DEFICIT IRRIGATION OF WHEAT UNDER SPRINKLER IRRIGATION IN THE NEWLY RECLAIMED SOILS OF EGYPT
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ABSTRACT

Two seasons field experiments were conducted at Sugar Beet region, West Nubaria on wheat (Triticum aestivum L.) cv. Sakha 8 under sprinkler irrigation system. The aim of this study was to investigate the effect of deficit irrigation and N fertilization rate on yield and yield components of wheat grown in the newly reclaimed soils that facing conditions of limited irrigation water in order to accomplish optimum production. Five regimes of irrigation were randomly assigned as main plots, and two N fertilization rates 143 and 214 kg ha\(^{-1}\) (60 and 90 kg feddan) as sub-plots in a split plot design. The irrigation regimes were selected to impose water stress throughout the growing season, and stress at one of the growth stages of wheat (vegetative, flowering, and yield formation); in addition to full irrigation. Imposing the stress at a certain stage imply that only 50\% of the crop evapotranspiration (ET\(_{c}\)) was applied in irrigation.

Data showed that the five irrigation regimes resulted in grain yield of 2801, 4571, 4345, 3994, and 5390 kg ha\(^{-1}\), respectively. These values were corresponding to actual evapotranspiration (ET\(_{a}\)) of 207.9, 312.6, 381.4, 336.6, and 449.5 mm, crop factor (K\(_{c}\)) of 0.449, 0.676, 0.825, 0.728, and 0.973, yield response factor (K\(_{y}\)) of 0.735, 0.378, 0.538, 0.595, and 0.176, and water use efficiency (WUE) of 13.60, 14.60, 11.44, 11.69, and 11.98 kg ha\(^{-1}\) per mm ET\(_{a}\), respectively. The saving of irrigation water due to deficits at the vegetative, flowering, and yield formation stages were 26.8, 13.2, and 23.4\% resulted in reduction of grain yield 15.2, 19.4, and 25.9\%, respectively. Several water regimes of low water application gave grain yields, which were insignificantly different from the full irrigation treatment. Reducing the applied N fertilizer from 214 to 143 kg ha\(^{-1}\) (33.3\%) resulted in reduction of grain yield from 4504 to 3936 kg ha\(^{-1}\) (12.6\%), and had little effects on the other yield characteristics.

This study showed that the efficient use of limited amount of irrigation water available for wheat production was reached if applied to relieve stress during flowering (mid-late-February to mid-late-March) followed by yield formation (late-March to mid-April), and least during vegetative stage (mid-December to late-February). This can be coupled with the application of N fertilizer rate of 143 kg ha\(^{-1}\) which leads to optimum yield and environment sustainability.

INTRODUCTION

Water scarcity in the next decades is a real threat to food production in arid and semi-arid areas where water is the limiting factor in the expansion of cultivated land. Therefore, water management that maximize yield per unit of water consumed by plant are highly desired. In Egypt, limited water resources coupled with high population forced to a great competition for water supply that makes conservation and efficient use of water obligatory (Ibrahim, 1999; and Gaber, 2000). Moreover, the newly reclaimed soils facing numerous problems; amongst water shortage which is the most important factor for crop production. Subsequently, efficient and optimal scheduling of limited amounts
of water for high yields of some selected low water consuming and high valuable crops is urgently needed.

Wheat is a major strategic food and feed grain crop successfully grown under limited water conditions, i.e. the newly reclaimed soils, therefore, its growth, and high productivity depend mainly on the proper water and fertilizer management. The various crop development stages posses different sensitivities to moisture stress where time, duration, and the degree of the stress all affect yield (Doorenbos and Kassam, 1986; English and Nakamura, 1989; and Ghahraman and Sepaskhah, 1997).

Deficit irrigation is a strategy which allows a crop to sustain some degree of water stress in growth stages of less sensitive to water or throughout the whole growing season in order to save irrigation water (Kirda, 1999; and Labhsetwar, 2003). The knowledge of the critical stage/s to water deficit is very important for judicious water management (Gad El-Rab et al., 1988). The expectation is that any yield reduction will be insignificant compared with the benefits gained through diverting the saved water to irrigate other areas/crops. This strategy maximizing WUE, i.e.: producing more with less irrigation water applied, and where properly practiced, may increase profits and crop quality. For example, the protein content and baking quality of wheat increase under deficit irrigation (Kirda, 1999). Deficit irrigation can be practical choice for growers, and they must have prior knowledge of crop yield responses to deficit irrigation. The relationships between crop growth, soil-water, and fertilization level are complicated and must be justified in order to develop better soil, water, and crop management (Huang et al., 2003).

The objective of this study was to investigate the effect of imposed water stress through deficit irrigation in certain growth stages of wheat, and N fertilization rate aiming at the levels that optimizing the productivity and save water under limited supply of irrigation water of the newly reclaimed soils in Egypt.

