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Research Paper

Studying the risk effects of climatic variables on cotton production using different statistical methodologies

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ABSTRACT

Cotton yield is a function of growth rates, flower production rates and flower and boll retention during the fruiting period. Information on the relationship between climatic factors and the cotton plant's ability to produce and sustain flower buds, flowers and bolls will allow one to model plant responses to conditions that frequently occur in the field and to predict developmental rate or the formation of these organs. This study collects information about the nature of the relationship between various climatic factors and cotton boll development and the 15-day period both prior to and after initiation of individual bolls and also provide information on the effect of various climatic factors and soil moisture status during the development stage on flower and boll production in cotton. Evaporation, sunshine duration, relative humidity, surface soil temperature at 1800 h and maximum air temperature, are the important climatic factors that significantly affect flower and boll production. Evaporation; minimum humidity and sunshine duration were the most effective climatic factors during preceding and succeeding periods on boll production and retention. There was a negative correlation between flower and boll production and either evaporation or sunshine duration, while that correlation with minimum relative humidity was positive.

Key words: Cotton flower and boll production, evaporation, relative humidity, soil moisture status, sunshine duration, temperature.

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INTRODUCTION

Understanding the impacts of climatic factors on cotton production may help physiologists to determine the control mechanisms of boll retention in cotton. However, weather affects crop growth interactively, sometimes resulting in unexpected responses to prevailing conditions. The balance between vegetative and reproductive development can be influenced by soil fertility, soil moisture, cloudy weather, spacing and perhaps other factors such as temperature and relative humidity. The early prediction of possible adverse effects of climatic factors might modify their effect on production of cotton (Sawan, 2015). Climate affects crop growth interactively, sometimes resulting in unexpected responses to prevailing conditions. Many factors, such as length of the growing season, climate (including solar radiation, temperature, light, wind, rainfall, and dew), cultivar, availability of nutrients and soil moisture, pests and cultural practices affect cotton growth (El-Zik 1980). The balance between vegetative and reproductive development can be influenced by soil fertility, soil moisture, cloudy weather, spacing and perhaps other factors such as temperature and relative humidity (Guinn, 1982). Weather, soil, cultivars, and cultural practices affect crop growth interactively, sometimes resulting in plants responding in unexpected ways to their conditions (Sawan, 2013). Water is a primary factor controlling plant growth. Xiao et al. (2000) stated that, when water was applied at 0.85, 0.70, 0.55 or 0.40 ET (evapotranspiration) to cotton plants grown in pots, there was a close relationship between plant development and water supply. The fruit-bearing branches, square and boll numbers and boll size were increased with increased water supply. Barbour and Farquhar (2000) reported on greenhouse pot trials where cotton cv. CS50 plants were grown at 43 or 76% relative humidity (RH) and sprayed daily with abscisic acid (ABA) or distilled water. Plants grown at lower RH had higher transpiration rates, lower leaf temperatures and lower stomatal conductance. Plant biomass was also reduced at the lower RH. Within each RH environment, increasing ABA concentration generally reduced stomatal conductance, evaporation rates, superficial leaf density, plant biomass, increased leaf temperature and specific leaf area.

Temperature is also a primary factor controlling rates of plant growth and development. Burke et al. defined the optimum temperature range for biochemical and metabolic activities of plants as the thermal kinetic window (TKW). Plant temperatures above or below the TKW result in stress that limits growth and yield. The TKW for cotton growth is 23.5 to 32°C, with an optimum temperature of 28°C. Biomass production is directly related to the amount of time that foliage temperature is within the TKW. Schrader et al. (2004) stated that when the temperature is high plants are likely to experience inhibit photosynthesis. Species/cultivars that retain fruits at high temperatures would be more productive both in the present-day cotton production environments and even more in future warmer world (Sawan, 2014). Zhou et al. (2000) indicated that light duration is the key meteorological factor influencing the wheat-cotton cropping pattern and position of the bolls, while temperature had an important function on upper (node 7 to 9) and top (node 10) bolls, especially for double cropping patterns with early maturing varieties. In Egypt, field studies relating cotton flower and boll production to climatic factors are lacking. Cotton productions of field-grown plants are less sensitive to climatic fluctuations than production of greenhouse or growth chamber plants. For this reason, studies of simulated climatic factors conducted in the greenhouse or growth chamber cannot be reliably applied to field conditions.

The objectives of this investigation were to study

This study investigated and collected information about the nature of the relationship between various climatic factors and cotton boll development and the 15-day period both prior to and after initiation of individual bolls of field grown cotton plants in Egypt. This could pave the way for formulating advanced predictions as for the effect of certain climatic conditions on production of Egyptian cotton. It would be useful to minimize the deleterious effects of the factors through utilizing proper cultural practices which would limit and control their negative effects and this will lead to an improvement in cotton yield. Also, provide information on the effect of various climatic factors and soil moisture status during the development stage on flower and boll production in Egyptian cotton. This could result in formulating advanced predictions as for the effect of certain climatic conditions on production of Egyptian cotton. Minimizing the deleterious effects of the factors through utilizing proper cultural practices will lead to improved cotton yield.

DATA AND METHODS

Two uniform field trials were conducted at the experimental farm of the Agricultural Research Center, Ministry of Agriculture, Giza, Egypt (30^{o}N, 31^o: 28'E at an altitude of 19 m), using cotton cultivar Giza 75 (*Gossypium barbadense* L.) in 2 successive seasons (I and II). The soil texture was a clay loam, with an alluvial substratum (pH = 8.07, 42.13% clay, 27.35% silt, 22.54% fine sand, 3.22% coarse sand, 2.94% calcium carbonate and 1.70% organic matter) (Sawan et al., 2010). In Egypt, there are no rain-fed areas for cultivating cotton. Water for the field trials was applied using surface irrigation. Total water consumed during each of two growing seasons supplied by surface irrigation was about 6,000-m^3 h^{-1}. The criteria used to determine amount of water applied to the crop depended on soil water status. Irrigation was applied when soil water content reached about 35% of field capacity (0-60 cm). In season I, the field was irrigated on 15 March (at planting), 8 April (first irrigation), 29 April, 17 May, 31 May, 14 June, 1 July, 16 July, and 12 August. In season II, the field was irrigated on 23 March (planting date), 20 April (first irrigation), 8 May, 22 May, 1 June, 18 June, 3 July, 20 July, 7 August and 28 August. Techniques normally used for growing cotton in Egypt were followed. Each experimental plot contained 13 to 15 ridges to facilitate proper surface irrigation. Ridge width was 60 cm and length was 4 m. Seeds were sown on 15 and 23 March in seasons I and II, respectively, in hills 20 cm apart on one side of the ridge. Seedlings were thinned to 2 plants per hill 6 weeks after planting, resulting in a plant density of about 166,000 plants ha^{-1}. Phosphorus fertilizer was applied at a rate of 54 kg P_2O_5 ha^{-1} as calcium super phosphate during land preparation. Potassium fertilizer was applied at a rate of 57 kg K_2O ha^{-1} as potassium sulfate before the first irrigation (as a concentrated band close to the seed ridge). Nitrogen fertilizer was applied at a rate of 144 kg N ha^{-1} as ammonium nitrate in two equal doses: the first was applied after thinning just before the second irrigation and the second was applied before the third irrigation. Rates of phosphorus, potassium, and nitrogen fertilizer were the same in both seasons. These amounts were determined based on the use of soil tests (Sawan et al., 2010).

After thinning, 261 and 358 plants were randomly selected (precaution of border effect was taken into consideration by discarding the cotton plants in the first

Table 1: Mean, standard deviation, maximum and minimum values of the climatic factors during the flower and boll stage (initial time) and the 15 days prior to flowering or subsequent to boll setting for I and II season at Giza, Egypt.

