrigation and Water Resources, 2014). Many challenges are found in the demand side, including seepage losses from canals and drains, evaporation loss from water surfaces, evaporation losses so as infiltration losses from agricultural lands and aquatic weeds in canals (Omar and Moussa, 2016). The fast filling of The Grand Ethiopian Renaissance Dam (GERD) has an impact on the Nile Basin hydrology and specifically the water storages increasing the risk of drought occurrence on Egypt (Kansara *et al.*, 2021). Rice is the dominating crop due to its low cultivation costs, as well as a solution to the soil salinity problem in the northern Nile Delta caused by seawater intrusion from the Mediterranean Sea (Ali *et al.*, 2020).

Paddy rice fields are grown at saturated (anaerobic) soil conditions. Rice irrigation water is used for land preparation and compensating the water losses by seepage, percolation, evaporation and transpiration (Bouman *et al.* 2007). Rice yield production is influenced by water stress according to the growth stage. Applying deficit irrigation during vegetative, flowering and grain filling stages reduced mean grain yield by 21, 50 and 21% on average in comparison to control respectively (Sarvestani *et al.*, 2008). Vegetative and ripening periods are more tolerant to water stress compared to head development and flowering (S. Lee *et al.*, 2012). Also, (Yang *et al.*, 2019) found that the drought stress at flowering stage has a strong influence on rice physiological traits and yield. When soil water tension was kept below 20 kPa, rice growth and grain yield were unaffected; however, water tensions of 40 kPa caused issues according to (Germani *et al.*, 2016). (Hassanein *et al.*, 2009)suggested that Giza 178 was the more tolerant of water stress than the other types evaluated, resulting in the highest absolute and relative grain yield per feddan.

The aim of this study was evaluating the impact of different deficit irrigation scenarios to be applied to each growth stage and whole season by yield production measurements and water use estimations.

## MATERIALS AND METHODS

**Experimental site:**

A field was chosen to conduct the field experiment which is located at 31°13'28" N and 31°17'58"E, at an altitude

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of 10 m above mean sea level. The field is irrigated directly from the Bahr Elmassara secondary canal. thus, irrigation water is readily available. The experiment was conducted during the summer seasons of 2018 and 2019. In order to estimate the soil characteristics, slope measurement, mechanical, hydrological, and chemical analysis were conducted Table (1). Mechanical and hydrological analysis were carried out for irrigation water requirements calculations. On the other hand, chemical analysis (included the major and minor elements content), assist on the preparation of the fertilizing program. Other measurements are conducted for field slope measurement using automatic level machine.

**Table 1. Slope measurement, mechanical, hydrological, and chemical analysis**

| **Slope measurement** | | | | | | |
|---|---|---|---|---|---|---|
| Slope | 10 mm/m | | | | | |
| | | | Mechanical analysis | | | |
| Particle Size Analysis<br>Clay (%) | Silt (%) | Sand (%) | Soil texture | Bulk density | | |
| 36 | 51% | 13 | Silt Clay loam | 760 kg/m$^3$ | | |
| | | | Hydrological analysis | | | |
| Saturation percentage (%) | Field capacity (%) | Permanent wilting point (%) | Hydraulic conductivity | | | |
| 85.9 | 42.9 | 21.5 | 9.3 mm/h | | | |
| | | | Chemical analysis | | | |
| Major elements (ppm) | Nitrogen | Phosphor | Potassium | | | |
| | 61.425 | 12 | 120 | | | |
| Minor elements (meg/100g) | Bicarbonate | Chloride | Sulfate | Calcium | Sodium | Magnesium |
| | 0.2 | 1.83 | 3.65 | 1.98 | 3.48 | 0.15 |
| Water Electrical Conductivity | 0.60 dS/m. | | | | | |
| Soil Electrical Conductivity (extract 1/5) | 1.11 dS/m | | | | | |
| Total soluble saults (%) | 0.36 | | | | | |
| pH | 7.44 | | | | | |
| Organic Matter (%) | 3 | | | | | |

**Experimental setup:**

Under the factorial scheme (3 x 4 + 1), the experiment was set up as a Randomized Complete-blocks Design with 3 replicates including four randomized test blocks for the whole growth period (FULL) and the three main growth stages: vegetative (VEG), reproductive (PRO), and ripening (RIP). Each of the four blocks is divided into three different treatment plots for deficit irrigation scenarios: low, moderate, and high-water stress, which was determined as 90, 75, and 60 % of Readily Available Water (RAW) respectively. In addition, the additional treatment plot (CONTROL) represents the full irrigation at 100% of RAW. The total numbers of plots are 39 for each season with dimensions of 5 m x 5 m each. The experimental layout design is shown in Fig (1). The medium duration variety (Giza178) was chosen for the study. Giza 178 is one of the major varieties in Northern Delta due to its high grain yield production (10-12 ton/ha) and resistance to the drought (Tantawi Badawi and Ghanem S.A., 1999).

| | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| R1 | CONTROL | RIP60 | RIP75 | RIP90 | PRO60 | PRO75 | PRO90 | VEG60 | VEG75 | VEG90 | FULL60 | FULL75 | FULL90 |
| R2 | FULL60 | FULL75 | FULL90 | VEG60 | VEG75 | VEG90 | CONTROL | RIP60 | RIP75 | RIP90 | PRO60 | PRO75 | PRO90 |
| R3 | PRO60 | PRO75 | PRO90 | RIP60 | RIP75 | RIP90 | FULL60 | FULL75 | FULL90 | VEG60 | VEG75 | VEG90 | CONTROL |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| CONTROL | 100 % | Vegetative Stage (VEG) | 85 - 90 %<br>70 - 75 %<br>55 - 60 % | Reproductive Stage (PRO) | 85 - 90 %<br>70 - 75 %<br>55 - 60 % | Ripening Stage (RIP) | 85 - 90 %<br>70 - 75 %<br>55 - 60 % | Full Growth Season (FULL) | 85 - 90 %<br>70 - 75 %<br>55 - 60 % |

**Fig .1. the experimental layout design**

**Development Irrigation Equipment:**

A movable equipment Fig (2), was developed for determination, distribution, and controlling the specified irrigation water applied amounts (m3) for each plot.

