ISSN : 1812-5379 (Print)
ISSN : 1812-5417 (Online)
http://ansijournals.com/ja

JOURNAL OF AGRONOMY

ANSInet
Asian Network for Scientific Information
308 Lasani Town, Sargodha Road, Faisalabad - Pakistan

Journal of Agronomy 4 (1): 75-82, 2005
ISSN 1812-5379

Prediciting the Interaction Between the Effect of Anti-transpirant and Climate on Productivity of Wheat Plant Grown under Water Stress

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Abstract: A filed experiments was executed on two wheat varieties Sakha 93 and Giza 168 grown in clay loam soil under water stress condition at the agricultural experimental station of National Research Centre, Shalakan, Kalubia Governorate, for improving water stress tolerance of wheat plant, using a reflectant type of Anti-transpirant $MgCO_3$, during plant growth. Water stress was imposed by withholding irrigation at milky and maturity stages. It has been proved that the weather parameters such as air temperature, soil temperature and relative humidity affected plant yield, also water shortage had a drastic effect on plant growth and yield. Prediction equations were developed and used to predict the performance of the Anti-transpirant use under water stress condition. It was evaluated that the amount of wheat yield reduction as a result of water stress was affected by genotype and stage of grain development. Sakha 93 was more tolerant to water stress than Giza 168. Soil temperature was a better predictor than air temperature in predicating straw yield but both were definitely good predictors for plant yield. Also reflectant application increased plant yield and seemed to be a promising method in combating drought stress. The percent reduction for Giza 168 grain yield was 24.25% before the application of $MgCO_3$ under water stress condition. However after the reflectant application the percent reduction in grain yield became 9.98%, while in Sakha 93 it was 12.86% and became 7.12%, whereas losses in grain, straw and biological yields were reduced by 7.12, 4.99 and 5.95%, respectively. Air temperature negatively affected plant attributes except for number of spikes/m^2 of water stressed plants, while soil temperature positively affected plant number of spike/m^2, grain and straw yield. Also relative humidity showed a positive correlation with the wheat yield and its components.

Key words: Wheat varieties, water stress, reflectant, growth, yield, agroclimatic factors, prediction equations, modeling

INTRODUCTION

Water stress in wheat, changes patterns of plant growth and development. Depressed water potential suppresses cell division, organ growth, net photosynthesis, protein synthesis and alters hormonal balances of major plant tissues[1]. Water stress during grain growth may cause a severe effect on final yield compared with stress occurred during other stage[2]. 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[3] and consequently influences yield[4]. The wheat shoot apex is located in the crown of the plant until soil temperature is a better measure for plant growth and could indirectly affect growth of roots more than the growth of shoots, in addition to it's great effect on the nutrients absorption by plants such as nitrogen[5]. Relative humidity also has a great effect on yield, where water losses to the atmosphere decreases with increasing relative humidity[5]. Wheat plant may react against drought stress by increasing pubescence on the leaves. If the hairs are shiny and reflective they help to reduce the heat load on the leaves and hence the transpiration rate. So, natural plant defensive mechanism sprouted out the idea of using reflectant. Dusting or spraying plants with reflectants might be useful to try to breed plants with a higher leaf albedo as a natural mean of reducing transpiration.

Also the reflected light may penetrate the interior of the plant canopy where normally the leaves are too shaded for maximum photosynthesis[6].

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Thus the aim of the present study was to (I) 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 $MgCO_3$ (reflectant type of Anti-transpirant) and (iii) to predict wheat yield under water stress condition in addition to reflectant application using either air mean temperature or soil mean temperature.

MATERIALS AND METHODS

A field experiment was conducted during too successive seasons of 2001/2002 and 2002/2003 at the Agricultural Experimental station of National Research Centre, Shalakan Kalubia Governorate. The preceded crop was maize in both seasons and the soil texture was clay loam of the following characteristics 7.5% Sand, 59.1 Silt and 33.4% Clay. pH, 7.55, Ec., 0.26 dS m^{-1}, Ca^{++}, 1.1 Mg^{++}, 0.5, Na^{+}, 1.3, K^{+}, 0.8 HCO_3^{-}, 0.4 Cl^{-}, 2.0, SO_4^{-}-, 0.58 (meq L^{-1}).