Climatic factors	First season*				Second season**			
	Mean	**S.D.**	**Max.**	**Min.**	**Mean**	**S.D.**	**Max.**	**Min.**
Max temp [°C] (X_1)	34.1	1.2	44.0	31.0	33.8	1.2	38.8	30.6
Min temp [°C] (X_2)	21.5	1.0	24.5	18.6	21.4	0.9	24.3	18.4
Max-Min temp [°C] (X_3)♦	12.6	1.1	20.9	9.4	12.4	1.3	17.6	8.5
Evapor [mm d^{-1}](X_4)	10.6	1.6	16.4	7.6	6.0	0.7	9.8	4.1
0600 h temp [°C] (X_5)	17.5	1.1	21.5	13.9	17.6	1.2	22.4	13.3
1800 h temp [°C] (X_6)	24.2	1.9	32.3	19.6	23.7	1.1	27.4	20.6
Sunshine [h d^{-1}] (X_7)	11.7	0.8	12.9	9.9	11.7	0.4	13.0	10.3
Max hum [%] (X_8)	85.6	3.3	96.0	62.0	72.9	3.8	84.0	51.0
Min hum [%] (X_9)	30.2	5.2	45.0	11.0	39.1	5.0	52.0	23.0
Wind speed [m s^{-1}] (X_{10})	ND	ND	ND	ND	4.6	0.9	7.8	2.2

*Flower and boll stage (68 days, from 23 June through 29 August).
**Flower and boll stage (62 days, from 29 June through 29 August).
♦ Diurnal temperature range.
ND not determined (Sawan et al., 2005)

and last two hills of each ridge) from 9 and 11 inner ridges of the plot in seasons I, and II respectively. Pest control management was carried out on an-as-needed basis, according to the local practices performed at the experimental. Flowers on all selected plants were tagged in order to count and record the number of open flowers and set bolls on a daily basis. The flowering season commenced on the date of the first flower appearance and continued until the end of flowering season (31 August). The period of whole September (30 days) until the 20th of October (harvest date) allowed a minimum of 50 days to develop mature bolls. In season I, the flowering period extended from 17 June to 31 August, whereas in season II, the flowering period was from 21 June to 31 August. Flowers produced after 31 August were not expected to form sound harvestable bolls, and therefore were not taken into account. For statistical analysis, the following data of the dependent variables were collected: number of tagged flowers separately counted each day on all selected plants (Y_1), number of retained bolls obtained from the total daily tagged flowers on all selected plants at harvest (Y_2), and (Y_3) percentage of boll retention ([number of retained bolls obtained from the total number of daily tagged flowers in all selected plants at harvest]/[daily number of tagged flowers on each day in all selected plants] x 100). As a rule, observations were recorded when the number of flowers on a given day was at least 5 flowers found in a population of 100 plants and this continued for at least five consecutive days. This rule omitted eight observations in the first season and ten observations in the second season. The number of observations (n) was 68 (23 June through 29 August) and 62 (29 June through 29 August) for the two seasons, respectively. Variables of the soil moisture status considered were, the day prior to irrigation, the day of irrigation and the first and second days after the day of irrigation (Sawan et al., 2010).

The climatic factors (independent variables) considered were daily data of: maximum air temperature (°C, X_1); minimum air temperature (°C, X_2); maximum-minimum air temperature (diurnal temperature range) (°C, X_3); evaporation (expressed as Piche evaporation) (mm day^{-1}, X_4); surface soil temperature, grass temperature or green cover temperature at 0600 h (°C, X_5) and 1800 h (°C, X_6); sunshine duration (h day^{-1}, X_7); maximum relative humidity (maxRH) (%, X_8), minimum relative humidity (minRH) (%, X_9) and wind speed (m s^{-1}, X_{10}) in season II only. The source of the climatic data was the Agricultural Meteorological Station of the Agricultural Research Station, Agricultural Research Center, Giza, Egypt. No rainfall occurred during the two growing seasons (Sawan et al., 2005). Daily records of the climatic factors (independent variables) were taken for each day during production stage in any season including two additional periods of 15 days preceding and after the production stage. Range and mean values of the climatic parameters recorded during the production stage for both seasons and overall data are listed in Table 1. Daily number of flowers and number of bolls per plant which survived till maturity (dependent variables) during the production stage in the two seasons are graphically illustrated in Figures 1 and 2 (Sawan et al., 2010)

RESULTS AND DISCUSSION

Response of flower and boll development to climate factors before and after anthesis day

The effects of specific climatic factors during both pre- and

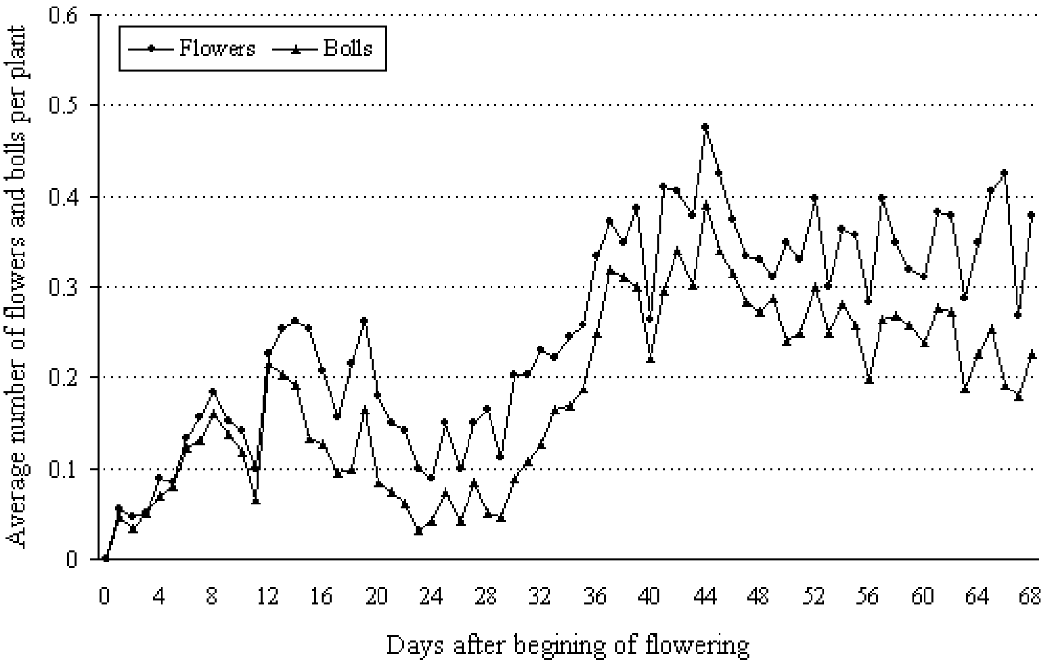

Figure 1: Daily number of flowers and bolls during the production stage (68 days) in the first season (I) for the Egyptian cotton cultivar Giza 75 (*Gossypium barbadense* L.) grown in uniform field trial at the experimental farm of the Agricultural Research Centre, Giza (30°N, 31°:28'E), Egypt. The soil texture was a clay loam, with an alluvial substratum, (pH = 8.07). Total water consumptive use during the growing season supplied by surface irrigation was about 6000 m^3ha^{-1}. No rainfall occurred during the growing season. The sampling size was 261 plants (Sawan et al., 2005).

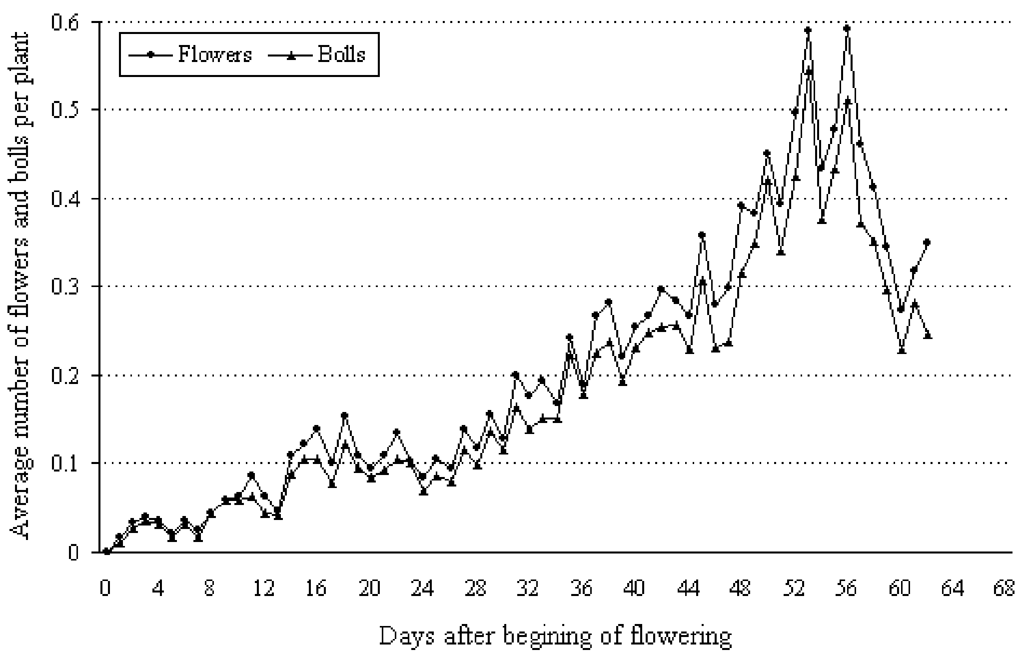

Figure 2: Daily number of flowers and bolls during the production stage (62 days) in the second season (II) for the Egyptian cotton cultivar Giza 75 (*Gossypium barbadense* L.) grown in uniform field trial at the experimental farm of the Agricultural Research Centre, Giza (30°N, 31°:28'E), Egypt. The soil texture was a clay loam, with an alluvial substratum, (pH = 8.07). Total water consumptive use during the growing season supplied by surface irrigation was about 6000 m^3ha^{-1}. No rainfall occurred during the growing season. The sampling size was 358 plants (Sawan et al., 2005).

Table 2: Example of the effects of specific climatic factors in the first season.