MATERIALS AND METHODS

The field experiments were conducted at West Nubaria, Sugar Beet region, Village 3 of youth graduates (30°20'N, 30°40'E) during the successive seasons of 2000/2001 and 2001/2002. The soil of the experimental site is calcareous (Typic Calcids), non-saline, loamy sand with bulk density of 1.32-1.42 Mg m⁻³. Wheat was drilled in soil at 0.2 m × 0.2 m spacing on December 14, 2000 and November 29, 2001. The wheat variety was Sakha 8 (local) with about 160-165 days of growing season. Five levels of deficit irrigation were tested as main plots, and two N fertilization rates 143 and 214 kg ha⁻¹ (60 and 90 kg/ feddan), divided in two doses 3 and 8 weeks from planting, as sub-plots in a split plot design with three replications. The irrigation regimes include full watering (1111) and stress (0000) throughout the growing season, and stress at the vegetative including tillering and head development (0111), flowering (1011), and yield formation known as seed filling (1101) growth stages. The selected growth stages are most relatively sensitive to water
stress (Zhang, 2003). The development of uniform water deficit at all growth stages (0000) was necessary for valid comparisons and rarely attempted in the field (Doorenbos and Kassam, 1986). The vegetative stage was the longest and extended to March 3 and February 20 in the first and second season, respectively. The irrigation system was hand-moved sprinkler system of 12 m×12 m spaces. Imposing the stress at a specified growth stage of wheat imply that only 50% of the ETc was applied in irrigation. The potential evapotranspiration (ET0) was calculated from weather data according to Penman-Monteith formula (Allen et al., 1998) using the CROPWAT software, FAO, and related to ETc through the kc as:

\[ ET_c = k_c \times ET_0 \]

Catchments cans of 100 mm in diameter were placed at 0.5, 1, 2, 4 and 6 m distances from each of two successive sprinklers to estimate the average water applied. To prevent distortion of water application patterns, irrigation was applied every fourth day during periods of no or minimum wind movement.

The water-balance equation was used to estimate actual evapotranspiration in the root zone:

\[ ET_a = I + P + \Delta S - R_U - D_r \]

where I is irrigation, P is precipitation, \( \Delta S \) is soil water depletion (change in moisture content) in the root zone, \( R_U \) is runoff, and \( D_r \) is drainage below root zone. Irrigation was applied with assurance that \( R_U \) and \( D_r \) were minimal or zero. Gravimetric soil samples were collected every 15 cm-interval down to 75 cm depth before and after irrigation from the center of each plot at two replicates of each irrigation treatment to monitor the moisture regime. Soil samples were collected before planting and after harvesting to monitor salt balance with different water regimes.

The general recommended agricultural practices for commercial wheat production were followed. Harvesting was carried out on May 9 and May 2, respectively for the first and second seasons. The yield and yield characteristics were estimated from 0.5 m strip along the sprinklers line. The deficit irrigation stress index (DISI) and nitrogen stress index (NSI) were calculated as 100×[(highest value-parameter value)/highest value] for each deficit irrigation and fertilizer treatment, respectively.

**RESULTS AND DISCUSSION**

Yield and Yield Characteristics:

The averages of yield and yield components of wheat in the two growing seasons for the five irrigation regimes and the two N fertilizer rates are given in Table 1.
I) Gross Yield:

Irrigation regimes resulted in no significant differences in gross yields with the application of 143 kg N ha\(^{-1}\) in both seasons, but all were higher than 0000 regime in the second season. The application of 214 kg N ha\(^{-1}\) fertilization showed that the 0111 and 1011 were not significantly different, but higher than other regimes in the first season, and the 1111 was the highest regime and not differed from 0111 regime in the second season. The average of irrigation regimes data showed that 0111 and 1011 in the first season, 1111 and 0111 in the second season were the highest regimes in gross yield and not differed from each other. The DIsI were in this order 0000>1101>1111>1011>1011 and 0000>1101>1011>1011>1111 in the first and second season, respectively. Reducing the amount of applied water by 1120 (26.7%) and 1240 (26.8%) m\(^3\)ha\(^{-1}\) (from 1111 to 0111 regime) resulted in 12.4% more and 7.8% less gross yield in the first and second season, respectively.