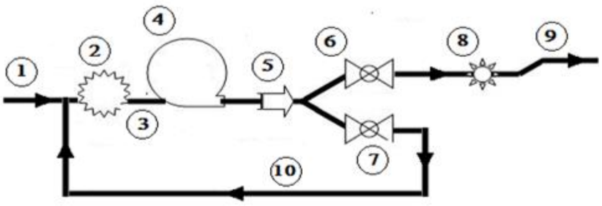



**Fig .2. Schematic diagram for the movable irrigation equipment**

**1- Open ditch 2- Pre filter 3- Water pump suction hose 4- Centrifugal pump with engine 5- Check valve 6- Manual Ball Valve 7- Backflow Ball Valve 8- Water meter 9- Distributor Hose 10- Safety Back Hose**

The main components of the equipment are: a centrifugal water pump with engine for lifting water from water ditches (diameter: 80 mm, capacity: 66.7 m3/hr, total lift: 25.9 m, power: 4.8 hp). and Cast-Iron Industrial Water Meter Horizontal Dry Dial (LXLG-800B) were installed at metal frame and provided with solid rubber wheels for flexible movement to all plots.

**Field management:**

The nursery area was selected near the experiment field with 100m$^2$ of area. The land was tilled and filled to saturation for three days before seeds broadcasting. The area was puddled in the third day to reduce percolation rate; therefore. Then, pre-germinated seeds are sown at the rate of 1.2 kg/m$^2$ (at 14 May 2018 and 18 May 2019) for first and second summer seasons respectively. Plots were soaked at soil saturation one day before transplanting. The seedlings were manually transplanted with 20cm × 20cm spacing into the experimental plots (at 17 June 2018 and 21 June 2019). The irrigation treatments started after 10 days of transplanting. All field management procedures include: tilling, leveling, fertilization, seeding, transplanting spacing, and weed and pest resistance were applied equally for all plots according to Agricultural Research Center recommendations and the Preliminary tests.

**Experimental measurements:**

These measurements included irrigation water scheduling measurements and measurements of evaluating deficit irrigation (DI) scenarios.

**1. The irrigation water scheduling measurements**

The measurements were carried out before irrigation directly to calculate the irrigation water requirements by measuring effective root zone depth and soil moisture content (SMC). SMC was measured by oven dry method and using soil moisture meter PMS-714.

**2. Evaluating DI scenarios measurements**

These measurements were conducted after harvesting (at 19 September 2018 and 21 September 2019). 25 seedlings were impartially selected and automatically threshed for each plot of the 39 plots. then the measurements were carried out as follows:

1. Grain yield weight, gm: After threshing, the grain yield (Y) was measured. The grain yield and straw were normalized to a moisture content of 14% according to (Murugan and Ranjit Singh, 2012).
2. Straw yield weight, gm: Before threshing, the biomass was weighted. Then the straw weight (St) is the subtract of the grains weight from the full seedling weight.
3. Water content in grains, %: Moisture content in grains was measured by Handheld Portable Rice Moisture Meter.
4. Water content in straw, %: The water content of straw was measured with by Oven dry method
5. 1000 grains weight ($W_g$), gm: grains of each plot were counted manually then the weight was measured.
6. Grains filling ratio ($F_g$), %: The grains samples were taken for each plot and its weight was measured ($G_W$). Then, the empty grains were separated by a Laboratory Aspirator. The grains filling ratio ($F_g$) is the percentage of the filled grains weight to the full sample weight as follows:

$$F_g = \frac{G_f}{G_W}\ \% \qquad (1)$$

**Where:**

**$F_g$ = Grains filling ratio (%)**
**$G_f$ = filled grains weight (g)**
**$G_W$ = full sample grains weight (g)**

**Calculations**

**Irrigation water requirements calculations:**

The following equation was used to calculate the daily net irrigation demand for rice according to (T. S. Lee *et al.*, 2005):

$$NIR_j = ET_j + P_j + RP_j - WD_{j-1} \qquad (2)$$

**Where:**

**NIR = net irrigation requirement (mm),**
**ET = crop evapotranspiration (mm),**
**RP = required ponding depth (mm),**
**WD = water depth in the field (mm)**
**P = daily percolation rate (mm)**
**j = period of water management.**

**Deep Percolation rate (P):**

Darcy's law was used to calculate the daily percolation rate out of the root zone layer, according to (Chowdary *et al.*, 2004):

$$P = \frac{-K_r\,\Delta h}{\Delta z} \qquad (3)$$

**Where:**

**P = percolation out of the root zone (mm/day);**
**$K_r$ = the saturated hydraulic conductivity (mm/day); and**
**$\Delta h/\Delta z$ = the measured head gradient.**

**Maximum evapotranspiration:**

FAO CROPWAT model was used to estimate reference crop evapotranspiration based on The FAO Penman – Monteith method presented by (Allen *et al.*, 1998):

$$ET_0 = \frac{0.408\,\Delta\,(R_n - G) + \gamma \frac{900}{T+273} u_2 (e_s - e_a)}{\Delta + \gamma(1 + 0.34 u_2)} \qquad (4)$$

**Where;**

**$ET_0$ = Reference evapotranspiration (mm/day)**
**G = Soil heat flux density (MJ $m^{-2}$ $day^{-1}$)**
**$e_s - e_a$ = Saturation vapour pressure deficit (kPa)**
**$F(u)$ = wind function (km/day),**
**$u_2$ = Wind speed at 2 m height (m/s)**
**$\Delta$ = Slope of saturation vapour pressure curve ( kPa /°C)**
**$\gamma$ = Psychometric constant ( kPa /°C)**
**$R_n$ = Net radiation at the crop surface (MJ $m^{-2}$ $day^{-1}$)**