File	Data of any dependent variable (for each flowers and bolls)		Any independent variable (for each climatic factors)			
	Production stage		In case of original file and files before production stage		In case of original file and files after production stage	
	Date	Days	Date	Days	Date	Days
Original file	23 Jun -29 Aug	68	23 Jun -29 Aug	68	23 Jun -29 Aug	68
1st new file	23 Jun -29 Aug	68	22 Jun -28 Aug	68	24 Jun – 30 Aug	68
2nd new file	23 Jun -29 Aug	68	21 Jun -27 Aug	68	25 Jun -31 Aug	68
15th new file	23 Jun -29 Aug	68	8 Jun -14 Aug	68	8 Jul – 13 Sept	68

post-anthesis periods on boll production and retention are mostly unknown. However, by determining the relationship of climatic factors with flower and boll production and retention, the overall level of production can be possibly predicted. Thus, an understanding of these relationships may help physiologists to determine control mechanisms of production in cotton plants (Sawan et al., 2005). Daily records of the climatic factors (independent variables) were taken for each day during production stage in any season including two additional periods of 15 days before and after the production stage (Table 1) (Sawan et al., 2005). In each season, the data of the dependent and independent variables (68 and 62 days) were regarded as the original file (a file which contains the daily recorded data for any variable during a specific period). Fifteen other files before and another 15 after the production stage were obtained by fixing the dependent variable data, while moving the independent variable data at steps each of 1 day (either before or after production stage) in a matter similar to a sliding role (Sawan et al., 2005). Table 2 is an example (in the first season).

Thus, the climate data were organized into records according to the complete production stage (68 days the first year and 62 days the second year) and 15 day, 14 day, 13 day,….and 1 day periods both before and after the production stage. This produced 31 climate periods per year that were analyzed for their relationships with cotton flowering and boll production (Sawan et al., 2005). Simple correlation coefficients were computed between the original dependent variable (boll setting and boll retention) and the independent variables for each of the original file and the 15 new files just before or after flowering in each season. The significance of the simple correlation at a probability level not exceeding 5% was tested to determine the factors affecting the dependent variables. The relationship between the most effective and consistent climatic factors affecting flower and boll production and retention was computed using the step-wise regression analysis method. Linear regression equations comprising selected predictive variables were computed and coefficients of determination (r^2 for simple or R^2 for multiple linear regression equations) were calculated to measure the efficiency of the regression models in explaining the variation in the data. The statistical analysis was carried out according to Draper and Smith (1966), by means of the computer program SAS package using the procedures outlined in the general linear model (GLM) (SAS Institute, Inc 1985).

Correlation estimates

A. Results of the correlation between climatic factors and each of flower and boll production during the 15 day periods before flowering day (Tables 3 and 4) revealed the following (Sawan et al., 2005):

First season

Daily evaporation and sunshine duration showed consistent negative and statistically significant correlations with both flower and boll production for each of the 15 moving window periods before anthesis (Table 3) (Sawan et al., 2005). Evaporation appeared to be the most important climate factor affecting flower and boll production. Daily maximum and minimum humidity showed consistent positive and statistically significant correlations with both flower and boll production in most of the 15 moving window periods before anthesis. Maximum daily temperature showed low but significant negative correlation with flower production during the 2-5, 8, and 10 day periods before anthesis. Minimum daily temperatures generally showed insignificant correlation with both production variables. The diurnal temperature range showed few correlations with flower and boll production. Daily soil surface temperature at 0600 h showed a significant positive correlation with boll production during the period extending from the 11-15 day period before anthesis, while its effect on flowering was confined only to the 12 and the 15 day periods prior anthesis. Daily soil surface temperature at 1800 h showed a significant negative correlation with flower production during the 2-10 day periods before anthesis.

Second season

Daily Evaporation, the diurnal temperature range, and sunshine duration were negatively and significantly

Table 3: Simple correlation coefficients (r) between climatic factors and number of flower and harvested bolls in initial time (0) and each of the 15–day periods before flowering in the first season (I).

	Climate period	Air temp. (°C)			Evap. (mm d-1)	Surface soil temp. (°C)		Sunshine duration (h d-1)	Humidity (%)	
		Max. (X1)	Min. (X2)	Max-Min (X3)	(X4)	0600 h (X5)	1800 h (X6)	(X7)	Max. (X8)	Min. (X9)
0#	Flower	-0.07	-0.06	-0.03	-0.56**	-0.01	-0.2	-0.25*	0.40**	0.14
	Boll	-0.03	-0.07	-0.01	-0.53**	-0.06	-0.16	-0.14	0.37**	0.1
1	Flower	-0.15	-0.08	-0.11	-0.64**	-0.01	-0.17	-0.30*	0.39**	0.2
	Boll	-0.07	-0.08	-0.02	-0.58**	-0.06	-0.1	-0.23*	0.36**	0.13
2	Flower	-0.26*	-0.1	-0.22	-0.69**	-0.07	-0.30*	-0.35**	0.42**	0.30*
	Boll	-0.18	-0.08	-0.14	-0.64**	-0.05	-0.21	-0.25*	0.40**	0.2
3	Flower	-0.28*	-0.02	-0.31**	-0.72**	0.15	-0.29*	-0.37**	0.46**	0.35**
	Boll	-0.19	-0.02	-0.21	-0.65**	0.11	-0.2	-0.30*	0.37**	0.25*
4	Flower	-0.26*	-0.03	-0.26*	-0.67**	0.08	-0.24*	-0.41**	0.46**	0.35**
	Boll	-0.21	-0.04	-0.21	-0.63**	0.04	-0.18	-0.35**	0.39**	0.29*
5	Flower	-0.27*	-0.02	-0.27*	-0.68**	0.16	-0.29*	-0.45**	0.49**	0.38**
	Boll	-0.22	0	-0.24*	-0.63**	0.16	-0.21	-0.39**	0.44**	0.32**
6	Flower	-0.21	0.05	-0.25*	-0.73**	0.16	-0.28*	-0.46**	0.47**	0.42**
	Boll	-0.15	0.08	-0.21	-0.67**	0.19	-0.19	-0.46**	0.43**	0.35**
7	Flower	-0.17	-0.01	-0.17	-0.69**	0.1	-0.27*	-0.43**	0.46**	0.35**
	Boll	-0.11	-0.06	-0.15	-0.64**	0.14	-0.19	-0.46**	0.43**	0.32**
8	Flower	-0.24*	-0.03	-0.24*	-0.71**	0.09	-0.30*	-0.44**	0.45**	0.45**
	Boll	-0.14	0.04	-0.17	-0.63**	0.16	-0.17	-0.48**	044**	0.39**
9	Flower	-0.23	-0.1	-0.19	-0.68**	0.05	-0.33**	-0.32**	0.43**	0.44**
	Boll	-0.14	0.04	-0.17	-0.61**	0.15	-0.21	-0.40**	0.42**	0.41**
10	Flower	-0.26*	0.05	-0.30*	-0.67**	0.13	-0. .29*	-0.29*	0.40**	0.48**
	Boll	-0.14	0.13	-0.22	-0.58**	0.22	-0.17	-0.36**	0.46**	0.41**
11	Flower	-0.2	0.1	-0.27*	-0.62**	0.21	-0.19	-0.29*	0.42**	0.44**
	Boll	-0.04	0.22	-0.16	-0.53**	0.27*	-0.04	-0.38**	0.45**	0.36**
12	Flower	-0.17	0.16	-0.26*	-0.62**	0.29*	-0.15	-0.40**	0.44**	0.45**
	Boll	0	0.25*	-0.13	-0.51**	0.35**	-0.04	-0.45**	0.40**	0.30*
13	Flower	-0.13	0.16	-0.22	-0.62**	0.23	-0.12	-0.42**	0.43**	0.45**
	Boll	0	0.22	-0.11	-0.51**	0.30*	-0.03	-0.49**	0.41**	0.33**
14	Flower	-0.08	0.18	-0.18	-0.56**	0.21	-0.15	-0.44**	0.41**	0.46**
	Boll	0.01	0.21	-0.1	-0.47**	0.26*	-0.09	-0.49**	0.42**	0.33**
15	Flower	-0.08	0.22	-0.21	-0.51**	0.24*	-0.22	-0.42**	0.39**	0.38**
	Boll	-0.03	0.19	-0.13	-0.45**	0.24*	-0.17	-0.44**	0.43**	0.30*

*: Significant at 5% level and **: significant at 1% level.
\# 0 = Initial time.
Diurnal temperature range (Sawan et al., 2005).

correlated with both flower and boll production in all the 15 day periods, while maximum daily temperature was negatively and significantly related to flower and boll formation during the 2- 5 day periods before anthesis (Table 4). Minimum daily temperature showed positive and statistically significant correlations with both production variables only during the 9-15 day periods before anthesis, while daily minimum humidity showed the same correlation trend in all the 15 moving window periods before anthesis. Daily soil surface temperature at 0600 h was positively and significantly correlated with flower and boll production for the 12, 14, and 15 day periods prior to anthesis only. Daily soil surface temperature at 1800 h showed negative and significant correlations with both production variables only during the first and second day periods before flowering while daily maximum humidity showed insignificant correlation with both flower and boll production except for one day period only (the 15th day). Generally, the results in the two seasons indicated that daily evaporation, sunshine duration and minimum humidity were the most effective and consistent climatic factors, which exhibited significant relationships with the production variables for all the 15 day periods before anthesis in both seasons (Sawan et al., 2005).