The statistical design was split-plot with three replicates. The main plot included the irrigation treatment, while different varieties and or/reflectant(Anti-transpirant) were distributed in subplots. Foliar spraying of $MgCO_3$ was conducted twice at 45 and 65 days after sowing.
The design of the experiment was as follows:

- Normal irrigation.
- Withholding irrigation once at the milky stage and another at maturity stage,
- Withholding irrigation at milky and maturity stage + reflectant application,
- Two wheat varieties Sakha 93 and Giza 168.

Wheat seeds (*Triticum aestivum* L.) Cv. Sakha 93 and Giza 168 were sown on mid December for the two growing seasons plants received recommended dose of fertilizers. At harvest, plants were selected randomly from the three replicates of each treatment for estimating plant height (PLH cm), spike length (SPL, cm), spike number/m^2 (Sp/m^2), grain number/spike Gn/Sp), grain weight/spike (Gwt/Sp), grain yield/fed (GrY, ton/fed), straw yield/fed (St Y, ton/fed) and biological yield/fed (Bio Y, ton/fed).

The combined data of two successive seasons were statistically analyzed according to the following procedures:

a) Analysis of variance for randomized complete blocks design according to Sendecor and Cochran[7] was done to find out the significance of the studied treatments. Means of the studied characters were compared by Least Significant Difference (LSD).

b) Percent decease in wheat yields as a result of skipping irrigation during grain milk and maturity stages were calculated. Moreover, percent decease in yields as a result of application of $MgCO_3$ was also calculated.

c) Simple correlation coefficients[7] between wheat yields and its components were calculated to determine the strength of the relationship between them. Furthermore, simple correlation coefficients between wheat yield attributes and weather parameters were also calculated.

d) Regression analysis[8] as used to develop equations to predict wheat yield under the above mentioned treatments. Multiple linear regression is a technique utilized to fit a line through a set of observations and test how a single dependent variable is affected by the value of one or more independent variables. As a result, a prediction equation is developed and used to predict the performance of the dependent variable, when values of these independent variables vary. Two parameters, coefficient of determination (R^2) and standard error of estimates (SE%) were used to increase 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 and straw yields. 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.

RESULTS AND DISCUSSION

Results of Table 1 showed that in the second growing season, the soil mean temperature and relative humidity were higher than the first growing season, although the air mean temperature was lower.

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

Season	Air mean temperature (°C)	Soil mean temperature (°C)	Relative humidity (%)
2001/2002	17.55	16.73	45.45
2002/2003	16.72	17.50	59.73
Mean	17.13	17.11	52.59

Table 2: Interactive effect of water stress and Anti-transpirant use on growth and yield of wheat plant cultivars

	Characters									
Treatments	Plant (cm) height	Spike length (cm)	No. of grains/spike	Grains wt (g)	100-grains wt (g)	No. of spikes/m^2	Grain yield (ton/fed)	Straw yield (ton/fed)	Biological yield (fed)	Harvest index (HI)
Cultivar										
Sakha 93	96.19	10.60	63.68	2.27	3.51	285.68	2.67	3.32	5.99	44.51
Giza 168	94.68	12.19	71.29	2.24	3.21	263.98	2.33	2.89	5.22	44.46
LSD 5%	NS	0.16	1.56	0.05	0.49	3.68	0.03	0.04	0.50	N.S
Control	79.44	11.59	69.31	2.43	3.65	290.06	2.82	3.37	6.19	45.58
T_1	76.38	11.34	63.63	2.10	3.33	260.19	2.33	3.00	5.33	43.54
T_2	77.13	11.44	67.88	2.16	3.21	267.06	2.30	2.97	5.27	43.58
T_3	71.06	11.45	71.31	2.29	3.22	274.88	2.46	3.10	5.56	44.28
T_4	73.16	11.15	65.27	2.31	3.39	281.94	2.58	3.10	5.68	45.44
LSD 5%	NS	0.25	2.47	0.07	0.07	5.82	0.05	0.06	0.08	0.77
Sakha 93										
Control	101.88	10.79	62.08	2.38	3.94	294.63	2.90	3.56	6.46	44.90
T_1	98.50	10.27	61.38	2.10	3.42	281.00	2.59	3.16	5.75	45.00
T_2	100.75	10.64	60.78	2.11	3.46	285.50	2.53	3.17	5.69	44.37
T_3	89.00	10.82	70.83	2.42	3.29	284.83	2.63	3.35	5.99	43.98
T_4	90.81	10.49	63.33	2.36	3.44	282.33	2.69	3.38	6.07	44.32
Ciza 168										
Control	97.00	12.39	76.54	2.49	3.36	285.50	2.74	3.19	5.93	46.25
T1	94.25	12.42	65.89	2.11	3.25	239.33	2.07	2.84	4.91	42.08
T2	93.50	12.24	74.99	2.21	2.96	248.63	2.08	2.77	4.85	42.80
T3	93.13	12.09	71.80	2.16	3.15	264.83	2.29	2.84	5.13	44.59
T4	95.50	11.82	67.21	2.25	3.34	281.50	2.47	2.83	5.30	46.56
LSD 5%	NS	0.35	3.50	0.09	0.10	8.23	0.08	0.08	0.11	1.08