**Table 1. Yield and yield components of wheat grown at Village 3, Sugar Beet Region, West Nubaria.**

<table>
<thead>
<tr>
<th>Season</th>
<th>Applied N (kg ha(^{-1}))</th>
<th>Irrigation Regime(^{t})</th>
<th>Avg. N Tr't</th>
<th>NSI(^{t}) (%)</th>
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<td>Gross Wt. (kg ha(^{-1}))</td>
<td>143</td>
<td>12450(^{t})</td>
<td>13833(^{t})</td>
<td>13666(^{t})</td>
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<td>214</td>
<td>12583(^{t})</td>
<td>16441(^{t})</td>
<td>16803(^{t})</td>
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<td>Grains Wt. (kg ha(^{-1}))</td>
<td>143</td>
<td>2655(^{t})</td>
<td>3963(^{t})</td>
<td>4116(^{t})</td>
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<td></td>
<td>214</td>
<td>2966(^{t})</td>
<td>4850(^{t})</td>
<td>4764(^{t})</td>
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<td>Straw Wt. (kg ha(^{-1}))</td>
<td>143</td>
<td>9795(^{t})</td>
<td>9879(^{t})</td>
<td>9540(^{t})</td>
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<td></td>
<td>214</td>
<td>9617(^{t})</td>
<td>11834(^{t})</td>
<td>12193(^{t})</td>
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<td>Plant Height (cm)</td>
<td>143</td>
<td>85.5(^{t})</td>
<td>92.4(^{t})</td>
<td>90.5(^{t})</td>
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<td>214</td>
<td>85.1(^{t})</td>
<td>97.1(^{t})</td>
<td>96.4(^{t})</td>
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<td>Avg. No. of Grains per Spike</td>
<td>143</td>
<td>10.41(^{t})</td>
<td>0.37</td>
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<td>214</td>
<td>36(^{t})</td>
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<td>100-Kernel Wt. (g)</td>
<td>143</td>
<td>6.37(^{t})</td>
<td>6.86(^{t})</td>
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<td>6.13(^{t})</td>
<td>6.45(^{t})</td>
<td>6.44(^{t})</td>
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<td>Avg. Spike Length (cm)</td>
<td>143</td>
<td>6.20(^{t})</td>
<td>1.34</td>
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<td>214</td>
<td>3.45(^{t})</td>
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<td>No. of Spikes m(^{-2})</td>
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<td>333(^{t})</td>
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<tr>
<th>Parameter</th>
<th>SEASON II</th>
<th>Avg. N</th>
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<td>DISI (%)</td>
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Other options were the reduction of 560 (13.3%) m³ ha⁻¹ (from 1011 to 0111 regimes) and 1080 (23.4%) m³ ha⁻¹ (from 1111 to 1101 regime) resulted in 1% and 13.2% less gross yields in the first and second season respectively. Increasing the applied N fertilization (from 143 to 214 kg ha⁻¹) resulted in significant (9.5%) and non-significant (4.3%) increases in gross yield in the first and second season, respectively. The interactions of irrigation regime × N fertilization were significant and highly significant in the first and second season, respectively.
ii) Grain Yield:

Different irrigation regimes resulted in significantly higher grain yield than 0000 except 1101 regime with both applications of 143 and 214 kg N ha⁻¹ in the first growing season. In the second growing season, the highest 1111 regime was not significantly differed from 0111 and 1011 regimes with 143, and from 0111 with 214 kg N ha⁻¹, but higher than 0000 regime. Additionally, the 1011 was not significantly differed from 0111 and 1101, and all higher than 0000 regime with the application of 143 kg N ha⁻¹, and the pairs 0111 and 1011, 1101 and 1101, and 1011 and 0000 were not significantly different with 214 kg N ha⁻¹. The average of irrigation regimes data showed that 1111 was the highest in both seasons, but not significantly differed from 0111, 1011, and 1101 in the first, and differed from other irrigation regimes in the second season. The DISI were in this order 0000>1101>0111>1011>1111 in the first and second growing season, respectively. Generally, decreasing the amount of irrigation water resulted in less grain yield of wheat. It is worth to note that seasonal stress resulted in 44.7% and 51.0% reduction in grain yield. Also, reducing the amount of applied water by 1120 (26.7%) and 1240 (26.8%) m³ha⁻¹ (from 1111 to 0111 regime) resulted in 15.9% and 14.5% reduction in grain yield in the first and second season, respectively. Other options were the reduction of 560 (13.3%) m³ha⁻¹ and 640 (13.9%) m³ha⁻¹ (from 1011 to 0111 regime) resulted in 3.3% less and 10.9% more grains yields in the first and second season respectively. Increasing the applied N fertilization (from 143 to 214 kg ha⁻¹) resulted in significant 11.0% and 14.2% increases in grain yield in the first and second season, respectively. The interactions of irrigation regime x N fertilization were highly significant in both seasons.

iii) Straw yield:

The straw yield showed non-significant responses to different irrigation regimes in both seasons, except 0111 and 1011 were higher than others with 214 kg N ha⁻¹ fertilization in the first season. The DISI were in this order 1111>1101>0000>0111>1011 and 0000>1101>0111>1111>1011 in the first and second season, respectively. The reduction in applied water by 1120 (26.7%) and 1240 (26.8%) m³ha⁻¹ (from 1111 to 0111 regime) resulted in 24.9% and 3.6% reduction in straw yield in the first and second season, respectively. Increasing the applied N fertilization (from 143 to 214 kg ha⁻¹) resulted in significant increase (8.8%) in the first season, while there was a non-significant change in the second season, respectively. The interactions of irrigation regime x N fertilization were significant and non-significant in the first and second season, respectively.

iv) Plant height:

Data of plant height showed non-significant differences between 1111, 0111, and 1011 and all higher than 1101 and 0000 irrigation regimes in the first season. The 1111 irrigation regime resulted in the highest plant height with non-significant differences from 0111 with 143 kg N ha⁻¹, and 0111 highest with no differences than 1111 and 1101 with 214 kg N ha⁻¹ fertilization rate in the second season. No significant differences were
observed between 0111 and 1011, 1011 and 1101 with 143 kg N ha\(^{-1}\), and 1101 and 1011 with 214 kg N ha\(^{-1}\), and all significantly higher than 0000 irrigation regime in the second season. Seasonal averages of water regimes showed that 0111 was the highest with no significant differences from 1111, no differences between 1111, 1101, and 1011, and all significantly higher than 0000 irrigation regime in the second season. The DISI were in this order 0000>1101>1011>0111>1111 and 0000>1011>1101>1111>0111 in the first and second growing season, respectively. Reducing the amount of applied water by 1120 (26.7%) and 1240 (26.8%) m\(^3\)ha\(^{-1}\) (from 1111 to 0111 regime) resulted in non-significant (0.4% and 0.8%) changes in plant height in the first and second season, respectively. Increasing the applied N fertilization (from 143 to 214 kg ha\(^{-1}\)) resulted in non-significant and significant (4.1%) increase in plant height in the first and second season, respectively. The interactions of irrigation regime × N fertilization were significant and highly significant in the first and second season, respectively.

vi) Average number of grains per spike:

The 1111 regime resulted in the highest average no. of grains without significant differences than 0111 and 1011 regimes in the first season. Also, no significant differences were observed between 1011, 0111 and 1101, 0111, and 0000 with 143 kg N ha\(^{-1}\), and 1101, 0111, and 0000 with 214 kg N ha\(^{-1}\) in the first season. In second season, the 1111 regime was significantly higher than 0000 regime with 143 kg N ha\(^{-1}\), and 1101 and 0000 regimes with 214 kg N ha\(^{-1}\), while other regimes showed non-significant differences. The DISI were in this order 0000>1101>1011>0111>1111 for both growing seasons. Reducing the amount of applied water by 1120 (26.7%) and 1240 (26.8%) m\(^3\)ha\(^{-1}\) (from 1111 to 0111 regime) resulted in 9.1% and 7.5% reduction in the average number of grains in the first and second season, respectively. Different applied N rates did not significantly affect the average number of grains in both growing seasons. The interactions of irrigation regime × N fertilization were highly significant in both growing seasons.

vii) 100-Kernels weight:

No significant differences in kernels weights were noticed between irrigation regimes except 1111 and 0000 with 143 kg N ha\(^{-1}\) rate in the first season. In the second season, the highest weights were observed with 1011, 1111 and 1011 with no significant between others, no significant than 0111 and 1011, and no significant than 1111 and 0111, while 0000 was the lowest than all with 143, 214 kg N ha\(^{-1}\), and seasonal averages, respectively. The DISI were in this order 0000>1101>1011>0111>1111 and 0000>1101>1011>0111>1111 in the first and second season, respectively. Increasing the N rate from 143 to 214 kg ha\(^{-1}\) significantly not affected and increased kernels weight by 14.6% in the first and second season, respectively. The interactions of irrigation regime × N fertilization were significant in both seasons.

vii) Average spike length:

The irrigation regimes had no significant differences in spike lengths with the application of 143 kg N ha\(^{-1}\), while 1111 regime showed highest
lengths with no differences than 0111 and 1011 with 214 kg N ha⁻¹ and for
seasonal averages in the first season. The lowest spike length was noticed
with 0000 irrigation regime, and no differences were noticed between the
highest 1111 and other regimes, 0111, and 0111 and 1011 with 143 and 214
kg N ha⁻¹, and seasonal averages, respectively in the second season. The
DISt were in this order 1101>0000>0111>1011>1111 and
0000=1101>1011>0111>1111 in the first and second season, respectively.
Increasing the N rate from 143 to 214 kg ha⁻¹ significantly not affected and
increased spike lengths by 8.5 % in the first and second season, respectively.
The interactions of irrigation regime × N fertilization were significant and
highly significant in the first and second season, respectively.

viii) Number of spikes per square meter:

No significant differences in number of spike were observed between
irrigation regimes with different rates of N application, and for seasonal
averages in the first season. In the second season, the 1111 regime resulted
in the highest number of spikes with no significant differences than 0111 and
1011 with N rates and seasonal averages. The DISt were in this order
0000=1101>1011>0111>1111 for both growing seasons. Different applied N
rates did not significantly affect the number of spikes in both growing
seasons. The interactions of irrigation regime × N fertilization were not-
significant and significant in the first and second season, respectively.

Salinity Profiles Observed with Irrigation Regimes:

The averages of salinity profiles measured pre-cultivation and after
harvesting for different irrigation regimes are given in Fig.1. Different irrigation
regimes resulted in different soil salinity profiles. The lower salinities were
noticed at the surface layer, and increased with depth. The less the amount
of water applied to soil (i.e. stress condition) the higher the salinity was
observed as compared to full watering condition. The stress at early stage
(i.e. vegetative) leads to less salinity at the root zone of wheat as compared
to stresses at the other growth sages. The relation of salinity and applied
water was found inversely linear for the top 25 cm of soil, and non-linear for
the profile averages.