The factors in this study which had been found to be associated with boll development are the climatic factors that would influence water loss between plant and atmosphere (low evaporation demand, high humidity and shorter solar duration). This can lead to direct effects on the fruiting forms themselves and inhibitory effects on mid-

Table 4: Simple correlation coefficients (r) between climatic factorsz and number of flower and harvested bolls in initial time (0) and each of the 15–day periods before flowering in the second season (II).

	Climate period	Air temp. (°C)			Evap. (mm d-1)	Surface soil temp. (°C)		Sunshine duration (h d-1)	Humidity (%)	
		Max (X_1)	Min. (X_2)	Max-Min♦ (X_3)	(X_4)	0600 h (X_5)	1800 h (X_6)	(X_7)	Max. (X_8)	Min. (X_9)
1	Flower	-0.42**	0.1	-0.42**	-0.63**	-0.08	-0.29*	-0.41**	0.05	0.48**
	Boll	-0.41**	0.11	-0.42**	-0.62**	-0.07	-0.28*	-0.41**	0.05	0.47**
2	Flower	-0.40**	0.08	-0.43**	-0.65**	-0.09	-0.27*	-0.39**	0.02	0.49**
	Boll	-0.40**	0.08	-0.43**	-0.64**	-0.08	-0.26*	-0.40**	0.03	0.49**
3	Flower	-0.38**	0.13	-0.43**	-0.61**	-0.06	-0.17	-0.38**	0	0.45**
	Boll	-0.37**	0.15	-0.44**	-0.61**	-0.05	-0.15	-0.38**	0.01	0.46**
4	Flower	-0.36**	0.17	-0.41**	-0.61**	-0.04	-0.18	-0.38**	0.02	0.45**
	Boll	-0.35**	0.18	-0.41**	-0.60**	-0.03	-0.16	-0.36**	0.03	0.44**
5	Flower	-0.30*	0.13	-0.36**	-0.60**	-0.07	-0.23	-0.32**	-0.05	0.43**
	Boll	-0.28*	0.15	-0.35**	-0.58**	-0.05	-0.21	-0.31**	-0.05	0.41**
6	Flower	-0.24	0.21	-0.38**	-0.61**	-0.02	-0.12	-0.28*	0.02	0.40**
	Boll	-0.22	0.24	-0.38**	-0.59**	0	-0.07	-0.29*	0.02	0.40**
7	Flower	-0.19	0.23	-0.29*	-0.54**	-0.03	-0.05	-0.26*	-0.04	0.32**
	Boll	-0.18	0.23	-0.27*	-0.53**	-0.02	-0.03	-0.27*	-0.04	0.30*
8	Flower	-0.15	0.24	-0.25*	-0.52**	-0.03	-0.07	-0.24*	-0.05	0.28*
	Boll	-0.14	0.22	-0.22	-0.51**	-0.03	-0.06	-0.22*	-0.05	0.26*
9	Flower	-0.16	0.34**	-0.32**	-0.56**	0.08	-0.02	-0.25*	0.05	0.30*
	Boll	-0.14	0.34**	-0.31**	-0.56**	0.09	-0.01	-0.23*	0.07	0.29*
10	Flower	-0.16	0.31**	-0.30*	-0.56**	0.11	-0.06	-0.27*	0.11	0.33**
	Boll	-0.14	0.28*	-0.27*	-0.55**	0.09	-0.07	-0.25*	0.09	0.31**
11	Flower	-0.16	0.31**	-0.27*	-0.55**	0.1	-0.02	-0.31**	0.08	0.32**
	Boll	-0.15	0.29*	-0.26*	-0.53**	0.1	0	-0.29*	0.08	0.29*
12	Flower	-0.17	0.44**	-0.37**	-0.57**	0.26*	0.02	-0.36**	0.17	0.34**
	Boll	-0.17	0.42**	-0.36**	-0.55**	0.25*	0.01	-0.34**	0.16	0.32**
13	Flower	-0.14	0.40**	-0.33**	-0.56**	0.21	0.03	-0.28*	0.1	0.34**
	Boll	-0.15	0.38**	-0.34**	-0.56**	0.21	0.01	-0.27*	0.09	0.33**
14	Flower	-0.19	0.39**	-0.38**	-0.59**	0.25*	0.04	-0.34**	0.16	0.35**
	Boll	-0.2	0.39**	-0.40**	-0.59**	0.26*	0.03	-0.36**	0.17	0.36**
15	Flower	-0.24	0.49**	-0.45**	-0.62**	0.37**	0.16	-0.38**	0.27*	0.42**
	Boll	-0.24	0.51**	-0.48**	-0.63**	0.40**	0.15	-0.40**	0.26*	0.43**

*: Significant at 5% level and **: significant at 1% level.

0 = Initial time.

♦ Diurnal temperature range.

z Wind speed did not show significant effect upon the studied production variables, so it is not reported (Sawan et al., 2005).

afternoon photosynthetic rates even under well-watered conditions. Boyer et al. (1980) found that soybean plants with ample water supplies can experience water deficits due to high transpiration rates. Also, Human et al. (1990) stated that, when sunflower plants were grown under controlled temperature regimes, water stress during budding, anthesis and seed filling, the CO_2 uptake rate per unit leaf area as well as total uptake rate per plant, significantly diminished with stress, while this effect resulted in a significant decrease in yield per plant.

B. The correlation between climatic factors and each of boll production and boll retention over a period of 15 day periods after flowering (boll setting) day (Tables 5 and 6) (Sawan et al., 2005) revealed the following:

First season

Daily evaporation showed significant negative correlation with number of bolls for all the 15 day periods after flowering (Table 5). Meanwhile its relationship with

Table 5: Simple correlation coefficient (r) values between climatic factors and number of harvested bolls and retention ratio in initial time (0) and each of the 15–day periods after flowering in the first season (I).

	Climate period	**Air temp. (°C)**			**Evap. (mm d-1)**	**Surface soil temp. (°C)**		**Sunshine duration (h d-1)**	**Humidity (%)**	
		Max. (X1)	**Min. (X2)**	**Max.-Min (X3)**	**(X4)**	**0600 h (X5)**	**1800 h (X6)**	**(X7)**	**Max. (X8)**	**Min. (X9)**
0#	Retention ratio	-0.05	-0.03	-0.03	-0.1-0.1	-0.11	0.1	0.2	-0.04	-0.02
	No. of bolls	-0.03	-0.07	-0.01	-0.53**	-0.06	-0.16	-0.14	0.37**	0.1
1	Retention ratio	-0.07	-0.08	-0.01	-0.1	-0.16	0.04	0.15	0.04	0.05
	No. of bolls	0.02	-0.08	0.08	-0.49**	-0.09	-0.05	-0.2	0.35**	0.09
2	Retention ratio	-0.08	-0.14	0.02	-0.08	-0.19	0.03	0.17	0.02	-0.02
	No. of bolls	0.02	-0.04	0.07	-0.46**	-0.06	-0.01	-0.19	0.33**	0.09
3	Retention ratio	-0.09	-0.21	0.06	-0.08	-0.24*	0.02	0.19	0.01	-0.1
	No. of bolls	0.03	-0.03	0.06	-0.44**	-0.04	0.05	-0.18	0.32**	0.08
4	Retention ratio	-0.05	-0.2	0.09	-0.01	-0.24*	0.01	0.22	0	-0.15
	No. of bolls	0.01	-0.05	0.05	-0.40**	-0.03	0.04	-0.16	0.31*	0.08
5	Retention ratio	-0.03	-0.21	0.13	0.07	-0.25*	0	0.26*	-0.02	-0.22
	No. of bolls	0	-0.07	0.05	-0.37**	-0.02	0.03	-0.13	0.29*	0.07
6	Retention ratio	0.01	-0.19	0.15	0.12	-0.24*	0.02	0.27*	-0.03	-0.2
	No. of bolls	-0.01	-0.08	0.04	-0.38**	-0.02	0.04	-0.15	0.31*	0.13
7	Retention ratio	0.05	-0.17	0.17	0.18	-0.25*	0.05	0.29*	-0.02	-0.21
	No. of bolls	-0.03	-0.09	0.03	-0.39**	-0.04	0.06	-0.14	0.34**	0.18
8	Retention ratio	0.06	-0.08	0.13	0.21	-0.2	0.07	0.28*	-0.06	-0.19
	No. of bolls	-0.05	-0.07	-0.01	-0.35**	-0.02	0.02	-0.17	0.28*	0.17
9	Retention ratio	0.08	0	0.08	0.26*	-0.14	0.08	0.29*	-0.12	-0.2
	No. of bolls	-0.08	-0.06	-0.05	-0.33**	-0.01	0	-0.23	0.2	0.16
10	Retention ratio	0.06	-0.02	0.05	0.27*	-0.13	0.09	0.27*	-0.1	-0.08
	No. of bolls	-0.11	-0.1	-0.07	-0.34**	-0.03	-0.03	-0.19	0.18	0.21
11	Retention ratio	0.04	-0.04	0.08	0.28*	-0.12	0.08	0.26*	-0.09	-0.05
	No. of bolls	-0.18	-0.18	-0.06	-0.37**	-0.1	-0.04	-0.14	0.15	0.28*
12	Retention ratio	0.02	0.01	-0.08	0.32**	-0.05	0.05	0.25*	-0.08	-0.03
	No. of bolls	-0.17	-0.13	-0.08	-0.32**	-0.06	-0.07	-0.11	0.16	0.24*
13	Retention ratio	-0.04	0.04	-0.09	0.38**	0	0.01	0.27*	-0.09	-0.02
	No. of bolls	-0.15	-0.09	-0.09	-0.29*	-0.03	-0.1	-0.08	0.18	0.2
14	Retention ratio	-0.07	0.04	-0.13	0.34**	0.06	-0.02	0.18	-0.08	-0.01
	No. of bolls	-0.15	-0.1	-0.1	-0.28*	-0.01	-0.1	-0.15	0.17	0.17
15	Retention ratio	-0.13	0.03	-0.18	0.33**	0.09	-0.04	0.06	-0.07	0
	No. of bolls	-0.16	-0.10	-0.11	-0.28*	0.00	-0.11	-0.13	0.17	0.15