T_1: Skipping irrigation at milky stage T_2: Skipping irrigation at maturity stage T_3: Skipping irrigation at milky + $MgCO_3$ application
T_4 : Skipping irrigation at maturity stage + $MgCO_3$ application

Table 3: Percent decrease in wheat cultivars yield components as a result of skipping irrigation at milky and maturity stages

	Cultivars			
	Sakha 93		Giza 168	
Yield components	% decrease at milky	% decrease at maturity	% decrease at milky	%decrease at maturity
Grain yield/fed	14.15	12.86	34.51	24.25
Straw yield/fed	12.79	11.03	22.23	12.99
Biological yield/fed	18.67	11.85	27.91	18.20

Table 4: Percent decrease in wheat cultivars yield components under water stress in addition to reflectant application

	Cultivars			
	Sakha 93		Giza 168	
Yield components	% decrease at milky	% decrease at maturity	% decrease at milky	%decrease at maturity
Grain yield/fed	9.15	7.12	16.52	9.98
Straw yield/fed	5.76	4.99	10.86	11.24
Biological yield/fed	7.28	5.95	13.48	10.66

In Table 2, it has been proved that cultivars showed a significant effect on all parameters except for grain weight, harvest index and plant height, while the interactive effect of cultivars, water stress and Anti-transpirant use showed a significant effect on all plant growth and yield characters except for plant height.

Previous mentioned results were supported by Karmer[9] who pointed out that the reduction in growth and yield parameters under water stress may be attributed to losses of tissue water which inhibit cell division and enlargement. Also Thompson and Chase[10] concluded that water stress reduced yield of wheat through decrease in number of spikes/plant, number of grain/spike and individual grain weight. Yadav and Pandey[11] found that Anti-transpirant use increased plant water status, chlorophyll content, biological yield and harvest index. Wang and Chu[12] found that spraying Anti-transpirants increased yield by lowering water loss from plants.

Results in Table 3 showed that skipping irrigation at grain milk stage decreased yields more than skipping irrigation at final maturity stages for both cultivars. This could be attributed to the fact that water stress during that stage affect cells expansion, reduce grain growth rate and consequently reduce yield[13]. However, reduction in Giza 168 yield were more severe than Sakha 93 and that could be attributed to that Sakha 93 is more tolerant to water stress during grain growth than Giza 168.

Percent decrease in wheat yield components as a result of skipping irrigation in addition to the application of $MgCO_3$ were presented in Table 4. The application of $MgCO_3$ reduced yields losses, especially for Giza 168, where percent reduction for grain yield, 24.25% before the application of $MgCO_3$ under water stress at maturity stage. However, after the application percent reduction in grain yield was 9.98%. Similarly, the same trend was observed by Sakha 93, whereas percent reduction for grain yield was 12.86% before the application of $MgCO_3$ and 7.12% after the application (Table 4). It could be concluded that saving the last irrigation could be useful if plants were sprayed with $MgCO_3$ during grain maturity

Table 5: Simple correlation coefficient between wheat grain yield and its components for the two cultivars over the two seasons