The source of meteorological data is (*Bilqas Weather|World Weather Online*, n.d.) which was utilized for estimating $ET_0$. using minimum daily meteorological data. Maximum crop evapotranspiration (ETc) was determined using the following equation:

$$ET_c = ET_o \times K_c \qquad (5)$$

**Where:**

**$k_c$= crop coefficient**

Rice Kc values were considered to be 1.05, 1.20, and 0.90 during the vegetative, reproductive, and ripening growth stages of the crop, respectively. The crop coefficient values for the mid and end stages $K_{C\,mid}$, $K_{C\,end}$, were calculated in a sub-humid climate with where $RH_{min}$= 45 % and $u_2$= 2 m/s which needs to be adjusted to the real values under local climatic conditions as follows:

$$K_{C\,mid\,adj} = k_{C\,mid\,(tab)} + [0,04\,(u_2 - 2) - 0,04\,(RH_{min} - 45)] \left(\frac{h}{3}\right)^{0,3} \qquad (6)$$

$$K_{C\,end\,adj} = k_{C\,end\,(tab)} + [0,04\,(u_2 - 2) - 0,04\,(RH_{min} - 45)] \left(\frac{h}{3}\right)^{0,3} \qquad (7)$$

**Where;**

**h = The Plant height for each growth stage [m] (0.1 m < h < 10 m).**

**Readily available water (RAW):**

The Readily available water was determined using equation (9) derived from (Allen *et al.*, 1998):

$$D_{sat} = 1000\,(SAT - W_P) \times Z_r \qquad (8)$$

$$RAW = 1000\,(1 - p) \times D_{sat} \times Z_r \qquad (9)$$

**Where:**

**$Z_r$ = measured root zone depth (mm)**
**$D_{sat}$ = soil water content (mm) at saturation (mm)**
**SAT = Soil water content at saturation in percentage of volume**
**$W_P$ = the soil water content at wilting point in percentage of volume**
**RAW = Readily available water (mm)**
**p = the fraction of water that can be depleted before moisture stress occurs and represents 20% of the saturation for rice. (0.2 of SAT)**

When the root zone depletion exceeds RAW, evapotranspiration is limited to less than potential levels, and crop evapotranspiration begins to decline in proportion to the amount of water remaining in the root zone.

**Actual evapotranspiration ($ET_a$):**

Reducing the value for the crop coefficient describe the impact of soil water stress on crop evapotranspiration, by multiplying the $K_c$ by $K_s$ as follows:

$$ET_a = K_s \times K_c \times ET_o \quad (10)$$

**Where:**

**$K_s$ = water stress coefficient**

**$K_s$ is a dimensionless transpiration reduction factor dependent on available soil water [0 - 1], for soil water limiting conditions, Ks < 1. Where there is no soil water stress, Ks = 1.**

### Harvest index (HI):

The ratio of actual yield (kg) to biomass (kg) according to (Murugan and Ranjit Singh, 2012).:

$$HI\ \% = \frac{Ya}{B} \quad (11)$$

### Water Productivity (WP):

Water productivity defined or Crop water use efficiency is generally defined as crop yield per unit volumetric unit of used water, including effective rainfall and irrigation water according to (Djaman *et al*., 2019) evapotranspiration water productivity (ETWP), and seasonal irrigation water use efficiency (IWP) were estimated by the following equations:

$$ETWP = \frac{Ya}{ETa} \quad (12)$$

$$IWP = \frac{Ya}{IWR} \quad (13)$$

**Where:**

**IWR= Irrigation water requirements ($m^3$)**

### Statistical Analysis:

Data were analyzed by one way analysis of variance (ANOVA) in randomized blocks and means were compared based on the least significant difference (LSD) test at the 5% probability level using Costat 6.311. in addition to, compare means analysis for multiple comparison of means' tests and organizing in groups of significance levels.

## RESULTS AND DISCUSSION

### Soil moisture content of the treatments (SMC%):

Figs (3) and (4) show the soil moisture content of the treatments vegetative, reproductive, ripening stages and throughout the season under three treatments of water stress (90%; 75% and 60%) and for the seasons 2018 and 2019 respectively. The figures show that the moisture water content significantly varied according to the growth stage and the treatments. The soil moisture content (SMC%) was increasing after irrigation and then decreased until reaching the required water stress for the treatment before the next irrigation. Moreover, it is noticeable that at all stages, the reduction rate of the soil moisture content decreased by reaching the stress threshold.

The control treatment is the highest in the moisture content in all growth stages and is similar to the deficit irrigation treatments that were not prone to water stress; the reproductive and ripening treatments during the vegetative growth stage, vegetative and ripening stage during the reproductive growth stage and the vegetative and productive treatments during the ripening growth stage. Moreover, full season water stress treatments are closed to treatments at the same water stress level for each growth stage. The values of SMC at ripening stage were decreased for all treatments until the end of the season due to irrigation stopping for 12 days before harvesting for both seasons 2018 and 2019.