* and ** Significant at 5% and 1% levels of significance, respectively.
\# 0 = Initial time
• Retention ratio: (the number of retained bolls obtained from the total number of each daily tagged flowers in all selected plants at harvest/each daily number of tagged flowers in all selected plants) x 100.
♦ Diurnal temperature range (Sawan et al., 2005).

retention ratio was positive and significant in the 9-15 day periods after flowering. Daily sunshine duration was positively and significantly correlated with boll retention ratio during the 5-13 day periods after flowering. Daily maximum humidity had a significant positive correlation with the number of bolls during the first 8 day periods after flowering, while daily minimum humidity had the same correlation for only the 11, and 12 day periods after flowering. Daily maximum and minimum temperatures and the diurnal temperature range, as well as soil surface temperature at 1800 did not show significant relationships with both number of bolls and retention ratio. Daily soil surface temperature at 0600 h had a significant negative correlation with boll retention ratio during the 3-7 day periods after anthesis.

Second season

Daily evaporation, soil surface temperature at 1800 h, and sunshine duration had a significant negative correlation with number of bolls in all the 15 day periods after anthesis (Table 6). Daily maximum and minimum temperatures and the diurnal temperature range and soil surface temperature at 0600 h had a negative correlation with boll production. Their significant effects were observed during the 1 and 10-15 day periods for maximum temperature, and the 1-5 and 9-12 day periods for the diurnal temperatures range.

Table 6: Simple correlation coefficient (r) values between climatic factorsz and number of harvested bolls and retention ratio in initial time (0) and each of the 15–day periods after flowering in the second season (II).

	Climate period	Air temp.	(°C)		Evap.(mm d-1)	Surface soil temp. (°C)		Sunshine duration (hd1)	Humidity (%)	
		Max (X1)	Min. (X2)	Max.-Min. (X3)	(X4)	0600 h (X5)	1800 h (X6)	(X7)	Max. (X8)	Min. (X9)
0#	Retention ratio	-0.04	0.2	-0.31*	-0.14	0.12	-0.2	0.01	-0.04	0.17
	No. of bolls	-0.42**	0.02	-0.37**	-0.59**	-0.13	-0.36**	-0.36**	0.01	0.46**
1	Retention ratio	-0.1	-0.03	-0.22	-0.21	-0.15	-0.05	-0.04	-0.02	0.23
	No. of bolls	-0.25*	-0.01	-0.36**	-0.63**	-0.15	-0.30*	-0.25*	0.06	0.44**
2	Retention ratio	-0.15	-0.06	-0.1	-0.15	-0.08	-0.21	-0.01	-0.04	0.12
	No. of bolls	-0.18	-0.01	-0.34**	-0.65**	-0.11	-0.25*	-0.32*	0.13	0.43**
3	Retention ratio	-0.03	-0.01	-0.02	-0.21	-0.01	-0.17	-0.08	0.09	0.12
	No. of bolls	-0.15	-0.06	-0.30*	-0.62**	-0.05	-0.28*	-0.31*	0.14	0.33**
4	Retention ratio	0.08	-0.02	0.07	-0.09	-0.03	-0.09	-0.1	0.05	-0.04
	No. of bolls	-0.15	-0.05	-0.28*	-0.63**	-0.06	-0.25*	-0.33**	0.15	0.32*
5	Retention ratio	0.23	-0.03	0.12	-0.06	-0.06	-0.01	-0.11	0.01	-0.16
	No. of bolls	-0.14	-0.05	-0.25*	-0.62**	-0.06	-0.24*	-0.35**	0.15	0.31*
6	Retention ratio	0.09	-0.08	0.12	-0.09	-0.07	-0.01	-0.09	0	-0.05
	No. of bolls	-0.15	-0.04	-0.22	-0.61**	-0.08	-0.25*	-0.34**	0.13	0.22
7	Retention ratio	-0.03	-0.12	0.12	-0.1	-0.11	-0.01	-0.04	-0.03	0.02
	No. of bolls	-0.15	-0.02	-0.19	-0.60**	-0.1	-0.29*	-0.32*	0.1	0.18
8	Retention ratio	-0.02	0.05	0.03	-0.1	-0.04	-0.03	-0.02	-0.01	0.01
	No. of bolls	-0.2	-0.03	-0.23	-0.61**	-0.1	-0.28*	-0.32*	0.19	0.22
9	Retention ratio	-0.02	0.13	-0.05	-0.1	0.08	-0.05	-0.01	0.03	0
	No. of bolls	-0.24	-0.04	-0.29*	-0.62**	-0.11	-0.30*	-0.33**	0.13	0.27*
10	Retention ratio	-0.04	0.12	-0.08	-0.09	0.05	0.11	-0.02	0.04	0.02
	No. of bolls	-0.27*	-0.07	-0.30*	-0.60**	-0.16	-0.34**	-0.34**	0.11	0.26*
11	Retention ratio	-0.07	0.1	-0.1	-0.08	0.03	0.2	-0.03	0.05	0.04
	No. of bolls	-0.30*	-0.12	-0.30*	-0.61**	-0.18	-0.39**	-0.36**	0.1	0.27*
12	Retention ratio	-0.11	0.09	-0.14	-0.11	0.04	0.13	-0.08	0.11	0.09
	No. of bolls	-0.32*	-0.19	-0.26*	-0.60**	-0.22	-0.42**	-0.37**	0.09	0.27*
13	Retention ratio	-0.14	0.09	-0.17	-0.18	0.06	-0.06	-0.14	0.16	0.12
	No. of bolls	0.33**	-0.26*	-0.23	-0.59**	-0.28*	-0.48**	-0.39**	0.08	0.27*
14	Retention ratio	-0.11	-0.04	-0.1	-0.13	-0.15	-0.05	-0.09	0.01	0.12
	No. of bolls	-0.34**	-0.32*	-0.21	-0.61**	-0.32*	-0.48**	-0.38**	0.06	0.27*
15	Retention ratio	-0.08	-0.11	0.02	-0.08	-0.22	-0.05	-0.02	-0.03	0.12
	No. of bolls	-0.35**	-0.37**	-0.18	-0.61**	-0.38**	-0.48**	-0.37**	0.03	0.27*

* and ** Significant at 5% and 1% levels of significance, respectively.
# 0 = Initial time
• Retention ratio: (the number of retained bolls obtained from the total number of each daily tagged flowers in all selected plants at harvest/each daily number of tagged flowers in all selected plants) x 100.
♦ Diurnal temperature range.
z Wind speed did not show significant effect upon the studied production variables, so it is not reported (Sawan et al., 2005).

Meanwhile, the daily minimum temperature and soil surface temperature at 0600 h had a significant negative correlation only during the 13-15 day periods. Daily minimum humidity had a significant positive correlation with number of bolls during the first 5 day periods, and the 9-15 day periods after anthesis. Daily maximum humidity showed no significant relation to number of bolls produced and further no significant relation was observed between any of the studied climatic factors and boll retention ratio. The results in the two seasons indicated that evaporation and humidity, followed by sunshine duration had obvious correlation with boll production. From the results obtained, it appeared that the effects of air temperature, and soil surface temperature tended to be masked in the first season, i.e. did not show any significant effects in the first season on the number of bolls per plant. However, these effects were found to be significant in the second season. These seasonal differences in the impacts of the previously mentioned climatic factors on the number of bolls per plant are most likely ascribed to the sensible variation in evaporation values in the two studied seasons where their means were 10.2 mm.d^{-1} and 5.9 mm d^{-1} in the first and second seasons, respectively (Sawan et al., 2005).

