Journal of Applied Sciences Research, 3(12): 1766-1773, 2007

Increasing Water Use Efficiency for Wheat Grown under Water Stress Conditions

[1]S.A. Ouda, [2]T. El-Mesiry and [2]M.S. Gaballah

[1]Water Requirements and Field Irrigation Research Department; Soil, Water, and Environment Institute; Agriculture Research Center; Egypt.
[2]Water Relations and Field Irrigation Department; National Research Centre, Egypt.

Abstract: Two field experiments were carried out at Shalakan, Kalubia governorate during 2004/05 and 2005/06 growing seasons to study the effect of the application of $MgCO_3$ on increasing water use efficiency of wheat grown under water stress. Five irrigation treatments (control, skipping irrigation at grain milk stage, skipping irrigation at milk stage and the application of $MgCO_3$, skipping irrigation at maturity stage, skipping irrigation at grain maturity stage and the application of $MgCO_3$) and two wheat varieties (Sahka 93 and Giza 168) were arranged in spilt plot design with four replications. Results showed that Sakha 93 was more tolerant to water stress than Giza 168, where yield reduction under skipping irrigation at milk stage where 14.15 and 34.51% for Sahka 93 and Giza 168, respectively. Whereas, skipping irrigation at maturity stage reduce grain yield by 12.86 and 24.25% for Sahka 93 and Giza 168, respectively. The highest water use efficiency was obtained for Sakha 93 and skipping irrigation at grain maturity stage with the application of $MgCO_3$. Either air temperature or soil temperature was good predictor for wheat grain yield. However, soil temperature was better predictor than air temperature in predicting straw yield. Therefore, it could be concluded that to save irrigation water, to maintain low yield losses and to increase water use efficiency, the last irrigation could be skipped if Sakha 93 was sown and sprayed with $MgCO_3$.

Keywords: Water use efficiency, wheat, skipping irrigation at grain milk stage, skipping irrigation at grain maturity stage, $MgCO_3$

INTRODUCTION

Wheat is a very important cereal crop in Egypt. The crop is very sensitive to the timing of a water deficit period rather than the total reduction of applied irrigation water. Exposing wheat plants to high water stress reduced seasonal consumptive use and grain yield[3,10]. During vegetative growth, phyllochron decreases in wheat under water stress[11] and leaves become smaller, which might reduce the leaf area index[6] and decrease the number of reproductive tillers, in addition to limit their contribution to grain yield[15]. Furthermore, water stress occurring during grain growth could have a severe effect on the final yield compared with stress occurring during other stages[8]. During grain growth, different sources for photosynthesis exist. The main one is flag leaf, in addition to spike components and stem tissue. Moreover, under water stress conditions, mobilization of stem nonstructural reserve increases[11]. Therefore, stomatal closure and the reduction of carbon exchange rate for photosynthesis at that stage could be overcome by mobilization of stem reserve[6]. The amount of wheat yield reduction as a result of water stress is affected by the stage of grain development, where the early grain development stage is the most vulnerable[4].

Weather parameters, such as air temperature, soil temperature and relative humidity have great effect on wheat yield. Air temperature is the primary factor driving wheat development[19], and consequently influences yield[11]. The wheat shoot apex is located in the crown of the plant until internode elongation raises the apex above the soil surface. Therefore, during that time soil temperature is a better measure for plant growth and that could indirectly affect final yield[13]. Furthermore, soil temperature affects the growth of roots more than the growth of shoots, in addition to it has a great affects on nutrients absorption by plants such nitrogen[6]. Relative humidity also has a great effect on yield, where water losses to the atmosphere decreases with increasing relative humidity[6]. Relative humidity is a measure of water vapor concentration in the air, expressed as a fraction of saturation water vapor concentration[18].

The objectives of this work are (i) to determine percent reduction in wheat yield as a result of skipping irrigation either at the grain milk stage or at final seed maturation stage; (ii) to determine percent improvement in wheat yield as a result of the application of $MgCO_3$ as a anti-transpiration; (iii) to determine water use efficiency under the above mentioned conditions; (iv)

Corresponding Author: M.S. Gaballah, Water Relations and Field Irrigation Department; National Research Centre, Egypt.
E-mail: Msgaballa54@yahoo.com

to predict wheat yield under the above mentioned conditions using either air mean temperature or soil mean temperature.