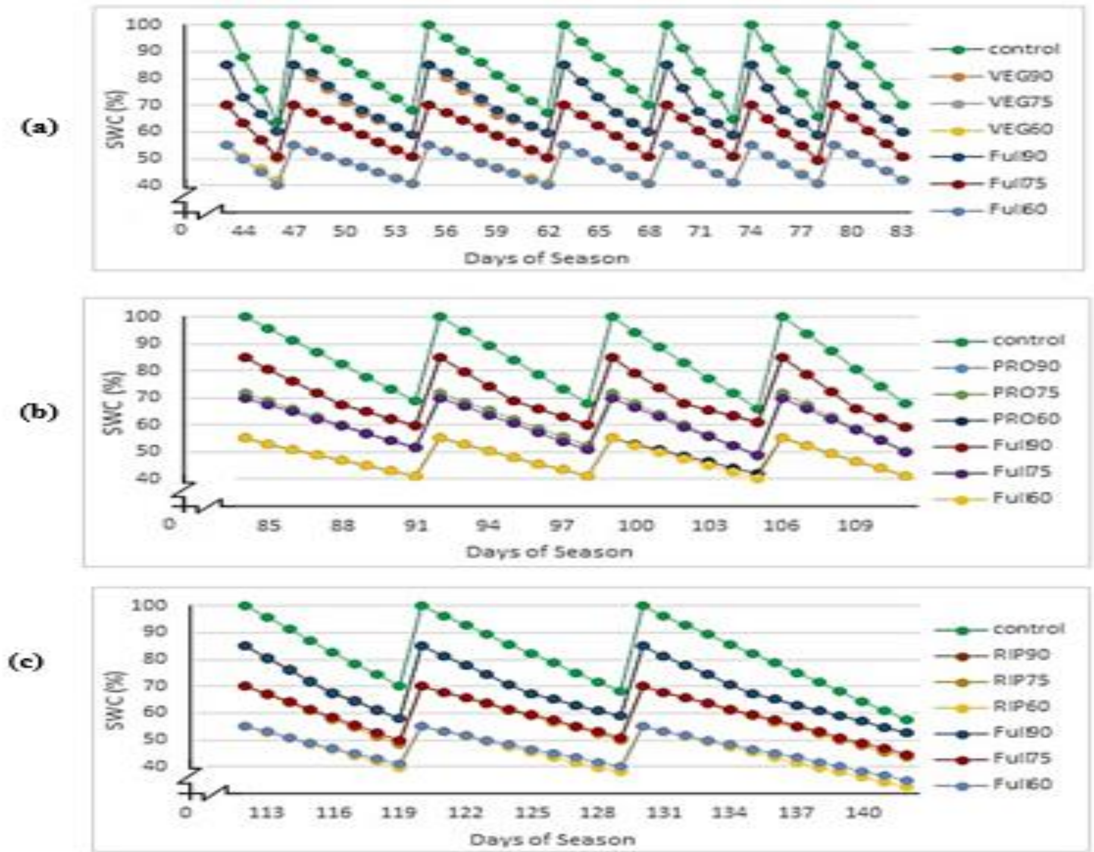



**Fig .3. Soil moisture content (SMC%) of the treatments at (a) vegetative, (b) reproductive, and (c) ripening stages for the season 2018**

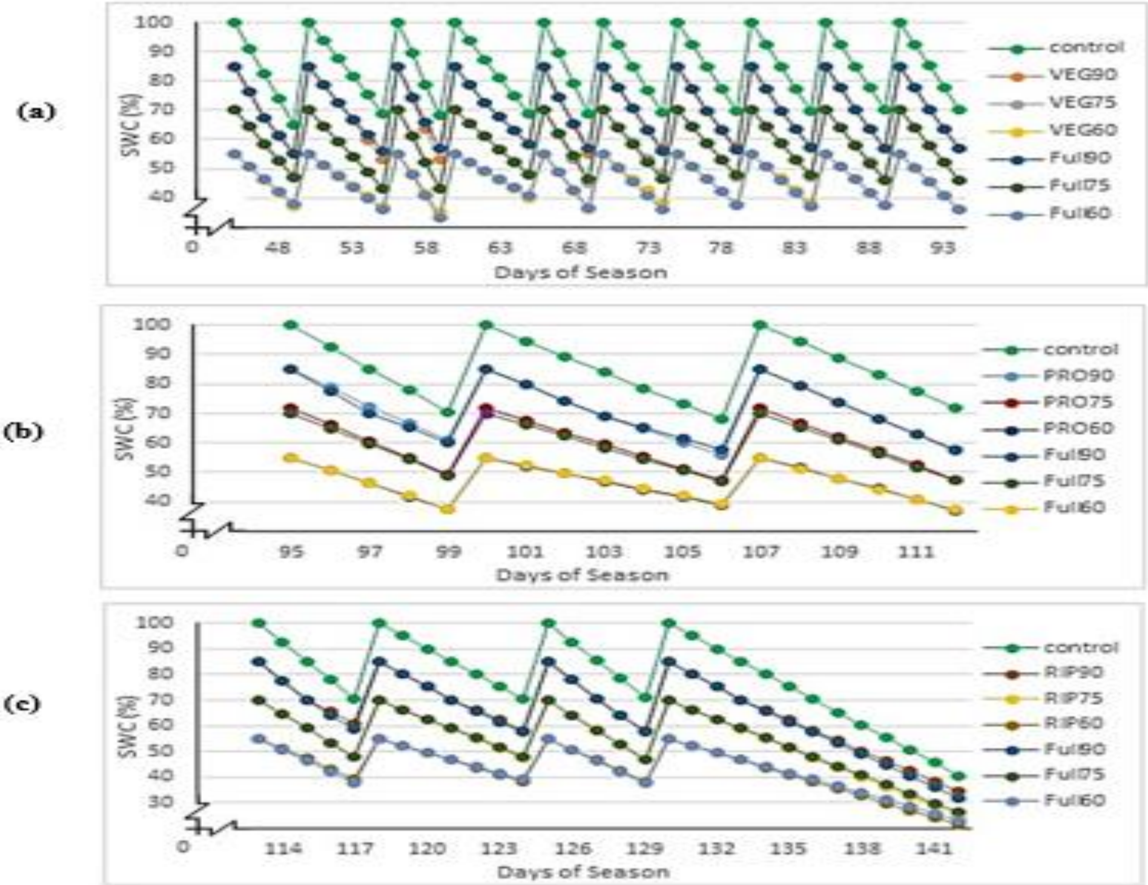



**Fig .4. Soil moisture content (SMC%) of the treatments at (a) vegetative, (b) reproductive, and (c) ripening stages for the season 2019**

**Total applied irrigation water amounts:**

Fig (5) shows the average summation of applied irrigation water amount during the deficit irrigation scenarios throughout the two seasons, while the rest of the season is completed without applying any stress other than any treatment. The water amounts applied to full growth season treatments are the same as the full depths applied throughout the season, which are the largest applied amount during the DI scenarios besides recording the largest reduction compared to other treatments. Furthermore, Fig 5 shows the average total irrigation water amount for each treatment throughout the season compared to the control treatment (100%) which didn't expose to water stress. The summation takes into account water amounts that added to the nursery, pre-treatments, and land preparation which equal 4030 and 4390 $m^3$/ha for seasons 2018 and 2019 respectively.