There is an important question here concerning, if there is a way for forecasting when evaporation values would mask the effect of the previous climatic factors. The answer would be possibly achieved through relating humidity values to evaporation values which are naturally liable to some fluctuations from one season to another (Sawan et al., 2005). It was found that the ratio between the mean of maximum humidity and the mean of evaporation in the first season was 85.8/10.2 = 8.37, while in the second season this ratio was 12.4. On the other hand, the ratio between the mean minimum humidity and the mean of evaporation in the first season was 30.8/10.2 = 3.02, while in the second season this ratio was 6.75 (Table 1). From these ratios it seems that minimum humidity which is closely related to evaporation is more sensitive than the ratio between maximum humidity and evaporation. It can be seen from the results and formulas that when the ratio between minimum humidity and evaporation is small (3:1), the effects of air temperature, and soil surface temperature were hindered by the effect of evaporation, i.e. the effect of these climatic factors were not significant. However, when this ratio is high (6:1), the effects of these factors were found to be significant. Accordingly, it could be generally stated that the effects of air, and soil surface temperatures could be masked by evaporation when the ratio between minimum humidity and evaporation is less than 4:1(Sawan et al., 2005; Sawan, 2016; Sawan, 2016). Evaporation appeared to be the most important climatic factor (in each of the 15-day periods both prior to and after initiation of individual bolls) affecting number of flowers or harvested bolls in Egyptian cotton. High daily evaporation rates could result in water stress that would slow growth and increase shedding rate of flowers and bolls. The second most important climatic factor in our study was humidity. Effect of maximum humidity varied markedly from the first season to the second one, where it was significantly correlated with the dependent variables in the first season, while the inverse pattern was true in the second season.

This diverse effect may be due to the differences in the values of this factor in the two seasons; where it was on average 87% in the first season, and only 73% in the second season (Table 6) (Sawan et al., 2005). Also, was found that, when the average value of minimum humidity exceeded the half average value of maximum humidity, the minimum humidity can substitute the maximum humidity on affecting number of flowers or harvested bolls. In the first season (Table 6) the average value of minimum humidity was less than half of the value of maximum humidity (30.2/85.6 = 0.35), while in the second season it was higher than half of maximum humidity (39.1/72.9 = 0.54). The third most important climatic factor in our study was sunshine duration, which showed a significant negative relationship with boll production. The r values of (Tables 3-6) indicated that the relationship between the dependent and independent variables preceding flowering (production stage) generally exceeded in value the relationship between them during the entire and late periods of production stage. In fact, understanding the effects of climatic factors on cotton production during the previously mentioned periods would have marked consequences on the overall level of cotton production, which could be predictable depending on those relationships.

Regression models

An attempt was carried out to investigate the effect of climatic factors on cotton production via prediction equations including the important climatic factors responsible for the majority of total variability in cotton flower and boll production. Hence, regression models were established using the stepwise multiple regression technique to express the relationship between each of the number of flowers and bolls/plant and boll retention ratio (Y), with the climatic factors, for each of the a) 5, b) 10, and c) 15 day periods either prior to or after initiation of individual bolls (Tables 7 and 8) (Sawan et al., 2005). Concerning the effect of prior days the results indicated that evaporation, sunshine duration, and the diurnal temperature range were the most effective and consistent climatic factors affecting cotton flower and boll production (Table 7). The fourth effective climatic factor in this respect was minimum humidity. On the other hand, for the periods after flower the results obtained from the equations (Table 8) indicated that evaporation was the most effective and consistent climatic factor affecting number of harvested bolls. Regression models obtained demonstrate of each independent variable under study as an efficient and important factor (Sawan et al., 2005). Meanwhile, they explained a sensible proportion of the variation in flower and boll production, as indicated by their R^2, which ranged between 0.14-0.62, where most of R^2 prior to flower opening were about 0.50 and after flowering all but one are less than 0.50. These results agree with Miller et al. (1996) in their regression study of the relation of yield with rainfall and temperature.

They suggested that the other 0.50 of variation related to management practices, which can be the same in this study. Also, the regression models indicated that the relationships between the number of flowers and bolls per plant and the studied climatic factors for the 15 day period before or after flowering (Y_3) in each season explained the highly significant magnitude of variation ($P < 0.05$). The R^2 values for the 15 day periods before and after flowering were higher than most of those obtained for each of the 5 and the 10 day periods before or after flowering. This clarifies that the effects of the climatic factors during the 15 day periods before or after flowering are very important for Egyptian cotton boll production and retention. Thus, an

Table 7: The models obtained for the number of flowers and bolls per plant as functions of the climatic data derived from the 5, 10, and 15 day periods prior to flower opening in the two seasons (I, II).

Season	Model [z]	R^2
First flower		
$Y_1 = 55.75 + 0.86X_3 – 2.09X_4 – 2.23X_7$	0.51	**
$Y_2 = 26.76 – 5.45X_4 + 1.76X_9$	0.42	**
$Y_3 = 43.37 – 1.02X_4 – 2.61X_7 + 0.20X_8$	0.52	**
Boll		
$Y_1 = 43.69 + 0.34X_3 – 1.71X_4 – 1.44X_7$	0.43	**
$Y_2 = 40.11 – 1.82X_4 – 1.36X_7 + 0.10X_8$	0.48	**
$Y_3 = 31.00 – 0.60X_4 – 2.62X_7 + 0.23X_8$	0.47	**
Second flower		
$Y_1 = 18.58 + 0.39X_3 – 0.22X_4 – 1.19X_7 + 0.17X_9$	0.54	**
$Y_2 = 16.21 + 0.63X_3 – 0.20X_4 – 1.24X_7 + 0.16X_9$	0.61	**
$Y_3 = 14.72 + 0.51X_3 – 0.20X_4 – 0.85X_7 + 0.17X_9$	0.58	**
Boll		
$Y_1 = 25.83 + 0.50X_3 – 0.26X_4 – 1.95X_7 + 0.15X_9$	0.61	**
$Y_2 = 19.65 + 0.62X_3 – 0.25X_4 – 1.44X_7 + 0.12X_9$	0.60	**
$Y_3 = 15.83 + 0.60X_3 – 0.22X_4 – 1.26X_7 + 0.14X_9$	0.59	**

[z]Where Y_1, Y_2, Y_3 = number of flowers or bolls per plant at the 5, 10 and 15 day periods before flowering, respectively, X_2 = minimum temperature (°C), X_3 = diurnal temperature range (°C), X_4 = evaporation (mm day^{-1}), X_7 = sunshine duration (h day^{-1}), X_8 = maximum humidity (%) and X_9 = minimum humidity (%)(Sawan et al., 2005).

accurate climatic forecast for the effect of these 15 day periods provides an opportunity to avoid any possible adverse effects of unusual climatic conditions before flowering or after boll formation by utilizing additional treatments and/or adopting proper precautions to avoid flower and boll reduction. The main climatic factors from this study (Sawan et al., 2005) affecting the number of flowers and bolls, and by implication yield, is evaporation, sunshine duration and minimum humidity, with evaporation (water stress) being by far the most important factor. Various activities have been suggested to partially overcome water stress.

Table 8: The models obtained for the number of bolls per plant as functions of the climatic data derived from the 5, 10, and 15 day periods after flower opening in the two seasons (I, II).

Season	Model [z]	R^2	Significance
First	$Y_1 = 16.38 - 0.41X_4$	0.14	**
	$Y_2 = 16.43 - 0.41X_4$	0.14	**
	$Y_3 = 27.83 - 0.60X_4 - 0.88X_9$	0.15	**
Second	$Y_1 = 23.96 - 0.47X_4 - 0.77X_8$	0.44	**
	$Y_2 = 18.72 - 0.58X_4$	0.34	**
	$Y_3 = 56.09 - 2.51X_4 - 0.49X_6 - 1.67X_7$	0.56	**

[z] Where Y_1, Y_2, Y_3 = number of bolls per plant at the 5, 10, and 15 day periods after flowering, respectively, X_4 = evaporation (mm day^{-1}), X_6 = soil surface temperature (°C) at 1800, X_7 = sunshine duration (h day^{-1}), X_8 = maximum humidity (%) and X_9 = minimum humidity (%)(Sawan et al., 2005).