MATERIALS AND METHODS

Two field experiments were conducted at Shalakan, Kalubia governorate to study the effect of the application of $MgCO_3$ on increasing water use efficiency of wheat grown under water stress. The sstatistical design was spilt plot with three replications. The irrigation treatments (control, skipping irrigation at grain milk stage, skipping irrigation at milk stage and the application of $MgCO_3$, skipping irrigation at maturity stage, skipping irrigation at grain maturity stage and the application of $MgCO_3$) were included in the main plot the, whereas the varieties were in the subplots (Sakha 93 and Giza 168). The preceded crop was maize in both growing seasons. Soil texture was clay loam with 7.5% sand, 59.1% silt and 33.4% clay. Soil pH is 7.55, EC is 0.26 dS/m, Ca^{++} is 1.1, Mg^{++} is 0.5, Na^{+} is 0.5, K^{+} is 1.13, and $HCO3^{-}$ is 0.8. Sowing was done on the last week of December for the two growing seasons of 2004/05 and 2005/06. The growing plants received recommended dose of fertilizers. Agricultural practices were performed as usual. Wheat plants received six irrigations. Either the 5^{th} or the 6^{th} irrigation was skipped. The 5^{th} irrigation occurred during grain milk stage and the 6^{th} irrigation occurred during final maturity period. Foliar spray of $MgCO_3$ was done twice 45 and 65 days after sowing on the wheat plants to reduce transpiration and water loss from plants surface by causing stomatal closure.

At harvest, ten plants were selected randomly from the three replicates of each treatment for estimating yield and its components. Plant height (PLH, cm), spike length (SpL, cm), number of spikes/m^2 (Sp/m^2), number of grain/spike (Gn/Sp), grain weight/spike (Gw/Sp), grain yield/fed (GY, ton/fed), straw yield/fed (SY, ton/fed) and biological yield/fed (BY, ton/fed) were measured.

Data for air mean temperature (AirMT, °C), soil mean temperature at the depth of 20 cm (Soil MT, °C) and relative humidity (RH) were collected and averaged over the two growing seasons of 2004/05 and 2005/2006 (Table 1).

Crop-water Relation Parameters:

Seasonal Actual Water Consumptive Use (Evapotranspiration): Actual evapotranspiration (ET) was estimated by soil sampling just before and after 48 hours of each irrigation, and before harvest and calculated according to the equation of Israelsen and Hansen[7] as follows:

$$CU = (\Theta_2 - \Theta_1) * Bd * RD \qquad (2)$$

Table 1: Average of air and soil temperature and relative humidity for the two growing seasons.

Season	Air mean temperature (°C)	Soil mean temperature(°C)	Relative humidity %
2004/05	17.55	16.73	45.45
2005/06	16.72	17.50	59.73
Average	17.13	52.59	17.11

Soil moisture constants (% per weight) and bulk density (g/cm^3) in the depth of 0-60 cm are shown in Table (2).

Where: CU is water consumptive use (cm), Θ_2 is soil moisture percentage by weight 48 hours after irrigation, Θ_1 is soil moisture percentage by weight 48 hours before next irrigation, Bd is bulk density in (g/cm^3) and RD is root depth.

Water Use Efficiency (WUE): Water use efficiency (kg/m^3) values for the different treatments were calculated by the following equation.

$$WUE = \text{Seed yield (kg/fed)} / \text{Consumptive use}(m^3/\text{fed}) \qquad (3)$$

Statistical Analysis:

- Analysis of variance for split plot design according to Snedecor and Cochran[16] was done to find out the significance of the studied treatments. Means of the studied characters were compared by least significant difference ($LSD_{0.05}$).
- Percent decease in wheat yields as a result of skipping irrigation was calculated. Moreover, percent improvement in yields as a result of application of $MgCo_3$ was also calculated.
- Regression analysis[2] was used to develop equations to predict wheat yield under the above mentioned treatments. Two parameters, coefficient of determination (R^2) and standard error of estimates (SE%) were used to test the precision. In order to obtain a precision prediction, R^2 should be near to one and SE% should be near to zero. Coefficient of determination is the amount of variability due to all independent variables, and standard error of estimates is a measurement of precision i.e. closeness of predicted and observed yield to each other. Two sets of prediction equations were developed to predict wheat grain. One set used air mean temperature, in addition to relative humidity and yield components, and the other set used soil mean temperature instead of air mean temperature with the rest of the above mentioned variables. The developed equations were compared with its R^2 and SE% to determine its accuracy.