The best-fit of data resulted in the following relationships of soil
electrical conductivity (EC) in dS m⁻¹ and applied water (AW) in mm:

\[ EC = 5.18 - 0.00714 \times AW \] \hspace{1cm} r = 0.817 \hspace{1cm} \text{at 0 - 25 cm depth}

\[ EC = 10.77 - 0.0441 \times AW + 0.0000634 \times AW^2 \] \hspace{1cm} R^2 = 0.671 \hspace{1cm} \text{at 25 - 50 cm depth}

\[ EC = 10.32 - 0.0339 \times AW + 0.0000488 \times AW^2 \] \hspace{1cm} R^2 = 0.547 \hspace{1cm} \text{at 50 - 75 cm depth}

\[ EC = 8.44 - 0.0263 \times AW + 0.0000343 \times AW^2 \] \hspace{1cm} R^2 = 0.818 \hspace{1cm} \text{Overall}
Fig. 1: Averages of soil electrical conductivities (dS m⁻¹) pre-cultivation (initial) and after harvesting with different irrigation regimes, at Sugarbeet region, West Nubaria (0000=stress throughout the growing season, 1111=full irrigation, 0111=stress at vegetative, 1011=stress at flowering, and 1101=stress at yield formation stage).

Actual Evapotranspiration and Applied Irrigation Water Relationships:
The ETₐ was positively increased with increasing the amount of irrigation water. Factors affecting the ETₐ values were irrigation regimes developed through deficit irrigation, N fertilizer rates, and growing seasons. The average ETₐ values of 207.9, 312.6, 381.4, 336.6 and 449.5 mm were obtained with 0000, 0111, 1011, 1101, and 1111 irrigation regimes, respectively. The revealed variations in ETₐ are due to water stress at various growth stages causing stomatal closure to certain levels. This considered as the primary cause for the decrease in transpiration and photosynthesis rates (Shimshi, 1982), and affecting yield and other characters. Seasonal averages of ETₐ were 334.4 and 340.7 mm with 143 and 214 kg N ha⁻¹, and 318.3, 356.8, and 337.6 mm for wheat in the first, second, and overall seasons, respectively. Reported values of seasonal ETₐ for wheat over several water treatments were 455-489 mm (Seif El-Yazal et al., 1983) on cv. Giza 157, 209-349 mm (Gad El-Rab et al., 1988) and 292.6-562.9 mm (Gaber, 2000) on cv. Sakha 8, and 292.5-392.1 mm (Ibrahim, 1999) on cv. Giza 163 under shallow water table. The overall equation of ETₐ (mm) and AW (mm) is quadratic as:

\[ ETₐ = -22.3 + 0.982 \times AW - 1.954 \times 10^{-4} \times AW^2 \]

R² = 0.985

Gross Yield and Applied Water Relationships:
The amount of water applied in different irrigation regimes significantly affected the gross yield with the two N fertilizer rates in the two growing seasons. High rates of N fertilization enhancing root and shoot
growth and make more water available for crop use especially under mild stress (Huang et al., 2003). Non-linear relationships between gross yield and the amount of irrigation water were observed in the two growing seasons. The best-fit of the responses data of gross yield (GSY) in kg ha\(^{-1}\) to AW in mm are as follow:

1) First season:
   
   \[
   GSY = 6258 + 42.59\, \text{AW} - 0.0635\, \text{AW}^2 \\
   GSY = -6391 + 129.9\, \text{AW} - 0.1937\, \text{AW}^2 
   \]
   
   \[ R^2 = 0.434 \quad \text{at N} = 143 \, \text{kg ha}^{-1} \]
   \[ R^2 = 0.371 \quad \text{at N} = 214 \, \text{kg ha}^{-1} \]

2) Second season:
   
   \[
   GSY = 16.07(0.9975)^{\text{AW}} (\text{AW})^{1.3} \\
   GSY = 11720 - 4.295\, \text{AW} - 0.0266\, \text{AW}^2 
   \]
   
   \[ R^2 = 0.973 \quad \text{at N} = 143 \, \text{kg ha}^{-1} \]
   \[ R^2 = 0.740 \quad \text{at N} = 214 \, \text{kg ha}^{-1} \]

3) Averages of the two seasons:
   
   \[
   GSY = 7351 + 24.91\, \text{AW} - 0.0224\, \text{AW}^2 \\
   GSY = \frac{\text{AW}}{0.0000548\, \text{AW} + 0.00545} \\
   GSY = 3212.45(\text{AW})^{0.248} 
   \]
   
   \[ R^2 = 0.536 \quad \text{at N} = 143 \, \text{kg ha}^{-1} \]
   \[ R^2 = 0.296 \quad \text{at N} = 214 \, \text{kg ha}^{-1} \]
   \[ R^2 = 0.402 \quad \text{Overall} \]

These functions provided different gross yield-water options for the region.

**Grain Yield and Applied Water Relationships:**

The amount of water applied in different irrigation regimes significantly affected the grain yield with the two N fertilizer rates in the two growing seasons. Several studies showed significant increase in the grain yield with the increase in water application rates (Gad El-Rab et al., 1988; Al-Kaisi et al., 1997; Ibrahim, 1999; and Gaber 2000). Positive trends were clearly noticed and the best-fit of the responses data of grain yield (GY) in kg ha\(^{-1}\) to AW in mm are given in Fig. 2.