**Evaluation of Deficit Irrigation Scenarios Over the Growth Stages:**

The impact of deficit irrigation scenarios on yield production and the variation between treatments was measured based on yield production measurements and water use estimations. Yield production measurements includes yield production (ton/ha), harvest index (%), 1000 grains weight (g), and grain filling ratio (%). Water use estimations includes water productivity (WP) and evapotranspiration water productivity (ETWP). Table (2) shows the correlation among the relative evapotranspiration ($\frac{ET_a}{ET_m}$) and the parameters. As shown in the table, there is a high correlation between yield production and relative evapotranspiration. Furthermore, the correlation is very high among yield production, 1000 grains weight and grain filling ratio. However, these parameters and relative evapotranspiration have high correlation with harvest index, water productivity, and evapotranspiration productivity.

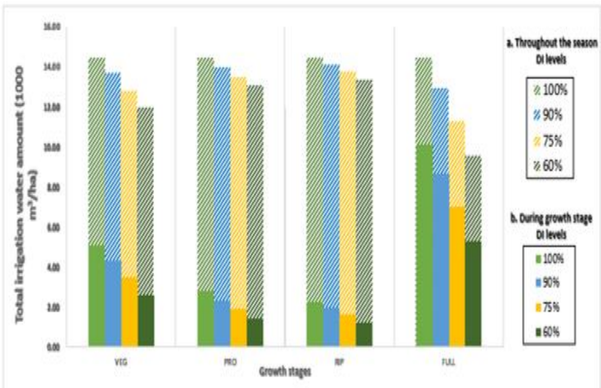



**Fig .5. Average irrigation water amount added to the treatment (a) throughout the season and (b) during deficit irrigation scenarios.**

**Table 2. Correlation among yield production techniques and relative evapotranspiration**

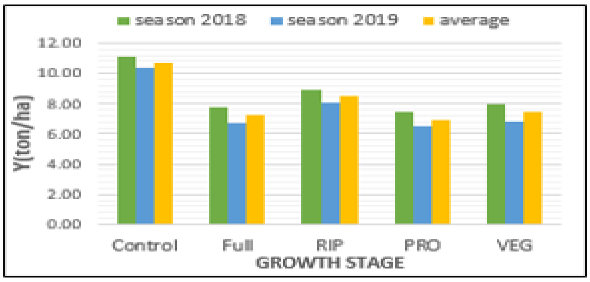
| | Yield (ton/ha) | Harvest index % | 1000 Grains Weight | Grain filling ratio % | WP ($kg/m^3$) | ETWP ($kg/m^3$) | $\frac{ET_a}{ET_m}$ |
|---|---|---|---|---|---|---|---|
| Yield (ton/ha) | 1.00 | | | | | | |
| Harvest index | 0.75 | 1.00 | | | | | |
| 1000 Grains Weight | 0.96 | 0.83 | 1.00 | | | | |
| Grain filling ratio % | 0.94 | 0.82 | 0.98 | 1.00 | | | |
| WP ($kg/m^3$) | 0.73 | 0.88 | 0.75 | 0.70 | 1.00 | | |
| ETWP ($kg/m^3$) | 0.73 | 0.93 | 0.77 | 0.73 | 0.99 | 1.00 | |
| $\frac{ET_a}{ET_m}$ | 0.87 | 0.67 | 0.86 | 0.89 | 0.60 | 0.64 | 1.00 |

**Impact of Deficit Irrigation Scenarios Based on Yield Measurements:**

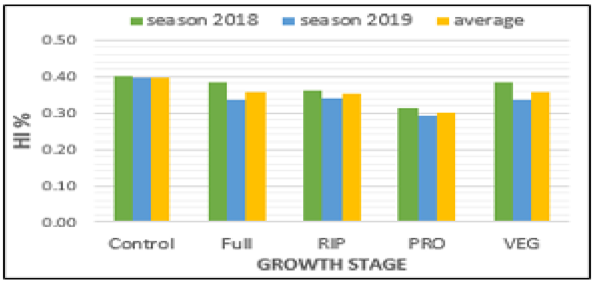
**Yield productivity measurements:**

Fig (6) shows the grain yield production and harvest index during seasons 2018, 2019 and the average of the seasons that represent the impact of deficit irrigation scenarios on growth stages. Yield production at ripening stage treatments (8.52ton/ha) has the lowest reduction compared to control treatments (10.72 ton /ha). according to the analysis of variance (ANOVA) for the data of yield production. The average yield production are 7.41, 7.26, and 6.96 ton/ha for the vegetative stage, full growing season, and reproductive stage treatments respectively.

On the other hand, the data analysis for harvest index indicated to the lowest HI% was recorded by reproductive growth stage treatments (0.30) which was highly significantly different of other treatments under water stress that had no significant difference between each other. HI percentages are 0.40, 0.36, 0.36, and 0.35 for treatments control, full growth season, vegetative, and ripening stages respectively. Furthermore, there are highly significant difference in yield production and harvest index among the water stress levels. The total interaction between different treatments shows a significant effect with coefficient of variation $R^2$ =0.94165 and 0.824622 in addition to, coefficient of variation CV = 5.189373% and 4.673362% for yield production and harvest index respectively.




(a)




(b)

**Fig .6. Average values of (a) grain yield (ton/ha) and (b) harvest index throughout growth stages treatments**

Multiple comparisons of means' tests compared several means and organize into groups of significance levels based on LSD. The highest mean of yield production was obtained from the control treatment (100%) level throughout the season, followed by the 90% level during the ripening growth stage. The highest mean of harvest index also was recorded by control treatment followed by the 90% level during the vegetative growth stage; however, the lowest mean was obtained from the 60% level during the reproductive stage for both yield production and harvest index

The relationship between relative evapotranspiration and harvest index (%) is shown in Fig (7). it is obvious that there is a positive linear regression between $^{ET_a}/_{ET_m}$ and HI, through multiple equations that illustrated in Table (3) at coefficient of determination $R^2$ = 0.9906, 0.9827, 0.9925, 0.9445 for Vegetative, Reproductive, Ripening stages and full growth season.