RESULTS AND DISCUSSIONS

Effect of Wheat Varieties: Results in Table (3) showed that there a significant difference between Sakha 93 and Giza 168 was found in all the studied characters, except for number of spike/m^2 in the second

Table 2: Soil moisture constants of the experimental field at experimental site

Depth (cm)	Field capacity (%, w/w)	Wilting point (%, water)	Available water (mm)	Bulk density g/cm^3
0 – 15	42.15	19.01	40.0	1.15
15 – 30	34.62	16.90	30.1	1.24
30 – 45	27.36	16.92	20.6	1.20
45 – 60	27.15	16.24	22.1	1.28

Table 3: Effect of wheat varieties on yield and its related characters during 2004/05 and 2005/06 growing seasons.

Characters	Variety					
	Sakha 93		Giza 168		L.S.D $_{0.05}$	
	2004/05	2005/06	2004/05	2005/06	2004/05	2005/06
Plant height (cm)	98.65	101.05	102.05	103.85	3.19	2.17
Spike length (cm)	10.53	10.98	12.04	12.11	0.35	0.64
No. of grain/spike	63.33	63.60	70.37	71.54	4.02	2.62
Grains weight/ spike (g)	2.20	2.35	2.16	2.32	0.10	0.10
100–grain weight (g)	3.43	3.43	3.12	3.58	0.12	0.09
No. of spikes/m^2	286.9	281.05	267.30	276.0	34.90	n.s
Crop index	79.49	80.60	79.79	81.26	5.14	3.51
Harvest index	44.41	44.62	44.32	44.80	0.09	0.97
Grain yield (ton/fed)	2.61	2.73	2.25	2.40	0.09	0.07
Straw yield (ton/fed)	3.26	3.38	2.84	2.95	0.10	0.10
Biological yield (ton/fed)	5.78	6.11	5.11	5.36	0.16	0.05

Table 4: Effect of irrigation treatments on wheat yield and its components during 2004/05 and 2005/06 growing seasons.

	Irrigation treatments											
	Control		skipping irrigation at grain milk stage		skipping irrigation at grain milk stage and $MgCO_3$		Skipping irrigation at grain maturity stage		Skipping irrigation at grain maturity stage and $MgCO_3$		L.S.D. $_{0.05}$	
	S1	S2	S1	S2	S1	S2	S1	S2	S1	S2	S1	S2
PLH	103.5	104.38	97.88	101.25	99.25	101.25	99	102.13	102.13	103.25	1.47	0.94
SpL	11.4	11.71	11	11.46	11.33	11.56	11.3	11.57	11.04	11.27	0.37	0.26
Gn/Sp	68.69	68.74	62.88	63.99	67.24	68.53	71.48	71.15	63.96	65.45	7.4	2.47
Gw/Sp	2.3	2.52	2.02	2.1	2	2.2	2.23	2.35	2.23	2.3	0.13	n.s
100-G	3.57	3.81	3.11	3.52	3.11	3.39	3.13	3.4	3.311	3.39	0.16	0.34
Sp/m2	311.38	281.38	261	289.38	263.5	270.13	271.38	277.5	287.25	274.25	6.45	4.87
CI	83.89	83.75	76.46	78.44	76.42	78.31	78.7	80.43	82.72	83.73	n.s	n.s
HI	45.61	45.55	43.71	43.91	43.28	43.89	44.02	44.55	45.23	45.64	n.s	n.s
GY	2.75	2.85	2.25	2.41	2.22	2.37	2.42	2.54	2.51	2.65	0.06	0.06
SY	3.31	3.43	2.96	3.06	2.91	3.03	3.04	3.16	3.04	3.16	0.59	0.05
BY	6.09	6.3	5.26	5.47	5.13	5.4	5.42	5.69	5.55	5.81	0.09	0.07

S1=2004/05 growing season; S2= 2005/06 growing season; PLH=plant height (cm); SpL=spike length (cm); Gn/Sp=grain number/spike; Gw/Sp=grain weight/spike (g); 100-G=100-grain weight (g); Sp/m^2= number of spikes/m^2; CI=crop index; HI=harvest index; GY=grain yield (ton/fed); SY=straw yield (ton/fed); BY=biological yield (ton/ha).