1) First season:
   
   \[
   \text{GY} = \frac{\text{AW}}{0.00003658\, \text{AW} + 0.07162} \\
   \text{GY} = 9431.7 \exp\left(\frac{-244.6}{\text{AW}}\right) \\
   \text{GY} = 10660 \exp\left(\frac{-343.5}{\text{AW}}\right) \\
   \text{GY} = 480 + 11.86\, \text{AW} 
   \]
   
   \[ R^2 = 0.973 \quad \text{at N} = 143 \, \text{kg ha}^{-1} \]
   \[ R^2 = 0.959 \quad \text{at N} = 214 \, \text{kg ha}^{-1} \]
   \[ R^2 = 0.969 \quad \text{at N} = 143 \, \text{kg ha}^{-1} \]
   \[ r = 0.803 \quad \text{at N} = 214 \, \text{kg ha}^{-1} \]
3) Averages of the two seasons:

\[ GY = -964.7 + 18.86AW - 0.01265AW^2 \quad R^2 = 0.933 \] ... at \( N = 143 \text{ kg ha}^{-1} \)

\[ GY = \frac{AW}{0.00003988AW + 0.06275} \quad R^2 = 0.798 \] ... at \( N = 214 \text{ kg ha}^{-1} \)

\[ GY = -225.0 + 15.65AW - 0.00739AW^2 \quad R^2 = 0.782 \] ... Overall

The quadratic production function was also reported to describe the response of wheat grain yield at different locations of China, Syria, and USA (Zhang and Oweis, 1999; and Zhang, 2003). Generally, these non-linear response functions offer suitable yield-water options for the region.

**Fig. 2:** Wheat grain yield as related to net applied irrigation water with different N fertilizer rates (143 kg/ha=low N and 214 kg/ha=high N), and the overall quadratic relation.

**Crop Factor:**

The crop factor reflects all the crop characteristics, sowing date, rate of crop development, and length of growing season under certain climatic conditions. Stresses at different growth stages affected the obtained \( k_c \) values (estimated from ETs and ETc data) that greatly lowered with the prolonged stress. Seasonal averages of wheat \( k_c \) values of 0.449, 0.676, 0.825, 0.728, and 0.973 were obtained with 0000, 0111, 1011, 1101, and 1111 irrigation regimes, respectively. Deviation from the \( k_c \) of normal watering (i.e. 1111 irrigation regime) may considered as stress factor for different growth stages. The average \( k_c \) values of 0.707, 0.753, and 0.730 were obtained in the first, second, and overall seasons, respectively. Increasing the applied N fertilizer from 143 to 214 kg ha\(^{-1}\) increased the \( k_c \) from 0.703 and 0.744 to 0.711 and 0.762 in the first and second seasons, respectively. Reported values of seasonal \( k_c \) for wheat were 0.87 (El-Sayed, 1982), 0.35-0.59 (Gad El-Rab et/
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al., 1988), and 0.78 under shallow water table (Amer et al., 1989). For most crops, Doorenbos and Kassam (1986) reported $k_c$ value between 0.8-0.9 for the total growing period. The relation of seasonal $k_c$ and $AW$ (mm) is exponential as:

$$k_c = 9.334 \times 10^{-4} AW^{1.141} \quad R^2 = 0.999$$

Grain Yield Responses to Water:

The grain yield responses to water was determined through the yield response factor according to Doorenbos and Kassam (1986) which relates the relative yield decrease \(1 - (\frac{GY}{GY_m})\) to relative evapotranspiration deficit \(1 - (\frac{ET_a}{ET_m})\), as $GY$ and $GY_m$ are actual and maximum yield, $ET_a$ and $ET_m$ are actual and maximum evapotranspiration, respectively.

$$\left[1 - \frac{GY}{GY_m}\right] = k_y \left[1 - \frac{ET_a}{ET_m}\right]$$

The higher $k_y$ value refers to a greater yield loss under the condition of limited water (Doorenbos and Kassam, 1986). The obtained values of $k_y$ were lower than 1 (Fig. 3) and varies with different irrigation regimes, N fertilizer rates, and growing seasons. A response factor lower than unity indicates that the expected relative yield decrease for a given evapotranspiration deficit is proportionately less than the relative decrease in evapotranspiration. The $k_y$ greatly reduced with increasing the applied water with different deficit regimes. The average $k_y$ values of 0.735, 0.378, 0.538, 0.596, and 0.176 were obtained with 0000, 0111, 1011, 1101, and 1111 irrigation regimes, respectively. Different N fertilizer rates showed contrasted trends between the two growing seasons, but on the averages basis there were no changes. Seasonal averages of $k_y$ were 0.422, 0.526, and 0.484 for wheat in the first, second and overall seasons, respectively. Kirda (1999) reported seasonal $k_y$ values of 0.76 and 0.93 for wheat under sprinkler and basin irrigation, respectively. Only those crops and growth stages with a lower crop yield response factor ($k_y<1.0$) can generate significant savings in irrigation water through deficit irrigation (Kirda 1999) and well shown in the results of this study. The relation of seasonal $k_y$ and $AW$ (mm) is quadratic as:

$$k_y = 0.6594 + 1.454 \times 10^{-3} AW - 5.509 \times 10^{-6} AW^2 \quad R^2 = 0.692$$

The $k_y$ factor may apply for planning, design, and operation of irrigation projects allows quantification of water supply and water use in terms of crop yield and total production of the area.