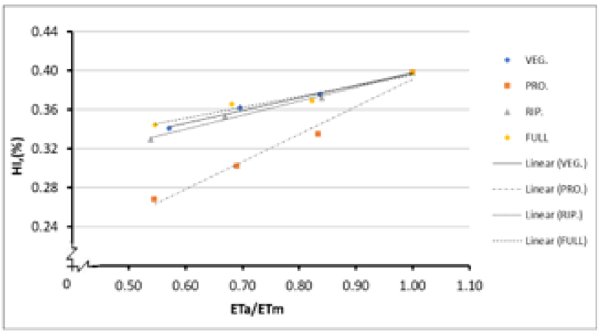



**Fig .7. The relationship between Harvest index % and Eta/ETm for Vegetative, Reproductive, Ripening stages, and full growth period for the average of the seasons 2018 and 2019 $F_g$**

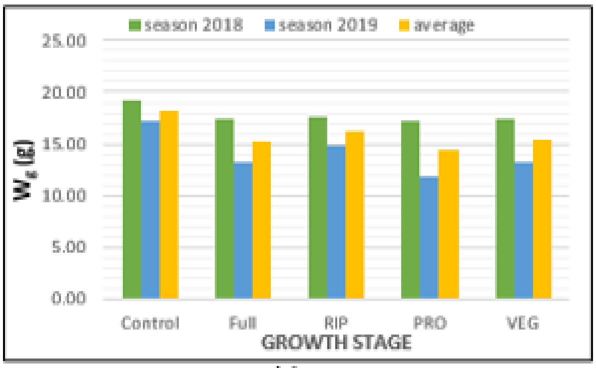
**Table 3. Equation relating relative evapotranspiration and Harvest index % at various growth stages and full growth season**

| Stage | Equation | $R^2$ |
|---|---|---|
| VEG | $HI = 0.1286 \times {}^{ET_a}/_{ET_m} + 0.2691$ | 0.99 |
| PRO | $HI = 0.2816 \times {}^{ET_a}/_{ET_m} + 0.1094$ | 0.983 |
| RIP | $HI = 0.1429 \times {}^{ET_a}/_{ET_m} + 0.2541$ | 0.993 |
| FULL | $HI = 0.1093 \times {}^{ET_a}/_{ET_m} + 0.2858$ | 0.945 |

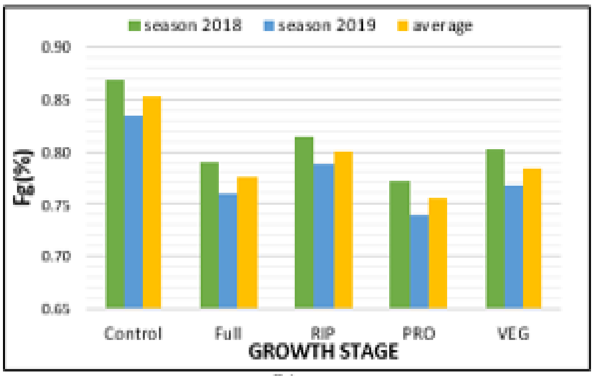
**Grain filling measurements:**

As shown in Fig (8), 1000 grains weight were 18.19 g for control treatments followed by16.26 g for ripening stage treatments which was significantly different of other treatments according to the analysis of variance (ANOVA). As well, vegetative stage (15.37 gm). However, there was no statistically significant difference between reproductive stage (15.23 gm) and full season treatments (14.47 g). in addition, grain filling ratio were 0.85, 0.80, 0.78, 0.78, and 0.76 for control, ripening, vegetative stages, full growth season and reproductive stage treatments respectively that had highly significant difference between each other.

Moreover, there are a highly significant difference in 1000 grains weight (g) and grain filling ratio (%) among the water stress levels. The total interaction between different treatments shows a significant effect with coefficient of variation R2 = 0.791342 and 0.88249 in addition to, coefficient of variation CV = 5.5060203% and 2.1875876% for 1000 grains weight (gm) and grain filling ratio (%) respectively. According to Compared mean test, there are also a high agreement among 1000 grains weight (g) and grain filling ratio (%), and yield production (ton/ha).




(a)




(b)

**Fig .8. Average values of (a) 1000 grains weight (g) and (b) Grain filling ratio throughout growth stages treatments**

The relationship between relative evapotranspiration and 1000 grain weight (g) was studied and analyzed. Fig (9) shows the positive effect of increasing ${ET_a}/{ET_m}$ on $W_g$. Multiple equations illustrate the positive regression as shown in Table (4) at coefficient of determination $R^2$ = 0.9902, 0.9878, 0.9856, 0.9531 for Vegetative, Reproductive, Ripening stages and full growing season. Likewise, the relationship between 1000 g weight and relative evapotranspiration studied, the relationship between relative evapotranspiration and grain filling ratio illustrated at Fig (10). The positive linear regression between ${ET_a}/{ET_m}$ and $W_g$ was identified by multiple equations illustrates in (Table 5) at coefficient of determination $R^2$ = 0.9868, 0.9574, 0.963, 0.9766 for Vegetative, Reproductive, Ripening stages and full growing season respectively.

Grain filling indicators includes weight of 1000 grains and grain filling ratio agreed with the yield production (ton/ha) on the impact of deficit irrigation scenarios throughout the growth stages. Furthermore, increasing relative evapotranspiration produces increasing in grain filling according to the indicators of 1000 g weight and grain filling ratio.