Table 5: Effect of the interaction between wheat varieties and irrigation treatments on yield and its attributes during 2004/05 growing season.

Character	Varieties	I1	I2	I3	I4	I5	$L.S.D_{0.05}$
PLH	V1	100.00	95.75	98.50	100.00	100.25	n.s
	V2	107.00	100.00	99.25	95.00	104.00	
SpL	V1	10.86	10.20	10.70	10.53	10.38	n.s
	V2	12.28	11.35	11.98	12.13	12.45	
Gn/Sp	V1	60.98	60.53	71.65	60.08	60.40	7.40
	V2	76.40	65.23	71.30	74.40	64.53	
Gw/Sp	V1	2.30	2.03	2.36	2.02	2.28	0.13
	V2	2.40	2.01	2.11	2.12	2.17	
100-G	V1	3.52	3.50	3.41	3.40	3.33	0.16
	V2	4.10	3.55	3.88	3.39	3.46	
Sp/m^2	V1	315.75	277.00	281.50	281.75	278.50	14.42
	V2	307.00	245.00	261.25	245.25	278.00	
CI	V1	82.54	78.56	77.91	79.19	79.24	n.s
	V2	85.24	74.36	79.50	73.65	86.20	
HI	V1	45.22	44.69	43.78	44.18	44.20	1.09
	V2	45.99	42.73	44.25	42.38	46.25	
GY	V1	2.84	2.51	2.63	2.55	2.63	0.17
	V2	2.66	2.00	2.21	1.99	2.39	
SY	V1	3.50	3.10	3.29	3.11	3.32	0.13
	V2	3.13	2.82	2.78	2.71	2.79	
BY	V1	6.38	5.61	5.86	5.56	5.95	n.s
	V2	5.79	4.91	4.71	4.71	5.16	

I1= control treatment; I2=skipping irrigation at grain milk stage; I3=skipping irrigation at grain milk stage and application of $MgCO_3$; I4= skipping irrigation at grain maturity stage; I5= skipping irrigation at grain maturity stage and application of $MgCO_3$; PLH=plant height (cm); SpL=spike length (cm); Gn/Sp=grain number/spike; Gw/Sp=grain weight/spike (g); 100-G=100-grain weight (g); Sp/m^2= number of spikes/m^2; CI= crop index; HI=harvest index; GY=grain yield (ton/fed); SY=straw yield (ton/fed); BY=biological yield (ton/ha); V1=Sakha 93; V2= Giza 168.

season. Furthermore, variety Sakha 93 out yielded variety Giza 168 in both growing seasons. Therefore, it could be concluded that under the condition of Kalubia governorate, growing Sakha 93 could gave high yield. This result in agreement with what was found by El-Kholy *et al.,*[4].

Effect of Irrigation Treatments: Results presented in Table (4) showed that irrigation treatments had significant effect on all the studied characters in both season, except of grain weight/spike in the second growing season, and crop index and harvest index in both growing seasons. However, all the studied characters were decreased as a result of skipping irrigation either at grain milk stage or at grain maturity stage. Khater *et al.,*[10] concluded that the number of spikes/m^2, 1000 grain weight, straw and grain yield/fed were significantly decreased with decreasing available soil moisture content. The highest grain, straw and biological yields were obtained under the control treatment (full irrigation amount). Skipping irrigation at grain milk stage had less bad effect on wheat yield, compared with skipping the irrigation at grain milk stage. This could be attributed to the fact that water stress during that stage affect cells expansion, reduces grain growth rate and consequently reduces yield[12]. Furthermore, the spraying wheat plants with $MgCO_3$ reduce the harm effect of water stress at both growth stages. Similar results were obtained for wheat by El-Kholy *et al.,*[4] when plants were sprayed with MgCO3.