Water Use Efficiency:

The WUE (kg grains ha$^{-1}$ per mm $ET_a$) values were affected by irrigation regimes based on different water deficit at different growth stages, and N fertilization rates. The average WUE values of 13.60, 14.60, 11.44,
11.89, and 11.98 kg ha\(^{-1}\) mm\(^{-1}\) were found with 0000, 0111, 1011, 1101, and 1111 irrigation regimes, respectively. Seasonal stress or stress at early stage (i.e. vegetative) resulted in higher WUE. The lowest WUE was noticed with the stress at flowering or yield formation stages. Increasing the applied N fertilizer rate from 143 to 214 kg ha\(^{-1}\) increased the WUE from 11.92 to 13.48 kg ha\(^{-1}\) mm\(^{-1}\) due to the increase in grain yield. Seasonal average of WUE was 12.70 kg ha\(^{-1}\) mm\(^{-1}\) for wheat in the W. Nubaria region. Reported values of seasonal WUE for wheat were 7.6-14.8 (Singh et al., 1980) in India, 9.8-11.9 (Seif EI-Yazal et al., 1983) on cv. Giza 157, 23.9-31.3 (Gad EI-Rab et al., 1988) and 10.5-14.0 (Gaber, 2000) on cv. Sakha 8, and 13.6-16.4 kg ha\(^{-1}\) per mm (Ibrahim, 1999) on cv. Giza 163 under shallow water table. Generally, the higher the applied irrigation water, the lower the WUE of the wheat. The linear relationship of WUE (kg ha\(^{-1}\) mm\(^{-1}\)) and AW (mm) is given as:

\[
WUE = 16.175 - 0.0102AW
\]

\(r = 0.609\)

Fig. 3: The relations of growing season relative yield decrease and relative evapotranspiration deficit for wheat grown in West Nubaria region (\(I=first\) season, \(II=second\) season, \(N143=143\) kg N/ha, and \(N214=214\) kg N/ha)

**CONCLUSION**

This study showed that the averages of irrigation regimes 0000, 0111, 1011, 1101, and 1111 were 11930, 14521, 14544, 12920, and 14159 kg ha\(^{-1}\) for gross yield, 2801, 4571, 4345, 3994, and 5390 kg ha\(^{-1}\) for grain yield, and 9129, 9950, 10199, 8946, and 8769 kg ha\(^{-1}\) for straw yield, respectively. This corresponding to \(ET_a\) of 207.9, 312.6, 381.4, 336.6, and 449.5 mm, \(k_\alpha\) of 0.449, 0.676, 0.825, 0.728, and 0.973, \(k_\gamma\) of 0.735, 0.378, 0.538, 0.595, and 0.176, and WUE of 13.60, 14.60, 11.44, 11.89, and 11.98 kg ha\(^{-1}\) mm\(^{-1}\), respectively. The region overall averages of all treatments were
For gross, grain, and straw yields, respectively, corresponding to \( \text{ET}_t \) of 337.6 mm, \( k_e \) of 0.711, \( k_y \) of 0.464, and WUE of 12.70 kg ha\(^{-1}\) mm\(^{-1}\). The yield and yield characteristics increased while the efficiency of water utilization decreased as the quantities of irrigation water increased. These results stood in great agreements with the reported data of wheat growth with different water application rates of Seif El-Yazal et al. (1983), Gad El-Rab et al. (1988), Amer et al. (1989), Al-Kaisi et al. (1997), Ibrahim (1999), Gaber (2000), and Moussa (2000).

The saving in irrigation water was 26.8% due to stress at the vegetative stage and resulted in reduction of 0.2% gross, 15.2% grain, and 2.4% straw yields, and minor effects on the other yield characteristics. The effects exhibited by the stress at the flowering stage were close to those of the stress at the vegetative stage, and the resulted saving in irrigation water was 13.2%. Saving 23.4% of irrigation water due to the stress at the yield formation stage leads to reduction of 11.0% gross, 25.9% grain, and 12.3% straw yields, and double reduction of the other characteristics as compared to the stress at vegetative stage. Imposing water stress throughout the whole season caused great loss in grain yield and other yield characteristics. English and Raja (1996) suggested that deficits between 15 and 59% would be economical. Therefore, if the amount of irrigation water available for wheat production is limited, it could be used more efficiently if applied to relieve stress during flowering (mid-late-February to mid-late-March) followed by yield formation (late-March to mid-April), and least during vegetative stage (mid-December to late-February).