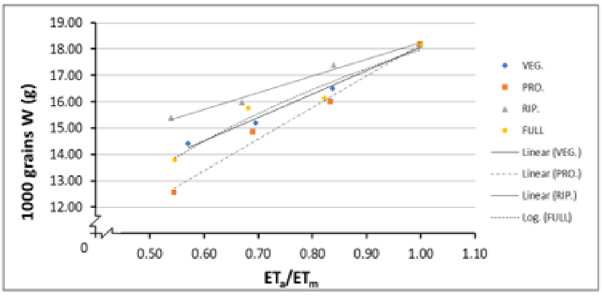



**Fig .9. The relationship between 1000 grains weight (g) and Eta/ETm for Vegetative, Reproductive, Ripening stages, and full growth period for the average of the seasons 2018 and 2019**

**Table 4. Equation relating relative evapotranspiration and 1000g weight at various growth stages and full growing season**

| Stage | Equation | $R^2$ |
|---|---|---|
| VEG | $W_g = 8.894 \times {ET_a}/{ET_m} + 9.177$ | 0. 99 |
| PRO | $W_g = 11.982 \times {ET_a}/{ET_m} + 6.202$ | 0.988 |
| RIP | $W_g = 6.335 \times {ET_a}/{ET_m} + 11.91$ | 0.986 |
| FULL | $W_g = 9.038 \times {ET_a}/{ET_m} + 9.078$ | 0.953 |

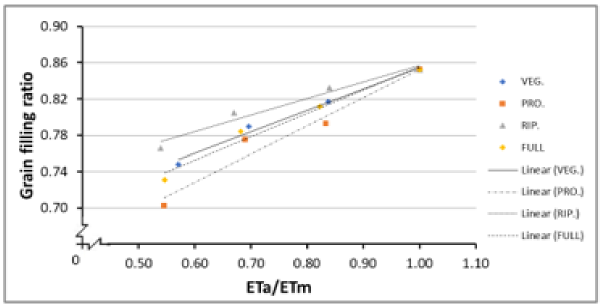


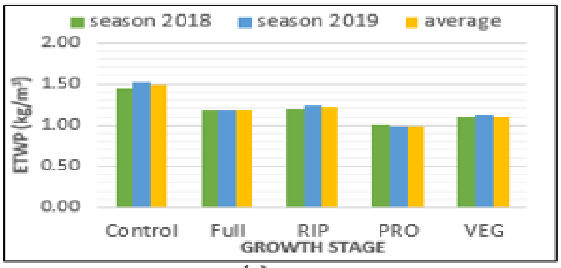

**Fig .10. The relationship grains filling ratio and Eta/ETm for Vegetative, Reproductive, Ripening stages, and full growth period for the average of the seasons 2018 and 2019**

**Table 5. Equation relating relative evapotranspiration and grain filling ration at various growth stages and full growing season**

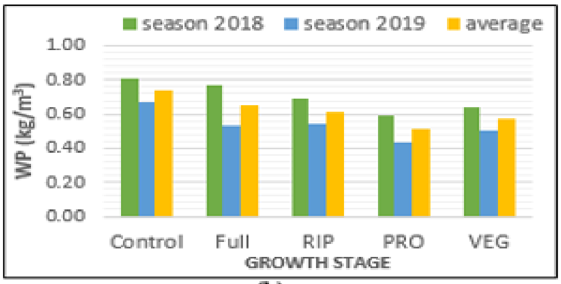
| Stage | Equation | $R^2$ |
|---|---|---|
| VEG | $F_g = 0.236 \times {ET_a}/{ET_m} + 0.619$ | 0.987 |
| PRO | $F_g = 0.31 \times {ET_a}/{ET_m} + 0.542$ | 0.957 |
| RIP | $F_g = 0.183 \times {ET_a}/{ET_m} + 0.675$ | 0.963 |
| FULL | $F_g = 0.259 \times {ET_a}/{ET_m} + 0.597$ | 0.977 |

**Impact of Deficit Irrigation Scenarios Based on Water Use:**

The purpose of this evaluation is judging on the effectiveness of the water consumption by the treatments. There was a large difference in the irrigation amounts applied among the treatments for every irrigation event during the two seasons. The impact of deficit irrigation scenarios based on water use by estimating Water productivity (WP) and evapotranspiration water productivity (ETWP) is shown in Fig (11) for the average of various growth stages treatements; vegitative, reproductive, and ripenning compared to the control and throughout the season treatments. The highest average WP and ETWP was obtained from the control treatments with 0.74 Kg/m$^3$ and 1.49 kg/ m$^3$ respectively. The highest values of WP were recorded by ripening stage and full season treatments, there was no statistically significant difference between them with 0.65 and 0.61 kg/ m$^3$ respectively for WP as well as 1.22 and 1.18 kg/ m$^3$ for ETWP respectively. While there is no significant difference between reproductive stage and vegetative stage treatments with 0.51 and 0.57 kg/ m$^3$ for WP while ETWP values were 1.11 and 0.99 respectively. According to compared mean test results for WP and ETWP, there are also high agreements between the results and; grains weight (g) and grain filling ratio (%), and yield production (ton/ha).




(a)




(b)

**Fig .11. Average values of (a) water productivity (kg/m$^3$), (b) Evapotranspiration water productivity (kg/m$^3$) throughout growth stages treatments**

The relationships between relative evapotranspiration and both of water productivity and evapotranspiration water productivity at various growth stages and full growth season were studied and analyzed. Figs (12) and (13) shows the positive regressions between $^{ET_a}/_{ET_m}$ and both of WP and ETWP.

The relationships are linear during the individual growth stages for both of WP and ETWP. The coefficient of determination $R^2$= 0.9636, 0.8537, and 0.9941 under vegetative, reproductive and ripening stages treatments respectively for the relationship between WP and $^{ET_a}/_{ET_m}$. Moreover, $R^2$= 0. 9171, 0. 9449, and 0.9677 under vegetative, reproductive and ripening stages treatments respectively for the relationship between ETWP and $^{ET_a}/_{ET_m}$.

On the other hand, polynomial positive regressions were obtained for the relationship for both of WP and ETWP with $^{ET_a}/_{ET_m}$ throughout the full season with $R^2$= 0.8658 and 0. 9677 respectively. The obtained equation for estimating WP and ETWP from $^{ET_a}/_{ET_m}$ are related to Table 6 and 7 respectively.