Effect of the Interaction Between Wheat Varieties and Irrigation Treatments: Results in Table (5) showed that, in 2004/05 growing season, the interaction between wheat varieties and irrigation treatments was significant for all the studies characters, except for plant height, spike length, crop index and biological yield. These results were in agreement with the results obtained by Agrawal[1], and Mohamed and Tammam[14].

Similar trend was observed in 2005/06 growing season (Table 6), where all the studied characters were found significant, except for plant height, spike length, number of spikes/m^2, and crop index. These results were in agreement with the results obtained by Khalil *et al.,*[9].

Table 6: Effect of the interaction between wheat varieties and irrigation treatments on yield and its attributes during 2005/06 growing season.

Character	Varieties	I1	I2	I3	I4	I5	$L.S.D_{0.05}$
PLH	V1	102.00	100.00	101.50	100.00	101.75	n.s
	V2	106.75	102.50	102.75	10.50	104.75	
SpL	V1	10.98	9.88	10.93	10.07	10.61	n.s
	V2	12.51	11.53	12.21	12.11	12.18	
Gn/Sp	V1	60.80	62.48	70.00	61.48	63.25	5.53
	V2	76.68	56.50	72.30	75.58	67.65	
Gw/Sp	V1	2.46	2.17	2.49	2.20	2.44	0.17
	V2	2.57	2.19	2.20	2.30	2.34	
100-G	V1	3.52	3.50	3.41	3.40	3.33	0.20
	V2	4.10	3.55	3.88	3.39	3.46	
Sp/m^2	V1	285.25	293.50	279.75	267.50	279.25	n.s
	V2	277.50	285.25	275.25	272.75	269.25	
CI	V1	80.48	82.91	79.14	80.44	80.05	n.s
	V2	87.02	73.96	81.73	76.18	78.41	
HI	V1	44.59	45.32	44.17	44.56	44.44	6.17
	V2	46.51	42.51	44.94	43.21	46.84	
GY	V1	2.91	2.67	2.70	2.59	2.75	0.14
	V2	2.80	2.15	2.37	2.16	2.55	
SY	V1	3.62	3.22	3.41	3.23	3.44	0.12
	V2	3.25	2.90	2.90	2.83	2.89	
BY	V1	6.53	5.89	6.11	5.82	6.19	0.16
	V2	6.07	5.05	5.27	4.99	5.44	

I1= control treatment; I2=skipping irrigation at grain milk stage; I3=skipping irrigation at grain milk stage and application of $MgCO_3$; I4= skipping irrigation at grain maturity stage; I5= skipping irrigation at grain maturity stage and application of $MgCO_3$; PLH=plant height (cm); SpL=spike length (cm); Gn/Sp=grain number/spike; Gw/Sp=grain weight/spike (g); 100-G=100-grain weight (g); Sp/m^2= number of spikes/m^2; CI= crop index; HI=harvest index; GY=grain yield (ton/fed); SY=straw yield (ton/fed); BY=biological yield (ton/ha); V1=Sakha 93; V2= Giza 168.

Table 7: Percent difference between wheat yield under control and under the rest of irrigation treatments over the two growing seasons

Irrigation treatment	Percent difference in grain yield than the control	
	Sakha 93	Giza 168
I2	14.15	34.51
I3	9.15	16.52
I4	12.86	24.25
I5	7.12	9.98

I2=skipping irrigation at grain milk stage; I3=skipping irrigation at grain milk stage and application of $MgCO_3$; I4= skipping irrigation at grain maturity stage; I5= skipping irrigation at grain maturity stage and application of $MgCO_3$

Reduction in Wheat Yield under Irrigation Skipping and Improvement in Wheat Yield under $Mgco_3$ Application: Results in Table (7) showed that skipping irrigation at grain milk stage decreased grain yield more than skipping irrigation at final grain maturity stage averaged over the two growing seasons. Furthermore, percent of yield reduction was higher for Giza 168, compared with Sakha 93. The application of $MgCO_3$ reduced yields losses, especially for Giza 168, where percent reduction in grain yield was 34.51% under skipping irrigation at grain milk stage and was lowered to 16.52% under skipping irrigation at grain milk stage and $MgCO_3$ application. Therefore, it could be concluded that to save irrigation water and maintain low yield losses, the last irrigation at final grain maturity stage could be skipped if Sakha 93 was sown and sprayed with $MgCO_3$.