Similar to that reported by Zhang and Oweis (1999) grain yield linearly increased with the increase in \( \text{ET}_t \) and better trend was observed with relative wheat yield vs. relative growing season ET (Fig. 4) because of avoiding variations in yield in different years and normalizing the relationship (Singh et al., 1980). The fitted GY (kg ha\(^{-1}\)) with \( \text{ET}_t \) (mm), and the relative relation are given as:

\[
\begin{align*}
\text{GY} &= 954.5 + 9.674\text{ET}_t \\
\frac{\text{GY}}{\text{GY}_m} &= 0.175 + 1.136 \frac{\text{ET}_t}{\text{ET}_m} \\
r &= 0.845 \\
r &= 0.871
\end{align*}
\]

The reduction in \( \text{ET}_t \) due to stresses at one growth stage between vegetative and yield formation were 15.1-30.5% resulted in 15.2-25.9% reduction in grain yield. Zhang (2003) reported that 40% reduction in ET during same period reduced yield by 15-20% in Syria.

Reducing the applied N fertilizer from 214 to 143 kg ha\(^{-1}\) (33.3 %) resulted in reduction from 14107 to 13130 kg ha\(^{-1}\) (6.9 %), 4504 to 3936 kg ha\(^{-1}\) (12.6 %), and 9603 to 9194 kg ha\(^{-1}\) (4.3 %) of gross, grain, and straw yields, respectively, and had minor effects on the other yield characteristics. Amer et al. (1989) suggested that the rate of 150 kg N ha\(^{-1}\) is optimum for high grain yield of wheat. Thus, N application of 143 kg ha\(^{-1}\) can be of environmental advantage. However, it is better matching N application with wheat needs under sprinkler irrigation (Eck, 1988).
Fig. 4: The relations of (a) wheat grain yield vs. growing season actual evapotranspiration, and (b) relative wheat yield vs. relative growing season actual evapotranspiration.

Deficit irrigation is an efficient strategy for higher productivity of wheat with the same amount of water resources compared with full irrigation under water shortage conditions found in the newly reclaimed soils. Higher productivity of applied water is achieved at water supply level lower than that of maximum yield. The risk with deficit irrigation is low because the response curve of yield to water supply often has a wide plateau, and can be minimized through proper irrigation scheduling by avoiding water stress especially during the growth stages more sensitive to water stress. Thus, a considerable amount of water can be saved without a significant yield reduction compared with full irrigation.

This work may provide guidelines for practicing deficit irrigation with wheat in the newly reclaimed soils of Egypt for identifying likely growth stages for imposing reduced irrigation (or ET), and for assessing the economic feasibility and acceptability of deficit irrigation through the estimation of expected relative yield decreases.

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El-Haris, Mamdouh K.


إنقاص رئي الفمح تحت نظام الرى بالرش في الأراضي المستصلاحة حديثا بمصر

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قسم الأراضي والبيئة - كلية الزراعة - جامعة الأسكندرية - الشاطئية - الأسكندرية 2045

مصر

أجريت تجربة تحتلية على محصول الفمح تحت نظام الرى بالرش في 8 مدام
موري في منطقة الجرار - غرب الدور - بدء دراسة تأثير اقتصار الرى وعمال التسديد
التي تواجه نقص في المياه المتوفرة للرى في أوائل الفصل الأمامي من المشحوضة،
والتي تنخفض دراسة بتعظيم العوامل لفسك نظام سهولة الرى للنظام الرئيسية ودبيها للتسديد
التي وصلت 114 كجم/ككتار (رج. 140 كجم/ككتار) للقطاع تحت النظامائي في نظام الفصل
المنشأة. أخذت محصولات الرى للقدرة الأجهزة مقابل طفول موسم النمو، وإيجاد الرى في واحد
من كل من اقتصار الرى نمو الفمح الثالثة وهي الفخصري، والى الرى، وتكوين المحصول، بالإضافة
لدى الشريكتين، نمو الفمحات خالصة طور متبقي للمفع وبتفاعلي مع طور 50% من
البرتقال، تنتج المحصول.

أظهرت نتائج التجربة أن اقتصار الرى النمو أدّى إلى محصول جزء

المكون من 22.6 كجم/ككتار (رج. 23.5 كجم/ككتار) إلى 100% من النمو النمو، ثم أخذت 24.5% من المحصولات الرى ذات الإضافات
بمعدلات منخفضة محصول حبوب غير متصلف معنوي غير المحصولات اللى الكاملاً، أدّى اقتصار معدل إضافية السمنة
البيئية من 214 إلى 123 كجم/ككتار (رج. 23.5 كجم/ككتار) إلى نقص في محصول الحبوب من
إلى 230 كجم/ككتار (رج. 230 كجم/ككتار) وحدث تأثيرات بسيطة في الصرف المحصولات الأخرى.

هذه الدراسة أظهرت أن الاستخدام الكافي لكمية ماء الري المدفعة والمتاحة لإنتاج الفمح-
لم تؤثر على الإنتاج الإيجابي للموطن الجديد على طول الرى (من أواسط-أواخر شهري فبراير إلى
أواخر-أواخر شهر مارس) بلبل طور كوكبة الحبوب (أواخر شهر مارس إلى أواسط-أواخر وزار)،
وبالإضافة إلى طور فصل الم márما (أواخر شهر فبراير إلى أواسط-أواخر شهر إبريل). هذا مع إضافة سمادة
نيترات الهيدروجين بعمال 24 كجم/ككتار مما يؤدي إلى محصول اقل وبينة مستدامة.