Yield components	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 $MgCO_3$
PLH (cm)	-0.551	-0.419	0.172	-0.319	0.227
SpL (cm)	-0.624	-0.896	-0.776	-0.640	-0.311
Sp/m^2	0.521	0.990	0.981	0.942	0.686
Gn°/Sp	-0.645	-0.457	-0.868	-0.041	-0.495
Gwt/Sp (g)	0.103	0.245	0.805	0.181	0.595

Table 6: Simple correlation coefficient between wheat straw yield and its components for the two cultivars over the two seasons

Yield components	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 $MgCO_3$
PLH (cm)	0.579	0.481	-0.196	0.228	-0.123
SpL (cm)	0.698	-0.793	0.865	-0.843	0.697
Sp/m^2	0.421	0.900	0.824	0.723	0.120

Table 7: Simple correlation coefficient between plant attributes and weather parameters of the control treatment for the two cultivars over the two seasons

Plant attributes	Weather parameters: Air temperature	Soil temperature	Relative humidity
PLH (cm)	-0.567	0.178	0.340
SpL (cm)	-0.373	-0.435	0.118
Sp/m^2	-0.283	0.654	0.444
Gn°/Sp	-0.331	-0.488	0.062
Grain yield	-0.169	0.786	0.440
Straw yield	-0.046	0.652	0.270

Table 8: Simple correlation coefficient between plant attributes and weather parameters under water stress at milky stage in addition to $MgCO_3$ over the two seasons

	Plant Weather parameters					
	Skipping irrigation at milky stage			Skipping irrigation at milky stage + $MgCO_3$		
Plant attributes	Air temperature	Soil temperature	Relative humidity	Air temperature	Soil temperature	Relative humidity
PLH (cm)	-0.637	0.043	0.485	-0.572	0.521	0.592
SPL (cm)	-0.345	-0.472	0.105	-0.376	-0.375	0.161
Sp/m^2	0.071	0.699	0.179	-0.080	0.628	0.270
Gn°/Sp	-0.231	-0.238	0.080	0.041	-0.093	0.045
Grain yield	-0.046	0.778	0.296	-0.127	0.767	0.356
Straw yield	-0.093	0.748	0.322	0.024	0.713	0.220

Table 9: Simple correlation coefficient between plant attributes and weather parameters under water stress at maturity stage in addition to $MgCO_3$ over the two seasons

	Plant Weather parameters					
	Skipping irrigation at milky stage			Skipping irrigation at milky stage + $MgCO_3$		
Plant attributes	Air temperature	Soil temperature	Relative humidity	Air temperature	Soil temperature	Relative humidity
PLH (cm)	-0.599	0.415	0.577	-0.554	0.239	0.427
SPL (cm)	d-0.359	-0.418	0.134	-0.324	-0.333	0.136
Sp/m^2	0.057	0.656	0.175	-0.332	0.313	0.356
Gn°/Sp	-0.299	-0.439	0.081	-0.266	-0.403	0.079
Grain yield	-0.054	0.768	0.301	-0.236	0.767	0.442
Straw yield	-0.039	0.750	0.280	0.040	0.723	0.211

stage, where as grain, straw and biological yields were reduced by 7.12, 4.99 and 5.95%, respectively (Table 4).

Simple correlation coefficient between grain and straw yields and their components. In addition, simple correlation coefficients between wheat attributes and weather parameters were also calculated.

Results in Table 5 showed that plant height was negatively correlated with wheat grain yield under the control treatment and water stress treatments. Whereas, it was positively correlated with grain yield under the application of anti-transpirant. This could be attributed to the role of stem reserve mobilization that play under the condition of stomatal closure and photosynthesis reduction[4]. Spike length and grain number/spike were found to be also negatively correlated to grain yield under all treatments. The negative effect of grain number/spike on grain yield could be attributed to fact that both grain number and grain weight are correlated, the increase in one of them could reduce the other[5]. Number of spikes/m^2 and grain weight per spike were positively correlated to grain yield under all treatments. Results in Table 5 also revealed that the highest positive correlation coefficient was obtained for number of spikes/m^2 for all treatments, whereas the highest negative correlation coefficient was obtained for grain number/spike for all treatments, except for skipping irrigation at grain maturity stage where spike length had the highest negative correlation coefficient.