Temperature conditions during the reproduction growth stage of cotton in Egypt do not appear to limit growth even though they are above the optimum for cotton growth (Sawan, 2013). This is contradictory to the finding of Holaday et al. (1997). A possible reason for that contradiction is that the effects of evaporation rate and humidity were not taken into consideration in the research studies conducted by other researchers in other countries. The matter of fact is that temperature and evaporation are closely related to each other to such an extent that the higher evaporation rate could possible mask the effect of temperature (Sawan, 2014). Sunshine duration and minimum humidity appeared to have secondary effects, yet they are in fact important players. The importance of sunshine duration has been alluded to by Moseley et al. (1994) and Oosterhuis (1997). Also, Mergeai and Demol (1991) found that cotton yield was assisted by intermediate relative humidity.

Cotton (*Gossypium barbadense*) flower and boll production as affected by climatic factors and soil moisture status

Basic Variables

A. Dependant variables as defined above: (Y_1) and (Y_2) [11].
B. Independent variables (Xs):
1. Irrigation on day 1 = 1. Otherwise, enter 0.0 (soil moisture status) (X1)
2. The first and second days after the day of irrigation (soil moisture status) = 1. Otherwise, enter 0.0 (X2).
3. The day prior to the day of irrigation (soil moisture status) to check for possible moisture deficiency on that day = 1. Otherwise, enter 0.0 (X3).
4. Number of days during days 1 (day of flowering)-12 (after flowering) that temperature equaled or exceeded 37.5 °C (high temperature) (X4).
5. Range of temperature (diurnal temperature) [°C] on day 1 (day of flowering) (X5).
6. Broadest range of temperature [°C] over days 1 (day of flowering)-12 (after flowering) (X6).
7. Minimum relative humidity (minRH) [%] during day 1 (day of flowering) (X7).
8. Maximum relative humidity (maxRH) [%] during day 1 (day of flowering) (X8).
9. Minimum relative humidity (minRH) [%] during day 2 (after flowering) (X9).
10. Maximum relative humidity (maxRH) [%] during day 2 (after flowering) (X10).
11. Largest maximum relative humidity (maxRH) [%] on days 3-6 (after flowering) (X11).
12. Lowest minimum relative humidity (minRH) [%] on days 3-6 (after flowering) (X12).
13. Largest maximum relative humidity (maxRH) [%] on days 7-12 (after flowering) (X13).
14. Lowest minimum relative humidity (minRH) [%] on days 7-12 (after flowering) (X14).
15. Lowest minimum relative humidity (minRH) [%] on days 50-52 (after flowering) (X15).

Table 9: Simple correlation coefficient (r) values between the independent variables and the dependent variables in the first season (I).

Independent variables (Irrigation and climatic factors)		Dependent variables (First season)	
		Flowers	Bolls
(X1)	Irrigation on day 1	-0.1282	-0.0925
(X2)	Irrigation on day 0 or –1 (1st and 2nd day after irrigation)	-0.1644	-0.1403
(X3)	1 is for the day prior to irrigation	-0.0891	-0.0897
(X4)	Number of days that temperature equaled or exceeded 37.5 °C	0.1258	0.1525
(X5)	Range of temperature [°C] on day 1	-0.0270	-0.0205
(X6)	Broadest range of temperature [°C] over days 1 -12	0.0550	0.1788[d]
(X7)	MinRH [%] during day 1	0.1492	0.1167
(X8)	MaxRH [%] during day 1	0.2087[c]	0.1531
(X9)	MinRH [%] during day 2	0.1079	0.1033
(X10)	MaxRH [%] during day 2	0.1127	0.0455
(X11)	Largest maxRH [%] on days 3-6	0.3905[a]	0.2819[b]
(X12)	Lowest minRH [%] on days 3-6	0.0646	0.0444

16. Daily light period (hour) (X16).

Statistical analysis

Simple correlation coefficients between the initial group of independent variables (climatic factors and soil moisture status) (X's) and the corresponding dependent variables (Y's) were computed for each season and the combined data of the two seasons. These correlation coefficients helped determine the significant climatic factors and soil moisture status affecting the cotton production variables. The level for significance was $P \leq 0.15$. Those climatic factors and soil moisture status attaining a probability level of significance not exceeding 0.15 were deemed important (affecting the dependent variables) (Sawan et al., 2010). Those factors were combined with dependent variables in multiple regression analysis to obtain a predictive model as described by Cady and Allen. Multiple linear regression equations (using the stepwise method) comprising selected predictive variables were computed for the determined interval. Coefficients of multiple determinations (R^2) were calculated to measure the efficiency of the regression models in explaining the variation in data. Correlation and regression analysis were computed according to Draper and Smith (1996) using the procedures outlined in the general linear model (GLM) (SAS Institute, Inc 1985).

Correlation estimates

Simple correlation coefficients between the independent variables and the dependent variables for flower and boll production in each season and combined data of the two seasons are shown in Tables 9-11 (Sawan et al., 2010). The simple correlation values indicated clearly that relative humidity was the most important climatic factor. Relative humidity also had a significant positive relationship with flower and boll production; except for lowest minRH on days 50-52 (after flowering). Flower and boll production were positively and highly correlated with the variables of largest maxRH (X11, X13) and lowest minRH (X14, X15) in the first season, minRH (X7, X9), largest maxRH (X11), and lowest minRH (X12, X14, X15) in the second season and the combined data of the two seasons. Effect of maxRH varied markedly from the first to the second season. MaxRH was significantly correlated with the dependent variables in the first season, while the inverse pattern was true in the second season. This diverse effect may be best explained by the differences of 87% in the first season, and only 73% in the second season (Table 1). Also, when the average value of minRH exceeded the half average value of maxRH, the minRH can substitute for the maxRH on affecting number of flowers or harvested bolls. In the first season (Table 1) the average value of minRH was less than half of the value of maxRH (30.2/85.6 = 0.35), while in the second season it was higher than half of maxRH (39.1/72.9 = 0.54). Sunshine duration (X16) showed a significant negative relation with fruit production in the first and second seasons and the combined data of the two seasons except for boll production in the first season, which was not significant.

Flower and boll production were negatively correlated in the second season and the combined data of the two seasons with the number of days during days 1 -12 that temperature equaled or exceeded 37.5 °C (X4), range of temperature (diurnal temperature) on flowering day (X5) and broadest range of temperature over days 1-12 (X6). The soil moisture status showed low and insignificant correlation with flower and boll production. The positive relationship between relative humidity with flower and boll production means that low relative humidity rate reduces significantly cotton flower and boll production.This may be due to greater plant water deficits when relative humidity decreases. Also, the negative relationship between the

Table 10: Simple correlation coefficient (r) values between the independent variables and the dependent variables in the second season (II).

	Independent variables (Irrigation and climatic factors)	Dependent variables (Second season)	
		Flowers	Bolls
(X1)	Irrigation on day 1	-0.0536	-0.0467
(X2)	Irrigation on day 0 or –1	-0.1116	-0.1208
(X3)	1 is for the day prior to the day of irrigation	-0.0929	-0.0927
(X4)	Number of days that temperature equaled or exceeded 37.5 °C	-0.4192[a]	-0.3981[a]
(X5)	Range of temperature [°C] on day 1	-0.3779[a]	-0.3858[a]
(X6)	Broadest range of temperature [°C] over days 1-12	-0.3849[a]	-0.3841[a]
(X7)	MinRH [%] during day 1	0.4522[a]	0.4665[a]
(X8)	MaxRH [%] during day 1	0.0083	0.0054
(X9)	MinRH [%] during day 2	0.4315[a]	0.4374[a]
(X10)	MaxRH [%] during day 2	0.0605	0.0532
(X11)	Largest maxRH [%] on days 3-6	0.2486[c]	0.2520[b]
(X12)	Lowest minRH [%] on days 3-6	0.5783[a]	0.5677[a]
(X13)	Largest maxRH [%] on days 7-12	0.0617	0.0735
(X14)	Lowest minRH [%] on days 7-12	0.4887[a]	0.4691[a]
(X15)	Lowest minRH [%] on days 50-52	-0.6246[a]	-0.6113[a]
(X16)	Daily light period (hour)	-0.3677[a]	-0.3609[a]

[a] Significant at 1 % probability level.
[b] Significant at 5 % probability level.
[c] Significant at 10 % probability level (Sawan et al., 2010).

Table 11: Simple correlation coefficient (r) values between the independent variables and dependent variables in the combined two seasons (1 and I2).