Measured Consumptive Water Use and Water Use Efficiency: Results in Table (8) indicated that the highest water consumptive use was obtained under control treatment, followed by skipping irrigation at grain milk stage and skipping irrigation at grain milk stage and application of $MgCO_3$ treatments, followed by skipping irrigation at grain maturity stage and skipping irrigation at grain maturity stage and application of $MgCO_3$ treatments. Results in that table also showed that water use efficiency was higher for Sakha 193 than Giza 168 under all irrigation treatments in both growing seasons. The highest water used efficiency was obtain under skipping irrigation at grain maturity stage and application of $MgCO_3$ for Sakha 93 i.e. 1.94 and 2.03 kg/fed for both growing seasons, respectively. This result proved the previous

Table 8: Consumptive water use (CU) and water use efficiency (WUE) for wheat under different irrigation treatments

		CU (m^3/fed)			WUE (kg/fed)				
Season	Variety	I1	I2 & I3	I4 & I5	WUEI1	WUEI2	WUEI3	WUEI4	WUEI5
S1	V1	1871	1482	1358	1.52	1.84	1.78	1.88	1.94
	V2	1858	1469	1345	1.43	1.49	1.50	1.48	1.77
S2	V1	1866	1477	1353	1.56	1.97	1.83	1.92	2.03
	V2	1863	1474	1350	1.50	1.59	1.61	1.60	1.89

S1=2004/05 growing season; S2=2005/06 growing season, V1=Sakha 93; V2= Giza 186; I1= control treatment; I2=skipping irrigation at grain milk stage; I3=skipping irrigation at grain milk stage and application of $MgCO_3$; I4= skipping irrigation at grain maturity stage; I5= skipping irrigation at grain maturity stage and application of $MgCO_3$; WUEI1= water use efficiency for treatment I1; WUEI2= water use efficiency for treatment I2; WUEI3= water use efficiency for treatment I3; WUEI4= water use efficiency for treatment I4; WUEI5= water use efficiency for treatment I5.

conclusion, which is planting Sakha 93 and skipping the last with the application of $MgCO_3$ could save irrigation water, maintain low yield losses and increase water use efficiency.

Wheat Yield Prediction: Wheat yield components in addition to relative humidity and air temperature or soil temperature were used to predict yield under the different treatments. Different equations were developed.

Control Treatment: For wheat grown under optimum conditions, equation [2] was a little bit accurate than equation [1] in predicting grain yield because R^2 was higher (0.911) and SE% was lower (1.418), from its counterpart in equation [1]. Under these conditions, it seemed that soil temperature could be an important predictor for wheat yield. The sign of all predictors coefficients in both equations are consistent, where the negative sign of plant height, spike length, and number of spikes/m^2 means that any increase in the three yield components decrease wheat grain yield by the value of its coefficients. Whereas, number of grains/spike, air mean temperature and relative humidity increased grain yield by the value of its coefficient.

[1] $\hat{y}_{grain} = -0.240 - 0.013(PLH)^{**} - 0.101(SpL) - 0.002(Sp/m^2) + 0.09(Gn/Sp) + 0.263(AirMT)^{*} + 0.03(RH)^{**}$

$R^2 = 0.891$ SE% = 1.773

[2] $\hat{y}_{grain} = -5.896 - 0.612(PLH) + 0.102(SpL) - 0.105(Sp/m^2)^{**} + 0.12(Gn/Sp)^{**} + 0.880(SoilMT)^{**} + 0.13(RH)^{**}$

$R^2 = 0.911$ SE% =1.418

Skipping the 5th Irrigation at Grain Milk Stage: Under the condition of skipping irrigation at grain milk stage, either equation [3] or [4] could be used to predict wheat yield because the value of R^2 and SE% are very close to each other. Furthermore, the sign of number of spikes/m^2 coefficient changed from negative in the control treatment to positive. That could be indication that under water stress number of spikes/m^2 could be important predictor for grain yield.