Results in Table 6 revealed that correlation between plant height and straw yield followed different trend than that of grain yield, where under control and water stress, treatments plant height was positively correlated with straw yield and was negatively correlated with straw yield under the application of anti-transpirant. Probably, because mobilization from stem reserve indirectly affected plant height and negatively affected straw yield. Spike length was negatively affected with straw yield under water stress treatments and positively affected with straw yield under the application of anti-transpirant. The growth rate of apical grains on the spike usually is slower than basal grains[4]. Therefore, it is expected that under water stress all assimilate would go to basal grains and apical grains might fall to complete its growth and its could indirectly reduces spike length. Number of spike/m^2 was found to be positively increasing with straw yield.

The effects of air temperature, soil temperature and relative humidity on wheat plant attributes were almost consistent for all treatments (Table 7-9). Air temperature negatively affected plant attributes, except for number of spikes/m^2 of water stressed plants (Table 8 and 9) and for grain number/spike under water shortage condition at grain milk stage in addition to application of $MgCO_3$ (Table 9), approved that, high temperature usually decease both vegetative and reproductive growth[4,14,15].

Also, results showed that soil temperature negatively affected spike length and grain number/spike and positively affected plant, number of spike/m^2, grain and straw yields for all treatments (Table 7-9). The positive effect of soil temperature was on plant height and number of spikes/m^2 (indicator for number of tillers/m^2). This could be attributed to the role of soil temperature which play in the growth of shoot apex[16] and could indirectly affected final grain and straw yields.

Furthermore, relative humidity was positively correlated with wheat and its yield components (Table 7-9). It was found that under water stress conditions, high relative humidity reduced water losses from the stomata to the outside air.

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.

Prediction equations for grain yield using air or soil temperature

Control treatment: For wheat grown under optimum condition, Eq. 2 was somewhat accurate than Eq. 1 in predicting grain yield because R^2 was higher (0.911) and SE% was lower (1.418), from its counterpart in Eq. 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 indicated that any increase in all of the three yield components decrease wheat grain yield by the value of its coefficient. Whereas, grain number/spike, air mean temperature and relative humidity increased grain yield by the value of its coefficient.

$$\hat{y}_{grain} = -0.120-0.019\ (PLH)^{**} - 0.104\ (SpL)-0.002\ (Sp/m^2) + 0.12\ (Gn^o/Sp) + 0.263\ (AirMT)^{*} + 0.03\ (RH)^{**}$$

$$R^2 = 0.891 \qquad SE\% = 1.772 \qquad (1)$$

$$\hat{y}_{grain} = -7.096-0.012\ (PLH) + 0.002\ (SpL)-0.005\ (Sp/m^2)^{**} + 0.02\ (Gn^o/Sp)^{**} + 0.78\ (Soil\ MT)^{**} + 0.03\ (RH)^{**}$$

$$R^2 = 0.911 \qquad SE\% = 1.418 \qquad (2)$$

Skipping irrigation at the milky stage: Under the condition of skipping irrigation at grain milk stage, either Eq. 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 an indication that under water stress the number of spikes/m^2 could be an important predictor for grain yield.

$$\hat{y}_{grain} = -1.705-0.001\ (PLH)-0.008\ (SpL) + 0.012\ (Sp/m^2)^{**} + 0.002\ (Gn^o/Sp) + 0.026\ (Air\ MT) + 0.006\ (RH)$$

$$R^2 = 0.995 \qquad SE\% = 0.913 \qquad (3)$$

$$\hat{y}_{grain} = -1.886+0.001\ (PLH) - 0.002\ (SpL) + 0.011\ (Sp/m^2)^{**} + 0.002\ (Gn^o/Sp) + 0.055\ (Soil\ MT) + 0.001\ (RH)$$

$$R^2 = 0.995 \qquad SE\% = 0.910 \qquad (4)$$

Skipping irrigation at milky stage in addition to $MgCO_3$ application: Under the condition of skipping irrigation at grain milk stage and the application of $MgCO_3$, either Eq. 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 the role of mobilization from the stem became more pronounced in grain growth process, under water stress condition in addition to reflectant application.