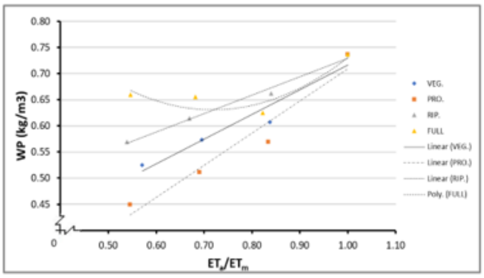



**Fig. 12. The relationship between water productivity and Eta/ETm for Vegetative, Reproductive, Ripening stages, and full growth period for the average of the seasons 2018 and 2019**

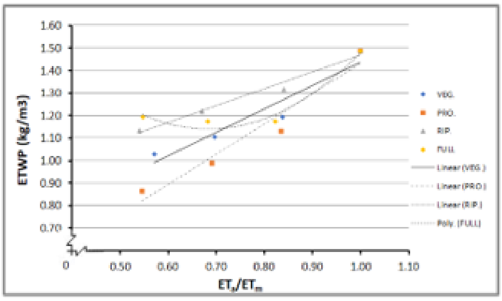



**Fig. 13. The relationship between evapotranspiration water productivity and Eta/ETm for Vegetative, Reproductive, Ripening stages, and full growth period for the average of the seasons 2018 and 2019**

**Table 6. Equation relating relative evapotranspiration and water productivity at various growth stages and full growing season**

| Stage | Equation | $R^2$ |
|---|---|---|
| VEG | $WP = 0.44 \times {}^{ET_a}/_{ET_m} + 0.35$ | 0.96 |
| PRO | $WP = 0.53 \times {}^{ET_a}/_{ET_m} + 0.24$ | 0.85 |
| RIP | $WP = 0.43 \times {}^{ET_a}/_{ET_m} + 0.44$ | 0.99 |
| FULL | $WP = 1.42 \times ({}^{ET_a}/_{ET_m})^2 + 2.23 \times {}^{ET_a}/_{ET_m} + 0.60$ | 0.72 |

**Table 7. Equation relating relative evapotranspiration and evapotranspiration water productivity at various growth stages and full growth season**

| Stage | Equation | $R^2$ |
|---|---|---|
| VEG | $ETWP = 1.04 \times {}^{ET_a}/_{ET_m} + 0.40$ | 0.92 |
| PRO | $ETWP = 1.34 \times {}^{ET_a}/_{ET_m} + 0.09$ | 0.95 |
| RIP | $ETWP = 0.75 \times {}^{ET_a}/_{ET_m} + 0.72$ | 0.98 |
| FULL | $ETWP = 3.4 \times ({}^{ET_a}/_{ET_m})^2 - 4.67 \times {}^{ET_a}/_{ET_m} + 2.74$ | 0.97 |

## CONCLUSION

A field experiment was conducted to estimate the impact of deficit irrigation scenarios by applying various water stress levels throughout the main growth stage and the whole season. A medium duration variety (Giza178) was chosen for the study. The main results gained from the study may be summarized as follows:

There is a high correlation between grain production and actual evapotranspiration (ETa/ETm). The correlation was also very high among grain yield production (ton/ha), 1000 grains weight (g) and grain filling ratio (%).

- Compared to the fully irrigated treatment, the yield reduction which occurs as a result of water stress is depending on reduction of grain filling ratio.

- The highest yield reduction occurs in the reproductive stage (average 34.7%) however, the lowest occurs in the ripening stage (average 20%).
- The highest grain yield and water productivity of the deficit irrigation treatments were given when a low water stress level was applied to ripening growth stage treatment. On the other hand, applying high water stress level to reproductive growth stage produced the lowest grain yield and water productivity.

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# تقييم تطبيق الري الناقص على محصول الارز في شمال دلتا الدنيا بمصر

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## الملخص

يعتبر تطبيق الري الناقص احد الحلول الفعالة لزيادة انتاجية وحدة المياه تحت ظروف محدودية مياة الري والتى اصبحت ضرورة ملحة. خاصة في حالة الأرز ، أحد أكبر المحاصيل التي تستهلك المياه ، تبذل الجهود لإيجاد طرق لترشيد وزيادة إنتاجية المياه. انطلاقا من ذلك؛ أجريت تجربة حقلية محدودة على موسمين متتاليين خلال موسمي صيف 2018 و 2019 لتقييم تأثير مستويات الري الناقص على مراحل النمو الرئيسية لصنف الأرز (جيزه 178): الأولى (الخضرية)، والثانيه (الانتاج)، والثالثة (النضج) بالاضافه الى لفترة النمو الكاملة من خلال تطبيق معاملة رى بأربع مستويات للإجهاد المائي التي تم تحديدها على أنها اجهاد مائي منخفض (90%) ومتوسط (75%) وعالى (60٪) من المياه المتاحة بسهولة (RAW). وكان مستواها الرابع كمعاملة حاكمة (كنترول) تمثل الري الكامل بنسبة 100٪ من RAW. وقد تم الحصول على النتائج عبارة عن تأثير مستويات الري الناقص على إنتاج الحبوب بناءً على قياسات إنتاج الحبوب و استخدام المياه. شملت القياسات على الحبوب :[إنتاجية الحبوب (طن / هكتار) ، مؤشر الحصاد (٪) ، وزن 1000 حبة (جم) ، ونسبة ملء الحبوب (٪)]. كما شملت تقديرات استخدام المياه: [إنتاجية المياه (WP) وإنتاجية البخر نتح (ETWP)]. أظهرت النتائج وجود ارتباط كبير بين إنتاج الحبوب ونسبة البخر نتح الفعلية ($\frac{ET_a}{ET_m}$). كما ان الارتباط عالى جدًا بين إنتاج الحبوب ووزن 1000 حبة ونسبة ملء الحبوب، من ناحية أخرى ، كانت المرحلة الثانية (الانتاج) هى الاكثر حساسيه لنقص المياه. أفضل النتائج التي تم الحصول عليها من المعاملة عند تطبيق مستوى 90٪ من RAW خلال المرحلة الثالثه، والاقل في النتائج: مستوى 60٪ من RAW أثناء المرحلة الثانية.