	Independent variables (Irrigation and climatic factors)	Dependent variables (Combined two seasons)	
		Flowers	Bolls
(X1)	Irrigation on day 1	-0.0718	-0.0483
(X2)	Irrigation on day 0 or –1	-0.1214	-0.1108
(X3)	1 is for the day prior to the day of irrigation	-0.0845	-0.0769
(X4)	Number of days that temperature equaled or exceeded 37.5 °C	-0.2234[b]	-0.1720[c]
(X5)	Range of temperature [°C] on day 1	-0.2551[a]	-0.2479[a]
(X6)	Broadest range of temperature [°C] over days 1-12	-0.2372[a]	-0.1958[b]
(X7)	MinRH [%] during day 1	0.3369[a]	0.3934[a]
(X8)	MaxRH [%] during day 1	0.0032	-0.0911
(X9)	MinRH [%] during day 2	0.3147[a]	0.3815[a]
(X10)	MaxRH[%] during day 2	-0.0094	-0.1113
(X11)	Largest maxRH [%] on days 3-6	0.0606	-0.0663
(X12)	Lowest minRH [%] on days 3-6	0.3849[a]	0.4347[a]
(X13)	Largest maxRH [%] on days 7-12	-0.0169	-0.1442[d]
(X14)	Lowest minRH [%] on days 7-12	0.3891[a]	0.4219[a]
(X15)	Lowest minRH [%] on days 50-52	-0.3035[a]	-0.2359[a]
(X16)	Daily light period (hour)	-0.3039[a]	-0.2535[a]

[a] Significant at 1 % probability level.
[b] Significant at 5 % probability level.
[c] Significant at 10 % probability level.
[d] Significant at 15 % probability level(Sawan et al., 2010).

variables of maximum temperature exceeding 37.5 °C (X4), range of diurnal temperature on flowering (X5), and sunshine duration (X16) with flower and boll production revealed that the increased values of these factors had a detrimental effect upon Egyptian cotton fruit production. Results obtained from the production stage of each season, and the combined data of the two seasons showed marked variability in the relationships of some climatic variables with the dependent variables. This may be best explained by the differences between climatic factors in the two seasons as illustrated by the ranges and means shown in Table 1. For example, maximum temperature exceeding

Table 12: Model obtained for cotton production variables as functions of climatic data and soil moisture status in individual and combined seasons.

Season	Model	R^2
Season I (n = 68)	$Y_1 = -557.54 + 6.35X_6 + 0.65X_7 + 1.92X_{11} + 4.17X_{13} + 2.88X_{14} - 1.90X_{15} - 5.63X_{16}$	0.63
	$Y_2 = -453.93 + 6.53X_6 + 0.61X_7 + 1.80X_{11} + 2.47X_{13} + 1.87X_{14} - 1.85X_{15}$	0.53
Season II (n = 62)	$Y_1 = -129.45 + 25.36X_1 + 37.02X_4 + 1.48X_7 + 1.69X_9 + 4.46X_{12} + 2.55X_{14} - 4.73X_{15}$	0.72
	$Y_2 = -130.23 + 24.27X_1 + 35.66X_4 + 1.42X_7 + 1.61X_9 + 4.00X_{12} + 2.18X_{14} - 4.09X_{15}$	0.71
Combined data: I & II (n = 130)	$Y_1 = -557.36 + 6.82X_6 + 1.44X_7 + 0.75X_9 + 2.04X_{11} + 2.55X_{12} + 2.01X_{13} + 3.27X_{14} - 2.15X_{15}$	0.57
	$Y_2 = -322.17 + 6.41X_6 + 1.20X_7 + 0.69X_9 + 1.81X_{11} + 2.12X_{12} + 2.35X_{14} - 2.16X_{15}$	0.53

(Y1) Number of cotton flowers; (Y2) Number of cotton bolls.
(X1) Irrigation on day 1; (X4) Number of that temperature equaled or exceeded 37.5 °C; (X6) Broadest range of temperature [°C] over days 1-12; (X7) MinRH [%] during day 1; (X9) MinRH [%] during day 2; (X11) Largest maxRH [%] on days 3-6; (X12) Lowest minRH [%] on days 3-6; (X13) Largest maxRH [%] on days 7-12; (X14) Lowest minRH [%] on days 7-12; (X15) Lowest minRH [%] on days 50-52; (X16) Daily light period (hour).
All entries significant at 1% level(Sawan et al., 2010).

37.5 °C (X4) and minRH did not show significant relations in the first season, while that trend differed in the second season. These results indicated that relative humidity was the most effective and consistent climatic factor affecting boll production. The second most important climatic factor in our study was sunshine duration, which showed a significant negative relationship with boll production.

Multiple linear regression models, beside contribution of climatic factors and soil moisture status to variations in the dependent variables

Regression models were established using the stepwise multiple regression technique to express the relationship between the number of flowers and bolls per plant^{-1} (*Y*) with the climatic factors and soil moisture status (Table 12) (Sawan et al., 2010). Relative humidity (%) was the most important climatic factor affecting flower and boll production in Egyptian cotton [minRH during day 1 (X7), minRH during day 2 (X9), largest maxRH on days 3-6 (X11), lowest minRH on days 3-6 (X12), largest maxRH on days 7-12 (X13), lowest minRH on days 7-12 (X14) and lowest minRH on days 50-52 (X15)]. Sunshine duration (X16) was the second climatic factor of importance affecting production of flowers and bolls. Maximum temperature (X4), broadest range of temperature (X6) and soil moisture status (X1) made a contribution affecting flower and boll production. The soil moisture variables (X2, X3), and climatic factors (X5, X8, X10) were not included in the equations since they had very little effects on production of cotton flowers and bolls. Relative humidity showed the highest contribution to the variation in both flower and boll production (Table 12). This finding can be explained in the light of results found by Ward and Bunce (1986) in sunflower (*Helianthus annuus*). They stated that decreases of relative humidity on both leaf surfaces reduced photosynthetic rate of the whole leaf for plants grown under a moderate temperature and medium light level.

Reddy et al. (1993) found that cotton (*Gossypium hirsutum*) fruit retention decreased rapidly as the time of exposure to 40°C increased. Gutiérrez and López (2003) studied the effects of heat on the yield of cotton in Andalucia, Spain, during 1991-98, and found that high temperatures were implicated in the reduction of unit production. There was a significant negative relationship between average production and number of days with temperatures greater than 40°C and the number of days with minimum temperatures greater than 20°C. Wise et al. (2004) indicated that restrictions to photosynthesis could limit plant growth at high temperature in a variety of ways. In addition to increasing photorespiration, high temperatures (35-42°C) can cause direct injury to the photosynthetic apparatus. Both carbon metabolism and thylakoid reactions have been suggested as the primary site of injury at these temperatures. Regression models obtained explained a sensible proportion of the variation in flower and boll production, as indicated by their R^2, which ranged between 0.53-0.72. These results agree with Miller et al. (1996) in their regression study of the relation of yield with rainfall and temperature. They suggested that the other R^2 0.50 of variation was related to management practices, which coincide with the findings of this study. Thus, an accurate climatic forecast for the effect of the 5-7 day period during flowering may provide an opportunity to avoid possible adverse effects of unusual climatic conditions before flowering or after boll formation by utilizing additional treatments and/or adopting proper precautions to avoid flower and boll reduction (Sawan, 2015; Sawan, 2013).

CONCLUSIONS

From the results obtained in the present study, it could be generally concluded that during the 15-days period both prior to and after initiation of individual bolls minimum relative humidity and sunshine duration, were the most significant climatic factors affecting cotton flower and boll production and retention in Egyptian cotton beside soil moisture status. The positive correlation between minimum relative humidity value along with the negative correlation between each of high air temperature and sunshine duration with flower and boll formation, indicate that high value of minimum relative humidity, short period of sunshine duration and low value of temperature would enhance flower and boll formation. Temperature appeared to be less important in the reproduction growth stage of cotton in Egypt than minimum relative humidity (water stress) and sunshine duration. These findings concur with those of other researchers except for the importance of temperature. A possible reason for that contradiction is that the effects of evaporation rate and humidity were not taken into consideration in the research studies conducted by other researchers in other countries. The matter of fact is that temperature and evaporation are closely related to each other to such an extent that the higher evaporation rate could possible mask the effect of temperature.

Water stress is in fact the main player and other authors have suggested means for overcoming its adverse effect, which could be utilized as for the Egyptian cotton. It must be kept in mind that although the reliable prediction of the effects of the aforementioned climatic factors could lead to higher yields of cotton, only 50% of the variation in yield could be statistically explained by these factors and hence consideration at the same time should be given to the management practices presently being in use. The least important independent variable was soil moisture status. In conclusion, the early prediction of possible adverse effects of climatic factors could pave the way for adopting adequate precautions regarding the effect of certain climatic factors on production of Egyptian cotton (Sawan et al., 2010). This would be useful to minimize the deleterious effects of these factors, through the application of adequate management practices, i.e. adequate irrigation regime (Oosterhuis, 1997; Orgaz et al., 1992) as well as utilization of specific plant growth regulators (Moseley et al., 1994; Zhao and Oosterhuis 1997; Meek et al., 1999) which would limit and control the negative effects of some climatic factors, and this will lead to an improvement in cotton yield production in Egypt.

Nevertheless, it could be stated that during the production stage, an accurate weather forecast for the next 5-7 days would provide an opportunity to avoid any adverse effects of climatic factors on cotton production. It would be useful to minimize the deleterious effects of those factors through utilizing proper cultural practices which would limit and control their negative effects, and this will lead to an improvement in cotton yield. Methods of early detection of stress in cotton in order to (may) allow timely management inputs were investigated (Sawan, 2016).

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