$$\hat{y}_{grain} = -2.266+0.005\ (PLH)-0.089\ (SpL)^{**} + 0.010\ (Sp/m^2)^{**} + 0.005\ (Gn^o/Sp) + 0.026\ (Air\ MT) + 0.006\ (RH)$$

$$R^2 = 0.981 \qquad SE\% = 1.504 \qquad (5)$$

$$\hat{y}_{grain} = -2.048+0.003\ (PLH)-0.067\ (SpL) + 0.009\ (Sp/m^2)^{**} + 0.005\ (Gn^o/Sp) + 0.109\ (Soil\ MT)-0.001\ (RH)$$

$$R^2 = 0.982 \qquad SE\% = 1.467 \qquad (6)$$

Skipping irrigation at maturity stage: Either Eq. 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) changes from negative in Eq. 7 to positive in Eq. 8 and this could be an indicator for the role of soil temperature plays in shoot apex growth.

$$\hat{y}_{grain} = -0.699-0.002\ (PLH)-0.033\ (SpL)^{*} - 0.007\ (Sp/m^2)^{**} - 0.005\ (Gn^o/Sp) + 0.080\ (Air\ MT) + 0.010\ (RH)$$

$$R^2 = 0.995 \qquad SE\% = 0.934 \qquad (7)$$

$$\hat{y}_{grain} = -1.705-0.001\ (PLH)-0.009\ (SpL) + 0.007\ (Sp/m^2)^{**} - 0.004\ (Gn^o/Sp)^{**} + 0.161\ (Soil\ MT)^{**} - 0.002\ (RH)$$

$$R^2 = 0.996 \qquad SE\% = 0.739 \qquad (8)$$

Skipping irrigation at maturity stage in addition to $MgCO_3$ application: Either Eq. 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.

$$\hat{y}_{grain} = -6.719+0.005\ (PLH)-0.041\ (SpL)^{*} + 0.011\ (Sp/m^2)^{**} - 0.012\ (Gn^o/Sp)+ 0.309\ (Air\ MT)^{**} + 0.027\ (RH)^{**}$$

$$R^2 = 0.953 \qquad SE\% = 1.744 \qquad (9)$$

$$\hat{y}_{grain} = -5.656 + 0.005\ (PLH)-0.013\ (SpL) + 0.010\ (Sp/m^2)^{**} + 0.001\ (Gn^o/Sp) + 0.339\ (Soil\ MT)^{**} - 0.015\ (RH)^{**})$$

$$R^2 = 0.985 \qquad SE\% = 0.968 \qquad (10)$$

Prediction equation for straw yield using air or soil temperature Control treatment: The trend of the relationship between weather parameters, straw yield and its components was similar to the one with grain yield. However, in most cases, soil temperature was better predictor of straw yield (R^2 is higher and SE% is lower than its counterpart equation using air temperature). This trend was observed for predicting straw yield under skipping irrigation at grain maturity stage and reflectant application represented by Eq. 19 and 20 (R^2 was 0.790 and SE% was 5.290 for using air temperature, versus R^2 was 0.959 and SE% was 2.322 for using soil temperature). This could be attributed to the effect of soil temperature on shoot apex during vegetative growth.

$$\hat{y}_{straw} = 9.793-0.030\ (PLH)-0.142\ (SpL)-0.004\ (Sp/m^2)-0.060\ (Air\ MT) + 0.011\ (RH)$$

$$R^2 = 0.676 \qquad SE\% = 5.105 \qquad (11)$$

$$\hat{y}_{straw} = -1.157-0.016\ (PLH)-0.001\ (SpL)-0.005\ (Sp/m^2) + 0.515\ (Soil\ MT)-0.016\ (RH)$$

$$R^2 = 0.688 \qquad SE\% = 5.050 \qquad (12)$$

Skipping irrigation at milky stage:

$$\hat{y}_{straw} = 4.136-0.018\ (PLH) + 0.001\ (SpL) + 0.006\ (Sp/m^2)-0.069\ (Air\ MT) + 0.002\ (RH)$$

$$R^2 = 0.881 \qquad SE\% = 2.872 \qquad (13)$$

$$\hat{y}_{straw} = 3.626-0.017\ (PLH)-0.002\ (SpL) + 0.006\ (Sp/m^2)-0.073\ (Soil\ MT) + 0.012\ (RH)$$

$$R^2 = 0.881 \qquad SE\% = 2.872 \qquad (14)$$

Skipping irrigation at milky stage in addition to $MgCO_3$ application:

$$\hat{y}_{straw} = -1.955-0.021\ (PLH)-0.261\ (SpL)^{**} + 0.003\ (Sp/m^2) + 0.220\ (Air\ MT) + 0.022\ (RH)$$

$$R^2 = 0.923 \qquad SE\% = 3.074 \qquad (15)$$

$$\hat{y}_{straw} = -2.818-0.014\ (PLH)-0.167\ (SpL)^{**} + 0.001\ (Sp/m^2) + 0.404\ (Soil\ MT)^{*} - 0.016\ (RH)$$

$$R^2 = 0.939 \qquad SE\% = 2.718 \qquad (16)$$

Skipping irrigation at maturity stage:

$$\hat{y}_{straw} = -0.861+0.019\ (PLH)^{**} - 0.215\ (SpL)^{**} - 0.001\ (Sp/m^2) + 0.200\ (Air\ MT) + 0.022\ (RH)^{*}$$

$$R^2\ 0.953 \qquad SE\% = 1.952 \qquad (17)$$

$$\hat{y}_{straw} = -3.817-0.012\ (PLH)^{**}-0.138\ (SpL)^{**}-0.003\ (Sp/m^2)^{**} + 0.495\ (Soil\ MT)^{**} - 0.021\ (RH)^{**}$$

$$R^2 = 0.981 \qquad SE\% = 1.245 \qquad (18)$$

Skipping irrigation at maturity stage in addition to $MgCO_3$ application:

$$\hat{y}_{straw} = -13.278 + 0.007\ (PLH)-0.164\ (SpL)^{**} + 0.007\ (Sp/m^2) + 0.726\ (Air\ MT)^{**} + 0.061\ (RH)^{**}$$

$$R^2 = 0.790 \qquad SE\% = 5.290 \qquad (19)$$

$$\hat{y}_{straw} = -10.684 + 0.005\ (PLH) + 0.011\ (SpL) + 0.001\ (Sp/m^2) + 0.906\ (Soil\ MT)^{**} - 0.0415\ (RH)^{**}$$

$$R^2 = 0.959 \qquad SE\% = 2.322 \qquad (20)$$

A number of scientists used different models to evaluate and predict the interactive effect between plant yield and climate.

Ittersum *et al.*[17] expressed the complex interaction between water, climate and wheat plant phenological development where they found that high temperatures had no linear effects could benefit clay soil but not sandy. Also Quiring and Papakryiakou[18] carried out a comparative performance analysis on four agricultural drought indices to determine the most appropriate index for monitoring agricultural drought and predicting wheat yield on prairies, they had generated a regression-based crop yield models. However, Ewert *et al.*[19] concluded that Crop Simulation Models (CSM) are often used to predict the impact of global atmospheric changes on food production and that CSM are able to reproduce wheat growth and that CSM are able to reproduce wheat growth and yield under drought stress condition in a field environment.

Wilhelmi *et al.*[20] conducted that agricultural drought is the leading cause for crop failure throughout the world and the use of models is beneficial for interpretating the interactive effect of climate and crop yield.

Also, Panayotov[21] established a main wheat model with best adaptability and yield potential for the soil and climatic conditions which he considered in the natural background of the breeding requirements. Similarly, Grossman *et al.*[22] deduced that models successfully explains the qualitative and quantitative behaviour of the wheat crop under water stress, Moreover, Triboi *et al.*[23] used modeling to study the relationship between the effect of major environmental factors, such as temperature and water supply, where he found that drought and temperature effects on plant yield are generally similar. Also, Li *et al.*[24] used modeling to prove that the increase in grain weight of well watered plants was due to long grain filling period and Later-formed tiller spikes were more responsive to drought stress than the main stem spikes.

In further due to climatic changes, where drought will be affecting Egypt as a part of Africa, saving irrigation water is a must. The amount of wheat yield reduction as a result of water stress is affected by genotype and the stage of grain development. Sakha 93 was more tolerant to water stress during grain growth stage than Giza 168. However, it is advisable to skip irrigation at maturity stage instead of skipping milky stage, yield losses in both varieties. Both air and soil temperatures were good predictors for wheat grain yield. However, soil temperature was a better predictor than air temperature in predicting straw yield. Further research in needed to identify the role of soil temperature in wheat growth and development.

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