[3] $\hat{y}_{grain} = -0.905 - 0.101(PLH) - 0.108(SpL) + 0.112(Sp/m^2)^{**} + 0.102(Gn/Sp) + 0.126(AirMT) + 0.106(RH)$

$R^2 = 0.995$ SE% =0.913

[4] $\hat{y}_{grain} = -1.886 + 0.001(PLH) - 0.002(SpL) + 0.011(Sp/m^2)^{**} + 0.002(G\#/Sp) + 0.055(SoilMT) + 0.001(RH)$

$R^2 = 0.995$ SE% =0.910

Skipping the 5th Irrigation at Grain Milk Stage and the Application of $MgCO_3$: Under the condition of skipping irrigation at grain milk stage and the addition of $MgCO_3$, either equation [5] or [6] could be used to predict wheat yield because the value of R^2 and SE% are very close to each other. Moreover, the sign of plant height coefficient changed from negative in the control treatment to positive. That could be attributed to that under water stress and the addition $MgCO_3$, the role of mobilization from the stem became more pronounced in grain growth process.

[5] $\hat{y}_{grain} = -2.266 + 0.005(PLH) - 0.089(SpL)^{**} + 0.010(Sp/m^2)^{**} + 0.005(G\#/Sp) + 0.026(AirMT) + 0.006(RH)$

$R^2 = 0.981$ SE% = 1.504

[6] $\hat{y}_{grain} = -2.048 + 0.003(PLH) - 0.067(SpL) + 0.009(Sp/m^2)^{**} + 0.005(G\#/Sp) + 0.109(SoilMT) - 0.001(RH)$

$R^2 = 0.982$ SE% =1.467

Skipping the 6th Irrigation at Grain Maturity Stage: Either equation [7] or [8] could be used to predict wheat yield because the value of R^2 and SE% are close to each other. Furthermore, the sign of number of spikes/m^2 coefficient (indicator of number of tillers/ m^2) changed from negative in equation [7] to positive in equation [8] and this could be an indicator of the role that soil temperature plays in shoot apex growth.

[7] $\hat{y}_{grain}$ = - 0.699 - 0.002(PLH) - 0.033(SpL)* - 0.007(Sp/m^2)** - 0.005(G#/Sp) + 0.080(AirMT) + 0.010(RH)
R^2 = 0.995 SE% = 0.934

[8] $\hat{y}_{grain}$ = -1.705 - 0.001(PLH) - 0.009(SpL) + 0.007(Sp/m^2)** - 0.004(G#/Sp)** + 0.161(SoilMT)** - 0.002(RH)
R^2 = 0.996 SE% = 0.739

Skipping the 6th Irrigation at Grain Maturity Stage and the Application of $MgCO_3$: Similarly, either equation [9] or [10] could be used to predict wheat yield because the value of R^2 and SE% are close to each other. The sign of both plant height and number of spikes/m^2 coefficient were positive in both equations as an indicator of their important role in yield prediction under this treatment.

[9] $\hat{y}_{grain}$ = - 6.719 + 0.005(PLH) - 0.041(SpL)* + 0.011(Sp/m^2)** - 0.012(G#/Sp) +0.309(AirMT)** +0.027(RH)**
R^2 =0.953 SE% =1.744

[10] $\hat{y}_{grain}$ = - 5.656 + 0.005(PLH) - 0.013(SpL) + 0.010(Sp/m^2)** + 0.001(G#/Sp) + 0.339(SoilMT)** - 0.015(RH)**
R^2 = 0.985 SE% = 0.968

Conclusion: In Egyptian agriculture, more irrigation water is applied than crops need. On the contrary, eliminating unnecessary irrigation water could help in conserving irrigation water, provided that can be done with low yield losses. Our results showed that Sakha 93 was more tolerant to water stress during grain growth stage than Giza 168. The amount of wheat yield reduction as a result of water stress is affected by genotype and the stage of grain development. Yield reduction as a result of skipping irrigation at grain milk stage was higher than skipping irrigation at final grain maturity stage. Our results also showed that the application of $MgCO_3$ reduced wheat yield losses in both grain growth stages and improved water use efficiency for both varieties. Therefore, it is advisable to plant Sakha 93 and to skip the last irrigation at final grain maturity stage and spray it with $MgCO_3$ to save irrigation water and maintain low yield losses and to increase water use efficiency.

Because grain yield is an integration of many variables that affect plant growth throughout the growing season. Hence, it is essential to detect the characters having the greatest influence on yield. Our results showed that either air temperature or soil temperature could be good predictor for wheat grain yield. However, soil temperature was better predictor than air temperature in predicting straw yield.

REFERNCES

1. Agrawal, J.P., 1997. Studies on scheduling irrigation to wheat crop in Kabob soil of BundelKhand, India. J. Agron., 22(2): 123-134.
2. Draper, N.R. and H. Smith, 1987. Applied Regression Analysis. John Wilay and Sons, Imc. New York., pp: 397-402.
3. El-Kalla, S.E., A.A. Leilah, A.H. Basiony and S.M. Hussien, 1994. Effect of Irrigation and foliar nutrition treatments on growth and yield of some wheat cultivars under El-Arish area condition. 6th conf. Agron., Fac. Agric., Al-Azhar Uni., Egypt.
4. El-Kholy, M.A., S.A. Ouda, M.S. Gaballah and M. Hozayn, 2005. Predicting the interaction between the effect of anti-transpirant and weather on productivity of wheat plant grown under water stress. J. Agron., 4(1): 75-82.
5. Friend, D.J.C., 1965. Ear length and spiklete number of wheat grown at different temperatures and light intensities. Cand. J. Bot., 43: 343-353.
6. Gardner, F.P., R.B Pearce and R.L. Mitchell, 1985. Physiology of Crop Plants. Iowa State University Press. Ames.
7. Israelsen, O.W. and V.E. Hansen, 1962."Irrigation Principles and Practices" 3rd Ed. John witey × Sons Inc., New york , U.S.A.
8. Hanson A.D. and E.C. Nelson, 1980. In the biology of crop production, ed. P. S. Carlson. New York Academic Press.
9. Khalil, F.A.F., A.M. Tammam, I.A. Amin and K.A. Mohamed, 2006. Scheduling irrigation for some wheat cultivars under Upper Egypt conditions. J.Agric. Sci. Mansoura Univ., 31(1): 561-572.
10. Khater, A.N, Abdel H.H Maksoud and H.M. Eid, 1997. Response of some wheat cultivars and their water relations to different irrigation level in Middle Delta. Egypt, J. Appl. Sci., 11(2): 15-29.
11. McMaster, G.S., 1997. Phonology, development, and growth of wheat (*Triticum aestivum* L.) shoot apex: A review. Advaces in Agron., 59: 63-118.
12. McMaster, G.S. and D.E. Smika, 1988. Estimation and evaluation of winter wheat phenology in the Central Great Plains. Agric. For. Moteorol., 43: 1-18.
13. McMaster, G.S. and W.W. Wilhelm, 1998. Is soil temperature is better than air temperature in predicting winter wheat phenology. Agron. J., 90: 602-607.
14. Mohamed, K.A. and A.M. Tammam, 1999. Drought resistance of some wheat varieties in Upper Egypt. Third Conf. on On–farm Irri. & Agroclimtology. SWERI , A R C, Egypt, 1(2): 623-632.

15. Mosaad, M.G., G. Ortiz-Ferrara and Mahalak-V. Shmi, 1995. Tiller development and contribution to yield under different moisture regimes in two Triticum species. J. Agron., 174: 173-180.
16. Snedecor, G.W. and W.G. Cochran, 1988. Statistical Method. 7th Edition. Iowa State University Press. Ames, Iowa, USA.
17. Sofield, I., L.T. Evans and I.F. Wardlaw, 1977. The effect of temperature and light on grain filling in wheat. R. Soc. N. Z. Bull., 12: 909-915.
18. Taiz, L. and E. Zeiger, 1991. Plant Physiology. The Benjamin/Cummings Publishing Company, Inc. USA.
19. Wilhelm, W.W. and G.S. McMaster, 1995. The importance of phyllochron in studying the development of grasses. Crop Sci., 53: 1-3.